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Whooping Crane Stopover Site Use Intensity Within the Great Plains

Open-File Report 2015–1166

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph. Migrating whooping cranes in Beadle County, South Dakota, April 3, 2015. Photograph taken by Chris Bailey.

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SALLY JEWELL, Secretary

U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2015

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Suggested citation:
Pearse, A.T., Brandt, D.A., Harrell, W.C., Metzger, K.L., Baasch, D.M., and Hefley, T.J., 2015, Whooping crane stopover site use intensity within the Great Plains: U.S. Geological Survey Open-File Report 2015–1166, 12 p., http://dx.doi.org/10.3133/ofr20151166.

ISSN 2331-1258 (online)

Acknowledgments

Logistic, administrative, and financial support was provided by the Canadian Wildlife Service, Crane Trust, U.S. Fish and Wildlife Service, and the Platte River Recovery Implementation Program, with additional support from the Gulf Coast Bird Observatory, International Crane Foundation, and Parks Canada. F. Chavez-Ramirez, B. Strobel, M. Bidwell, M. Harner, G. Wright, and T. Stehn were integral to the initiation and continuation of this work. We thank B. Hartup, M. Folk, S. Herford, W. Wehtje, and J. Dooley for assistance and support during crane capture or other aspects. J. Fieberg and E. Vander Wal provided comments to earlier versions of this report.

The U.S. Geological Survey–Platte River Priority Ecosystems Program provided partial financial support. Northern Prairie Wildlife Research Center supported logistical and administrative aspects of this work.

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Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Velocity	
meter per second (m/s)	3.281	foot per second (ft/s)
kilometer per hour (km/h)	0.6214	mile per hour (mi/h)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Whooping Crane Stopover Site Use Intensity Within the Great Plains

By Aaron T. Pearse,[1] David A. Brandt,[1] Wade C. Harrell,[2] Kristine L. Metzger,[3] David M. Baasch,[4] and Trevor J. Hefley[5]

Abstract

Whooping cranes (*Grus americana*) of the Aransas-Wood Buffalo population migrate twice each year through the Great Plains in North America. Recovery activities for this endangered species include providing adequate places to stop and rest during migration, which are generally referred to as stopover sites. To assist in recovery efforts, initial estimates of stopover site use intensity are presented, which provide opportunity to identify areas across the migration range used more intensively by whooping cranes. We used location data acquired from 58 unique individuals fitted with platform transmitting terminals that collected global position system locations. Radio-tagged birds provided 2,158 stopover sites over 10 migrations and 5 years (2010–14). Using a grid-based approach, we identified 1,095 20-square-kilometer grid cells that contained stopover sites. We categorized occupied grid cells based on density of stopover sites and the amount of time cranes spent in the area. This assessment resulted in four categories of stopover site use: unoccupied, low intensity, core intensity, and extended-use core intensity. Although provisional, this evaluation of stopover site use intensity offers the U.S. Fish and Wildlife Service and partners a tool to identify landscapes that may be of greater conservation significance to migrating whooping cranes. Initially, the tool will be used by the U.S. Fish and Wildlife Service and other interested parties in evaluating the Great Plains Wind Energy Habitat Conservation Plan.

Introduction

The whooping crane (*Grus americana*) is a well-recognized endangered species endemic to North America. The only self-sustaining and wild population of whooping cranes, the Aransas-Wood Buffalo population, nests at Wood Buffalo National Park and surrounding lands near the border of the Northwest Territories and the Province of Alberta, Canada. Birds from this population migrate nearly 4,000 kilometers (km) through the Great Plains and winter along the Gulf Coast of Texas at Aransas National Wildlife Refuge and surrounding lands (Stevenson and Griffith, 1946; Allen 1952). Persistence and recovery of the species is contingent on continued growth of the Aransas-Wood Buffalo population, because attempts to reestablish migratory or resident populations from captive birds have been largely unsuccessful to date (Canadian Wildlife Service and U.S. Fish and Wildlife Service, 2007).

Twice yearly movements between summering and wintering areas serve as defining periods for migratory birds, and these migrations can be energetically taxing and risky (Newton, 2008; Stehn and Haralson-Strobel, 2014). For whooping cranes and other diurnally migrating birds, successful completion of migration requires suitable sites for birds to rest and reside for one to multiple nights, which are generally referred to as stopover sites. Opportunistic whooping crane sightings have largely shaped understanding of routes and timing of migrating cranes, as well as provided documentation of a wide variety of wetland and upland habitats used (Johns, 1992; Austin and Richert, 2005; Tacha and others, 2010). Although efforts to identify and prioritize areas of importance along the migration corridor using opportunistic sightings have provided useful insights, studies using these data have included caveats related to potential biases inherent with opportunistic sightings (Austin and Richert, 2005; Belaire and others, 2014; Hefley and others, 2013, 2014, in press).

Expansion of wind-energy development and related infrastructure within the whooping migration corridor has been identified as a conservation concern (Canadian Wildlife Service and U.S. Fish and Wildlife Service, 2007; Belaire and others, 2014). Collisions with manmade obstacles, mainly power lines, have been listed as significant threats to seven species of cranes, including whooping cranes (Harris and Mirande, 2013). Identification and assessment of risk factors during migration informs development of conservation and management programs targeted at minimizing risk and identifying potential areas in need of protection. In response to large-scale planned development of wind-energy projects across the migration corridor of whooping cranes, multiple companies began developing a habitat conservation plan

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in 2009 under Section 10 of the Endangered Species Act (16 U.S.C. §1531 et seq. 1973). The Great Plains Wind Energy Habitat Conservation Plan covers whooping cranes as well as other threatened and endangered species. The overall goal of the plan is avoidance, minimization, and mitigation of risks to covered species to the maximum extent practical while providing regulatory certainty for the plan's developers. The U.S. Fish and Wildlife Service has been in consultation with those developing this plan and will be charged with evaluating the final plan. This report provides the U.S. Fish and Wildlife Service and other interested parties assistance in evaluations and negotiations related to the Great Plains Wind Energy Habitat Conservation Plan.

