Surveys

Fall Age-Ratio Survey Design for Eastern Population Greater Sandhill Cranes

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Abstract

For migratory birds, wildlife managers can use the recruitment rate of young into an adult population to model population dynamics, manage harvest, or evaluate habitat. Few recruitment estimates exist for Eastern Population greater sandhill cranes Antigone canadensis tabida, and estimates are outdated and local in scale. Wildlife managers can use age ratios as an index to recruitment, and surveying at fall staging areas is efficient and cost effective. We created a systematic survey design for surveying eastern population crane age ratios in the Kankakee River valley (2013–2015) in northwestern Indiana and the south-central counties of Michigan (2014–2015). Using logistic regression, we investigated factors that may cause spatial and temporal variation in age ratios, including flock size, timing within season, state, year, random vs. incidental survey routes, and observer. We stratified our selection of survey routes using a core area of high crane abundance, but do not recommend stratifying due to the added complexity and low utility. Observers determined the age of 53,371 cranes and found that the proportion of juveniles in Eastern Population crane flocks (π = 0.113, 95% CI: 0.105 – 0.122) was similar to previous estimates for the population. Proportion of juveniles was greater for south-central Michigan than for the Kankakee River valley, decreased with flock size, increased with lateness in the season, and varied among observers. Our design accounted for both ecological sources of variation in age ratios as well as nuisance variation. We recommend that future surveys use our design as part of a monitoring plan for Eastern Population cranes to support harvest management of the population and ensure that future survey results are comparable across years.

Keywords: age-ratio survey; Antigone canadensis tabida; greater sandhill cranes

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Introduction

Recruitment, the process by which young are added to an avian population, is an instrumental component of population dynamics (Cowardin and Blohm 1992). Fall age ratios are a useful index to recruitment (Cowardin and Blohm 1992), and wildlife managers can use them to determine potential effects from harvest (Miller and Botkin 1974), as a means for harvest allocation (Pacific Flyway Council and Central Flyway Council 2016), and as an indicator for environmental changes on breeding grounds (Drewien et al. 1995). Sandhill cranes have the lowest known recruitment of any hunted bird in North America (Tacha et al. 1994; Drewien et al. 1995). Eastern
Population greater sandhill cranes *Antigone canadensis tabida* (hereafter, EP cranes) have increased in population size and expanded their breeding range (Amundson and Johnson 2010). Recognizing the expansion of EP cranes, the Mississippi and Atlantic Flyway Councils endorsed establishing a management plan for EP cranes (hereafter, EP management plan; Van Horn et al. 2010). Priority objectives in the plan include monitoring the EP crane population through the U.S. Fish and Wildlife Service (USFWS) Cooperative Fall Survey (Amundson and Johnson 2010) and allowing harvest throughout the U.S. portion of the EP crane range. Although the USFWS Cooperative Fall Survey monitors the abundance of the population, it does not currently monitor vital rates, such as recruitment, as recommended by the EP management plan. Having vital rate estimates would allow managers to better understand and model population dynamics for EP cranes, which is especially important for setting harvest limits and otherwise managing a harvested species.

Published recruitment or age-ratio surveys for EP cranes have been local in scale: Ontario (Urbanek 1988), Wisconsin (Bennett 1978; Crete and Grewe 1982), Michigan (McMillen 1988), and Indiana (Lovvorn and Kirkpatrick 1982). These surveys were short-term, characterized by a limited geographic representation of EP cranes, and have not been conducted for over three decades. Moreover, survey methodologies among these surveys were not standardized and resulting estimates may not be comparable. Understanding recruitment across the range of EP cranes would require surveys to be completed at a regional scale and conducted with systematic, comparable methods. Because age ratios are an index to recruitment (Cowardin and Blohm 1992), it is important to consider other factors that may affect age ratios, including spatial and temporal variation. Wildlife managers perform age-ratio surveys at fall staging areas, and arrival and departure dates and total days spent at those staging areas vary among EP cranes (Fronczak et al. 2017). The proportion of juveniles at staging areas may increase with time throughout the migratory period (Lovvorn and Kirkpatrick 1982), but managers do not know how arrival and duration of stay at these areas varies among age classes. The proportion of juvenile cranes is also known to decrease with increased flock size and varies spatially within large flocks (Lovvorn and Kirkpatrick 1982; Drewien et al. 1995). Observers often find juveniles on the fringes of large flocks or in smaller family groups separated from large flocks (Lovvorn and Kirkpatrick 1982). Accounting for spatial and temporal variation in age-ratio surveys will provide a more reliable index to recruitment and improve inferences from age-ratio surveys.

