Reproductive Success and Survival in the Eastern Population of Sandhill Cranes

F12AP00996

2014 Progress Report

Submitted to:

U.S. Fish and Wildlife Service
Webless Migratory Game Bird Program

Principal Investigators

Jeffrey Fox, Brad Semel, Michael Ward

Summary Background

The Eastern Population (EP) of Greater Sandhill Cranes (*Grus canadensis tabida*) has demonstrated an impressive recovery since the population's historic low circa the 1930s (e.g. ≈25 breeding pairs documented in Wisconsin; Henika 1936, Meine and Archibald 1996). At present, the EP perhaps numbers more than 70,000 birds (Kruse and Dubovsky 2015) and interest in harvest for recreation and to mitigate crop depredation has come to the forefront of discussions on the population's management. The Management Plan for the Eastern Population of Sandhill Cranes (2010) has proposed a harvest-management strategy based on fall surveys to monitor the population and maintain running three-year average indices above 30,000 cranes (Ad Hoc Eastern Population Sandhill Crane Committee 2010). While precedents set by the harvest of the Mid-Continent Population (MCP) and Rocky Mountain Population (RMP) of Sandhill Cranes support this approach, the landscape within the EP's range is far more varied than the landscapes in the MCP and RMP ranges and continues to be rapidly urbanized (Fig. 1). If cranes are able to thrive in these urbanizing landscapes it is likely that the EP will continue to increase, perhaps mirroring the population trajectory of the Giant Canada Goose throughout the Midwest in the last 33 years (17.5% per year; Sauer et al. 2011). However, there remain several knowledge gaps in the demographics of the EP including landscape-dependent reproductive success and juvenile and adult survival (e.g. two studies published on reproductive success in or near urban environments; Dwyer and Tanner 1992, Toland 1999). Evaluating these vital rates in different landscapes of the EP's range and at different population densities is essential to refining models of population growth and abundance under different land-use and management scenarios (e.g. urban sprawl and EP harvest).

Project Objectives

The primary objectives of this study are to (1) investigate reproductive success of Sandhill Cranes at different population densities and in different landscapes of the EP's range and (2) evaluate age-specific survival, status-dependent survival (i.e. breeding vs. non-breeding), and survivorship to breeding-age. Conducting this work through consecutive years will help to distinguish the relative role(s) of annual stochasticity from potential density-, landscape-, and state-dependent effects. These data will then be applied to (3) generate models of EP growth and abundance under different management and land use scenarios.

1) Evaluate Density- and Landscape-Dependent Reproductive Success

-Defined Parameters of Reproductive Success

-Nest Productivity – The probability of a nest producing at least one fledged young.

-Fledging Success – The probability of young surviving from hatching until capable of flight (≈10 weeks old; Drewien 1973 *in* Gerber et al. 2014).

a. Density-Dependent Reproduction

i. Assess reproductive success in the densely populated core of the EP's range in central Wisconsin and at the population's peripheries in southeastern Wisconsin and northeastern Illinois (Fig. 2).

b. Landscape-Dependent Reproduction

i. Assess reproductive success in the rural-agricultural region of central Wisconsin and the rural-agricultural-urban matrix of southeastern Wisconsin and northeastern Illinois (Fig. 2).

2) Evaluate Age-Specific and Status-Dependent Survival and Survivorship to Breeding Age

   a. Age-Specific Survival – Survival of known-age birds (i.e. marked during hatch year) during their juvenile stage (i.e. post-fledging to independence at approximately 9 to 10 months of age; Gerber et al. 2014), subsequent annual adult survival, and the probability of transitioning from one age-class to the next.

   b. Status-Dependent Survival – Annual survival of breeding and non-breeding adult birds and the probability of transitioning from a non-breeding to a breeding state or a breeding to a non-breeding state.

   c. Survivorship to Breeding Age – Survivorship of known-age individuals to first confirmed successful reproduction and survivorship to previously reported earliest and average ages of first successful reproduction (3 and 4.3 years of age, respectively; Nesbitt 1992).

3) Population Growth

   a. Population Projection Modeling

      i. Density- and Landscape-Dependent Vital Rates

         1. Reproduction – Objectives 1a-b

         2. Survival – Objectives 2a-c

Additionally, automated telemetry receiving units (a.k.a. automated receiving units or "ARUs"; JDJC corp) positioned in the EP flyway and at a primary migratory stopover site at Jasper-Pulaski State Fish and Wildlife Area in Indiana (JP) are being used to record the movements of radio-marked juvenile and adult cranes. This method increases the probability of detecting marked birds during migration and thus the precision of survival analyses. Moreover, these units are expected to provide insight into potential status-dependent (e.g. breeding vs. non-breeding) migratory timing and behavior as well as generating data on birds from geographically distinct regions of the EP breeding range.

Project Timeline

These objectives and the annual project timeline for accomplishing them are illustrated below. Note that this report outlines work conducted from May, 2008, to July, 2015, and thus includes data collected both prior to and following the 2012-2014 project approved by the Webless Migratory Game Bird Program (F12AP00996). The following sections discuss preliminary results based on these data. A final report is expected to be completed after the spring migration of 2016.

<table>
<tr><th colspan="12">Annual Project Timeline</th></tr>
<tr><th>January</th><th>February</th><th>March</th><th>April</th><th>May</th><th>June</th><th>July</th><th>August</th><th>September</th><th>October</th><th>November</th><th>December</th></tr>
<tr><td></td><td></td><td colspan="2">Spring Surveys</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>Aerial Nest Survey</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="4">Evaluate Fledging Success</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="4">Mark Pre-Fledged and Fledged Young</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="8">Mark Adult Birds (Breeding Pairs > Non-Breeding Pairs)</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Fall Surveys</td><td></td></tr>
<tr><td colspan="12">Survival of Marked Burds During Migration ⟵ ARU ⟶ Survival of Marked Burds During Migration</td></tr>
<tr><td colspan="3">Data Analysis</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Data Analysis</td></tr>
</table>