Strategic conservation of habitats that provide resources throughout the annual life cycle of the whooping crane will assist in species recovery (National Resource Council, 2005; Canadian Wildlife Service and U.S. Fish and Wildlife Service, 2007). Locations of individuals based on telemetry data provide one example of information that could be used to prioritize conservation and management (Sawyer and others, 2009; Wilson and others, 2009; Corre and others, 2012; Grecian and others, 2012). The purpose of the report is to provide a simple, objective, and transparent examination of the distribution of stopover sites used by radio-tagged whooping cranes. Specifically, we used whooping crane locations acquired during 2010–14 to (1) estimate intensity of stopover site use by radio-tagged whooping cranes along their migration corridor in the Great Plains and (2) identify categories of stopover site use intensity for prioritizing conservation and management actions. We included data from 2010 to 2014, yet data collection continues during 2015 and will likely extend into 2016; therefore, we consider results presented here as provisional. Also, analytical methods for describing telemetry-based data have increased in the past decade; thus, we acknowledge methods applied herein are but one of many potentially appropriate ways to describe patterns in intensity of use within the migration corridor. This report represents the first analyses of these data, with additional work expected to follow that may supersede results presented in this report.

Methods

Study Area

Most whooping crane sightings during migration have occurred within Canadian Provinces and U.S. States in the Great Plains (Texas, Oklahoma, Kansas, Nebraska, South Dakota, North Dakota, Saskatchewan, and Alberta; Johns, 1992; Tacha and others, 2010). The study area included a region encompassing all stopover locations collected during migration, which included parts of the previously identified States and Provinces, and also areas within Missouri, Iowa, Minnesota, Montana, Manitoba, and the Northwest Territories (fig. 1).

Field Methods and Locations

We captured cranes and attached platform transmitting terminals with global position system (GPS) capabilities (North Star Science and Technology LLC, Baltimore, Maryland) at Wood Buffalo National Park and sites along the Texas Gulf Coast. Capture teams consisted of individuals with experience handling endangered cranes, including a licensed veterinarian. We captured pre-fledged juvenile cranes at breeding sites by locating family groups from helicopters and positioning personnel nearby for ground pursuit and hand capture (Kuyt, 1979). We captured cranes in Texas using leg snares that enclosed on the lower tarsus upon triggering. Transmitters were mounted on two-piece leg bands (Haggie Engraving, Crumpton, Md.) placed on the tibia-tarsus of captured birds (fig. 2). Transmitters had solar panels integrated on three exposed surfaces and were expected to provide a 3- to 5-year lifespan. The transmitter and leg band weighed approximately 75 grams (g), which represented approximately 1 percent of body weight of adult whooping cranes. Transmitters were programmed to record 4–5 GPS locations daily at equal time intervals, which provided daytime and nighttime locations. Capture and marking procedures were approved by the Animal Care and Use Committee at Northern Prairie Wildlife Research Center.

We initially inspected GPS locations from all birds to remove locations collected or transmitted potentially with error. We performed multiple assessments to determine plausibility of locations and omitted locations outside the expected time sequence, with an implausible rate of displacement (greater than 100 kilometers per hour [km/h]), or forming an acute angle (less than 5 degrees [°]) at distances greater than 50 km (distance/angle; see Douglas and others, 2012). After removing potential errors, we retained only GPS locations recording an instantaneous velocity of less than 2.1 meters per second (m/s), which we assumed was indicative of locations acquired while the crane was on the ground rather than flying.

We identified each point as being collected during migration (spring and fall) based on manual inspection of movement patterns with respect to time of year (Krapu and others, 2011). Each migration season, we identified specific stopover sites for individual whooping cranes by identifying clusters of locations based on distance, movement pattern, and manual inspection. Unique stopover sites were identified if birds moved more than 15 km between nighttime locations from one day to the next, although we occasionally deviated from this rule based on expert opinion. After identifying a set of locations as a unique stopover, we calculated its centroid and enumerated total days that the animal remained at each stopover site. In some instances, information indicated only daytime use at a site. We identified these as daytime stopovers and assigned a value of 0.5 day duration of stay.

Locations were originally collected in degrees of latitude and longitude using the World Geodetic System 1984 datum. We projected locations to a Transverse Mercator projection with a central meridian of 102°W, which serves as the

Base map from Esri and is used herein under liscence (500 meter resolution).
Univeral Transverse Mecator projection, zones 13–14 N
North American Datum of 1983 (NAD 83)

Map data modified from Esri, U.S. Fish and Wildlife Service, and U.S. Geological Survey digital data, various resolutions.

Figure 1. Migration corridor of whooping cranes, including primary breeding areas in Wood Buffalo National Park and wintering areas near Aransas National Wildlife Refuge.

Figure 2. Platform transmitting terminals were secured to the tibia-tarsus of captured whooping cranes with a two-piece leg band. Leg bands were secured with blind rivets and glue. Photograph taken by David Baasch, Platte River Recovery Implementation Program.

boundary between Universal Transverse Mercator zones 13 and 14. This projection allowed for 98 percent of locations to be included within 10° of the central meridian (fig. 1). We also converted locations to the North American Datum of 1983.

