Assessment of resident Canada goose management in Kansas

by

John Louis Malanchuk II

B.S., Rhodes College, 2014
M.S., University of Wisconsin – Stevens Point, 2017

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Division of Biology
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Abstract

Resident Canada geese (*Branta canadensis*, geese nesting in the conterminous United States) was one of the many wildlife species declining by the early 1900s due to large-scale human disturbance (e.g., overharvest and habitat destruction). After decades without recognized breeding populations, many thought resident Canada geese were extinct in Kansas and the rest of the United States. Today, certain populations of resident Canada geese are so abundant they can be a nuisance; especially during spring breeding season. Resident Canada geese provide intrinsic value to Kansans as well as economic value through hunting licenses, travel, lodging, and taxes leveed on guns and ammunition. My goal was to address information gaps necessary to make science-based management decisions for resident Canada geese in Kansas. My objective for the first chapter was to determine the effect of translocation on urban-banded nuisance geese. My objective for the second chapter was to assess potential changes to the statewide spring breeding population survey for nesting geese in Kansas, to reduce bias and variation while maintaining or reducing survey cost. My objective for the third chapter was to determine the effect of latitude on age-class specific recovery patterns for resident Canada geese in the eastern tier of the Central Flyway. I estimated survival and recovery probabilities from hunter-harvested band recoveries for normal and translocated (i.e., urban geese relocated to rural areas) resident Canada geese. Annual survival differed between normal ($\hat{S}$ = 0.761, 95% CI 0.734-0.785) and translocated ($\hat{S}$ = 0.598, 95% CI 0.528-0.665) geese. Recovery probability also differed between normal and translocated adults (normal wild $\hat{f}$ = 0.074, 95% CI = 0.069-0.078; translocated $\hat{f}$ = 0.138, 95% CI = 0.120-0.158) and juveniles (normal wild $\hat{f}$ = 0.067, 95% CI = 0.059-0.075; translocated $\hat{f}$ = 0.250, 95% CI = 0.199-0.310). Recovery probability did not differ between status in the sub-adult age class (normal wild $\hat{f}$ = 0.126, 95% CI = 0.115-0.137; translocated $\hat{f}$ = 0.090, 95% CI =

0.055-0.144). Since 2014, Kansas Department of Wildlife and Parks has used fixed-wing aircraft to survey 160 1-mi^2 plots in 2 landcover strata (80 high and 80 medium strata) based on expected abundance of breeding Canada geese. I used survey data from 2019 to estimate change in bias of potential plot reallocation scenarios focusing on inter-plot count variation. I simulated design scenarios by reallocating plots in groups of 10 (e.g., 90 medium, 70 high). I simulated each scenario 100 times and calculated density and associated standard deviation, 90% confidence intervals, and coefficient of variation (CV) for each iteration. The top-ranked survey design based on the greatest reduction in bias predicted reallocating 40 medium stratum plots to the high strata would be the most effective method to increase statistical power and reduce coefficient of variation. Finally, I investigated the effects of banding latitude (i.e., banding state) and age-class on geospatial recovery patterns of resident Canada geese in the eastern-tier states of the Central Flyway, 2012–2019. I used optimized hot spot analyses and inverse distance weighting to measure how recoveries of sub-adult and adult geese differed spatially as insight into latitudinal effects of molt migration. Sub-adult geese from southern-banding states were recovered disproportionately at more northerly latitudes than sub-adult geese from northern banding states. Adult geese were disproportionately recovered in their respective banding state. These results will be used to inform the Kansas Department of Wildlife and Parks revision of the state resident Canada goose management plan.

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Preface

This dissertation is the outcome of research that I developed in collaboration with my advisor and co-authors. Publishing research in peer reviewed academic journals should always be a top priority for a graduate student. As such, the writing is presented in third person format, and plural where applicable, following traditional peer-review journal guidelines to match specific journals in order to swiftly transition from dissertation to scientific journal. At the time of this writing, Chapter 1 is published in Ecosphere with Beth Ross, David Haukos, Thomas Bidrowski, and Richard Schultheis as co-authors. Chapter 2 has been formatted for submission to the Wildlife Society Bulletin: Tools and Technology with Beth Ross, David Haukos, and Thomas Bidrowski as co-authors. Chapter 3 is formatted for submission to PLoSOne with David Haukos as co-author.

Chapter 1 - Translocation, Survival, and Recovery of Kansas-banded Canada Geese

Abstract

Temperate-breeding, or resident, Canada geese were once extirpated in Kansas, but currently provide abundant viewing and hunting opportunities. Kansas Department of Wildlife, Parks, and Tourism (KDWPT) began reintroducing geese in 1980 with a goal of re-establishing a breeding population. Successful reintroductions led to translocating flocks to regions with no previous records of nesting geese; however, KDWPT continues to translocate individuals from nuisance flocks in urban areas to rural reservoirs to reduce human conflicts with urban geese. Our goal was to determine the effects of such translocations on survival and recovery of adult, sub-adult, and juvenile temperate-breeding Canada geese. We used Brownie dead-recovery models in Program MARK to compare survival and recovery probabilities between translocated and nontranslocated (normal wild) Kansas-banded Canada geese for 2012-2017. Model-estimated annual survival differed between status (normal wild $\hat{S}$ = 0.761, 95% CI 0.734-0.785; translocated $\hat{S}$ = 0.598, 95% CI 0.528-0.665). Recovery probability differed between normal and translocated adults (normal wild $\hat{f}$ = 0.074, 95% CI = 0.069-0.078; translocated $\hat{f}$ = 0.138, 95% CI = 0.120-0.158) and juveniles (normal wild $\hat{f}$ = 0.067, 95% CI = 0.059-0.075; translocated $\hat{f}$ = 0.250, 95% CI = 0.199-0.310). Recovery probability did not differ between status in the sub-adult age class (normal wild $\hat{f}$ = 0.126, 95% CI = 0.115-0.137; translocated $\hat{f}$ = 0.090, 95% CI = 0.055-0.144).

Translocation is a viable management option to successfully reduce survival and increase recovery probability of urban nuisance geese in Kansas.

Key words: *Branta canadensis*; Canada Geese; Kansas; nuisance wildlife; Program MARK; translocation

Introduction

There is an ecological cost to relocating vertebrates to a novel environment. That cost may be manifested at the individual (e.g., survival, fecundity) or the ecosystem levels (e.g., species diversity, habitat degradation, public safety). Traditionally, the goal of wildlife relocations is to establish a population in a recovery area. Conversely, overabundant wildlife may be relocated to reduce negative impacts on an ecosystem (i.e., habitat degradation, agricultural damage, human/wildlife conflicts; Conover 2002). Overabundance is not limited to exotic or invasive species and often native species may cause ecological issues (e.g., lesser snow geese [*Chen caerulescens*]; Koons et al. 2014). Migratory (i.e., seasonal movement) wildlife complicate our ability to predict how individuals will respond to relocation. Survival is the most informative parameter to measure the effect of relocation on a long-lived bird species (e.g., Canada geese [*Branta canadensis*]; Coluccy et al. 2004). Monitoring survival and movement on a continental scale can be logistically challenging and expensive (e.g., GPS/GSM satellite transmitters). For waterfowl, there is an existing citizen science-based framework for estimating survival, recovery, and movement using mark-recapture methods (i.e., leg banding). Temperate-breeding Canada geese, defined as those nesting in the conterminous United States, present a unique opportunity to measure the effects of translocation on survival and recovery on the broad scale.

Canada geese were one of the many wildlife species declining by the early 1900s due to large-scale human disturbance (e.g., overharvest and habitat destruction). After decades without recognized temperate-breeding populations, many thought giant temperate-breeding Canada geese were extinct. It was not until 1962 when Dr. Harold Hanson rediscovered 55,000 individuals nesting on a lake in Rochester, Minnesota, that contemporary temperate-breeding Canada geese were identified (Heller 2010). Restoration efforts, led by Forrest B. Lee and U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Station, Jamestown, North Dakota, began captive breeding efforts to reintroduce temperate-breeding geese to much of their pre-1900s breeding range (Lee et al. 1984). The continental population began exceeding historical population estimates by 1991 and has grown at approximately 8% per year since (USFWS 2006). The return of temperate-breeding Canada geese is an unequivocal North American wildlife conservation success story (Lee et al. 1984).

Kansas Fish and Game Commission (now Kansas Department of Wildlife, Parks, and Tourism [KDWPT]) began coordinated efforts to restore temperate-breeding geese in 1980. In total, KDWPT released 32,000 Canada geese statewide between 1980 and 2001. By 2001, KDWPT stopped efforts to increase and expand populations of geese and began addressing nuisance concerns caused by local overabundances, including agricultural damage, eutrophication and sedimentation of lakes, hazards to aircraft, and concerns for human health and safety (KDWPT, unpublished report). Canada geese went from a rare sight to an “embarrassment of riches” in 20 years (Ankney 1996, Barry 1999). Other states, mainly in the Atlantic and Mississippi flyways, have experienced similar overabundance issues and current population estimates far exceed objectives (Atlantic Flyway Council 2011, USDA APHIS 2015).

Canada geese have adapted to thrive in urban and suburban communities (Gabig 2000). Manicured grass, few predators, and ample nesting and roosting habitat have resulted in populations exceeding historical estimates (Conover and Chasko 1985). Many people enjoy hearing, seeing, and interacting with geese, being one of the few species common in urban and suburban areas (Gabig 2000). Problems arise when geese become overabundant and cause physical damage to parks, lawns, golf courses, and agricultural crops (Powell et al. 2004). Geese using manicured grass, ponds, and lakes near airports are especially dangerous to the public because of the risk of goose-aircraft collisions (Dolbeer et al. 2017, Askren et al. 2019). U.S. Department of Agriculture, Wildlife Services, assist >800 airports nationwide manage issues related to Canada geese (Dolbeer et al. 2014). Overall, public tolerance of overabundant geese has decreased since the 1990s (USFWS 2006, Atlantic Flyway Council 2011).

In 2000, a Canada goose management plan was developed to guide management of depredation, nuisance, and human health and safety concerns caused by temperate-breeding Canada geese in the Central Flyway (USFWS 1999, Gabig 2000). The goal of the plan was to manage temperate-breeding Canada geese in the Central Flyway to achieve maximum benefits (e.g., viewing and hunting opportunity) while minimizing conflicts between geese and humans (Gabig 2000). Canada geese are protected by the 1918 Migratory Bird Treaty Act and subsequent amendments and, therefore, require federal permits for lethal management outside of normal hunting periods. State wildlife agencies and Wildlife Services began addressing overabundance issues by oiling and addling eggs and destroying nests to reduce production of young (Gabig 2000). Other areas, including airports, used noise makers, pyrotechnics, and other forms of harassment to discourage nesting attempts (Gosser et al. 1997, Gabig 2000, Dolbeer et al 2017). In more serious cases, geese are translocated from urban nuisance areas to other areas in-state (Holevinski et al. 2006). Coluccy et al. (2004) estimated managers would need to oil/destroy 71% of local nests to have same effect on population growth rate as a 10% reduction in adult survival. Hunting alone is not enough to manage temperate-breeding geese, because most nuisance geese are in areas where hunting is not allowed because of city or local ordinances or lack of access (Coluccy et al. 2001, Coluccy et al. 2004, Dorak et al. 2017).

Translocating adult and juvenile geese could reduce nuisance issues if most individuals do not return to their original capture location (Surrendi 1970, Fritzell and Soulliere 2004, Sanders and Dooley 2014, Flockhart and Clarke 2017). Translocating nuisance geese >150 km to areas with legal harvest successfully reduced local nuisance issues and increased hunter harvest in New York (Smith et al. 1999, Holevinski et al. 2006). Results of translocation vary among age-classes (Holevinski et al. 2006). Although KDWPT has translocated geese for >50 years, the method has not been rigorously evaluated.

