Distribution, Migration Chronology, and Survival Rates of Eastern Population Sandhill Cranes

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Abstract

The Eastern Population (EP) of greater sandhill cranes (*Grus canadensis tabida*; hereafter, cranes) is rapidly expanding in size and geographic range. The core of their breeding range is in Wisconsin, Michigan, and southern Ontario, Canada. Little information exists regarding the geographic extent of breeding, migration, and wintering ranges of EP cranes, or migration chronology and use of staging areas. In addition, there are no published estimates of survival rates for EP sandhill cranes. To address these information needs we trapped and deployed solar Global Positioning System (GPS) Platform Transmitting Terminals (PTTs) on 29 sandhill cranes from December 2009 through September 2011, primarily in known fall and winter concentration areas, to assess movements throughout the year. This thesis explores EP sandhill crane distribution during the breeding season and winter, migratory routes, and migration chronology (Chapter 1) and also estimates survival rates during the study period (Chapter 2). EP cranes settled on summer areas beginning mid-March in Minnesota (11%), Wisconsin (36%), Michigan (29%), and Ontario (21%). On average, PTT-tagged cranes arrived at their winter terminus beginning mid-December in Indiana (29%), Kentucky (11%), Tennessee (79%), Georgia (11%), and Florida (32%). Twenty-three marked cranes returned to their summer area's calculated mean center after a second spring migration. The average linear distance between individual estimated mean activity centers for a summer area was 1.34 km (range: 0.01 – 7.82 km). EP cranes used fall and spring migration routes similar to those previously documented. Annual survival rates (from October through September) were estimated at 0.921 (2010-2011; SE = 0.058) and

0.913 (2011-2012; SE = 0.087) using the known fates platform in Program MARK (Chapter 2).

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CHAPTER 1: DISTRIBUTION AND MIGRATION CHRONOLOGY OF EASTERN POPULATION GREATER SANDHILL CRANES

At the turn of the 20th century, the Eastern Population (EP) of greater sandhill cranes (*Grus canadensis tabida*; hereafter, cranes) was nearly extirpated from its historical breeding range due to habitat alteration and uncontrolled hunting (Walkinshaw and Wing 1955, Lumsden 1971, Hunt et al. 1976). The EP of sandhill cranes has increased in size and its breeding range has expanded (Tacha et al. 1994, Amundson and Johnson 2011), which has been attributed to actions such as habitat conservation by state and federal agencies and non-government organizations, protection from uncontrolled hunting following passage of the Migratory Bird Treaty Act of 1916, and prohibition of hunting in 1918. However, an increase in population size has also been accompanied by management issues related to crop depredation, an interest in allowing sport harvest, and creating opportunity for non-consumptive wildlife viewing (Van Horn et al. 2010). Similar to other sandhill crane populations, basic biological and annual life cycle information is needed to better manage EP cranes, especially information related to spatial distribution of the population, current migration patterns, potential overlap with neighboring migratory and non-migratory populations, and identification of important habitats during the annual life cycle (D. J. Case and Associates 2009).

In 2009, the Migratory Shore and Upland Game Bird Task Force under the direction of the Association of Fish and Wildlife Agencies identified priority information needs that were specific to developing a better monitoring program to reflect current distributions and migration patterns of EP cranes. This effort identified as an essential information need documenting the geographic extent of breeding, migration, and wintering ranges so that appropriate changes to the spatial-temporal design of the current U.S. Fish and Wildlife Service (USFWS) Cooperative Fall Abundance Survey (hereafter, USFWS fall survey) are implemented (D. J. Case and Associates 2009).

The USFWS fall survey is a long-term survey established in 1979 that consists of efforts by volunteers and state and federal agencies from the Atlantic and Mississippi flyways (Wisconsin, Michigan, Indiana, Tennessee, Georgia, and Florida). The main goal of the survey is to count EP cranes that concentrate in Indiana, Michigan, and Wisconsin during fall migration. The survey was initially designed to begin the last week of October to count birds migrating from the Manitoulin Island staging area in northern Lake Huron, Ontario (Van Horn et al. 2010). The initial survey conducted in 1979 estimated 14,385 cranes and since, estimates have increased to 87,800 cranes in 2012 with a 2010-2012, 3-year average of 74,698 cranes (S. Kelly, USFWS, pers. comm.).

We addressed this priority information need by capturing a representative sample of EP cranes during migration and winter, affixing Global Positioning System (GPS) satellite Platform Transmitting Terminals (PTTs), and monitoring crane movements over multiple years. Specifically, we addressed 3 questions: (1) what are the current migration staging areas, travel routes, and migration chronology for EP cranes; (2) determine the current areas settled during the breeding season (hereafter, summer area) and winter and duration of stay for EP cranes; and (3) estimate the proportion of EP cranes that occurs within the areas surveyed during the USFWS fall survey. We monitored PTT-marked EP cranes for 2 years, and describe summer and winter area distributions and migration routes, identify key staging and stopover areas, and summarize migration chronology throughout the annual cycle.

STUDY AREA

Our study area included the breeding and wintering grounds and migration corridors of EP cranes as determined by GPS locations of PTT-marked cranes and consisted of states and provinces within the Canadian Shield, Great Lakes, Mississippi Valley, and Southeast geographic regions of North America (Fig. 1). We conducted the majority of trapping on the Jasper-Pulaski Fish and Wildlife Area (JP FWA) and the Hiwassee Wildlife Refuge (HWR), which are 2 major staging and stopover areas within the EP range. The JP FWA is owned and managed by the Indiana Department of Natural Resources and encompasses 3,263 ha and is located in Jasper and Pulaski counties in northwest, Indiana (41°.2 N, -86°.9) within the Kankakee Outwash and Lacustrine Plain physiographic region (Indiana Department of Natural Resources 1985). Small dunes and low marsh lands dominate the area as a result of the retreat of the Saginaw Lobe of the Wisconsin Glacier. The land use surrounding JP FWA was predominantly agriculture, dominated by corn and soybean production. Land cover on the JP FWA was approximately 810 ha of wetland, shallow aquatic impoundments, and upland composed of 2,023 ha of woodlands (dominated by *Quercus* spp.) and 405 ha of upland-cropland. Crops produced for wildlife included corn, soybeans, and winter wheat. Hunting wildlife was allowed in designated zones within the JP FWA; however, protection zones were incorporated within the JP FWA for crane roosting, feeding, and loafing.

The HWR is owned and managed by the Tennessee Wildlife Resource Agency and is located in Miegs and Rhea counties in southeast, Tennessee (35°.4 N, -85°.0) within the Southern Ridge and Valley Physiographic System 13 (Partners In Flight 2014: Physiographic Area 13) and the tablelands of the Southern Cumberland Plateau. The most abundant land-cover types were oak-hickory (*Quercus-Carya* spp.) or oak-pine (*Quercus-Pinus* spp.) mesophytic forest, with scattered agricultural fields comprising a small portion of the total landscape. The HWR encompasses approximately 2,428 ha (1,112 ha land and 1,416 ha water) located within the Chickamauga Reservoir at the confluence of the Hiwassee and Tennessee rivers. Included are 162 ha of Hiwassee Island. Land use was approximately 30% agricultural that was cropped annually, and 70% a wooded mix, primarily of pine and hardwood forest. Crops produced for wildlife consumption included corn, winter wheat, soybeans, milo, varieties of millet, and buckwheat (Tennessee Ornithological Society 2006). Adjacent sand bars and low water levels on Chickamauga Lake provided roosting habitat for waterfowl and sandhill cranes during the fall and winter months. The refuge was managed to provide habitat for wildlife, specifically wintering waterfowl.

In addition to these 2 primary sites, we also trapped and placed PTTs on EP cranes at Goose Ponds FWA, west-central Indiana (39°.0 N, -87°.2) during spring 2010; Sherburne National Wildlife Refuge, east-central, Minnesota (45°.5 N, -93°.8) during fall 2010; and Crex Meadows Wildlife Area, northwestern Wisconsin (45°.8 N, -92°.6) during fall 2011. Similar to both JP FWA and the HWR, these areas encompassed sufficient protected roosting and feeding habitats for EP cranes to stage, stopover, and winter. However, cranes did not concentrate or stopover at these locations to the extent they did at either JP FWA or HWR.

METHODS

Trapping

EP cranes occur across broad geographic areas during both the breeding season and winter, and exhibit considerable variation in timing of migration across their range. To mark a representative sample of EP cranes with PTTs, we used a strategy similar to that used by Krapu et al. (2011) in a comparable study of Mid-continent Population (MCP) cranes. MCP cranes funnel through the Nebraska Platte River Valley, which is a geographic bottleneck during spring for migrating cranes to their North American and Asian breeding grounds (U.S. Fish and Wildlife Service 1981). Their sample of cranes was captured and tagged in proportion to estimated numbers of cranes present within the Platte River Valley spring staging grounds and trapping was continued throughout the spring staging period to help ensure a sample of the MCP representative of use both geographically and temporally. Similarly, we identified the JP FWA and the HWR as the major migration staging areas used by EP sandhill cranes, based on previous studies that described migratory routes (Walkinshaw 1960, Crete and Toepfer 1978) and from EP abundance surveys (e.g., Mississippi Flyway Cooperative Midwinter Survey [MWS] and state periodic surveys). For each stopover area, we selected trapping periods before, during, and after estimated peak abundance based on periodic surveys of cranes (J. Bergens, Indiana Department of Natural Resources, unpublished and R. Klippel, Tennessee Wildlife Resource Agency, unpublished) during fall migration to incorporate temporal variation in EP crane movements into our sampling strategy.

We used a rocket-propelled net assembly as the primary method to capture EP cranes. We began by identifying potential trapping sites using the protocol developed for rocket netting MCP cranes by Krapu et al. (2011), giving priority to daytime loafing sites with >20 cranes present in pasture or other open land-cover types and then baited loafing sites with whole kernel corn. When cranes responded to bait for 2 consecutive days, we assembled a 13.1 x 19.7-m rocket-propelled net (Wheeler and Lewis 1972, D. Brandt, U.S. Geological Survey [USGS], Northern Prairie Wildlife Research Center, pers. comm.). We conducted trapping primarily in the morning because cranes consistently returned to baited sites after leaving nocturnal roosts. We attempted to identify and affix PTTs to adult female cranes that we observed as part of a family group or as a member of a male-female pair. We targeted female cranes on the basis that they were more likely to return to their natal breeding grounds the following spring (Walkinshaw 1949, Drewien 1973). We identified adult female cranes based on the physical and social characteristics as described by Tacha (1998) as smaller body-sized cranes, with red skin on the crown of the head, more likely to be viewed as following larger-bodied male sandhill cranes, and less likely to display agnostic behaviors. However, following capture, if family groups were not identifiable, we isolated a smaller-bodied, adult crane, that we presumed to be a female (sex was subsequently determined via blood analyses for all cranes marked with PTTs, see below).

For each PTT-marked bird in our sample we collected morphological measurements as described by Dzubin and Cooch (1992), and drew blood, which we placed in a lysis buffer anticoagulant solution (Jones et al. 2005). We subsequently had blood analyzed (Avian Biotech International Tallahassee, FL) to determine the sex of the bird. We affixed a 30-g, 3-solar-paneled GPS satellite PTT (North Star Science and Technology LLC., Baltimore, MD) to captured cranes via flanged leg bands. PTTs were modified with 2 additional solar panels to allow for continuous data collection, more accurate location data, and potential increase in longevity of the transmitter compared with a standard battery-powered or single solar-paneled Argos Doppler system. We mounted PTTs on a 7.6-cm, 2-piece, color-coated polyvinyl chloride (PVC), alpha-numeric engraved coded leg band (Haggie Engraving, Crumpton, MD) and attached the leg band above the distal tibio-tarsus joint (Krapu et al. 2011). PTT and flanged auxiliary markers weighed approximately 80-g, ≤ 2% of average body mass at capture ($\bar{x}$ = 4.68 kg, SE = 1.07 kg) and under the 3% of body mass guidelines recommended by the USGS-Bird Banding Laboratory (U.S. Geological Survey, -Bird Banding Laboratory 2012). For captured cranes not marked with PTTs, we affixed a 7.6-cm, 1.5-wrapped, alpha-numeric-engraved coded, PVC tarsus auxiliary leg band above the distal tibio-tarsus joint. All birds captured received a USGS-BBL 1-800 telephone number, size 8, aluminum, butt-end band and were released as a group within 30 minutes of being captured.

