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APPENDIX A

Aerial Thermal Infrared Imaging of Sandhill Cranes on the Platte River, Nebraska

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We counted sandhill cranes on thermal infrared images recorded by the Nebraska Air National Guard's AN/AAD-5 infrared reconnaissance system above the Platte River, Nebraska, in March and April 1989. Individual cranes roosting in the river at night were readily visible on the imagery. Cranes roosted in channel widths averaging 150 m, and there was a correlation between roost site and distance to wetland meadow. Wide channels and wetland meadows have declined greatly. The AN/AAD-5 can be used to supplement current sandhill crane population and habitat monitoring.

INTRODUCTION

Attempts to resolve large aquatic birds on aerial thermal infrared imagery have yielded mixed results. The technique is not well established for the monitoring of waterfowl and other large water birds. Best (1981) and Best et al. (1982) used a Daedalus thermal scanner and distinguished Canada geese (*Branta canadensis*), which measure 56–122 cm in length, from a background of water and ice on aerial thermal infrared imagery of reservoirs in South Dakota. However, they believed that the visual interpretation of Canada geese on their imagery was often subjective due to the small size of the Canada geese and lack of temperature contrast under certain environmental conditions.

Pucherelli (1985; 1988) successfully detected sandhill cranes (*Grus canadensis*) (86–122 cm in length) along the Platte River with an undescribed and classified sensor in a privately owned aircraft. Faced with the task of resolving sandhill cranes roosting at night along the Platte River, Nebraska, we employed, in 1989, the Nebraska Air National Guard's infrared reconnaissance system, then a still somewhat classified device (now declassified). The sensor supposedly had better resolution and other characteristics than the Daedalus thermal scanner.

The objectives of this study were to test the utility of a military infrared sensor to detect roost-

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ing sandhill cranes and apply observed sensor performance to the conservation of sandhill crane habitat along the central Platte River. We sought to determine factors that influence the nocturnal distribution of sandhill cranes. We tested the null hypotheses that variation in channel width, river braiding, number of channels, number of islands, and the distance of roost to nearest wetland meadow and bridge had no influnce on number of cranes or number of roosts in river segments. The sandhill crane data obtained from the military sensor should assist regulatory efforts to protect the Platte River (Federal Energy Regulatory Commission, 1992).

STUDY AREA AND METHODS

The Platte River

Most of the North American sandhill crane population (400,000 +) spends 4–6 weeks in the Platte and North Platte River valleys during March and early April (Benning and Johnson, 1987; Iverson et al., 1987; Folk and Tacha, 1991). The cranes roost in the river channel at night (Frith, 1974; Norling et al., 1991) and are often concentrated in flocks of over 10,000. During the day they are scattered, within 5 km of the river, in cropland, grassland, hayland, and wetland meadow, where they feed on invertebrates and high energy foods, such as corn, necessary for reproduction (Krapu et al., 1985; Tacha et al., 1987).

Major roosting areas on the Platte River are between Lexington and Highway 34, east of Grand Island (USFWS, 1981). The distribution of roost sites on the Platte River is viewed often as a function of channel habitat features such as isolation from human disturbance, wide channels with sparsely vegetated shorelines, and shallow water (Frith, 1974; Lewis, 1974; Iverson et al., 1987; Krapu et al., 1982, USFWS, 1981).

