Sandhill Crane Use of Riverine Roost Sites along the Central Platte River in Nebraska, USA

Authors: Baasch, David M., Farrell, Patrick D., Caven, Andrew J., King, Kelsey C., Farnsworth, Jason M., et al.

Source: Monographs of the Western North American Naturalist, 11(1) : 1-13

Published By: Monte L. Bean Life Science Museum, Brigham Young University

URL: https://doi.org/10.3398/042.011.0101

Monographs of the Western North American Naturalist 11, © 2019, pp. 1–13

Sandhill Crane use of riverine roost sites along the central Platte River in Nebraska, USA

David M. Baasch[1,*], Patrick D. Farrell[1], Andrew J. Caven[2], Kelsey C. King[2], Jason M. Farnsworth[1], and Chadwin B. Smith[1]

[1]*Executive Director's Office for the Platte River Recovery Implementation Program, 4111 4th Ave., Ste. 6, Kearney, NE 68845*
[2]*Platte River Whooping Crane Maintenance Trust, 6611 West Whooping Crane Drive, Wood River, NE 68883*

Abstract.—Wide channels with short bank vegetation, access to nearby foraging habitat, shallow water areas (<30 cm deep), and absence of disturbance features are factors commonly associated with suitable roost sites for Sandhill Cranes (*Antigone canadensis*). However, since channel width has typically been evaluated independently of channel depth and flow, it is possible that use of narrow channels is not limited so much by a requirement for wider channels but by deeper water that flows through these narrow channels. We used a discrete-choice modeling framework and 9 years of roost location data to evaluate the influence of channel-width measures and flow per linear unit of channel width on roost-site selection by Sandhill Cranes. Roost-site selection was influenced by maximum unvegetated channel width and flow per unit length of total unvegetated channel width of all channels. The relative selection ratio increased as maximum unvegetated channel width increased to 131 m for small groups (≤500 cranes) and 275 m for large groups (>5000 cranes), but the ratio was statistically similar across a wide range of maximum unobstructed channel widths. Medium-sized Sandhill Crane groups (501–5000 cranes) were less influenced by in-channel vegetated islands, and these groups selected channels based on wide total unvegetated channel widths. Our results also suggest that flows ≤39.05 m^3/s (cms; 1379 cfs) in channels that are 275 m in unvegetated width maximize selection ratios for medium and large crane groups, so flows above this level may not improve Sandhill Crane roosting habitat conditions during the spring migration and staging season within the central Platte River. While Sandhill Cranes stage within the central Platte River valley for a longer time interval in the spring, Whooping Cranes (*Grus americana*) also use the Platte River as a stopover point. Both species share similar indices for roosting habitat, such as unobstructed channel width and shallow water depths. The results of our investigation could be used to identify a range of flows and channel width configurations expected to generate the highest amount of suitable habitat for Sandhill Cranes roosting along the central Platte River.

Resumen.—Los canales anchos con riberas de escasa vegetación, accesibilidad a hábitats de forrajeo cercanos, áreas de aguas poco profundas (<30 cm) y ausencia de perturbación, son factores comúnmente asociados, a los sitios que son adecuados para la percha de las grullas canadienses (*Antigone canadensis*). Sin embargo, dado que la amplitud del canal ha sido típicamente evaluado, independientemente de su profundidad o de su flujo, es posible que el uso de canales estrechos no limite tanto al requisito de los canales más amplios, como aguas más profundas que fluyen a través de canales estrechos. Para evaluar la influencia que tienen la amplitud del canal y el flujo por unidad lineal, en la selección del sitio de percha de la grulla canadiense, usamos el marco del modelo de elección discreta y los datos obtenidos durante nueve años de la localización de los sitios de percha de la grulla canadiense. En todos los canales, la selección de sitio se relacionó, por la amplitud máxima del canal sin vegetación y con el flujo por unidad de longitud. La proporción relativa de selección de sitio, incrementó a medida que la amplitud máxima del canal sin vegetación aumentó, a 131 m en los grupos pequeños (≤500 grullas) y a 275 m en los grupos grandes (>5000 grullas), pero fue estadísticamente similar a lo largo de un amplio rango de amplitudes de canales sin obstrucciones. Los grupos medianos de grullas (501–5000 grullas) fueron menos influenciados por islas que poseen canales con vegetación. En este caso, los sitios seleccionados se basaron en la amplitud total de los canales sin vegetación. Nuestros resultados también sugieren que los flujos ≤39.05 cms (1379 cfs) en canales sin vegetación con 275 m de amplitud, maximizan la proporción de selección de los grupos medianos y grandes de grullas. Por lo tanto, aumentar el flujo por encima de este nivel podría no mejorar las condiciones del hábitat de percha de las grullas canadienses durante la migración de primavera y el inicio de la temporada, dentro del área central del Platte River. Mientras que las grullas canadienses permanecen dentro del área central del valle del Platte River durante un intervalo de tiempo largo en primavera, las grullas trompeteras (*Grus americana*) también usan el Platte River como punto de descanso. Ambas especies comparten índices similares en cuanto a su hábitat de percha, tales como la amplitud del canal sin obstrucciones y aguas poco profundas. Los resultados de nuestra investigación podrían usarse para identificar un rango de configuraciones de flujos y de amplitud de canales, que se espera generen hábitats más adecuados para que las grullas canadienses descansen a lo largo del área central del Platte River.

*Corresponding author: baaschd@headwaterscorp.com

DMB orcid.org/0000-0003-0747-1449 PDF orcid.org/0000-0002-2861-8182 JMF orcid.org/0000-0002-9146-0162

Each spring approximately 600,000 Sandhill Cranes (*Antigone canadensis*) migrate through the central Great Plains from the wintering grounds in Texas, New Mexico, southeastern Arizona, and Mexico en route to their breeding grounds in Siberia, Alaska, and central and northern Canada (Kinzel et al. 2005, Krapu et al. 2011, Kruse and Dubovsky 2015, Dubovsky 2016). Nearly 80% of these cranes stage each spring along the Big Bend Reach of the Platte River in Nebraska, USA (Lewis 1976, Krapu et al. 1985, 2014, Pearse et al. 2017). While in this area, Sandhill Cranes forage during the day for waste grain in cornfields and for native sedges and macroinvertebrates in lowland meadows. At night they roost in shallow braided channels of the Platte River (Sparling and Krapu 1994, Pearse et al. 2017). This annual phenomenon is of critical conservation concern because it is one of the largest remaining mass wildlife migration events in the world (Johnsgard 2002).

The central Platte River is a steep, sand-bed braided river (Simons and Associates Inc. and URS Greiner Woodward Clyde 2000). As with most braided rivers, the central Platte is highly dynamic with a high width-to-depth ratio and a channel dissected by emergent bedforms at low discharges (Simons and Associates Inc. and URS Greiner Woodward Clyde 2000, Murphy et al. 2004). Sandhill Cranes roost in shallow water (<25 cm; 10 inches) that flows over submerged bedforms, and occasionally cranes will roost on aerially exposed sandbars (Norling et al. 1992, Kinzel et al. 2005) in areas with views unobstructed by dense vegetation (Folk and Tacha 1990). It is hypothesized that Sandhill Cranes roost in wide, shallow unvegetated channels because they rely heavily on eyesight to detect approaching predators (Armbruster and Farmer 1982, Krapu et al. 1984, Folk and Tacha 1990, Davis 2001, 2003, Pearse et al. 2017).