In addition to using a rocket-propelled net, we used a Coda NetLauncher (Coda Enterprises INC., Mesa, AZ) to capture cranes in locations where using a rocket-propelled net was not feasible. We followed the standard Coda NetLauncher protocol developed for sandhill cranes by the Ohio Department of Natural Resources (D. Sherman, Ohio Department of Natural Resources, pers. comm.). We also used modified Victor #3 softcatch leghold traps as described by King et al. (1998) to capture 1 crane. We captured sandhill cranes under protocol no. 1103A97333 of the University of Minnesota Institutional Animal Care and Use Committee.

Platform Transmitting Terminals collected GPS location data, which allowed determination of a 3-dimensional position, velocity, and time 24 hours a day, in all weather, anywhere in the world by measuring the distance from a receiver to each of several satellites. There are 24 operational satellites in 6 circular orbits above the earth spaced so that at any time a minimum of 6 satellites will be in view of the transmitter (U.S. Department of Homeland Security, U.S. Coast Guard, 2013). Accuracy for GPS locations was based on 4 quality levels: < 26 m, 26 m – 50 m, 51 m – 75 m and 76 m – 100 m. At the time of manufacture PTT units were programmed to follow 1 of 3 duty cycles. We tested the data collection capabilities of multi-paneled PPTs by programming the initial 6 of 12 PTTs to collect a GPS location on a 5-hour interval and the remainder on a 6-hour interval. An advance in technology allowed for differential duty cycles in which the remaining 18 units were programmed to maximize the number of GPS locations during migration by collecting locations every 6 hours and switching to collecting locations every 8 hours during non-migratory periods in the summer and winter.

PTTs transmitted Argos Sensor data and stored GPS location data to satellites for an 8-hour period every 3 days to allow for sufficient intervals between transmission and non-transmission periods for recharging the battery. Transmitter signals were received by 5 National Oceanic and Atmospheric Administration (NOAA) and 1 European Organization for the Exploration of Meteorological Satellites (EUMETSAT) weather satellites. Argos locations are calculated from Doppler shift in signal frequency as the satellite passes over the transmitter. We received Argos positions by Location Class (LC) codes 0, 1, 2, and 3, which are generally a quality of < 1,500 m and LC codes 0, A, and

B, which are generally a quality of >1,500 m (Argos 2013). In addition to location data, sensors built into the transmitters provided ambient temperature, battery voltage reading, activity, and current duty cycle information.

Data Analysis

We used GPS locations for EP cranes with 2 full annual cycles beginning from the date of capture to describe distribution and migration chronology. For cranes that had < 2 annual cycles due to either signal loss or death, we used GPS data for any completed migration and completed duration of stay at a winter or summer terminus. If needed, we incorporated Argos Doppler system locations for quality LC 3, 2, 1, and 0 as an alternative source of information to describe migration routes when GPS data locations were > 5 days between signals due to environmental conditions that result in insufficient battery voltage that caused a delayed transmission to satellites.

We retrieved raw satellite data from Collecte Localisation Satellites (CLS)-America, Inc. website (http://www.argos-system.org, Largo, MD), which we decoded into a Geograhic Information System (GIS) shapefile format through satellite data decoder software (DSDCODE, version 4.d) developed by North Star Science and Technologies, LLC (Baltimore, MD). We filtered GPS locations using an adapted location filtering system based on the Douglas Argos-Filter Algorithm version 6.5 (Douglas et al. 2012, developed by D. Douglas and modified by USGS, Northern Prairie Wildlife Research Center).

The modified Douglas filter algorithm extracts GPS record locations from the decoded GIS shapefile database and incorporates a binary (pass-fail) output of filtered data sets including all locations (no filtering), Geofence-filtered locations, Time-Interval-filtered locations, Redundant-Point-filtered locations, Distance-Angle filtered locations, and Rate-filtered locations. Description of the filters are as followed: (1) Geofence filter identifies unrealistic locations that are outside of continual winter or summer area, staging, or migration corridor locations, (2) Time-Interval filter determines if a location was collected approximately within the scheduled duty cycle interval (i.e., 5, 6, 8 hours), (3) Redundant-Point filter determines if multiple locations have been collected within a 12-minute period of each other, (4) Distance-Angle filter uses a combination of distance (> 50 km) and angle (< 5 degrees) formed by 3 locations to inspect changes in movement between 2 consecutive locations, and (5) Rate filter calculates a speed of the animal between successive locations and identifies locations > 100 km/h. We created a final GIS shapefile format database for analysis in Environmental Systems Research Institute (ESRI) ArcGIS software (Redlands, CA) based on the output of the modified algorithm of filtered GPS locations. We reexamined each filtered GPS location marked for deletion and made decisions based on the legitimacy of the location and by reevaluating any additional locations that appeared unrealistic that the filtering software might not have flagged.

We assigned attributes to GPS location records identifying 4 periods of the annual cycle (e.g., spring migration, summer area, fall migration, winter area; Krapu et al. 2011). We classified summer and winter area locations as the terminus of migration based on a major departure from the previous location and where a crane stayed in a localized area for > 10 days. We assigned fall and spring migration staging areas that we defined as a departure > 15 km for > 5 days from the summer and winter area. We defined staging areas as locations where a crane stayed at a single geographic area for > 5 consecutive days during migration. We considered areas where birds stayed for a shorter duration as stopover sites (Warnock 2010). We assigned winter attributes to staging and stopover locations for cranes that had not yet reached their winter terminus at a date when 85% of marked cranes had settled at their southernmost geographical extent during migration.

Proportion of PTT-marked cranes during the USFWS fall survey - To assess the proportion of PTT-marked cranes that were potentially available to be counted in areas surveyed during the USFWS fall survey, we spatially matched observer survey location descriptions for surveyed areas during the 2010-2012 surveys to GPS locations of marked cranes during the same periods. USFWS fall survey observer location descriptions ranged from general names of townships, nearest towns, or natural areas, to specific GPS coordinates. We assumed that observers were more likely to survey areas with a concentration of cranes (e.g., agricultural fields or roosts). We determined that PTT-marked cranes could potentially have been counted in the survey if their GPS coordinates were located within a described area or if the GPS locations of PTT-marked cranes were < 3 km from an observer's GPS location. We summarized the proportion of PTT-marked cranes that we determined were outside surveyed areas of the total number of PTT-marked cranes that we assumed were counted during the USFWS fall survey periods between 2010 and 2012.

Philopatry to summer area – To assess philopatry to summer area, we compared centroids of locations of cranes marked for consecutive summers during the period they occupied their summer ranges. We calculated centroids of locations for each summer area with ESRI ArcGIS v 9.2 spatial analysis software. We summarized the difference in linear distance between these centroids between or among years for individual cranes and report an overall mean.

RESULTS

From 2009 through 2011, we captured 152 EP sandhill cranes; 144 using rocket-propelled nets, 7 with a Coda NetLauncher, and 1 crane with a softcatch leghold trap. In total, we deployed 28 PTTs on 29 EP sandhill cranes (we recovered 1 PTT and deployed it on a second crane; Table 1). We fitted 37 cranes with a 3-digit alpha-numeric coded tarsus auxiliary band and banded 90 cranes with USGS-BBL, 1-800, aluminum, butt-end bands. Of the 29 PTT-marked cranes, 5 (18%) cranes died (4 PTTs were subsequently recovered), we lost communication with 8 (28%) PTTs, and 16 (57%) of PTTs we deployed lasted for ≥ 2 years.

We monitored EP cranes between December 2009 and February 2013, tracking an average of 18 cranes per calendar year (range = 6 – 26), which generated 61,377 GPS locations over 19,172 tracking days (Table 2). The average number of GPS locations per day for PTTs was 3 (range = 2 – 4) locations where 55% and 32% of the location quality levels were registered as < 26 m and 26 m - 50 m , respectively. The precision of GPS locations enabled us to retrieve 4 PTTs from cranes that died and to visually locate 3 marked cranes on summer areas through GPS locations identifying primary roosting sites. We observed gaps in GPS location data in association with lower battery voltage readings from transmitter sensor data. We presume that the likely explanations for low battery voltage were due to cranes occupying dense vegetation, cranes retracting their legs during long migration flights, or periods of continual cloud cover.

Distribution of Summer Areas

Summer areas of marked EP sandhill cranes were dispersed across 3 states and 1 province of the Great Lakes region; 3 (11%) settled in Minnesota, 10 (36%) settled in Wisconsin, 8 (29%) settled in Michigan, and 6 (21%) settled in Ontario (Fig. 2). Marked sandhill cranes in Minnesota occupied summer areas in the east-central portion of the state (Benton and Sherburne counties; Appendix 1). Cranes that summered in Wisconsin were widely distributed throughout the state, including in the southwest (Crawford County), the northwest (Washburn County), the north-central (Lincoln County), the east-central (Fond du Lac, Green Lake, Outagamie, Waupaca, and Winnebago counties), and the southeast (Racine and Waukesha counties) portions of the state. Cranes that summered in Michigan occupied the eastern portion of the Upper Peninsula (Chippewa and Mackinac counties) and the south-south central portion of the Lower Peninsula (Ingham, Jackson, Kent, and Muskegon counties). Marked EP cranes that summered in Canada occupied areas along the north shore of Lake Huron (Algoma District) and areas in east-central (Cochrane and Sudbury districts) Ontario.

Summer Area Philopatry

There were 23 PTT-marked cranes that returned to their initial summer area after a second spring migration. We were unable to assess summer area philopatry for 6 cranes that either died or for which we no longer received location data, presumably due to PTT failure. The average linear distance among centers of summer areas across years for individual cranes was 1.34 km (range: 0.01 – 7.82 km). Of the 23 cranes for which we were able to describe summer areas in multiple years, 16 (70%) settled < 1 km from the estimated mean center of the summer area of the previous year.

Description of Fall Migration

Migration from Summer Areas to South of Lake Michigan- PTT-marked sandhill cranes in south-central Minnesota and northwest Wisconsin (*n* = 4) departed in mid-October for staging areas at Sherburne National Wildlife Refuge and Crex Meadows Wildlife Area, located in east-central Minnesota and northwest Wisconsin, respectively. These cranes used additional staging areas in central and south-central Wisconsin near the Necedah National Wildlife Refuge and along the Wisconsin River Valley (south of the Wisconsin Dells, Wisconsin), respectively upon initiation of fall migration (Fig. 3a and Fig. 3b). Cranes (*n* = 2, 7%) that summered in southwestern and north-central Wisconsin migrated from their summer areas to staging areas in central Wisconsin as did birds from Minnesota and northwest Wisconsin. Cranes using staging areas in central Wisconsin departed in early-December on a southeastern path through north-central and northeastern Illinois.

EP cranes (*n* = 4, 14%) that summered in east-central Wisconsin departed summer areas by mid-October and flew short distances ($\bar{x}$ = 34.9 km) to staging areas surrounding Lake Poygon and Green Lake in east-central Wisconsin. These cranes then departed staging areas mid-November on a direct south-southeastern route to northeastern Illinois. Several cranes (*n* = 4, 14%) from east-central Wisconsin also used areas surrounding Horicon Marsh National Wildlife Refuge-State Wildlife Area and areas north of the Illinois border, southwest of Milwaukee, as they exited the state into northeastern Illinois. Two cranes that summered in southeastern Wisconsin, specifically, west and southwest of Milwaukee departed early-October from their summer areas in a south-southeastern direction and traveled through northeastern Illinois to staging areas within the Kankakee River Valley, northwest Indiana.