To address this information need, we endeavored to determine the effects of translocation on survival and recovery of Kansas-banded Canada geese. Our research goal was to determine the effects of translocation on the survival and recovery of Kansas-banded Canada geese. More specifically, we aimed to determine if translocating nuisance temperate-breeding geese reduced annual survival and increased recovery probability between translocated and nontranslocated (i.e., normal wild) individuals. We hypothesized survival and recovery of Canada geese would vary between translocated and nontranslocated (i.e., normal wild) groups, and predicted lower survival of translocated geese as they are moved from protected urban areas to reservoirs with public hunting. We further hypothesized survival and recovery would vary among adults, sub-adults, and juveniles within and between groups. We predicted survival of sub-adult geese would be lower than adult and juvenile geese, because sub-adults would travel greater distances, and be more vulnerable to hunter harvest.

Methods

Study area

Kansas is a prairie-dominated state in the central Great Plains of North America. There are three grassland ecoregions in Kansas including short-grass prairie in the west, mixed-grass prairie in the center, and tall-grass prairie in the east. Total land area is 213,100 km^2 and the climate is temperate continental characterized by extreme differences with hot summers (July daily average = 26° C) and cold winters (January daily average = 1.6° C). Annual precipitation ranges from <40 cm in western Kansas to >100 cm in eastern Kansas (K-State Climate 2018).

Approximately 3 million people occupy Kansas, mainly in two large metropolitan areas, Kansas City (2.2 million approximate metropolitan population, including Missouri) and Wichita (650,000 approximate metropolitan population). Agriculture and grazing dominate the Kansas landscape with >98% of land in private ownership (rank 2nd nationwide). Kansas is home to lakes and reservoirs in both the Missouri and Arkansas river basins (U.S. Geological Survey Kansas Water Science Center 2018). There are 24 major reservoirs in Kansas, mainly in the eastern half of the state, managed by the U.S. Bureau of Reclamation and Army Corps of Engineers.

Goose Capture and Banding

Banding and translocation efforts increased during 2012–2017 as part of an eastern-tier Central Flyway survival and recovery study (Gabig 2000, Dooley et al. 2019). This led to varying numbers of individuals banded in Kansas (range 659–4002). Each summer, KDWPT bands at multiple sites in three banding regions. Each banding site within each region is revisited on a 5-year cycle and banding location is influenced by opinion of flock size and likelihood of successful capture among local biologists. The 5-year banding interval between capture at individual sites limits recapture records at banding; therefore, recapture data were not included in our analysis. Banding effort was similar between urban and rural counties.

Geese were corralled while molting flight feathers and flightless; typically, during a 2-week period in June (Cooch 1953; pre-season banding). Birds were held in mesh panel pens while individuals were aged (hatch-year [HY], local [L], or after-hatch-year [AHY]), sexed (male, female, or unknown; determined by cloacal exam; Pyle 2008), and fitted with a standard U.S. Geological Survey Bird Banding Lab (USGS BBL) size 8 numbered aluminum leg band. All birds captured, banded, and released with standard aluminum leg bands at the capture site were classified as normal wild-caught Canada geese (according to standard USGS BBL terminology). All bird handling adhered to guidelines for the use of wild birds in research (Fair et al. 2010; Bird Banding Lab Permit #07339; translocation USFWS MB046901; KDWPT Wildlife Division scientific permit SC-055-2017).

Translocation

In response to citizen complaints, KDWPT translocated some of the banded Canada geese from state-identified nuisance areas to rural areas as a strategy for reducing nuisance issues (e.g., public health concerns, overabundance at urban parks, and harassment). The banding process for translocated individuals was similar to normal, wild-caught birds except individuals were not always sexed and instead of being immediately released, birds were trailered to Cedar Bluff Reservoir State Park (38.786, -99.770). Geese were held in mesh pens (approximately 30,000 m^2) with fresh open water and processed goose feed mix (i.e., crushed corn, milo, alfalfa, and soybean meal). Primary flight feathers were trimmed twice to prevent geese from escaping. Prior to release in late August, KDWPT plucked flight feathers so geese molted new feathers and remained at release sites (Lee et al. 1984). Geese were released at multiple reservoirs in western Kansas and sites varied by year. We grouped all translocated individuals, regardless of capture or release location, to estimate the effect of translocation on annual survival and recovery. Original translocated banding records were provided by KDWPT to cross-reference translocated band number with complete BBL recovery file. We classified all birds captured, banded, translocated, and released with standard aluminum leg bands at Cedar Bluff Reservoir or another site as translocated Canada geese following standard USGS BBL terminology.

Band Recoveries

We obtained all banding and recovery data from the USGS BBL (2012–2017; USGS 2019). We limited the time period to 2012–2017 because there are limited records of translocation effort outside of that period. Banded individuals were categorized into one of three groups. Status 1, normal, wild-caught birds, were banded with standard aluminum leg bands during June and released at capture site. Status 2, translocated, wild-caught birds, were banded during June and translocated from urban capture sites to Cedar Bluff Reservoir or other rural reservoirs and released. Status 3, other marked birds, were removed from any subsequent analysis to reduce bias (e.g., reported to BBL as hit by car, re-sighted with spotting scope, or reported outside of legal hunting seasons). In 2013, all translocated geese were banded with alpha/numeric-coded plastic neck collars and removed from this analysis because of differential harvest bias (Castelli and Trost 1996, Alisauskas and Lindberg 2002). Only hunter-harvested birds were included in survival and recovery analyses. Age at banding was collapsed into two groups, adults (after-hatch-year [AHY]) and juveniles (hatch-year and local [HY]). Juveniles transitioned into sub-adults after 1 year and were categorized as sub-adults for 2 years following Dooley et al. (2019). Geese with unknown age were removed from both normal and translocated groups.

Survival and Recovery Models

We used Brownie dead-recovery (2-encounter) models to estimate annual survival and recovery in Program MARK from direct recoveries for juveniles and adults and indirect recoveries for sub-adults (Brownie et al. 1985, White and Burnham 1999, Cooch and White 2019). Survival probability is the probability that a banded bird in year *t* survives to the middle of the banding period in year *t* +1. Recovery probability is the probability that a bird was shot, recovered, and reported during the hunting season in year *t*. Harvest estimates are not available for temperate-breeding Canada geese in Kansas; therefore, direct recoveries were used as an index to harvest (Johnson and Moore 1996).

Direct recovery rate is the probability of a bird being shot, retrieved, and reported during the first hunting season following banding. We did not adjust for potential differences in annual band reporting rate because of the short time span between banding and harvest. Banded recoveries were reported to BBL by phone (1-800-327-2263) or website (reportband.gov).

We categorized geese into 1 of 4 groups: normal adults, normal juveniles, translocated adults, or translocated juveniles. Normal geese were released on-site following banding at urban and rural banding sites. Preliminary analyses indicated no difference in annual survival for normal birds between urban and rural banding sites. We did not estimate the effect of sex (male or female) in our analysis.

We chose 3-age class models based on evidence of bias in 2-class dead-recovery models, especially in the juvenile age class (Heller 2010, Dooley et al. 2019). We developed seven *a priori* candidate survival models intended to explain variation in survival with respect to variables of interest, including status (normal wild or translocated) and age (juvenile, sub-adult, and adult) for specific state management questions. To build the model set, we held survival constant (.) and tested three recovery models to determine the top-ranked recovery structure (Dooley et al. 2019). We then kept the top ranked recovery structure constant and tested survival models. We included a constant (i.e., null) model of no difference between status or age for survival and recovery and a global model that tested for differences among all potential main and interactive effects of status or age for survival and recovery. Models were ranked according to Akaike's Information Criterion corrected for small sample size (AIC_c), informative beta coefficients, and model weight (Burnham and Anderson 2002).

Variables in the top-ranked model were considered influential if associated beta coefficients did not overlap zero at the 85% confidence interval. Additional models with $\Delta AIC_c \leq 2$ and holding model weight (w_i) were considered competitive (Arnold 2010).

Results

We used 13,639 bandings and 1,073 direct recoveries from 2012–2017 to estimate survival and recovery rates (total and direct recoveries; Table 1.1). Normal, Kansas-banded, Canada geese were recovered primarily in Kansas (82%), as well as 14 other states, and 3 Canadian provinces. Translocated geese were recovered primarily in Kansas (91%), and also in 5 other states and 1 Canadian province (Table 1.2). All recoveries occurred in the Central and Mississippi flyways (Figure 1.2).

Using 859 direct recoveries from normal wild geese and 214 from translocated geese, we determined the direct recovery rate was 2.5 times greater for translocated geese (17.4%) than normal geese (6.9%) during 2012–2017 (Table 1.1). Direct recovery rate of translocated geese was always at least twice that of normal geese in any given year; except in 2017, when no translocated geese were recovered and reported.

The top-ranked direct recovery model indicated survival varied by status (normal wild or translocated) and recovery varied by status and age (3-age class; Table 1.3). The top-ranked model held all model weight (w_i = 1.00). The second-ranked model, accounting for constant survival and recovery, varied by status and age, was 15 ΔAIC_c units from the top model and accounted for no model weight. Beta estimates for the top model did not overlap zero (normal survival beta coefficient = 0.398, 85% CI = 0.188-0.608). Model-estimated annual survival differed between status (normal wild $\hat{S}$ = 0.761, 95% CI 0.734-0.785; translocated $\hat{S}$ = 0.598, 95% CI 0.528-0.665). Recovery probability differed between normal and translocated adults (normal wild $\hat{f}$ = 0.074, 95% CI = 0.069-0.078; translocated $\hat{f}$ = 0.138, 95% CI = 0.120-0.158) and juveniles (normal wild $\hat{f}$ = 0.067, 95% CI = 0.059-0.075; translocated $\hat{f}$ = 0.250, 95% CI = 0.199-0.310; Figure 1.2). Recovery probability did not differ between status in the sub-adult age class (normal wild $\hat{f}$ = 0.126, 95% CI = 0.115-0.137; translocated $\hat{f}$ = 0.090, 95% CI = 0.055-0.144; Figure 1.2).

Discussion

Understanding how translocation affects survival of nuisance species is necessary to successfully monitor and manage wildlife populations (Koons et al. 2014). We found translocation influenced survival of Kansas-banded Canada geese. Adult annual survival (normal wild $\hat{S}$ = 0.76) was similar to the estimate reported by Dooley et al. (2019) for Kansas-banded Canada geese ($\hat{S}$ = 0.75). Translocated adult survival ($\hat{S}$ = 0.59) differed from previous normal wild adult survival estimates (Dooley et al. 2019). Translocated adult survival was also less than other mid-latitude states' survival estimates for temperate-breeding Canada geese ($\hat{S}$ = 0.66-0.91, Virginia, Ladin et al. 2020; $\hat{S}$ = 0.66, Ohio, rural, Shirkey et al. 2018; Table 1.4).

We found translocation increased recovery probability of adult and juvenile geese. Normal wild direct recovery rate (0.069) in Kansas was less than reported for a similar latitude in Ohio (0.135-0.158, Shirkey et al. 2018), but increased when geese are translocated (0.174). Our normal wild recovery probability estimates were similar to those of Dooley et al. (2019) for all normal status age-classes: adults (0.074 and 0.064, respectively), sub-adults (0.126 and 0.105, respectively), and juveniles (0.067 and 0.049, respectively). Recovery probability of translocated geese was approximately two times greater in adults and four times greater in juveniles. Increased recovery probability of juvenile geese is unlikely to affect the long-term viability of translocated populations because population dynamics are largely driven by adult survival (Coluccy et al. 2004). We may not have observed a difference in sub-adult recovery probability between translocated and normal geese because sub-adults typically do not breed and may undergo a northward migration to molt flight feathers, away from predation and competition with brood flocks (Sterling and Dzubin 1967, Salomonsen 1968). These long-distance molt migration flights likely result in normal and translocated sub-adults being equally available for harvest. Luukkonen et al. (2008) and Dorak et al. (2017) found molt migrants have lower survival and greater recovery probabilities than geese that do not molt migrate. Lower annual survival and increased recovery probability is most closely linked to increased hunter harvest in the autumn as birds return from molt migrations (Lawrence et al. 1998a, b; Holevinski et al. 2007).