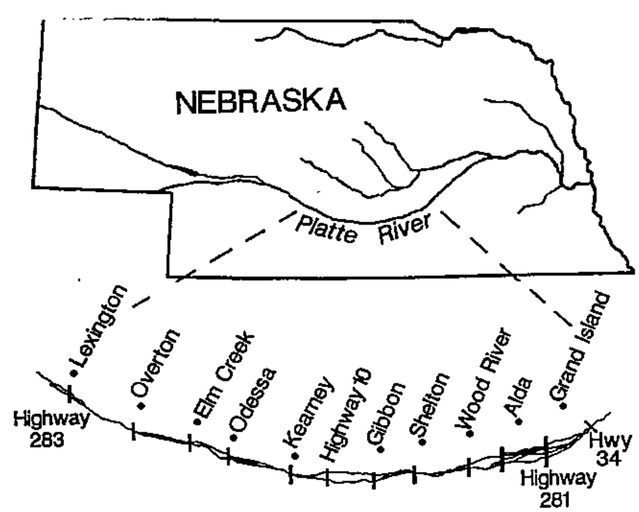
Channel width has decreased dramatically because of ecological changes wrought by reservoir storage and water diversions in Colorado, Wyoming, and western Nebraska for irrigated agriculture and electrical power generation (Eschner et al., 1981; Currier et al., 1985; Hadley and Eschner, 1981; Williams, 1978). A broad band of mature deciduous woodland now occurs where a wide, largely unvegetated, and active channel once occurred (Johnson, 1990; Sidle et al., 1989; USFWS, 1981). Wetland meadows, areas important to sandhill crane pair bond formation and a major source of invertebrates, have declined greatly.

Infrared Imagery

The Nebraska Air National Guard (155th Tactical Reconnaissance Group), Lincoln, Nebraska, recorded the Platte River between U.S. Highway 283 near Lexington and U.S. Highway 281 near Grand Island (Fig. 1) with an AN / AAD-5 infrared reconnaissance system (Loral Infrared and Imaging Systems, Lexington, Massachusetts) on 28 March and 5 April 1989. The weather was clear on 28 March, the winds were light and variable, and the day's temperature was a high of 22.2°C and a low of 4.4°C. On 5 April it was partly cloudy, the winds were light and east / southeast, and the temperature was a high of 15.5°C and a low of −2.2°C.

The AN / AAD-5 system is an infrared sensor on board a reconnaissance F-4 phantom jet (RF-4C) (U.S. Air Force Flight Manuals TO 1F-4(R)C-1 and TO 1F-4(R)C-1-2). The infrared system provides a high-resolution film map of the terrain directly beneath the aircraft. A scanning optical system, consisting of a four-sided scanning mirror, folding mirrors, and parabola, focuses infrared radiation upon two detector arrays for narrow (60°) field of view (30° on both sides of nadir

Figure 1. The central segment of the Platte River, Nebraska.



transverse to ground track) and wide (120°) field of view. The detector arrays are enclosed in a vacuum-sealed Dewar assembly and maintained at approximately −193°C by a cryogenic refrigerator, a closed-cycle nitrogen cooling system. The detectors are made of mercury–cadmium telluride and are sensitive to infrared radiation over the 3–12 μm wavelength interval.

Detected energy is processed and displayed on a 13-cm (5-in.) cathode-ray tube as video. The video is then reflected and focused by an optical system and recorded on 13-cm Kodak RAR2494 film as a continuous map of the terrain. The film is blue-sensitive, medium resolution with an Estar AH base, and designed for recording images from cathode-ray tubes. The film magazine holds 106 m of film. Film transport speed is determined by a velocity-to-height ratio signal from the Aircraft Parameter Control. Auxiliary parameters, such as latitude and longitude and radar altitude, are recorded once every 0.3 m of film in a small data block.

The AN/AAD-5 gives continuous coverage of the ground radiation for all changes in temperature and pressure between the altitudes of 152 m and 15,240 m and for all velocity-to-height ratios between 0.6 rad/s and 0.05 rad/s in narrow field of view and for all velocity-to-height ratios between 2.4 rad/s and 0.05 rad/s in the wide field of view. The airborne resolution is 0.375 mrad for 60° field of view and 0.75 mrad for 120° field of view. The noise equivalent temperature is not >0.2°C when measured against a 300°K background for targets large enough to fill the instantaneous field of view (IFOV). At 400 m, the above ground altitude flown, the IFOV is 0.14 m (60° field of view) and 0.29 m (120° field of view). The thermal sensitivity is at least 1.5°K when measured against a 300°K background for targets the same size as the IFOV. Geometric fidelity errors across track are <15% at least 80% of the time. Errors are determined using distances between points on the film >0.64 cm and <5.1 cm. The Daedalus thermal scanner used by Best et al. (1982) had a wave band of 8.7–11.5 μm, a minimum resolvable temperature of 0.5°C, and a spatial resolution of 2.5 mrad, features inferior to those of the AN/AAD-5.

