ABSTRACT

RUTLEDGE, MARTHA ELIZABETH. Impacts of Resident Canada Goose Movements on Zoonotic Disease Transmission and Human Safety at Suburban Airports. (Under the direction of Drs. Christopher S. DePerno and Christopher E. Moorman).

Over the past two decades, an increase in resident (non-migratory) Canada geese (*Branta canadensis*) in suburban areas of the United States has heightened the awareness of human-goose interactions and the associated risks to human health and safety. Resident geese may cause goose-aircraft collisions, transmit zoonotic diseases, decrease water quality through fecal deposition, and show aggression toward humans. In response, we evaluated resident Canada goose movements at and around a suburban airport, tested geese for zoonotic diseases, and provided monitoring strategies for geese. In 2008, we neck- and leg-banded 763 resident geese at 14 sites in and around Greensboro, North Carolina. We affixed satellite transmitters to a subset of geese and collected fecal samples for analysis. To evaluate goose movements, we resighted the geese with spotting scopes 2-3 times per week for 18 months and analyzed telemetry data. We calculated survival rates, home range sizes, and core areas, and evaluated the speed, altitude, and distance of goose movements. Additionally, we monitored site recolonization of nuisance geese after conducting a lethal removal. The annual survival of marked geese was 0.9 and the frequency of satellite-tagged goose movements peaked daily within the first 2 hours after sunrise and again at sunset, and all goose movements occurred at altitudes $\leq$ 64 m. We determined that 2.8% of goose movements occurred during the molt (1 Jun-15 Jul), 20.7% during post-molt I 2008 (16 Jul-31 Oct), 15.2% during post-molt II (1 Nov-31 Jan), 32.3% during breeding/nesting (1 Feb-31 May), and 29.0% during post-molt I 2009 (16 Jul-31 Oct). The mean distance travelled per day by satellite-tagged geese was between 2.0 km (SE = 0.3) and 4.9 km (SE = 0.4) with

results varying by sex and season. The mean fixed kernel home range and core area estimates (95 and 50% UD) were 991.8 ha (SE = 241.1) and 120.4 ha (SE = 24.6), respectively. The controlled removal of 60 resident geese from 1 site eliminated 24.2% of those initially marked at the site in 2008, but individual geese quickly recolonized the site following removal. The movements of resident Canada geese on or adjacent to the airport and rapid recolonization of the removal site suggests that removals should be conducted frequently and on larger spatial scales to reduce the potential for goose-aircraft collisions.

We used novel spatial mark-resight techniques to estimate seasonal changes in adult resident goose densities. The model determined that goose densities varied by sex and season, ranging from 11.1 individuals/km^2 (SE = 0.2) during breeding/nesting to 16.0 individuals/km^2 (SE = 0.3) during post-molt II. These results provide species-specific ecological information and are useful for determining when and where management strategies are needed to achieve desired population numbers to reduce negative human-goose interactions in suburban areas.

With regard to disease testing, all detected campylobacters were *C. jejuni* and prevalence in 2008 and 2009 was 5.0% and 16.0%, respectively. *Salmonella* was not detected. All *C. jejuni* isolates were susceptible to a panel of six antimicrobial agents (tetracycline, streptomycin, erythromycin, kanamycin, nalidixic acid, and ciprofloxacin). Multilocus sequence typing of representative isolates revealed six sequence types, of which two (ST-3708 and ST-4368) were new, two (ST-702 and ST-4080) were detected previously among *C. jejuni* from geese, and two (ST-991 and ST-4071) were first reported in *C. jejuni* from an environmental water source and a human case of illness. These results indicate a diverse population of antibiotic-susceptible *C. jejuni* in resident Canada geese in and around

Greensboro, North Carolina and suggest a need for additional assessment of the public health risk associated with resident geese in suburban areas.

Impacts of Resident Canada Goose Movements on Zoonotic Disease Transmission and Human Safety at Suburban Airports

by
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DEDICATION

I would like to dedicate my dissertation to J. C. and E. L. Beasley.

BIOGRAPHY

M. Elizabeth Rutledge completed a Bachelor of Science in Biology at Wingate University, a Master of Science in Natural Resources at North Carolina State University, and began working on her Ph.D. in Fisheries, Wildlife, and Conservation Biology at North Carolina State University in 2007.

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ABSTRACT

Resident (non-migratory) Canada goose (*Branta canadensis*) populations in suburban environments pose risks to human health and safety. Specifically, the relatively large size and gregarious behavior of geese combined with an overlap in aircraft flight space have resulted in property damage and human fatalities from goose-aircraft collisions. We determined the survival rates and home range and core use area estimates of resident Canada geese and evaluated goose movements to better define the risk of goose-aircraft collisions around Piedmont Triad International Airport in Greensboro, North Carolina, USA. We placed satellite transmitters on 16 geese and neck- and leg-banded 763 individuals to identify and track the geese over an 18-month study period. The frequency of satellite-tagged goose movements peaked daily within the first 2 hours after sunrise (28.1%) and again near sunset (27.2%). All in-flight goose movements occurred ≤ 64 m above ground level. Geese flying at these altitudes pose a risk to aircraft that are in the take-off and landing phases of flight. Of the satellite-tagged goose movements, 2.8% occurred during the molt (1 Jun-15 Jul), 20.7% during post-molt I 2008 (16 Jul-31 Oct), 15.2% during post-molt II (1 Nov-31 Jan), 32.3% during the breeding/nesting season (1 Feb-31 May), and 29.0% during post-molt I 2009. Satellite-tagged geese travelled an average distance of between 2.0 km (SE = 0.3) and 4.9 km (SE = 0.4) per day, depending on sex and season, which supports the need for intense goose management within a minimum distance of 5 km from suburban airports. Their mean

fixed 95% kernel home range and 50% core use area were 991.8 ha (SE = 241.1) and 120.4 ha (SE = 24.6), respectively. Annual survival of the marked geese was 0.9, and 15.3% (n = 117) died during the approximate 18-month study period. Additionally, we monitored site recolonization of nuisance geese after the controlled removal of 60 resident geese from 1 site, which eliminated 24.2% of those initially marked at the site in 2008, but other geese began to recolonize the site within 27 days. Rapid recolonization of the removal site suggests that lethal removal should be conducted at all molt locations within a minimum distance of 5 km of suburban airports and any additional resources should be applied to greater distances.

KEY WORDS airport risk, *Branta canadensis*, birdstrikes, Canada geese, controlled removal, home range, movements, North Carolina, survival.

INTRODUCTION

Resident Canada goose (*Branta canadensis*) movements across suburban landscapes may increase the number and severity of human-goose interactions. Geese contaminate water sources (Manny et al. 1994, Allan et al. 1995), degrade habitat, can be aggressive toward humans (Smith et al. 1999), and may have the potential to transmit zoonotic diseases (Graczyk et al. 1998, Smith et al. 1999, Kullas et al. 2002, Rutledge et al. 2013). Additionally, resident Canada geese pose a threat to human safety near airports. To properly manage suburban goose populations and alleviate the risk for goose-aircraft collisions, it is important to know where the geese are moving and at what altitude, how often these movements occur, and how much time is spent at sites where geese pose risks to human health and safety.

Wildlife-aircraft strikes have resulted in more than 250 human fatalities and 229

aircraft destroyed since 1988, of which birds account for 97% of these strikes (Dolbeer et al. 2013). Numerous species (e.g., Canada geese, vultures, gulls, blackbirds, pelicans, herons, and raptors) have been implicated in birdstrikes, causing concern for public safety at and near airports (Dolbeer et al. 2013). Additionally, populations of many large bird species have increased (Dolbeer and Eschenfelder 2003), and an estimated 80% of birdstrikes go unreported (Cleary et al. 2005). Geese have been ranked as the third most hazardous wildlife species to aircraft with approximately 240 goose-aircraft collisions occurring in the United States each year (Smith et al. 1999, Dolbeer et al. 2000). In 1995, 13 Canada geese were ingested by a U.S. Air Force jet at takeoff, killing all on board (Smith et al. 1999). In 2009, a commercial plane carrying 155 people made an unexpected landing in the Hudson River in New York after engine failure following the ingestion of Canada geese (Marra et al. 2009).

Resident Canada geese have high survival rates in suburban areas due to ample resources (e.g., water bodies and open areas of grass) and protection from hunting and natural predators (McCoy 2000). The adaptability of geese to human-dominated environments and public opposition to lethal management have made efforts to control goose populations difficult (Ankney 1996). Between 1990 and 2009, the number of resident Canada geese in the United States increased from an estimated 2.5 million to more than 5 million birds, intensifying the concern for human safety at or near suburban airports (Dolbeer 2011). Aircraft are particularly vulnerable to goose-aircraft collisions at takeoff and landing (Cleary and Dolbeer 2005) because of the relatively large size (~3.6-5.4 kg) of geese, their gregarious behavior, and overlap in altitude with aircraft; 74% of birdstrikes occur at <152 m in altitude and nearly 95% occur at ≤ 1,067 m (Dolbeer 2006, Martin et al. 2011).