Summary of Preliminary Analyses

Objective 1: Evaluate Density- and Landscape-Dependent Reproductive Success

Known fate models were constructed in program MARK (v.7.0) to estimate nest productivity and fledging success (Tables 1 and 2). Nineteen percent of 240 nests throughout central Wisconsin and southeastern Wisconsin/northeastern Illinois study regions were successful in fledging at least one bird (mean brood size at fledging was 1.2; Fig. 3). Individual survivorship from hatching to fledging was 27% (n=482 young from 341 broods). Top-ranked models revealed study region – a proxy for crane population density – explained the preponderance of variation observed in reproductive success (Tables 1 and 2). Specifically, nests in the core region of the EP in central Wisconsin were 10% more likely to fledge young than those at the peripheries of the EP in southeastern Wisconsin/northeastern Illinois (Fig. 4). Contrasting survivorship of individuals from hatching to fledging in central Wisconsin (45%) and southeastern Wisconsin/northeastern Illinois (22%) was even more evident (Fig. 4). Only a single model testing landscape-dependence in reproductive success was well supported. This model was the highest ranked fledging success model and revealed a positive correlation between fledging success and the percentage of urban development within 1500m of nests (Table 2; Fig. 5). Alternatively, the top-ranked model of nest productivity highlighted the strength with which intra-brood fates were intertwined (Table 1). Specifically, the mortality of one colt in a brood of two precipitated a 46% reduction in survivorship to fledging for the remaining individual in the brood. Additive models including study region and year were the second best supported models for both nest productivity and fledging success, supporting a prominent role for annual variation in reproductive success (Tables 1 and 2; Fig. 6).

Objective 2: Evaluate Age-Specific and Status-Dependent Survival and Survivorship to Breeding Age

One hundred and twenty-eight hatch-year birds and 66 adults were equipped with leg-band VHF transmitters to facilitate the acquisition of data on post-fledging vital rates. These transmitters broadly and prematurely failed and principal sources of data on post-fledging vital rates were consequently lost (see **Project Notes**). Fortunately, the sum of available data on all banded birds (n=265) was sufficient to construct simple multi-state models in program MARK (v.7.0) evaluating age- and status-dependent survival (Table 3). Juvenile survival (i.e. survivorship post-fledging to 1 year old adult) was 65% (n=170; Fig. 7). Annual survival of adult birds was 94% (n=124; Fig. 7) and was not well correlated with breeding status or study region (Table 3). The results of Objectives 1 and 2 together revealed survivorship from egg to three (earliest breeding age), four (average breeding age), and five years of age of 9%, 8.5% and 8%, respectively (Fig. 7). Additional data (e.g. 2015 resightings and third-party reports) continue to be incorporated to help compensate for transmitter failure and improve the preliminary estimates reported here. These data will be applied to models of population growth (**Objective 3**) and presented in the final report.

Project Notes

A primary focus of this research was to establish longitudinal data via equipping 120 birds with leg-band VHF transmitters (Advanced Telemetry Systems Model #A3590, >1400 day battery life). These transmitters exhibited multiple modes of premature failure: Detachment from leg-bands, antenna degradation, and antenna detachment. Recovery of transmitters that had detached from leg-bands within the first year of deployment revealed that the materials with which each transmitter had been painted and clear-coated had rapidly degraded with exposure and begun to peel and crack. Photographs of recovered units were provided to the manufacturer (Fig. 8). The manufacturer confirmed that this was the cause of transmitter detachment and that none of the units should have been assembled and shipped in this condition. Concurrently, the antennas on transmitters began to degrade, exposing frayed stainless steel cable (Fig. 9). This posed clear potential to diminish birds' quality of life. These issues were resolved at our expense and efforts were reoriented to recapture and re-equip previously marked birds with the modified transmitters. Transmitters were subsequently and increasingly noted without antennas within the second year post-deployment (Fig. 10). Despite mutual agreement that none of the units had been manufactured to specification and almost unilaterally began to fail within the warranty period (708 days) it was only after protracted deliberation that the manufacturer agreed to provide a limited number of replacements (85).

Surprisingly, these replacements were not constructed according to mutually agreed upon – and manufacturer recommended – specifications. These replacement units were unable to be modified and, per the manufacturer's original claims, were therefore more apt to have antennas detach. These obstacles largely confounded our efforts to reliably track birds beyond their established territories and during migration via the ARUs (e.g. inconsistent probabilities of detection of radio-marked individuals) and necessitated manual relocation of each bird to visually confirm status, which has proven both timely and costly. More importantly, these experiences have highlighted a much broader issue. Comprehensive reviews of specific transmitter manufacturers and models are broadly unavailable. Researchers are thus overly dependent on anecdotal reports and manufacturers' claims regarding the performance of their own products. Faulty designs are therefore likely to plague one research project after another because manufacturers are presented with little incentive to resolve issues brought to their attention. A centralized database where researchers can submit and access performance reviews of wildlife transmitters and associated equipment is sorely needed to incentivize product improvement.

Also of note is the inclusion of additional measurements of young with known hatch dates collected each year. These data will increase the precision of age estimates for young with unknown hatch dates. Previous age-estimates may therefore differ by as much as one week.

Acknowledgements

We would like to thank the U.S. Fish and Wildlife Service Webless Migratory Game Bird program, Illinois Department of Natural Resources, University of Illinois at Urbana-Champaign, Illinois Natural History Survey, and Sandi and David Whitmore for funding this work. We are also grateful for the International Crane Foundation's assistance and generosity in permitting this research to be conducted in their long-term Briggsville, WI, study region during 2012. Furthermore, we acknowledge and appreciate the diligence of the International Crane Foundation in coordinating banding protocols and seamlessly connecting crane researchers to each other and the public. We would also like to thank the U.S. Fish and Wildlife Service, Illinois

Department of Natural Resources, Indiana Department of Natural Resources, Wisconsin Department of Natural Resources, Lake County Forest Preserves, and McHenry County Conservation District for their generous contributions in manpower and facilitating access to state and county properties. We furthermore thank all of the private land owners for granting access to their properties and all of the volunteers, friends, and family that have contributed their time and energy to this project. Lastly, I would like to thank Mike Ward and Brad Semel and my Ph.D. committee for all their time, advice, and input while this work has progressed.

References

Ad Hoc Eastern Population Sandhill Crane Committee. 2010. Management Plan for the Eastern Population of Sandhill Cranes. Special Report in files of the Mississippi Flyway Representative. Minneapolis, MN. 36pp.