Marked cranes (n = 3, 11%) with summer areas in south-central Ontario departed late-August for fall staging areas along the western edge of the North Channel of Lake Huron ($\bar{x}$ = 227.1 km, range 137.7 - 388.7 km). Cranes that summered in the eastern Upper Peninsula of Michigan (n = 2, 7%) and south-central Ontario migrated in 1 of 2 separate directions around Lake Michigan (Fig. 3a). The first route consisted of moving west through the Upper Peninsula of Michigan directly to staging areas surrounding Lake Poygon in east-central Wisconsin. From east-central Wisconsin, these birds followed similar routes as cranes that summered in eastern Wisconsin, south-southeast through northeast Illinois to staging areas in northwest Indiana. The second route consisted of moving southwest from the staging area west of Lake Huron, crossing at the Straits of Mackinac, Michigan, using multiple sites throughout central and west-central Michigan to additional staging areas near Kalamazoo, Michigan (including areas surrounding the Audubon Society's Benard W. Baker Bird Sanctuary) or continued in a southwest direction crossing into northwest Indiana. The 4 (14%) PTT-marked cranes that summered adjacent to or along the North Channel of Lake Huron migrated south through the central portion of southern Michigan and staged in and around the Audubon Society's Benard W. Baker Bird Sanctuary or continued moving south and southwest to staging grounds in Indiana.

PTT-marked sandhill cranes (n = 3, 11%) that summered in the southern portion of Michigan departed summer areas in November and migrated directly to staging grounds in south-central Michigan (surrounding areas of Audubon's Society's Benard W. Baker Bird Sanctuary and west of Jackson, Michigan). They then departed south to their winter areas through northeastern Indiana and western Ohio.

Migration South of Lake Michigan to Winter Areas – As marked cranes continued south from Illinois and Michigan through northwest Indiana to their respective winter areas, 18 (64%) cranes used the JP FWA and the Kankakee River Valley throughout the course of our study. There were 8 (29%) cranes that summered in Minnesota, Wisconsin, southern Michigan, and Ontario that bypassed the Kankakee River Valley at least 1 year during fall migration from 2010 to 2012. These cranes would leave northern staging areas in early-December and made brief stops in west-central Indiana and east-central Illinois and in east-central Indiana and Ohio as they moved south to their winter terminus (Fig. 3a).

Marked cranes that continued their migration south of JP FWA and the Kankakee River Valley moved either through west or central Indiana and then converged on similar routes through central Kentucky. Cranes (n = 2, 7%) that moved through western Indiana utilized Goose Ponds FWA and surrounding area as a staging area. Cranes (n = 8, 29%) that moved through central Indiana staged in the area along the White River Valley (Ewing Bottoms), southwest of Seymour, Indiana. As marked EP cranes continued their migration through central Kentucky and into north-central Tennessee, 5 (18%) and 4 (14%) used staging areas in north-central Kentucky (areas surrounding Cecilia, Kentucky) and south-central Kentucky (Barren River Lake State Park and surrounding area), respectively.

Cranes (n = 12, 43%) that continued south from central Kentucky moved through central Tennessee, then used the Chickamauga Reservoir (specifically, HWR) as a staging area prior to completing their migration. Marked cranes that continued to winter areas in Georgia and Florida made multiple stops in a narrow migration corridor in western Georgia and continued to the Florida Peninsula. There were 29 and 95 locations we identified as staging areas (length of stay; > 5 days) and stopover sites (length of stay; ≤ 5 days) during fall migration, respectively (Fig. 3b), with the Kankakee River Valley, Indiana (JP FWA), Chickamauga Reservoir, Tennessee (HWR), and Benard W. Baker Audubon Bird Sanctuary and surrounding area, Michigan (Barry, Calhoun, and Kalamazoo counties) staging areas used most frequently during migration (Table 3).

Distribution of Winter Areas

The distribution of winter areas for PTT-marked EP sandhill cranes extended from Indiana to Florida (Fig. 4; Table 4). The majority of marked cranes (n = 22, 79%) settled in southeast Tennessee within the HWR and surrounding areas within the Chickamauga Reservoir (Meigs, Rhea, and Hamilton counties; Table 5). South of Tennessee, 9 (32%) PTT-marked EP cranes wintered throughout the Florida Peninsula (Alachua, Highlands, Lake, Marion, Okeechobee, Osceola, and Pasco counties) and 3 (11%) wintered in southern Georgia (Baker, Brooks, and Crisp counties). North of Tennessee, 3 (11%) PTT-marked cranes wintered in south-central (Benton County) and north-central (Harden and Larue counties) Kentucky and 8 (29%) wintered in northwest (Jasper, Pulaski, and Starke counties) and southern (Green and Jackson counties) Indiana.

Description of Spring Migration

PTT-marked cranes used spring migration routes similar to the routes they used during fall migration (Fig. 5a). Cranes that wintered in Florida and southern Georgia moved through central and western Georgia and eastern Alabama en route to southeastern Tennessee. Four (14%) PTT-marked cranes that wintered in Florida or Georgia stopped in the HWR and surrounding areas within the Chickamauga Reservoir, Tennessee as a staging area during spring migration (Fig. 5b). Individuals that wintered in Florida or southern Georgia either migrated to southern Kentucky or settled at stopover sites north of the Chickamauga Reservoir. Cranes that moved to southeastern Tennessee from southern wintering areas and cranes that wintered in the Chickamauga Reservoir migrated in a northwest direction through central Kentucky. These cranes used multiple staging areas in Kentucky, with concentrations of areas centered in south-central Kentucky (n = 11, 39%; Barren River Lake State Park) and north-central Kentucky (n = 19, 68%; surrounding area of Cecilia, Kentucky).

Cranes migrating north from Kentucky moved to southern Indiana with concentrations of staging areas in the White River Valley (Ewing Bottoms; n = 19, 68%; Jackson County) and Goose Ponds FWA and surrounding area (n = 10, 36%; Greene County). Most cranes (n = 25, 89%) used stopover sites at the JP FWA and the Kankakee River Valley after departing southern Indiana, and from there, continued migration to their respective summer areas. Cranes that summered in Minnesota, Wisconsin, and southern Michigan used similar spring migration routes and staging areas comparable to those used during fall migration. Nine (32%) cranes that summered in the Upper Peninsula of Michigan, the North Shore of Lake Huron, and central Ontario migrated either to the west of Lake Michigan through eastern Wisconsin or to the east of Lake Michigan through west and central Michigan. Two (22%) of these 9 cranes alternated spring migration routes in subsequent years around Lake Michigan during spring migration. We identified 23 staging (length of stay; > 5 days) and 109 stopover (length of stay; < 5 days) sites (Fig. 5b), with the Kankakee River Valley, Indiana (JP

FWA) and Hardin County, Kentucky (Cecilia) staging areas used most frequently during spring migration (Table 6).

Chronology of Annual Movements

EP cranes on average arrived at their summer areas on 23 March (*n* = 53; range: 27 February – 3 May) and stayed on these areas an average of 192.8 days (*n* = 48; range: 116 – 268 days). Cranes departed for staging areas by 7 October (*n* = 47: range: 10 August – 28 December; Table 7) and traveled an average distance of 1270.4 km (range: 265.6 – 2334.5 km) over 69.5 days (range: 2 - 148 days) from summer areas to winter termini (Table 8). PTT-marked cranes used an average of 4.7 stops (range: 2 – 13 stops) during fall migration: we classified 1.8 (*n* = 80) stops as staging areas and 3.0 (*n* = 135) as stopover sites (Fig. 3b). We identified 29 individual sites as staging areas and 95 sites as stopover sites. Number of days spent on individual staging areas averaged 31.7 days (range: 6 – 114 days), where 35% and 12% of the cumulative migrating days were spent in the Kankakee River Valley and central Michigan, respectively (Table 9) . Average cumulative distance traveled between subsequent stops from summer areas during the breeding season to winter termini during fall migration was 236.0 km (range 8.8 – 938.3 km; Table 10).

Average arrival date of EP cranes at their winter areas was 15 December (range: 21 September - 27 January) and they remained on winter areas an average of 51.6 days (range: 5 – 115 days). Average departure date of PTT-marked cranes from winter areas was 9 February (range: 2 January – 14 March, Table 11) and they traveled an average distance of 1328.9 km (range: 288.8 – 2389.7 km) over 36.5 days (range: 4 – 73 days) from winter areas to summer areas (Table 12). Cranes stopped on average 6.5 times (range: 1 – 15 stops) during spring migration: we classified 4.7 (*n* = 250) stops as stopover sites and 1.8 (*n* = 95) stops as staging areas. We identified 23 individual sites as staging areas and 109 sites as stopover sites (Fig. 5b). Average number of days spent on staging areas during spring migration was 14.4 days (range: 6 – 37 days), where 37% and 8% of the cumulative migrating days were spent in the Kankakee River Valley and the White River Valley, respectively (Table 13). Average distance traveled between sequential stops prior to reaching areas settled during the breeding season was 180.2 km (range: 111.6 – 343.5 km; Table 14).

USFWS Fall Survey

There were 31%, 22%, and 23% of PTT-marked EP sandhill cranes located outside of areas surveyed during the 2010, 2011, and 2012 USFWS fall surveys, respectively. Locations of marked cranes that were not within areas surveyed during the survey periods included north and east-central Wisconsin and central and north-central Michigan. All of the birds that summered in Canada were present in surveyed locations during the periods of the survey for all 3 annual survey periods.

DISCUSSION

Summer Area Distribution

Geographic distribution and the migration routes used by our sample of PTT-marked EP cranes coincided with previously reported geographic distribution (Walkinshaw 1949, Tacha et al. 1994) and migration routes (Walkinshaw 1960, Melvin and Temple 1982), which indicated that our sample likely was representative of the EP. Summer areas of the PTT-marked cranes in our sample were widely distributed throughout Minnesota, Wisconsin, Michigan, and in the eastern portion of Ontario, Canada, and occurred within the current estimated breeding range of the EP of cranes (D. J. Case and Associates 2010). However, at smaller spatial scales, some areas thought to support breeding EP cranes were not represented by our sample of PTT-marked cranes, including northwest Wisconsin-northeast Minnesota (Wisconsin Society for Ornithology 2014, Minnesota Breeding Bird Atlas Project 2014) and eastern Ontario, including Manitoulin Island, the eastern shore of Lake Huron, and the southern peninsula of Ontario (Bird Studies Canada et al. 2006). None of the PTT-marked cranes in our sample overlapped the summer range of MCP greater sandhill cranes identified by Krapu et al. (2011). Summer area locations of our sample of PTT-marked crane were concentrated in east-central Wisconsin and the north shore of Lake Huron, Ontario. Sandhill crane breeding distribution maps for Wisconsin (Van Horn et al. 2010) and Ontario (Bird Studies Canada et al. 2006) depict that these 2 areas support relatively high densities of breeding cranes, which suggests that our sample may have over-represented these portions of the breeding distribution.

EP cranes arrived on summer areas during mid-March and departed for staging areas during mid-September. PTT-marked cranes consistently returned to the same summer areas in subsequent years, similar to Rocky Mountain Population (Drewien 1973) and MCP (Krapu et al. 2011) cranes. Both our PTT-marked EP cranes and MCP cranes (Krapu et al. 2011) on average used subsequent summer areas < 10 km of one another; 82% of PTT-marked EP cranes used subsequent summer areas within 1 km of one another, compared to 38% for MCP cranes (Krapu et al. 2011). We observed only 1 instance when an individual crane moved a substantial distance (49.2 km) between subsequent summer areas, and we speculate that this crane may have been a sub-adult.