Management techniques (e.g., scare tactics, habitat alteration, lethal removal, bird avoidance mechanisms) have been effective at reducing the immediate threat of goose-aircraft collisions on airport property, but little has been done to reduce the risk posed by geese outside of airport boundaries (Dolbeer 2011). Research is needed to evaluate daily and seasonal movements of resident geese within 8 km of suburban airports because it is the recommended distance that should be between an airport's air operations area and a hazardous wildlife attractant (e.g., retention/detention ponds, on-site mitigation projects with visible hydrology, marsh areas; FAA 2007, Dolbeer 2011, Martin et al. 2011). Therefore, our objectives were to: 1) determine survival and home range and core use areas of resident Canada geese, 2) evaluate goose movements on and around a suburban airport, 3) conduct a controlled goose removal and monitor recolonization rates, and 4) use study results to guide management of resident Canada goose populations near suburban airports.

STUDY AREA

We conducted our study around Piedmont Triad International (PTI) Airport in Greensboro, North Carolina, which has a human population of approximately 277,000, and covers nearly ~344 km^2 (City of Greensboro 2013). PTI Airport (36°1´05´´N, 79°93´73´´W) is operated by the PTI Airport Authority, and encompasses more than 1,135 ha (USDA 2005). In 2009, there were 1.7 million passengers and ~242 aircraft operations per day (J. Beadle, personal communication).

The airport property was comprised of mature hardwood and pine stands, areas of open grass, and natural and man-made drainage areas (USDA 2005), with approximately 62 retention (corporate and residential) and recreational ponds within 1.6 km of the airport

(Google Earth 2010). PTI Airport enforces a no-goose policy within the ~3 m high perimeter fence, but there have been 6 documented Canada goose-aircraft related strikes at PTI Airport in the last 15 years. The most notable occurred in October 2002, when a B-737-300 struck 16 geese (4 were ingested into the engines and 12 collided with the front of the plane) while landing; there were no human fatalities (USDA 2005).

METHODS

We neck- and leg-banded 763 Canada geese at 14 sites within 8 km of PTI Airport in June of 2008 (Fig. 1.1). Banding sites, selected based on goose presence, consisted of airport property (n = 1), local parks and lakes (n = 4), a residential area (n = 1), corporate landscapes (n = 6), a golf course (n = 1), and a rock quarry (n = 1). We live-captured geese and recorded the sex (cloacal examination), weight, and age (plumage evaluation) of each goose at banding. To identify and track individual geese, we used auxiliary neck bands (Spinner Plastics, 1108 North First Street, Springfield, IL 62702) with unique 4-character alpha-numeric codes and standard U.S. Fish and Wildlife Service aluminum bands (size 8; U.S. Geological Survey Bird Banding Lab [Laurel, MD]).

In August 2008, we attached Platform Transmitting Terminals (PTT)-100 70-g solar-powered Argos/Global Positioning Systems (GPS) satellite telemetry units (Microwave Telemetry, Inc., Columbia, MD 21045) to 16 geese randomly selected from the population of previously marked geese. We placed the satellite transmitters between the wings of each goose and tightly secured them with Teflon straps (Bally Ribbon Mills, Bally, PA) looped across the breast. We set the duty cycle to obtain 19 locations/goose/day during 0500 and 2300 hrs Eastern Standard Time (EST). For each GPS location obtained, we received the

associated flight speed (km/h) and altitude (m above sea level). Additionally, we analyzed data for the following seasons: molt (1 Jun-15 Jul), post-molt I (16 Jul-31 Oct), post-molt II (1 Nov-31 Jan), and breeding/nesting (1 Feb-31 May).

Flight and Movement Analysis

To quantify flight characteristics, we used all telemetry locations that were considered in-flight (i.e., corresponding speed ≥6 km/h and an altitude >1 m) and assigned a value of 22 m above ground level (AGL) to all location points that were inconsistent with known elevation estimates (Klaassen et al. 2008, Washburn and Olexa 2011). We calculated the mean altitude for all satellite-tagged geese combined and used the telemetry data to quantify the average percent of locations within 8 km of PTI Airport because it is the recommended distance between an airport's air operations area and a hazardous wildlife attractant. We determined the mean distance of the farthest recorded locations of geese from their banding sites, the maximum distance travelled from each goose's banding site, the average percentage of locations at each goose's banding site, the maximum distance travelled between 2 consecutive locations, and the mean distance travelled per day (by sex and season). We used 2-way ANOVA to determine if the mean distance geese travelled per day varied between sexes or among seasons (Zar 1996). We considered differences significant at $P \leq 0.05$.

We created an altitude occurrence matrix (Avery et al. 2011) using 217 in-flight locations to determine the percentage of goose movements within designated altitudinal ranges (0-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70 m AGL) and predefined seasons (molt, post-molt I, post-molt II, and breeding/nesting). Post-molt I was analyzed by year (2008 and 2009). All telemetry data were adjusted based on sunrise for Greensboro, North

Carolina. Then, we determined the frequency of occurrence and mean altitude of goose movements based on hours after sunrise (0 to 15 hrs; -1 represented the hour prior to sunrise) and the predefined seasons. We determined the proportion of movement and non-movement for all satellite-tagged geese combined by dividing the number of in-flight locations by the total number of locations collected.

Home Range Analysis

We used Home Range Tools (HRT; Rodgers et al. 2007) in ArcGIS version 9.3.1 (ESRI, Redlands, CA) to estimate the home range and core use area of each satellite-tagged goose. Prior to analysis, we converted all telemetry data collected between August 2008-November 2009 to EST and Universal Transverse Mercator coordinates. We calculated 95% and 50% utilization distributions (UD) using the fixed-kernel density estimation technique (Seaman and Powell 1996). Least-squares cross-validation frequently is used for kernel density estimation (kde) with animal movements, but HRT was unable to minimize the mean integrated square error for our data sets; therefore, we used H_{ref} to maintain the integrity of the data. We used the reference bandwidth (H_{ref}) as the primary method of determining the smoothing parameter; however, we used defined proportions of the H_{ref} when HRT was unable to create proper UDs. We rescaled to unit variance as needed (<0.5 or >1.5 x/y ratio; Rodgers et al. 2007) and used a reference grid-cell resolution of 10 m and a scaling factor of 1,000,000. Additionally, we used HRT to estimate the home range and core use area of each satellite-tagged goose for the following seasons: molt (1 Jun-15 Jul), post-molt I (16 Jul-31 Oct), post-molt II (1 Nov-31 Jan), and breeding/nesting (1 Feb-31 May). We used these 4 predefined seasons to evaluate changes in the frequency and distance of movements

throughout a goose's annual cycle. Post-molt I represents the time period after the molt has occurred leading up to post-molt II, which is indicative of the potential arrival of migratory geese during the winter months. We analyzed the post-molt I data for 2008 and 2009 for comparison between years. We used 2-way ANOVA to determine if the 95% home ranges and 50% core use areas varied between sexes or among seasons (Zar 1996).

Survival and Mortality

We resighted marked geese with spotting scopes 2-3 times per week in and around Greensboro from June 2008-December 2009. We varied our driving route and continuously added new sampling sites based on goose presence. We used a combination of telemetry data and visual resightings to track and identify individuals or groups of geese that frequented the area. We used the Kaplan-Meier method with censoring (Pollock et al. 1989) to estimate annual survival for the marked geese. We included mortality events due to hunting, but censored research-related mortalities and individual geese after they were last detected. We determined the cause of mortality from researcher observations and U.S. Geological Survey Bird Banding Lab reports.

Controlled Removal

In June 2009, we conducted a controlled goose removal at an original banding site to evaluate the rate of goose recolonization. We removed all resident geese from the site and determined the rate of recolonization by recording resightings on 13 random sampling days between 30 June and 3 December 2009. We determined the origin of the recolonizing geese based on neckband resightings from prior locations. All activities involving geese were conducted in accordance with the North Carolina State University Institutional Animal Care

and Use Committee (#08-038-O) and state and federal permits.

RESULTS

Flight and Movement Analysis

More than 99% of the telemetry locations were within 8 km of PTI Airport and 5.9% of these locations were on airport property. Based on the satellite telemetry data, geese were in flight 0.43% (SE = 0.1) of the time and flew at a mean altitude of 17.6 m (SE = 0.7) AGL with a maximum recorded altitude of 64 m AGL. The altitude occurrence matrix revealed that 28.1% (61 observations) of in-flight movements occurred within the first 2 hours after sunrise and an additional 27.2% (59) occurred close to sunset. The remaining 44.7% (97) were dispersed throughout the day (Fig. 1.3). Overall, 29.0% (63) of movements occurred within 0-10 m AGL, 18.9% (41) within 11-20 m AGL, 46.1% (100) within 21-30 m AGL, and 6.0% (13) at an altitude > 30 m AGL.

Of all in-flight movements, 20.7% (45) occurred during the 2008 post-molt I season, 15.2% (33) during the post-molt II season, 32.3% (70) during the breeding/nesting season, and 29.0% (63) during the 2009 post-molt I season. Only 2.8% (6) of in-flight movements occurred during the molt (Fig. 1.4). During the breeding/nesting season, resident geese made localized movements, typically within 2 km of their banding site, at all hours of the day (0-15 hours after sunrise). The frequency of movements during the post-molt I season peaked at 1 and 14 hours after sunrise (Fig. 1.4), and the mean altitudes were relatively constant across the 4 seasons.