Analytical Methods

To explore stopover site use intensity, we estimated a utilization distribution (Worton, 1989), which provided relative densities of stopover sites used by radio-tagged cranes over the entire migration corridor. Using a grid-based approach, we divided the study area into grid cells and summarized information about stopovers within each cell (Adams and Davis, 1967; MacDonald and others, 1980; Powell, 2000). We used this approach rather than techniques that smooth observed data (kernel density estimation) because we desired a relatively simple and transparent measure of stopover density and distribution. We combined years (2010–14) and migration seasons (spring and fall) and justified pooling data by reasoning that many conservation and management actions would be based on factors irrespective of the calendar year or migration season in which stopovers occurred.

Although we avoided applying smoothing techniques, we acknowledge that the grid-based method implicitly smoothed data, where size of grid cells determined smoothing level. We therefore considered multiple factors when identifying an appropriate cell size. Generally, analysts may consider ecological context and intended use when choosing a cell size or other smoothing parameters (Powell, 2000). In the context of migration ecology, selection of a stopover site best fits within a hierarchy of habitat selection choices (Johnson, 1980). Because we summarized multiple locations at a stopover site into a single centroid, we were inherently interested in where a bird chose to reside within a larger landscape. Of the locations, 95 percent were within 6.8 km of stopover centroids and 99 percent were within 12.5 km, which corresponded to circular

Table 1. Categories of stopover site use intensity used to identify areas of conservation priority within the migration corridor of Aransas-Wood Buffalo whooping cranes.

[≥, greater than or equal to; >, greater than; ≤, less than or equal to]

Category	Criterion	Description
Unoccupied	0 stopover sites	Cell lacks evidence of use.
Low intensity	≥ 1 stopover sites > critical cumulative stopover volume	Cell has evidence of use and low stopover site use intensity.
Core intensity	≤ critical cumulative stopover volume > critical cumulative crane day volume	Cell contains density of stopovers identified as high use intensity and crane days of lower intensity.
Extended-use core intensity	≤ critical cumulative stopover volume ≤ critical cumulative crane day volume	Cell contains high use intensity of stopovers and crane days.

areas of 14,520 and 48,063 hectares (ha), respectively. More importantly, the intended application was to identify potential co-occurrence with commercial wind towers, facilities, and associated infrastructure. Average area of wind tower arrays built within the study area as of July 2013 was 12,083 ha (median = 8,210 ha; Diffendorfer and others, 2014). When including a 6.5-km buffer surrounding towers, which was the average distance of wintering sandhill cranes (*Grus canadensis*) locations less than 10 km from established wind towers in Texas (A.T. Pearse, U.S. Geological Survey, unpub. data, 2015), average footprint increased to 50,783 ha (median = 44,774 ha). Based on these assessments, we identified a cell size of 20 square kilometers (km^2) (40,000 ha) as best fitting specific requirements.

We initially considered each stopover site used by a radio-tagged crane with equal weight and, in a secondary classification, we included duration of stay to further identify grid cells that had greater stopover site intensity and greater longevity of use. We calculated number of days individual cranes spent at a particular stopover site and enumerated number of days for all stopovers within grid cells (crane days). We first identified occupied grid cells (greater than or equal to [≥] 1 stopover site). For those cells, we enumerated stopovers, enumerated crane days over all stopovers within the cell, identified the first migration year in which a stopover was detected (for example, fall 2010), and determined during which migration season(s) stopovers occurred (fall only, spring only, or both seasons). We ranked grid cells by stopover density and determined cumulative sum and proportion of stopovers found within cells (volume and cumulative proportion volume). We used volume metrics to identify areas of more intense stopover site use. Specifically, we used a method described by Vander Wal and Rodgers (2012), where utilization distribution area and volume were plotted against one another (Powell, 2000). We used a fitted exponential model to estimate this association and determined the point at which the slope equaled 1.0. The volume at this inflection point represented a transition where, at cumulative volume values above, proportion of occupied area increases at a greater rate than probability of use. This method uses characteristics of the data to define a critical value rather than an analyst selecting an arbitrary volume to define core or intensely used regions compared with peripheral areas of lower intensity. We determined this method required some modification because the critical volume could fall within a group of cells with equal density (for example, two stopovers per cell). If this occurred, we identified the next greatest difference in cell density to serve as delimiter between categories (for example, transition between two and three stopovers per cell). We further divided identified core intensity grid cells into two categories based on volume of crane days. We used the same procedures as above, but considered only core intensity cells.

Our analyses allowed for identification of four mutually exclusive categories for grid cells (table 1). Unoccupied cells had no identified stopover sites. Low intensity cells were occupied but at densities above the cumulative stopover volume described above. Core intensity cells had densities of stopover sites below the cumulative stopover volume. These sites also had lower densities of crane days, as compared with the final category, extended-use core intensity, which had high intensity stopover site use and numerous crane days.

We calculated a corridor centerline of stopover sites for illustration and comparative purposes. First, we grouped cells into 36 equally spaced categories based on northing coordinates (latitude) and calculated median northing and easting coordinates from grid centroids, weighting by number of stopover sites in grid cells. The 36 derived vertices formed a line that represented the central tendency of stopover sites within the migration corridor. Weighting by number of stopovers in each cell, we calculated distance percentiles for all stopover sites and those associated only in cells identified as core intensity or extended-use core intensity.

We intersected spatial databases with results as a preliminary evaluation of protections and risks faced by migrating whooping cranes. We used the Protected Areas Database of the United States and the Conservation Areas Reporting and Tracking System to identify lands under some type of conservation or land protection (U.S. Geological Survey, Gap Analysis Program, 2012; Canadian Council on Ecological Areas 2015). We also included locations of wind turbines constructed within the United States as of July 2013 to characterize one potential and relevant hazard (Diffendorfer and others, 2014).

We were not able to obtain specific wind tower locations for Canada. We determined percentage of all occupied and core (core intensity and extended-use core intensity categories) grid cells that contained protected lands and calculated percentage of grid cell area identified as protected lands, because most cells contained a mix of protected and unprotected lands. For wind turbines, we determined the number of grid cells within the United States that contained ≥1 wind turbine and summarized information for each stopover use category. We tested the null hypothesis that turbines were randomly associated with stopover use categories using a chi-square test (Iman, 1994).