The aircraft began recording at 7:15 p.m. CST on 28 March and 7:50 p.m. CST on 5 April and was traveling at about 300 knots. The pilot navigated over the Platte River with the aid of on-board forward looking radar.

Analysis of Imagery

We divided the river into 10 segments using bridges as dividers (Fig. 1) and calculated standard distances of the segments using U.S. Geological Survey 7.5 minute series quadrangle maps (1962). A scale (cm/1.6 km) was obtained for each of the river segments to compensate for varying aircraft altitude recorded on the imagery, and to determine the average density of cranes in each bridge segment.

We counted cranes using a Bausch & Lomb dissecting binocular microscope with 0.7×–3.0× magnification and a Whipple Disk inserted into the eyepiece. The microscope was placed over the film on a light table. An area of 5 mm × 5 mm was utilized within the Whipple Disk. For example, using the scale obtained from the 5 April 1989 imagery of the Highway 10 to Gibbon segment, the area on the Whipple Disk equaled an area of 18.7 m × 18.7 m (350 m^2) on the infrared imagery. The river segments, Lexington to Overton, Highway 10 to Gibbon, and Wood River to Alda, were used to calculate the average density of cranes. These segments represent low and high concentrations of cranes.

Six samples of roosting sites were taken for each of the above three river segments. The number of cranes within the area designated by the Whipple Disk were counted. An average of the six samples was computed, and this number was divided into the corresponding area on the film. An average density of one crane per 3.5 m^2 was calculated. This is similar to the one crane per 3.3 m^2 value reported by Pucherelli (1985; 1988) from nighttime aerial thermography. The area of roosting sites was determined with a dot-grid overlay. The number of cranes per roost site was calculated by dividing the total area of the roost by 3.5 m^2. A roost had to be separated by at least 100 m from another roost to be considered a separate roost (Iverson et al., 1987).

The Platte River can consist of many channels in a given segment. River channel width at roost sites was width of the channel with an unobstructed view. At least three measurements of channel width were taken along the length of the roost and averaged.

River channel anabranching data (number of channels), as well as the distance from crane roost to wetland meadow, were measured from aerial color infrared photographs (1:24,000) taken on 1 November 1984. The segments of river examined on the photography corresponded to the examined segments on the infrared imagery. Using the standard distances of river segments, a scale was calculated for each river segment. The distance from two bridges was measured in centimeters and divided by the standard distance of the segment.

We defined wetland meadow after Currier (1982), and island, braiding, and braiding index after Williams (1978). Our definition of a channel was any branch $\geq$24 m. The number of cranes found roosting in channels narrower than 24 m was negligible. A 1.6-km segment of river under analysis was divided into three equal parts. The number of channels was counted where the transects divided the segment and then averaged.

We used the ABSTAT statistical program on an IBM computer for correlations, multiple regression analyses, and descriptive statistics. The ABSTAT stepwise forward regression begins with the independent variable that has the highest correlation with the dependent variable. At each step the program adds the specified independent variable that would add most to the coefficient of determination (R^2). The program adds a variable only if its probability is not greater than the limit the user specifies. At each step, the program will remove any independent variables already included which have a probability greater than that same limit.

RESULTS AND DISCUSSION

Infrared Imagery

There was enough thermal contrast between the infrared emissivity of the river and the temperature of sandhill crane feathers to distinguish cranes from their background. Roosting cranes were easily visible as small gray dots (Fig. 2). The AN-AAD-5 system detected cranes in small and large groups. However, the aircraft's banking at bends in the river caused distortion, and cranes could not be resolved. An image motion compensator reduces image distortion, but beyond 20° of aircraft roll the capabilities of the compensator are exceeded, the system no longer looks straight down, and the recorded imagery is not usable.