The mean of the farthest distance the satellite-tagged geese were recorded from their banding site was 9.5 km (SE = 2.0), and the mean distance travelled per day was between 2.0

km (SE = 0.3) and 4.9 km (SE = 0.4) with results varying by sex and season (Table 1.4). Males moved an average distance of 3.5 km per day while females moved 2.8 km. Geese moved significantly farther during post-molt I and post-molt II than during the breeding/nesting or molt seasons. We detected a significant sex by season interaction ($F_{3,1213}$ = 14.3, $P < 0.0001$); males moved greater distances than females during the post-molt I and post-molt II seasons but the sexes moved similarly during the breeding/nesting and molt seasons. The maximum distance a satellite-tagged goose was located from its banding site was 26.1 km and the farthest distance travelled between consecutive locations was 6.2 km, which occurred between 1700 and 1800 hours. The average percent of telemetry locations recorded at each goose's banding site during the study period was 38.6% (SE = 6.7).

Home Range Analysis

The telemetry data used in the home range and core use area analysis encompassed the entire study period (Jun 2008-Dec 2009) and ranged from 513 to 5,440 locations per goose (Table 1.1). All telemetry data analyses included 16 individuals. The fixed kernel 95% UD for geese ranged from 76.0 to 3,755.6 ha (μ = 991.8 ha, SE = 241.1) and the core use area estimate (50% UD) ranged from 14.2 to 326.2 ha (μ = 120.4 ha, SE = 24.6) (Table 1.1; Fig. 1.2). The mean 95 and 50% UD seasonal estimates ranged from 81.0 (SE = 29.8) to 866.4 (SE = 384.7) and 12.1 ha (SE = 4.3) to 114.2 (SE = 51.1), respectively (Table 1.2). On average, geese traversed larger areas during the post-molt I season than all other seasons, which was consistent between years (2008 and 2009). As expected, resident geese traversed less area during the molt, followed by the breeding/nesting and post-molt II seasons (Table 1.2). During the breeding/nesting season, geese were located within the general vicinity of

their molt sites, with the concentration of telemetry locations increasing with onset of the molt. In 2008 and 2009, geese used the same sites to molt 93.8% of the time.

Although the home range ($F_{4,65}$ = 2.9, P = 0.03) and core use area ($F_{4,65}$ = 3.5, P = 0.01) sized varied among seasons, the home range ($F_{1,65}$ = 0.2, P = 0.67) and core use area ($F_{1,65}$ = 2.2, P = 0.14) sizes did not vary between male and female geese. The mean fixed kernel home range (95% UD) and core use area (50% UD) estimates for males (n = 5) were 963.2 ha (SE = 177.8) and 147.8 ha (SE = 40.4) and estimates for females (n = 11) were 1,004.8 ha (SE = 348.0) and 108.0 ha (SE = 31.2), respectively (Table 1.3). Although there were no significant differences between sexes, males in our study covered slightly larger areas than females during the breeding/nesting, molt, and post-molt II seasons, whereas the results from the post-molt I season varied by year (Table 1.3).

Survival and Mortality

We conducted 81 days of resightings and recorded 14,392 observations of marked geese. Ninety percent of these resightings were within 8 km of PTI Airport. We resighted marked geese at 87 locations throughout Greensboro with 5.3% of geese resighted at a distance greater than 8 km from the airport, and 4.7% were never resighted following capture. All goose resightings occurred in North Carolina except for 1 individual, which was resighted in Burlington, Ontario, Canada.

Of the 763 marked geese, 44% were male and 56% were female, and 89% were adults (after hatch year) and 11% were juveniles (hatch year). The mean weight for all male and female geese was 4.0 kg (SE = 0.1) and 3.5 kg (SE = 0.1), respectively. During the 18-month study period, 117 (15.3%) marked geese died. Direct and indirect causes of mortality

included hunting (32.5%, n = 38), controlled study removal and alpha-chloralose removal (26.5%, n = 31), airport property management (20.5%, n = 24), vehicles (11.1%, n = 13), unknown (4.3%, n = 5), predation (2.6%, n = 3), contact with electrical or grid wire (1.7%, n = 2), and controlled removal unrelated to the study (0.9%, n = 1). Based on resighting events and excluding mortality from the removal, the annual survival rate estimated from the Kaplan-Meier method was 0.9.

Controlled Removal

On 25 June 2009, we removed 60 (22 marked; 38 unmarked) resident Canada geese from 1 site (Fig. 1.5; site A). Of the removed geese that were marked, 68.2% (15) were marked at site A in 2008 and 31.8% (7) were marked at sites B and C in 2008 (Fig. 1.5). The site remained unoccupied for 27 days before geese (7 marked; 10 unmarked) were sighted. During the first 2 resighting events, all geese were originally marked at site A or site B (Fig. 1.5). Goose presence peaked at 46 days post-removal, with 31 marked and 73 unmarked geese. At that time, 87.0% (n = 27) of the marked geese originated from sites A or B and the remaining 13.0% (n = 4) originated from sites C, D, and E (Fig. 1.5). Thirteen percent of these geese had not been resighted at the removal site during the previous year. Newly identified marked geese continued to access the site post-removal from sites F, G, and H, with the farthest site being 10.5 km (Fig. 1.5).

DISCUSSION

Resident Canada geese pose the greatest risk to aircraft at take-off and landing during morning and evening hours as they move to and from foraging and roosting sites. During our study, all resident Canada goose movements were recorded at altitudes ≤ 64 m AGL.

Interestingly, within the last 15 years all 6 documented goose-aircraft collisions at PTI Airport occurred at ≤ 65 m AGL. Of the 6 previously documented collisions, 2 occurred during take-off, 2 during approach, and 2 during the landing roll phase of the aircraft.

Lethal removal of geese only from airport property will not completely eliminate the risk of goose-aircraft collisions because geese access airport space from much greater distances (Dolbeer 2011). Geese in our study often moved up to 5 km per day, which supports the need for intense goose management within a minimum distance of 5 km of airports. In fact, an individual goose travelled 21.8 km in a single day, which suggests geese can access runway departure and landing corridors from a much greater distance, but these events are less frequent. Our data suggests removal of geese from all molt sites within 5 km of suburban airports likely would reduce the risk geese would traverse runway space and cause goose-aircraft collisions.

The rapid recolonization of the site where we removed geese suggests localized lethal removals of resident geese have only short-term benefits. Although the site remained largely unused for 27 days, resident geese soon after began accessing it from a distance of up to 10.5 km. Recolonization likely coincided with the completion of the molt. All new geese recolonizing the site were resighted at other locations during the 12 months prior to removal, suggesting the benefits of one removal will be most successful if paired with removals at surrounding locations. Areas of concentrated goose-use (e.g., molt and breeding/nesting sites) within 5 km of suburban airports are ideal locations for lethal removal and habitat modification.

In suburban areas, resident (non-migratory) Canada geese have high survival rates

due to adequate habitat, and decreased predation and hunting opportunities (Balkcom 2010; Dunton and Combs 2010). Current management techniques (e.g., egg addling, hazing, and nest destruction) are effective at eliminating nuisance individuals (Smith et al. 1999), but are ineffective at reducing population numbers (Coluccy 2001). Study survival was similar to previous Canada goose studies (Groepper et al. 2008, Balkcom 2010). High survival rates require that intensive management strategies (i.e., annual removal, habitat modification) be implemented to reduce risks posed to human health and safety by stabilizing local resident goose populations.

Additionally, communication between airports and surrounding corporate facilities, local landowners, residents, and city and county park officials is imperative to building public support for lethal removal of geese in suburban areas. Water sources should be removed from within a 5-km radius of airports and new water bodies should not be constructed. The numerous retention ponds and drainage areas near PTI Airport were known attractants for waterfowl; therefore, reduction or removal of geese from the landscape surrounding PTI Airport either would require frequent and large-scale controlled removal of geese or elimination of these water sources. Future research should evaluate the effects of multiple controlled removals of nuisance geese within 5 km of airports and determine which lethal and non-lethal management strategies are acceptable to the public.

MANAGEMENT IMPLICATIONS

We determined that goose movements were greatest around dawn and dusk each day and peaked between mid-July and the end of October, so increased vigilance is imperative during these periods when the potential for goose-aircraft collisions is heightened. Our results

indicate that 1-time removal of resident geese at sites adjacent to airport property may provide a short-term reduction in the risk of goose-aircraft collisions because geese quickly recolonize removal sites. Therefore, removal programs must occur frequently and over an extensive land area surrounding an airport to successfully reduce the risk of goose-airport collisions for an extended time period. The majority of resources should be focused within a 5 km radius of the airport and, when available, management should extend farther than 5 km from airport property where geese are likely to still access the airport, but at a less frequent interval. Additionally, the use of non-lethal techniques (e.g., habitat modification, hazing, no-feeding programs) in combination with lethal removals may be an option to further reduce the risk geese pose to aircraft near suburban airports.

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LITERATURE CITED

Allan, J. R., J. S. Kirby, and C. J. Feare. 1995. The biology of Canada geese *Branta canadensis* in relation to the management of feral populations. Wildlife Biology 1: 129-143.

Ankney, C. D. 1996. An embarrassment of riches: too many geese. Journal of Wildlife Management 60: 217-223.

Avery, M. L., J. S. Humphrey, T. S. Daughtery, J. W. Fischer, M. P. Milleson, E. A. Tillman, W. E. Bruce, and W. D. Walter. 2011. Vulture flight behavior and implications for aircraft safety. Journal of Wildlife Management 75: 1581-1587.