Migration Routes and Chronology

Our sample of PTT-marked sandhill cranes used migration routes similar to previous EP crane migration studies of VHF-marked cranes in south-central Minnesota (Crete and Toepfer 1978) and for ARGOS Doppler PTT-marked cranes on Manitoulin Island, Ontario, Canada (S. Petrie, Bird Studies Canada, unpublished data). However, in contrast to those studies, we demonstrated that individual cranes that summered within the Upper Peninsula of Michigan and in north-central Ontario, Canada used migration routes on the west side of Lake Michigan to and from staging areas in Indiana. This is the first time this behavior and migration routes have been documented.

Recent satellite telemetry studies suggest that EP cranes may use migration routes west of routes used by our sample of marked cranes. King et al. (2010) found that 2 cranes in his sample of PTT-marked sandhill cranes that wintered in central Louisiana migrated north through the Mississippi Alluvial Valley towards summer areas within the EP summer distribution. One marked crane in their study used a migration route through west-central Illinois to southwest Wisconsin, and then into the Upper Peninsula of Michigan where the signal from the PTT was lost. The other crane traveled a similar route used by some of the cranes in our sample through west-central Indiana (Goose Ponds FWA), northwest Indiana (Kankakee River Valley), east-central Wisconsin, and then through the Upper Peninsula of Michigan to a summer area in north-central Ontario. In 2010, PTT-marked EP cranes that summered on Manitoulin Island, Ontario (E. Hanna, University of London Ontario, unpublished data) included 1 crane that migrated west from the White River Valley staging area in southern Indiana and wintered at the Hop-In Wildlife Refuge in northwest Tennessee.

PTT-marked EP cranes consistently used staging areas along migration routes but made fewer stops for a longer duration during fall migration (Tables 8 and 10) in contrast to spring migration (Tables 12 and 14). Locations where cranes stopped during migration along the north shore of Lake Huron, Algoma District, Ontario; Lake Poygon, east-central Wisconsin; the Kankakee River Valley, northwest Indiana; and the Benard W. Baker Bird Sanctuary, south-central Michigan were more frequented by cranes during fall migration (Fig. 6). These areas support shallow marsh roosting habitat, are in most cases protected, and have an abundant food supply in the form of agricultural production. PTT-marked cranes utilized Hardin County, north-central Kentucky; White River Valley (Ewing Bottoms), south-central Indiana; and the Kankakee River Valley, northwest Indiana more frequently during spring than during fall migration. The Kankakee River Valley located in northwest Indiana was the most frequented of all staging areas during fall and spring migration where cranes spent 35% and 37% of cumulative migration days, respectively.

Winter Area Distribution

Distribution of winter areas for PTT-marked EP sandhill cranes extended from Indiana to Florida, well north of the areas previously described by Tacha et al. (1994), who indicated that EP cranes wintered mainly in the southeastern states of Georgia and Florida. Our PTT-marked EP cranes wintered in Florida, Georgia, Tennessee, Kentucky, and Indiana with the Chickamauga Reservoir in southeast Tennessee having the highest proportion of use among all winter areas (Table 5). The proportion of PTT-marked cranes that used the Chickamauga Reservoir for the winters of 2009 and 2010 are biased high because we trapped the majority of cranes (n = 6, 2009-2010; n = 12, 2010-2011) at the HWR during December and January of those years. However, the proportion of PTT-marked EP cranes that utilized the Chickamauga Reservoir during 2010 may be a more accurate reflection of the total EP, because during 2010, relatively cold weather conditions north of Tennessee likely influenced most EP cranes to winter farther south. In 2010, the MWS index for the Chickamauga Reservoir indicated a record number of cranes (n = 48,300; J. R. Kelley, USFWS-Migratory Bird Management, pers. comm.), likely as a result of cold weather north of HWR.

EP crane use at Chickamauga Reservoir has increased during winter months over the last decade due to the abundance of waste grain planted for wildlife on managed lands and roosting habitat that is protected from disturbance (R. Klippel, Tennessee Wildlife Resource Agency, pers. comm.). Counts of cranes for the Chickamauga Reservoir during the January MWS for the period 2009-2013, averaged 20,100 (range: 11,540 – 48,328) sandhill cranes wintering throughout the valley (J. R. Kelley, pers. comm.).

Locations of winter areas varied among years for PTT-marked cranes in our sample; 8 (33%) of PTT-marked cranes returned to the same winter area in subsequent winters (Table 4). EP cranes have recently been observed wintering at staging areas at higher latitudes than previously reported, perhaps related to winter conditions with roosting habitat that remains unfrozen later into the season and abundant food resources in the form of agricultural crop residue. Ten (36%) PTT-marked cranes that wintered north of Tennessee used migration staging areas in Kentucky (Barren River Lake State Park) and throughout Indiana (White River Valley, Goose Ponds Fish and Wildlife, and the Kankakee River Valley). Four (14%) PTT-marked cranes that summered throughout the EP breeding range used the Kankakee River Valley as a winter area. These cranes used the JP FWA until all available roosting sites froze, then roosted within the Schahfer Generating Station property in Wheatfield, Indiana about 10 km north-northwest of JP FWA. The power station provided roosting habitat that remained ice-free for EP cranes throughout winter (J. Bergens, pers. comm).

Location data from previous satellite studies suggest that EP sandhill cranes used winter areas in northern Louisiana (King et al. 2010) and northwest Tennessee (E. Hanna, unpublished data) west of previously reported wintering areas for EP sandhill cranes. MWS data can be used as another measure to track cranes that winter in areas not previously reported. Observations at Hop-In Wildlife Refuge, northwest Tennessee and the Wheeler NWR, north-central Alabama, both indicated an increase in the abundance of wintering sandhill cranes with an average of 2,830 (2,000 – 3,450) cranes at Hop-In Wildlife Refuge and 7,722 (range: 3,904 – 12,032) cranes at Wheeler NWRduring the 2009-2013 period. One PTT-marked crane from our sample staged at Wheeler NWR for 29 days during December 2011 prior to terminating fall migration in Florida.

MANAGEMENT IMPLICATIONS

Evaluation of the USFWS fall survey has been identified as a priority need by the Migratory Shore and Upland Game Bird Task Force (D. J. Case and Associates 2009). Amundson and Johnson (2011) assessed the historical USFWS fall survey data in relation to the North American Breeding Bird Survey (BBS) and drew 2 conclusions; that both surveys track the population's growth and that the BBS was also able to track geographic expansion. However, under current protocol, the USFWS fall survey is not designed to track the geographic expansion of the population. By evaluating where our sample of PTT-marked cranes was located during survey periods across 3 years, we were able to provide an assessment of what proportion of cranes were not in areas currently covered by the USFS fall survey.

A key component for the USFWS fall survey is to begin at the end of October. This assumes that cranes that summer in Canada have arrived on southern staging areas by the start of the survey period (S. Kelly, pers. comm.). During the 2010-2012 USFWS fall survey periods, GPS locations for PTT-marked cranes that occupied summer areas in Canada were from staging areas in central and south-central Michigan and east-central Wisconsin during the survey, and in locations included in the survey (Fig. 7). The timing for the survey was designed to occur when EP cranes are concentrated on staging areas. During the 2010-2012 survey periods, we estimated that between 21% and 31% of PTT-marked cranes that summered in both Wisconsin and the Lower Peninsula of Michigan were not in areas included in the USFWS fall survey. We speculate these cranes represent a portion of the EP that is not associated with known concentration areas, and may therefore be widely dispersed across a large geographic area. If that is the case, designing and conducting a survey to estimate the size of this portion of the EP would likely be expensive and require considerable resources. However, if there is a substantial portion of the EP that is not associated with areas included in the fall survey during the period when the survey is conducted, the resulting estimate of fall population size is likely underestimated for EP cranes. A substantial undercount of EP cranes has at least 2 potential implications for the USFWS fall survey. First, if there is no change in protocol, the fall survey should be recognized as a survey that provides what is likely a conservative index of population size. Second, the survey period could perhaps be moved later into the fall or early winter, when a larger portion of EP cranes are likely to be associated with concentration areas. The effects of moving the survey period would need to be evaluated to avoid issues related to EP cranes arriving on wintering areas in Florida and distinguishing EP cranes from the Florida non-migratory greater sandhill cranes (*G. c. pratensis*).

Our location data identified specific areas EP cranes used during stages of their annual life cycle. EP Sandhill cranes are known for their gregarious nature and use areas that provide a combination of shallow roosting habitat within an agricultural landscape for staging during migration. Information on the location and timing of use of those areas by EP cranes can be used to target management activities at both the local (e.g., state or province) and flyway scales.

Table 1. Trap location, capture date, and summer location for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2009-2011.

Trap Location[a]					Summer Area
State/Province	Latitude	Longitude	PTT ID	Trap Date	State/Province
IN	39°.0 N	-87°.2	98791	4 Mar 2010	MI
	41°.2 N	-86°.9	98789	25 Oct 2010	ON
			98793	25 Oct 2010	ON
			98790	25 Oct 2010	MI
			67140	25 Oct 2010	WI
			67147	19 Nov 2010	ON
			67141	20 Nov 2010	Unknown
			67119	22 Nov 2010	MI
			67152	22 Nov 2010	MI
MN	45°.5 N	-93°.7	98797	13 Oct 2010	MN
TN	35°.4 N	-84°.9	98795	17 Dec 2009	ON
			98799	21 Dec 2009	WI
			98792	21 Dec 2009	WI
			98798	12 Jan 2010	WI
			98796	13 Jan 2010	WI
			98788	15 Jan 2010	WI
			67141[b]	8 Dec 2010	WI
			67149	8 Dec 2010	MI
			67143	9 Dec 2010	ON
			67144	9 Dec 2010	MN
			67142	10 Dec 2010	MI
			67146	10 Dec 2010	ON
			67145	22 Jan 2011	MI
			67154	22 Jan 2011	WI
			67148	22 Jan 2011	Unknown
			67151	22 Jan 2011	WI
			67153	24 Jan 2011	MN
			67150	24 Jan 2011	Unknown
WI	45°.8 N	-92°.6	67155	14 Sep 2011	WI

[a] Units are decimal degrees [b] Redeployed transmitter

Table 2. Number of GPS locations for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2009-2013.

PTT Identification[a]	Year					Total
	2009	2010	2011	2012	2013	
67119		255	1,147	960	91	2,453
67140		424	1,197	1,128	100	2,849
67141		235	1,086	317		1,638
67142		93	771	586		1,450
67143		268	1,056	334		1,658
67144		214	1,187	1,125	37	2,563
67145			361			361
67146		170	1,324	871	81	2,446
67147		356	1,210	1,150		2,716
67148			172			172
67149		97	1,085	1,056		2,238
67151			618	542		1,160
67152		337	803	163		1,303
67153			1,185	185	16	1,386
67154			1,110	298		1,408
67155			387	550		937
98788		1,358	1,170	1,327		3,855
98789		380	1,114	881	11	2,386
98790		410	1,124	1,389		2,923
98791		1,094	1,159	681		2,934
98792	71	1,378	348			1,797
98793		450	1,273	1,170		2,893
98795	270	1,120	1,455	1,459	64	4,368
98796		1,539	1,428	1,328		4,295
98797		523	55			578
98798		1,452	1,332	1,470		4,254
98799	159	1,441	1,368	1,388		4,356
Total	500	13,594	26,525	20,358	400	61,377

[a]Not shown original PTT 67141 and PTT 67150

Table 3. Most frequented staging and stopover areas by state or province for fall migrating Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2013.

