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Survival, Abundance, and Geographic Distribution of Temperate-Nesting Canada Geese (Branta canadensis) in Arkansas

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ABSTRACT

Temperate-nesting Canada geese in Arkansas have grown in abundance and range since reintroduction in the 1980s. The Arkansas Game and Fish Commission uses harvest and other methods to maintain the population at desired levels. However, continued management of temperate-nesting geese requires knowledge of the population's demographics and current range to help establish quantifiable management goals.

To assess the need and effect of changing hunting regulations, survival and recovery rates and abundance were estimated for this population. Annual survival rates of temperate-nesting Canada geese banded and recovered in Arkansas from 2005 to 2011 were estimated using the Burnham joint live-dead recovery model in program MARK. Candidate models were created to allow survival to vary by age (adult, young), time (year), and potential hunting pressure (pre- vs. post-liberalization). The abundance of temperate-nesting Canada geese in Arkansas from 2002-2011 was estimated using the Lincoln Index and either an unadjusted Lincoln Index, using a Mississippi Flyway Canada goose harvest rate, or an adjusted Lincoln Index, using a regional harvest rate estimate. Target harvest rates based on the Potential Biological Removal framework were estimated for a range of recovery factors associated with different potential management strategies using model-averaged survival rates and unadjusted Lincoln Index estimates. Despite recent relaxed hunting regulations, neither annual survival rates nor abundance of temperate-nesting Canada geese in Arkansas have declined.

Range from 2004-2012 was estimated using volume contour maps from citizen science observations using eBird and hunter recovery locations from the U.S. Geological Survey Bird Banding Laboratory. Dispersal of temperate-nesting Canada geese banded and recovered in Arkansas was examined. Emigration, molt migration, and immigration between Arkansas and other states and provinces was examined using geese banded in Arkansas and recovered elsewhere and geese banded elsewhere and recovered in Arkansas. Emigration and immigration interactions were greatest between Arkansas and Missouri. Molt migrant interactions were greatest between Arkansas and Manitoba and Minnesota. Factors explaining molt migration/emigration were examined, and both age and sex were the best predictors. Overall, geographic analysis indicated the range of temperate-nesting Canada geese in Arkansas is expanding, but individual geese do not frequently move long distances from banding sites.

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DEDICATION

This thesis is dedicated to my grandfather, William O'Neal Prescott Sr., for sitting me down by the window when I was young to watch the birds at his many feeders and inspiring in me such great wonder and love for nature.

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INTRODUCTION

Temperate-nesting Canada geese

Temperate-nesting Canada geese (*Branta canadensis*) pose an interesting conundrum for waterfowl managers throughout the Atlantic and Mississippi Flyways. Giant Canada geese (*B. c. maxima*), the subspecies of Canada goose from which temperate-nesting populations developed, simultaneously represent a highly successful reintroduction effort and an increasing nuisance across their range.

Giant Canada geese formerly had the largest nesting range of any North American goose, with an estimated pre-colonial breeding range covering the Great Plains from central Alberta to southeastern Missouri (Hanson 1965). However, like many other avian species in the Great Plains, unregulated hunting, egg gathering, and wetland habitat destruction led the giant Canada goose population into precipitous decline (Hanson 1965). By the early twentieth century, no less than six authors declared the giant race of Canada geese extinct, and debate over the subspecies' existence continued for nearly three decades (Hanson 1965).

By the 1940s, wildlife biologists confirmed the presence of several breeding populations in Minnesota, North and South Dakota, and Canada (Nelson and Oetting 1998). Waterfowl managers across the Mississippi and Atlantic Flyways obtained individuals from these populations to establish or re-establish resident giant Canada geese in their own states, and reintroduction programs continued through the 1990s (Mississippi Flyway Council 1996; Atlantic Flyway Council 1999). The success of reintroduction prompted the need for flyway-wide strategic planning for management of the new populations. The Giant Canada Goose Committee of the Mississippi Flyway Council (1996) met in 1996 to establish management objectives and to describe strategies for achieving each objective. The ultimate goal of the committee was to create guidelines to allow the flyway "to manage the population of giant Canada geese in the Mississippi Flyway at a level that provides maximum recreational opportunities consistent with social acceptability." In addition to then-current estimates of abundance and geographic range, the Mississippi Flyway Council (1996) defined abundance goals for each state and province, outlined standard harvest management objectives, and described potential experimental harvest strategies such as early hunting seasons. While harvest was and remains a preferred method of population management, the Mississippi Flyway Council (1996) also acknowledge the increasing prevalence of geese in urban habitats and of nuisance goose complaints in many reintroduction areas, and the committee provided strategies for lethal and non-lethal population control in regions where harvest is either not a viable option or has been ineffective at maintaining local goose subpopulations. As reintroduced populations throughout the Mississippi Flyway have grown, several states and provinces have adopted many of the Mississippi Flyway Council (1996) strategies, including egg and nest destruction, translocation or removal of geese, and the use of early hunting seasons designed to minimize harvest of migratory populations while targeting temperate-nesting populations.

Temperate-nesting Canada geese in Arkansas

The Arkansas Game and Fish Commission (AGFC) began reintroduction of temperate-nesting Canada geese for recreational hunting and viewing opportunities in 1981 (Moser 1996). The objective of reintroduction was to establish a self-sustaining resident population of geese capable of supporting an annual harvest (Moser 1996; Yaich 1994) with a goal of 25,000 geese in the state by 2006 (Mississippi Flyway Council 2006). The initial population consisted of 430 giant Canada goose eggs and 11 goslings from Canada. The University of Arkansas-Fayetteville and Tyson Inc. cared for the eggs and goslings until they reached 7 weeks of age, when the AGFC would release the geese. Release occurred first at holding pens at Holla Bend National Wildlife Refuge along the Arkansas River, and later these birds were moved to the Lake Dardanelle area. Of the initial 444 geese, 248 were released (Yaich, 1994). The AGFC obtained an additional 432 eggs in 1982, which were incubated at Valmac Hatchery in Russellville, Arkansas, and 202 of which the AGFC later released. To supplement the young geese, the AGFC brought mixed-age geese to Arkansas in 1982 and 1983 from Ontario, Noxubee National Wildlife Refuge in Mississippi, and Northern Illinois. The AGFC switched from stocking programs to within-state breeding programs for financial reasons, bringing in a final group of out-of-state geese in 1985. The final release of captive geese from hatching and breeding facilities occurred in 1987 (Yaich, 1994).

By the 1990s, amidst reports of a flourishing population, the AGFC developed a strategic plan including proposals for banding and monitoring programs and identifying needs for formal abundance and range estimates and research on the effects of harvest on survival (Moser 1996). Banding of Canada geese in Arkansas during the summer flight-feather molt began in 1988, though efforts remained sporadic through 2000. Banding began in earnest in the early 2000s, and the AGFC has expanded efforts to include locations throughout the Arkansas River Valley and northwestern and southwestern Arkansas. Harvest of Canada geese in Arkansas began with a 14-day experimental season in 1992 with a bag limit of 1 in the northwestern region (Moser 1996). The AGFC has since liberalized hunting regulations to include more regions, longer normal seasons with larger bag limits, and a special early season in September designed to increase hunting opportunity and stabilize the temperate-nesting Canada goose population (Moser 1996).

Objectives

As the AGFC considers future objectives and management strategies for the reintroduced temperate-nesting Canada goose population, decisions informed by formal research on abundance, survival, recovery, distribution, and dispersal of geese in Arkansas will be necessary. I therefore conducted the following studies to explore the demographics and geographic distribution of Arkansas's temperate-nesting Canada geese and to provide insight for management of the population.

The objectives of my studies were: 1) to estimate annual survival and hunter recovery rates in Arkansas from 2005-2011 and to determine whether annual survival rates have decreased with liberalized hunting regulations; 2) to estimate the abundance of temperate-nesting Canada geese in Arkansas from 2002-2011 and to project future abundance; and 3) to estimate the annual geographic range of temperate-nesting Canada geese in Arkansas from 2004-2012 and predict future range based on past and present range and dispersal.

Chapter One of this thesis examines my first and second objectives and is intended for submission for publication to *Waterbirds* or *Journal of Wildlife Management* with Dr. David G. Krementz and Luke W. Naylor as coauthors. Chapter Two examines my third objective and is not intended for submission for publication, though I maintained the same formatting and style as Chapter One.

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CHAPTER I

SURVIVAL AND ABUNDANCE OF TEMPERATE-NESTING CANADA GEESE (*BRANTA CANADENSIS*) IN ARKANSAS

M. E. Ronke, D. G. Krementz, and L. W. Naylor

ABSTRACT

The reintroduced temperate-nesting Canada goose (*Branta canadensis*) population in Arkansas was thought to have grown in range and abundance. Based on this apparent population growth, harvest regulations in Arkansas were liberalized in 2007. To assess the need and effect of these regulation changes, survival and recovery rates and abundance were estimated for this population. Annual survival rates of temperate-nesting Canada geese banded and recovered in Arkansas from 2005 to 2011 were estimated using the Burnham joint live-dead recovery model in program MARK. Candidate models were created to allow survival to vary by age (adult, young), time (year), and potential hunting pressure (pre- vs. post-liberalization). The top two models both included only age effects. The estimated annual survival rate of the top model was 0.759 (SE=0.0151) for adult geese and 0.847 (SE=0.0210) for first-year geese. The abundance of temperate-nesting Canada geese in Arkansas from 2002-2011 was estimated using the Lincoln Index and either an unadjusted Lincoln Index, using a Mississippi Flyway Canada goose harvest rate, or an adjusted Lincoln Index, using a regional harvest rate estimate. The unadjusted Lincoln Index estimated 311,248 (SE=49,192) geese in Arkansas in 2011 while the adjusted Lincoln Index estimated 226,279 (SE=31,858) geese in Arkansas in 2011. Target harvest rates based on the Potential Biological Removal framework were estimated for a range of recovery factors associated with different potential management strategies using model-averaged survival rates and unadjusted Lincoln Index estimates. Target harvest rates ranged from 0.051 (SE=0.0094) to 0.102 (SE=0.0187). Despite recent relaxed hunting regulations, neither annual survival rates nor abundance of temperate-nesting Canada geese in Arkansas have declined.

INTRODUCTION

Management of Canada geese (*Branta canadensis*) has evolved over the past decades, especially with the reintroduction of the giant Canada goose (*B. c. maxima*) throughout the central and eastern United States (Nelson 1963; Nelson and Oetting 1998). Management of these temperate-nesting populations is a unique challenge because of their continuing growth and their expansion from the initial rural reintroduction sites into suburban habitats (Ankney 1996). Population estimates of temperate-nesting Canada geese in the Mississippi Flyway suggest rapid increases in temperate-breeding individuals and a leveling out of subarctic-breeding individuals (Leafloor 2003). The harvest management objective for temperate-nesting Canada geese, as identified in the Mississippi Flyway Council (1996) Giant Canada Goose Committee's Management Plan, is to "Provide maximum harvest opportunity for Giant Canada geese that is consistent with the population objectives…, the objectives for other [migratory] Canada goose populations in the Flyway…,and the control of over-abundant goose populations in areas with high human/goose conflicts."

As reintroduced populations throughout the Mississippi Flyway have grown, several states and provinces have instituted special early season harvests in particular regions or statewide. Special seasons occur at the end of the nesting season to minimize harvest of migratory populations while targeting temperate-nesting populations. The first early seasons in the Mississippi Flyway occurred in Michigan and Illinois in 1986. Minnesota followed in 1987, and by 1995 at least 8 states and Ontario had incorporated some form of early harvest (Mississippi Flyway Council 1996).