Detection of cranes with the AN/AAD-5 has not always been successful. Cranes could not be resolved on some imagery of the Platte River in 1988. Degraded images can occur if the selected field of view is incorrect for the velocity to height ratio signal. Erroneous velocity to height information from either a malfunctioning altimeter or inertial navigation system (ground speed) will also degrade the imagery. Poor navigation sometimes did not put the aircraft over the river. Other conditions such as thermal crossover, humidity, wind, and alignment of the AN/AAD-5 system may have degraded some of the imagery.

Analysis of Imagery

We estimated a total of 455,241 cranes, 169,391 on 28 March 1989 and 285,850 on 5 April 1989 (Table 1). Solberg (1990) estimated 326,995 (±51,349) cranes in the Platte River valley from a daytime aerial visual count along transects on 28 March. Our estimate is different than Solberg's (1990) probably because all of the cranes had not returned to the river by the time of the Air National Guard jet's passage. The 5 April estimate is greater than the 28 March estimate probably because the aircraft passed overhead at 7:50 p.m. CST, later than 7:15 p.m. on 28 March. Both times are less than 1 h after sunset. Cranes continue to flock to the river for over 1 h after sunset. In addition, we may have missed some cranes because of image distortion at river bends. Moreover, the aircraft did not fly over the north and middle channels of the river between Alda and Highway 281, where several thousand cranes were observed roosting during the early morning of the day after the flights. Nor did the aircraft record between Highway 34 and Highway 281, where tens of thousands of cranes also were observed roosting on the day after the flights.

The mean channel width at roost sites was 150 m. About 68% of the cranes were in channel widths greater than 150 m (Table 2). There were not many roosts in very wide channels because few such widths were available. The average braiding index of 3.24 indicates that the sum of the lengths of all the islands in a 1.6 km (1 mile) reach was more than three times the length of the reach. The average number of islands per 1.6