Translocation may effectively reduce nuisance concerns in urban areas and increase hunter opportunity in rural areas (Griggs and Black 2004, Holevinski et al. 2006). Although we did not explore this explicitly, maintaining and increasing hunter opportunity by increasing populations on rural reservoirs with legal hunting may be valuable for recruiting and retaining waterfowl hunters or other user groups (Smith et al. 1999, Vrtiska et al. 2013). Most other nuisance abatement efforts provide few benefits for hunters or bird watchers, are expensive, and often ineffective (e.g., harassing with dogs, egg oiling and addling, nest removal, and others; Beaumont et al. 2017). Culling may be the most effective method for reducing adult survival, and therefore nuisance issues, but the general public does not agree on which management action is most acceptable for controlling nuisance Canada geese (Shirkey et al. 2018, Brasch 2019).

Long-term success requires public education, public support for mitigation, habitat modification, and comprehensive management of temperate-breeding Canada geese. Translocating geese remains a viable option in Kansas because temperate-breeding geese are mainly distributed around the 2 major cities, Kansas City and Wichita, in the eastern portion of the state. This allows managers in Kansas to translocate geese to the vast and sparsely populated western half of the state; other states in the Atlantic, Mississippi, and Central flyways tend to have statewide distributions of geese. Translocating geese can be expensive and cost should be considered with the long-term feasibility of a translocation program (total translocation cost = $0.13 per bird per kilometer [range = $54-$74 per bird annually or $40-$60 for capture by nuisance control operators plus $14 per bird for food, wing clipping, and monitoring at Cedar Bluffs Reservoir for 90-day holding period]). Thus, where feasible, artificially managing source-sink dynamics via translocation may be an effective and socially acceptable method to manage nuisance geese. This translocation program will be monitored long-term to ensure geese do not become overabundant in western Kansas.

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Table 1.1 Banding and recovery (direct recoveries included in parentheses) of normal wild (*n* = 12,412) and translocated (*n* = 1,227) resident Canada geese banded in Kansas, 2012-2017 and recovered 2012 through the 2017–2018 hunting season.

	Normal Wild		Translocated		Total	
Year	No. Banded	Total Recoveries	No. Banded	Total Recoveries	No. Banded	Total Recoveries
2012	1943	500 (93)	225	94 (46)	2168	594 (139)
2013	2008	448 (119)	0	0 (0)	2008	448 (119)
2014	2722	641 (231)	266	92 (64)	2988	733 (295)
2015	3663	751 (230)	339	77 (45)	4002	828 (275)
2016	1462	194 (125)	352	80 (59)	1814	274 (184)
2017	614	61	45	0	659	61
Total	12412	2594	1227	343	13639	2938

Table 1.2 Recovery distribution of normal, wild (*n* = 12,412) and translocated (*n* = 1,227) resident Canada geese banded in Kansas, 2012-2017 and recovered during the 2012 through 2017–2018 hunting seasons.

	Normal Wild		Translocated	
State/ Province	**Recoveries**	**% of Total**	**Recoveries**	**% of Total**
Alberta	1	0.0	0	0.0
Arkansas	1	0.0	0	0.0
Colorado	3	0.1	0	0.0
Illinois	5	0.2	0	0.0
Iowa	16	0.5	1	0.3
Kansas	2736	81.9	345	90.6
Kentucky	1	0.0	0	0.0
Manitoba	99	3.0	7	1.8
Minnesota	42	1.3	0	0.0
Mississippi	1	0.0	0	0.0
Missouri	55	1.7	0	0.0
Nebraska	55	1.7	12	3.2
North Dakota	113	3.4	9	2.4
Oklahoma	106	3.2	2	0.5
Saskatchewan	18	0.5	0	0.0
South Dakota	72	2.2	5	1.3
Texas	7	0.2	0	0.0
Wisconsin	10	0.3	0	0.0

Table 1.3 Brownie dead-recovery models for survival ($\widehat{S}$), recovery ($\hat{f}$), Akaike's Information Criterion corrected for small sample size (AIC_c), difference between the top model and the next best model (ΔAIC_c), model weight (w_i), deviance (Dev), and number of parameters (*K*) for resident Canada geese banded in Kansas, 2012-2017.

$\hat{S}$	$\hat{f}$	AIC_c	ΔAIC_c	w_i	*K*	Dev
Status	Status * Age	21353.95	0	1	8	21337.9
(.)	Status * Age	21369.28	15.33	0	7	21355.3
Status * Age	Status * Age	21409.6	55.65	0	10	21389.6
(.)	Age	21479.58	125.63	0	4	21471.6
(.)	Status	21535.61	181.66	0	3	21529.6
Age	Status* Age	21561.67	207.72	0	5	21551.7
(.)	(.)	21582.38	228.43	0	2	21578.4

Table 1.4 Summary of resident Canada goose survival estimates from Atlantic, Mississippi, and Central Flyway U.S. states (including Quebec). Survival rates were recorded in literature as no designation, urban, or rural.

Author	**Location**	**Annual Survival Rate**		
		No Designation	Urban	Rural
Dorak et al. 2017	Illinois		1.00	0.48
Luukkonen et al. 2008	Michigan		0.88	0.74
Pilotte et al. 2014	Quebec	0.82		
Dooley et al. 2019	Kansas	0.75		
Heller 2010	Mississippi Flyway	0.72		
Ladin et al. 2020	Virginia	0.66 - 0.91		
Shirkey 2018	Ohio		0.60	0.66
Dieter and Anderson 2009	South Dakota	0.52		
Groepper et al. 2008	Nebraska	0.49		

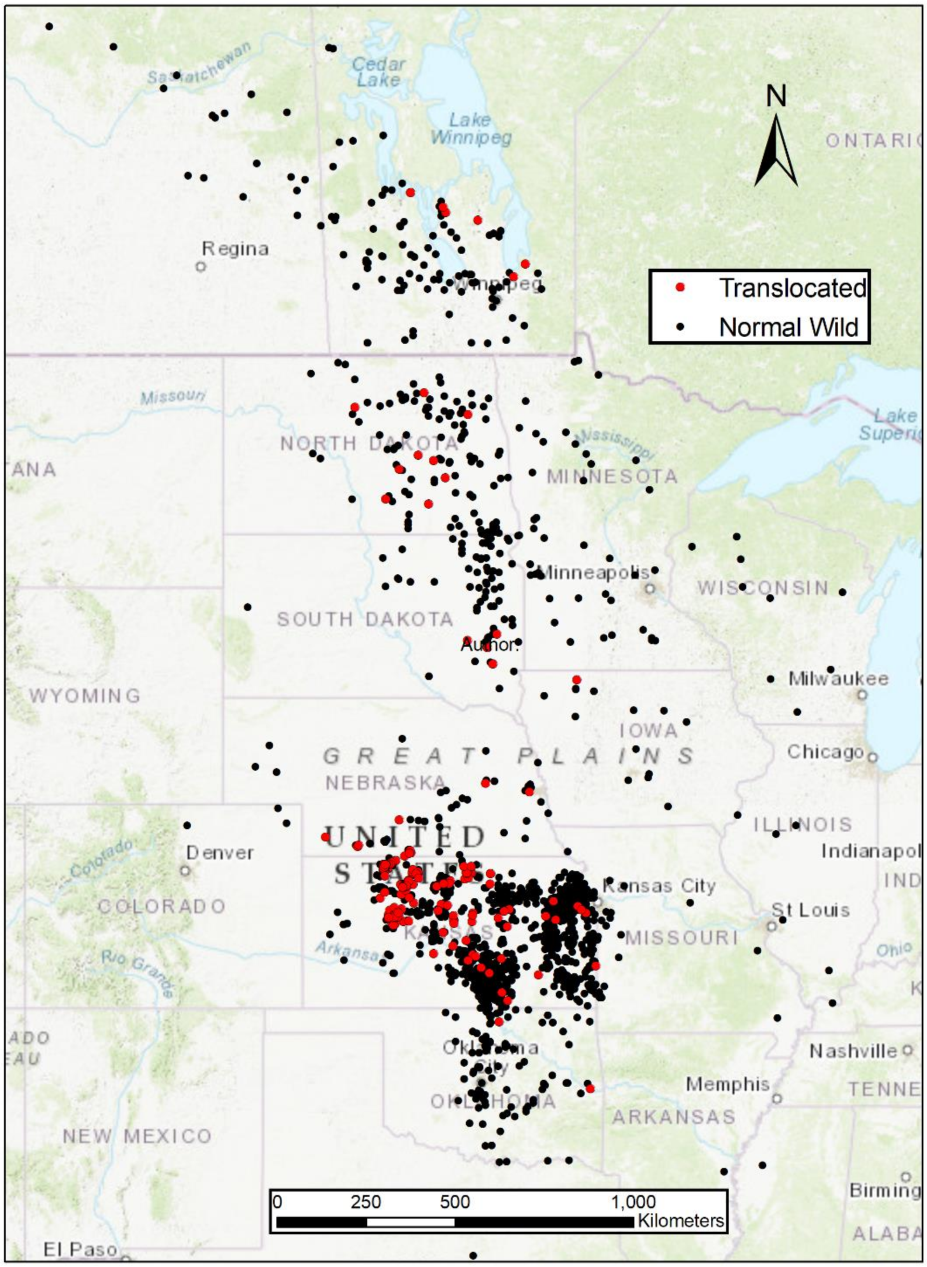

Figure 1.1 Recovery locations of Kansas-banded Canada geese compared between normal wild and translocated status groups, 2012-2018.

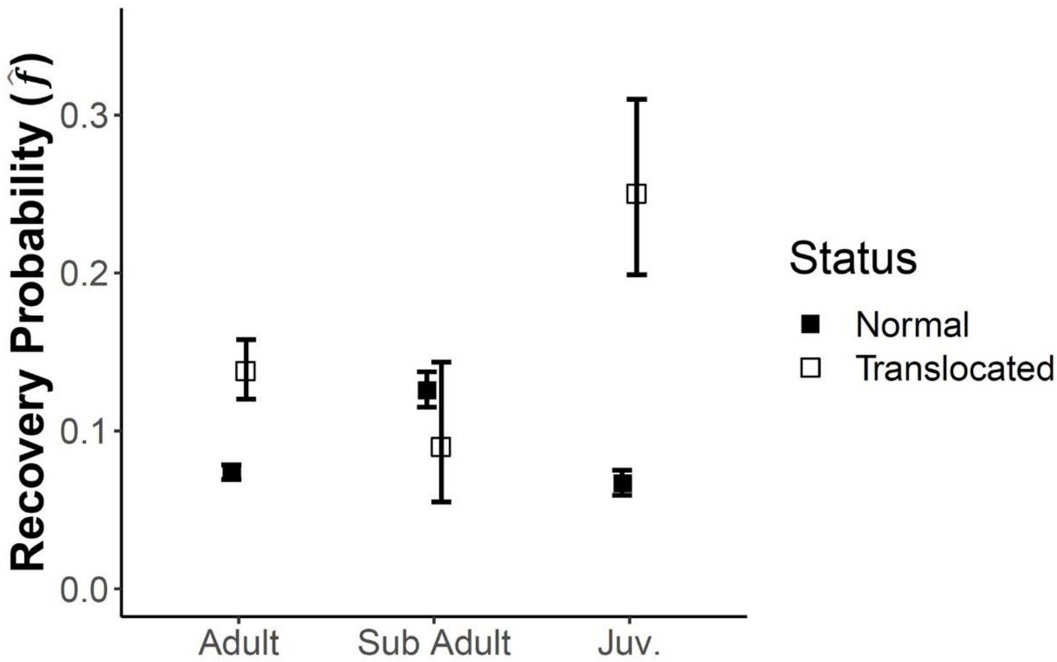

Figure 1.2 Comparison of recovery probability for Kansas-banded Canada geese between normal wild and translocated groups of different ages classes with 95% confidence intervals in Kansas, 2012–2017, based on top approximating model [$\hat{S}$ (status) $\hat{f}$ (status * age)].