Inferences about recruitment of a widely distributed population like EP cranes require surveying a wide geographic representation of the population. Estimating recruitment on breeding grounds can be prohibitively labor intensive, as nesting pairs are spread over a very large area. Surveying age ratios at fall staging areas, where EP cranes accumulate in large numbers, is more efficient and cost effective. There are numerous fall staging areas throughout migration for EP cranes (Fronczak et al. 2017; R. Pierce, U.S. Fish and Wildlife Service, personal communication) and the Kankakee River valley (KRV) in northwestern Indiana and the south-central counties of Michigan (Barry, Calhoun, Eaton, and Kalamazoo counties; hereafter, SCMI) are identified as key areas for EP cranes (Tacha et al. 1994; Castrale and Bergens 1999; Fronczak et al. 2017).

The KRV is a useful area for age-ratio surveys due to the concentration of EP cranes and the assumption that the KRV is a bottleneck for EP cranes throughout their summer range (Lovvorn and Kirkpatrick 1982; Castrale and Bergens 1999). Fronczak et al. (2017) found that a majority of platform transmitting terminal (PTT)-marked EP cranes moved through the KRV at least one time during fall migration, but also found a proportion of EP cranes breeding in Ontario and Michigan that staged in the SCMI without moving through the KRV. Fronczak et al. (2017) also found that EP cranes had a higher fidelity and staged longer during fall migration at both the KRV and SCMI than at any other fall staging area within the EP crane range. Therefore, we selected KRV and SCMI as our study areas to have a robust geographical representation of EP cranes. To address research needs from the EP management plan, we created a systematic survey design and standard operating procedure for estimating EP crane age ratios as an index to recruitment. Our objectives were to estimate age ratios for EP cranes that would serve as an index to recruitment, analyze factors affecting variation in crane age-ratio estimates, and provide a survey scheme that will be repeatable for future surveys.

### Methods

#### Study area

We conducted age-ratio surveys in the KRV of northwestern Indiana, in proximity of the Indiana Department of Natural Resource, Jasper–Pulaski Fish and Wildlife Area (41°12′N, 86°54′W) and an area 6 km southwest of Walkerton, Indiana (41°24′N, 86°30′W). Within the SCMI, surveys centered around the Michigan Audubon Society, Bernard W. Baker Sanctuary (42°18′N, 84°54′W; Figure 1). These areas included eastern tallgrass prairie and prairie hardwood transition Bird Conservation Regions (Bird Studies Canada and the North American Bird Conservation Initiative 2014), where agriculture (e.g., corn and soybeans) is the dominant land cover.

#### Survey design

We sampled age ratios of EP crane flocks in 2013–2015 using methods similar those used for previous surveys at KRV (Lovvorn and Kirkpatrick 1982) and for the Rocky Mountain Population of greater sandhill cranes (Drewien et al. 1995; Data S1, *Supplemental Material*). We modified protocols from previous studies by conducting five single-day age-ratio surveys of staging EP cranes in and around the KRV and SCMI in mid- and late October, mid- and late November, and mid-December to capture temporal variation in age ratios (Krapu et al. 2011;
Time periods were determined from fall migration arrival and departure dates from previous satellite telemetry studies on EP cranes that used the areas (Fronczak et al. 2017). We reduced the number of single-day age ratio surveys for each area from five (2013 and 2014) to three (2015) by omitting the mid-October and mid-December surveys, thus targeting time periods when a large number of cranes were using the study area. We surveyed cranes in the KRV in 2013 and surveyed in both KRV and SCMI in 2014 and 2015.