Balkcom, G. D. 2010. Demographic parameters of rural and urban adult resident Canada geese in Georgia. Journal of Wildlife Management 74: 120-123.

City of Greensboro, North Carolina. 2013. 300 West Washington Street, Greensboro, North Carolina 27401. http://www.greensboro-nc.gov. Accessed November 2013.

Cleary, E. C., and R. A. Dolbeer. 2005. Wildlife hazard management at airports, a manual for airport personnel (2nd edition). U.S. Department of Transportation, Federal Aviation Administration, Office of Airport Safety and Standards. Washington, D.C., USA.

Cleary, E. C., R. A. Dolbeer, and S. E. Wright. 2005. Wildlife strikes to civil aircraft in the United States 1990-2004. U.S. Department of Transportation, Federal Aviation Administration, Serial Report No. 11 DOT/FAA/AS/00-6 (AAS-310). Washington, D.C., USA.

Coluccy, J. M., R. D. Drobney, D. A. Graber, S. L. Sheriff, and D. J. Witter. 2001. Attitudes of central Missouri residents toward local giant Canada geese and management alternatives. Wildlife Society Bulletin 29: 116–123.

Dolbeer, R. A., S. E. Wright, and E. C. Cleary. 2000. Ranking the hazard level of wildlife species to aviation. Wildlife Society Bulletin 28: 372-378.

Dolbeer, R. A., and P. Eschenfelder. 2003. Amplified bird-strike risks related to population increases of large birds in North America. Proceedings of the International Brid Strike Committee 26: 49-67.

Dolbeer, R. A. 2006. Height distribution of birds recorded by collisions with civil aircraft. U.S. Department of Agriculture, National Wildlife Research Center-Staff Publications. Paper 500.

Dolbeer, R. A. 2011. Increasing trend of damaging bird strikes with aircraft outside the airport boundary: implications for mitigation measures. Human-Wildlife Interactions 5: 235-248.

Dolbeer, R. A., S. E. Wright, J. Weller, and M. J. Begier. 2013. Wildlife Strikes to Civil Aircraft in the United States 1990-2012. Federal Aviation Administration, National Wildlife Strike Database. Serial Report Number 19. Office of Airport Safety and Standards, Washington, D.C., USA.

Dunton, E. M. and D. L. Combs. 2010. Movements, habitat selection, associations, and survival of giant Canada goose broods in central Tennessee. Human-Wildlife Interactions 4: 192-201.

Federal Aviation Administration (FAA). 2007. Hazardous wildlife attractants on or near airports. Advisory Circular AC150/5200-33B.

Graczyk, T. K., R. Fayer, J. M. Trout, E. J. Lewis, C. A. Farley, I. Sulaiman, and A. A. Lal. 1998. *Giardia* sp. Cysts and infectious *Cryptosporidium parvum* oocysts in the feces of migratory Canada geese (*Branta canadensis*). Applied and Environmental Microbiology 64: 2736-2738.

Groepper, S. R., P. J. Gabig, M. P. Vrtiska, J. M. Gilsdorf, S. E. Hygnstrom, and L. A. Powell. 2008. Population and spatial dynamics of resident Canada geese in southeastern Nebraska. Human-Wildlife Conflicts 2: 270-276.

Klaassen R. H. G., R. Strandberg, M. Hake, and T. Alerstam. 2008. Flexibility in daily travel routines causes regional variation in bird migration speed. Behavioral Ecology and Sociobiology 62: 1427-1432.

Kullas, H., M. Coles, J. Rhyan, and L. Clark. 2002. Prevalence of Escherichia coli serogroups and human virulence factors in faeces of urban Canada geese (*Branta canadensis*). International Journal of Environmental Health Research 12: 153-162.

Manny, B. A., W. C. Johnson, and R. G. Wetzel. 1994. Nutrient additions by waterfowl to lakes and reservoirs: predicting their effects on productivity and water quality. Hydrobiologia 279/280: 121-132.

Marra, P. P., C. J. Dove, R. Dolbeer, N. F. Dahlan, M. Heacker, J. F. Whatton, N. E. Diggs, C. France, and G. A. Henkes. 2009. Migratory Canada geese cause crash of US Airways Flight 1549. Frontiers in Ecology and the Environment 7: 297-301.

Martin, J. A., J. L. Belant, T. L. DeVault, B. F. Blackwell, L. W. Burger Jr., S. K. Riffell, and G. Wang. 2011. Wildlife risk to aviation: a multi-scale issue requires a multi-scale solution. Human-Wildlife Interactions 5: 198-203.

McCoy, N. H. 2000. Economic tools for managing impacts of urban Canada geese. U.S. Department of Agriculture, National Wildlife Research Center Symposia. University of Nebraska, USA. <http://digitalcommons.unl.edu/nwrchumanconflicts/12> Accessed 18 April 2013.

Pollock, K. H, S. R. Winterstein, C. M. Bunck, and P. D. Curtis. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53: 7-15.

Rodgers, A. R., A. P. Carr, H. L. Beyer, L. Smith, and J. G. Kie. 2007. Home Range Tools (HRT) for ArcGIS, version 1.1. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada.

Rutledge M. E., R. M. Siletzky, W. Gu, L. A. Degernes, C. E. Moorman, C. S. DePerno, and S. Kathariou. 2013. Characterization of *Campylobacter* from resident Canada geese in an urban environment. Journal of Wildlife Diseases 49: 1-9.

Seaman, D. E., and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77: 2075-2085.

Smith, A. E., S. R. Craven, and P. D. Curtis. 1999. Managing Canada geese in urban environments. Jack Berryman Institute Publication 16, and Cornell University Cooperative Extension, Ithaca, New York.

United States Department of Agriculture (USDA). 2005. Wildlife hazard assessment for Piedmont Triad International airport Greensboro, North Carolina February 2004-February 2005. U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services. Raleigh, NC.

Washburn, B. E., and T. J. Olexa. 2011. Assessing BASH risk potential of migrating and breeding osprey in the mid-Atlantic Chesapeake Bay region. Final Report to the U.S. Department of Defense, Legacy Resources Management Program, Arlington, Virginia, USA.

Zar, J. H. 1996. Biostatistical analyses. Third edition. Prentice-Hall, Upper Saddle River, New Jersey, USA.

Table 1.1 Home range (95% utilization distribution; UD) and core use area (50% UD; ha) estimates for resident Canada geese (n = 16) in and around Greensboro, North Carolina, 2008-2009. The number of points (*N*) used to determine the home range and core use area estimates (ha), sex, weight (kg), and the collection time period (Dates) are provided for each goose.

Goose	Sex	Weight	N	Dates	95%	50%
1	F	3.4	1,745	08/08-09/09	421.6	33.2
2	F	4.1	3,985	08/08-11/09	3,755.6	193.2
3	M	4.1	3,908	08/08-10/09	540.9	97.4
4	F	4.8	2,997	08/08-06/09	2,656.3	326.2
5	M	3.9	3,487	08/08-10/09	1,476.2	174.9
6	F	3.1	3,525	08/08-08/09	1,183.2	219.8
7	M	3.6	4,964	08/08-10/09	1,285.9	294.2
8	F	3.0	2,689	08/08-08/09	514.1	19.4
9	M	4.8	513	08/08-02/09	779.1	74.9
10	F	4.3	4,240	08/08-10/09	572.1	68.8
11	F	3.9	1,528	08/08-05/09	843.4	171.4
12	F	4.5	1,214	06/09-10/09	297.6	46.4
13	M	3.9	5,240	08/08-10/09	733.9	97.6
14	F	3.6	2,567	10/08-04/09	266.8	32.0
15	F	3.4	4,027	08/08-05/09	466.3	63.8
16	F	3.4	5,440	08/08-09/09	76.0	14.2

Table 1.2 Home range (95% utilization distribution; UD) and core use area (50% UD; ha) estimates for resident Canada geese (n = 16) in and around Greensboro, North Carolina, 2008-2009 by season (molt [1 Jun-15 Jul], post-molt I [16 Jul-31 Oct], post-molt II [1 Nov-31 Jan], and breeding/nesting [1 Feb-31 May]).

	95%	SE	50%	SE
Season				
Molt	81.0	29.8	12.1	4.3
Post-Molt I (2008)	562.1	136.9	87.9	20.9
Post-Molt II	222.7	52.8	26.3	6.6
Breeding/Nesting	194.6	60.6	34.5	13.0
Post-Molt I (2009)	866.4	384.7	114.2	51.1

Table 1.3 Home range (95% utilization distribution; UD) and core use area (50% UD; ha) estimates for 5 male and 11 female resident Canada geese in and around Greensboro, North Carolina, 2008-2009 during molt (1 Jun-15 Jul), post-molt I (16 Jul-31 Oct), post-molt II (1 Nov-31 Jan), and breeding/nesting (1 Feb-31 May).