Chapter 2 - Wildlife Survey Allocation by Simulation: Breeding Resident Canada Geese

Abstract

Annual monitoring of abundance and distribution of organisms is important for successful long-term management. Aerial survey is one of the most efficient methods to sample large populations of visible animals (i.e., birds and mammals). Rigorously designed plot stratification and allocation is imperative to gain actionable information from often expensive monitoring. Simulating survey scenarios may be the most cost-effective method to test potential designs before executing surveys in the field. We tested 7 plot reallocation scenarios for a spring breeding survey for resident Canada geese (*Branta canadensis*) in Kansas, USA, with the goal of reducing variance (<20% coefficient of variation [CV]) at similar or reduced cost. Since 2014, Kansas Department of Wildlife and Parks has surveyed 160 1-mi^2 plots in 2 landcover strata (80 high and 80 medium strata) based on expected abundance of Canada geese. We used survey data from 2019 to estimate bias (i.e., likelihood of the 90% confidence interval around the population estimate containing the true value) of potential plot reallocation scenarios focusing on inter-plot count variation. Our top-ranked survey simulation design for reducing bias predicted reallocation of medium stratum plots to the high strata would be the most effective method to increase power and reduce CV. Our real-world test of the top-ranked survey design yielded similar CV (23.8%) to the long-term average (24.2% CV, range 20.7–28.6% CV) of the existing survey but with a slightly reduced cost and reduced bias. Although we did not achieve our goal of CV below 20%, the survey will be

flown at the updated allocation to account for annual variation. Simulated survey analysis is an effective method to test survey reallocation scenarios at minimal cost.

Key words: aerial survey, *Branta canadensis*, Canada geese, Kansas, power analysis, simulation.

Introduction

Abundance and distribution of organisms is fundamental to the study of ecology, conservation biology, and wildlife management (Kingsford and Porter 2009). Understanding wildlife population demography and distribution requires sampling portions of a given population to make inferences about the entire population. Data from long-term, designed monitoring studies produce the most reliable results (e.g., population estimates, trends; White 2019). Accurately surveying organisms, especially birds and large mammals, can be expensive, time consuming, and potentially dangerous (Nichols and Williams 2006, Conn et al. 2016, Southwell et al. 2019). Aerial surveys are often the best option to sample widely distributed and conspicuous animals at broad spatial scales (e.g., statewide; Caughley 1977, Kingsford 1999). A statistically designed sample (i.e., survey) of a population should provide an accurate estimate of abundance and trends with minimal uncertainty (Eggeman et al. 1997, Pollock et al. 2002). Post-hoc statistical analyses rarely overcome poor observation-based survey design.

Long-term population monitoring programs are essential for advancing our understanding of conservation science (Hughes et al. 2017, Giron-Nava et al. 2017, White and Bahlai 2021). We can leverage existing information to survey a system more effectively (Zurell et al. 2010, White and Bahlai 2021). Using a virtual ecologist approach, we can test the power of different survey scenarios using existing data (Zurell et al. 2010, Southwell et al. 2019). Variation among sites, especially interannual variation, can make study duration more important than the number of sampling sites (Thogmartin et al. 2007, Urquhart 2012, Weiser et al. 2019). Additionally, large differences in measures among sites within the same landcover type (i.e., stratum) can add additional error. Statistical power declines as variation increases among sample sites (Urquhart 2012, Weiser et al. 2019). Local (i.e., strata-specific) populations can increase or decrease separately from the overall population trend or statewide abundance estimate (Weiser et al. 2019). Where, how often, and when we draw samples is one of the few aspects of wildlife surveys under user control.

Simulation is a cost-effective method to test potential survey designs (Pearse et al. 2009, Conn et al. 2016). Data from previous surveys can be used to test design updates relative to an existing survey while estimating realistic variation. State and federal agencies commonly have these data readily available for game species and may be able to increase survey quality with minor revisions to an existing survey. Simulating surveys gives us the ability to compare scenarios with minimal additional cost. For statewide aerial surveys of birds and mammals, optimizing survey design can result in considerable savings. In 1998, large mammal surveys in the western United States cost between US$440,000 and US$1,700,000 (Rabe et al. 2002). Simulating alternate survey scenarios based on historic data can increase statistical power, decrease uncertainty, and reduce survey costs.

Resident Canada geese (*Branta canadensis*) are expanding geographically and in total abundance across North America (Schmidt 2004). While populations of breeding resident Canada geese in some northern midwestern states (e.g., South Dakota, USA) are estimated as part of the U.S. Fish and Wildlife Service May Waterfowl Breeding Habitat and Population Survey (Smith 1995, Baldassarre and Bolen 2006), mid-latitude and southern states survey breeding geese at the state level. Current survey designs and methods vary between states ranging from no survey to a ~400 plot helicopter survey. Kansas, USA, represents a transitional zone where there is still perceived available habitat for resident Canada geese, but the population has not yet reached carry capacity. Populations of resident Canada geese are likely expanding in Kansas and accurate population estimates are needed for proper long-term management. Surveys of Canada geese focused on estimating population abundance of resident breeding pairs, using spring fixed-wing aerial surveys. The Kansas statewide spring breeding population survey for Canada geese began in 1996 as a biologist-directed line-transect survey. In 2012, the survey was updated to a randomized aerial plot survey based on landcover strata to reduce bias and error relative to the mean (CV).

Our goal was to improve the precision and reduce bias of future population estimates by simulating sample designs, based on bias and variation from a previous survey, while maintaining or reducing cost (i.e., flight hours). To maintain the existing structure of the survey, we aimed to reallocate plots among strata to reduce variation with the same number of total plots (n = 160). We hypothesized relocating plots more optimally would reduce the overall survey CV. We predicted reallocating medium stratum plots to the high stratum would increase our statistical power and reduce survey CV.

Study Area

Kansas was a prairie-dominated state in the central Great Plains of North America (Figure 2.1). Landcover shifted in response to a precipitation gradient from <40 cm of precipitation in short-grass prairie in the west to >100 cm in tall-grass prairie in the east (K-State Climate 2018). Approximately 3 million people occupied Kansas, mainly in 2 large metropolitan areas: Kansas City–Topeka (2.2 million approximate metropolitan population, including Missouri, USA) and Wichita (650,000 approximate metropolitan population). Kansas was home to lakes and reservoirs in both the Missouri and Arkansas river basins (U.S. Geological Survey Kansas Water Science Center 2018). There were 24 major reservoirs in Kansas, mainly in the eastern half of the state, managed by the U.S. Bureau of Reclamation and Army Corps of Engineers. Resident Canada geese were concentrated near reservoirs and urban and suburban development, mainly near Topeka, Kansas City, and Wichita (Malanchuk et al. 2021). Geese also nested in low densities near man-made stock ponds in the drier (western) third of the state.

Methods

Current Plot Survey

In 2014, Kansas Department of Wildlife and Parks (KDWP) modified an existing aerial survey for resident Canada geese into a 1-mi^2 (2.6-km^2; total land area = 213,100 km^2) randomized plot survey based on a correlation analysis of how strongly landcover variables effected prior use by geese. Public Land Survey Sections (PLSS) were stratified according to local parks (74% weight), reservoirs and ponds (22% weight), wetlands (3% weight; Wilson 2017). Each PLSS section with ≥2,000 m^2 of ponded water was classified into either medium or high strata based on mean combined value of landcover variables for all PLSS sections; above the mean was classified as high, below was classified as medium. No survey plots were allocated to the low expected abundance stratum as this stratum represented primarily semi-arid landscapes without water in the western half of the state. Stratified landcover was 42.3%, 50.9%, and 6.8% in the low, medium, and high strata, respectively.

Sample plots were drawn randomly and equally from medium and high stratum PLSS sections for 160 total plots (80 medium/80 high stratum plots). Each plot was flown using a single permanent observer in fixed-wing aerial surveys once during peak nesting in April (~8 flight days within 4-week period). Square section-based plots made navigation easier because plot corners typically matched rural road intersections. The pilot and observer made as many observation passes as necessary to determine presence (count) or absence of geese. A single individual was recorded as a pair as previous studies have suggested males will swim to open water while females remain on the nest in response to low-level disturbance (Caughley 1977, McAllister et al. 2017; T. Bidrowski, *personal observation*). Flocks (multiple individuals) were counted and recorded as individuals and considered as a separate group from nesting (i.e., paired) geese. Individual and pair (2 individuals) abundance was estimated by extrapolating average density of geese per plot for every PLSS plot in the associated strata. Total pairs and total non-paired individual geese were estimated separately but combined to derive the estimate for the statewide abundance. We did not correct for visibility bias as the observer reasonably confirmed absence before leaving the plot area (Pearse et al. 2008a,b). Occasionally weather or logistical constraints would limit the total number of plots flown each year. Coefficient of variation was calculated as (standard deviation/mean) *100 to provide a relative measure of variability.

Survey Simulation

We focused the simulation on paired geese, not unpaired individuals, because the main goal of the survey is to estimate the breeding population. We used data from the 2019 survey to estimate nesting pair density of resident Canada geese in Kansas per 4,047 m^2 (1 acre) for medium and high strata plots based on 58 observed geese on 80 plots in the medium stratum (*n* = 4 pairs; 5.0% plot use) and 80 plots in the high stratum (*n* = 54 pairs; 36.3% plot use). We estimated state-wide pair density as total number of pairs per strata by total area surveyed (205.8 km^2 per strata at 80 high/80 medium allocation), multiplied by 2 to represent total individuals. Pair density was multiplied by the total area in each stratum (medium = 107,920.7 km^2, high = 14,597.1 km^2) to estimate total statewide abundance of resident Canada geese. For each strata, we calculated sample variance as the average squared differences from the mean (corrected as *n*–1 in the denominator) and standard deviation as the square root of the variance.

We simulated pair density for all sites within each stratum and randomly drew 80 plot densities from each stratum from a Poisson distribution with the mean intensity of our estimated abundance from 2019. We tested 7 logistically feasible scenarios for reallocating survey effort (Table 2.1). We simulated the survey at the current design (80 medium stratum, 80 plots high stratum) to set a baseline for testing alternate scenarios. We simulated design scenarios by reallocating plots in groups of 10 (e.g., 90 medium, 70 high). Additionally, we simulated maintaining the medium plot allocation and increasing the total number of high plots (e.g., 80 medium, 100 high). We simulated each scenario

100 times and calculated mean density and associated standard deviation, 90% confidence intervals, and CV for each iteration. We also calculated the number of times the true value was included in the 90% CIs for each scenario, which we referred to as "bias". Data were processed and simulated in Program R (R Core Team 2021).

Results

The existing survey (80 high/80 medium plots) average total abundance estimate was 16,202 (range = 14,140 – 19,899) and an average CV of 24.2% (range = 20.7–28.6%) for 2014–2019. The average breeding pair abundance estimate was 6,292 pairs (range = 5,049 – 6,935 pairs) and a CV of 25.0% (range = 21.8–30.7%) for 2014–2019 (Table 2.1). Traditionally, the 160-plot survey is flown in 8 flight days (approximately 36 hours) and costs ~US$6,000.