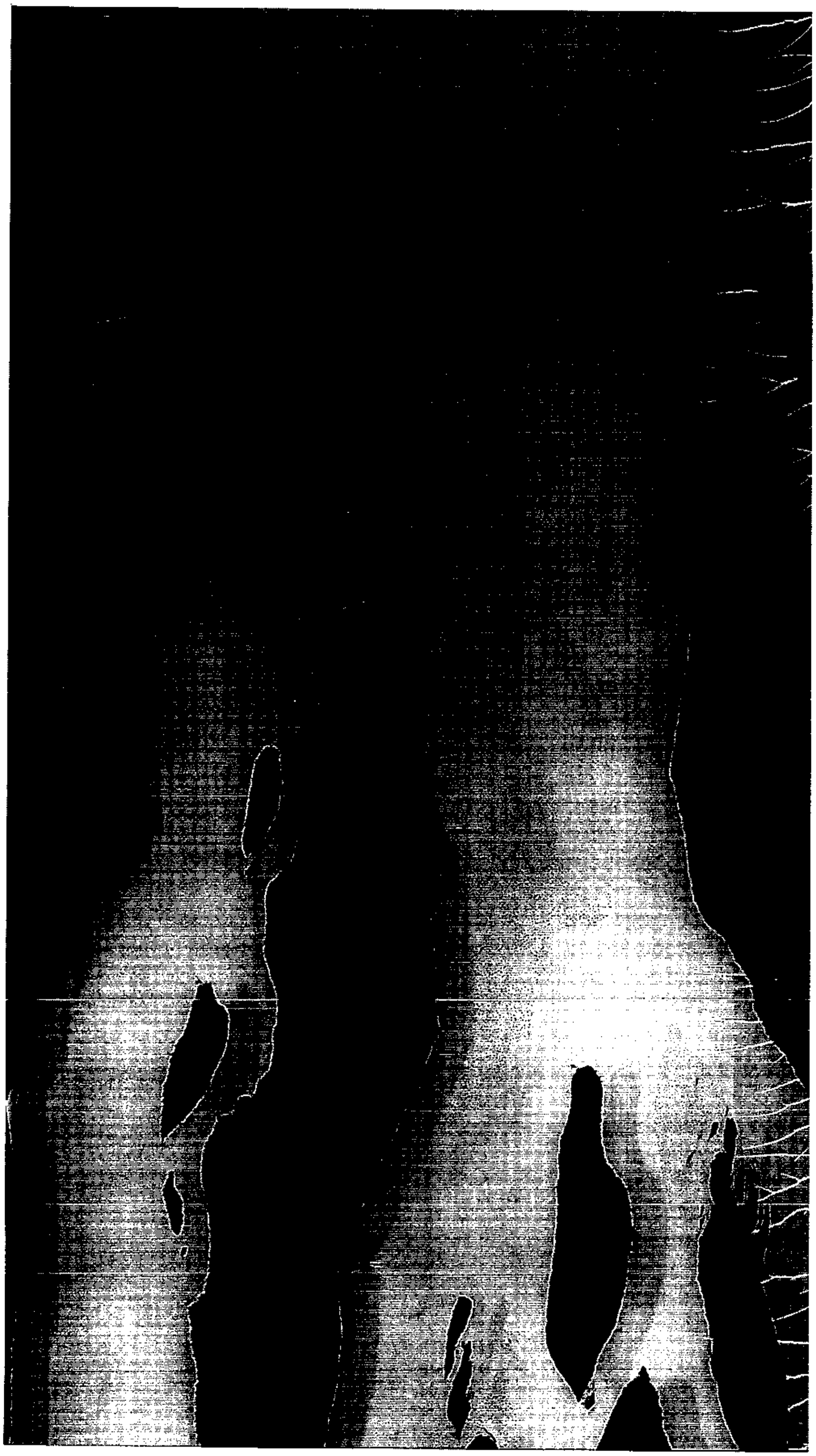


Figure 2. Roosting sandhill cranes appear as small dots on this nighttime thermal infrared image of the Platte River at U.S. Army Corps of Engineers river mile 197 (T9N R13W, Section 34, Buffalo County, Nebraska) (image by 155th Tactical Reconnaissance Group, Nebraska Air National Guard).

Table 1. Total Number of Sandhill Cranes Counted per Bridge Segment (Fig. 1) on Aerial Thermal Infrared Imagery on 28 March and 5 April 1989 on the Platte River between Lexington and U.S. Highway 281 near Grand Island

River Segment	*Cranes*	*% Cranes*	*Cranes / 1.6 km*
Lexington–Overton	16,963	3.7	1,462
Overton–Elm Creek	2,850	0.6	331
Elm Creek–Odessa	36,397	8.0	5,352
Odessa–Kearney	1,821	0.4	192
Kearney–Highway 10	24,048	5.3	3,340
Highway 10–Gibbon	110,046	24.2	20,008
Gibbon–Shelton	48,018	10.5	7,622
Shelton–Wood River	87,893	19.3	9,876
Wood River–Alda	54,324	11.9	10,060
Alda–Highway 281	72,881	16.0	11,212
Total	455,241		

km was 17, and so the total length of 17 islands averaged 5.2 km. The number of channels per 1.6 km averaged 4.32. The distance to the nearest wetland meadow averaged 818 m, and the mean distance from bridges to the roost site was 2908 m. The mean number of cranes per 1.6 km was 5544.

Stepwise multiple regression with number of crane roosts (RO) as the dependent variable showed distance to wetland meadow (WM), number of islands (IS), and number of channels (CH) to be significant ($P = 0.05$) (Tables 3 and 4). Channel width (CW) and braiding index (BI) were nearly significant ($P = 0.08$) and distance to bridges (BR) did not produce a significant effect.

Five independent variables accounted for 33% of the variation in number of crane roosts (RO) per 1.6 km. Distance to wetland meadow (WM) was most highly correlated with roost location, was therefore entered first into the regression, and accounted for 18.3% of the variation in crane roosts. The combined effect of the other four variables added only 15% predictability to roost numbers. However, there was a high degree of multicollinearity between several of the independent variables (Table 4). For example, WM and channel width produced a correlation coefficient of -0.4507 and with CH a value of 0.3504. If either variable was entered first, they would have accounted for much of the variation predicted by WM.