The Arkansas Game and Fish Commission (AGFC) reintroduced a population of temperate-nesting Canada geese into the Western Arkansas River Valley beginning in 1981 with continuing supplements through 1983 (Moser 1996). The objectives of reintroduction were to establish a self-sustaining resident population of geese capable of supporting an annual harvest (Moser 1996; Yaich 1994) with a goal of 25,000 geese by 2006 (Mississippi Flyway Council 2006). After early setbacks, the population flourished in the late 1980s (Moser 1996). The AGFC developed a strategic plan in the 1990s outlining needs for banding, monitoring, estimation of population abundance, and research into the effects of harvest on survival, movements and population abundance (Moser 1996).

Banding of Canada geese in Arkansas began in 1988 with only 128 bands being attached and, through 2000, banding efforts were sporadic or non-existent. James (2003) attempted to calculate formal estimates of survival and abundance of temperate-nesting Canada geese in Arkansas based on 1988-2000 banding data but sample sizes were insufficient to achieve good model fit.

Canada goose hunting in Arkansas was first opened in 1992 with a season length of 14 days in northwest Arkansas (originally the “West Zone”) with a bag limit of 1 (Moser 1996). Harvest regulations have since been liberalized, and now include an early season akin to other states in the Mississippi Flyway. Currently, the early season length is 15 days with a bag limit of 5, and the regular season length is 84 days with a bag limit of 2 (Table 1). The AGFC implemented the relaxed season length and bag limits to increase hunting opportunity and to stabilize the purported temperate-nesting Canada goose population growth rate (Moser 1996).

Estimates of vital rates of temperate-nesting Canada geese in Arkansas may help better inform future management. Potential Biological Removal (PBR), a fixed harvest-rate strategy, is one method of assessing harvest management options (Garrettson 2007; Runge *et al.* 2004). The PBR framework based on maximum intrinsic growth can produce estimates of total allowable take and subsequent annual allowable take rates (Garrettson 2007). Recovery factors based on management goals applied to the annual allowable take rate calculations provide target harvest rates for populations (Garrettson 2007). Target harvest rates can inform regulatory decisions and present a range of regulatory options for adaptive management of game species (Garrettson 2007; Runge *et al.* 2004).

The objectives of our study were: 1) to determine whether annual survival rates of temperate-nesting Canada geese in Arkansas have decreased with the introduction of the early season; 2) to estimate the current abundance and project future abundance of temperate-nesting Canada geese in Arkansas; and 3) to estimate target harvest rates based on Potential Biological Removal for temperate-nesting Canada geese in Arkansas.

METHODS

The AGFC banded temperate-nesting Canada geese in Arkansas annually during flight-feather molt, typically the last week of June and first week of July from 1999-2012 at locations in the Arkansas River Valley and southwestern and northwestern Arkansas, including public parks like Lake Dardanelle State Park, AGFC facilities like Andrew H. Hulsey State Fish Hatchery, and private farm ponds (Fig. 1). Geese nesting at these locations were herded into enclosures then individually sexed, aged, and banded (Coluccy 1996). From 1999-2012 the AGFC banded approximately 13,000 geese with federal aluminum leg bands. We retrieved banding and recovery data for the years 2001 to 2011 from U.S. Geological Survey Bird Banding Laboratory (BBL) in October 2012 for analysis. We used only normal, wild hunter harvested band recoveries from Arkansas. We retrieved data on live recaptures of banded geese for the years 2006-2011 from the AGFC in August 2012.

Survival

We estimated annual survival rates using the Burnham joint live-dead capture-mark-recapture model (Burnham 1993) in Program MARK (White and Burnham 1999). To incorporate live recapture data, we included only 2006-2011 banding and recovery data.

We estimated four parameters in the Burnham model: 1) annual survival rate from time i to i+1 (S_i); 2) annual recapture probability given alive at i (p_i); 3) annual conditional reporting rate or recovery probability at i given dead at i+1 (r_i); and 4) annual fidelity probability to area of capture (F_i) (Burnham 1993). As only annual survival rates were relevant to study objectives, we assigned treatments to each of the three other parameters, varying p by year [year] and holding r constant [.]. We held the parameter F constant for young geese considered locals (from years zero to one) and for adults. We assigned a different F for young geese in the molt migrant years (from years one to two and years two to three) because we expected this cohort to have lower site fidelity than adults and locals since subadult molt migrants may not all return to the breeding grounds after the migration [moltmig] (Zicus 1981). The resulting base model was S[x]p[year]r[.]F[moltmig] where S[x] represents the different treatments of the annual survival rate parameter. We created treatments of survival based on combinations of potential hunting pressure, age, and individual year to create a set of candidate models (see below).

The survival models examined the effects of the potential hunting pressure in the year of recovery. We assigned recovery years to two categories, pre-liberalization (2005-2006) and post-liberalization (2007-2011) based on the introduction of the September hunting season in 2007 thinking survival rates would decline after this season was introduced. We designated models incorporating the effect of the early hunting season as S[hunt].

We incorporated age into the models in two different ways. We excluded 84 geese with an age of "unknown" from the models and categorized the remaining geese either as "adult" or as “young”, including geese identified as both “hatch-year” and “local”. The first model used the traditional 2-age approach. The 2-age model assigns different annual survival rates for adult and young geese in their first year after banding. Young geese then adopt the adult annual survival rate after their first year. We designated models incorporating the 2-age approach as S[2age]. The second age model followed the [B3age] model described by Heller (2010). The model still uses two age groups but assigns different survival values to young geese in their first three years after banding so as to account for potential differences associated with subadult molt migrations. These cohorts migrate northward around May-June to molt and return to temperate regions in August-September (Zicus 1981; Luukkonen *et al.* 2007). Molt migrations complicate parameter estimation because molt migrants are not included in breeding season banded samples and may not be susceptible to early harvest in Arkansas. Young geese have one annual survival rate for the first year after banding and another for the second and third year after banding before adopting the adult annual survival rate in their fourth year. We designated models incorporating the 3-age approach as S[3age].

We designated models incorporating both age and hunting season as S[2age*hunt] or S[3age*hunt]. We designated models incorporating both age and individual year as S[2age*year] or S[3age*year]. We also created a null model in which all annual survival rates were held constant across age and time, and we designated the null model as S[.]. We created a total of seven candidate models (Table 2). Sample Parameter Index Matrices (PIMs) for annual survival rate estimation may be found in Appendix A.

We used Akaike’s Information Criterion (AIC) (Akaike 1973) to select among candidate models. We used Quasi-likelihood (QAIC) to account for overdispersion as Canada geese are social and do not display independent fates (Lebreton *et al.* 1992; Burnham and Anderson 1998).

We ranked models using the resulting ΔQAIC values and selected the model with the lowest QAIC as the model most plausible given the data. We considered all models within ΔQAIC ≤ 2.00 acceptable models for the data to account for model-selection uncertainty. We then determined model averages for annual survival rates of adult and young geese and used the delta method to determine the variance of the model averages (Seber 1982; Powell 2007).

To further relate the annual survival rates to hunter recoveries of Canada geese, we calculated the annual hunter recovery rate, *f*, from the Brownie parameterization (Brownie *et al.* 1985). Recovery probability, *f*, relates to survival, *S*, and the conditional reporting rate, *r*, from the Burnham model through the formula $f_i = r_i\,(1 - S_i)$ (Burnham 1993). For all models we calculated f_i, and we calculated the variance of f_i using the delta method (Seber 1982; Powell 2007).

Abundance

We used the Lincoln Index to estimate temperate-nesting Canada goose abundance in Arkansas (Lincoln 1930). We used the reporting rate of Zimmerman *et al.* (2009) for the Mississippi Flyway Giant Canada goose and Arkansas harvest totals from the Cooperative State-Federal Migratory Bird Harvest Information Program (HIP) hunter surveys in the Lincoln Index (Fronczak 2012). We applied the 0.61 Canada goose correction factor reported by Padding and Royal (2012) to the HIP harvest totals to account for survey bias. To address the potential for migratory Canada geese included in the corrected HIP harvest totals, we derived a percent of temperate-nesting geese. We used BBL data on all banded Canada geese harvested in Arkansas, including those geese banded in other states, to determine what percent of geese recovered in Arkansas originated in Arkansas ($\bar{x}$=93.6%, SE=4.59%). We then applied the percent of Arkansas geese to the corrected HIP harvest totals. We fit a best fit power curve using the exponential population growth formula to the Lincoln abundance estimates from 2002-2011 to predict the growth of goose populations in Arkansas. We used the delta method (Seber 1982; Powell 2007) to calculate variance for each year's Lincoln abundance estimate.

The Lincoln Index uses a harvest rate derived from the direct recovery rate of banded geese. Initial abundance estimates using a harvest rate derived from the Arkansas direct recovery rate of banded geese produced a statewide abundance estimate for 2011 of over 300,000 individuals, nearly 20% of the 1.6 million temperate-nesting Canada geese estimated for the Mississippi Flyway in 2011 (Fronczak 2012). One possible explanation of the high initial estimate relates to the harvest rate of Arkansas Canada geese. The harvest rates derived from the Arkansas direct recovery rate ($\bar{x}$=0.034, SE=0.005) are well below the Mississippi Flyway average harvest rate ($\bar{x}$=0.167, SE=0.008) for Giant Canada geese (Zimmerman *et al.* 2009). Therefore we created an adjusted Lincoln estimate using a regional estimate of harvest rate ($\bar{x}$=0.055, SE=0.007) based on the average direct recovery rates of Arkansas, Kentucky, Missouri Oklahoma, and Tennessee, states thought to have similar temperate-nesting Canada goose population characteristics (James 2003).

Preliminary Lincoln estimates suggested large fluctuations between yearly abundance estimates. We sought to determine whether these fluctuations were a result of changes in harvest pressure or changes in productivity as a result of environmental variables. To examine the effect of HIP hunting pressure on the Lincoln abundance estimates we determined correlations between total hunters and days afield and harvest estimates from HIP reports (Fronczak 2012). To examine environmental variables, we assumed changes in productivity due to flooding or drought would be consistent across Arkansas and neighboring states. We therefore compared harvest totals for Missouri, Mississippi, and Oklahoma for 2002-2011 with Arkansas harvest totals to determine if fluctuations in harvest were consistent across multiple states.

Target Harvest Rates

We used the PBR allowable take rate framework Garrettson (2007) described to estimate target harvest rates (h^*) for potential management objectives for temperate-nesting Canada geese in Arkansas. We calculated h^* for six different recovery factors (F_R=1, 1.25, 1.5, 1.75, and 1.99). F_R values between 1 and 2 are appropriate for nuisance species and management objectives of maintenance (F_R =1) or reduction (1< F_R <2) of population size (Runge *et al.* 2009). We derived the maximum intrinsic growth rate (r_{max}) for 2005-2011 for geese in Arkansas from estimates of the annual survival rate in the absence of harvest (S_o) and the annual recruitment rate at low densities. We derived S_o from our model-averaged survival (S) and hunter recovery rates (f) for adults and juveniles, the standard crippling loss rate of 0.20 (Anderson and Burnham 1976; Martin and Carney 1977), and the reporting rate of Zimmerman *et al.* (2009) for the Mississippi Flyway Giant Canada goose. We derived recruitment from harvest age ratios from BBL data, our model-averaged f for adults and juveniles, and our adjusted Lincoln Index abundance estimates. We calculated the variance of S_o for adults and juveniles and the recruitment rate using the delta method (Seber 1982; Powell 2007). We generated 10,000 random replicates of S_o for adults and juveniles and the recruitment rate from normal distributions. We constructed Leslie matrices (Leslie 1945) using the replicated survival and recruitment rates and calculated the associated eigenvalues. We converted the eigenvalues to h^* for F_R=1, 1.25, 1.5, 1.75, and 1.99. We determined the average and standard error of each h^* for each F_R value.