Survey Simulation

The simulated 80/80 allocation approach generated unbiased populations estimates in 82 of 100 simulations (i.e., the estimated value was within the 90% CI). The top-ranked tested scenario included 120 high plots and 40 medium plots, which generated unbiased estimates in 96 of 100 simulations. The second-ranked scenario, 110 high/50 medium allocation, estimated unbiased results in 94 of 100 simulations (Table 2.2). We also tested scenarios in the opposite allocation (i.e., 70 high/90 medium) to determine how bias changed by reallocating high stratum plots to the medium stratum. Reallocating high stratum plots to the medium stratum increased bias with each successive reallocation. We determined greater bias (78 of 100 simulations unbiased) with 60 high/100 medium stratum plots was sufficient to confirm the negative effect of decreasing high stratum and increasing medium stratum plots.

Aerial Survey (2021)

Kansas Department of Wildlife and Parks tested the top-ranked reallocation scenario in 2021. Paired geese were observed on 40 of 120 high plots (n = 78 pairs, 33.3% plot use) and 2 of 40 medium plots (n = 2 pairs, 5.0% plot use). Individuals, or unpaired geese, were observed on 12 high plots (n = 112, 10.0% plot use) and zero medium plots. For the reallocated survey flown in 2021, we estimated a 27.3% CV for paired and 23.8% CV for the combined population estimate. The total population CV for spring breeding geese (23.8%) was within the range estimated in the reallocation scenario (80% of simulated CV estimates 15–30% CV; Figure 2.2). The 2021 statewide pair estimate was 5,792 geese (90% CI 2,599–8,381; 5-year average = 5,757), with a total population estimate of 16,891 geese (90% CI 10,196–23,586; 5-year average = 15,802).

Cost Analysis

Kansas Highway Patrol flight services (Cessna 205/6) cost approximately US$160/hr. Previous surveys (2014–2019) averaged 35 flight hours in 8 days from 4 airports to complete the 160-plot survey. In 2021, the full-time observer flew a total of 31 flight hours in 7 days from 4 airports as high strata plots are more concentrated on the landscape, reducing taxi time between plots. Excluding 7 days of salary for the observer, the total cost to KDWP was approximately US$5,000. The survey simulation, and subsequent real-world test, maintained survey CV and increased statistical power with 4 fewer flight hours and a 12% reduction in total cost.

Discussion

Our duty as wildlife researchers is to use the best available techniques to make science-based decisions at a reasonable cost to the public (Organ et al. 2012). Our survey simulation, and subsequent real-world test, maintained survey CV and increased statistical power with reduced flight hours and total cost. High stratum plots are more densely located near large cities (e.g., Kansas City and Wichita), which reduced the total amount of taxi time between plots. The high stratum is only 6.8% of the total land area but estimated to contain >75% of the statewide population of resident Canada geese (T. Bidrowski, KDWP, *personal observation*). Focusing survey resources in the high stratum may provide the most valuable results for understanding how resident Canada geese are adapting to increased urbanization and perceived available habitat.

We did not achieve our goal of reducing CV below 20% but our results were within the simulated CV range (15–30% CV). We believe annual variation was a factor in the real-world test of the reallocated survey. The updated 120 high/40 medium plot allocation will continue to be flown each April to assess the benefits of the redesign. Adding more total plots might reduce the CV but we must consider the tradeoffs of the information gained versus the cost of monitoring and agency resources (Bennett et al. 2018, White 2019).

Simulating alternate survey designs enables managers to make informed decisions about best use of resources to monitor wildlife populations. Information gained from survey simulations may benefit managers in 2 main ways. First, managers may learn they are over sampling and wasting resources while reliable estimates are possible with reduced survey effort. Second, managers may reduce error and gain more valuable (i.e., actionable) data for future management decisions. Testing a variety of plot reallocation scenarios allowed us to estimate where survey effort would be most effective at reducing variance without major survey design changes (i.e., re-stratifying). Maintaining the general survey design is important for continuing the established time series of population estimates, especially with the loss of the 2020 survey due to Covid-19. Survey simulation is a science-based tool that will continue to aid wildlife management related decisions at reduced cost and infield effort.

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Table 2.1 Spring breeding estimate of resident Canada geese in Kansas, USA, during 2014– 2021 including extrapolated pair estimate based on pair and individual density and coefficient of variation (CV).

Year[a]	Plots Surveyed	Pair Estimate	CV (%)	Total Goose Estimate	CV (%)
2021	160	5,792	27.3	16,891	23.8
2019	160	5,928	21.8	16,664	22.6
2018	160	5,049	21.5	14,140	23.5
2017	160	6,935	30.7	16,989	28.6
2016	156	5,080	23.5	14,326	20.7
2015	160	5,887	30.1	15,195	27.1
2014	166	8,873	22.3	19,899	22.5

[a] The survey was not conducted in 2020 due to COVID-19.

Table 2.2 Plot reallocation scenarios (*n* = 7) and number of simulation population estimates that fell within the true estimated 90% confidence interval (i.e., true value), including current survey design (80 high/80 medium expected abundance stratum), for the statewide breeding resident Canada goose survey, Kansas, USA.

	Stratum			
Plots	**Low**	**Medium**	**High**	**True Value**
160	0	100	60	**78**
160	0	90	70	**83**
160	0	80	80	**82**
160	0	70	90	**89**
160	0	60	100	**92**
160	0	50	110	**94**
160	0	40	120	**96**

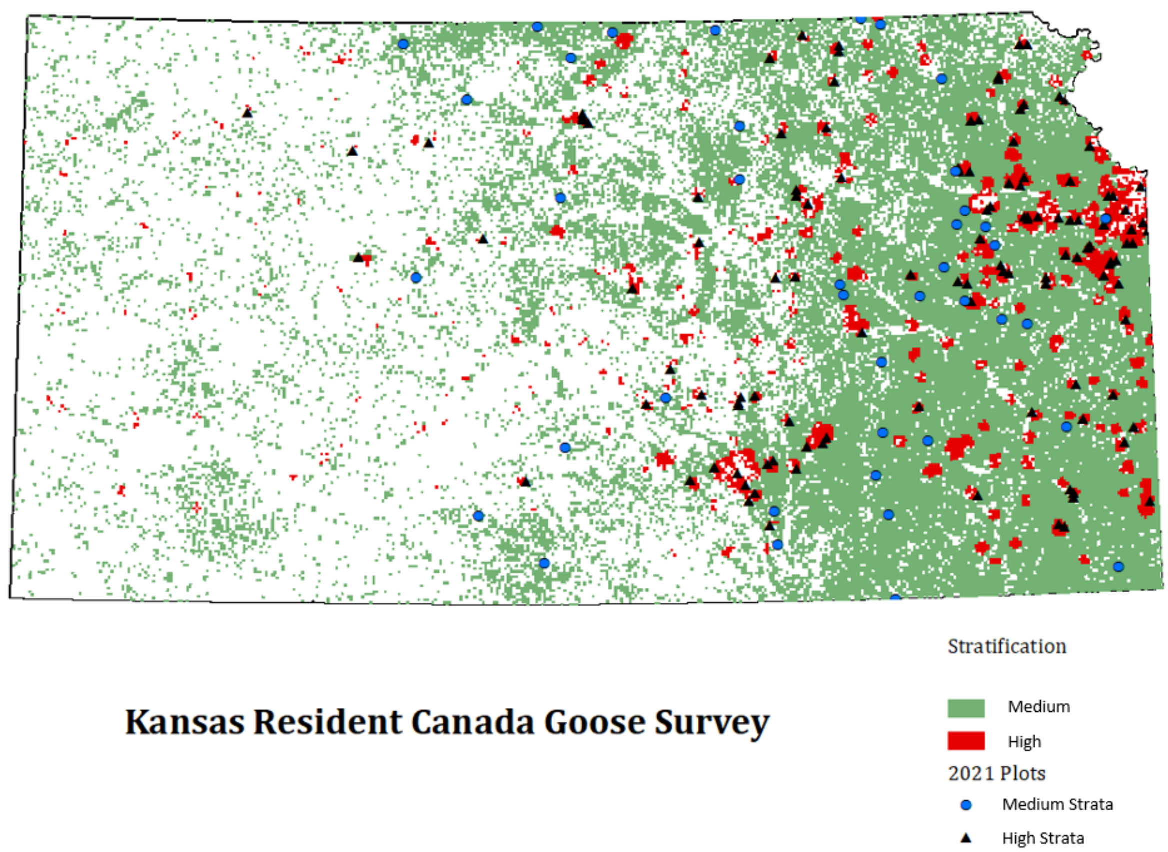

Figure 2.1 Statewide habitat and expected abundance stratification with updated plot allocation (120 high/40 medium strata) to estimate resident Canada geese in Kansas, USA.

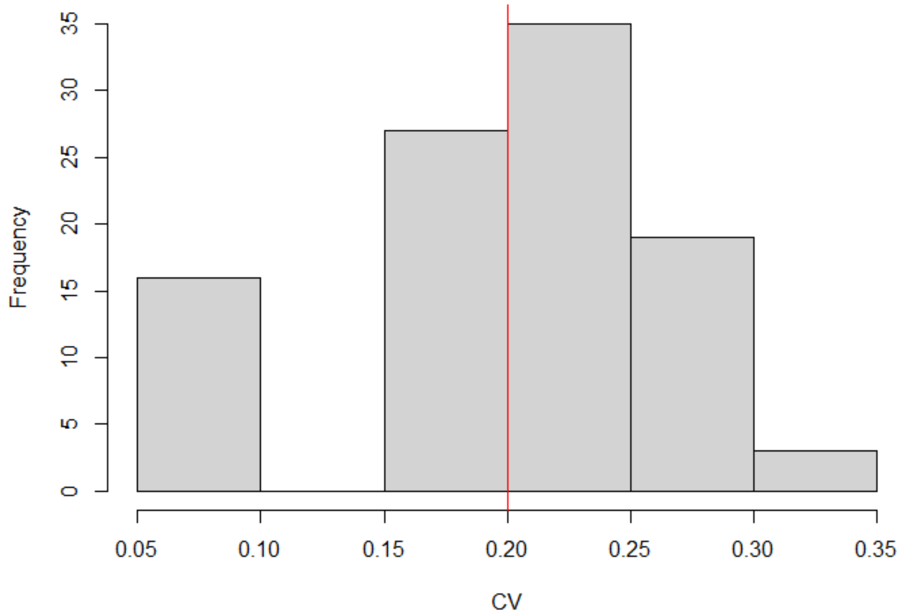

Figure 2.2 Frequency distribution of simulated coefficient of variation (CV) for the top-ranked model (120 high/40 medium expected abundance stratum) with 0.20 CV objective (red line) for the statewide breeding resident Canada goose survey, Kansas, USA.

Chapter 3 - Latitudinal Influence of Molt Migration on Band Recovery for Resident Canada Geese in the Central Flyway

Abstract

Molt migration is a poorly understood yet commonly accepted phenomenon where resident birds migrate northward to molt flight feathers in areas with longer daylight and reduced competition for resources before migrating south. Molt migration patterns likely change with initial latitude and age class but there is scant information focused on non-manipulated populations. Populations of resident Canada geese (*Branta canadensis*) are ideal for studying latitudinal variation in molt migration patterns as they are long-lived, banded with coded leg bands, and recovered and reported by hunters across North America. We investigated the effects of banding latitude (i.e., banding state) and age-class on geospatial recovery patterns of resident Canada geese in the eastern-tier states of the Central Flyway, 2012–2019. We used optimized hot spot and inverse distance weighting to measure how recoveries of sub-adult and adult geese differed spatially as insight into latitudinal effects of molt migration. Sub-adult geese from southern-banding states were recovered disproportionately at more northerly latitudes than sub-adult geese from northern banding states. Adult geese were disproportionately recovered in their respective banding state. Recovery patterns changed as latitude increased with no discernible difference between age-classes for geese banded in South Dakota. Geese banded in North Dakota showed the reverse trend as both sub-adult and adult recovery hot spots were south of banding latitude. Sub-adult geese were recovered disproportionally, compared to adults, in northern latitudes because of age-class specific

molt migrations. Historically molt migration was thought to increase survival but the advantage of differential sub-adult movement is not understood on the modern landscape.