Case, D. J. and S. J. Sanders. 2009. Priority Information Needs for Sandhill Cranes – A Funding Strategy. Special Report in the Files of the Central Flyway Representative. Denver, CO. 13pp. Desroberts, K. J. 1997. Survival and Habitat Use of Greater Sandhill Crane Colts on Modoc National Wildlife Refuge, California. Proc. North Am. Crane Workshop 7: 18-23.

Dwyer, N. C., and G. W. Tanner. 1992. Nesting Success in Florida Sandhill Cranes. The Wilson Bulletin 104(1): 22-31.

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, *PE&RS*, Vol. 77(9):858-864

Gerber, B.D., Dwyer, J.F., Nesbitt, S.A., Drewien, R.C., Littlerfield, C.D., Tacha, T.C., Vohs, P.A., 2014. Sandhill Crane (*Grus canadensis*). The Birds of North America Online (A. Poole, Ed.) Ithaca, Cornell Lab of Ornithology. Retrieved from the Birds of North america Online: http://bna.birds.cornell.edu.proxy2.library.illinois.edu/bna/species/031 doi:10.2173/bna.31.

Henika, F. S. 1936. Sand-hill Cranes in Wisconsin and Other Lake States. Proceedings of the North American Wildlife Conference 1: 644-646.

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

Meine, C. D., and G. W. Archibald (eds.). 1996. The Cranes: Status Survey and Conservation Action Plan. IUCN, Gland, Switzerland, and Cambridge, U.K.: 294pp. Northern Prairie Wildlife Research Center Online. Retrieved 10/15/2010: http://www.npwrc.usgs.gov/resource/birds/cranes/index.htm.

Nesbitt, S. A. 1992. First Reproductive Success and Individual Productivity in Sandhill Cranes. Journal of Wildlife Management 56(3): 573-577.

Nowak, D.J. and J.T. Walton. 2005. Projected Urban Growth (2000-2050) and Its Estimated Impact on the US Forest Resource. Journal of Forestry 103(8): 383-389.

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2011. The North American Breeding Bird Survey, Results and Analysis 1966 - 2010. Version 12.07.2011 USGS Patuxent Wildlife Research Center, Laurel, MD.

Su, L., J. Harris, and J. Barzen. 2004. Changes in Population and Distribution for Greater Sandhill Cranes in Wisconsin. The Passenger Pigeon 66(4): 317-326.

Toland, B. 1999. Nesting Success and Productivity of Florida Sandhill Cranes on Natural and Developed Sites in Southeast Florida. Florida Field Naturalist 27(1): 10-13.

Table 1: Known-fate models constructed in Program Mark (v.7.0) evaluating the probability of Sandhill Crane nests producing at least one fledged young (“nest productivity) relative to study region and land cover within 1500m of nests (urban, urban open space, agriculture, grassland/savanna, wooded, wetland, and open water). Models are ranked by Akaike’s Information Criterion (AICc; Delta AICc 2nd column). Note study region is a proxy for population density – “region” models distinguish nests in areas with high crane population densities in central Wisconsin from nests in areas with low crane population densities in southeastern Wisconsin/northeastern Illinois (Fig. 2). “Nest date” models distinguish nests initiated during peak nesting in April from those initiated later. “Renest” models distinguish confirmed renests from initial nesting attempts. “Year” models distinguish nests according to year. “Brood size” models distinguish broods of 1 from broods of two. Note that the top ranked models reveal a strong correlation between the mortality of one individual in a brood and subsequent mortality of the second and that variations in productivity were most apparent between study regions and years.

PRODUCTIVITY MODELS	Δ AICc	AICc Weights	Model Likelihood	Evidence Ratios	# Par.	Deviance
AGE + BROOD SIZE + SIB FATE	0.00	0.50	1.00	1.00	14	1414.88
AGE + REGION + YEAR	1.91	0.19	0.38	2.60	19	1406.62
AGE + REGION + AGRICULTURE	4.73	0.05	0.09	10.66	14	1419.61
AGE + REGION + URBAN	4.80	0.05	0.09	11.00	14	1419.67
AGE + REGION	5.23	0.04	0.07	13.65	13	1422.13
AGE + REGION + OPEN WATER	5.93	0.03	0.05	19.35	14	1420.80
AGE + WETLAND	6.08	0.02	0.05	20.91	13	1422.98
AGE + REGION + WETLAND	6.75	0.02	0.03	29.22	14	1421.62
AGE + REGION + GRASSLAND/SAVNANNA	7.10	0.01	0.03	34.72	14	1421.97
AGE + REGION + URBAN OPEN SPACE	7.20	0.01	0.03	36.56	14	1422.07
AGE + REGION + WOODED	7.25	0.01	0.03	37.50	14	1422.12
AGE + AGRICULTURE	7.41	0.01	0.02	40.57	13	1424.31
AGE	7.52	0.01	0.02	42.89	12	1426.45
AGE + YEAR	7.73	0.01	0.02	47.77	18	1414.47
AGE + NEST DATE	8.55	0.01	0.01	71.86	13	1425.45
AGE + BROOD SIZE	8.67	0.01	0.01	76.40	13	1425.58
AGE + GRASSLAND/SAVANNA	8.80	0.01	0.01	81.28	13	1425.70
AGE + URBAN OPEN SPACE	8.88	0.01	0.01	84.90	13	1425.79
AGE + WOODED	9.03	0.01	0.01	91.48	13	1425.93
AGE + URBAN	9.30	0.00	0.01	104.60	13	1426.20
AGE + OPEN WATER	9.38	0.00	0.01	108.97	13	1426.29
AGE + NEST DATE + RENEST	9.91	0.00	0.01	142.07	14	1424.79
AGE + ALL LAND COVER	13.56	0.00	0.00	885.38	19	1418.26

Table 2: Known-fate models constructed in Program Mark (v.7.0) evaluating the probability of individual Sandhill Crane chicks fledging relative to study region and land cover within 1500m of nests (urban, urban open space, agriculture, grassland/savanna, wooded, wetland, and open water). Models are ranked by Akaike's Information Criterion (AICc; Delta AICc 2nd column). Note study region is a proxy for population density – "region" models distinguish birds in areas with high crane population densities in central Wisconsin from birds in areas with low crane population densities in southeastern Wisconsin/northeastern Illinois (Fig. 2). "Nest date" models distinguish young hatched from nests initiated during peak nesting in April from those that hatched later. "Renest" models distinguish birds hatched from confirmed renests from those hatched from initial nesting attempts. "Year" models distinguish birds based on year. "Brood size" models distinguish broods of 1 from broods of two. Note that the top ranked models reveal a strong correlation between individual fledging success and study region, urban development, and year of the study.