For each fall staging area, we identified survey boundaries using previous global positioning system (GPS) locations of PTT-marked EP cranes during fall migration over a 3-y period (2010–2012; Fronczak et al. 2017). We created boundaries for the two survey areas using a 90% kernel density estimation polygon around crane GPS locations using ESRI ArcGIS software (Redlands, CA; Figures 1A and 1B). The total survey area was 172,835 ha for the KRV and 370,907 ha for the SCMI. We stratified the survey area for selecting survey routes, giving priority to routes within a core area defined by a 25% kernel density estimation polygon. We created a point file of public road intersections at 1.609-km intervals within the survey boundary, which served as starting points for 3.219-km survey routes. For each survey period, we randomly selected 60 intersections as starting points for survey routes in each survey area (KRV and SCMI), including 40 intersections within the core area and 20 intersections outside the core area. An additional 30 intersections were randomly selected as alternate routes, including 15 inside and 15 outside the core area. Alternate routes were used if initial routes were not available for surveying cranes due to obstructions (forest or standing crops) or inaccessible roads.

We drew survey routes on a map at each selected intersection and assigned a unique identifier. We randomly selected the initial cardinal direction for the start of the survey route and randomly designated a new cardinal direction when the route encountered an intersection. The survey route was completed when a total distance of 3.219 km was reached. We evaluated core areas for both KRV and SCMI after the initial year of surveying was completed. In 2014 and 2015, we reduced the number of core routes and surveyed additional noncore routes to the west and southwest of the KRV core area due to a high number of cranes using these areas (maintaining 60 routes total). We therefore surveyed the core area in slightly greater proportion in 2013 than in other years. For SCMI, we surveyed more routes in the core area and fewer in the noncore area in...
2014 and 2015 to focus on the area that surrounded the Bernard W. Baker Sanctuary, which had the greatest concentration of cranes relative to the entire SCMI.

Observers surveyed cranes from 0830 to 1300 hours, or approximately 0.5 h after sunrise until heat waves distorted viewing (Lovvorn and Kirkpatrick 1982). We assigned four observers to survey the KRV and two observers to survey the SCMI to complete all survey routes for a given area and time frame. We gave observers training prior to the survey on how to identify juvenile plumages as described by Gerber et al. 2014 (Figures 2A and 2B). Observers surveyed all visible cranes on both sides of the survey route and used window-mounted high-powered spotting scopes to count cranes with distances $< 0.40$ km. We defined a flock as two or more cranes separated from other cranes by $> 50$ m (Drewien et al. 1995). We surveyed flocks with estimated size $\geq 300$ by spot samples, in which samples of 10–25 birds were identified at intervals along random zig-zag lines within the interior and perimeters of the flock (Drewien et al. 1995). We recorded the number of juveniles present, number of adults present, date, location, and flock size or estimated flock size (for flocks $> 300$ cranes). To maximize the number of cranes surveyed, we instructed observers to survey routes giving priority to routes selected inside the core area (i.e., highest density), then routes outside the core area, and finally alternate routes.

Data analysis

We used logistic regression to analyze variation in age ratios of crane flocks. The response variable was the proportion of juveniles in each flock. If transformed to a percentage, this response variable is comparable to the response variable of Drewien et al. (1995): $(\text{juveniles} / \text{total cranes}) \times 100$. We examined the following covariates: ln(flock size) ($F$, continuous), within-season survey period ($T$, continuous), observer identity ($O$, 10 factors: AG, AK, AR, DF, GK, JD, JF, KJ, KR, and RP), whether a flock was outside the core area ($C$, 1 = outside core, 0 = inside core), whether a sighting occurred on a route that was chosen randomly a priori or incidentally ($R$, 1 = randomly selected, 0 = incidental), state ($S$, two factors: Indiana and Michigan), and year ($Y$, three factors: 2013, 2014, 2015). For years 1 and 2, we used five survey periods; for year 3, we used three survey periods. For the first year of analysis (2013), we also examined a covariate for region or area in which routes occurred ($A$, three factors: east, west, northeast). This covariate could not be assessed alongside $S$ because of collinearity. We therefore replaced $A$ with $S$ for later analyses. For covariate $F$, we transformed flock size with a natural log because of

![Figure 2. Example of variation in plumages among Eastern Population greater sandhill cranes Antigone canadensis tabida (A, B) used as training materials for age-ratio survey observers (Gerber et al. 2014). Juveniles are identified by the presence of orange-brown to salmon feathering on crown, nape, and secondary wing coverts whereas adults are identified by the distinct grey plumage, the unfeathered red pappillose crown, and absence of juvenile characterized plumage.](image-url)
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Table 1. Coefficients for generalized linear models of the proportion of juveniles in Eastern Population greater sandhill crane Antigone canadensis tabida flocks in Indiana and Michigan during 2013–2015. We report coefficients and standard errors for linear models using a dummy-coded contrast (UCLA Statistical Consulting Group 2011), with DF as the reference observer, Indiana as the reference state, and 2013 as the reference year. We rescaled continuous covariates survey period and ln(flock size) to allow comparison among all coefficients (Gelman 2008). To be conservative, given the moderate level of overdispersion, we used standard errors from the quasi-binomial model to calculate confidence intervals and perform tests.