RESULTS

Survival

Both the S[2age] and S[3age] models were equally plausible while neither harvest regulations nor year were important in explaining variation in survival rates (Table 3). In the top models, young survival rate confidence intervals were higher than adult survival rate confidence intervals while subadult and adult survival rate confidence intervals overlapped (Table 4). Although the subadult survival rate point estimate was lower than the young survival rate point estimate, the confidence intervals only barely overlapped (Table 4). The third ranked model S[2age*hunt], while not within ΔQAIC $\leq$ 2.00, was still of interest for estimates of survival before and after introduction of the early season in 2007. Point estimates of young and adult survival rates were higher pre-liberalization than post-liberalization, but confidence intervals overlapped (Table 5).

Model-averaged annual adult survival rates were 0.761 (SE=0.0103) while young survival rates were 0.847 (SE=0.0143). Model-averaged hunter recovery rates (f) were 0.078 (SE=0.0067) for adults and 0.050 (SE=0.0066) for young.

Abundance

The unadjusted Lincoln Index for temperate-nesting Canada geese in Arkansas in 2011 was 189,861 (SE=30,007). The trendline index for 2011 was 333,678 (SE=198,299) and using this trendline index, we project over 460,000 geese by 2020 (Fig. 2).

The Lincoln Index adjusted with the regional average harvest rate for temperate-nesting Canada geese in Arkansas in 2011 was 138,268 (SE=19,433). The trendline index for 2011 was 200,783 (SE=91,063) and using this trendline index, we project over 260,000 geese by 2020 (Fig. 3).

Correlation coefficients (R^2) between total Canada goose harvest in Arkansas and HIP estimates of total goose hunters afield and total days afield were essentially zero (0.006 and

0.009, respectively). Fluctuations in total Canada goose harvest for Arkansas, Kentucky, Missouri, Oklahoma, and Tennessee did not vary in concert, with peaks in some states offset from peaks in other states (Fig. 4).

Target Harvest Rates

Survival in the absence of hunting (S_o) of adult and juvenile temperate-nesting Canada geese in Arkansas were 0.877 (SE=0.0166) and 0.926 (0.0193), respectively. The recruitment rate at low densities was 0.269 (SE=0.0177). The average maximum intrinsic growth rate (r_{max}) of temperate-nesting Canada geese in Arkansas from 2005-2011 was 0.103 (SE=0.0189). Average target annual harvest rates ($h*$) ranged from 0.051 (SE=0.0094) for maintenance of the population (F_R=1) to 0.102 (SE=0.0187) for substantial reduction of the population (F_R=1.99) (Table 6).

DISCUSSION

The AGFC reintroduction of temperate-nesting Canada geese to Arkansas has met their stated goals of developing a self-supporting population and providing recreational hunting opportunity (Moser 1996; Yaich 1994). However, the continued success and maintenance of the reintroduced population requires management informed by formal estimates of demographics. We therefore quantified the population’s abundance and annual survival to fill knowledge gaps regarding Arkansas’s temperate-nesting Canada geese and estimated target harvest rates for potential management goals.

Future management of Arkansas’s temperate-nesting population requires estimates of past, current, and projected future abundance. The Mississippi Flyway Council (2006) goal for Arkansas by the year 2006 was 25,000 geese. Informal “Agency’s best estimates” for Arkansas range from 3,000 geese in 1993-1994 to 35,000 geese in 2007-2012 (Fronczak 2012). The agency's estimates suggest the AGFC already suspected higher-than-expected abundance in the state by the mid-2000s. Our Lincoln Index abundance estimates indicate the population has far exceeded and continues to exceed both original Mississippi Flyway Council (2006) expectations and agency estimates (Fronczak 2012).

Our abundance estimates suggest the population has grown between 2002 and 2011 with a few fluctuations. We wondered if year-to-year fluctuations, especially in 2006, were a result of differences in harvest pressure or differences in annual production. We believed greater numbers of hunters and days afield could increase total harvest and subsequently decrease abundance in the following years. However, we compared the HIP harvest totals to number of active hunters and to the number of days afield but found no correlations between these variables and the HIP harvest totals, suggesting yearly goose abundance fluctuations may not be feedback from changing harvest pressure. An alternative source of the fluctuations may be changes in production due to environmental patterns such as drought or flooding. We compared Arkansas harvest with harvest in surrounding states to determine if regional environmental changes may have caused differential annual production resulting in simultaneous fluctuations in abundance across several states. However, Arkansas's and surrounding states' harvest totals did not vary in concert, suggesting large-scale environmental factors may not be the source of yearly goose abundance fluctuations either.

In addition to the year-to-year estimates, we fit a smooth trendline to the estimates. Trendline values from our adjusted estimate suggest a current abundance of more than 200,000 geese in Arkansas, nearly six times greater than the informal agency estimate for 2007-2012. In addition, the fitted trendline predicts further increase in abundance.

Arkansas is not alone in high abundance and growth rate estimates of temperate-nesting Canada geese. Of the 14 states and 2 provinces included in the Mississippi Flyway Council (2006) giant Canada goose abundance goals, Arkansas is one of 9 states/provinces to exceed the 2006 goals (Fronczak 2012). Alabama, Illinois, Indiana, Iowa, Manitoba, Minnesota, Mississippi, and Wisconsin all reported larger populations than corresponding Mississippi Flyway Council (2006) goals for 2006, ranging from approximately 4,100 more geese than expected (Alabama) to approximately 126,000 more geese than expected (Minnesota). In the Atlantic Flyway, states have reported similar phenomena of high abundance and growth rates (Atlantic Flyway Council 1999). For example, Georgia experienced an approximately sixteen-fold increase in temperate-nesting Canada geese from 1992 to 1999 (Powell *et al.* 2001), and New Jersey experienced an approximate annual growth rate for temperate-nesting Canada geese of 14% per year (Guerena 2011). In general, patterns of high goose abundance and high population growth rates have become commonplace throughout the range of reintroduced temperate-nesting Canada geese.

In Arkansas, in response to the suspected high abundance and growth rates of the temperate-nesting population, the AGFC liberalized Canada goose harvest regulations. Following the example of other states with reintroduced temperate-nesting Canada goose populations, the AGFC increased season length and bag limits and instituted a special early season in September to increase harvest and to hopefully decrease survival of temperate-nesting geese and subsequently stabilize the population.

As the AGFC continues to evaluate the condition of the Arkansas population of temperate-nesting Canada geese, annual survival rates may provide insight into the relationship between liberalization of harvest and population demographics. James (2003) was unable to produce a formal estimate of survival of temperate-nesting Canada geese in Arkansas due to poor model fit, but did produce models for surrounding states (Kentucky, Missouri, Oklahoma, and Tennessee) for a report to the AGFC. James (2003) created an informal estimate of annual survival for temperate-nesting Canada geese in Arkansas ranging from 0.682-0.776 between 1986 and 2000 based on the surrounding states' survival rates. After the introduction of an early hunting season beginning in 2007 targeting temperate-nesting Canada geese in Arkansas, we expected annual survival rates to decrease. Models incorporating different annual survival rate estimates for pre-liberalization and post-liberalization years were not supported by the data. Rather, only age effects were supported by the data. In addition, estimates of annual survival rates fall within or above the range estimated by James (2003), further suggesting the liberalization of hunting has not yet reduced survival in temperate-nesting Canada geese in Arkansas.

We may gain additional insight about the effect of liberalized hunting on survival from the third-ranked model, S[2age*hunt]. Though the model was not supported by the data, the model produced point estimates indicating a decrease in survival after the introduction of the early season in 2007. However, confidence intervals for these estimates overlapped. These values suggest the early season may reduce survival but has not yet substantially decreased survival for either adult or young geese.

Currently, model averaged recovery rates for temperate-nesting Canada geese in Arkansas are below the Mississippi Flyway average. Heller (2010) estimated Mississippi Flyway average annual recovery rates for adults and juveniles between 0.096-0.115 and 0.081-0.137, respectively. Neither the adult nor the young annual recovery rates for Arkansas fall within these ranges. Furthermore, as previously mentioned, harvest rate estimates for Arkansas and the surrounding states we used for our adjusted Lincoln estimate are below the Mississippi Flyway average harvest rate reported by Zimmerman *et al.* (2009). The discrepancy in recovery rates and harvest rates between Arkansas and flyway averages may indicate northern states, such as Minnesota which has for the past decade harvested more Canada geese than the total harvest of all five states included in our regional harvest rate estimate (Fronczak 2012), are distorting flyway averages. Regional averages based on latitude of annual survival, harvest, and annual recovery may therefore provide more valuable information for state and local management than flyway-wide averages. In addition, estimates of target harvest rates for reduction of the population are approximately double Arkansas harvest rates. The discrepancy in rates suggests Arkansas's current harvest is insufficient to reduce survival and maintain the population at a desirable level.

Other studies exploring survival and recovery rates have similarly concluded current harvest pressure is not effective at preventing further growth of temperate-nesting Canada goose populations. Iverson *et al.* (2013) determined harvest in Ontario was only partially additive for reproductive cohorts and partially compensatory for non-reproductive cohorts. The additive effects on reproductive cohorts may be even less effective at lower latitudes where fertility is typically higher (Hanson 1965). Heller (2010) found evidence supporting the lower latitude effect in Iowa, concluding September seasons had no effect on annual survival rates, instead causing only a temporal shift in recoveries. Special early seasons in metropolitan areas worked to greater effect, but not in all cases. Groepper *et al.* (2012) drew similar conclusions in Nebraska, detecting only a temporal shift in recoveries and no decrease in survival. Alternatively, in Michigan, Luukkonen and Soulliere (2004) found evidence supporting the use of early seasons primarily to reduce pressure on migratory populations, stabilizing temperate-nesting goose numbers while remaining well within harvest guidelines for migratory interior geese. Without encouraging or conclusive evidence of the efficiency of early seasons at reducing survival and increasing recovery of temperate-nesting geese, many authors, Iverson *et al*. (2013), Heller (2010), and Groepper *et al.* (2012) included, now cite the importance of targeting harvest towards individuals of high reproductive value, possibly including geese in urban areas, in addition to standard practices of hunting regulation liberalization.

Urban subpopulations of temperate-nesting Canada geese are not susceptible to harvest—except in rare instances like Iowa's metropolitan seasons (Heller 2010)— and are particularly productive. In Georgia, Balkcom (2010) compared survival in urban versus rural subpopulations, and urban goose survival (S=0.958) was substantially higher than rural goose survival (S=0.682). Assuming the difference in urban versus rural survival rates reported in Georgia by Balkcom (2010) occurs throughout the range of reintroduced temperate-nesting geese, the early season harvest strategy alone, while potentially useful for rural subpopulations, is unlikely to stabilize temperate-nesting goose populations as a whole (Balkcom 2010; Iverson *et al.* 2013). Lethal removal strategies at the local level like special metropolitan seasons for specific nuisance populations may be necessary to control urban subpopulations (Powell 2001; Heller 2010). Avian contraceptive methods such as Ovo-Control-G® (Innolytics LLC) mixed with bait may be another alternative management strategy which can reduce hatchability about 50% of the time (Bynum *et al.* 2005). Unfortunately, public opinion of management strategies other than traditional hunting in rural areas and non-feeding ordinances in urban areas is controversial (Coluccy *et al.* 2001), so public outreach and structured decision making will be crucial to incorporation of targeted management.