Finally, we were interested in examining how cell occupancy changed with increased data collection. We explored the trend in accumulation of occupancy (≥1 stopover site identified) of grid cells during 10 migrations in spring 2010 (S10) to fall 2014 (F14). We fit this function using linear regression and logit transforming proportion of occupied cells. Explanatory variables included season (sequentially increasing integers) and number of transmitters deployed per season. We extrapolated results to include an additional 10 migrations, which assumed a similar number of active transmitters would be monitored.

Results

We marked 68 unique whooping cranes with transmitters between December 2009 and February 2014, including 35 juvenile and 33 subadult or adult birds. Two birds were recaptured and fitted with new transmitters after original transmitters failed. Of the 68 marked cranes, 58 unique cranes provided migration locations for analyses (10 in 2010, 23 in 2011, 33 in 2012, 33 in 2013, 27 in 2014). The average number of cranes monitored during each migration was 20.7. Radio-tagged cranes provided data for an average of 3.6 migrations and an average of 37 stopover sites (6–84 stopover sites, median = 40). Overall, we identified 2,158 stopover sites; the average number of sites identified per year was 432 (110 in 2010, 321 in 2011, 527 in 2012, 676 in 2013, 524 in 2014). More stopovers occurred during spring (54 percent, n = 1,163) than fall (46 percent, n = 995), whereas a larger percentage of crane days occurred during fall (57 percent, n = 3,680.5) compared with spring (43 percent, n = 2,792.5).

Our study area included 5,431 grid cells, 20 percent (n = 1,095) of which contained ≥1 stopover site. Of the occupied grid cells, 30 percent received only fall stopover use, 47 percent exclusively spring use, and 23 percent had use during both migration seasons. Percentage of occupied cells increased each migration as we accumulated more data (fig. 3). Newly occupied cells continued to be identified after cessation of marking new birds before migrations in 2014. During the 10 migrations included in analyses, an average of 120 (standard error = 15.3) new grid cells per migration were identified as used. Provided that a similar sample of transmitters continued to be monitored, the cumulative percentage of cells that may be identified as occupied would be expected to continue increasing and reach approximately 34 percent (95 percent prediction interval: 22–55 percent) in 5 additional

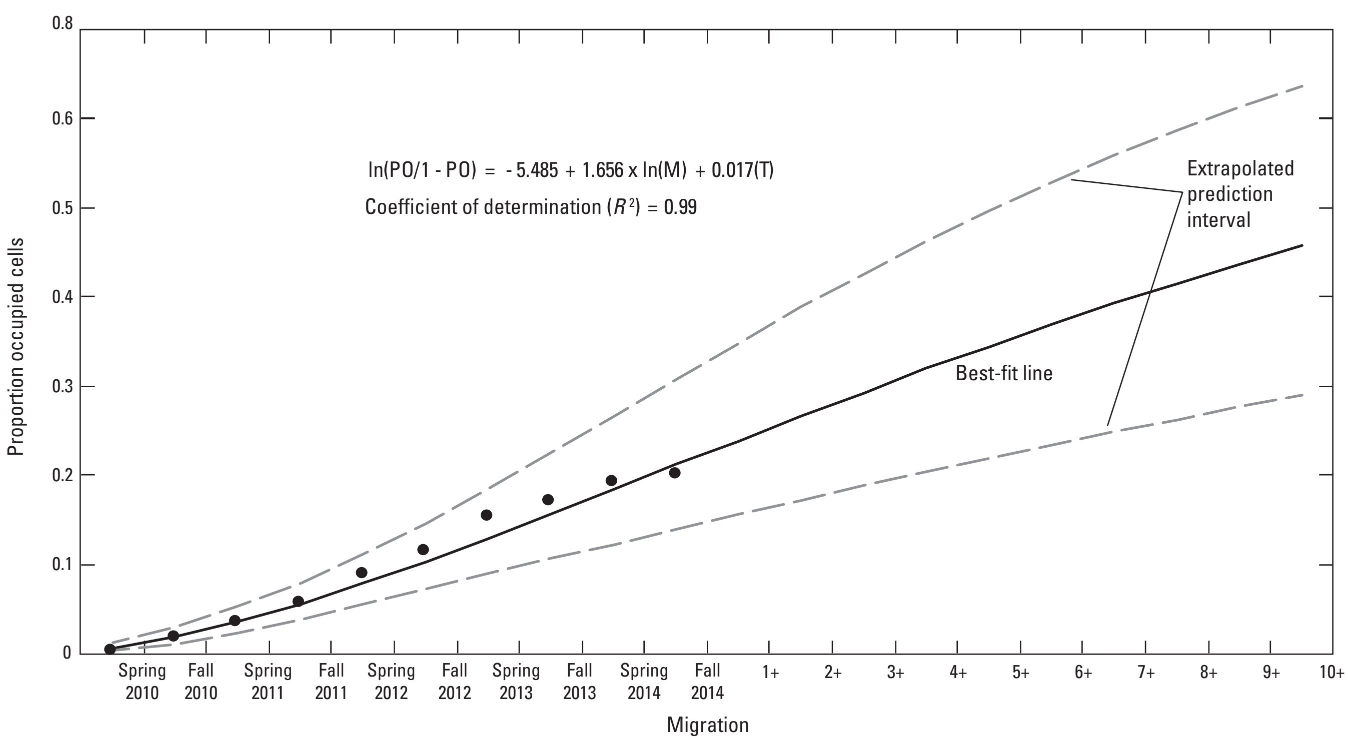


Figure 3. Cumulative proportion of grid cells containing 1 or more whooping crane stopover sites (PO) by migration (M; spring 2010 = 1), assuming that an average of 20.7 transmitters (T) remain active.