Introduction

Migration is one of the most vulnerable time periods in the annual cycle of migratory birds (Newton 2006, Tonra and Reudink 2018). Molt migration is a spring or summer migration from traditional nesting areas to northerly locations where the individual completes a full wing molt before migrating south in autumn. Molt migration is a common yet poorly understood phenomenon observed in waterfowl, auks (*Alcidae*), rails (*Rallidae*), and other long-lived water bird species (Salomonsen 1968). These migrations are thought to be undertaken by sub-adult and nonbreeding individuals (Sterling and Dzubin 1967, Salomonsen 1968). Additionally, some successful nesters may molt migrate after losing or abandoning their brood (Krohn and Bizeau 1979, Zicus 1981, Lawrence et al. 1998, Dieter and Anderson 2009). The distance of molt migration differs greatly among different families of birds, from 40 km to >3,000 km (Martin 1964, Luukkonen et al. 2008). Timing of molt migration depends on regular nesting period, latitude, and environmental harshness during spring (Salomonsen 1968, Luukkonen et al. 2008). Molt migration flights tend to occur over a short period and individuals typically follow a direct route from breeding or staging areas to molting areas (Salomonsen 1968).

Evolutionary drivers of molt migration are poorly understood. The two main theories pose predation risk, competition for food, or a combination of both, as drivers of this innate behavior (Salomonsen 1968, Tonra and Reudink 2018). Longer daylight allows for longer foraging periods and increased nutrient intake leading to increased body condition. Abundant resources allow for quicker molts and shorter flightless periods;

potentially increasing survival due to shortened predation-risk periods (specifically in waterfowl; Lima and Dill 1990). Reduced predation risk may be a main driver of molt migration, but there is scant research supporting this hypothesis. Even more poorly understood is how nesting latitudes influence patterns of molt migration. For example, extensive northward molt migrations may increase body condition in the short term but at the cost of reduced survival during return flights (Greenberg 1980). Optimal molt migration distance may be controlled more by survival on return flights and less by longer daylight and increased foraging time at northern latitudes. Quantifying large-scale molt migration is extremely difficult, even with modern techniques (i.e., stable isotopes, Global Positioning System [GPS] transmitters, and experimental manipulation; Kelly et al. 2002).

Temperate-breeding, resident, or giant Canada geese (e.g., *Branta canadensis*; geese nesting in the conterminous United States) populations are ideal for studying molt migration because they are locally abundant, marked as part of regular state wildlife management programs, and recovered and reported by hunters throughout North America. A proportion of resident Canada geese may undergo a molt migration, predominately northward, during spring and early summer with a subsequent southward migration during autumn as part of flocks of fully migratory Canada or cackling geese (*B. c*. subsp or *B. hutchinsii* subsp). Traditional use of the term “resident” Canada geese may be misleading as many temperate-breeding Canada geese still migrate >3,000 km annually (Luukkonen et al. 2008). Sterling and Dzubin (1967) and Zicus (1981) suggest molt migration by Canada geese is an innate life history trait that may have increased individual survival before European colonization (Dieter and Anderson 2009). Although molt migration behavior by Canada geese appears relatively common, environmental pressures that once caused geese to molt migrate may no longer exist. Geese in urban environments are largely free from predation and have access to nearly unlimited food (e.g., turf grass and human feeding) year around.

Zicus (1981) observed 97% of non-nesting (i.e., mainly sub-adults) and 90% of failed nesting geese molt migrated. Luukkonen et al. (2008) experimentally destroyed nests to simulate the effect of nest loss, and found 80% of geese molt migrated. Dieter and Anderson (2009) found 50-60% of adult temperate-breeding Canada geese molt migrate from eastern South Dakota, USA. Molt migration is still poorly understood because of the vast distance traveled by these birds, logistical and financial constraints of marking sufficient individuals with radio or GPS transmitters, and working in the remote northern areas of North America. Most previous research on molt migration has been conducted on extremely small subsets of overall statewide populations; many of which had experimental manipulation (e.g., intentionally destroyed nests). Passive marking with aluminum leg bands presents an opportunity to study molt migration at the flyway scale with a low-cost marking and recovery system that has been used since the 1930s. Using recoveries of hunter-harvested resident Canada geese marked with U.S. Geological Survey (USGS) Bird Banding Lab leg bands, we can infer molt migration patterns for different age classes based on latitude of banding.

To address this information need, we evaluated the geospatial band-recovery patterns of age-specific resident Canada geese in the eastern tier of the Central Flyway, USA, without experimental manipulation. More specifically, we determined if sub-adult and adult resident geese are recovered in statistically different areas (i.e., latitudinal gradient) inferring the presence of a molt migration by a distinct age group. We hypothesized patterns of recoveries of sub-adult geese would be spatially unique from adults. We predicted sub-adult geese would be recovered disproportionately north of adult geese indicating presence of molt migration. Additionally, we predicted this pattern may be influenced by latitude of banding and more apparent in southern banding states (Oklahoma, Kansas, Nebraska, USA) compared to northern banding states (South Dakota and North Dakota, USA) as southern-banded geese are more likely to molt migrate north to take advantage of longer daylight and more abundant resources.

Study Area

The eastern tier of the Central Flyway includes Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota in the Great Plains of North America (34° N – 49° N). Ecosystems and land use in the Great Plains are structured by an east-west precipitation gradient (average annual range = 1,200 mm–300 mm) and a north-south mean annual temperature gradient (0° C – 20° C; Gutmann et al. 2005). Main habitat types include short-grass prairie in the west and mixed and tall grass prairie in the east. Resident Canada geese are typically concentrated near cities with urban and suburban development, limited natural predators, and ample ponded water and mown grass (Holevinski et al. 2007). Resident geese will also forage on waste grain in agricultural fields in rural areas with legal hunting (i.e., recovery) opportunity.

Methods

Sample Population

Resident Canada geese were banded with size 8 aluminum leg bands during 2012 – 2019 during the molting (flightless, pre-basic) period in June and July (timing varies by latitude; Cooch 1953). We obtained all banding and recovery data from the USGS Bird Banding Lab (BBL [2012-2019]; USGS 2019). Any bird that was not captured, banded, and released with only an aluminum leg band at the capture site was removed from all analyses. Only hunter-harvested band recoveries were included and no recapture or resighting records were used because of potential bias. All bird handling adhered to guidelines for the use of wild birds in research and conducted under state-specific BBL permits (Fair et al. 2010; e.g., BBL Permit #07339 [Kansas]). Banded recoveries were reported to BBL by phone (1-800-327-2263) or website (reportband.gov) by hunters. We did not account for differential harvest or recovery rates among states as we were only interested in recovery locations. Sub-adult and adult birds are indistinguishable at banding and misidentifying age-class would bias our results; therefore, only birds banded as local or hatch-year were included in our analysis. This limited the total number of individuals but was necessary to examine our age-specific recovery questions. To reach the adult age-class, individuals had to survive 2 years (from hatch year to sub-adult to adult) before being harvested, recovered, and reported. Recovered geese were separated into 2 age-classes; recovered as sub-adult or recovered as adult. Geese recovered during their first year were not included in this analysis as first-year individuals remain with adult birds for most of the year following hatch (Schultz et al. 1988). Geese aged into the subsequent age-class one year post the mid-point of the banding period. Geese were classified and analyzed by the state they were banded to stratify the banded sample by latitude.

Optimized Hotspot Analysis

We used an Optimized Hot Spot Analysis in ArcGIS to test for geographic differences in patterns of band recoveries between age-classes and if banding latitude influences patterns of band recoveries (ArcGIS 10.7, ESRI, Redwood, CA, USA). Optimized hot spot analysis executes the hot spot analysis (Getis-Ord Gi*) tool using parameters derived from recovery locations of band recovery data. Optimized hot spot analysis examines the spatial distribution of the recovery locations and computes the average distance that would yield K neighbors for each recovery. We computed K as 0.05 * N, where N was the number of recoveries in the state-specific recovery dataset. This analysis produced *z*-score (standard deviations), *P*-value, and confidence level (85%, 90%, 95%, and 99% confidence) results for each recovery in the banded population. To be a statistically significant hot spot, a recovery point had to have other high *z*-score neighboring points, representing isolated age-specific recovery. The clustered *z*-score sum was compared proportionally to the sum of all other recovery points in the data set, by state. The larger the *z*-score, the more intense the clustering and the more intense the hotspot. When the clustered sum was different than expected by random chance (i.e., mixed age-class recoveries) the cluster appeared as a hot spot. Greatest density of sub-adult or adult recoveries was not estiamted in this analysis.

These calculations were used to determine geo-spatial differences in recovery location between age classes (Getis and Ord 1992, Ord and Getis 2010). For example, adult and sub-adult recoveries are largely mixed geospatially but hot spot analysis computed where recoveries were unmixed, by age class. The results were then interpreted as uniquely sub-adult recovery, uniquely adult recovery, or no measurable different (i.e., recoveries are evenly mixed between age-classes). We then used inverse distance weighting (IDW; spatial analysis tools) to smooth weighted points on the mapping surface. Using IDW enabled us to view differential harvest as local regions instead of mapping blocks. The resulting maps showed where patterns of band recoveries between sub-adult and adult geese differed the most (85%, 90%, 95%, and 99% confidence) not where the greatest number of sub-adults or adults were recovered; an important distinction.

Results

We used 7,559 total bandings in five states from 2012–2019 to calculate the statistical difference of recovery latitude between sub-adult and adult resident Canada geese (Table 3.1). Recovery of sub-adults represented between 40–50% of the total recoveries for each banding state. Differential recoveries of sub-adults were not at a specific latitude for all states combined. We did find geospatial (i.e., latitudinal) unique recovery locations between age classes based on state of banding with the exception of South Dakota. Sub-adults banded in Oklahoma, Kansas, and Nebraska were recovered north of banding latitude in more statistically unique areas compared to adults (Figures 3.1–3.3). Oklahoma-banded sub-adult hot spot (99% confidence) covered the largest total area latitudinally, including Nebraska, South Dakota, North Dakota, and Manitoba. Oklahoma-banded adult recovery also covered the largest total area, including differential recovery in Oklahoma, Kansas, Arkansas, and portions of Nebraska, Missouri, Colorado, and Texas. Kansas-banded differential sub-adult recovery was focused in Minnesota and Manitoba while differential adult recovery remained in Kansas. Nebraska-banded sub-adults had the smallest concentration of differential recoveries including hot spots in

South Dakota, Minnesota, Manitoba, and Saskatchewan. Nebraska-banded differential adult recovery remained included 2 unique hot spots, both in Nebraska.

Geese banded in South Dakota were harvested in 11 states and 2 Canadian provinces, but there was no spatial difference in harvest locations between adults and sub-adults (Figure 3.4). While South Dakota banded adults and sub-adults were recovered on a large latitudinal gradient, there were no unique sub-adult or uniquely adult recovery regions. Recoveries of adult geese banded in North Dakota were differentially recovered along the Missouri river corridor in Iowa and Nebraska (Figure 3.5). The North Dakota-banded differential sub-adult recovery hot spot was south of the adult recovery hotspot, focused in Kansas and Missouri.

The number of state-specific recoveries affected the resolution of the hot spot analysis. For example, Nebraska Game and Parks Commission banded, and therefore recovered (n = 2,798), the greatest number of geese that revealed 5 unique sub-adult recovery concentrations statistically different from adults. Oklahoma-banded recoveries (n = 336) showed the same latitudinal sub-adult recovery pattern but on a coarser scale. While the interpretation remains the same, we are unable to see focal areas where sub-adult geese are recovered differently than adults because of limited banding and recovery records.