In addition to urban geese, molt migrants further complicate estimates of temperate-nesting Canada goose survival and recovery and the effects of various harvest regulations and management strategies. As Heller (2010) demonstrated through model simulations, the absence of banded molt migrants results in over-estimates of juvenile annual survival rates and under-estimates of adult annual survival rates. Poor model fit, which occurred in both preliminary and final models in our study, may also result from the absences of banded molt migrants. We made adjustments for the lack of molt migrants in the sample by using the 3-age structure created by Heller (2010). One of the two top models incorporated the 3-age structure, and point estimates for adult and young survival were identical to the traditional 2-age model, suggesting the model is a relatively effective method of accounting for molt migrants in samples taken during the breeding season without biasing survival estimates in the other cohorts. However, the 3-age model only accounts for subadults as molt migrants. Though early descriptions of temperate-nesting geese included only subadult males as the primary molt migrant cohort (Hanson 1965), more recent research has revealed geese follow few rules regarding molt migrations (Luukkonen *et al.* 2007; Zicus 1981). Individuals from a range of cohorts, including both males and females, subadults and adults, perform molt migrations, especially following nest destruction or nest failure (Luukkonen *et al.* 2007; Zicus 1981). Our model with the 3-age structure produced point estimates for subadult survival very similar to adult survival. Zicus (1981) reported higher survival rates in molt migrants than non-molt migrants, concluding high molt migrant survival may result in more geese performing migrations. However, other studies suggest geese who perform molt migrations can have lower survival than geese who remain in temperate zones (Dieter and Anderson 2009; Heller 2010; Luukkonen *et al.* 2007). Luukkonen *et al.* (2007) concluded inducing molt migration through nest destruction may aid management and population control by reducing survival for more individuals, but molt migrants can negatively affect management of both resident and migratory Canada goose populations at northern latitudes. In addition, Iverson *et al.* (2013) attributed part of the early season ineffectiveness to high take of molt migrants from lower latitudes spending the breeding season in Ontario, which precluded sufficient take of local geese targeted with early seasons. The absence of molt migrants in typical temperate-nesting Canada goose banding samples and the presence of molt migrants on breeding grounds of migratory Canada geese can muddle analysis and disrupt management for both temperate-nesting and migratory populations (Heller 2010; Luukkonen *et al.* 2007; Iverson *et al.* 2013). Development of a method for sampling geese from all cohorts, including potential molt migrants, may be necessary to avoid biased estimates of population demographics and to better inform management strategies.

Management Implications

Current harvest management strategies like liberalization of normal seasons and addition of special early seasons do not yet appear to have reduced survival or abundance of temperate-nesting Canada geese in Arkansas. The partial additive effect of harvest on reproductive cohorts reported by Iverson *et al.* (2013) and the point estimates of survival from our S[2age*hunt] model suggest potential for early seasons to reduce survival in the short term but do not promise sufficient results in the long term, especially with increasing urban subpopulations not susceptible to harvest. To address urban subpopulation management, we need further research examining the efficiency of non-harvest population control methods. Lethal removal strategies or contraceptive-laced baits are likely to work better than egg oiling or egg removal since nest destruction can induce molt migrations and further complicate management in northern latitudes (Heller 2010; Iverson *et al.* 2013; Luukkonen *et al.* 2007).

As temperate-nesting goose populations throughout flyways and in individual states like Arkansas continue to grow and boast high annual survival rates, leading to further increases in nuisance goose issues, management should change to reflect such growth. Target harvest rates may provide guidance for harvest goals based on management objectives. Further liberalization of hunting regulations and introduction of alternative lethal and non-lethal methods of control (along with associated public outreach) in local areas of particular concern will be necessary to maintain populations at an acceptable level and to meet state and flyway management objectives.

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Table 1. Canada goose (*Branta canadensis*) hunting seasons in Arkansas from 1992-2012. Numbers indicate daily bag limits.

Zone	Type of Season	1992	‘93-‘98	‘99-2000	2001	2002	2003	2004	2005
East	Normal[1]		2	2	2	2	2	2	2
	Early[2]								
West/Northwest	Normal	1	1	2	2	2	2	2	2
	Early								
Southwest	Normal				2	2	2	2	2
	Early								

Zone	Type of Season	2006	2007	2008	2009	2010	2011	2012
East	Normal	2	2	2	2	2	2	2
	Early							5
West/Northwest	Normal	2	2	2	2	2	2	2
	Early		5	5	5	5	5	5
Southwest	Normal	2	2	2	2	2	2	2
	Early		5					5

[1]Normal seasons occur in one or more of the following months: Jan., early Feb., late Sep., Oct., Nov., and Dec.

[2]Early seasons occur from 1 September to 15 September.

Table 2. Candidate models for temperate-nesting Canada goose (*Branta canadensis*) annual survival rate (*S*) in Arkansas from 2005 to 2011.

Model Notation	Description
S[.] (Null Model)	Survival is constant over all time and age cohorts
S[2age]	Survival incorporates 2-age structure[1]
S[3age]	Survival incorporates Heller (2010) 3-age structure[2]
S[2age*hunt]	Survival incorporates 2-age[1] structure interacting with pre-liberalization and post-liberalization[3]
S[3age*hunt]	Survival incorporates Heller (2010) 3-age[2] structure interacting with pre-liberalization and post-liberalization[3]
S[2age*year]	Survival incorporates 2-age structure[1] interacting with individual year of recovery[4]
S[3age*year] (Global Model)	Survival incorporates Heller (2010) 3-age structure[2] interacting with individual year of recovery[4]

[1]Young geese adopt the adult annual survival rate after their first year after banding.

[2]Young geese adopt a subadult annual survival rate after their first year after banding and adopt the adult survival rate after their third year after banding.

[3]Distinct annual survival rates are assigned for 2005-2006 versus 2007-2011.

[4]Distinct annual survival rates are assigned for each individual year from 2006 to 2011.

Table 3. Model selection results for temperate-nesting Canada goose annual survival rate (*S*) in Arkansas from 2005 to 2011. Covariates represent the number of age cohorts incorporated in the model (2age or 3age), the incorporation of pre- versus post-liberalization of hunting regulations in recovery years (hunt), and individual recovery years (year). Only models with fit better than or equal to the null model S[.] are reported.

Model	K^*	QAIC*	ΔQAIC*	w_i^*
S[2age]	11	4118.64	0.00	0.625
S[3age]	12	4120.64	2.00	0.230
S[2age*hunt]	13	4122.33	3.69	0.099
S[3age*hunt]	14	4123.86	5.22	0.046
S[.]	10	4135.23	16.59	0.000

**K* – no. parameters, QAIC – Quasi-likelihood Akaike's Information Criterion adjusted for overdispersion, ΔQAIC – difference in QAIC relative to smallest value, w_i – QAIC weight.

Table 4. Annual survival rate (*S*) estimates for top temperate-nesting Canada geese survival models in Arkansas from 2005 to 2011.

Model	Parameter	Estimate	*SE*	95% CI
S[2age]	Adult *S*	0.759	0.0151	0.729, 0.788
	Young *S*	0.847	0.0210	0.801, 0.884
S[3age]	Adult *S*	0.759	0.0156	0.727, 0.788
	Young *S*	0.847	0.0210	0.801, 0.884
	Subadult *S*	0.761	0.0242	0.710, 0.805

Table 5. Annual survival rate (S) estimates for S[2age*hunt] Canada geese survival model in Arkansas from 2005 to 2011. Pre-liberalization incorporates years before the introduction of the special early season in 2007. Post-liberalization incorporates years after the introduction of the special early season in 2007.

	Parameter	Estimate	*SE*	95% CI
Pre-Liberalization	Adult *S*	0.792	0.0255	0.737, 0.837
	Young *S*	0.959	0.0274	0.856, 0.989
Post-Liberalization	Adult *S*	0.747	0.0162	0.714, 0.777
	Young *S*	0.815	0.0254	0.760, 0.860

Table 6. Target harvest rates (*h**) for temperate-nesting Canada geese in Arkansas for various recovery factors (F_R).

F_R	*h**	*SE*	95% CI
1	0.051	0.0094	0.033, 0.070
1.25	0.064	0.0118	0.041, 0.087
1.5	0.077	0.0141	0.049 0.105
1.75	0.090	0.0165	0.057, 0.122
1.99	0.102	0.0187	0.065, 0.139

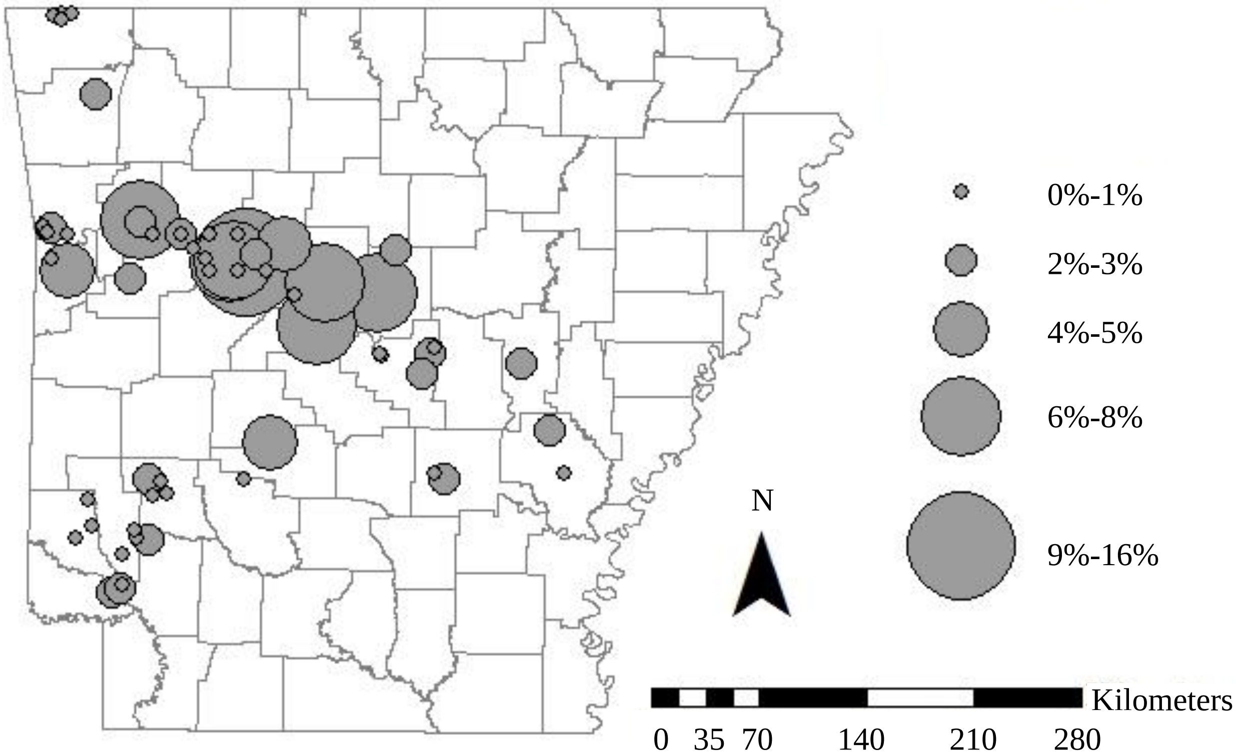

Figure 1. Locations of temperate-nesting Canada goose (*Branta canadensis*) breeding season banding in Arkansas from 1999-2012. Circle size indicates the percent of the total number of banded temperate-nesting Canada geese from 1999-2012 at a location.