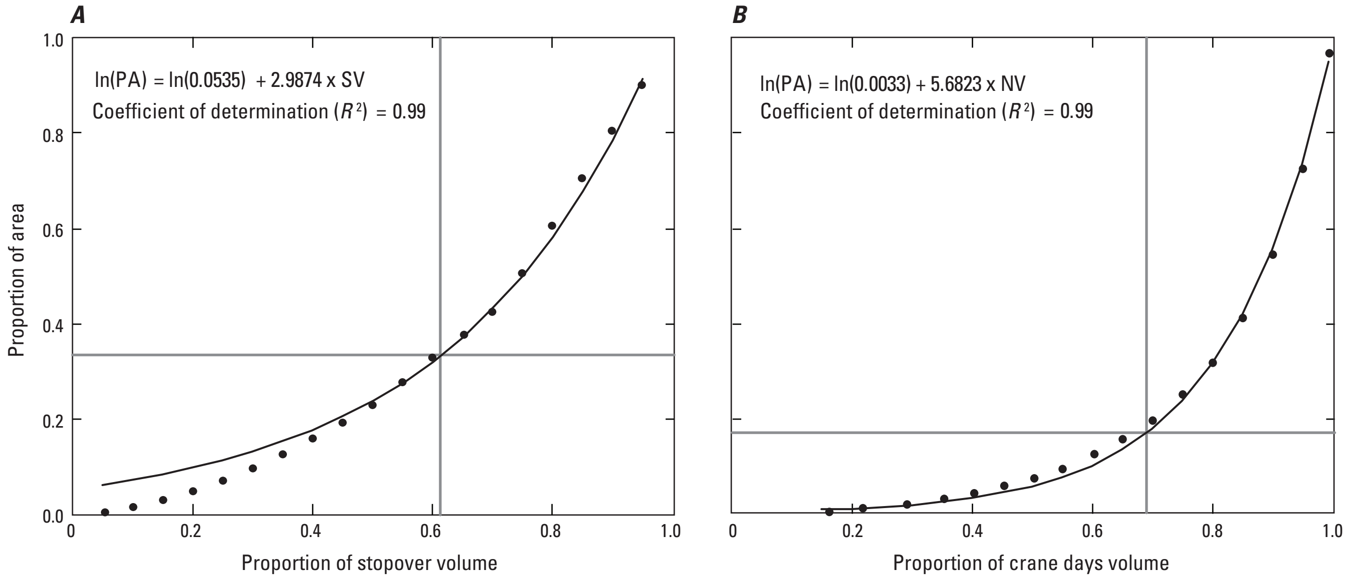


Figure 4. Cumulative proportion of grid cells (proportion area) that contained *A*, whooping crane stopover site volume (SV) within the migration corridor and *B*, crane day volume. An exponential function provided a means to identify the critical volume where the slope of this association was 1.0.

migrations and 46 percent (95 percent prediction interval: 29–64 percent) in 10 migrations (fig. 3).

Stopover sites per occupied cell ranged from 1 to 29 (average = 2.0, standard deviation = 2.0). Of the occupied cells, 56 percent contained only one stopover site. The association of cumulative percent stopover volume and area was fit with an exponential model and the resulting critical value used to delineate core cells was 0.614 (fig. 4*A*). This percentage volume was located among cells of equal intensity; therefore, we located a crucial value at the first available difference in intensity (less than or equal to 0.484), which corresponded with an intensity difference of 2 and 3 stopovers per cell. Based on this critical value, 233 grid cells were identified as core intensity grid cells.