| Table 1 | Coefficients for generalized linear models of the proportion of juveniles in Eastern Population greater sandhill crane Antigone canadensis tabida flocks in Indiana and Michigan during 2013–2015. We report coefficients and standard errors for linear models using a dummy-coded contrast (UCLA Statistical Consulting Group 2011), with DF as the reference observer, Indiana as the reference state, and 2013 as the reference year. We rescaled continuous covariates survey period and ln(flock size) to allow comparison among all coefficients (Gelman 2008). To be conservative, given the moderate level of overdispersion, we used standard errors from the quasi-binomial model to calculate confidence intervals and perform tests. | Binomial model | Quasi-binomial model |
|---------|------------------------------------------------|------------------|---------------------|
|         | Coefficient | SE | z | P value | SE | t | P value |
| Intercept | -2.231 | 0.034 | -66.3 | < 0.001 | 0.043 | -52.1 | < 0.001 |
| ln(flock size) | -0.471 | 0.040 | -11.7 | < 0.001 | 0.051 | -9.19 | < 0.001 |
| Survey period | 0.230 | 0.037 | 6.24 | < 0.001 | 0.047 | 4.91 | < 0.001 |
| Observer (AG) | 0.003 | 0.102 | 0.03 | 0.979 | 0.129 | 0.02 | 0.983 |
| Observer (AK) | 0.215 | 0.064 | 3.34 | < 0.001 | 0.082 | 2.63 | 0.009 |
| Observer (AR) | -0.059 | 0.081 | -0.73 | 0.468 | 0.104 | -0.57 | 0.568 |
| Observer (AS) | -0.108 | 0.082 | -1.32 | 0.187 | 0.104 | -1.04 | 0.300 |
| Observer (JD) | -0.377 | 0.075 | -5.06 | < 0.001 | 0.095 | -3.98 | < 0.001 |
| Observer (KJ) | -0.238 | 0.050 | -4.76 | < 0.001 | 0.064 | -3.74 | < 0.001 |
| Observer (KR) | 0.071 | 0.079 | 0.90 | 0.368 | 0.100 | 0.71 | 0.479 |
| Observer (KG) | 0.073 | 0.172 | 0.42 | 0.672 | 0.219 | 0.33 | 0.739 |
| Observer (RP) | -0.376 | 0.099 | -3.80 | < 0.001 | 0.126 | -2.99 | 0.003 |
| Year (2014) | 0.126 | 0.043 | 2.97 | 0.003 | 0.054 | 2.33 | 0.020 |
| Year (2015) | 0.049 | 0.055 | 0.89 | 0.375 | 0.070 | 0.70 | 0.486 |
| State (Michigan) | 0.386 | 0.053 | 7.26 | < 0.001 | 0.068 | 5.71 | < 0.001 |

the wide range of flock sizes observed (range: 2–3,500). We rescaled input variables T and F by subtracting the mean and dividing by 2 standard deviations, allowing direct comparison of coefficients between continuous and binary covariates (Gelman 2008). We analyzed all regression models using the generalized linear model (glm) function of Program R (R Development Core Team, Vienna, Austria, available at http://www.R-project.org).

Our global model was therefore

\[
\text{Logit}(\pi) = \beta_0 + \beta_1 F + \beta_2 T + \beta_3 O + \beta_4 C + \beta_5 R + \beta_6 S + \beta_7 Y,
\]

where \(\pi\) = the probability of an individual within a flock being a juvenile.

We first examined the global model (including all covariates) for overdispersion by calculating dispersion (\(\phi\)),

\[
\phi = \frac{D}{n - p},
\]

where \(D\) = residual deviance, \(n\) = number of flocks surveyed, and \(p\) = number of parameters in the model including the intercept (Zuur et al. 2009). We used binomial generalized linear models with a logit link to analyze these data, and examined quasi-binomial models in parallel to note any differences in results. Coefficient estimates are the same for binomial and quasi-binomial models, although standard errors for estimates increase for quasi-binomial models (Agresti 2002). To be conservative, given a moderate level of overdispersion, we used standard errors from the quasi-binomial model to calculate confidence intervals and perform tests. For comparison to other studies, binomial standard errors are reported in Table 1; otherwise, we report quasi-binomial standard errors.