Given the importance of the central Platte River in the annual Sandhill Crane migration, ecologists have conducted numerous studies since the early 1980s to assess in-channel habitat suitability for roosting and to identify threats to the quantity and quality of that habitat (USFWS 1981, Faanes and LeValley 1993, Davis 2003, Pfeiffer and Currier 2005, Krapu et al. 2014, Pearse et al. 2017). Several of these studies were conducted using sophisticated physical/hydrodynamic modeling based on surveys of channel topography at roost locations (Prince 1990, Simons and Associates Inc. 1990, Kinzel et al. 2005). These investigations have primarily focused on assessing the channel widths and river discharges necessary to optimize the area of shallow water habitat in reaches that are suitably wide for roosting. Various researchers have proposed suitable channel width targets ranging from 50 m (164 feet) to ≥250 m (820 feet) and optimal river discharges ranging from 30 m^3/s (cms; 1059 cfs) to 57 cms (2013 cfs; Currier and Eisel 1984, Platte River Management Joint Study Biology Workgroup 1990, Prince 1990, Kinzel et al. 2005). The high degree of variability in proposed width and discharge targets is likely due to the dynamic nature of the Platte River channel where bedforms and unvegetated channel width vary widely across the reach and at a single location through time. Furthermore, discharge can vary by up to 28 cms (1000 cfs) in a day during the spring migration season, substantially changing the quantity and spatial distribution of available roosting habitat (Kinzel et al. 2009).

Sandhill Cranes that use the Platte River during the spring migration season utilize a system that is far from static. Spatial shifts in roost locations that appear to correspond to flow variability are commonly noted during observational studies (J. Jenniges and M. Peyton personal communication) and during our systematic aerial monitoring surveys. For example, a large number of Sandhill Cranes have been observed roosting in fields and wet meadows under high discharge conditions when shallow-water habitat is limited (Davis 2001). These observations led us to hypothesize that the distribution of Sandhill Crane roost locations within and across years is a function of the interaction between available channel widths and discharge as it affects the distribution and availability of suitably shallow roosting habitat. The objective of this study was to test this hypothesis and to utilize the results to describe flexible flow targets that acknowledge the range of spatial and temporal variability present in this system. As such, we evaluated the influence that channel-width measures and flow per linear unit of

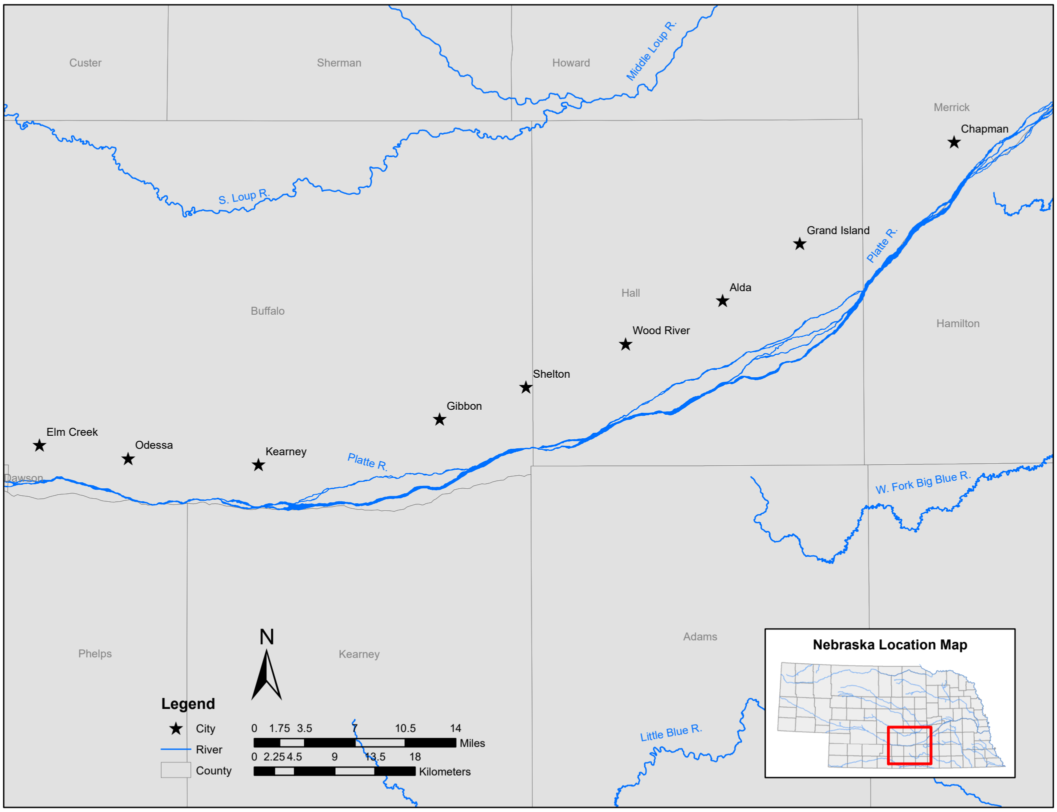

Fig. 1. Platte River channels within the study area between Elm Creek and Chapman, Nebraska, USA, with the locations of cities included for reference.

channel width (i.e., average channel depth) have on roost-site selection by Sandhill Cranes. The results of our analysis could be used to help identify ideal flow conditions for all channel widths for Sandhill Cranes roosting on the central Platte River.

METHODS

Identifying Sandhill Crane Group Locations

To determine distribution patterns of Sandhill Crane roosts, aerial surveys of Platte River channels between Chapman and Elm Creek, Nebraska, USA (Fig. 1), were conducted annually by personnel of the Platte River Whooping Crane Maintenance Trust. Surveys were conducted via a fixed-wing single-engine airplane (generally a Cessna 172) once every week from mid-February to mid-April, as appropriate weather conditions and aircraft availability permitted. This 120-km stretch of river was flown 6 to 9 times per year at approximately 135 km/h and at an elevation of 200 m above ground. The surveys were initiated 15–25 min prior to sunrise and took approximately 1 h to complete. Survey flights were generally flown from east to west; however, flights were flown from west to east later in the seasons when the highest concentration of birds shifted from east to west (Krapu et al. 2014). One observer was responsible for estimating the size of each group of Sandhill Cranes by first counting a portion of each roost, then counting spatial replicates of that area within the roost as a whole (Gregory et al. 2004, Bowman 2014). A second researcher collected the latitude and longitude over the center of each Sandhill Crane roost using a handheld Global Positioning System (Garmin® eTrex, 72, or 72H handheld GPS, Olathe, KS) and recorded count estimates obtained by the observer. Individual roosts were defined as a group of cranes that were separated from another group by more than 100 m (Iverson et al. 1987).