Cranes use wetland meadows for feeding, loafing, and courtship, and often congregate there before entering the river at dusk. Most studies indicate that cranes prefer wide channels for roosting. A large number of islands would reduce overall CW. CW did not produce a significant effect, possibly because WM was more closely correlated to CW than to CH (-0.4507 vs. 0.3504) and WM removed the same variability as did CW. IS was not highly corrrelated (0.0756) but still produced a significant effect in the regression.

Norling et al. (1990) suggested that roost sites near islands may contain a greater proportion of suitable water depths for roosting than sites adjacent to river banks. Although distance to bridges (BR) has been shown to be a significant factor in the distribution of the number of crane roosts (RO) (Norling et al., 1990), we found a correlation coefficient of only -0.1058, and bridges were excluded from the regression equation. Most

Table 2. Abundance of Sandhill Cranes in Relation to Channel Width along the Platte River, 28 March and 5 April 1989

Channel Width (m)	*No. Roosts*	*Cranes / Roost*	*% Cranes*
0–30	5	168	0.19
30–60	78	270	4.96
60–91	86	314	6.37
91–122	83	371	7.26
122–150	94	655	14.52
150–183	131	462	14.26
183–213	152	689	24.70
213–244	113	615	16.37
244–274	74	402	7.01
274–305	29	395	2.70
305–335	8	221	0.42
335–366	2	2596	1.23

Table 3. Stepwise Multiple Regression[a] of Roosts per 1.6 km on Independent Variables Listed in Order of Entry

Independent Variable	*Sum* R^2	*Regression Coefficient*	*Probability*	*Correlation Coefficient*
Wetland meadow	0.183	−0.0013	0.0058	−.4281
Channel width	0.225	0.0096	0.0834	.3753
Number of islands	0.264	0.3743	0.0141	.0756
Number of channels	0.303	−3.2089	0.0082	−.2740
Braiding index	0.330	2.0555	0.0843	−.1058

[a] In this forward selection regression in the ABSTAT program, probability value to add / remove variables was 0.200, which removed bridges as an independent variable. The coefficient of determination for the multiple regression was 0.329, the adjusted R^2 was 0.285, and the multiple correlation coefficient was 0.574. ANOVA for the multiple regression produced an F of 7.472 ($P = 0.00001$, $N = 82$).

roosts were several kilometers from a bridge, so we did not expect a highly significant effect from BR.

The stepwise multiple regression with number of cranes (CR) as the dependent variable showed CW with the highest correlation to CR (Tables 4 and 5). This relationship has been observed in other studies (USFWS, 1981; Pucherelli, 1988; Norling et al., 1990), and is further supported by our measurements of channel widths (Table 2). CW explained 11% of the variation in CR. Variation in IS explained more variability in CR than did CW (Table 5) probably because of the availability of proper water depths near islands (Norling et al., 1990). CH explained about 11% of the variability. CH was negatively related to CR, indicating that where the Platte River occurs in many channels cranes do not roost in large numbers.

Several independent variables become significant when CW is left out of the regression. IS (16% of variation accounted for), WM (15%), and BI (2%) produce significant effects. Multicollinearity between CW and WM and CW and BI caused these two variables to be eliminated when CW was entered first.

The channel width used by cranes was similar to that reported by others (USFWS, 1981; Pucherelli, 1988). Pucherelli (1988) found that 88% of

Table 4. Correlation Matrix of Dependent and Independent Variables Associated with Sandhill Crane Roosting Habitat along the Platte River, Nebraska, 28 March and 5 April 1989[a]

	RO	*CW*	*BI*	*CH*	*IS*	*WM*	*BR*	*CR*
RO	1.0							
CW	0.3753	1.0						
BI	−0.0781	−0.3132	1.0					
CH	−0.0274	−0.4210	0.7965	1.0				
IS	0.0756	−0.2230	0.5198	0.5407	1.0			
WM	−0.4281	−0.4507	0.2482	0.3504	0.2002	1.0		
BR	−0.1058	−0.2488	0.1906	0.2014	0.0579	0.2784	1.0	
CR	0.6923	0.3319	−0.1385	−0.2105	0.2778	−0.2361	−0.0204	1.0

[a] Significant ($P < 0.05$) variables are underlined. Sampling units were 1.6 km. RO = number of roosting sites; CW = channel width; BI = braiding index; CH = number of channels; IS = number of islands; WM = distance to nearest wetland meadow; BR = distance to bridge; CR = number of cranes.