We assessed the strength of the covariates in two ways. First, as suggested by Zuur et al. (2009), we determined the effect of dropping each variable in the model in turn via an analysis of deviance test, using Program R function drop1. For binomial models, the difference in deviance between two models was \(\chi^2\) distributed with \(p_1 - p_2\) degrees of freedom and for quasi-binomial models, the difference in deviance was \(F\)-distributed with \(p_1 - p_2\) degrees of freedom (Zuur et al. 2009). For every model assessed to have a nonsignificant covariate, we created and assessed a new model without the most poorly performing covariate, until all covariates were significant. We estimated coefficients and standard errors for linear models using a dummy-coded contrast statement (UCLA Statistical Consulting Group 2011). We also estimated the grand mean of crane ratios across observer, state, and year factors by using a simple coding contrast matrix (UCLA Statistical Consulting Group 2011). The intercept produced by the simple coding contrast represents the average proportion of juveniles across all observers, states, and years rather than the proportion of juveniles for the reference observer, reference state, and reference year (as with a dummy variable contrast).

Results

Up to six observers participated in each year (four at KRV and two at SCMI), with 10 unique observers over the length of the project. The annual number of surveyors was determined by the availability of trained observers. We determined the age of 53,371 cranes over 3 y of surveys, 2013–2015. The global model, estimated dispersion was \(\phi = 1.65\), indicating a minor to moderate level of overdispersion (Zuur et al. 2009). Deviance tests indicated that \(C\) was not an important predictor of...
proportion of juveniles in flocks. Once C was dropped from the model, all covariates were significant for the binomial model ($P < 0.012$), but for the quasi-binomial model, R and Y were not significant ($P = 0.070$ and $P = 0.069$, respectively). We dropped R from the model but retained Y due to the potential for biological and management interest in variation among years (resulting $\phi = 1.65$). We report coefficients (Table 1) for the following model:

$$\text{Logit}(\pi) = \beta_0 + \beta_1 T + \beta_2 O + \beta_3 A + \beta_4 S + \beta_2 Y,$$

The intercept for the simple coding contrast was $-2.059$ (SE = 0.042), meaning the average proportion of juveniles in flocks was $\pi = 0.113$ (95% CI: 0.105–0.122) across all observers, states, and years, and for average values of flock size and survey period. Among years, the average proportion of juveniles across all observers and states and for average values of flock size and survey period was $\pi = 0.107$ (95% CI: 0.096–0.120) for 2013, $\pi = 0.120$ (95% CI: 0.110–0.131) for 2014, and $\pi = 0.112$ (95% CI: 0.100–0.126) for 2015. The greatest odds ratio among observers was 1.81, meaning that, for the observer who identified the most juveniles, the odds of a crane being identified as a juvenile was 1.81 times greater than for the observer who identified the fewest juveniles. Covariate T had a positive effect, with a greater proportion of juveniles observed later in the season. F had a negative effect, with a greater proportion of juveniles observed in small flocks (Figures 3A and 3B). The greatest odds ratio among years was 1.13, meaning that, in 2014, the odds of a crane being identified as a juvenile was 1.81 times greater than for 2013. Michigan flocks had a greater proportion of juveniles than Indiana flocks. When calculated separately for each state, the intercepts were $-2.252$ (SE = 0.0386) for Indiana and $-1.866$ (SE = 0.0657) for Michigan. Therefore, the average proportion of juveniles in flocks across all observers and for average values of flock size and survey period was $\pi = 0.0951$ (95% CI: 0.089–0.102) for Indiana and $\pi = 0.134$ (95% CI: 0.120–0.150) for Michigan.