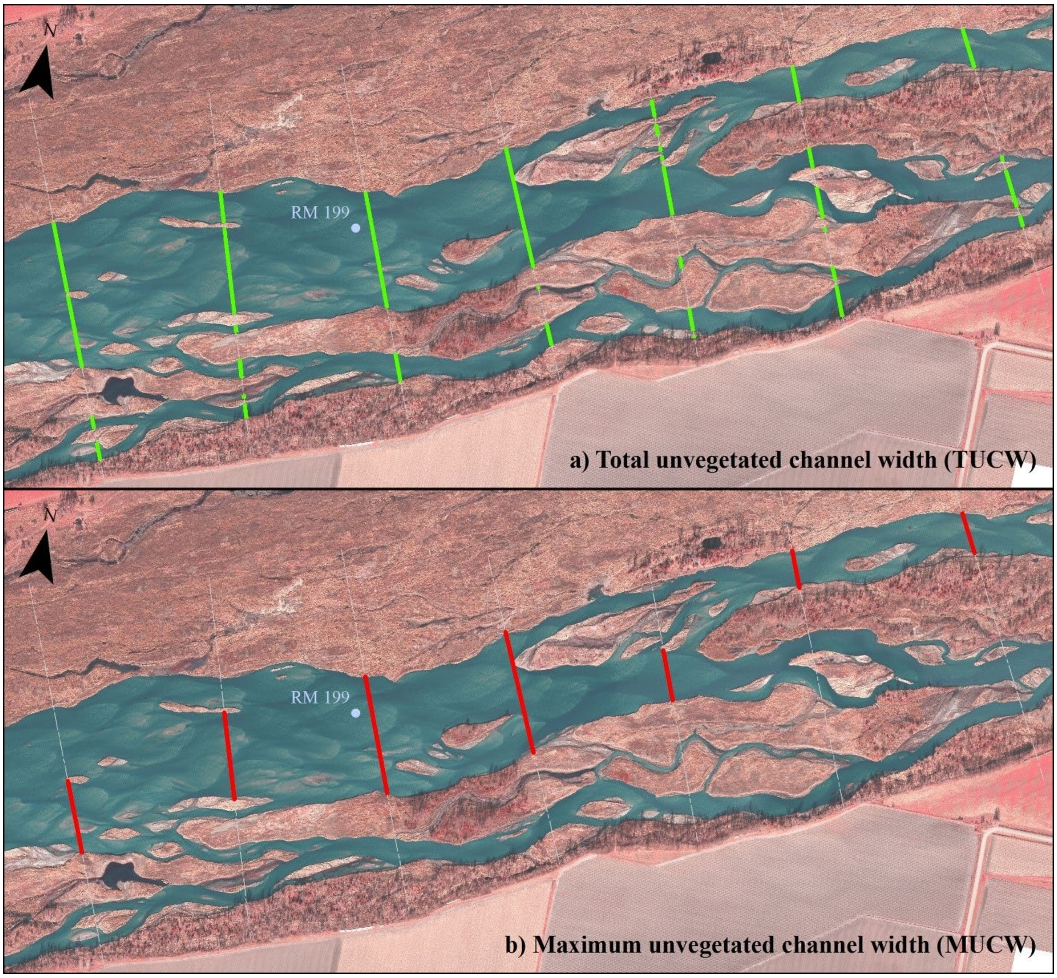

Fig. 2. Examples of how (**a**) total unvegetated channel width (TUCW) and (**b**) maximum unvegetated channel width (MUCW) were delineated.

Estimating Variables Included in Analyses

We used aerial imagery (≤15-cm resolution) collected annually during periods of low flow (July/August or October/November) to photo-interpret total unvegetated channel width (TUCW) of the channel that contained the use or available location and maximum unvegetated channel width (MUCW) of the channel that contained the use or available location throughout our study area during the period of 2007–2017 (Fig. 2). Unvegetated width metrics were delineated along 391 predefined transects using ESRI ArcMap Geographic Information System (GIS) software (Werbylo et al. 2017). All transects were oriented perpendicular to flow, were spaced at 300-m intervals along the channel throughout the study area, and encompassed all channels in split-flow reaches. Photo-interpretation of unvegetated width metrics was determined to provide acceptable measurement accuracy based on previous comparisons of field-measured and photo-interpreted unvegetated width measurements along the central Platte River (Werbylo et al. 2017). We divided the daily mean discharge, estimated from a U.S. Geological Survey gaging station near Grand Island, Nebraska (06770500), by the total unvegetated width of all channels to develop a metric that equates to flow per unit width of channel (DISCH) in order to describe water conditions encountered by cranes in all channels throughout the entire reach.

For each roost location, we developed individual choice sets by randomly generating 20 locations within 5.7 km of the used location to characterize available roosts based on the average observed distance between subsequent night roost locations calculated from telemetry data (Krapu et al. 2014). Thus a random selection of locations within this distance represented a choice set of roosts that a crane might have chosen on a particular night (Arthur et al. 1996, Compton et al. 2002, Baasch et al. 2010). All habitat metrics (MUCW, TUCW, and DISCH) were calculated for the center of each Sandhill Crane group use location and for the 20 corresponding randomly selected in-channel available points within 5.7 km upstream and downstream of the use location.

We constructed an *a priori* set of 5 models with the following variables: maximum unvegetated channel width (MUCW), total unvegetated channel width (TUCW), and flow per meter of unvegetated channel width (DISCH); models were tested on small (0–500 individuals), medium (501–5000 individuals), and large (>5000 individuals) crane groups separately. Although the same models were tested with use-available data from each crane group size, responses to channel width variables were expected to differ because large crane groups have been observed using wider channels than medium groups and small groups (Buckley 2011). Crane groups, regardless of size, require a suitable water depth to utilize a roost location regardless of channel widths. No variables were included in a model together if substantial correlation ($|r| \geq 0.50$) was present (Dormann et al. 2013).

We utilized general additive models (GAMs) within a discrete choice model (DCM) framework for group-specific sandhill crane roost location selection from 2007 to 2017. A GAM is a special case of a generalized linear model in which smoothing functions are applied to covariates (Hastie and Tibshirani 1990, Wood 2006). We employed GAMs with penalized regression splines, which estimate the degree of covariate smoothness with cross validation. An assumption of DCMs is that individuals or groups of individuals make choices to maximize their satisfaction, mirroring assumptions of resource selection functions (Ben-Akiva and Lerman 1985). DCMs have been applied to several studies of wildlife resource selection (Cooper and Millspaugh 1999, Baasch et al. 2010, Carter et al. 2010, Unger et al. 2015, Baasch et al. 2017). We used DCMs because changing habitat availability can be better captured within this framework compared to other techniques (Cooper and Millspaugh 1999).

We evaluated our model set using a Cox proportional hazards regression function in R statistical software (R Development Core Team 2015) with function gam in package mgcv, which utilizes reweighting least-squares fitting of the penalized likelihood to determine the smoothness of the line and associated degrees of freedom (Arthur et al. 1996, McCracken et al. 1998, Cooper and Millspaugh 1999, McDonald et al. 2006, Wood 2006). Additionally, generalized cross validation was used to determine the penalty for smoothing parameters of each iteration. Important habitat relationships were described for the top model in each group size–specific model selection process in which models were ranked using information theoretic methods with the Akaike information criterion (AIC), and top models were indicated as the most parsimonious model with an AIC value of ≤2.0 (Burnham and Anderson 2002).