Table 5. Stepwise Multiple Regression[a] of Cranes per 1.6 km on Independent Variables, Listed in Order of Entry

Independent Variable	*Sum* R^2	*Regression Coefficient*	*Probability*	*Correlation Coefficient*
Channel width	0.110	9.12	0.0053	0.3319
Number of islands	0.240	454.94	0.0000	0.2778
Number of channels	0.332	−1689.47	0.0017	−0.2105

[a] Forward selection regression ABSTAT program. The probability to add/remove variables was 0.20, which removed braiding index, distance to wetland meadow, and distance to bridge. The coefficient of determination for the multiple regression was 0.332, the adjusted R^2 was 0.306, and the multiple correlation coefficient was 0.576. ANOVA for the multiple regression produced an F of 12.899 ($P = 0.00001$, $N = 82$).

the crane population detected on aerial thermography between Highway 34 and Lexington used widths of 100–400 m with a mean of 194 m. Roosts on the North Platte River, which does not provide channels as wide as the Platte River, are closer to visual obstructions and in narrower channels than on the Platte River (Folk and Tacha, 1990). Eighty-two percent of the cranes preferred a channel width ⩾48 m.

WM was correlated at almost twice the degree with number of crane roosts (RO) as with crane numbers (CR). The number of crane roosts, however, may not be representative of number of cranes. The dependent variable, number of cranes, may not be as subject to confounding by variability, and therefore may be more reliable.

Cranes along the central Platte seem to roost in a wide channel free from extensive branching, with numerous relatively small islands, and access to a nearby wetland meadow. This study, using the six predictor variables, accounted for nearly 33% of roosting crane distribution. Other variables which may account for variation in the roosting behavior of cranes are water depth, height of surrounding vegetation, and existing weather conditions at the time of roosting (Norling et al., 1990; Folk, 1989; Folk and Tacha, 1990). Folk and Tacha (1990) also suggested that upland habitats were probably important. It seems important that efforts, including ours and Folk and Tacha's (1990), to describe where cranes roost have only been able to predict <50% of variation based on river characteristics. More predictability may result when habitat complexes of river and uplands are examined (Folk and Tacha, 1990).

MANAGEMENT IMPLICATIONS

The U.S. Fish and Wildlife Service (USFWS) currently monitors crane numbers with a diurnal aerial count of feeding and loafing cranes along transects (Solberg, 1990; Benning and Johnson, 1987). If conducted properly and later at night, after all of the cranes have returned to the river, annual infrared imagery could provide a valuable check against the diurnal crane count, a precise account of roost locations, and a permanent record of yearly river habitat conditions. We recommend that the USFWS continue to work with the Nebraska Air National Guard to obtain nocturnal imagery of the cranes.

The Nebraska Air National Guard routinely trains and, in our case, was willing to use the Platte River as a training exercise. Consequently, there was no additional cost to the National Guard and no charge to the USFWS. The U.S. Bureau of Reclamation's contracted aerial thermography of the Platte River (Pucherelli, 1985; 1988) cost tens of thousands of dollars. The AN / AAD-5 system is being discontinued by the U.S. Air Force and can be loaned or transferred to public agencies.

Folk and Tacha (1990) and Tacha (1988) stated that adjacent wetland meadows should be protected through acquisition. The correlation between roost sites and wetland meadow in our study may indicate that roost site selection is dependent on availability and distance to wetland meadow. The clearing of trees to widen channels and regulatory provision of instream flows will not alone suffice for management of crane habitat. Additional acquisition and management of wetland meadows is also required to provide critical habitat elements to migrating sandhill cranes (Federal Energy Regulatory Commission, 1992; U.S. Department of the Interior 1990).

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