Season	Sex	95%	SE	50%	SE
Entire Study	Female	1004.8	348.0	108.0	31.2
	Male	963.2	177.8	147.8	40.4
Molt	Female	59.6	33.1	8.3	4.0
	Male	123.9	61.5	19.7	9.9
Post-Molt I (2008)	Female	609.1	198.3	90.4	28.1
	Male	468.1	128.4	82.9	32.1
Post-Molt II	Female	154.6	37.2	16.6	3.6
	Male	375.7	129.0	48.3	15.8
Breeding/Nesting	Female	180.4	77.4	29.5	16.9
	Male	222.9	106.6	44.7	20.9
Post-Molt I (2009)	Female	810.2	559.7	73.2	43.6
	Male	964.9	505.0	186.0	120.9

Table 1.4 The mean distance geese travelled per day (km) categorized by sex and among 4 seasons (molt [1 Jun-15 Jul], post-molt I [16 Jul-31 Oct; 2008/2009], post-molt II [1 Nov-31 Jan], and breeding/nesting [1 Feb-31 May]). (*N)* is the number of days (19 data points/day) evaluated per analysis.

		Distance	
	N	km	SE
Molt			
Male	22	2.0	0.3
Female	30	2.1	0.2
Post-Molt I			
Male	197	4.8	0.2
Female	302	4.1	0.2
Post-Molt II			
Male	59	4.9	0.4
Female	98	2.4	0.2
Breeding/Nesting			
Male	188	2.2	0.1
Female	318	2.6	0.1

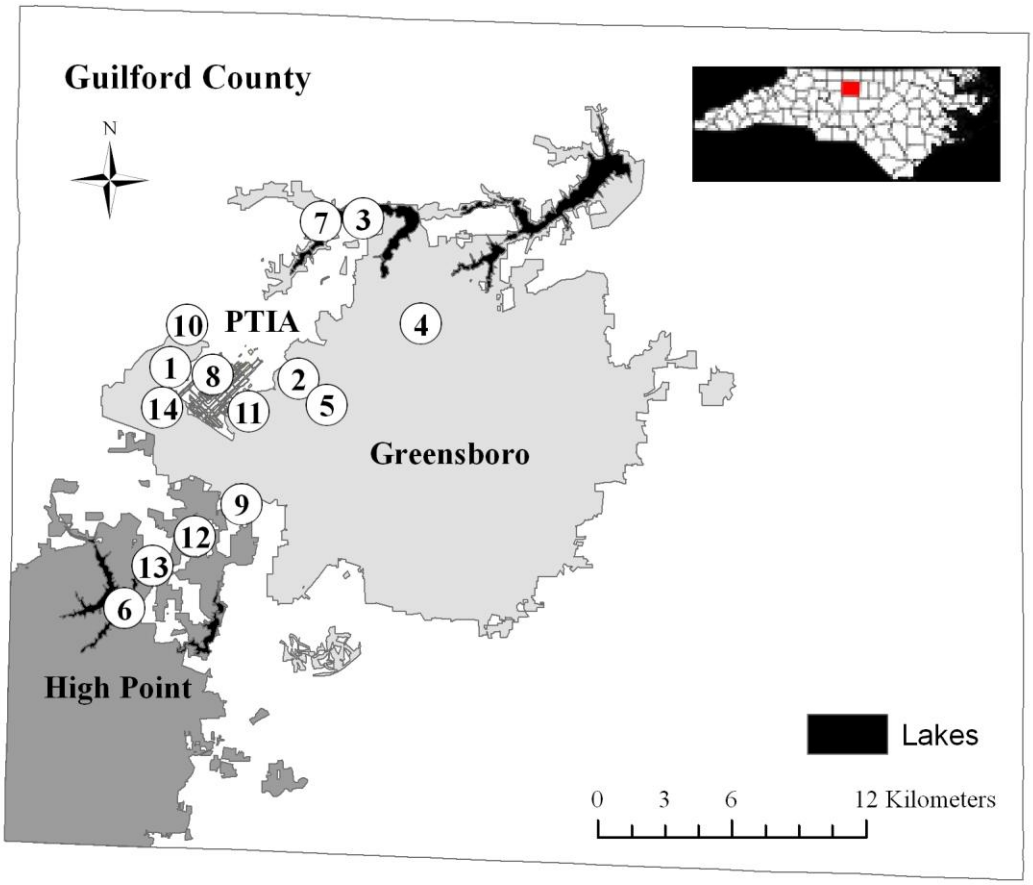


Figure 1.1 Map of Piedmont Triad International Airport and the location of 14 goose banding sites in and around Greensboro, North Carolina, 2008-2009.

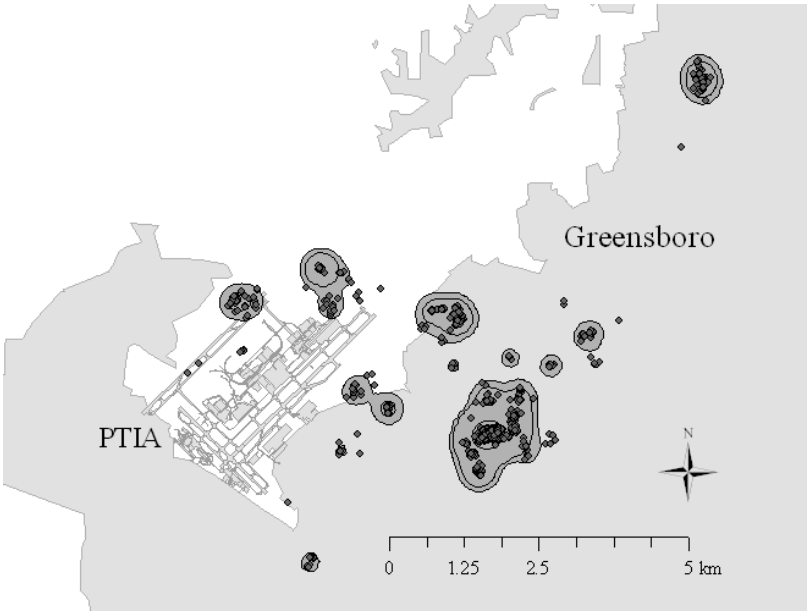
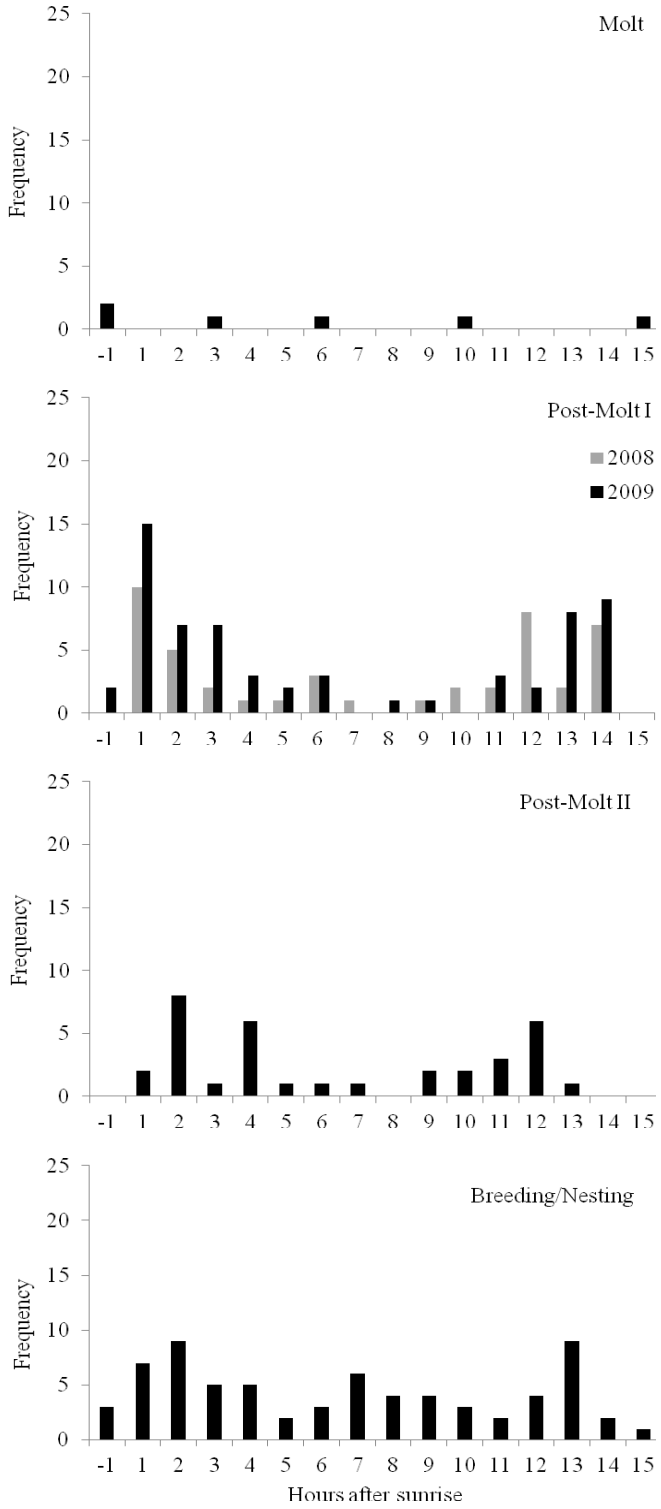


Figure 1.2 Graphical depiction of the annual home range and core use area estimates for Goose K3J2 on around Piedmont Triad International Airport in Greensboro, North Carolina, 2008-2009.