**Discussion**

Our estimate of the proportion of juvenile EP cranes in flocks ($\pi = 0.113$; 95% CI: 0.105–0.122) during the 2013–2015 fall migration was comparable to previous studies of EP cranes conducted in the late 1970s and 1980s, in which the proportion of juveniles averaged 0.120 (Drewien et al. 1995). Annual variation in the proportion of juveniles among years in our study was modest (odds ratio among years was ≤ 1.13). Relative to our study period, local-scale EP crane age-ratio surveys showed the proportion of juveniles averaged 0.175 throughout eastern Ontario and western Quebec (2015–2017; C. Sharp, Canadian Wildlife Service, personal communication) and 0.142 in north-central Kentucky (2011–2014; J. Brunjes, Kentucky Department of Fish and Wildlife, personal communication). Age ratios for other populations of greater sandhill cranes are variable, with lower recruitment estimated for western populations than for eastern populations (e.g., Drewien et al. 1995:table 4). Midcontinent Population productivity estimates averaged 0.113 from 2003 to 2006 for staging areas in Saskatchewan, Manitoba, and North Dakota (D. Brandt, U.S. Geological Survey, Northern Prairie Wildlife Research Center, personal communication), similar to estimates in the mid-1970s (Buller 1979; Johnson 1979). Long-term annual productivity estimates of the Rocky Mountain Population staging in the San Luis Valley, Colorado (1972–2016) averaged 0.082 (USFWS 2017). The Lower Colorado River Valley Population is noted as one of the
lowest production estimates with a reported average of 0.064 (1998–2015; Pacific Flyway Council 2017). Sandhill crane recruitment may be considered low, particularly when compared to waterfowl. Bellrose et al. (1961), for example, found mallards Anas platyrhynchos in Illinois had a proportion of juveniles with a range of 0.255–0.760 from 1939 to 1959. Despite annual harvest and low recruitment, sandhill crane population trends have not shown declines for the midcontinent, Rocky Mountain, and Eastern Populations (Dubovsky 2018). Larger species, such as cranes, tend to have higher adult survival rates (Johnson et al. 1992; Fronczak et al. 2015), which may balance lower recruitment. Recruitment can be useful in creating models of population dynamics (Miller and Botkin 1974; Johnson 1979; Gerber et al. 2014). Recruitment estimates alone will not directly indicate a population’s rate of increase (Caughly 1974), although wildlife managers may use recruitment as an indicator in order to assess environmental conditions on the breeding grounds (Drewien et al. 1995). Further investigations to assess the relationship of breeding conditions and recruitment would be useful to managers seeking to maintain stable sandhill crane populations. Understanding the relationship between recruitment, survival, and population size will also be important for managing harvest for EP cranes.

Many factors affected age ratios of EP crane flocks, some providing insight to the breeding ecology of the population (state and year) and others just nuisance variation (observer). We found a strong effect of flock size on age ratios, supporting previous research showing that family groups make up many smaller flocks (Drewien et al. 1995). Surveying these smaller flocks is therefore crucial, and surveys must not focus solely on large aggregations of cranes. We chose to stratify our selection of survey routes due to the known variation in age ratios due to flock size (Drewien et al. 1995) and our desire to sample large flocks (representing the bulk of the population) as well as small flocks (with a potentially higher ratio of juveniles). Using a core area was unwieldy, however, because the core area was delineated using locations from PTT-marked EP cranes over a 3-y period (Fronczak et al. 2017) and there was significant spatial variation in crane concentrations between that study and ours. We evaluated our core areas and adjusted the number of core and noncore routes after the initial survey year for each study site. In the KRV, we increased the number of routes to the west and southwest of the core area to survey areas with highly concentrated cranes during wet periods. In the SCMI, we decreased our core area and concentrated survey efforts around the Bernard W. Baker Sanctuary due to the low number of EP cranes using other areas, logistics and travel time, and unsafe road conditions in outlying areas.

Adjusting the number of core/noncore routes is not ideal for a long-running survey and may cause confusion. We recommend that future surveys prioritize randomly selected routes in a tighter area (we recommend using a 50–75% kernel density estimation if location data are available from a previous source) and allow the addition of a limited number of incidental survey routes if high concentrations of cranes are known to occur outside randomly selected routes. This strategy would ensure that most survey data are derived from a random selection of flocks, but also ensures that large congregations of cranes (potentially a major proportion of the population) are not missed. Using incidentally collected data might bias an abundance survey where it is crucial to document zero counts, but an age-ratio survey is not as strictly limited (no data are gathered when flock size = 0). Because we found no difference in age ratios between randomly selected routes and incidental routes, or between core and noncore areas, we believe these design modifications will not be detrimental to inferences. We also recommend continuing to record whether observations are from random routes or are incidental so that future analyses can test for bias.