			2010		2011		2012		2013		Total	
State - Province	Counties - Districts	Common name	Stopover	Staging	Stopover	Staging	Stopover	Staging	Stopover	Staging	Stopover	Staging
ON	Algoma, Cochrane		2	1		3		2			2	6
MI	Barry, Calhoun, Kalamazoo	Benard W. Baker Bird Sanctuary		1	3	4	1	5			4	10
	Chippewa				3	2	1	1			4	3
	Missaukee				2		1	3			3	3
	Statewide		1		7	1	5	1			13	2
WI	Waupaca, Wausharra, Winnebago	Lake Poygon				7		2			0	9
	Iowa, Juneau, Sawk	Wisconsin River (Wisconsin Dells)		1		3		3			0	7
	Lincoln		1	1		1		1			1	3
	Wood	Baraboo	1	1		1	1				2	2
	Dodge	Horicon WA			1	1	1				2	1
	Statewide		1	1	5	2	2	4			8	7
MN	Statewide			1		2		1			0	4
IL	Statewide						1				1	0
IN	Jasper, LaPorte, Pulaski, Starke	Kankakee River Valley	4	7		14	3	5			7	26
	Jackson	White River Valley (Ewing Bottoms)	2		1	3	5		1		9	3
	Washington		1				2				3	0
	Greene	Goose Ponds FWA					1	1			1	1
	Statewide		7		6		7		1		21	0
OH	Statewide				2						2	0
KY	Hardin	Cecilia			1	1		1	1	1	2	3
	Barren	Barren Lake State Park	2				2				4	0
	Statewide		4		1		4				9	0
TN	Meigs, Rhea	Chickamauga Reservoir	5	1	2	1	5	2			12	4
	Statewide		4		2		1		1		8	0
AL	Statewide					1					0	1
GA	Statewide		7	2	4		8				19	2
FL	Oscelola		3		1		1	1		1	5	2
	Alachua		2		1		1				4	0
	Marion		1				3				4	0
	Statewide		5		1		7		1		14	0

Table 4. Winter area locations by state for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2009-2012.

PTT ID	2009-2010	2010-2011	2011-2012	2012-2013
67119		FL	FL	TN
67140		TN	FL	FL
67141[a]		TN	TN	
67142		GA	GA	FL
67143		TN	KY	
67144		TN	IN	IN
67145[b]		TN		
67146		TN	TN	TN
67147		IN	IN	IN
67148[b]		TN		
67149		TN	KY	TN
67150[b]		TN		
67151		TN	TN	IN
67152		FL	TN	
67153		TN	IN	KY
67154		TN	TN	
67155			IN	
98788	TN	TN	TN	IN
98789		TN	TN	TN
98790		FL	FL	FL
98791		TN	TN	FL
98792	GA	GA		
98793		FL	FL	FL
98795	TN	TN	TN	TN
98796	TN	FL	IN	TN
98797		TN		
98798	TN	TN	IN	IN
98799	TN	FL	FL	GA

a Original bird died after initial trapping, PTT was redeployed

b Cranes died or lost of signal after capture on winter area

Table 5. The proportion of Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes using winter areas by state, 2010-2012.

	2010-11	2011-12	2012-13	All Years
Number of PTT-marked cranes	26	23	18	28
State				
Indiana	4%	26%	28%	29%
Kentucky	0%	9%	6%	11%
Tennessee	65%	39%	33%	79%
Georgia	8%	4%	6%	11%
Florida	23%	22%	28%	32%

Table 6. Most frequented staging and stopover areas by state or province for spring migrating Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012.

State - Province	County/Distict	Common Name	2010 Stopover	2010 Staging	2011 Stopover	2011 Staging	2012 Stopover	2012 Staging	Total Stopover	Total Staging
FL	Statewide				2		3	1	5	1
GA	Statewide				12		8		20	0
AL	Statewide				1				1	0
TN	Meigs, Rhea	Chickamauga Reservior	1		4		2		7	0
	Statewide				4	2	1		5	2
KY	Hardin, Larue	Cecilia	3	2	6	8	3	1	12	11
	Barrren, Metcalfe, Monroe	Barren River State Park	1	1	3	1			4	2
	Statewide		1		9		3		13	0
IL	Statewide		1				1		2	0
IN	LaPorte, Jasper, Pulaski, Starke	Kankakee River Valley	1	5	6	18	12	15	19	38
	Jackson	White River Valley (Ewing Bottoms)	1	2	6	4	7	3	14	9
	Greene	Goose Ponds FWA	2		4	2			6	2
	Morgan County				2	2	1	1	3	3
	Statewide		4	1	10	2	11		25	3
MI	Barry, Calhoun, Kalamazoo	Audubon's Benard W. Baker Bird Sanctuary		1	4	2	2	2	6	5
	Missaukee				3	1	1		4	1
	Cass				1		2	1	3	1
	Statewide			1	10		20	2	30	3
MN	Statewide				10	1	1		11	1
WI	Dodge	Horicon Wildlife Area	1		4		3		8	0
	Waupaca, Waushara, Winnebago	Lake Poygon	1			2	3	1	4	3
	Fond Du Lac, Green Lake, Marquette	Green Lake	1	1	1	2			2	3
	Jefferson				1	1	3		4	1
	Walworth						5		5	0
	Statewide		0		12	2	12		24	2
ON	Algoma		1		4		3	1	8	1

Table 7. Mean arrival date (ARD), duration of stay (DRS), and mean departure date (DPD) for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill crane summer area locations, 2010-2012.

			Year								
			2010			2011			2012		
PTT ID	Summer Area	Sex	ARD	DRS	DPD	ARD	DRS	DPD	ARD	DRS	DPD
67119	UP MI	M				12 Apr	150	12 Sep	17 Mar	154	9 Aug
67140	WI	F				2 Mar	230	22 Oct	10 Mar	203	3 Oct
67141	WI	F				9 Mar	209	8 Oct	7 Mar[a]		
67142	MI	M				2 May	235	27 Dec	7 Mar	257	24 Nov
67143	ON	M				13 Apr	116	9 Aug	--[a]		
67144	MN	F				18 Apr	208	16 Nov	16 Mar	235	11 Nov
67145	LP MI	F				10 Mar[b]					
67146	ON	F				31 Mar	197	17 Oct	21 Mar	195	6 Oct
67147	ON	F				21 Apr	125	26 Aug	7 Apr	141	28 Aug
67149	LP MI	F				15 Mar	194	29 Sep	13 Mar	204	7 Oct
67151	WI	F				7 Mar	189	16 Sep	10 Mar	184	14 Sep
67152	UP MI	F				12 Apr	150	12 Sep	21 Mar[b]		
67153	MN	F				15 Mar	178	13 Sep	17 Mar	166	3 Sep
67154	WI	F				8 Mar	193	23 Sep	12 Mar[a]		
67155	WI	F							19 Mar	231	10 Nov
98788	WI	F	1 Apr	219	20 Nov	18 Mar	237	15 Nov	11 Mar	249	20 Nov
98789	ON	F				10 Apr	188	18 Oct	3 Apr	177	30 Sep
98790	UP MI	F				6 Apr	173	29 Sep	19 Mar	190	29 Sep
98791	LP MI	M	7 Mar	214	11 Oct	11 Mar	222	23 Oct	27 Feb	268	25 Nov
98792	WI	F	16 Mar	166	2 Sep	15 Mar[a]					
98793	ON	F				7 Apr	172	29 Sep	17 Mar	189	26 Sep
98795	ON	M	1 Apr	152	13 Sep	18 Apr	136	4 Sep	7 Apr	141	28 Aug
98796	WI	F	16 Mar	245	22 Nov	14 Mar	245	19 Nov	11 Mar	245	16 Nov
98798	WI	F	9 Mar	196	25 Sep	2 Mar	207	29 Sep	11 Mar	187	18 Sep
98799	WI	F	21 Mar	167	8 Sep	5 Apr	145	31 Aug	14 Mar	180	14 Sep
Average among years			22 Mar	194	5 Oct	27 Mar	186	4 Oct	16 Mar	200	6 Oct

[a] Lost signal [b] Died

Table 8. Total linear distance (km; TLD) and total days migrated (TDM) from summer area to winter termini for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012.

		Year								
		2010			2011			2012		
PTT ID	Summer Area	TLD	TDM	Winter Area	TLD	TDM	Winter Area	TLD	TDM	Winter Area
67119	UP MI	*	*	FL	2334.5	83	FL	680.2	131	TN
67140	WI	*	*	TN	1269.0	70	FL	1965.7	104	FL
67141	WI	*	*	TN	1061.0	85	TN			
67142	LP MI	*	*	GA	899.9	7	GA	1580.1	25	FL
67143	ON	*	*	TN	1655.8	148	KY			
67144	MN	*	*	TN	408.4	51	IN	1083.9	75	IN
67146	ON	*	*	TN	1314.3	29	TN	1445.3	77	TN
67147	ON	*	*	TN	1116.1	35	IN	918.1	28	IN
67149	LP MI	*	*	TN	941.5	96	KY	927.6	83	TN
67151	WI	*	*	TN	1073.0	107	TN	427.6	81	IN
67152	UP MI	*	*	FL	1443.4	79	TN			
67153	MN	*	*	TN	765.8	85	IN	1163.0	124	KY
67154	WI	*	*	TN	1055.2	99	TN			
98788	WI	1049.2	7	TN	1038.7	47	IN	372.7	3	IN
98789	ON	*	*	TN	1210.6	74	TN	1297.3	63	TN
98790	UP MI	*	*	FL	2083.3	48	FL	2027.9	63	FL
98791	LP MI	836.6	56	TN	891.0	53	TN	1559.9	27	FL
98792	WI	1573.4	106	GA						
98793	ON	*	*	FL	2272.3	61	FL	2229.5	79	FL
98795	ON	1469.0	111	TN	1434.5	120	TN	1543.5	147	TN
98796	WI	1964.2	11	FL	683.4	11	IN	1104.5	12	TN
98798	WI	926.8	80	TN	519.4	117	IN	265.6	2	IN
98799	WI	2124.1	85	FL	1969.5	94	FL	1728.0	89	GA
Average among years:		1420.5	65.1		1247.3	73.2		1211.3	67.4	

* Unable to summarize category

Table 9. Number of stops and percentage of total migrating days during fall migration for staging areas used by Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012. Fall staging areas in the table are areas that had at least 1% of the total fall migrating days spent in that area.

Fall Migration Staging Areas				
State	County/District	Common Names	Number of Stops	Percent of Total Days
IN	LaPorte, Jasper, Pulaski, Starke	Kankakee River Valley	33	35.2
MI	Barry, Calhoun, Kalamazoo	Benard W. Baker Bird Sanctuary	14	11.6
WI	Iowa, Juneu, Sauk	Wisconsin River Valley	11	8.5
WI	Waupaca, Waushara, Winnebago	Lake Poygon	9	7.4
ON	Algoma	North Shore of Lake Huron	8	5.1
MN	Sherburne	Sherburne NWR	4	4.0
IN	Jackson	White River Valley	12	2.9
WI	Lincoln		4	2.8
WI	Burnet	Crex Meadows	1	2.3
WI	Green Lake		1	2.3
MI	Chippewa		7	2.0
TN	Meigs, Rhea	Chicamauga Reservoir	17	1.9
WI	Columbia		1	1.4

Table 10. Number of stops made between summer area and winter terminus and mean linear distance between sequential migration stops (MLD) during fall migration for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012.