Validating Variables Included in Analyses

To validate results of the best model, we randomly partitioned the data sets of use locations and corresponding available locations for small, medium, and large groups into training data sets (2/3 of the choice sets) and test data sets (1/3 of the choice sets). We used training data to develop parameter estimates for best models and a comparison of available and use locations of the test data set to understand the reliability of a binary response (use/available) model. Predicted values of available locations within the test data set were scaled to the number of use locations in the test data set. These were then binned into 20 percentile categories and compared to the number of test-data-set use locations in each bin. Predicted values were summed to calculate the number of expected use locations in each bin, which were then compared to the actual sum of use locations in each bin with a linear regression model in order to identify the reliability of the model based on the closeness of the slope-relationship of 1. This method was repeated 1000 times to develop the average slope and 95% confidence intervals of model fit. As defined by Howlin et al. (2004), a "good"

TABLE 1. Average and standard deviation (SD) of habitat variables evaluated in a use-availability discrete-choice analysis of Sandhill Crane (*Antigone canadensis*) roost locations on the central Platte River, 2007–2017. Variables include maximum unvegetated channel width of the channel where the use or available locations were (MUCW), total unvegetated channel width of the channel where the use or available locations were (TUCW), and discharge per linear meter of total unvegetated width of all channels (DISCH).

Crane group size	Use/available	*n*	MUCW		TUCW		DISCH	
			Average	SD	Average	SD	Average	SD
Large	Use	442	201	85	307	81	0.156	0.085
Large	Available	8819	181	87	289	83	0.166	0.089
Medium	Use	1116	160	78	258	72	0.159	0.091
Medium	Available	22,265	151	80	252	78	0.167	0.102
Small	Use	1084	135	67	239	74	0.163	0.108
Small	Available	21,613	141	75	242	77	0.163	0.113

TABLE 2. Akaike information criterion (AIC) model selection results of our use-availability roost-site selection analysis by crane group size. Variables included maximum unvegetated channel width of the channel where the use or available locations were (MUCW), total unvegetated channel width of the channel where the use or available locations were (TUCW), and flow per meter of total unvegetated channel width of all channels (DISCH).

Group size	Model	df	AIC	ΔAIC	Weight
Small	MUCW	1087.26	23892.88	0.00	0.54
	MUCW + DISCH	1087.79	23893.22	0.34	0.46
	TUCW + DISCH	1085.02	23905.07	12.19	0.00
	TUCW	1084.27	23908.67	15.79	0.00
	Null	1083.00	23910.83	17.95	0.00
	DISCH	1087.06	23911.24	18.36	0.00
Medium	TUCW + DISCH	1119.63	24642.15	0.00	0.72
	TUCW	1118.78	24645.14	2.99	0.16
	MUCW + DISCH	1119.16	24645.97	3.83	0.11
	DISCH	1116.02	24651.15	9.00	0.01
	MUCW	1118.46	24657.48	15.34	0.00
	Null	1115.00	24683.02	40.87	0.00
Large	MUCW + DISCH	448.55	8908.24	0.00	0.93
	TUCW	444.36	8914.66	6.42	0.04
	TUCW + DISCH	445.71	8916.45	8.21	0.02
	DISCH	445.25	8916.65	8.41	0.01
	MUCW	444.70	8919.28	11.04	0.00
	Null	441.00	8956.02	47.78	0.00

model had an average 95% confidence interval that incorporated 1 and not zero. An "adequate" model had an average 95% confidence interval that did not incorporate 1 or zero. If the average slope-relationship had a 95% confidence interval spanning zero, the model was deemed "poor."

RESULTS

We documented 2642 Sandhill Crane roost sites and 52,697 associated available locations within our study area between 2007 and 2017. Roost size averaged about 3500 individuals with a median of 1000 cranes (range 1–84,330 cranes). The average maximum unvegetated and total unvegetated channel widths were wider at roost sites of large crane groups than at roost sites of medium and small crane groups (Table 1). However, flow per meter of total unvegetated channel width was similar among crane group sizes (Table 1).

Statistical modeling of habitat selection indicated that aspects of channel width were important for all crane group sizes. Flow metrics were also important for medium and large crane groups, but not for small crane groups (≤500 individuals; Table 2). Maximum unvegetated channel width was an important predictor of small and large crane group roost locations. Selection ratios were maximized at 131 m for small crane groups and 275 m for large crane groups but were statistically similar from 26 m to 190 m and ≥150 m, respectively (Fig. 3A, D). For medium-sized crane groups, the selection ratio for TUCW was maximized at

267 m but was statistically similar from 69 m to 408 m (Fig. 3B). Flow per meter of total unvegetated channel width was an important predictor for medium and large crane groups. Selection ratios were maximized at the lowest flows observed for medium and large crane groups (0.0361 cms/m and 0.0382 cms/m of total unvegetated channel width of all channels, respectively). However, these results were statistically similar from 0.0361 cms/m to 0.1420 cms/m and 0.0382 cms/m to 0.1006 cms/m of total unvegetated channel width of all channels for medium and large groups, respectively (Fig. 3C, E). Model validation results indicated an adequate and good model fit for large and small groups, respectively, where the slope of the regression lines and 95% confidence intervals averaged 0.323 (95% CI 0.081–0.565) for large groups and 0.907 (95% CI 0.111–1.704) for small groups. However, model validation results for medium groups indicated an adequate to poor model fit where the slope of the regression line and 95% confidence interval averaged 0.205 (95% CI −0.055 to 0.465), so results for medium-sized groups should be interpreted with care. Arbitrary group size cutoffs are a potential reason for the reduced certainty in medium group size model fit. Groups of 500 Sandhill Cranes need less area of suitable depths to roost, whereas the larger groups of 5000 birds may select channels more like groups >5000 in size along the central Platte River and thus require wider channels that provide more area of suitable depth.

Discussion

The most important factor regulating the numbers of cranes using the central Platte River is roosting habitat availability (Krapu et al. 1984, Tacha et al. 1992, Faanes and LeValley 1993). Consequently, data on habitat availability and use are key components in understanding crane-habitat relationships and for developing sound conservation plans. Sandhill Crane distribution along the Big Bend of the Platte River is determined by the availability of adequate roosting habitat more than any other factor (Krapu et al. 1984, Sparling and Krapu 1994). Substantial changes in river characteristics, including changes in river flow, have been implicated in the cranes' abandonment of large portions of the Platte River in west central Nebraska (USFWS 1981, Faanes and LeValley 1993, Krapu et al. 2014). Changes in the spatial distribution of Sandhill Cranes along the Platte River have been associated with changes in river morphology (Krapu et al. 1982, Faanes and LeValley 1993). Reduced flows in the Platte River have allowed for the encroachment of willows (*Salix* spp.), cottonwood (*Populus deltoides*), eastern red cedar (*Juniperus virginiana*), and more recently phragmites (*Phragmites australis*) onto sandbars used by Sandhill Cranes for roosting (Lewis 1976, Williams 1978, Currier 1982, Norling et al. 1992). As woody and exotic encroachment have increased following the appropriation of 70% or more of the Platte River's flows, large western portions of the Big Bend region have been abandoned by spring-staging Sandhill Cranes as channels have become narrower and deeper (Krapu et al. 1982, Faanes and LeValley 1993, Currier 1997). Faanes and LeValley (1993) reported that the distribution of staging Sandhill Cranes shifted eastward along the Platte River from 1957 to 1989, decreasing where woody vegetation encroachment and channel narrowing were the greatest and increasing along reaches that remained relatively wide and unvegetated. This abandonment has resulted in higher concentrations of cranes in a smaller reach of river, increasing the potential for an epidemic outbreak of diseases (Vogel et al. 2013). Because of the increased risk of disease, active channel width has been artificially maintained and vegetation growth on sandbars has been mitigated over the last few decades by the efforts of environmental organizations such as the Platte Valley Weed Management Area, the USFWS Partners for Wildlife Program, the Platte River Whooping Crane Maintenance Trust, and the Platte River Recovery Implementation Program (Pfeiffer and Currier 2005). These groups currently manage in-channel vegetation in the central Platte River nearly every fall through use of heavy machinery and through airboat and aerial applications of herbicide.