Figure 1.3 Frequency of resident Canada goose movements categorized by hours after sunrise (1-15 hours; -1 represents the hour prior to sunrise). Telemetry locations (n = 217) were collected in and around Greensboro, North Carolina, 2008-2009.

Figure 1.4 The frequency of resident Canada goose movements categorized by hour after sunrise (-1 representing the hour prior to sunrise) during molt (1 Jun-15 Jul), post-molt I (16 Jul-31 Oct), post-molt II (1 Nov-31 Jan), and breeding/nesting (1 Feb-31 May). The post-molt I season was analyzed by year (2008 and 2009). Telemetry locations (n = 217) were collected in and around Greensboro, North Carolina, 2008-2009.


Molt
Post-Molt I
2008
2009
Post-Molt II
Breeding/Nesting
Frequency
Hours after sunrise
-1 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 5 10 15 20 25

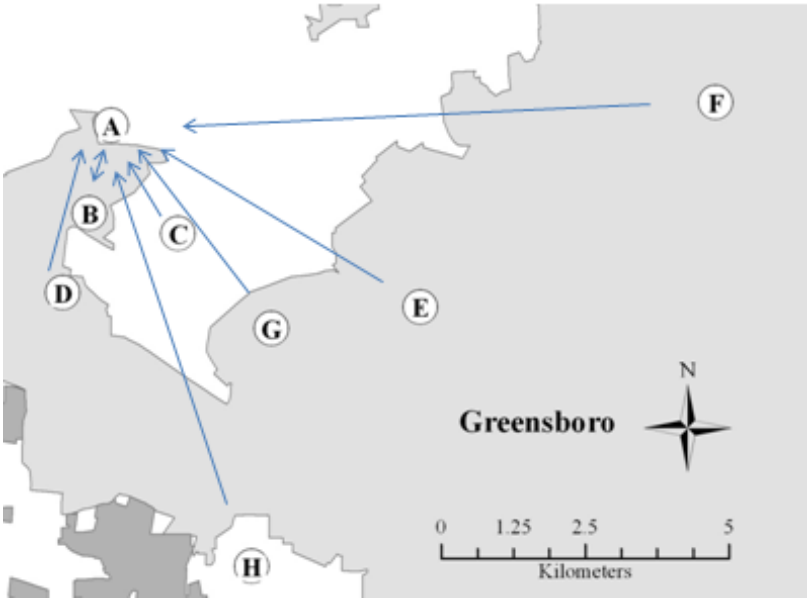


Figure 1.5 Resident goose movements between banding locations and the removal site (A). The geese originating from sites A and B used these 2 sites interchangeably.

USING NOVEL SPATIAL MARK-RESIGHT TECHNIQUES TO MONITOR RESIDENT CANADA GEESE IN A SUBURBAN ENVIRONMENT

ABSTRACT

Over the past two decades, an increase in the number of resident (non-migratory) Canada geese (*Branta canadensis*) in the United States has heightened the awareness of human-goose interactions. Accordingly, baseline demographic estimates for goose populations are needed to help better understand goose ecology in suburban areas. As a basis for monitoring efforts, we estimated adult resident goose densities in a suburban environment using a novel spatial mark-resight method. We resighted 763 neck- and leg-banded resident Canada geese 2-3 times per week in and around Greensboro, North Carolina over an 18-month period (June 2008-December 2009). We estimated the density, detection rates, proportion of male geese in the population, and the movements and home range radii of the geese by season (post-molt I 2008 [16 Jul-31 Oct], post-molt II 2008/2009 [1 Nov-31 Jan], breeding/nesting 2009 [1 Feb-31 May], and post-molt I 2009). Additionally, we used estimates of the number of marked individuals to quantify apparent monthly survival. Goose densities varied by season, ranging from 11.10 individuals/km^2 (SE = 0.23) in breeding/nesting to 16.02 individuals/km^2 (SE = 0.34) in post-molt II. The mean home range radii ranged from 2.60 to 3.86 km for males and 1.90 to 3.15 km for females and female home ranges were smaller than those of male geese during the breeding/nesting and post-molt II seasons. Apparent monthly survival across the study was high, ranging from 0.972 (SE = 0.005) to 0.995 (SE = 0.002). Spatial mark-resight models provide insight into wildlife population dynamics and are a valuable

tool to monitor Canada goose densities and movements over time.

KEY WORDS: *Branta canadensis*, density estimation, goose movements, home range, resident Canada geese, spatial mark-resight model.

INTRODUCTION

Canada geese (*Branta canadensis*) have become year-round residents in suburban areas across the United States, raising concern for human health and safety. Non-migratory geese have high survival rates and attain large numbers due to adequate habitat and decreased predation and hunting in suburban environments (Balkcom 2010, Dunton and Combs 2010). Consequently, between 1990 and 2009, the number of resident Canada geese in the United States increased from an estimated 2.5 million to more than 5 million birds (Dolbeer 2011). The presence and movement of resident Canada geese across suburban landscapes may contribute to zoonotic disease transmission (Graczyk et al. 1998, Kullas et al. 2002, Rutledge et al. 2013), contamination of water sources (Manny et al. 1994, Allan et al. 1995), habitat degradation (Smith et al. 1999), and the risk for goose-aircraft collisions (Dolbeer et al. 2013), leading to the need for a better understanding of resident goose population ecology.

Mark-resight models (White and Shenk 2001, McClintock et al. 2009) may be an appropriate alternative to estimate resident goose population sizes and movement characteristics when telemetry studies are unavailable due to financial or logistical constraints. Mark-resight models account for the inability to census wildlife populations because of imperfect detection of individuals and are less invasive than traditional capture-recapture methods. In mark-resight studies, researchers mark a random subset of individuals from the population and, subsequently, obtain noninvasive resighting data. The detection of

marked individuals in combination with the number of unmarked individuals sighted can be used to make inferences about population abundance. Once the geese have been marked, resighting using paid observers or volunteer citizens can be employed to collect the data needed for model analysis.

Previous studies have used mark-resight and band recovery techniques to estimate the movement, survival, site fidelity, home range, and brood ecology of Canada geese (Hestbeck et al. 1991, Kendall et al. 2006, Groepper et al. 2008, Balkcom 2010, Dunton and Combs 2010). However, traditional mark-resight models are limited when it comes to density estimation because the abundance estimate is not linked to a specific area. Hence, ad hoc methods need to be applied to effectively estimate the size of the sample area, much like traditional capture-recapture modeling (Karanth and Nichols 1998). Recent efforts to overcome this limitation have led to the development of spatial capture-recapture (Efford 2004, Royle and Young 2008) and spatial mark-resight models (Chandler and Royle 2013, Sollmann et al. 2013a,b). Spatial mark-resight models estimate the number of individuals living within a clearly defined area and incorporate where, relative to the array of resighting locations, individuals live and how far they move within the time frame of the study.

Here, we used novel spatial mark-resight (SMR) methods to estimate the density, detection rates, proportion of male geese in the population, survival, and movements and home range radii of resident Canada geese during 4 seasons across 18 months, in and around Greensboro, North Carolina. The study area was representative of a typical suburban landscape (e.g., airport, golf courses, retention ponds, recreational parks, and corporate lawns) where geese and humans interact daily and hunting opportunities are limited. To our

knowledge, this is the first study to use the SMR technique with an avian species of relatively high abundance and flocking behavior, which could be a promising approach for monitoring Canada geese in suburban environments.

STUDY AREA

The study was conducted in and around Greensboro, which is located in Guilford County, North Carolina. Greensboro encompassed nearly 344 km^2 and had approximately 277,000 human residents in 2012 (City of Greensboro 2013). Our study area contained a suburban airport (Piedmont Triad International) and numerous retention ponds and open grass areas frequented by resident Canada geese. The study site center was located at 36°1´05´´N, 79°93´73´´W.

METHODS

Marking and Resighting Canada Geese

From June 2008 until December 2009, we resighted 763 neck- and leg-banded resident Canada geese in the Greensboro, North Carolina area (Fig. 2.1). The geese were marked over a 3-day period (16-18 June) at 14 sites including airport property, corporate landscapes, golf courses, lakes, parks, residential areas, and a rock quarry. The banding sites were distributed randomly throughout the study area and the geese were considered resident because they were present in North Carolina between the months of April and August (USFWS 2011). We corralled geese from water and/or nearby grassy areas during the molt (flightless period) using walk-in panel traps, and recorded the sex (cloacal examination), age (plumage), and weight of each goose at the time of banding. For identification during resighting events, we attached a neck band (Spinner Plastics, 1108 North First Street,

Springfield, IL 62702) with a distinctive 4-character alpha-numeric code and a U.S. Fish and Wildlife Service aluminum band (size 8; U.S. Geological Survey Bird Banding Lab [Laurel, Maryland, USA]) to the right leg of each captured goose. All trapping and banding was conducted in accordance with the Institutional Animal Care and Use Committee protocol (ID#08-038-O). We released each goose immediately after banding and resighted the geese with a spotting scope 2-3 times per week in and around the Greensboro area from June 2008 until December 2009, resulting in 81 resighting surveys across 87 resighting locations (Fig. 2.1). In addition to recording marked individuals, we recorded the number of unmarked geese during each sampling event.