		Year								
		2010			2011			2012		
PTT ID	Summer Area	Number of Stops	MLD	Winter Area	Number of Stops	MLD	Winter Area	Number of Stops	MLD	Winter Area
67119	UP MI	*	*	FL	10	217.8	FL	7	168.8	IN
67140	WI	*	*	TN	7	206.5	FL	13	89.5	FL
67141	WI	*	*	TN	4	173.4	TN			
67142	LP MI	*	*	GA	2	175.9	GA			
67143	ON	*	*	TN	5	265.3	KY			
67144	MN	*	*	TN	5	224.5	IN	6	196.5	IN
67146	ON	*	*	TN	3	370.1	TN	5	120.0	TN
67147	ON	*	*	TN	3	271.9	IN	4	164.2	IN
67149	LP MI	*	*	TN	6	130.8	KY	2	72.8	TN
67151	WI	*	*	TN	3	224.4	TN	1	94.7	IN
67152	UP MI	*	*	FL	5	158.0	TN			
67153	MN	*	*	TN	3	116.9	IN			
67154	WI	*	*	TN	3	194.6	TN			
98788	WI	1	375.9	TN	1	332.0	TN	2	78.6	IN
98789	ON	*	*	TN	7	137.0	TN	4	160.7	TN
98790	UP MI	*	*	FL	3	330.8	FL	6	333.1	FL
98791	LP MI	2	152.9	TN	5	124.9	TN	5	110.5	FL
98792	WI	6	188.9	GA						
98793	ON	*	*	FL	6	369.8	FL	12	182.3	FL
98795	ON	6	179.7	TN	4	238.5	TN	5	276.0	TN
98796	WI	6	317.4	FL	2	93.2	IN	4	229.8	TN
98798	WI	4	215.4	TN	2	192.0	IN	1	75.2	IN
98799	WI	9	231.4	TN	9	196.8	FL	6	240.1	GA
Average among years:		4.9	248.0		4.5	212.6		5.2	171.1	

*Unable to summarize category

Table 11. Number of Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes (*n*), mean arrival date (ARD), mean duration of stay (DRS), and mean departure date (DPD) by state with sandhill crane winter termini, 2009-2012.

	Year															
	2009				2010				2011				2012			
State	*n*	ARD	DRS	DPD	*n*	ARD	DRS	DPD	*n*	ARD	DRS	DPD	*n*	ARD	DRS	DPD
IN					1	*	*	18 Feb	6	15 Dec	64.5	20 Feb	5	13 Nov	*	*
KY									2	7 Jan	14.5	21 Jan	1	17 Jan	*	*
TN	5	*	*	9 Feb	15	8 Dec	61.6	11 Feb	9	22 Dec	36.0	29 Jan	6	21 Dec	*	*
GA	1	10 Jan	41	20 Feb	2	24 Dec	40.0	4 Feb	1	5 Jan	10	15 Jan	1	13 Dec	*	*
FL					6	3 Dec	78.3	23 Feb	5	5 Dec	64.4	10 Feb	5	21 Dec	*	*

[*] Unable to summarize category

Table 12. Total linear distance (km; TLD) and total days migrated (TDM) from winter termini to summer areas for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012.

		Year								
		2010			2011			2012		
PTT ID	Summer Area	Winter Area	TLD	TDM	Winter Area	TLD	TDM	Winter Area	TLD	TDM
67119	UP MI				FL	2327.2	46	FL	2333.5	27
67140	WI				TN	883.5	26	FL	1817.5	19
67141	WI				TN	1042.5	17	TN	588.0	33
67142	LP MI				GA	1637.9	70	GA	890.7	37
67143	ON				TN	1846.1	51	KY	1688.6	61
67144	ON				TN	1786.3	73	IN	1023.1	20
67145	LP MI				TN	915.1	8			
67146	ON				TN	901.7	46	TN	1091.4	48
67147	ON				IN	1294.3	64	IN	1314.6	56
67149	LP MI				TN	745.1	19	KY	506.9	12
67151	WI				TN	1055.8	27	TN	688.8	22
67152	UP MI				FL	2312.5	46	TN	1480.4	48
67153	MN				TN	1463.2	40	IN	770.6	4
67154	WI				TN	1037.6	34	TN	1051.8	34
67155	WI							IN	1030.5	13
98788	WI	TN	1145.4	51	TN	1159.2	43	TN	871.4	21
98789	ON				TN	1379.3	65	TN	925.3	46
98790	UP MI				FL	2218.3	49	FL	2109.5	19
98791	LP MI				TN	893.2	36	TN	728.4	28
98792	WI	GA	1421.7	29	GA	1560.6	28			
98793	ON				FL	2389.7	42	FL	2321.4	24
98795	ON	TN	1533.6	54	TN	1657.6	62	TN	1480.6	49
98796	WI	TN	1071.7	29	FL	1901.5	25	IN	667.6	21
98798	WI	TN	1161.6	42	TN	931.8	28	IN	288.8	39
98799	WI	TN	1158.2	34	FL	1966.3	46	FL	1962.7	26
Average among years:			1248.7	39.8		1471.1	41.3		1201.4	30.7

Table 13. Number of stops and percentage of total migrating days during spring migration for staging areas used by Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012. Spring staging areas in the table are areas that had at least 1% of the total spring migrating days spent in that area.

Spring Migration Staging Areas				
State	County/District	Common Names	Number of Stops	Percent of Total Days
IN	LaPorte, Jasper, Pulaski, Starke	Kankakee River Valley	57	37.1
IN	Jackson	White River Valley	23	7.9
KY	Hardin	Cecilia	23	7.4
WI	Green Lake		5	4.6
WI	Waupaca, Waushara, Winnebago	Lake Poygon	7	4.3
IN	Morgan		6	4.0
MI	Barry, Calhoun, Kalamazoo	Benard W. Baker Bird Sanctuary	8	3.4
IN	Greene	Goose Ponds	8	2.8
KY	Barren	Barren River Valley Reservoir	4	2.3
MI	Mason		1	2.2
MI	Cass		5	2.0
ON	Algoma	North Shore of Lake Huron	9	1.5
MI	Oceana		1	1.4

Table 14. Number of stops made between summer area and winter termini and mean linear distance between sequential migration stops (MLD) during spring migration for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012.

		Year								
		2010			2011			2012		
PTT ID	Summer Area	Winter Area	Number of Stops	MLD	Winter Area	Number of Stops	MLD	Winter Area	Number of Stops	MLD
67119	UP MI				FL	9	232.8	FL	11	194.5
67140	WI				TN	4	176.7	FL	4	363.5
67141	WI				TN	4	208.6	TN	1	294.0
67142	LP MI				GA	13	117.0	GA	3	222.7
67143	ON				TN	10	167.8	KY	8	200.4
67144	ON				TN	15	111.6	IN	6	146.2
67145	LP MI				TN	5	152.5			
67146	ON				TN	5	150.3	TN	8	121.3
67147	ON				TN	9	129.4	IN	6	187.8
67149	LP MI				TN	3	186.3	KY	3	126.7
67151	WI				TN	3	264.0	TN	7	137.8
67152	UP MI				FL	8	256.9	TN	8	164.5
67153	MN				TN	5	243.9	IN	4	154.1
67154	WI				TN	5	172.9	TN	4	210.4
67155	WI							IN	8	114.5
98788	WI	TN	7	143.2	TN	6	165.6	TN	5	145.2
98789	ON				TN	8	153.3	TN	4	185.1
98790	UP MI				FL	12	170.6	FL	11	175.8
98791	LP MI				TN	6	127.6	TN	6	145.7
98792	WI	GA	6	203.1	GA	7	195.1			
98793	ON				FL	11	199.1	FL	10	211.0
98795	ON	TN	5	255.6	TN	7	207.2	TN	9	148.1
98796	WI	TN	5	178.6	FL	5	316.9	IN	2	222.5
98798	WI	TN	6	165.9	TN	4	186.4	IN	2	183.2
98799	WI	TN	5	193.0	FL	8	218.5	FL	9	196.3
Average among years:			5.7	189.9		7.2	188.0		6.0	184.8

Figure 1. Locations where Eastern Population sandhill cranes were trapped and marked with Platform Transmitting Terminals (PTTs) and the geographic extent of movements of marked cranes during the annual cycle (in gray), 2009-2013.

Figure 2. Summer area locations for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012.

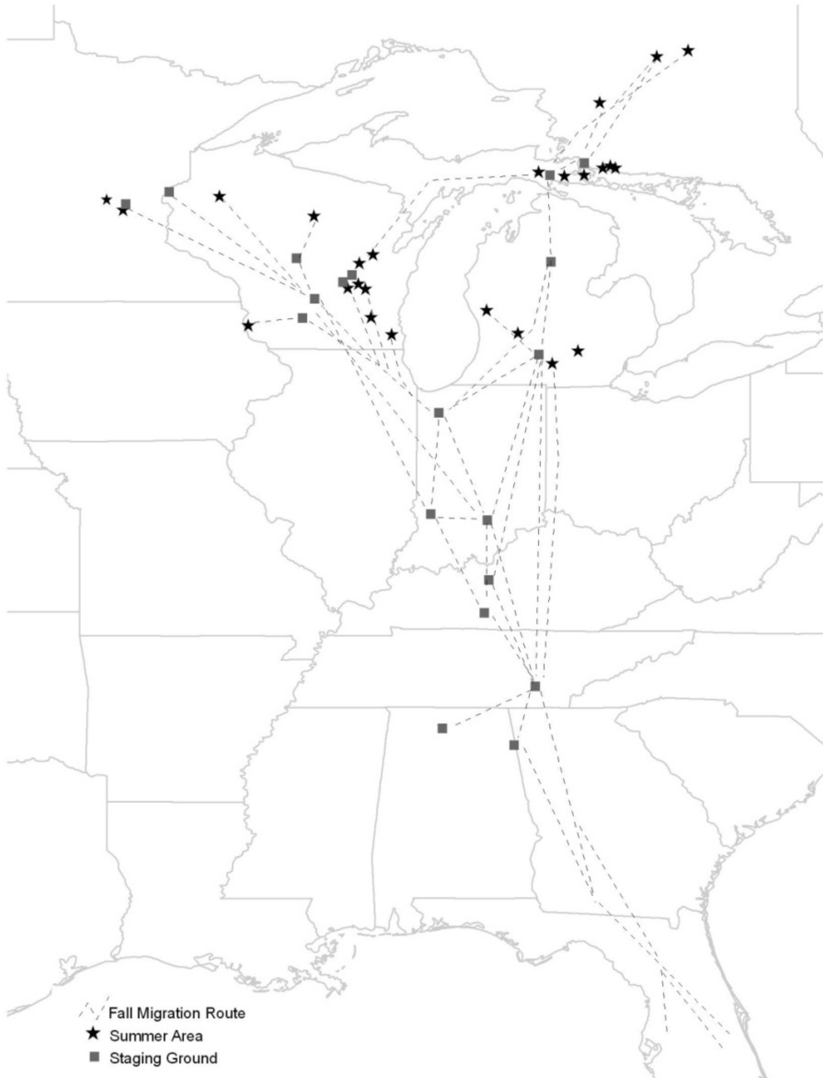

Figure 3 (a). Fall migration routes to staging areas for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012.

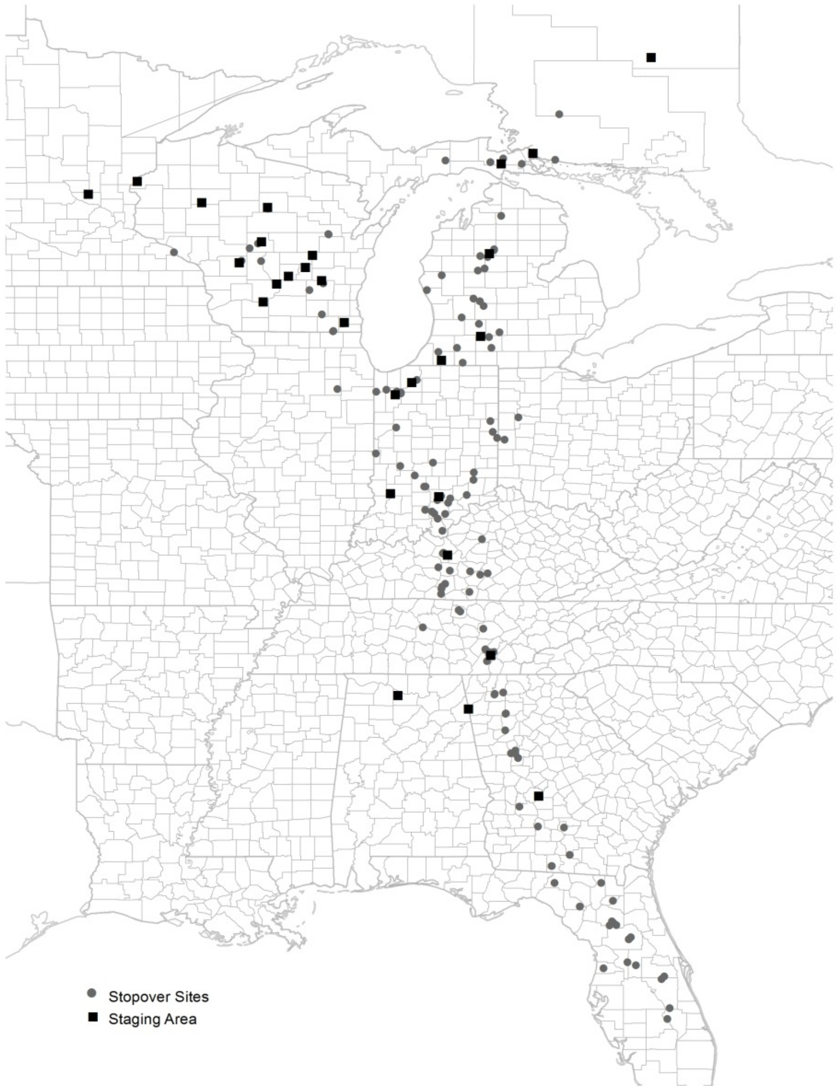

Figure 3(b). Fall migration staging and stopover sites for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012.