INDIVIDUAL FLEDGING SUCCESS MODELS	Δ AICc	AICc Weights	Model Likelihood	Evidence Ratios	# Par.	Deviance
AGE + REGION + URBAN	0.00	0.66	1.00	1.00	13	1628.38
AGE + REGION + YEAR	2.70	0.17	0.26	3.86	18	1620.94
AGE + REGION + AGRICULTURE	4.68	0.06	0.10	10.36	13	1633.05
AGE + REGION + GRASSLAND/SAVNANNA	5.96	0.03	0.05	19.67	13	1634.33
AGE + REGION	6.53	0.03	0.04	26.24	12	1636.93
AGE + REGION + OPEN WATER	7.05	0.02	0.03	33.89	13	1635.42
AGE + REGION + WETLAND	8.35	0.01	0.02	64.90	13	1636.72
AGE + REGION + URBAN OPEN SPACE	8.49	0.01	0.01	69.79	13	1636.87
AGE + REGION + WOODED	8.51	0.01	0.01	70.47	13	1636.89
AGE + ALL LAND COVER	13.43	0.00	0.00	821.83	20	1627.60
AGE + WETLAND	14.64	0.00	0.00	1494.23	12	1645.03
AGE + BROOD SIZE + SIB FATE	14.99	0.00	0.00	1776.92	13	1643.37
AGE + GRASSLAND/SAVANNA	17.43	0.00	0.00	5976.91	12	1647.83
AGE + NEST DATE	17.57	0.00	0.00	6574.60	12	1647.97
AGE + YEAR	18.20	0.00	0.00	9392.29	17	1638.47
AGE + NEST DATE + RENEST	19.47	0.00	0.00	16436.50	13	1647.84
AGE + AGRICULTURE	20.37	0.00	0.00	32873.00	12	1650.76
AGE + WOODED	21.08	0.00	0.00	32873.00	12	1651.48
AGE + URBAN OPEN SPACE	21.22	0.00	0.00	32873.00	12	1651.62
AGE	21.25	0.00	0.00	32873.00	11	1653.67
AGE + URBAN	22.74	0.00	0.00	65746.00	12	1653.13
AGE + BROOD SIZE	23.08	0.00	0.00	65746.00	12	1653.48
AGE + OPEN WATER	23.15	0.00	0.00	65746.00	12	1653.55

Table 3: Multi-state models with live-resight and dead recoveries constructed in Program Mark (v.7.0) evaluating survivorship from fledging to one year of age (approximating juvenile survival to independence) and adult survival (breeding, non-breeding, and combined breeding and non-breeding). "Study region" distinguished birds from central Wisconsin from those in southeastern Wisconsin/northeastern Illinois. Note that there was relatively little support for state-dependent survival in adults (i.e. breeding vs. non-breeding) or variation between study regions.

SURVIVAL MODELS	Δ AICc	AICc Weights	Model Likelihood	Evidence Ratios	# Par.	Deviance
{JUVENILE vs ADULT}	0.00	0.54	1.00	1.00	8	276.87
{JUVENILE vs NONBREEDING ADULT vs BREEDING ADULT}	1.46	0.26	0.48	2.08	9	276.22
{JUVENILE vs ADULT} + STUDY REGION	1.96	0.20	0.37	2.67	9	276.72