In agreement with the literature, medium and large Sandhill Crane groups selected areas with wider channel widths (USFWS 1981, Krapu et al. 1984, Norling et al. 1990, Sidle et al. 1993), while small groups selected channels with moderate widths. Nearly 100% of Sandhill Cranes observed in many studies of the central Platte River, including ours, roosted in river channels >50 m wide (Krapu et al. 1984, Norling et al. 1990, Sidle et al. 1993). Large

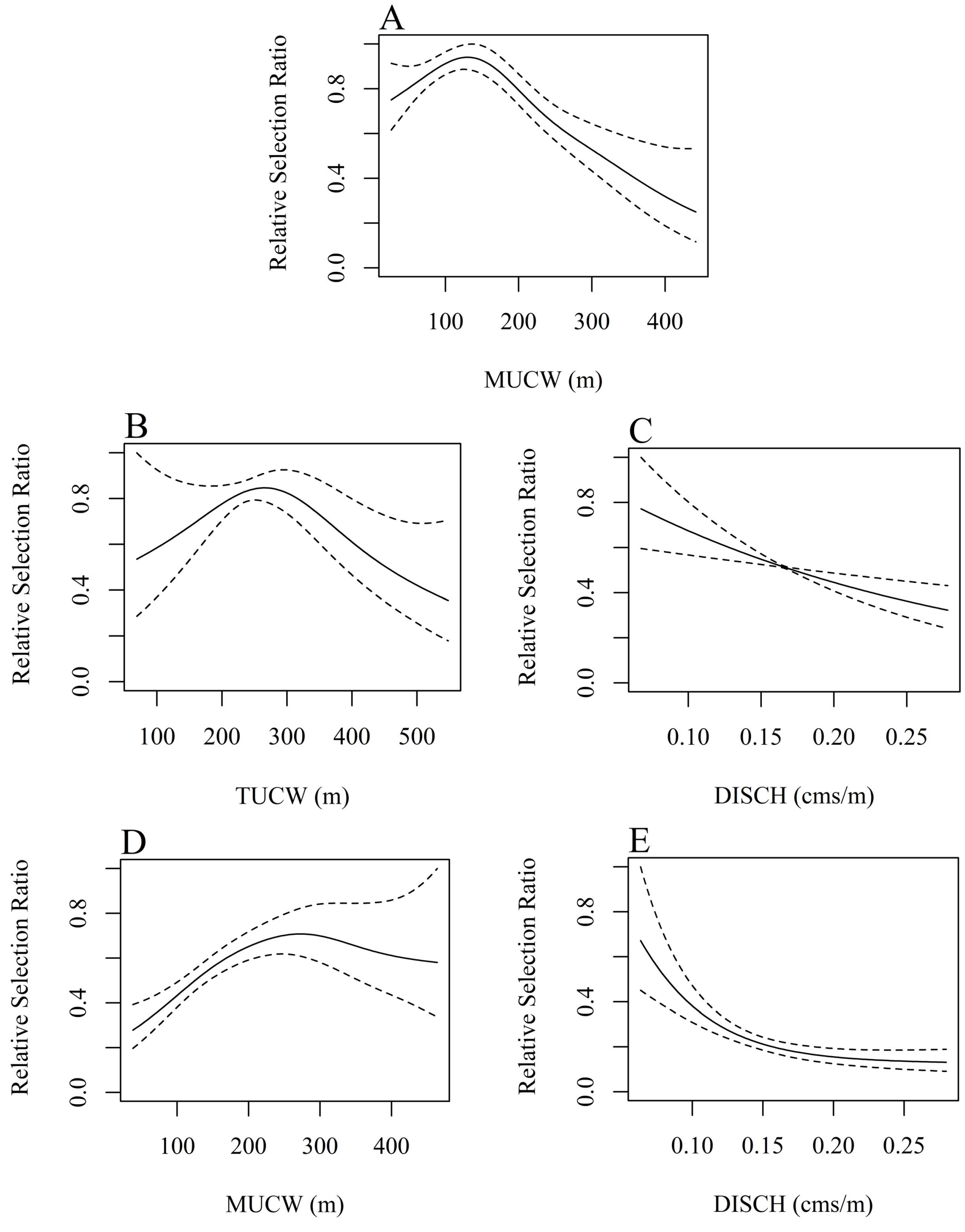

Fig. 3. Influence of variables included in the top model on predicted relative selection ratios, with 90% confidence intervals, for (**A**) small, (**B**, **C**) medium, and (**D**, **E**) large crane groups. Variables included maximum unvegetated channel width of the channel where the use or available locations were (MUCW), total unvegetated channel width of the channel where the use or available locations were (TUCW), and flow per meter of total unvegetated channel width of all channels (DISCH).

Sandhill Crane groups used channels where maximum unvegetated widths averaged 307 m and selection for MUCW was maximized at 275 m. Selection for small groups averaged 135 m and their selection was maximized at 131 m TUCW. Medium-sized Sandhill Crane groups used channels where maximum unvegetated widths averaged 258 m and selection for

TUCW was maximized at 267 m. Sidle et al. (1993) found that more than two-thirds of cranes roosted in river channels wider than 150 m. Krapu et al. (1984), Davis (2001, 2003), and Pearse et al. (2017) reported that most roosting Sandhill Cranes selected river channels with widths >150–200 m and avoided river channels with widths ≤100–150 m. Davis (2001, 2003) and Krapu et al. (1984) also reported that most roosting Sandhill Cranes were observed in the widest river channels and avoided narrow channels. In contrast, Norling et al. (1992) and Parrish et al. (2001) found that Sandhill Cranes selected channels with moderate widths and that large and small flocks were located in wide channels as well as narrow channels. However, the discrepancy in selection for various channel widths is likely related to the way that "channel width" was defined and estimated in each of these studies, the timing of flights (middle of the night vs. after twilight) if crane groups in narrower channels depart the river prior to being detected after twilight, or the flow during survey periods. Our findings indicate that the optimal channel width for roosting Sandhill Cranes largely depends on crane group size and water depth as a function of discharge and channel width (flow per unit width of channel).