Closed Population Spatial Mark-Resight Model

We analyzed goose resighting data using a SMR model, which is closely related to spatial capture-recapture (SCR) models (Efford 2004, Royle and Young 2008, Borchers 2012). In these models, we assume that each individual *i* has an activity center, $\mathbf{s}_i$, and that all $\mathbf{s}_i$ are distributed uniformly across the state space *S*, which is an area that includes the trapping or resighting grid and is sizable enough to include all individuals potentially exposed to sampling. When each individual can only be recorded once at a given site on a given occasion, the observed data (0 or 1) of individual *i* at trap *j* and occasion *k*, y_{ijk}, are Bernoulli random variables with the encounter probability p_{ij}. We model p_{ij} as a decreasing function of the distance from trap *j* to the individual's activity center $\mathbf{s}_{i,,}$ d_{ij},. Under a Gaussian (or half-normal) encounter model, $p_{ij} = p_0 * \exp(- d_{ij}^2/2\sigma^2)$, where p_0 is the baseline trap encounter rate at $d_{ij} = 0$ and σ is the scale parameter of the half-normal function, which is related to how far the sampled individuals move.

To estimate N, the number of activity centers in S, we employ data augmentation (Royle et al. 2007, Royle and Dorazio 2012) and let n be the number of observed individuals. This approach is equivalent to augmenting the observed data set with M - n "all-zero" encounter histories or "hypothetical individuals" that were never observed. Then, N is estimated as the sum of an individual auxiliary variable, z_i,

$$z_i \sim \text{Bernoulli}(\Psi)$$

where $i = 1,2,3\ldots M$ and $z_i = 1$ if the individual is part of the population and 0 otherwise. The prior probability of Ψ is uniform (0,1), which corresponds to a discrete uniform (0,M) prior probability for N. M is an arbitrary value set sufficiently large enough as to not truncate estimates of N and density, D, can be derived by dividing N by the area of S.

Extension of the SCR Model to a Mark-Resight Situation

This model has recently been extended to a mark-resight situation, where only part of the population can be individually identified (Chandler and Royle 2013, Sollmann et al. 2013a,b). Under these circumstances, only y_{ijk} for the m marked animals are observed. For the unmarked individuals, we observe only the accumulated counts $\eta_{jk} = \sum \mathbf{y}_{ujk,}$ where u = $\{m+1,..., N\}$ is an index vector of the $N - m = U$ unmarked individuals. Unobserved encounter histories are essentially missing data. By adopting a Bayesian framework and using Metropolis-within-Gibbs (MwG) Markov chain Monte Carlo sampling, we can update missing data using their full conditional distribution (Gelman et al. 2004). Under the Bernoulli observation model, the full conditional for the y_{ijk} from unmarked animals is multivariate hypergeometric with sample size η_{jk}:

$$y_{ujk} \sim \text{Multivariate Hypergeometric } (\eta_{jk}, p_{uj}/\sum p_{uj})$$

The remaining model parameters are then updated depending on the full set of encounter histories.

When the number of marked individuals, *m*, is unknown, we need to estimate both *m* and the number of unmarked individuals *U*, and we do so by applying data augmentation to the data set of marked and unmarked individuals separately (Royle et al. 2014). Meaning that we estimate the number of marked individuals we never observed and the number of unmarked individuals. The total population size *N* can then be derived as $m + U$.

An important model assumption in non-spatial mark-resight models is that marked individuals represent a random subset of the population (Otis et al. 1978). In spatial mark-resight situations, the marked individuals must represent a spatially random sample of individuals in the state-space *S*. Here, to describe the state-space, we buffered the resighting locations by 4.5 km. We believe the assumption that marked geese were a random sample from the resulting state-space was a reasonable approximation because: (a) marking took place across the extent of the resighting array (Fig. 2.1); and (b) marking was done during the molt when geese were fairly immobile. Therefore, it was reasonable to assume that once the molt was complete the marked geese redistributed themselves across the state-space.

Model Application to Canada Goose Resighting Data

The above model is a closed population model and assumes no gains or losses of individuals during the study. To account for changes in biological processes that may affect goose movements and abundance during their annual cycle, we divided the total study period into 4 seasons: post-molt I 2008 (16 Jul-31 Oct), post-molt II 2008/2009 (1 Nov-31 Jan), breeding/nesting 2009 (1 Feb-31 May), and post-molt I 2009 (16 Jul-31 Oct) and analyzed

seasons separately. We divided post-molt into 2 seasons to detect changes in density due to the potential presence of migratory geese during the winter months. We did not analyze data from the molt (1 June-15 July) because geese were largely immobile and because a controlled removal experiment was conducted during the molt in 2009 (Chapter 1, Rutledge 2013), thus violating the assumption of population closure.

We allowed movement (σ) and the baseline encounter probability (p_0) to differ between males and females. We were unable to confirm with certainty if a marked goose was still alive and available for resighting at any given period, so we left the number of marked individuals as unknown and estimated this parameter as part of the model. Of the original 763 marked geese, 12 were removed from the model analysis because of insufficient data. Therefore, the total number of marked geese (n=751) was used as the upper limit for the augmented marked data set and we augmented each unmarked data set to the following sizes: post-molt I (2008): 7,000; post-molt II: 7,500; breeding/nesting: 5,500; post-molt I (2009): 5,500. We implemented the model using a custom-made MwG sampler in the software R 2.13.0 (R Development Core Team 2011). For each survey period we ran a single chain with 50,000 iterations and discarded 5,000 iterations as burn-in. We reported the posterior mean (± standard error) and 95% Bayesian Credible Intervals (95BCI) for all parameters.

The parameter σ is the scale parameter of the half-normal detection function we assumed in our model and is directly related to how far individuals move (Reppucci et al. 2011). This model implies a bivariate normal movement model, and σ can be translated into a 95% home range radius, *r*, using the formula $r = \sigma * \sqrt{5.99}$ (Royle et al. 2014).

Finally, we used the estimated number of marked geese across the 4 seasons to obtain estimates of apparent survival. We let seasons be denoted by *t* and estimated the survival rate as m_t/m_{t-1}; where m_{t-1} was the total number of geese marked before the first resighting period. Because the resighting periods had different lengths, we scaled the estimates to monthly apparent survival using the number of months between the midpoints of each 2 subsequent seasons.

RESULTS

Over an 18-month period, we resighted 763 marked geese at 87 different locations in the Greensboro area. Of the original 763 marked geese, 12 were removed from the model analysis because of insufficient data. Of the marked geese, 44% were determined to be male and 56% were determined to be female at the time of banding. The model estimates of the proportion of males within the study area ranged from 0.36 to 0.55 depending on the season. Additionally, 89% of the marked geese were adults (after hatch year), whereas the remaining 11% were juveniles (hatch year). We did not remove the hatch year juveniles from the sample because we would not have been able to remove the geese from the unmarked counts because age cannot be determined reliably upon resighting. The mean weights for male and female geese were 4.0 kg (SE = 0.1) and 3.5 kg (SE = 0.1), respectively. We accumulated a total of 8,676 resightings of marked geese and 13,610 resightings of unmarked geese across the 81 sampling days. The total number of sites visited at least once ranged from 57 during the post-molt I (2008) to 65 during breeding/nesting while the number of geese resighted decreased steadily over time (Table 2.1).

The SMR models indicated that geese were present at densities ranging from 11.10

individuals/km^2 (SE = 0.23) during breeding/nesting to 16.02 individuals/km^2 (SE = 0.34) during post-molt II. Estimates of the movement parameter σ ranged from 1.06 km (SE = 0.02) to 1.58 km (SE = 0.03) for males and 0.78 km (SE = 0.02) to 1.29 km (SE = 0.02) for females (Table 2.2), and were greatest for males during post-molt I 2009, whereas movement estimates were greatest for females during post-molt I 2008. The corresponding 95% bivariate normal home range radii ranged from 2.60 km to 3.86 km for males and 1.90 km to 3.15 km for females (Table 2.3). Lastly, the estimates of apparent monthly survival taken from the mid points of each 2 consecutive seasons (banding to post-molt I 2008: 0.995 [SE = 0.002], post-molt I 2008 to post-molt II: 0.995 [SE = 0.004], post-molt II to breeding/nesting: 0.972 [SE = 0.005], and breeding/nesting to post-molt I 2009: 0.994 [SE = 0.005]) were relatively high within the sample population.

DISCUSSION

Using the SMR methods, we demonstrated that Canada goose density estimates varied seasonally. During our study, Canada goose populations increased during the winter months likely from the presence of migratory geese in North Carolina. Goose density then decreased as breeding/nesting began and estimates were relatively similar across years for the post-molt I season. Nevertheless, these seasonal changes in density are reflective of the behavior and biological processes of geese. The density estimates in our study may be considered low when compared to an estimate of ~20 geese per km^2 using similar methods in suburban Nebraska (Groepper et al. 2008).

Movement estimates from the SMR analysis largely were similar to values determined during a concurrent study of 16 geese fitted with Argos GPS telemetry harnesses.