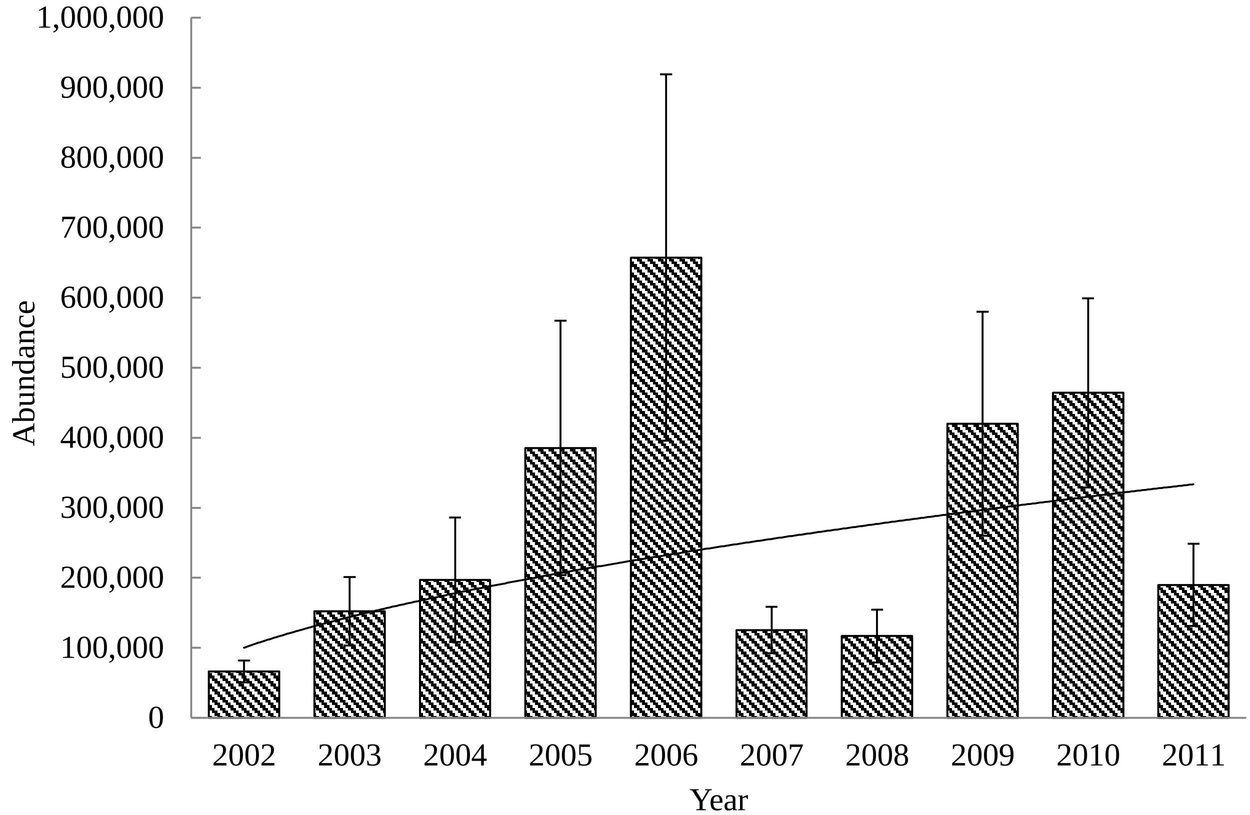

Figure 2. Unadjusted Lincoln Index estimates and associated trendline of temperate-nesting Canada goose (*Branta canadensis*) abundance in Arkansas from 2002-2011 (R^2=0.274). Error bars indicate 95% confidence intervals.

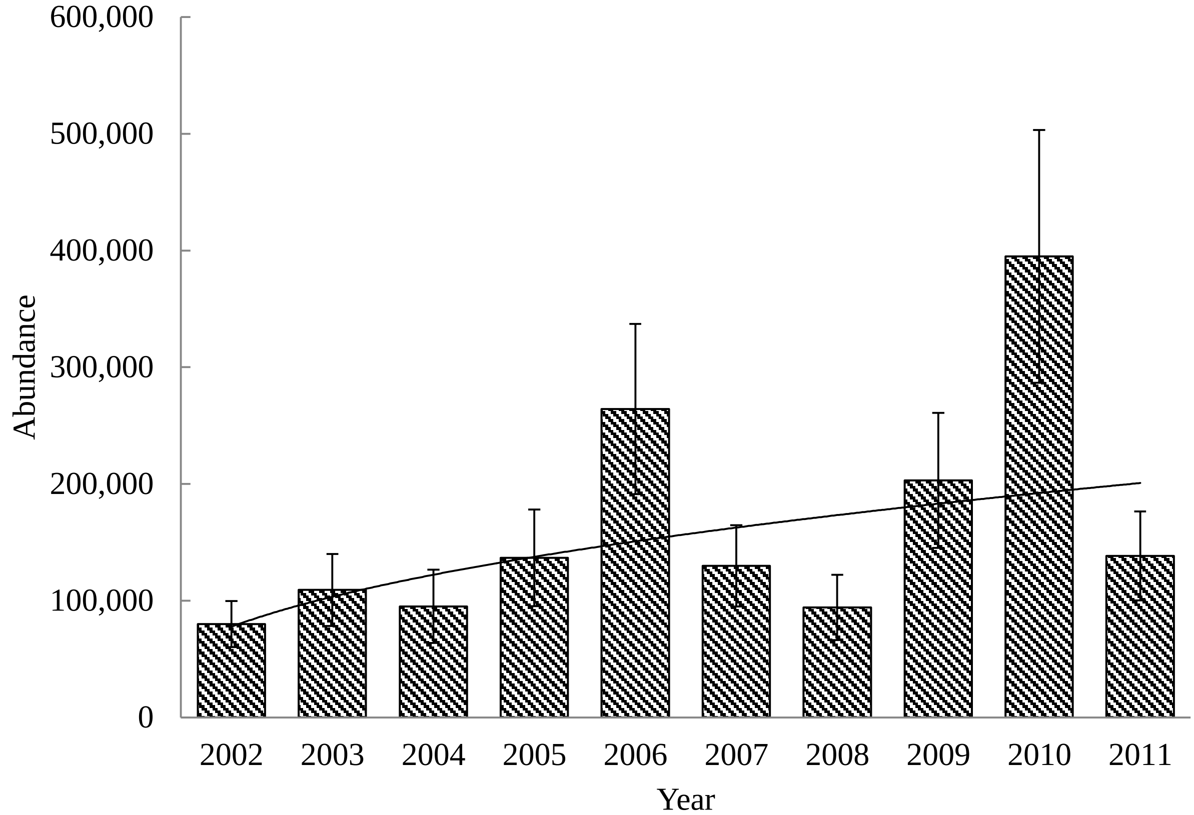

Figure 3. Lincoln Index estimates and associated trendline of temperate-nesting Canada goose (*Branta canadensis*) abundance in Arkansas from 2002-2011 adjusted with a regional (Arkansas, Kentucky, Missouri, Oklahoma, and Tennessee) average harvest rate (R^2=0.358). Error bars indicate 95% confidence intervals.

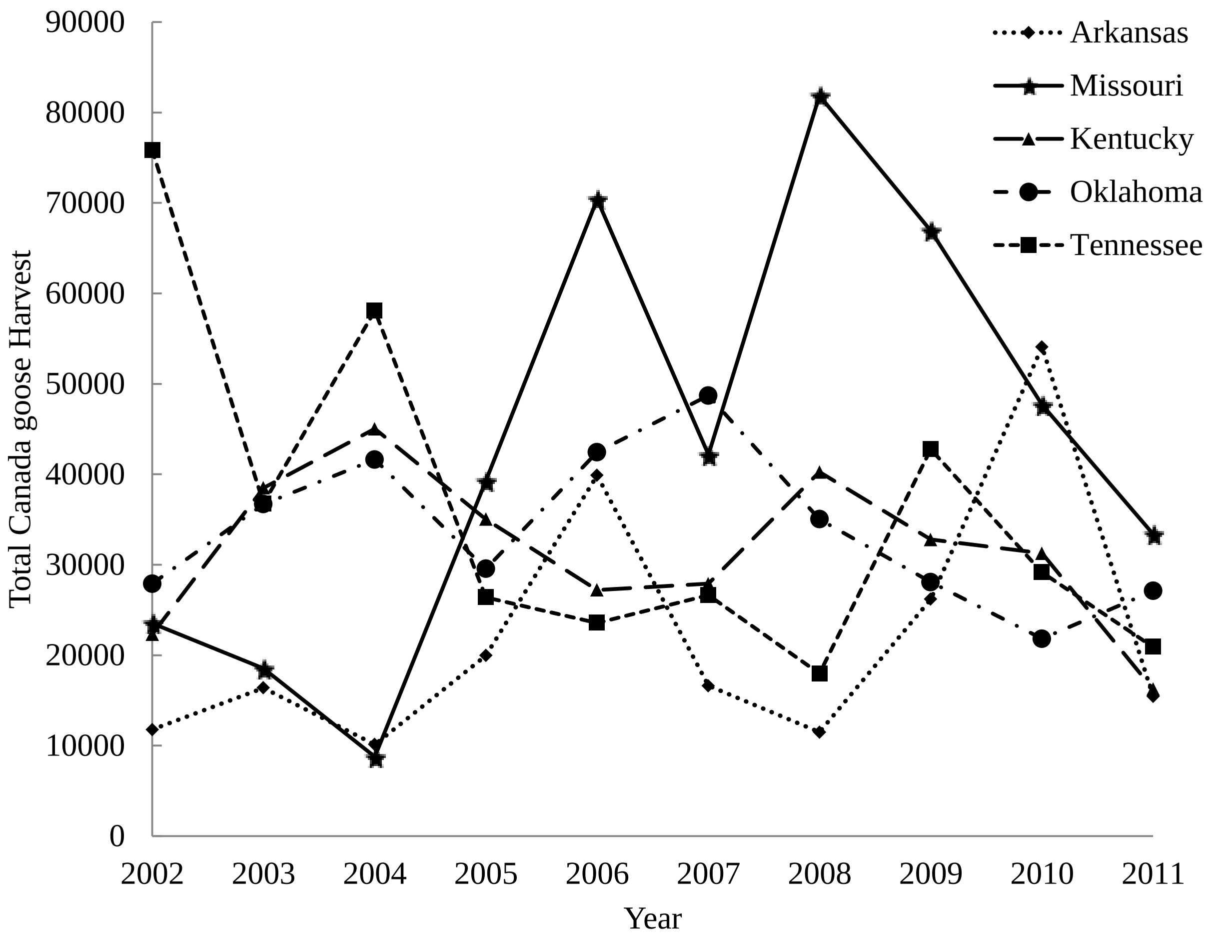

Figure 4. Cooperative State-Federal Migratory Bird Harvest Information Program (HIP) total Canada goose (Branta canadensis) harvest estimates for Arkansas, Missouri, Kentucky, Oklahoma, and Tennessee from 2002-2011.