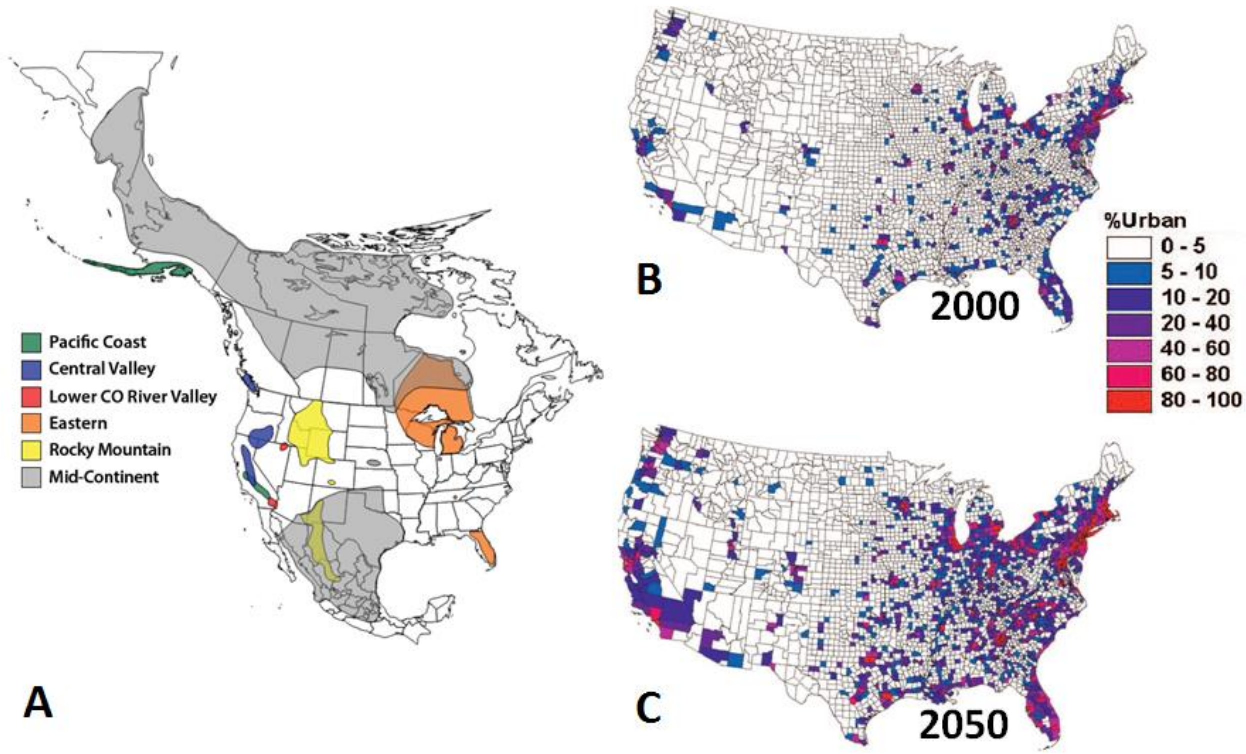

Figure 1: The distribution of migratory Sandhill Crane populations in North America (Case and Sanders 2009) and projected trends in urbanization, by county, from 2000 to 2050 (B and C respectively; Nowak and Walton 2005). Harvests of the Rocky Mountain Population (RMP; panel A, yellow) and Mid-Continent Population (MCP; panel A, grey) are established and monitored via annual population indices at migratory staging and stopover sites. A similarly managed harvest of the Eastern Population (EP; panel A, orange) has been proposed (Ad Hoc Eastern Population Sandhill Crane Committee 2010). Note the rapid urbanization projected for EP range relative to the RMP and MCP ranges.

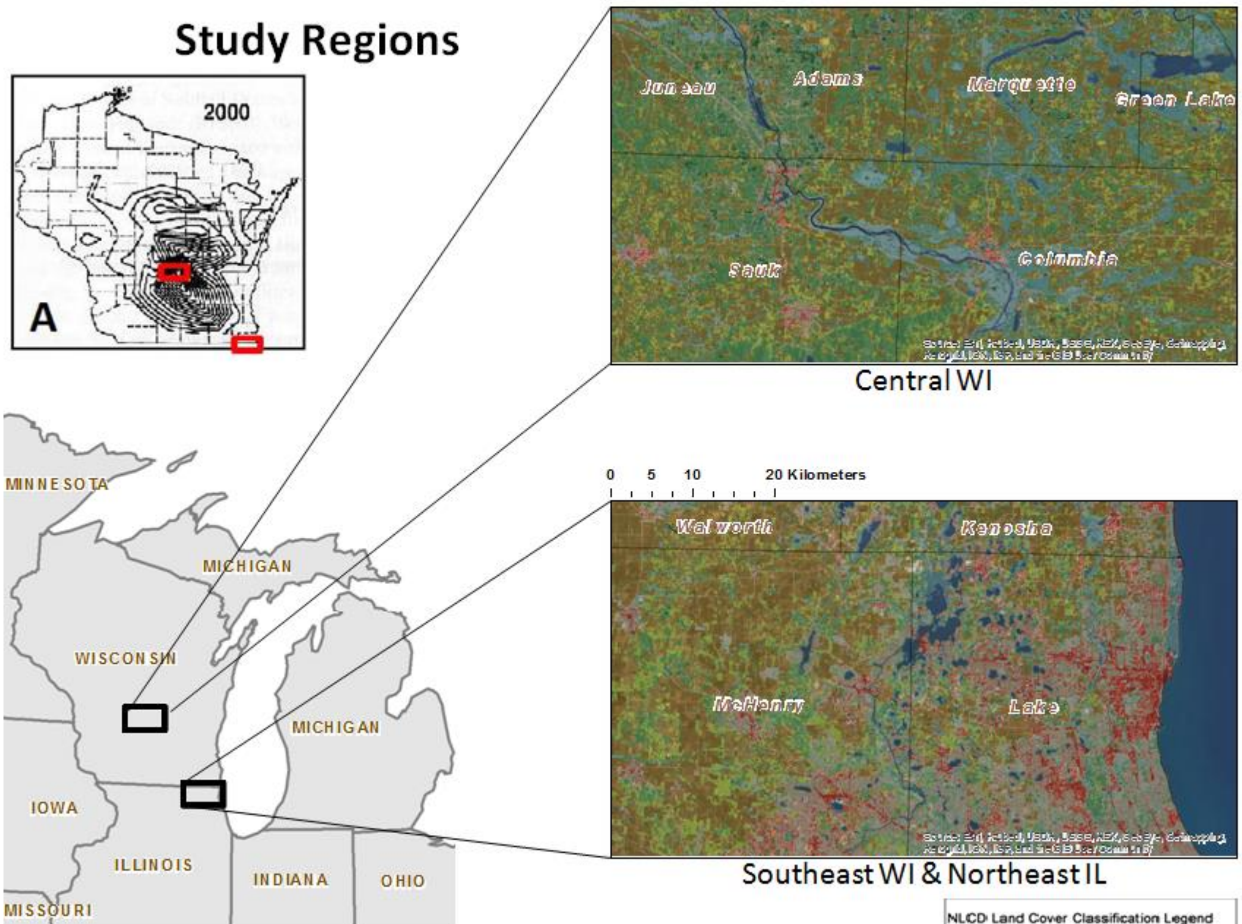

Figure 2: Location of primary study regions (red boxes, panel A) relative to Sandhill Crane densities (each line represents 100 bird intervals beginning from the outside; Su et al. 2004). Also, note the rural-agricultural (B) and rural-agricultural-urban matrix (C) of these study regions (land cover data from the National Land Cover Database 2006; Fry et al. 2011). Together these study regions allow reproductive success and survival to be evaluated relative to crane population densities and across a diversity of landscapes, including the urban habitats predicted to increase throughout the population's range (Fig. 1).