The availability of suitable roosting habitat for Sandhill Cranes can be maximized under certain flow conditions because factors such as water depth and velocity that are important in determining the suitability of an area for roost sites are related to flow (FERC 1994, Kinzel et al. 2009). Norling et al. (1992) and Kinzel et al. (2005) found that Sandhill Cranes generally roosted in shallow channels with velocities <70 cm/s. Because channel width has always been evaluated independently of channel depth, it is possible that narrow channel use is not limited so much by a requirement for wider channels but by deeper water that flows through these channels (Latka and Yahnke 1986, Folk and Tacha 1990). Differences in channel flow during study periods may explain why Norling et al. (1992) and Parrish et al. (2001) found that Sandhill Cranes selected moderately wide channels (50–200 m) and found no preference for the widest channels. Theoretically, the widest channels should be the most preferred in times of higher discharge when dry sandbars within wide reaches are temporarily submerged, creating shallow roosting habitat, whereas narrower, more incised channels may provide adequate roosting habitat during dryer periods when water in those channels is appropriately shallow. This may be especially true when narrower channels are in close proximity to high-value foraging locations such as wet meadows (Sparling and Krapu 1994). Flow per unit of channel width is an indirect measure of average channel depth and is an important metric to consider, one that has never been evaluated directly. Sandhill Cranes respond to changes in flow by adjusting where they roost within the channel. Davis (2001) indicated that Sandhill Cranes use narrow channels—those that are normally too deep for roosting—during periods of low flows and have been observed roosting in shallow water areas adjacent to islands, on top of cleared islands, and in grasslands adjacent to the river during periods of high flows. In March 2017, flows exceeded 100 cms (3550 cfs) and the majority of the Sandhill Cranes roosted on land, forgoing the river during a period of high winds that created white-capped waves in the main channel of the Platte River (Platt River Whooping Crane Maintenance Trust, Brice Krohn, Vice President, personal communication).

We found that suitable areas within the river channel for Sandhill Crane roosts are identified not only by unobstructed visibility but partially by water depth as well, which is similar to the results of a few other studies (Folk and Tacha 1990, Norling et al. 1992, Kinzel et al. 2009). Although Pearse et al. (2017) were unable to establish a link between their surrogate measure of water depth and Sandhill Crane roost-site selection, average maximum daily flows at Grand Island during the spring staging season were more than 50 cms (~1750 cfs) higher during our study period than they were during the time frame of the Pearse et al. (2017) study (100 cms in 2007–2017 vs. 45 cms in 2001–2005). Similarly, average daily flows at Grand Island during the spring staging season were nearly 25 cms (900 cfs) higher during our study period than they were during the Pearse et al. (2017) study period (51 cms [1791 cfs] and 26 cms [921 cfs], respectively). The difference in how the flow-to-depth relationship was estimated and included within the model sets and the very different ranges of flow observed during our study and the Pearse et al. (2017) study likely account for the differences in conclusions between the 2 studies about the importance of flow-to-depth relationships to roost-site selection by Sandhill Cranes along the central Platte River. Kinzel et al. (2009) predicted the area of suitable depth for crane roosts as a nonlinear relationship of river stage in which moderate flows corresponded to the greatest roost area. Likewise, Farmer et al. (2005) reported varying relationships between river discharge and available habitat for roosting Whooping Cranes (*Grus americana*), depending partially on channel width along the Platte River.

Our results suggest that flows between 0.0361 cms/m and 0.1420 cms/m of total unvegetated channel width of all channels would maximize selection ratios for medium and large Sandhill Crane groups. This equates to a flow of approximately 13.65 cms (482 cfs; lowest flows observed) to 39.05 cms (1379 cfs) for channel widths of medium and large Sandhill Crane roosts (~275 m); flows above these levels reduce habitat availability. Channels of these widths typically occur in areas that have been managed on a near-annual basis, such as the Rowe Sanctuary and properties of the Platte River Whooping Crane Maintenance Trust and the Platte River Recovery Implementation Program. Similarly, Kinzel et al. (2005) examined results at several stream flows and reported that the largest amount of available roosting habitat in channels that are generally 250 m wide occurs when the stream flow is about 35–40 cms (~1200–1400 cfs). Prince (1990) and Simons and Associates Inc. (1990), who used a Geographic Information System and hydraulic modeling approach, also estimated that optimum flows for Sandhill Crane roosting habitat were between 30 cms and 40 cms. Based on several models originally developed by the Platte River Management Joint Study Biology Workgroup (1990), optimum flows for Sandhill Crane roosting habitat on the Platte River near Grand Island, Nebraska, were generally between 30 cms and 50 cms. Currier and Eisel (1984), however, concluded that marginal roosting habitat was available on the central Platte River at lower flows (i.e., ≤30 cms), while adequate and ideal habitat was provided at the highest flows (i.e., ≥57 cms) within a 150-m-wide channel required by Sandhill Cranes, but these assessments were based on qualitative judgements rather than on statistical analyses (Safina et al. 1989).

Our results further clarify the dynamics of Sandhill Crane roosting habitat in relation to channel width and water depth as a factor of discharge along the Big Bend of the Platte River. Integrating our research with the existing literature can allow a specific target range of flows based on the management objective of optimizing Sandhill Crane habitat during the spring migration period. Relatively high summer flows that maintain the ecological integrity of wet meadows, which are important foraging areas for Sandhill Cranes (Currier 1990, Sparling and Krapu 1994, Currier and Henszey 1996), also maintain fish spawning habitat during summer months (Poff et al. 1997) and reduce the need for mechanical maintenance of riverine systems by preventing woody and exotic plant establishment within the high banks (Williams 1978, Currier 1997, Johnson 1997). While our flow estimates are lower than most reported in the existing literature (Currier and Eisel 1984, Kinzel et al. 2005), our findings are best applied and understood in the context of the Platte River ecosystem as a whole. They should be interpreted in the context of extensive riverine management that has maintained river segments at historically more similar but artificially wide MUCWs, given current hydrological conditions (Williams 1978, Currier 1997, Pfeiffer and Currier 2005). It is also important to note that our analyses of unobstructed channel width measurements suggest that regardless of flow, wide unvegetated channel widths represent selected roosting habitat for both medium and large Sandhill Crane roosts, which make up the majority of Sandhill Cranes counted along the Big Bend Reach of the Platte River. Sustained flows during the summer months help maintain these wide-open channels. Reserving and retiming flows that are not necessary during Sandhill Crane and Whooping Crane migrations to meet the aforementioned objectives may provide tangible ecological benefits to both species and save conservation resources by reducing the need for mechanical intervention to maintain wide channels during and following dry summers.

Acknowledgments

We thank all members of the Platte River Recovery Implementation Program's Technical Advisory Committee for their helpful and insightful comments. The Platte River Whooping Crane Maintenance Trust, the U.S. Fish and Wildlife Service Rainwater Basin Joint Venture, and the Platte River Recovery Implementation Program provided funding for this research.

LITERATURE CITED

ARMBRUSTER, M.J., AND A.H. FARMER. 1982. Draft Sandhill habitat suitability model. Pages 136–143 *in* J.C. Lewis, editor, Proceedings of the 1981 Crane Workshop. National Audubon Society, Tavernier, FL.

ARTHUR, S.M., B.E. MANLY, L.L. MCDONALD, AND G.W. GARNER. 1996. Assessing habitat selection when availability changes. Ecology 77:215–227.

BAASCH, D.M., P.D. FARRELL, J.M. FARNSWORTH, AND C.B. SMITH. 2017. Nest-site selection by interior Least Terns and Piping Plovers at managed, off-channel sites along the Central Platte River in Nebraska, USA. Journal of Field Ornithology 88:236–249.