APPENDIX A: SAMPLE PARAMETER INDEX MATRICIES (PIMs) FOR BURNHAM JOINT LIVE-DEAD CAPTURE-MARK-RECAPTURE MODEL OF ANNUAL SURVIVAL

Null Model

Adult and Young Geese PIM for S[.] Model

2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
1	1	1	1	1	1
	1	1	1	1	1
		1	1	1	1
			1	1	1
				1	1
					1

Models Incorporating Age Effects

Adult Geese PIM for S[2age] and S[3age] Models

2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
1	1	1	1	1	1
	1	1	1	1	1
		1	1	1	1
			1	1	1
				1	1
					1

Young Geese PIM for S[2age] Model

2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
2	1	1	1	1	1
	2	1	1	1	1
		2	1	1	1
			2	1	1
				2	1
					2

Young Geese PIM for S[3age] Model

2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
2	3	3	1	1	1
	2	3	3	1	1
		2	3	3	1
			2	3	3
				2	3
					2

Models Incorporating Age Effects and Pre- versus Post-Liberalization Hunting Effects

Adult Geese PIM for S[2age*hunt] and S[3age*hunt] Models

2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
1	1	2	2	2	2
	1	2	2	2	2
		2	2	2	2
			2	2	2
				2	2
					2

Young Geese PIM for S[2age*hunt] Model

2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
3	1	2	2	2	2
	3	2	2	2	2
		4	2	2	2
			4	2	2
				4	2
					4

Young Geese PIM for S[3age*hunt] Model

2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
3	4	6	2	2	2
	3	6	6	2	2
		5	6	6	2
			5	6	6
				5	6
					5

Models Incorporating Age Effects and Individual Year Effects

Adult Geese PIM for S[2age*year] and S[3age*year] Models

2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
1	2	3	4	5	6
	2	3	4	5	6
		3	4	5	6
			4	5	6
				5	6
					6

Young Geese PIM for S[2age*hunt] Model

2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
7	2	3	4	5	6
	8	3	4	5	6
		9	4	5	6
			10	5	6
				11	6
					12

Young Geese PIM for S[3age*hunt] Model

2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
7	8	9	4	5	6
	10	9	11	5	6
		12	11	13	6
			14	13	15
				16	15
					17

APPENDIX B: DOCUMENTATION OF AUTHORSHIP OF PAPER

J. William Fulbright College of Arts and Sciences
Department of Biological Sciences

Chapter 1, "Survival and abundance of temperate-nesting Canada geese (*Branta canadensis*) in Arkansas," of M. E. Ronke's thesis is intended for eventual submission for publication with two coauthors, D. G. Krementz and L. W. Naylor.

I, Dr. David G. Krementz, major advisor for M. E. Ronke, confirm M. E. Ronke will be first author and completed at least 51% of the work for this paper.

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CHAPTER II

GEOGRAPHIC DISTRIBUTION OF TEMPERATE-NESTING CANADA GEESE (*BRANTA CANADENSIS*) IN ARKANSAS

ABSTRACT

The reintroduced temperate-nesting Canada goose (*Branta canadensis*) population in Arkansas has recently grown in range and abundance. Management of temperate-nesting Canada geese requires knowledge of the population's current range. Geographic range from 2004-2012 was estimated using volume contour maps from citizen science observations using eBird and hunter recovery locations from the U.S. Geological Survey Bird Banding Laboratory. Resulting maps indicate an increase in temperate-nesting Canada goose encounters in northwestern Arkansas and the Arkansas River Valley. Dispersal of temperate-nesting Canada geese banded and recovered in Arkansas was examined. Forty-two percent of geese dispersed along the east-west axis, 25% went east and 17% went west. The average dispersal distance was 50.1 km (SE=1.13km). Emigration, molt migration, and immigration between Arkansas and other states and provinces were examined using geese banded in Arkansas and recovered elsewhere and geese banded elsewhere and recovered in Arkansas. Emigration and immigration interactions were greatest between Arkansas and Missouri, with Missouri recovering 21.5% of Arkansas-banded geese and contributing 42.5% of geese banded outside Arkansas and recovered in Arkansas. Molt migrant interactions were greatest between Arkansas and Manitoba and Minnesota, which each recovered 38.1% of molt migrant geese banded in Arkansas. Factors explaining molt migration/emigration were examined, and both age and sex were the best predictors. Age was positively correlated with distance, and males traveled relatively shorter distances than females. Overall, geographic analysis indicated the range of temperate-nesting Canada geese in Arkansas is expanding, but individual geese do not frequently move long distances from banding sites.

INTRODUCTION

As reintroduced populations of temperate-nesting giant Canada geese (*Branta canadensis maxima*) throughout the Mississippi and Atlantic Flyways continue to grow in abundance, expansion of the populations' ranges is inevitable. Management of temperate-nesting Canada geese has evolved to address this continuing growth, especially as, in many states, geese move from original rural reintroduction sites into suburban and urban areas (Conover and Chasko 1985; Nelson and Oetting 1998). Farm ponds, golf courses, and public parks provide refugia with abundant food and minimal risk of predation, but increased goose presence in suburban habitats has become an increasingly controversial public relations issue (Conover and Chasko 1985; Smith *et al*. 1999).

The Mississippi Flyway Council (1996) Giant Canada Goose Committee's Management Plan for giant Canada geese, in addition to goals regarding harvest in rural areas, includes specific goals regarding population control and alleviation of negative human-goose conflicts in portions of the reintroduced populations' ranges within urban and suburban environments. The Mississippi Flyway Council (1996) strategies for temperate-nesting Canada geese in sites where hunting or firearm use is restricted include non-lethal abatement techniques, habitat manipulation, and, if necessary, lethal methods such as egg destruction or capture of adults during the summer flightless period. However, limited funding, public concerns, and insufficient information about goose ranges and dispersal patterns hinder management strategies to achieve flyway and individual state goals regarding reintroduced populations (Ankney 1996).

Molt migrations further complicate management. Subadults and failed nesting adults will frequently perform molt migrations, flying northward around May-June and returning to temperate regions in August-September (Luukkonen *et al.* 2007). The distance of molt migrations may be up to 2,500km with geese moving from temperate zones to as far north as the 64^{th} parallel (Luukkonen *et al.* 2007). Molt migrants therefore may be harvested during special early seasons in states and provinces at higher latitudes.

The Arkansas Game and Fish Commission (AGFC) reintroduced a population of temperate-nesting Canada geese for harvest and viewing opportunities beginning in 1981 with continuing supplements through 1983 (Moser 1996). Release of geese occurred primarily at Lake Dardanelle State Park near Russellville and a secondary location southeast of Little Rock. In addition to these release locations, suspected isolated subpopulations of temperate-nesting Canada geese occurred in the northeastern and southwestern portions of the state, and a subpopulation existed at the north-central border between Arkansas and Missouri near the White River/Cache River Drainage Basin caused by bleed-over from the Missouri population (Mississippi Flyway Council 1996; Moser 1996). In the 1990s the AGFC developed a strategic plan outlining needs for banding, monitoring, and research on the population's demographics and movements (Moser 1996).

Banding of temperate-nesting Canada geese in Arkansas began in 1988, but efforts were sporadic or non-existent through 2000. The AGFC increased banding effort in the 2000s, including numerous banding locations across the Arkansas River Valley and northwestern and southwestern Arkansas at public parks, AGFC facilities, and private lands. Harvest of Canada geese began in 1992 with a short, experimental season in northwestern Arkansas (Moser 1996). The AGFC has since liberalized harvest in response to the purported temperate-nesting Canada goose population growth rate. Hunter recoveries now occur throughout much of the state.

In 2007 the AGFC introduced a special early season in the Northwest and Southwest regions. The early season continued only in the Northwest region from 2008-2011. The AGFC opened the early season to the entire state in 2012 again in response to the apparent growth in abundance and range of the temperate-nesting Canada goose population. As yet, no statewide efforts exist to control temperate-nesting Canada goose subpopulations in suburban environments, where harvest is not necessarily a viable management option. Before the AGFC can consider further liberalization of hunting regulations to control the overall population or site-specific nonlethal or lethal options to control suburban subpopulations, research must fill knowledge gaps regarding the current range and dispersal patterns of temperate-nesting Canada geese in Arkansas.

The objectives of my study were: 1) to estimate the geographic range of temperate-nesting Canada geese in Arkansas; 2) to estimate average dispersal distance and direction of temperate-nesting Canada geese between initial capture and final recapture or recovery within Arkansas; 3) to approximate interactions between Arkansas's temperate-nesting Canada geese and other states or provinces in terms of emigration, molt migration, and immigration; and 4) to determine if distance traveled by emigrating or molt migrating geese is related to age or sex.

METHODS

The AGFC banded temperate-nesting Canada geese in Arkansas annually during flight-feather molt, typically the last week of June and first week of July from 1999-2012 at locations in the Arkansas River Valley and Southwestern and Northwestern Arkansas. Geese nesting at these locations were herded into enclosures then individually sexed, aged, and banded. From 2001-2011 the AGFC banded approximately 13,000 geese with federal aluminum leg bands. I retrieved banding and recovery data for the years 2001 to 2011 from U.S. Geological Survey Bird Banding Laboratory (BBL) in October 2012 and recovery data for the year 2012 in January 2013 for analysis. I retrieved data on live recaptures of banded geese for the years 2006-2011 from the AGFC in August 2012. I also retrieved live Canada goose breeding season observations for the years 2004 to 2012 from eBird, a citizen science website Audubon and Cornell Lab of Ornithology organize (Sullivan *et al.* 2009).

Geographic Distribution

I created maps of the distribution of temperate-nesting Canada geese in Arkansas for 2004 to 2012 using coordinates of Canada goose hunter recoveries from the BBL and sightings during the breeding season from eBird. I excluded years before 2004 from analysis because eBird reported fewer than 30 observations in those years. After producing shapefiles of the observation points in ArcGIS for each year (ESRI 2012), I then created kernel density estimates in R using the home range estimation package, adehabitatHR (Calenge 2011). Each year used a smoothing parameter based on the reference bandwidth equal to:

$$h = \sigma \times n^{-1/6}$$

where

$$\sigma = 0.5 \times (\sigma_x + \sigma_y)$$

and σ_x and σ_y are the x and y coordinate standard deviations (Calenge 2011). Though the reference bandwidth method can result in oversmoothing, successive trials revealed this method as the most appropriate to produce visually useful maps(Calenge 2011). I used adehabitatHR to convert the kernel density output into volume utilization distribution rasters appropriate for computation of home range contours where contour line values indicate the probability level of given raster pixels falling within the species range (Calenge 2011). I used the series of resulting images to display the change in temperate-nesting Canada goose distribution over time.

Dispersal

Of the 13,118 temperate-nesting Canada geese the AGFC banded from 2001 to 2011, 4,469 were encountered again in Arkansas, either as a live recapture at a subsequent goose banding roundup or as a dead recovery by hunters reported to the BBL. I examined histograms of the distance between initial and final capture to determine a natural break between apparent local movement and dispersal. A break occurred at the median distance, 15km. I excluded 3,052 geese that moved less than or equal to 15km from dispersal analysis, treating those individuals as residents performing local movements only. I created a wind rose diagram of temperate-nesting Canada goose dispersal in Arkansas from 2001-2011 using the coordinates of the banding location and final recovery or live recapture location of each of the remaining 1,417 geese. I produced line shapefiles in ArcGIS connecting initial and final encounter points and measured the distance and angle of dispersal (ESRI 2012). I used the frequency of distances and directions to create the wind rose diagram with the grammar graphics package (ggplot2) in R (Wickham 2008).

Goose Emigration, Molt Migration, and Immigration

I examined the recovery locations of the 114 geese banded in Arkansas and recovered outside of Arkansas from 2001-2011, which I excluded from the Arkansas dispersal analysis. I determined which states or provinces recovered the most Arkansas-banded geese. I examined the time of recovery to determine which recoveries occurred during early hunting seasons in September. I considered geese recovered in early seasons above 45°N latitude molt migrants. Molt migrant geese are susceptible to harvest in northern latitudes during early seasons, frequently migrating above 45-50°N or even as far north as 60-65°N around May-June and return to mid latitudes in the fall (Zicus 1981; Luukkonen *et al.* 2007; Dieter and Anderson

2009). I considered all other geese— either recovered in normal hunting seasons or in early seasons below 45°N latitude— permanent emigrants from Arkansas to other locations.

I created generalized linear models examining the relationship between distance traveled and sex and minimum age at recovery in emigrants and suspected molt migrants. I created a total of four candidate models; a null model and three models which modeled distance as a function of sex, age, and the interaction of sex and age. I used Akaike's Information Criterion (AIC) (Akaike 1973) to select among candidate models. I considered all models within $\Delta AIC \leq 2.00$ acceptable models for the data to account for model-selection uncertainty.