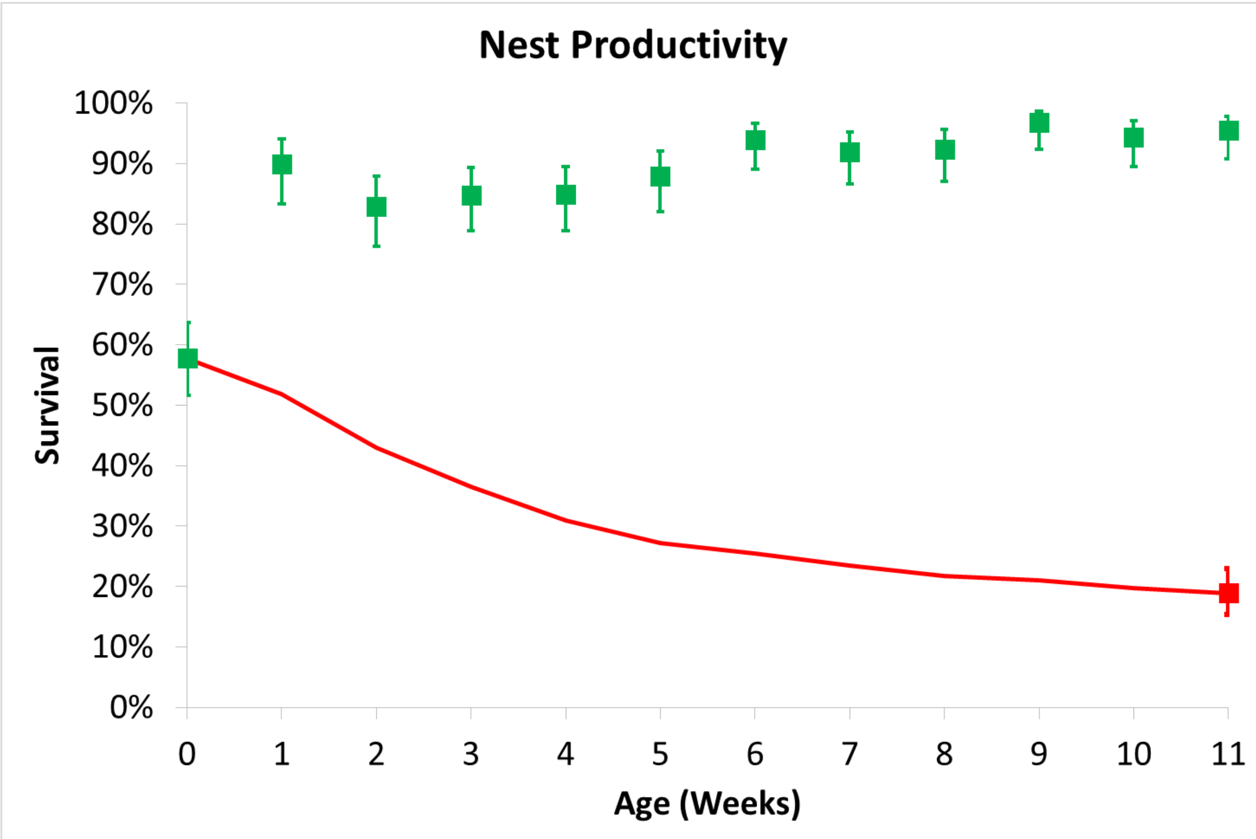

Figure 3: Survival probabilities (y-axis) of nests (i.e. hatching ≥ 1 egg; green square and 95%CI at age 0; x-axis) and subsequent weekly brood survival to fledging (green squares and 95%CIs, x-axis). Brood survivorship probabilities (y-axis) from nest to the x-axis stated age (red line) reveal 19% of all nests in central Wisconsin and southeastern Wisconsin/northeastern Illinois produced at least one fledged bird (red box with 95%CI; n=240). Note mean brood size at fledging was 1.2.

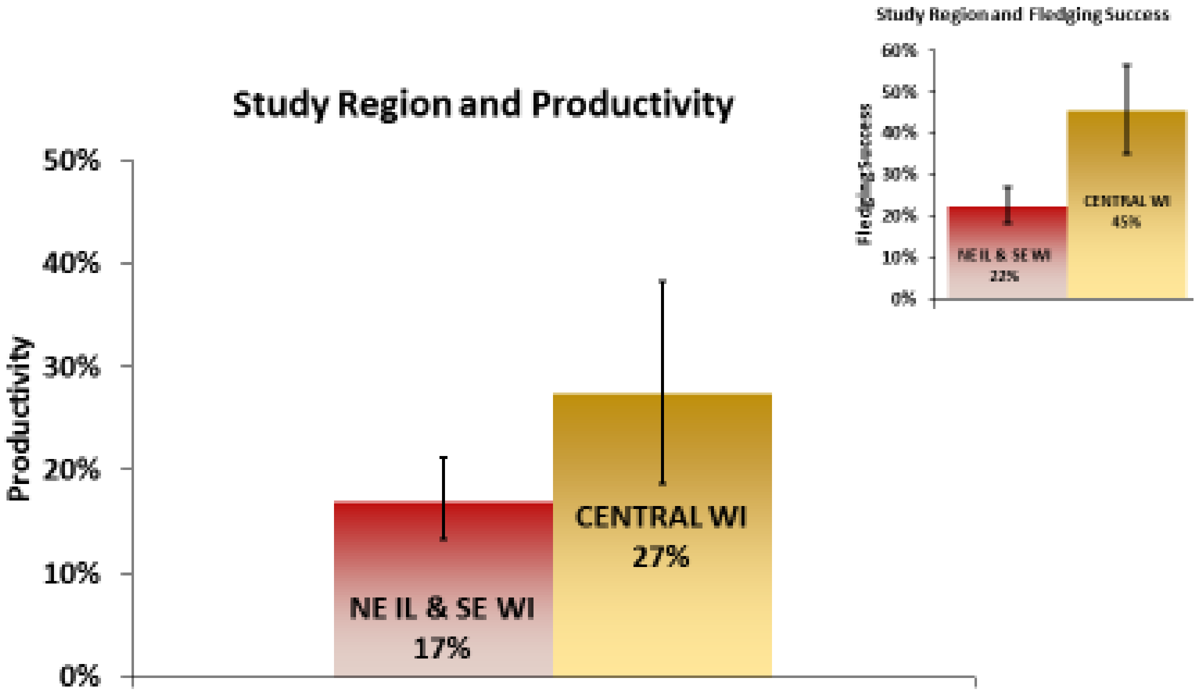

Figure 4: The probability of a nest producing at least one fledged young (y-axis) in central Wisconsin (orange bar with 95%CI, n=31) or in southeastern Wisconsin/northeastern Illinois (red bar with 95%CI, n=209). Note that the probabilities of individual fledging success in these study regions were 45% (n=106) and 22% (n=376), respectively (top right).