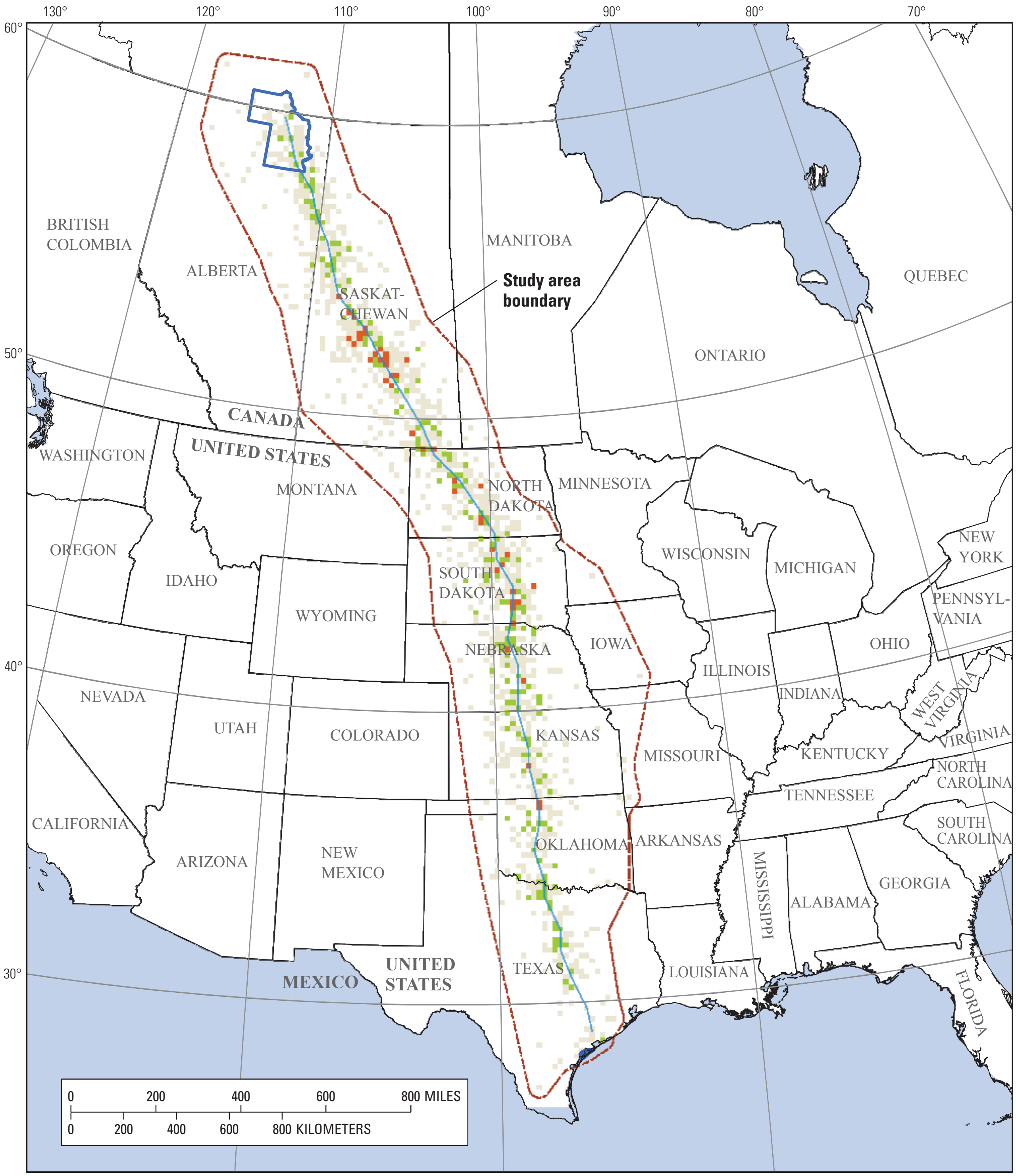
Within the 233 cells identified above, crane days per cell varied from 2.5 to 631 and averaged 16.6 (standard deviation = 46.8; median = 6). The association between cumulative percent crane day volume and area was fit with an exponential model and the resulting critical value was 0.698 (fig. 4*B*). This percentage volume was located among cells of equal intensity; therefore, we located a crucial value at the available difference in intensity (less than or equal to 0.691), which corresponded with an intensity difference between 18 and 19 crane days per cell. Based on this critical value, 44 grid cells were identified as having core intensity of crane days.

Using four defined mutually exclusive categories (table 1), 4,336 grid cells were included in the unoccupied group (80 percent), 862 in low intensity (16 percent; 79 percent of occupied), 189 in core intensity (3 percent; 17 percent of occupied), and 44 in extended-use core intensity (1 percent; 4 percent of occupied). Cells identified as low intensity included 52 percent of stopover sites and 40 percent of crane days. Core intensity grid cells included 35 percent of stopovers and 18 percent of crane days. Cells identified as extended-use core intensity represented 13 percent of stopover sites and 42 percent of crane days. Geographically, grid cells identified in the core intensity category were generally centrally located in the migration corridor, as identified by the centerline (fig. 5). Latitudinally, these cells were present throughout the corridor, except extended-use core intensity cells, which were more frequent in the northern part of the corridor in Saskatchewan, North Dakota, and South Dakota.

The average distance of stopovers to the centerline was 43.8 km (median = 27.5; SD = 31.4; max = 480.4). The 75th percentile was 58.8 km, 85th percentile was 82.3 km, and 95th percentile was 144.1 km (fig. 6). Including only stopovers within grid cells identified as core intensity or extended-use core intensity, average distance was 22.2 km (median = 17.1; SD = 51.2; maximum = 144.1). The 75th percentile was 31.4 km, 85th percentile was 41.2 km, and 95th percentile was 74.5 km (fig. 6).

Of grid cells with ≥1 stopover site, 75 percent contained at least one tract of protected land, and 83 percent of core grid cells (core and extended use designations) contained protected land. Protected lands covered a varying area of grid cells and, on average, 13 percent of land within all occupied cells and 32 percent of land within core grid cells had some measure of protection. Thus, lands with some type of protection covered approximately 10 percent of the migration corridor used by whooping cranes and approximately 27 percent of the core corridor.

We estimated that 7 percent of grid cells within the U.S. study area contained ≥1 wind turbine (9,765 turbines). To test the null hypothesis that wind turbines occurred within



Base map from Esri and is used herein under liscence (500 meter resolution).
Univeral Transverse Mecator projection, zones 13–14 N
North American Datum of 1983 (NAD 83)

EXPLANATION

Whooping crane migration corridor

- Low intensity
- Core intensity
- Extended-use core intensity

Centerline

Figure 5. Areas within the migration corridor of whooping cranes identified with varying levels of stopover site use intensity (category definitions shown in table 1).