I also examined 3,105 recoveries within Arkansas from 2001 to 2011 of temperate-nesting geese banded both in Arkansas and outside of Arkansas. I calculated what proportion of Arkansas's recoveries had been banded in other states to quantify immigration.

RESULTS

Geographic Distribution

Volume contour maps show an increase in Canada goose encounters in northwestern Arkansas and along the Arkansas River Valley between 2004 and 2012 (Fig. 1). Pockets of geese also occurred in southwestern and northeastern Arkansas. The highest concentrations of temperate-nesting Canada geese consistently occurred in the center and northwestern corner of the state.

Dispersal

The wind rose diagram of temperate-nesting Canada goose dispersal in Arkansas shows the greatest movement in the east and west directions (east: 75°<angle<105°, west: 255°<angle<285°)(Fig. 2). Forty-two percent of geese dispersed along the east-west axis (25% east and 17% west). The average dispersal distance was 50.1 km (SE=1.13km). The first quartile, median, and third quartile distances were 24km, 31km, and 63km, respectively. The maximum dispersal distance was 344km. The greatest average distance occurred within the east-northeast directional wedge ($\bar{x}$=87.8km, SE=10.68km). The lowest average distance occurred within the north directional wedge ($\bar{x}$=29.9km, SE=3.06km).

Of the 3,052 resident geese that performed only local movements and did not disperse and were excluded from dispersal analysis, the average local movement distance was 9.6km. The first quartile, median, and third quartile distances were 6km, 10km, and 15km, respectively.

Goose Emigration, Molt Migration, and Immigration

Of the 114 non-Arkansas recoveries we examined, 65 recoveries were permanent emigrants occurring either in normal hunting seasons or in early seasons below 45°N latitude. Recoveries occurred in 14 states (Table 1).

Forty-two recoveries were molt migrants occurring during special early seasons in September above 45°N latitude in Manitoba, Minnesota, North Dakota, Michigan, Wisconsin, and Saskatchewan (Table 2).

Both the models of distance as a function of age and of distance as a function of age and sex were equally plausible (Table 3). In both top models, age was positively correlated with distance, with older individuals traveling relatively longer distances than younger individuals. In the model incorporating age and sex, younger males traveled relatively the shortest distances, and older females traveled relatively the longest distances.

Of the 3,105 recoveries of temperate-nesting Canada geese banded either in Arkansas or elsewhere, 193 geese, comprising 6% of Arkansas's total recoveries, were immigrants banded in locations outside of Arkansas. Immigrants originated in 13 states (Table 4).

DISCUSSION

The AGFC reintroduction of temperate-nesting Canada geese to Arkansas has met stated objectives of developing a self-supporting population and providing hunting and viewing opportunities (Yaich 1994; Moser 1996). As the population has grown, the AGFC has expanded monitoring programs by including more banding locations, on both public and private lands, throughout the Arkansas River Valley and western Arkansas. In addition, the AGFC has included more regions in both normal and special early hunting seasons and have increased bag limits to extend recreation opportunities to citizens across the state. Continuation of monitoring and management protocols requires information about the current and potential future geographic characteristics of the population. I therefore explored the range and dispersal of Arkansas's temperate-nesting Canada geese.

Past and present range maps of temperate-nesting Canada geese in Arkansas may provide insight about potential future expansion. The Mississippi Flyway Council (1996) approximate range of giant Canada geese in Arkansas included a portion of the Arkansas River Valley and isolated pockets in southwestern, northeastern, and north-central Arkansas. My range maps display expansion of the population from original release locations at Lake Dardanelle and southeast of Little Rock throughout the Arkansas River Valley and into northwestern Arkansas. Additional pockets occurred in southwestern and northeastern Arkansas similar to the original Mississippi Flyway Council (1996) range estimate. The densest concentrations of goose encounters occurred consistently in the center and northwestern corner of the state. No pocket in the White River/Cache River Drainage Basin at the Missouri and Arkansas border appeared in my range maps despite historic evidence of a subpopulation in the area (Mississippi Flyway Council 1996; Moser 1996).

The absence of the White River/Cache River Drainage Basin subpopulation and the high concentrations around Little Rock and northwestern Arkansas are artifacts of the inherent biases in both BBL and eBird data in Arkansas. Banding of geese has historically been highly concentrated in the Arkansas River Valley, especially around Lake Dardanelle, and hunting of Canada geese is also highly concentrated around Lake Dardanelle and surrounding areas in the Arkansas River Valley. Alternatively, eBird data is highly biased towards high concentrations of human populations, especially at small spatial scales (Sullivan *et al.* 2009). The areas surrounding Little Rock, Texarkana, and northwestern Arkansas, where human population density is high, produced the greatest number of eBird observations throughout all years. Little to no observations occurred each year in areas of low population density. Combining the BBL data and eBird data helped partially compensate for each dataset's biases, but my resulting range maps remain only rough estimates of goose concentrations across Arkansas. Detailed inferences may be difficult to develop, but general patterns may be useful to future management decisions, such as the increase in geese through the Arkansas River Valley.

Further evidence of temperate-nesting Canada goose expansion along the Arkansas River Valley was apparent in my wind rose dispersal analysis. The wind rose data suggest dispersal of geese along the east-west corridor of the valley, with potential movement towards the Mississippi Alluvial Valley. If temperate-nesting Canada geese do not already occur (or occur only at low densities) in the Mississippi Alluvial Valley, I predict sustained subpopulations will arise in the near future. In addition to my directional analysis, distance analysis of dispersal within Arkansas may provide insight about the temperate-nesting Canada goose population. For geese which dispersed, traveling greater than 15km between banding and final recapture or recovery, the average dispersal distance (50 km) was comparable to the average dispersal distance James (2003) reported for the Central Mixed-Grass Prairie ($\bar{x}$=49.2km, SE=6.28km) and Oaks and Prairies ($\bar{x}$=61.3km, SE=14.35km) Bird Conservation Regions (BCRs). However, the majority of geese banded and recaptured or recovered within Arkansas performed only local movements, remaining within 15km of their original banding location. Other studies have found temperate-nesting Canada geese exhibit little movement between banding or release and subsequent recovery or recapture. Holevinski *et al.* (2006) and Powell *et al.* (2001) found geese translocated out of urban areas in New York and Georgia, respectively, remained at or near release sites. James (2003) encountered similar results in all six BCRs with high proportions of geese both banded and recovered within the same 10-minute block. Conover (2011) also reported minimal movement of non-migratory Canada geese in Connecticut. Because temperate-nesting geese appear to frequently move only short distances rather than dispersing long distances into other states or regions, Conover (2011) suggested populations in different geographic areas are unlikely to have significant interactions with each other and recommend an emphasis on management at the state and local level.

The importance of management at the state and local level is further supported by examination of interactions between Arkansas and other states and provinces in terms of emigration and immigration. Only 6% of Arkansas recoveries originated in other states, and only 4% of geese banded in Arkansas were recovered in other states, suggesting minimal influence of one goose population on populations in other geographic areas. James (2003) similarly concluded geographically separate subpopulations of temperate-nesting geese are unlikely to have much direct interaction. Conover (2011) reported not only minimal exchange of geese between states, but also an overall decline in the number of out-of-state recoveries over the past two decades. Of the geese I examined which did move between states, the greatest exchange of temperate-nesting Canada geese occurred between Arkansas and nearby Oklahoma, Missouri, and Iowa. For molt migrants, the majority of recoveries occurred in Manitoba and Minnesota. Northern latitude states and provinces like Michigan and Minnesota account for a substantial portion of the total Mississippi Flyway Canada goose harvest (Fronczak 2012). Molt migrants can experience lower survival due to early season harvest in higher latitudes (Luukkonen *et al.* 2007; Dieter and Anderson 2009), and high take of molt migrants in northern regions may aid in alleviation of high goose populations in temperate latitudes (Luukkonen *et al.* 2007).

To explore the potential role of molt migrant and emigrant recovery in other states, understanding the demographics of geese performing molt migrations and emigration out of Arkansas is necessary. My top models suggested older geese and females are likely to travel farther than younger geese and males, contrary to original theories on molt migrations, which identified subadult males as most likely to perform long-distance molt migrations (Hanson 1965). More recent research suggests no particular rules apply to molt migrants (Luukkonen *et al.* 2007). My model results may indicate a higher propensity to disperse or migrate longer distances amongst females with failed nest attempts rather than non-breeding subadults or males. Luukkonen *et al.* (2007) found approximately 80% of geese with destroyed nests performed molt migrations, which may provide a management option for discouraging reproductive females from remaining in urban nesting habitat.

Management Implications

As the goose population continues to expand, management across the entire range of temperate-nesting Canada geese in Arkansas, especially suburban environments, will become increasingly important. Continuation of hunting in all regions of Arkansas will be appropriate as the Canada goose population expands throughout the state. Research specifically exploring translocation of geese from urban to rural areas may provide insight to whether geese in Arkansas would remain in release areas subject to harvest as my local movement data suggest. Additionally, nest destruction to induce molt migration or emigration of reproductive females may aid population control. However, more detailed range and dispersal analysis will be necessary to inform management decisions.

Current monitoring protocols for temperate-nesting Canada geese in Arkansas, while suitable for analysis on certain demographics, do not provide a sufficient representative sample of the population across the state for unbiased range analysis. Citizen science data from eBird provides some supplementation to the geographic data but also has inherent biases. A structured sampling protocol to include regions of the state such as the Mississippi Alluvial Valley may aid future efforts to approximate temperate-nesting goose range in Arkansas. Especially as current range maps and dispersal data suggest movement of geese eastward along the Arkansas River Valley towards the Mississippi Alluvial Valley, monitoring along those corridors will become increasingly important. Also, exploration of the suspected subpopulation of geese shared between Arkansas and Missouri along the White River/Cache River Drainage Basin will require banding of geese in the north-central portion of the state, another currently unrepresented region. In addition to including banding locations in the northern and eastern regions of Arkansas, the AGFC may need to explore sampling methods which include representatives of all cohorts. Current roundups during flight-feather molt may exclude molt migrant geese. In order to better characterize molt migrant geese from Arkansas and to better distinguish between molt migrants and permanent emigrants, banding of geese during early spring when all cohorts are available may be necessary.

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Table 1. States and provinces recovering emigrant temperate-nesting Canada geese banded in Arkansas. Recoveries occurred during normal seasons or during early seasons below 45°N latitude.

State/Province	Emigrant Recoveries	Percent of Total Emigrant Recoveries
Oklahoma	16	24.6%
Missouri	14	21.5%
Iowa	10	15.4%
South Dakota	7	10.8%
Georgia	5	7.7%
Kansas	4	6.2%
Texas	4	6.2%
Colorado	3	4.6%
Indiana	3	4.6%
Illinois	2	3.1%
Minnesota	1	1.5%
Nebraska	1	1.5%
Tennessee	1	1.5%
Utah	1	1.5%

Table 2. States and provinces recovering molt migrant temperate-nesting Canada geese banded in Arkansas. Recoveries occurred during early seasons above 45°N latitude.

State/Province	Molt Migrant Recoveries	Percent of Total Molt Migrant Recoveries
Manitoba	16	38.1%
Minnesota	16	38.1%
North Dakota	7	16.7%
Michigan	2	4.8%
Saskatchewan	1	2.4%
Wisconsin	1	2.4%

Table 3. Model selection results for distance traveled by emigrant and molt migrant temperate-nesting Canada geese banded in Arkansas and recovered elsewhere from 2001 to 2011. Covariates represent the minimum age at recovery and sex. Only models with fit better than or equal to the null model are reported.