Figure 4. Winter area locations for Platform Transmitting Terminals (PTTs)-marked Eastern Population (EP) sandhill cranes, 2010-2012. The proportion of PTT-marked EP sandhill cranes using winter area for each year is indicated by bar graph.

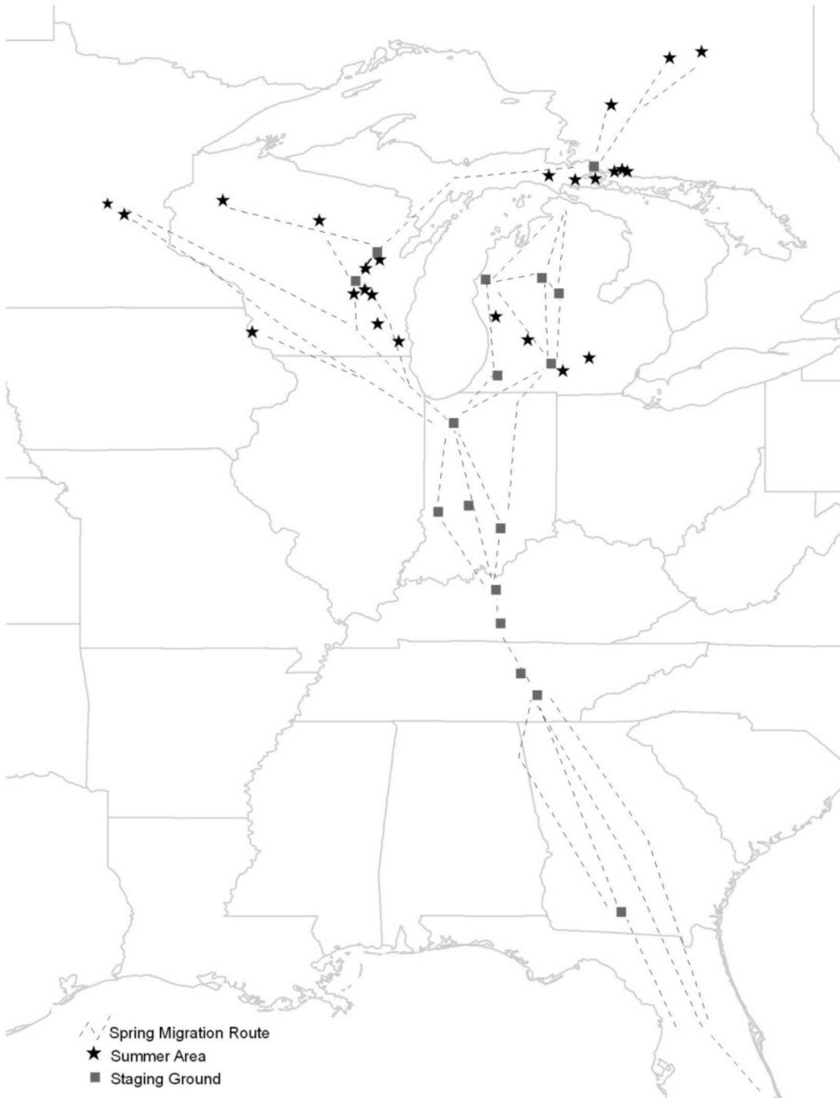

Figure 5(a). Spring migration routes to staging areas for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012.

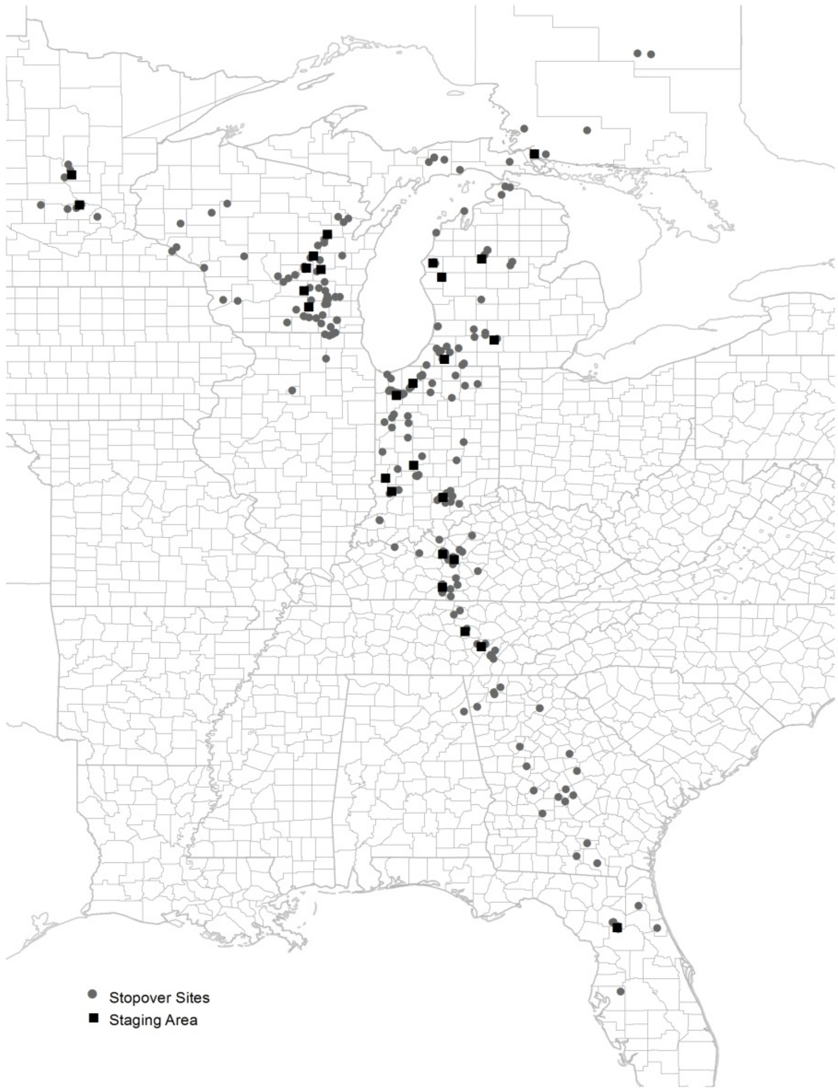

Figure 5(b). Spring migration staging and stopover sites for Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill cranes, 2010-2012.

Figure 6. Staging areas most frequently used during fall and spring migrations by Platform Transmitting Terminal (PTT)-marked Eastern Population sandhill, 2010–2012.

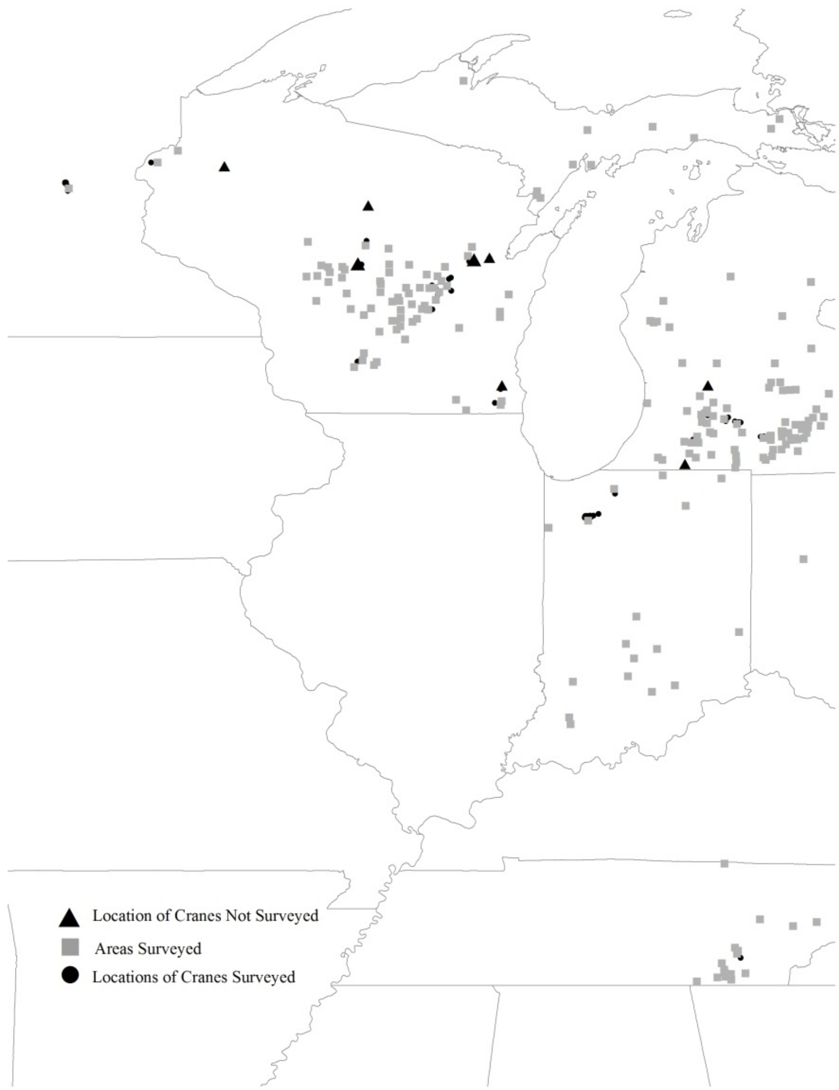

Figure 7. Locations of areas surveyed during USFWS fall survey; also shown are locations where Platform Transmitting Terminal (PTT)-marked sandhill cranes were in areas covered during the survey and in areas not included in 2010-2012 annual surveys. We present documented locations of areas surveyed during the 1979-2012, USFWS fall survey (S. Kelly, pers. comm.). Not all areas shown were surveyed during all 3 annual (2010-2012) surveys.

CHAPTER 2: ANNUAL SURVIVAL RATES FOR SATELLITE TRANSMITTER-MARKED EASTERN POPULATION GREATER SANDHILL CRANES

The Eastern Population (EP) of greater sandhill cranes (*Grus canadensis tabida*, hereafter cranes) has increased in size and expanded its breeding range over the past half century (Amundson and Johnson 2011). Growing concerns over management issues and an interest in providing hunting opportunity has increased over the last decade for states within the EP range (Van Horn et al. 2010), with hunting seasons recently opening in Kentucky (2011) and Tennessee (2013). Management of EP cranes currently includes both harvest and lethal control to mitigate crop depredation, but information that could be used to assess survival rates and mortality factors is lacking.