Discussion

Large-scale molt migration has important implications for our understanding of ecological theory. Molt migrating geese compete with northern resident and migratory geese for resources and space (Ankney 1996, Abraham et al. 1999). When molt migrants are out competed by northern residents, migrants may explore new territory. This added pressure at northern latitudes has already resulted in resident geese outnumbering migratory geese in North America (USFWS 2006). Additional successful molt migrations by southern flocks may lead to new resident populations of Canada geese, especially if annual survival increases. Traditionally migrant and resident geese are managed separately but this ongoing population mixing will create challenging management situations that are expected to become more complex (USFWS 1999).

Understanding how resident Canada geese are recovered differently is important for both our evolutionary understanding of molt migration and management of increasing resident populations. Sub-adult resident Canada geese are recovered spatially different from adult geese in northern latitudes. Adult geese are recovered different spatially than sub-adults in southern latitudes. These results suggest sub-adult geese undergo unique movements (i.e., molt migrations) compared to adults, especially when banded as residents in southern latitudes.

Spatially different recovery of adults was concentrated at original banding latitude, when compared to sub-adults, for all states excluding North Dakota. In North Dakota, differential sub-adult recovery latitude was south of original banding latitude and south of the differential adult recovery hot spot. We believe this unique pattern is due to leapfrog migration. Leapfrog migration is a movement where northern flocks (i.e., sub-adults that molt migrated) migrate south beyond other flocks (i.e., resident adults) to form the most southerly group during fall and winter (68% of all recoveries; Boland 1990). This additional movement is more energetically expensive than remaining closer to the snow line and previous studies have shown flocks that are forced to leapfrog have reduced survival and increased recovery (Newton 2006). The sub-adult flocks are forced to migrate further south, to previously unknown areas, because of socially dominate adult flocks. As such, North Dakota-banded adult geese are harvested further north than sub-adults.

While harvest location is not a perfect proxy for movement, band recoveries represent the largest dataset of migratory bird locations in North America. Hot spot analysis methods can be applied to other waterfowl species or any banded bird group with robust recovery sample sizes or long-term banding programs to understand differential movement between sample groups (i.e., control group vs. experimental group, before-after-control-impact study design, etc.). Results from hot spot analysis can be used to form groups to test the demographic effects of differential movement. Future studies on resident Canada geese should consider the effect of recovery location (i.e., region) on survival at the statewide and flyway scale. While we present evidence of differential sub-adult movement, we did not estimate the affect movement has on survival or recovery.

Traditional thinking and prior research suggest these differential molt migration movements should increase survival (Salomonsen 1968). Rapid human urban and suburbanization in the past 40 years has coincided with increasing total number of urban-dwelling resident Canada geese (Conover and Chasko 1985, Atlantic Flyway Council 2011, USDA APHIS 2015). Increased resident goose abundance could be a result of two factors, increased habitat availability because of human population sprawl or an increase in survival of urban-dwelling resident Canada geese (i.e., non-molt migrating geese; Holevinski et al. 2007). Molt migration in the modern landscape may decrease survival instead of increasing it, as we previously thought (Zicus 1981, Lawrence et al. 1998). Additionally, molt-migrating geese from southern states will put an increasing demand for resources in northern molting areas. Eventually, this may create the same density-dependent environment that geese are avoiding by molt migrating. This may further reduce the perceived molt migration advantage that is already under question in the modern landscape. While there is no evidence to suggest there are density-dependent resource shortages in molting areas today, there is little to no research focusing on the growing issue.

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Table 3.1 Resident Canada goose recoveries (banded as hatch-year only) by banding state for 2012–2019, eastern tier Central Flyway, USA.

State	Sub-adult	Adult	Total Recoveries
Oklahoma	152	184	336
Kansas	367	550	917
Nebraska	1362	1436	2798
South Dakota	1006	964	1970
North Dakota	741	797	1538
Total	3628	3931	7559

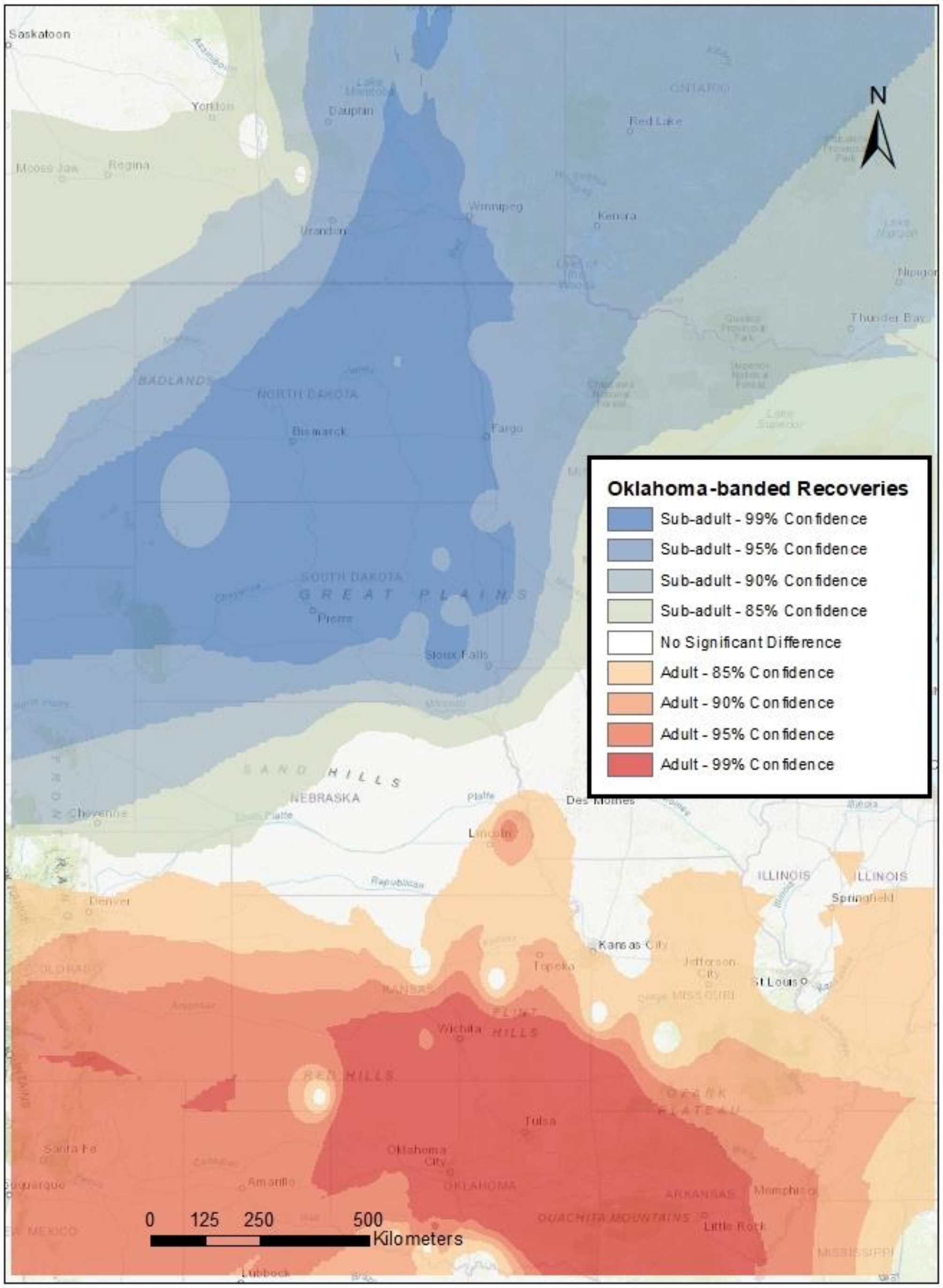

Figure 3.1 Optimized hot spot analysis and inverse distance weighting of differential age class recovery for Oklahoma-banded sub-adult and adult resident Canada geese, 2012–2019, USA.

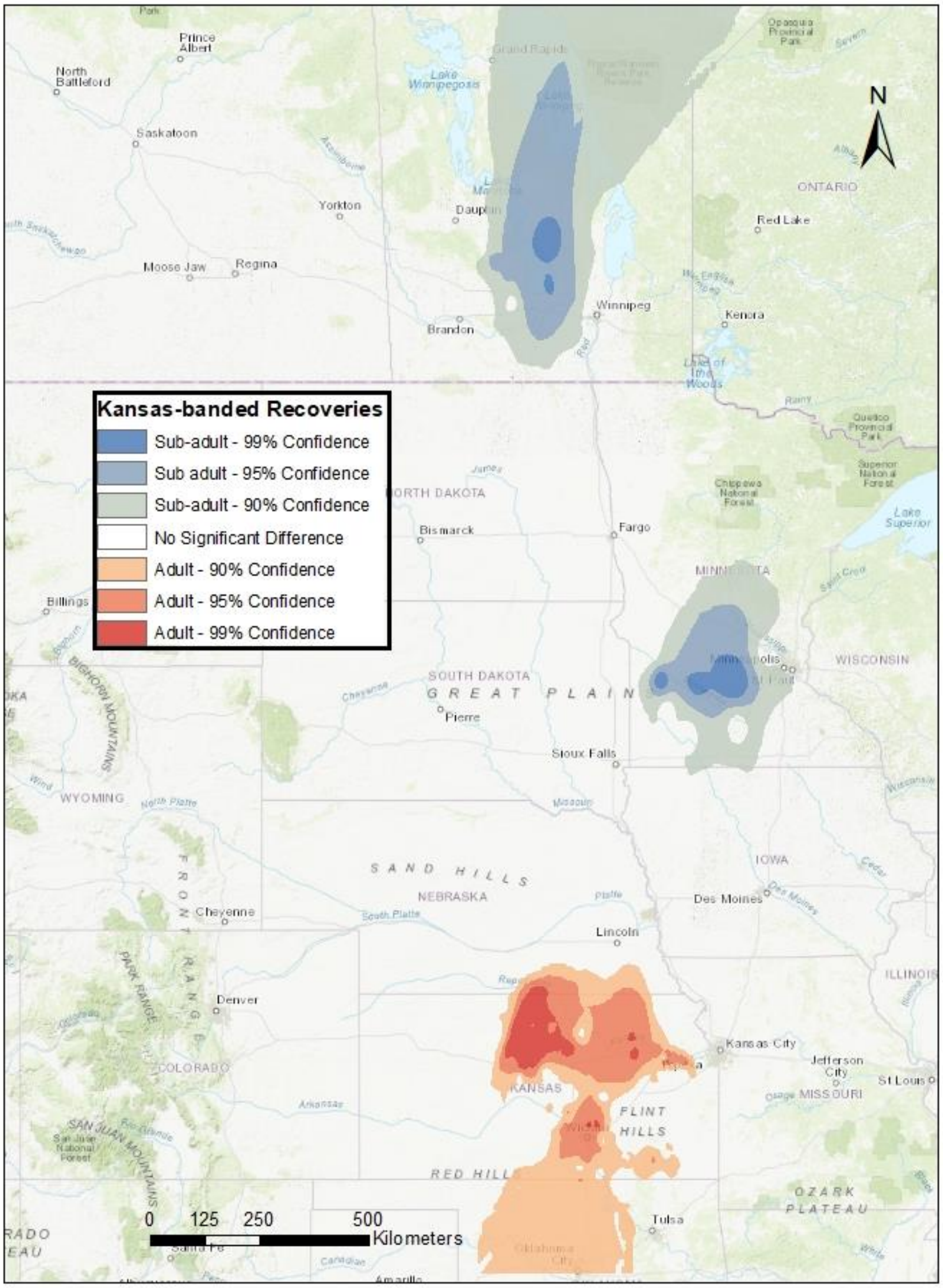

Figure 3.2 Optimized hot spot analysis and inverse distance weighting of differential age class recovery for Kansas-banded sub-adult and adult resident Canada geese, 2012–2019, USA.