Model	K^*	AIC*	ΔAIC*	w_i^*
Distance ~ Age	2	1774.9	0.0	0.555
Distance ~ Age and Sex	3	1775.7	0.8	0.372
Null	1	1780.2	5.3	0.039

*K – no. parameters, AIC –Akaike's Information Criterion, ΔAIC – difference in AIC relative to smallest value, w_i – AIC weight.

Table 4. States and provinces of origin of immigrant temperate-nesting Canada geese banded outside Arkansas and recovered in Arkansas.

State/Province	Immigrant Contribution	Percent of Total Immigrant Contribution
Missouri	82	42.5%
Iowa	37	19.2%
Tennessee	20	10.4%
Minnesota	16	8.3%
Wisconsin	11	5.7%
Illinois	7	3.6%
Indiana	5	2.6%
Michigan	4	2.1%
Kentucky	3	1.6%
Nebraska	3	1.6%
Kansas	2	1.0%
Ohio	2	1.0%
Colorado	1	0.5%

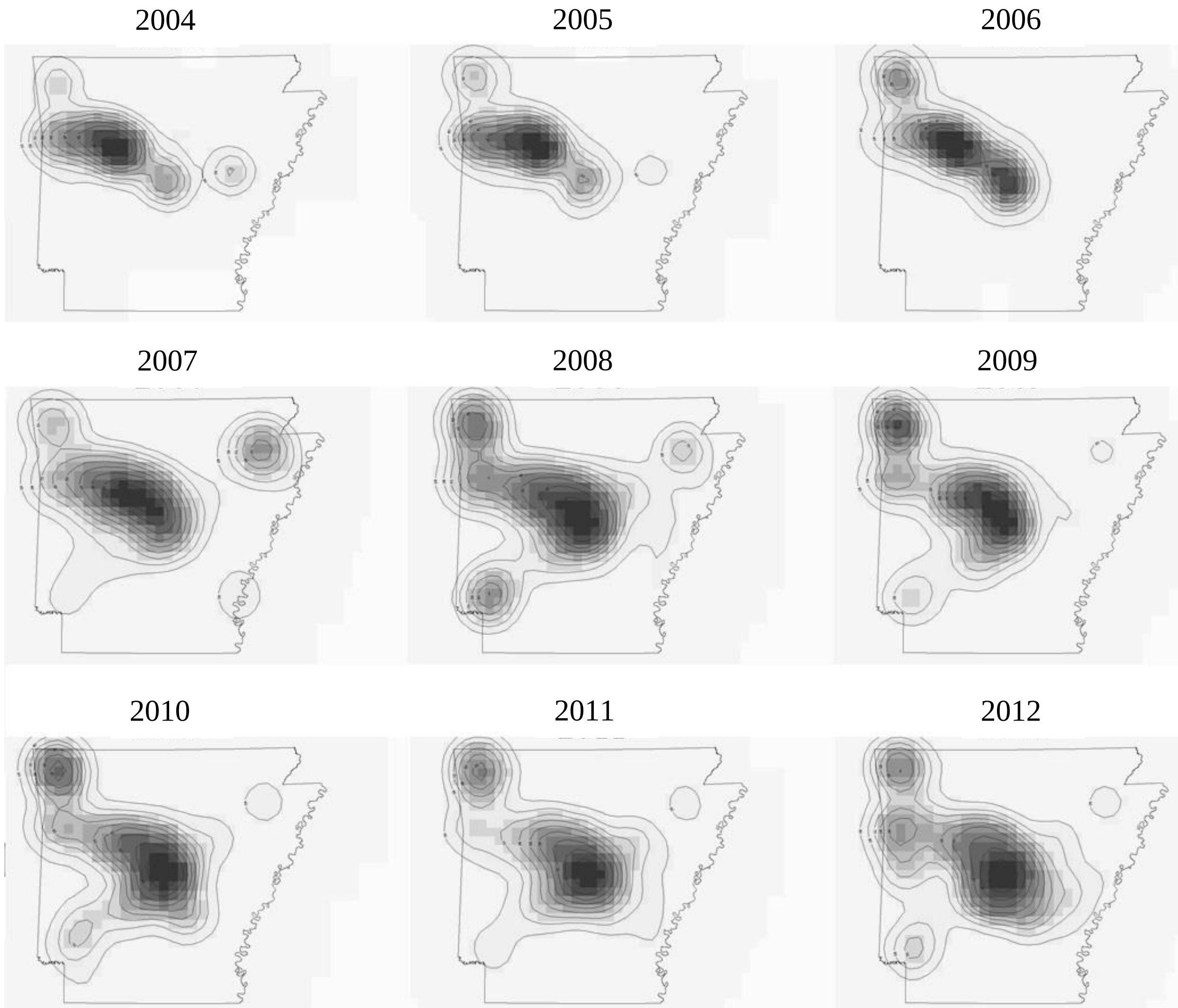

Figure 1. Volume contour maps of temperate-nesting Canada goose encounters in Arkansas from 2004-2012 from eBird and the U.S. Geological Survey Bird Banding Laboratory. Dark tones indicate a higher volume of observations. Light tones indicate a lower volume of observations. The contour interval is 10%.

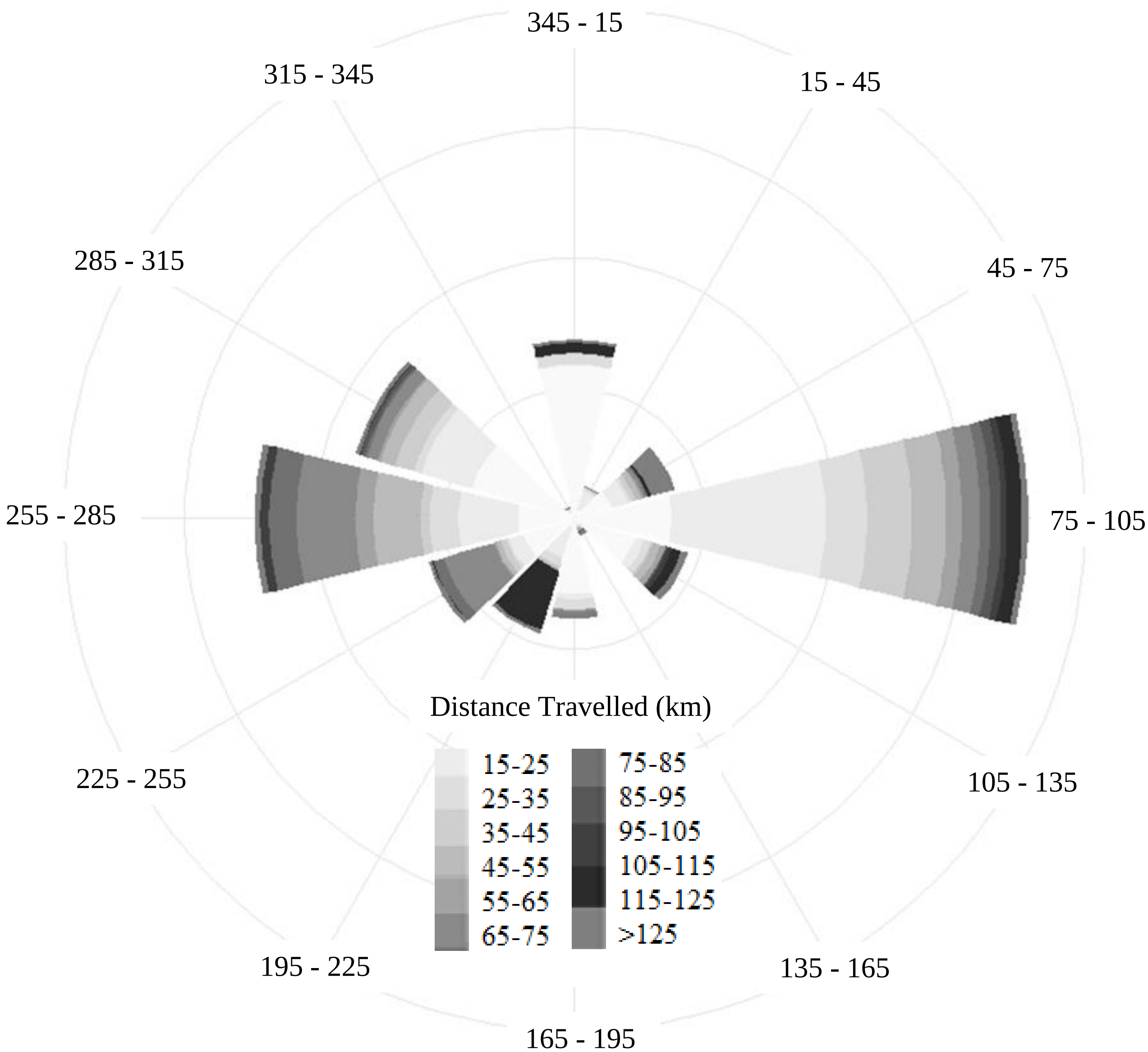

Figure 2. Wind rose of direction and distance travelled by temperate-nesting Canada geese banded in Arkansas from 2001-2011 and live-recaptured or hunter-recovered in Arkansas from 2001-2012.

CONCLUSION

The reintroduced temperate-nesting Canada goose population in Arkansas is self-sustaining and supports recreational opportunities for hunting and viewing throughout the state. The population has flourished since reintroduction began in 1981 and continues to grow in abundance and range. From 2002-2011, Canada goose abundance has roughly doubled. Within the same decade, the range of Canada geese has grown to encompass the Arkansas River Valley, northwestern Arkansas, and portions of northeastern and southwestern Arkansas, and dispersal patterns suggest the potential for further expansion of the population's range into the Mississippi Alluvial Valley. The AGFC liberalization of hunting regulations to accommodate the growing goose population does not appear to have sufficiently decreased survival or increased recovery rates to target harvest levels appropriate for population maintenance or reduction.

As the AGFC evaluates possible future management, continued liberalization of hunting and inclusion of all regions in hunting seasons will likely be necessary to achieve target harvest levels. In addition, strategies targeting highly productive cohorts, such as urban subpopulations, may also be critical for reducing overall survival and abundance. Nest destruction to induce molt migration or emigration is one potential option but may complicate management of geese in other states, especially in the northern latitudes (Luukkonen *et al.* 2007). Alternatively, lethal removal of geese may be necessary; however, the general public disapproves of most lethal strategies (Coluccy *et al.* 2001). Non-lethal methods such as contraception or translocation of geese from urban areas into rural areas susceptible to harvest may be appropriate control methods, but additional research on the effectiveness of such strategies will be necessary. For further research and evaluation of potential management options, the AGFC may consider increasing the banding program to include more locations within the suspected temperate-nesting

Canada goose range. For instance, banding sites within the Mississippi Alluvial Valley would improve monitoring of goose range expansion. In addition, banding and monitoring protocols which include molt migrants will be necessary to better characterize Arkansas's molt migrant demographics and behaviors and to better understand interactions between Arkansas's goose population and other states and provinces in the Mississippi Flyway.

As states throughout the Mississippi Flyway encounter similar growth in reintroduced temperate-nesting Canada goose populations, agencies may wish to revisit the Mississippi Flyway Council (1996) objectives and strategies to determine future management directions. High abundance and high survival— even as hunting regulations in normal and early seasons become increasingly liberal— pose challenges for agencies flyway-wide and contribute to the increasing number of negative human-goose encounters (Ankney 1996). Research and management on both lethal and non-lethal population control methods targeting highly reproductive and nuisance geese, especially in urban areas, will be necessary to maintain populations at appropriate levels. In addition, engagement of the public in decision making and implementation of population control methods, especially at the state and local level, may contribute to preventing further increase in human-goose conflict. In general, structured decision making regarding both harvest and non-harvest management will be crucial to achieving individual state and flyway objectives.

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