A continued challenge for surveying a wide-ranging population like EP cranes is geographic representation. Surveying at fall staging areas allowed us to survey many cranes with relatively low effort, but it is difficult to determine if cranes from all breeding areas are represented. Age ratios differed between states; while observer differences may have played a role, these differences also may indicate that EP cranes staging at SCMI had greater recruitment than cranes staging at KRV. South-central Michigan staging cranes breed in Michigan and Canada, while KRV cranes breed throughout the EP range (Fronczak et al. 2017). Eastern Population cranes in south-central Wisconsin have shown high nesting densities (A. Lacy, International Crane Foundation, personal communication), which, combined with low recruitment for cranes migrating through the KRV, may suggest a density-dependent effect (Einum et al. 2006) for dense EP crane summer areas. We recommend that future studies continue to survey EP crane age ratios at the KRV and SCMI at a minimum. We also recommend that future managers reexamine migration patterns of EP cranes and evaluate if additional survey areas are warranted. Staging areas would make particularly beneficial additions if they are used by EP cranes that do not pass through the KRV or SCMI.

Variation in age ratios due to within-season survey period was likely caused by differences in migration timing. Unsuccessful pairs were more likely to arrive early, while successful pairs were more likely to linger on breeding grounds to allow their young time to mature (Cowardin and Blohm 1992). Timing of migration may vary from year to year. We recommend using at least three survey periods within a season to capture some of the variation in age ratios throughout the season. Future studies could further examine the effect of timing on age ratios and researchers could, for example, choose to drop early or late surveys from the analysis if evidence suggested that other data were more reliable. Resources permitting, we recommend performing annual age-ratio surveys because annual surveys will be most sensitive at detecting variation in recruitment. If survey resources are scarce, we recommend conducting surveys for at least three consecutive years rather than a single year to capture variation among years. Managers should also avoid long gaps between survey periods and the interval...
between assessments should be left to managers based on their management objectives for EP cranes and survey resources.

Variation in the proportion of juveniles among observers indicated that observers varied in their detection of juveniles vs. adults. Observer variation is a nuisance, and should be reduced as much as possible. Observers should train for the range of conditions expected on survey routes, and should compare their observations to those of an experienced observer. We recommend using as few unique observers as possible and that observers spend at least half a day training with an experienced observer to identify key characteristics of hatched-year cranes. If the number of observers increases, we recommend treating observer as a random effect rather than a categorical variable to simplify interpretation of the model results. We also noted that the distribution and detection of cranes differed between the states. The landscape in the KRV consisted of flat terrain dominated by large agriculture fields bordered by thin mature hardwood wind rows. In contrast, the SCMI landscape had rolling terrain with smaller agriculture fields and more contiguous wooded lots. We observed that EP cranes in the KRV were more concentrated and cranes in the SCMI were more widely dispersed. While we do not believe these differences affected our ability to distinguish juveniles from adults, we recommend that future surveys be mindful of these differences, training observers for all conditions and potentially investigating state-specific detection and distribution as causes of variation in age ratios.

Our survey design is well suited as an index to recruitment for EP cranes because it takes into account sources of variation in age ratios that may inform management (state and year), other sources of variation related to the biology of the cranes (flock size and time within season), and nuisance variation (observer). The EP management plan highlights the continued need to monitor vital rates for the population, particularly because the number of states that allow EP cranes’ harvest is increasing. We therefore recommend using this design as part of a monitoring plan for EP cranes, with modifications to the route selection process, detailed above.

Supplemental Material

Please note: The Journal of Fish and Wildlife Management is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Data S1. Observation data used to examine factors affecting Eastern Population greater sandhill crane *Antigone canadensis tabida* age ratios using logistic regression.

Found at DOI: https://doi.org/10.3996/112018-JFWM-106.S1 (203 KB TXT).

Reference S1. Amundson CL, Johnson DH. 2010. Assessment of the eastern population of greater sandhill cranes (*Grus canadensis tabida*) fall migration survey, 1979–2009. Report to the U.S. Fish and Wildlife Service, Region 3, Bloomington, Minnesota.

Found at DOI: https://doi.org/10.3996/112018-JFWM-106.S2 (570 KB PDF).

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