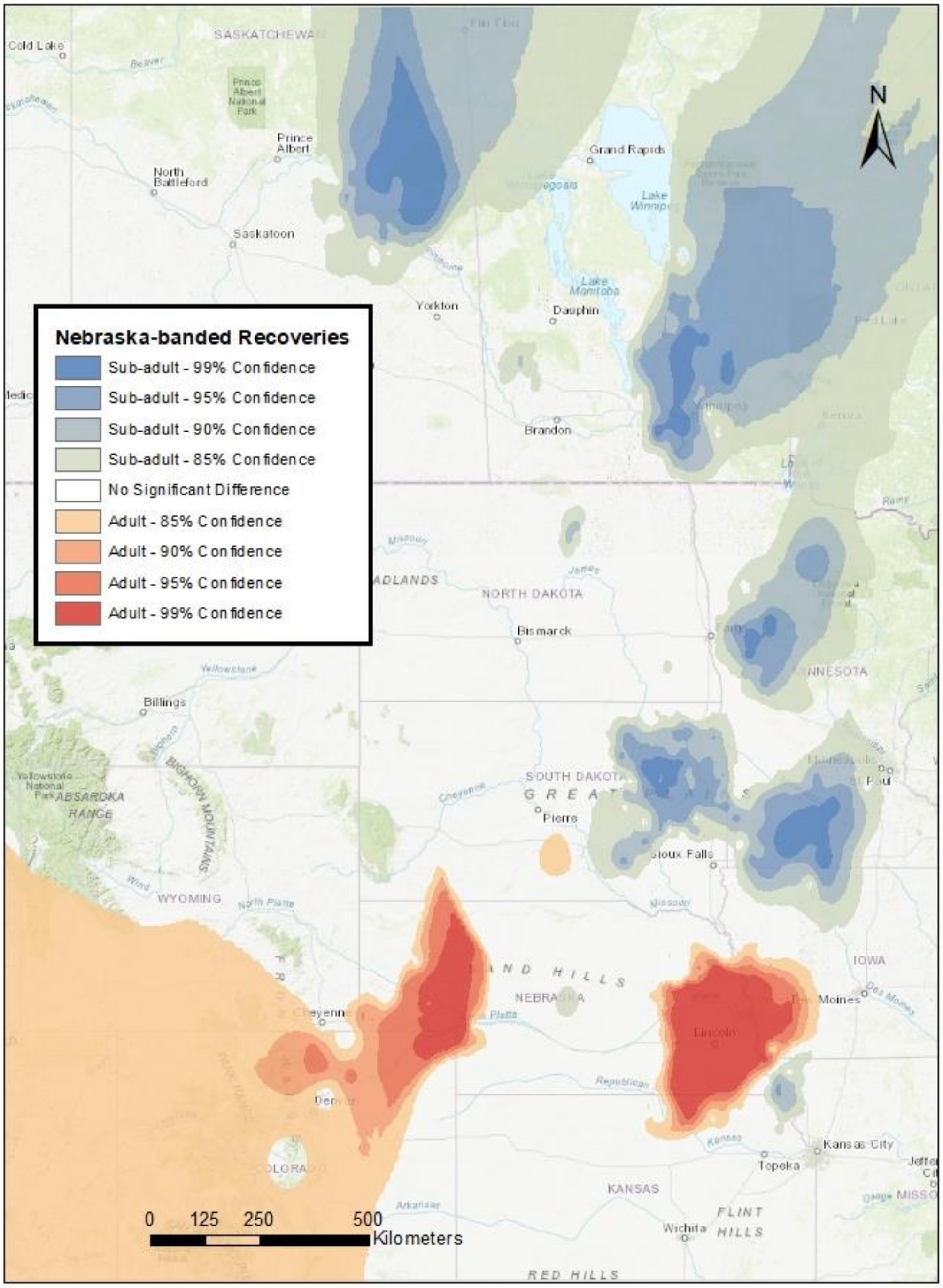

Figure 3.3 Optimized hot spot analysis and inverse distance weighting of differential age class recovery for Nebraska-banded sub-adult and adult resident Canada geese, 2012–2019, USA.

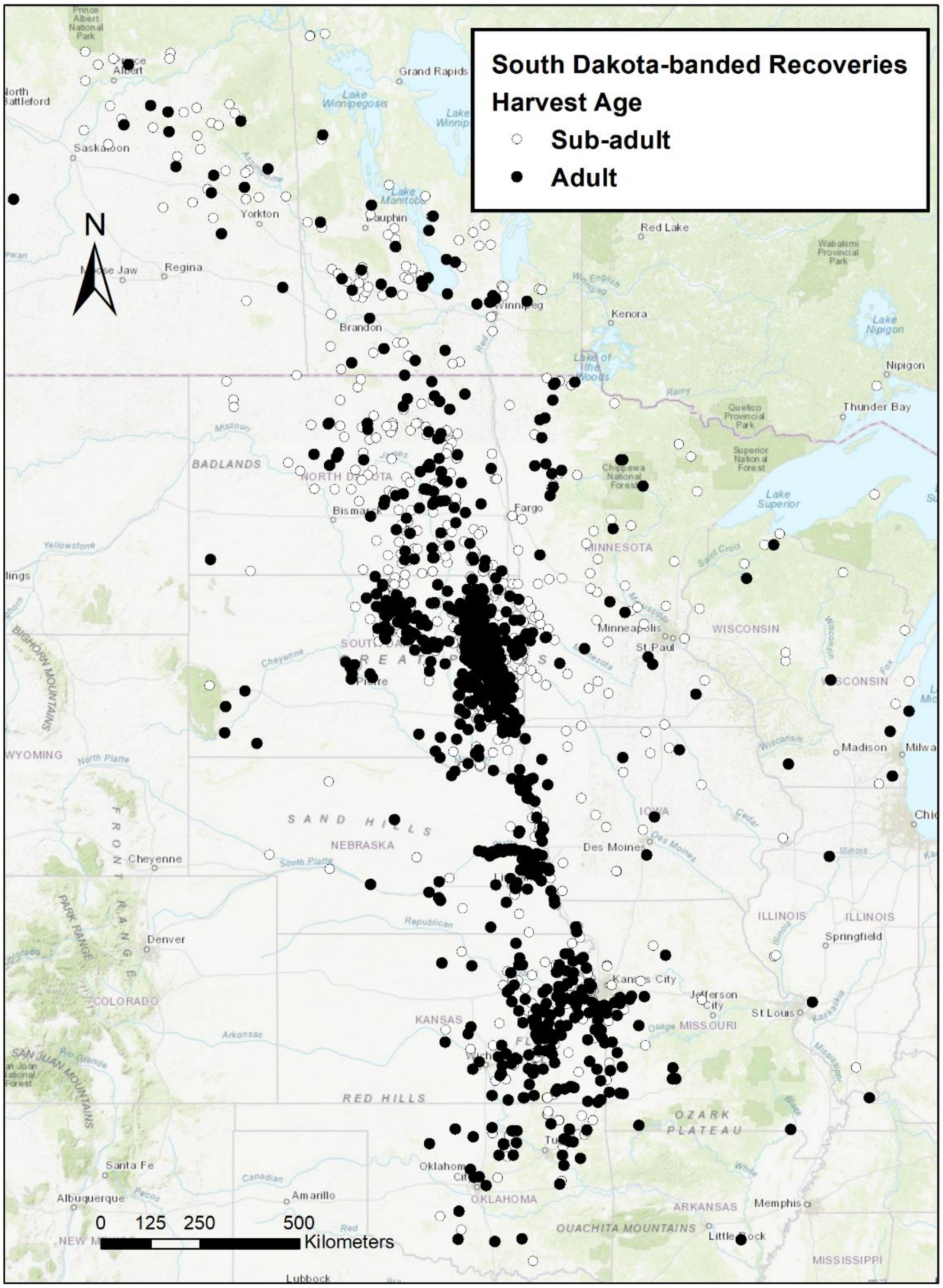

Figure 3.4 South Dakota-banded sub-adult and adult resident Canada goose recovery locations, 2012–2019, USA.

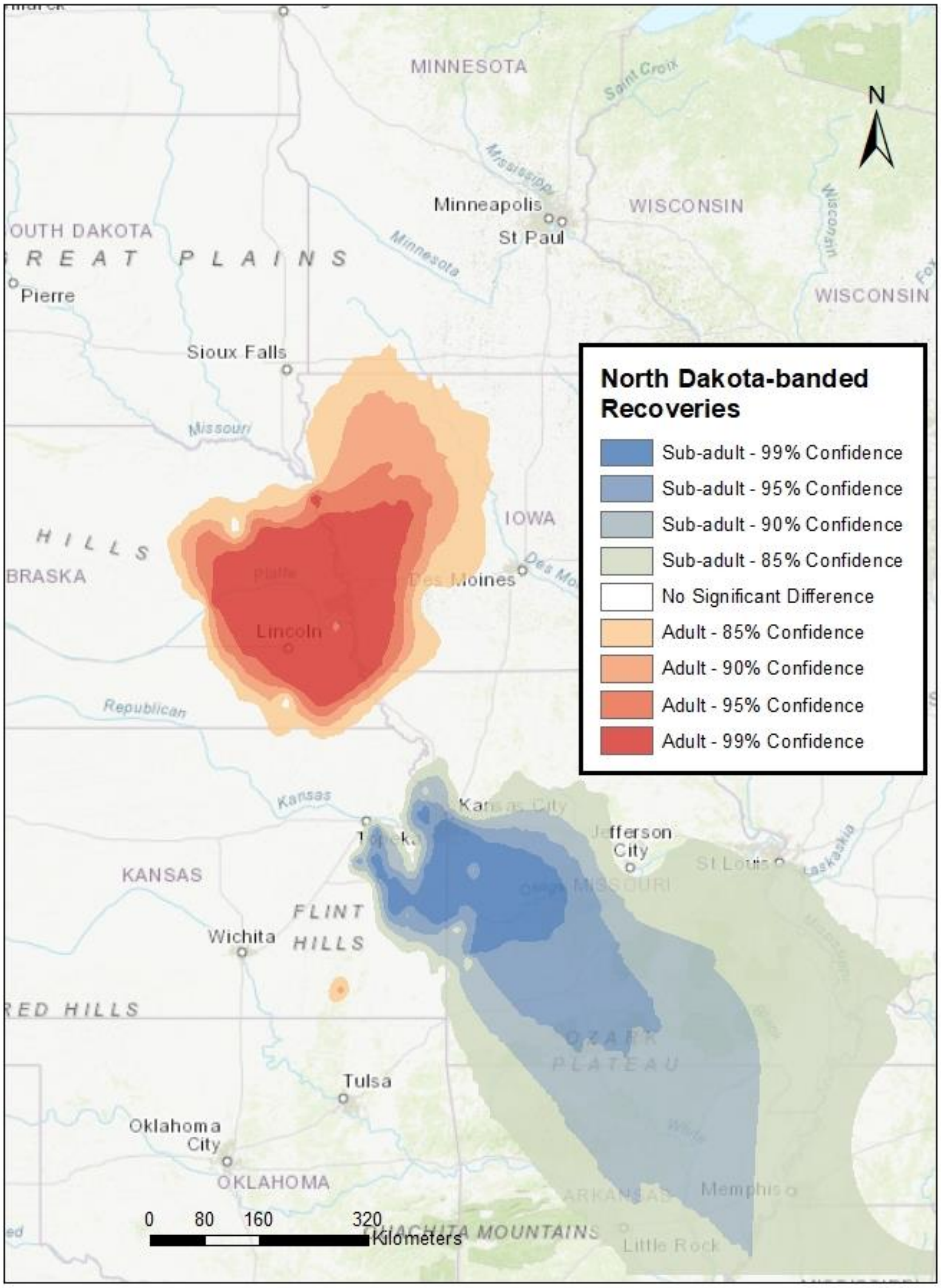

Figure 3.5 Optimized hot spot analysis and inverse distance weighting of differential age class recovery for North Dakota-banded sub-adult and adult resident Canada geese, 2012–2019, USA.