BAASCH, D.M., A.J. TYRE, S.E. HYGNSTROM, J.J. MILLSPAUGH, K.M. ESKRIDGE, AND K.C. VERCAUTEREN. 2010. An evaluation of three statistical methods used in resource selection modeling. Ecological Modeling 221:565–574.

BEN-AKIVA, M.E., AND S.R. LERMAN. 1985. Discrete choice analysis: theory and application to travel demand. Volume 9. MIT Press, Cambridge, MA.

BOWMAN, T.D. 2014. Aerial observer's guide to North American waterfowl: identifying and counting birds from the air. U.S. Fish and Wildlife Service, No. FW6003.

BUCKLEY, T.J. 2011. Habitat use and abundance patterns of Sandhill Cranes in the Central Platte River Valley, Nebraska, 2003–2010. Master's thesis, University of Nebraska–Lincoln, Lincoln, NE. 135 pp.

BURNHAM K.P., AND D.R. ANDERSON. 2002. Model selection and multi-model inference: a practical information-theoretic approach. 2nd edition. Springer-Verlag, New York, NY.

CARTER, N.H., D.G. BROWN, D.R. ETTER, AND L.G. VISSER. 2010. American black bear habitat selection in northern Lower Peninsula, Michigan, USA, using discrete-choice modeling. Ursus 21:57–71.

COMPTON, B.W., J.M. RHYMER, AND M. MCCOLLOUGH. 2002. Habitat selection by wood turtles (*Clemmys insculpta*): an application of paired logistic regression. Ecology 83:833–843.

COOPER, A.B., AND J.J. MILLSPAUGH. 1999. The application of discrete choice models to wildlife resource selection studies. Ecology 80:566–575.

CURRIER, P.J. 1982. The floodplain vegetation of the Platte River: phytosociology, forest development, and seedling establishment. Doctoral dissertation, Iowa State University, IA.

CURRIER, P.J. 1990. Plant species composition and groundwater levels in a Platte River wet meadow. Pages 19–24 *in* Proceedings of the 11th North American Prairie Conference (1988), Lincoln, NE.

CURRIER, P.J. 1997. Woody vegetation expansion and continuing declines in open channel habitat on the Platte River in Nebraska. North American Crane Workshop Proceedings. 210. http://digitalcommons.unl.edu/nacwgproc/210

CURRIER, P.J., AND L.M. EISEL. 1984. The impact of flow level on Sandhill Crane and Whooping Crane roosting habitat on the Platte River, Nebraska. Whooping Crane Habitat Maintenance Trust, Grand Island, NE.

CURRIER, P.J., AND R.J. HENSZEY. 1996. Platte River wet meadows: a primer on their flora, fauna, hydrology, management, and restoration. August 1996 draft submitted to the U.S. Fish and Wildlife Service, Grand Island, NE. 25 pp.

DAVIS, C.A. 2001. Nocturnal roost site selection and diurnal habitat use by Sandhill Cranes during spring in central Nebraska. North American Crane Workshop Proceedings. 52. http://digitalcommons.unl.edu//nacwgproc/52

DAVIS, C.A. 2003. Habitat use and migration patterns of Sandhill Cranes along the Platte River, 1998–2001. Great Plains Research 13:199–216.

DORMANN, C.F., J. ELITH, S. BACHER, C. BUCHMANN, G. CARL, G. CARRÉ, J.R.G. MARQUÉZ, B. GRUBER, B. LAFOURCADE, P.J. LEITÃO, ET AL. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36:27–46.

DUBOVSKY, J.A. 2016. Status and harvests of Sandhill Cranes: Mid-Continent, Rocky Mountain, Lower Colorado River Valley and Eastern populations. Administrative Report, U.S. Fish and Wildlife Service, Lakewood, CO. 15 pp.

FAANES, C.A., AND M.J. LEVALLEY. 1993. Is the distribution of Sandhill Cranes on the Platte River changing? Great Plains Research 3:297–304.

FARMER, A.H., B.S. CADE, J.W. TERRELL, J.H. HENRIKSEN, AND J.T. RUNGE. 2005. Evaluation of models and data for assessing Whooping Crane habitat in the central Platte River, Nebraska. U.S. Geological Survey Scientific Investigations Report 2005-5123, Reston, VA.

[FERC] FEDERAL ENERGY REGULATORY COMMISSION. 1994. Revised draft environmental impact statement. Washington, DC.

FOLK, M.J., AND T.C. TACHA. 1990. Sandhill Crane roost site characteristics in the North Platte River Valley. Journal of Wildlife Management 54:480–486.

GREGORY, R.D., D.W. GIBBONS, AND P.F. DONALD. 2004. Bird census and survey techniques. Pages 17–56 *in* W.J. Sutherland, I. Newton, and R. Green, editors, Bird ecology and conservation: a handbook of techniques. Techniques in Ecology and Conservation Series. Oxford University Press, Oxford.

HASTIE, T.J., AND R.J. TIBSHIRANI. 1990. Generalized additive models. Volume 43. Chapman and Hall/CRC, London.

HOWLIN, S., W.P. ERICKSON, AND R.M. NIELSON. 2004. A validation technique for assessing predictive abilities of resource selection functions. Pages 40–51 *in* S. Huzurbazar, editor, Proceedings of the Symposium on Resource Selection Methods and Applications. Omnipress, Madison, WI.

IVERSON, G.E., P.A. VOHS, AND T.E. TACHA. 1987. Habitat use by mid-continent Sandhill Cranes during spring migration. Journal of Wildlife Management 51: 448–458.

JOHNSGARD, P.A. 2002. Nebraska's Sandhill Crane populations, past, present and future. Nebraska Bird Review 70(4):175–178. https://digitalcommons.unl.edu/nebbirdrev/338/

JOHNSON, W.C. 1997. Equilibrium response of riparian vegetation to flow regulation in the Platte River, Nebraska. River Research and Applications 13: 403–415.

KINZEL, P.J., J.M. NELSON, AND A.K. HECKMAN. 2009. Response of Sandhill Crane (*Grus canadensis*) riverine roosting habitat to changes in stage and sandbar morphology. River Research and Applications 25: 135–152.

KINZEL, P.J., J.M. NELSON, AND R.S. PARKER. 2005. Assessing Sandhill Crane roosting habitat along the Platte River, Nebraska. USGS Fact Sheet 2005-3029. U.S. Geological Survey, Denver, CO.

KRAPU, G.L., D.A. BRANDT, K.L. JONES, AND D.H. JOHNSON. 2011. Geographic distribution of the mid continent population of Sandhill Cranes and related management applications. Wildlife Monographs 175: 1–38.

KRAPU, G.L., D.A. BRANDT, P.J. KINZEL, AND A.T. PEARSE. 2014. Spring migration ecology in the mid-continent population of Sandhill Cranes with an emphasis on the central Platte River Valley, Nebraska. Wildlife Monographs 189:1–41.

KRAPU, G.L., D.E. FACEY, E.K. FRITZELL, AND D.H. JOHNSON. 1984. Habitat use by migrant Sandhill Cranes in Nebraska. Journal of Wildlife Management 48: 407–417.