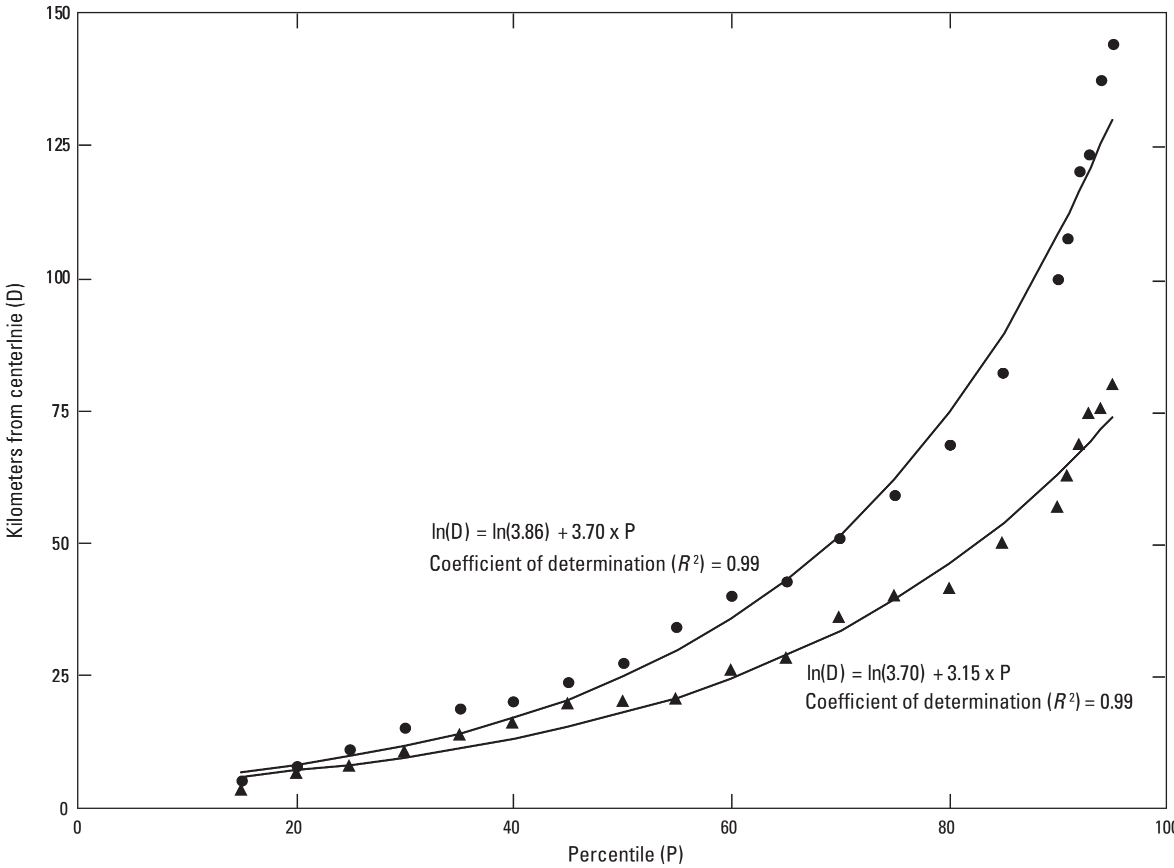


Figure 6. Percentiles of distances (kilometers) from the whooping crane migration corridor centerline for all grid cells with stopover sites (circles) and a subset of grid cells identified as having greater intensity of use (triangles).

stopover site use categories independently, we first combined core intensity and extended-use core intensity categories because we observed no turbines in the latter category (table 2). Observed grid cell frequencies by stopover site use category were not different from what would be expected by chance alone (chi-square = 3.2; degrees of freedom = 2; probability value = 0.10).

Table 2. Number of grid cells within the U.S. portion of the study area by stopover site use intensity category that contained no wind turbine or at least one wind turbine as of July 2013.

[≥, greater than or equal to]

Category	No wind turbines	≥ 1 wind turbine
Unoccupied	2,543	196
Low intensity	469	33
Core intensity	120	5
Extended-use core intensity	22	0
Total	**3,154**	**234**

Discussion

Various reports have defined the migration corridor of Aransas-Wood Buffalo whooping cranes (Allen, 1952). To date, corridor boundaries have been based on observational sightings and one radio telemetry study from the early 1980s (Kuyt, 1992; Johns, 1992; Tacha and others, 2010). The results support earlier findings regarding the migration corridor's general location (fig. 5). By comparison, intensity of use within the migration corridor has received less attention. Using all migration data available as of spring 2008 within the United States, Tacha and others (2010) identified migration corridor width using a distance-from-centerline approach and determined that 75 percent of stopover sites occurred within 48 km of the centerline, 85 percent within 80 km, and 95 percent within 136 km. The Tacha and others (2010) analysis provided greater definition of where the majority of stopovers occurred within the U.S. (approximately 60 percent of the entire migration centerline). We determined strikingly similar results for the entire migration corridor and, based on the derived centerline, 75 percent of stopover sites occurred within 59 km, 85 percent within 82 km, and 95 percent within 144 km of the centerline. This similarity provides initial evidence that observation data, even with known biases, may have value in this type of coarse and large-scale evaluation.

Using a grid-based approach, we summarized density of stopover sites to identify areas of greater use intensity. Areas with greater stopover site intensity were present through the migration corridor, with conspicuous clusters along the border of Texas and Oklahoma, north-central Nebraska, south-central and north-central South Dakota, northwestern North Dakota, the border of North Dakota and Saskatchewan, and south-central Saskatchewan (fig. 5). These results refine earlier efforts and represent one of the first estimates of site use intensity across the entire migration range not relying upon observational data.

Principal strengths of this work were data quality, data quantity, and a simple analytical approach. Transmitters provided locations across a vast landscape selected by cranes, presumably to meet a complex set of behavioral, physiological, and nutritional needs during migration. The GPS locations were more precise (10–100 meters) and not subject to observation biases as compared to previously reported opportunistic observations during migration (Tacha and others, 2010). The sample of whooping cranes represented approximately 20 percent of the population, a sampling proportion not often possible in wildlife or ecological research. This sample size allowed for identification of 2,158 stopover sites, which is a 9-percent increase from those identified in the United States, 1975–2008 (1,981; Tacha and others, 2010). We examined stopover site locations using relatively simple methods, which provided straightforward interpretations. These methods subdivided the entire migration corridor into categories for identifying potential conservation priority (table 1, fig. 5).