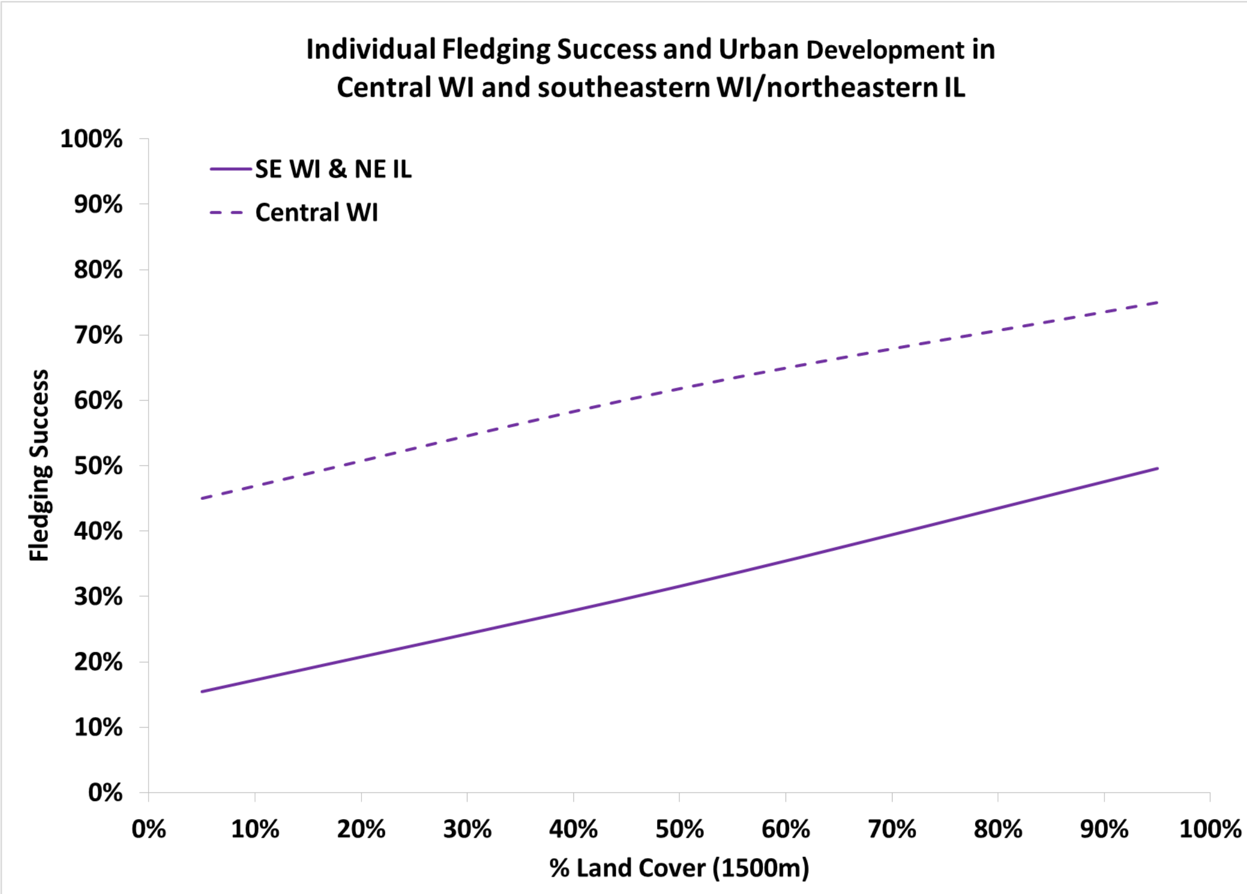

Figure 5: Survivorship from hatching to fledging (y-axis) relative to the percentage of urban development within 1500m of nests (x-axis) in central Wisconsin (hatched purple line) and in southeastern Wisconsin/northeastern Illinois (solid purple line). Note that urban development within 1500m of nests ranged from 2% to 32% in central Wisconsin (mean = 6%) and 3% to 77% in southeastern Wisconsin/northeastern Illinois (mean = 25%). Also note that urban development alone explained little of the variation in fledging success but together with study region represented the best supported model of individual fledging success (Table 2).

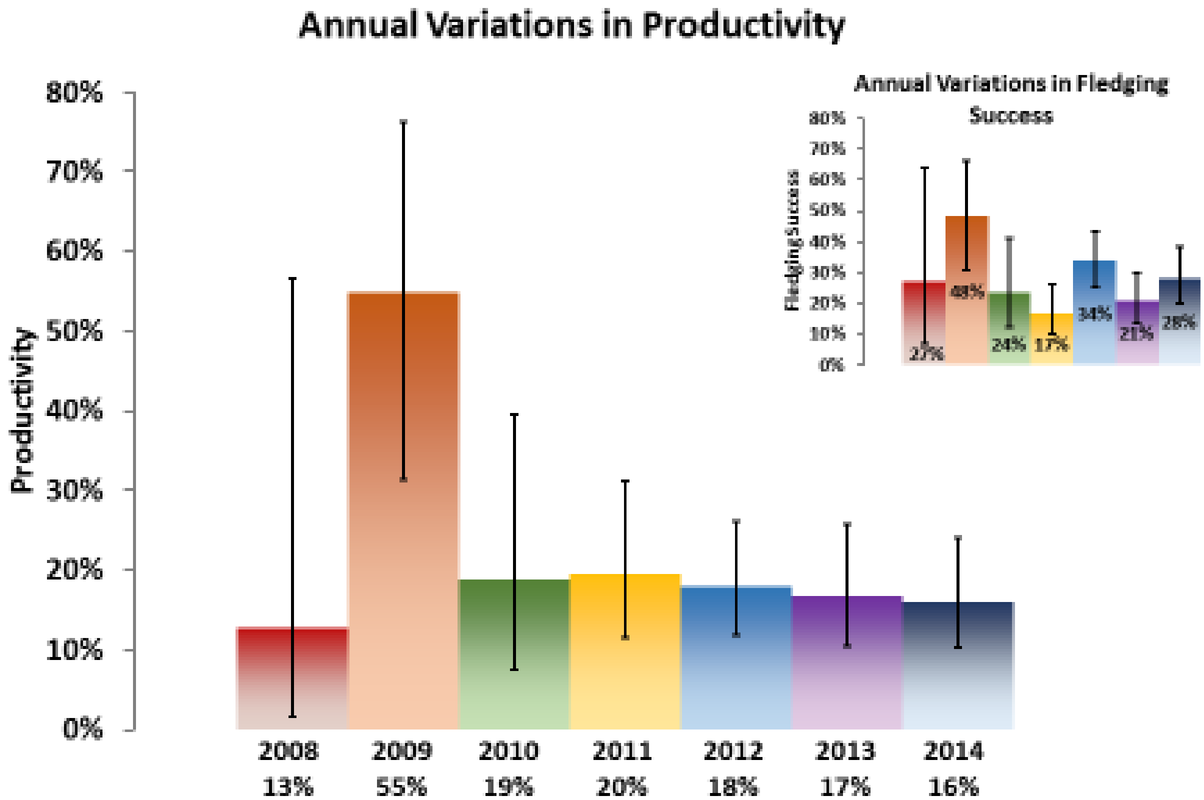

Figure 6: The probability of a nest producing at least one fledged young (y-axis) by year (vertical bars with 95%Cis). Note the greater annual variation in individual fledging success (top right) relative to overall productivity, suggesting that fledging success is more variable than nest success between years.