KRAPU, G.L., G.C. IVERSON, K.J. REINECKE, AND C.M. BOISE. 1985. Fat deposition and usage by Arctic-nesting Sandhill Cranes during spring. Auk 102: 362–368.

KRAPU G.L., K.J. REINECKE, AND C.R. FRITH. 1982. Sandhill Cranes and the Platte River. Transactions of the North American Wildlife and Natural Resources Conference 47:542–552.

KRUSE, K.L., AND J.A. DUBOVSKY. 2015. Status and harvests of Sandhill Cranes: Mid-Continent, Rocky Mountain, Lower Colorado River Valley and Eastern Populations. Administrative Report, U.S. Fish and Wildlife Service, Lakewood, CO. 14 pp.

LATKA, D.C., AND J.W. YAHNKE. 1986. Simulating the roosting habitat of Sandhill Cranes and validation of suitability-of-use indices. *In:* J. Vemer, M.L. Morrison, and C.J. Ralph, editors, Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, WI.

LEWIS, J.C. 1976. Roost habitat and roosting behavior of Sandhill Cranes in the southern Central Flyway. Pages 93–104 *in* J.C. Lewis, editor, Proceedings of the International Crane Workshop. International Crane Foundation, Stillwater, OK.

MCCRACKEN, M.L., B.F.J. MANLY, AND M. VANDER HEYDEN. 1998. The use of discrete choice models for evaluating resource selection. Journal of Agricultural, Biological, and Environmental Statistics 3:268–279.

MCDONALD T.L., B.F.J. MANLY, R.M. NIELSON, AND L.V. DILLER. 2006. Discrete-choice modeling in wildlife studies exemplified by Northern Spotted Owl nighttime habitat selection. Journal of Wildlife Management 70:375–383.

MURPHY, P.J., T.J. RANDLE, L.M. FOTHERBY, AND J.A. DARAIO. 2004. Platte River channel: history and restoration. Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group, Denver, CO.

NORLING, B.S., S.H. ANDERSON, AND W.A. HUBERT. 1990. The influence of water depth, unobstructed area, and disturbance features on the selection of roost sites by Sandhill Cranes along the Platte River, Nebraska. Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, WY. 104 pp.

NORLING, B.S., S.H. ANDERSON, AND W.A. HUBERT. 1992. Roost sites used by Sandhill Crane staging along the Platte River, Nebraska. Great Basin Naturalist 52:253–261.

PARRISH, T.L., W.A. HUBERT, S.H. ANDERSON, M. PUCHERELLI, AND W. MANGUS. 2001. Distributions of roosting Sandhill Cranes as identified by aerial thermography. Prairie Naturalist 33:93–99.

PEARSE, A.T., G.L. KRAPU, AND D.A. BRANDT. 2017. Sandhill Crane roost selection, human disturbance, and forage resources. Journal of Wildlife Management 81:477–486.

PFEIFFER, K., AND P.J. CURRIER. 2005. An adaptive approach to channel management on the Platte River. Pages 151–154 *in* F. Chavez-Ramirez, editor, Proceedings of the Ninth North American Crane Workshop, January 17–20, 2003. North American Crane Working Group, Sacramento, CA.

PLATTE RIVER MANAGEMENT JOINT STUDY BIOLOGY WORKGROUP. 1990. Biology Work Group – Final Report, July 20, 1990. Denver, CO.

POFF, N.L., J.D. ALLAN, M.B. BAIN, J.R. KARR, K.L. PRESTEGAARD, B.D. RICHTER, R.E. SPARKS, AND J.C. STROMBERG. 1997. The natural flow regime. BioScience 47:769–784.

PRINCE, H.H. 1990. Status and ecology of Sandhill Cranes in the Platte River Valley and relation to FERC Projects 1417 and 1835 and addendum responding to agency comments. *In*: Appendix X, Sandhill Cranes. Central Nebraska Public Power and Irrigation District and Nebraska Public Power District, Holdrege, NE.

R DEVELOPMENT CORE TEAM. 2015. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

SAFINA, C., L. ROSENBLUTH, C. PUSTMUELLER, K. STROM, R. KLATASKE, M. LEE, AND J. BEYEA. 1989. Threats to wildlife and the Platte River. Environmental Policy Analysis Department Report #33. [Accessed 13 July 2017]. http://cwcbweblink.state.co.us/WebLink/PDF/odz3xg45eh3yjr55am4vof45/1/Threats%20to%20Wildlife%20and%20the%20Platte%20River.pdf.

SIDLE, J.G., H.G. NAGEL, R. CLARK, C. GILBERT. D. STUART, K. WILLBUM, AND M. ORR. 1993. Aerial thermal infrared imaging of Sandhill Cranes on the Platte River, Nebraska. Remote Sensing of Environment. 43:333–341.

SIMONS AND ASSOCIATES INC. 1990. Geographic information system/hydraulic analysis of Sandhill Crane habitat (preliminary assessment). Simons and Associates Inc., Fort Collins, CO.

SIMONS AND ASSOCIATES INC. AND URS GREINER WOODWARD CLYDE. 2000. Physical history of the Platte River in Nebraska: focusing upon flow, sediment transport, geomorphology, and vegetation. Prepared for Bureau of Reclamation and Fish and Wildlife Service Platte River EIS Office, dated August 2000.

SPARLING, D.W., AND G.L. KRAPU. 1994. Communal roosting and foraging behaviour of staging Sandhill Cranes. Wilson Bulletin 106:62–77.

TACHA, T.C., S.A. NESBITT, AND P.A. VOHS. 1992. Sandhill Crane. Number 31 *in* The birds of North America. Academy of Natural Sciences, Philadelphia, PA, and American Ornithologists' Union, Washington, DC.

UNGER, A.M., E.P. TANNER, C.A. HARPER, P.D. KEYSER, F.T. VAN MANEN, J.J. MORGAN, AND D.L. BAXLEY. 2015. Northern Bobwhite seasonal habitat selection on a reclaimed surface coal mine in Kentucky. Journal of the Southeastern Association of Fish and Wildlife Agencies 2:235–246.

[USFWS] UNITED STATES FISH AND WILDLIFE SERVICE. 1981. The Platte River ecology study. Special research report. Jamestown, ND.

VOGEL, J.R., D.W. GRIFFIN,, H.S. IP, N.J. ASHBOLT, M.T. MOSER, J. LU, AND J.W. SANTO DOMINGO. 2013. Impacts of migratory Sandhill Cranes (*Grus canadensis*) on microbial water quality in the Central Platte River, Nebraska, USA. Water, Air, and Soil Pollution 224:1576.

WERBYLO, K.L., J.M. FARNSWORTH, D.M. BAASCH, AND P.D. FARRELL. 2017. Investigating the accuracy of estimated unvegetated channel widths in a braided river system: a Platte River case study. Geomorphology 278:163–170.

WILLIAMS, G.P. 1978. The case of the shrinking channels: the North Platte and Platte Rivers in Nebraska. Volume 781. Department of the Interior, Geological Survey.

WOOD, S. 2006. Generalized additive models: an introduction with R. Chapman and Hall/CRC, New York, NY. https://doi.org/10.1201/9781420010404

Received 19 June 2018
Revised 23 August 2018
Accepted 5 September 2018
Published online 23 April 2019