Despite these strengths, certain limitations of our study design require qualified interpretation. Location data identified stopover sites of radio-tagged individuals without providing information regarding accompanying unmarked cranes. Whooping cranes generally migrate in small groups depending on age and social status (Howe, 1989; Austin and Richert, 2005), although individual whooping cranes are known to migrate alone or with sandhill cranes. Juvenile cranes are accompanied by at least one and most likely both parents during the entirety of their first fall migration and most of their first spring migration (Howe, 1989; Kuyt, 1992). Understanding of associations of older-aged radio-tagged birds with unmarked birds relied on limited reported sightings. Thus, radio-tagged birds could represent an unknown multiple of birds, which could have provided another weighting factor at identified stopover sites. Group size information is generally available from observational whooping crane sightings. Hefley and others (in press) used group size information to model distribution of migrating whooping cranes in Nebraska and determined that variation in group size did not provide useful additional information; hence, lacking this information may be of only slight consequence. Also, the analytical method provided only a coarse identification of stopover site intensity over the entire corridor. This coarseness was driven by choice of grid cell size, which we justified based on multiple criteria, but we acknowledge that cell size limits the scale at which identification of priority areas can be discerned. Results were not intended to provide fine-scale site evaluation of potential whooping crane use in the migration corridor and would be poorly suited at that task. Site-level evaluations generally require modeling of landscape and local-scale characteristics that may influence site choice (Armbruster, 1990; Belaire and others, 2014; Hefley and others, 2014). In addition, the analytical approach provided interpretation of stopover density without regard to potential spatial association of stopover sites larger than the selected grid cell size. Identifying larger landscapes with clusters of stopover sites may be useful for certain applications. We plan to explore techniques that incorporate local and landscape covariates and spatial associations among stopover sites in future efforts.

As stated previously, we view results as provisional. The investigation of increasing evidence of used or occupied grid cells over time provides insight into how additional data might update results. Based on the predicted trend, monitoring birds for additional migrations will likely continue to identify new areas (fig. 3). We acknowledge that this function could asymptote more quickly than predicted, which would bias predictions. Fieberg (2007) noted a similar potential for home range analyses, where increasing study duration would likely lead to estimating larger home ranges as animals explored new areas over time. Although we did not investigate how core intensity cells might change with increasing sample size, we suspect these cells to remain more stable over time. Thus, we caution using occupancy (low intensity category) alone to prioritize conservation, because we believe it to be most sensitive to further data acquisition.

A significant percentage of the core migration range was identified to be under some measure of land protection (27 percent) in comparison to occupied grid cells (10 percent) and the study area overall (10 percent). Ownership, nature, and longevity of protection varied among lands within the migration corridor. Federal, State, tribal, and private ownerships were included, lands had access policies that ranged from open to restricted, and protection longevity varied from perpetual to time-limited easements. Given this variation, we consider the estimate of protected lands within the core migration area of whooping cranes as optimistic. Moreover, most protections were not put in place for the conservation of whooping cranes specifically, and therefore represent collateral benefits of other efforts to protect areas with natural, cultural, societal, and wildlife values.

Nearly 10,000 wind turbines have been constructed within the U.S. study area, occupying 7 percent of grid cells. Most grid cells with wind turbines did not contain whooping crane stopover sites (84 percent), and only 2 percent of cells were identified as core migration areas. The estimate of spatial overlap during migration provides a baseline that can be compared with future wind-energy development scenarios and future increases in the whooping crane population (Butler and others, 2013). The relatively low level of spatial overlap was not likely due to avoidance of turbines by cranes because we could not reject the hypothesis that wind turbines occurred within stopover use categories in proportion to availability. To maintain minimal spatial overlap of cranes and wind turbines, efforts could be made to place turbines in locations expected to have a low probability of crane use (Fargione and others, 2012).

Our evaluation over the entire corridor provided opportunity to compare use intensity relative to all other areas. This approach is in contrast to regional products available (Johns, 1992; Tacha and others, 2010; Belaire and others, 2014; Hefley and others, in press). This approach allows for flexibility in prioritizing areas for conservation and management of migrating whooping cranes. When using defined categories (table 1), practitioners may wish to scale or weight categories based on specific objectives. Because prioritization decisions will be fundamentally objective-driven, we do not attempt to identify a single set of scaling factors for determining conservation priority for migrating whooping cranes.

Summary

The whooping crane (*Grus americana*) is a well-recognized endangered species endemic to North America. For whooping cranes and other diurnally migrating birds, successful completion of migration requires suitable sites for birds to rest and reside for one to multiple nights, which are generally referred to as stopover sites. The purpose of the report is to provide a simple, objective, and transparent examination of the distribution of stopover sites used by radio-tagged whooping cranes. We used location data acquired from 58 unique individuals fitted with platform transmitting terminals that collected global position system locations. Radio-tagged birds provided 2,158 stopover sites over 10 migrations and 5 years (2010–14). Using a grid-based approach, we divided the study area into 20-square-kilometer grid cells and summarized information about stopovers within each cell. The study area included 5,431 grid cells, 20 percent (n = 1,095) of which contained 1 or more stopover sites. We identified 233 cells as having greater intensity of use and 44 of those as receiving numerous days of use by cranes. Areas with greater stopover site intensity were present through the migration corridor, and these results refine earlier efforts, representing one of the first estimates of site use intensity across the entire migration range not relying upon observational data. Lands with some type of conservation protection covered approximately 10 percent of the migration corridor used by whooping cranes and approximately 27 percent of the core corridor. Most grid cells that contained wind turbines as of July 2013 did not contain whooping crane stopover sites (84 percent), and only 2 percent of cells were identified as core migration areas. Results will be used initially by the U.S. Fish and Wildlife Service and other interested parties in evaluating the Great Plains Wind Energy Habitat Conservation Plan.

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Publishing support provided by:
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Pearse and others—**Whooping Crane Stopover Site Use Intensity Within the Great Plains**—Open-File Report 2015–1166

ISSN 2331-1258 (online)
http://dx.doi.org/10.3133/ofr20151166