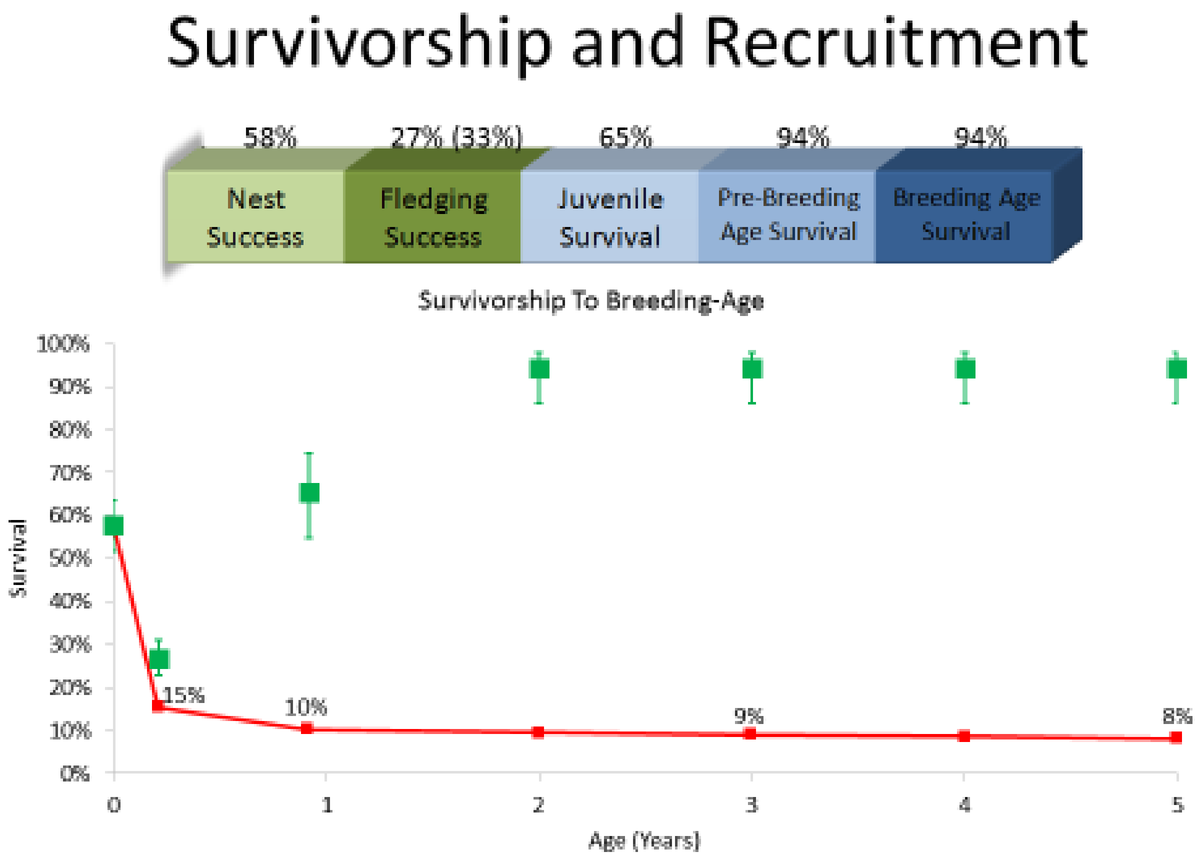

Figure 7: Survivorship (y-axis) to the x-axis specified age (red line) based on age-specific vital rate estimates (specified at top and green boxes with 95%CIs). Note that the estimates for fledging success represent post-hatching to fledging survivorship of individuals (27%) and broods (33%). For example, survivorship from egg to age of recruitment into the breeding population (i.e. 3-5 years old) was 8-9% (i.e. product of nest success, individual fledging success, juvenile survival, and two to four years of adult survival), whereas annual nesting productivity per breeding pair was 19% (i.e. product of nest success and brood survivorship to fledging; average size of fledged broods = 1.2).

Figure 8: Two examples of transmitter failure via detachment from leg-bands. The transmitter on the left was deployed on 6/21/2012 and was recovered on 5/13/2013. Note the pealing of the outer coating of the transmitter, remnants of which visibly remained on the bird's leg band. The transmitter on the right was deployed for a comparable length of time but was recovered prior to detachment (note the remnants of the old bands that remained attached to the epoxy). This example demonstrates how the colored coating underlying the clear coating cracked, which often resulted in separation from the epoxy used to attach transmitters to bands (i.e. epoxy was frequently observed on birds' leg bands post transmitter detachment, similar to the fragment on the right). The manufacturer refused to allow us to speak with their engineers to resolve these problems but confirmed that none of the units should have been assembled with these two outer coatings.

Figure 9: An assortment of transmitters exhibiting antenna degradation and frayed stainless steel cable. All were recovered within less than two years post-deployment. This problem was noted for 100% of the transmitters purchased. Because we had resolved the issue of detachment prior to observing this mode of transmitter failure these units raised serious concerns about potential long-term interference with nest incubation and quality of life. Significant effort was devoted to recapturing and removing these units from birds instead of increasing sample size and progressing with the funded research.

Figure 10: This transmitter was deployed on 7/27/2012 and removed from the bird during a recapture on 7/3/2014. Note that the antenna had completely fallen off and only the spring remained, resulting in a non-functional transmitter. This mode of failure was noted to begin occurring within less than two years post-deployment and appeared to be systemic. The manufacturer claimed that the antenna was not an integral component of a functional transmitter.