There are few studies that directly derive vital rates for adult migratory sandhill cranes, and there are no published estimates specifically for adult survival for EP cranes. Nesbitt and Moore (*in* Tacha et al. 1994) estimated annual survival at 0.858 and 0.874, during a mark-resight study for adult female and male EP cranes, respectively, wintering in Florida during the period from 1980 to 1989. The same study estimated annual survival for the Florida non-migratory population (*G. c. pratensis*) at 0.918 and 0.884 for adult females and males, respectively. Drewien et al. (1995) indirectly derived annual survival estimates for the Rocky Mountain Population (RMP) of sandhill cranes at 0.95, 0.94, and 0.91 for the periods of 1972-85, 1985-90, and 1990-92, respectively, using a population model requiring productivity parameters.

As part of a larger study of EP crane migration ecology, we marked a sample of adult cranes with Global Positioning System (GPS) Platform Transmitting Terminals (PTTs) on staging and wintering areas, which afforded us an opportunity to estimate survival rates. Herein, our objective is to estimate survival rates of adult EP cranes based on GPS satellite telemetry data for 2 12-month intervals from October through the following September beginning in 2010. Our survival rate estimates will provide managers a baseline comparison for future survival studies, particularly as hunting opportunity increases and provide current estimates of demographic parameters to incorporate into population models (Miller et al. 1972) to better understand population dynamics.

METHODS

We calculated survival rate estimates using the known fates platform in Program MARK (White and Burnham 1999) for PTT-marked cranes for the period between the initial month that we captured the majority of sandhill cranes (October 2010) and the end (September 2012) of our study. We excluded months prior to October 2010 and after September 2012 because estimated survival rates for these months was 1.00 with no variance (i.e., there were no fatalities during these periods), sample sizes for these periods were small, and because the period from October to the subsequent September represented a biologically meaningful period beginning with fall migration. The known fates platform in Program Mark is commonly used with telemetry data and has 1 basic assumption: the resighting probability is equal to 1. We constructed monthly binary encounter histories for each PTT-marked crane based on the White and Burnham (1999) LDLDLDLD, live (L)-dead (D) encounter format for entry into Program MARK. We classified each interval as 1,0 the crane survived the interval; 1,1 the crane died during the interval; or 0,0 the crane was right-censored for the interval (Table 1). We assigned right-censored to an interval when we did not receive a signal and if locations prior to loss of transmission were continuous and indicated movement depicting normal behavior. We assigned death to an interval when we recovered a PTT from a deceased crane or if PTT locations prior to loss of transmission indicated sedentary locations > 2 duty cycles (or > 6 days). We considered 2 models for our sample group: (1) constant parameters across time (.) and (2) time-specific parameters incorporating 2, 12-month intervals (October through September for 2010 and 2011). We did not consider any additional parameters in our models.

RESULTS

From 2009 through 2011, we deployed 29 PTTs on adult EP sandhill cranes (female: 75% [*n* = 22], male: 17% [*n* = 5], and undetermined: 7% [*n* = 2]). During this period, we recovered 3 marked cranes that died, we redeployed 1 PTT, and we stopped receiving signals from 4 PTTs. We recaptured a PTT-marked crane because of complications of the marker 8 months after initial deployment and right-censored data for that crane once it was removed from our marked sample. Of the 29 EP cranes in our marked sample, 2 (7%) died within a year after initial marking, and we right-censored 3 (10%). During the second year after initial marking, 2 (7%) PTT-marked cranes died and we right-censored 2 (7%) additional PTT-marked cranes (Table 1). In total, 19 (66%) PTT-marked cranes remained in "alive" status throughout the study. We incorporated 28 encounter histories of PTT-marked cranes into survival analysis in Program MARK. We excluded 1 crane from survival analyses because it died 3 days after capture, and we assumed that that fatality was related to capture.

The survival model assuming constant parameters across time was identified as the best-supported model, although the difference in QAIC*c* among the 2 competing models was small and the deviance was insignificant due to a low number of parameters (Table 2). We considered survival estimates for time-specific parameters because the model was more biologically meaningful based on analyzing 2 annual cycles beginning at fall migration. Annual survival for adult, PTT-marked EP sandhill cranes using time-specific parameters was 0.921 (SE = 0.058) for the 12-month period from October 2010 through September 2011 and 0.913 (SE = 0.087) for the 12-month period from October 2011 through September 2012.

DISCUSSION

There are few survival rate estimates derived from marked individuals for North American sandhill cranes, particularly for *G. c. tabida*. Our survival rate estimates for adult EP cranes of 0.921 (SE = 0.058) for the period from October 2010 through September 2011 and 0.913 (SE = 0.087) for the period from October 2011 through September 2012 were comparable to indirect and derived adult survival rate estimates for RMP greater sandhill cranes that ranged from 0.91 to 0.95 (Drewien et al. 1995). Our survival rate estimates were higher than survival rates estimated based on mark-resight observations of EP sandhill cranes wintering in Florida (Nesbitt and Moore *in* Tacha et al. 1994) during the period from 1980 through1989. However, cranes marked in Florida as part of that study may have been a non-representative sample of EP sandhill cranes due to the limited understanding of winter distribution of EP cranes at that time and because cranes only in Florida were considered.

We were unable to ascertain the cause of death of cranes in our study, due to logistical constraints related to determining that fatality had occurred and recovering carcasses. Sandhill cranes are long-lived with avian diseases and trauma (e.g., power line collisions and catastrophic weather events) thought to be the most important sources of non-hunting fatality (Windingstad 1988). We identified fatality of marked EP sandhill cranes in our study based on sequential sedentary locations that occurred during spring and summer (Table 1). We also surmised that 1 crane died due to capture myopathy based on the short period between capture and fatality and we recaptured 1 crane to address an issue with a broken flange on the PTT assembly. Photographs from bird watchers at JP FWA confirmed that antenna separation from the PTT was a cause of signal loss for 1 crane.

MANAGEMENT IMPLICATIONS

Harvest opportunity for EP sandhilll cranes has resumed in Kentucky and Tennessee and there has been increased interest in establishing hunting seasons, particularly within the EP breeding range. Our survival rate estimates will be useful when used with other population parameters such as the USFWS fall survey, harvest, and recruitment rates to assess the effects of harvest and evaluate the need for changes in management strategies. Drewien et al. (1995) noted that long-termed marking programs to evaluate survival are absent for most hunted sandhill crane populations. Although we present a 2-year survival rate estimate for adult EP cranes, we recognize that survival rates may fluctuate due to changes in harvest and environmental conditions. Long-termed monitoring programs assessing population parameters for hunted populations are necessary to make informed management decisions.

Table 1. Identification and known fates inclusion dates for Platform Transmitting Terminal (PTT)-marked Eastern Population greater sandhill cranes used for survival analysis in program MARK.

Identification	Occasion Periods		
PTT	Beginning	End	Fate
98795	Dec 2009	Feb 2013	Alive
98799	Dec 2009	Feb 2013	Alive
98792	Dec 2009	Jul 2011	Right Censored
98796	Jan 2010	Feb 2013	Alive
98788	Jan 2010	Feb 2013	Alive
98798	Jan 2010	Feb 2013	Alive
98791	Mar 2010	Feb 2013	Alive
98797	Oct 2010	May 2011	Right Censored
98789	Oct 2010	Feb 2013	Alive
98793	Oct 2010	Feb 2013	Alive
98790	Oct 2010	Feb 2013	Alive
67140	Oct 2010	Feb 2013	Alive
67147	Nov 2010	Feb 2013	Alive
67141	Nov 2010	Nov 2010	Died (removed)
67119	Nov 2010	Feb 2013	Alive
67152	Nov 2010	Apr 2012	Died
67141	Dec 2010	Apr 2012	Died
67149	Dec 2010	Feb 2013	Alive
67143	Dec 2010	Apr 2012	Right Censored
67144	Dec 2010	Feb 2013	Alive
67142	Dec 2010	Feb 2013	Alive
67146	Dec 2010	Feb 2013	Alive
67145	Jan 2011	Jun 2011	Died
67154	Jan 2011	May 2012	Right Censored
67148	Jan 2011	Feb 2013	Died
67151	Jan 2011	Feb 2013	Alive
67153	Jan 2011	Feb 2013	Alive
67150	Jan 2011	Mar 2011	Right Censored
67155	Sep 2011	Feb 2013	Alive

Table 2. Known fates models estimating 24-month survival probabilities (S) of Platform Transmitting Terminal (PTT)-marked Eastern Population greater sandhill cranes, 2010-2012.

	Model Statistic			
S	QAIC*c*	AIC Weight	No. of Parameters	Deviance
Constant (.)	49.009	0.732	1	16.630
Time-specific (t)	51.022	0.267	2	16.628

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Appendix 1. County (district) names and number of cranes for each summer area location of Platform Transmitting Terminal (PTT)-tagged EP sandhill cranes, 2010-2012.

State/Province	County/District	Region	Number of Cranes
Minnesota	Benton	SE Central	1
	Sherburne	SE Central	1
Wisconsin	Fond du Lac	E Central	1
	Green Lake	E Central	1
	Outagamie	E Central	2
	Waukesha	E Central	1
	Winnebago	E Central	1
	Lincoln	N Central	1
	Washburn	Northwest	1
	Crawford	Southwest	1
	Racine	Southeast	1
	Waupaca	Southeast	1
Michigan	Ingham	E Central	1
	Jackson	S Central	1
	Chippewa	U Peninsula	2
	Mackinaw	U Peninsula	1
	Kent	W Central	1
	Muskegon	W Central	1
Ontario	Algoma	N Shore Lake Huron	4
	Sudbury	E Central	1
	Cochrane	E Central	2

Appendix 2. Auxiliary marker identification codes and demographics for captured cranes that received auxiliary markers and Platform Transmitting Terminals (PTTs), 2009-2011.

PTT Markers					Auxiliary Markers		
PTT ID	Code	Age	Sex	Trap Location	Code	Age	Trap Location
67119	4C	AHY	M	IN	01T	AHY	MN
67140	2C	AHY	F	IN	02T	HY	IN
67141	3C[a]	AHY	F	IN	03T	AHY	IN
67141	3C	AHY	U	TN	04T	AHY	IN
67142	6E	HY	M	TN	05T	AHY	IN
67143	7E	AHY	M	TN	06T	HY	IN
67144	9E	AHY	F	TN	07T	HY	IN
67145	1E	AHY	F	TN	09T	AHY	TN
67146	8E	AHY	F	TN	10T	AHY	TN
67147	5C	AHY	F	IN	11T	AHY	TN
67148	7C	AHY	F	TN	12T	HY	TN
67149	9C	AHY	F	TN	13T	HY	TN
67150	2E	AHY	F	TN	14T	AHY	TN
67151	4E	AHY	F	TN	15T	AHY	TN
67152	6C	AHY	F	IN	16T	AHY	TN
67153	8C	AHY	F	TN	17T	AHY	TN
67154	0C	AHY	F	TN	18T	HY	TN
67155	3E	AHY	F	WI	19T	AHY	TN
98788	6A	AHY	F	TN	20T	AHY	TN
98789	9A	AHY	F	IN	21T	HY	TN
98790	8A	AHY	F	IN	22T	HY	TN
98791	0A	AHY	M	IN	23T	HY	TN
98792	4A	AHY	M	TN	24T	HY	TN
98793	7A	AHY	F	IN	25T	AHY	TN
98795	1A	AHY	F	TN	26T	AHY	TN
98796	3A	AHY	U	TN	27T	AHY	TN
98797	1C	AHY	F	MN	28T	AHY	WI
98798	5A	AHY	F	TN	29T	AHY	TN
98799	2A	AHY	F	TN	30T	AHY	WI
					41T	AHY	WI
					42T	AHY	TN
					43T	HY	TN
					44T	AHY	TN
					46T	AHY	TN
					48T	AHY	TN
					49T	AHY	TN

[a] Redeployed PTT