Goose home ranges from both SMR and the telemetry study consistently spanned larger areas during the post-molt I season (Chapter 1, Rutledge 2013). In comparison to male geese, the mean home range radii from SMR analysis for females were smaller during the post-molt II and breeding/nesting seasons (November-May), when female geese likely were preparing for and engaging in reproduction. Female resident Canada geese near Lincoln, Nebraska had a mean home range of 25.3 km^2 and the mean maximum distance moved between areas of use was 13 km (Groepper et al. 2008). We determined the mean home range size for female geese to be between 11.34 km^2 and 31.16 km^2, depending on the season. However, the mean home range estimate (9.92 km^2) of the telemetered geese was smaller, probably because the SMR estimates are based on the assumption the home range is circular. The SMR analysis indicated geese moved an average of < 4 km from their activity centers, which was similar to the mean distance travelled by the telemetered geese per day (2.0 km to 4.9 km) (Chapter 1, Rutledge 2013).

Resident goose movements varied by season and sex. Fluctuations in density estimates, home ranges, and goose movements across the landscape were likely related to habitat quality and availability. Interestingly, localized goose movements were concentrated around wetland areas which are known waterfowl attractants where breeding/nesting and molting occur. Many of the geese in our study flew short distances to access multiple small retention ponds on a regular basis, implying these concentrated areas of goose-use are ideal for monitoring and managing changes in goose density and movement across the landscape.

Survival rates of resident Canada geese were high in this suburban environment. The marked geese were continuously resighted within the study area throughout the entirety of

the study period, as indicated by the high estimates of apparent monthly survival within the sample population. A year after the initial marking, we estimated that 557/751 geese were still alive and within the study area and the annual survival of resident Canada geese in the Greensboro area was 0.9, which is indicative of adequate goose habitat with little predation and hunting (Chapter 1, Rutledge 2013). Similarly, a monthly survival rate of 0.94 and a study survival rate of 0.958 have been reported for resident Canada geese in other portions of their range (Groepper et al. 2008, Balkcom 2010).

While calculating relatively accurate survival, home range, and density estimates of resident geese, use of the current SMR model requires some knowledge of the distribution of geese across the study area. One caveat of the SMR method we used is the assumption that marked individuals represent a random sample, both demographically and spatially, from the state-space *S*. Ideally, this means that *S* needs to be defined before individuals are marked so that marking can take place across all of *S* (Royle et al. 2014). In the present application we set *S a posteriori*. Hence, estimates of density became sensitive to the choice of *S* and generally go down as *S* is increased. We believe that for our study, using *S* as the resighting area plus a 4.5-km buffer was adequate because geese were marked throughout most of the resighting area (Fig. 2.1) and during molt, when they are mostly immobile, giving them the chance to redistribute throughout *S* after marking. Although it is possible that absolute density estimates are influenced by the specific choice of *S*, relative changes in density across survey periods, as well as other estimates obtained from the SMR model (movement, apparent survival) should not suffer from this sensitivity to *S*. Ongoing development of SMR models is focusing on relaxing the assumption of marked individuals being a random spatial

sample from *S*.

Although defining the state-space of SMR models requires careful consideration, the technique represents a promising new tool to estimate and monitor the density and movement of free-ranging wildlife. Spatial mark-resight methods provide managers with estimates of population numbers and allow insight into animal movements without the need to employ more costly methods (e.g., telemetry). Also, when repeated across seasons or biologically important time periods, the use of SMR modeling techniques allow for inference about apparent survival. Because ample and accurate resighting data must be obtained, the approach would be most effective where proactive volunteers and citizen science programs can be incorporated into wildlife-related projects.

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LITERATURE CITED

Allan, J. R., J. S. Kirby, and C. J. Feare. 1995. The biology of Canada geese *Branta canadensis* in relation to the management of feral populations. Wildlife Biology 1: 129-143.

Balkcom, G. D. 2010. Demographic parameters of rural and urban adult resident Canada geese in Georgia. Journal of Wildlife Management 74: 120-123.

Borchers, D. 2012. A non-technical overview of spatially explicit capture–recapture models. Journal of Ornithology 152: 435-444.

City of Greensboro, North Carolina. 2013. 300 West Washington Street, Greensboro, North Carolina 27401. http://www.greensboro-nc.gov. Accessed November 2013.

Chandler, R. B. and J. A. Royle. 2013. Spatially-explicit models for inference about density in unmarked or partially marked populations. Annals of Applied Statistics 7: 936-954.

Dolbeer, R. A. 2011. Increasing trend of damaging bird strikes with aircraft outside the airport boundary: implications for mitigation measures. Human-Wildlife Interactions 5: 235-248.

Dolbeer, R. A., S. E. Wright, J. Weller, and M. J. Begier. 2013. Wildlife Strikes to Civil Aircraft in the United States 1990-2012. Federal Aviation Administration, National Wildlife Strike Database. Serial Report Number 19. Office of Airport Safety and Standards, Washington, D.C., USA.

Dunton, E. M., and D. L. Combs. 2010. Movements, habitat selection, associations, and survival of giant Canada goose broods in central Tennessee. Human-Wildlife Interactions 4: 192-201.

Efford, M. 2004. Density estimation in live-trapping studies. Oikos 106: 598–610.

Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin. 2004. Bayesian Data Analysis, Second Edition. CRC/Chapman and Hall, Boca Raton, Florida, USA.

Graczyk, T. K., R. Fayer, J. M. Trout, E. J. Lewis, C. A. Farley, I. Sulaiman, and A. A. Lal. 1998. *Giardia* sp. Cysts and infectious *Cryptosporidium parvum* oocysts in the feces of migratory Canada geese (*Branta canadensis*). Applied and Environmental Microbiology 64: 2736-2738.

Groepper, S. R., P. J. Gabig, M. P. Vrtiska, J. M. Gilsdorf, S. E. Hygnstrom, and L. A. Powell. 2008. Population and spatial dynamics of resident Canada geese in southeastern Nebraska. Human-Wildlife Conflicts 2: 270-276.

Hestbeck, J. B., J. D. Nichols, and R. A. Malecki. 1991. Estimates of movement and site fidelity using mark-resight data of wintering Canada geese. Ecology 72: 523-533.

Karanth, K. U., and J. D. Nichols. 1998. Estimation of tiger densities in India using photographic captures and recaptures. Ecology 79: 2852-2862.

Kendall, W. L., P. B. Conn, and J. E. Hines. 2006. Combining multistate capture-recapture data with tag recoveries to estimate demographic parameters. Ecology 87: 169-177.

Kullas, H., M. Coles, J. Rhyan, and L. Clark. 2002. Prevalence of Escherichia coli serogroups and human virulence factors in faeces of urban Canada geese (*Branta canadensis*). International Journal of Environmental Health Research 12: 153-162.

Manny, B. A., W. C. Johnson, and R. G. Wetzel. 1994. Nutrient additions by waterfowl to lakes and reservoirs: predicting their effects on productivity and water quality. Hydrobiologia 279/280: 121-132.

McClintock, B. T., G. C. White, M. F. Antolin, D. W. Tripp. 2009. Estimating abundance using mark-resight when sampling is with replacement or the number of marked individuals is unknown. Biometrics 65: 237-246.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62: 3-135.

R Development Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reppucci, J., B. Gardner, and M. Lucherini. 2011. Estimating detection and density of the Andean cat in the high Andes. Journal of Mammalogy 92: 140-147.

Royle, J. A., R. B. Chandler, R. Sollmann, and B. Gardner. 2014. Spatial capture-recapture. Academic Press, Waltham, MA, USA.

Royle, J. A., R. M. Dorazio, and W. A. Link. 2007. Analysis of multinomial models with unknown index using data augmentation. Journal of Computational and Graphical Statistics 16: 67–85.

Royle, J. A., and K. V. Young. 2008. A hierarchical model for spatial capture-recapture data. Ecology 89: 2281–2289.

Royle, J. A., and R. M. Dorazio. 2012. Parameter-expanded data augmentation for Bayesian analysis of capture–recapture models. Journal of Ornithology 152: 521–537.

Rutledge M. E., R. M. Siletzky, W. Gu, L. A. Degernes, C. E. Moorman, C. S. DePerno, and S. Kathariou. 2013. Characterization of *Campylobacter* from resident Canada geese in an urban environment. Journal of Wildlife Diseases 49: 1-9.

Smith, A. E., S. R. Craven, and P. D. Curtis. 1999. Managing Canada geese in urban environments. Jack Berryman Institute Publication 16, and Cornell University Cooperative Extension, Ithaca, New York.

Sollmann, R., B. Gardner, R. B. Chandler, D. B. Shindle, D. P. Onorato, J. A. Royle, and A. F. O'Connell. 2013a. Using multiple data sources provides density estimates for endangered Florida panther. Journal of Applied Ecology 50: 961-968.

Sollmann, R., B. Gardner, A. W. Parsons, J. J. Stocking, B. T. McClintock, T. R. Simons, K. H. Pollock, and A. F. O'Connell. 2013b. A spatial mark-resight model augmented with telemetry data. Ecology 94: 553–559.

U.S. Fish and Wildlife Service (USFWS). 2011. Final Environmental Impact Statement: Resident Canada Goose Management. Accessed April 2012. http://www.fws.gov/migratorybirds/CurrentBirdIssues/Management/cangeese/finaleis.htm.

White, G. C., and M. T. Shenk. 2001. Population estimation with radio-marked individuals, in: Millspaugh, J., and J. M. Marzluff (Eds.), Radio Tracking and Animal Populations. Academic Press, San Diego, USA, pp. 329-350.

Table 2.1 The number of sites visited, individual marked geese resighted, and marked (*m*) and unmarked (*U*) resightings used in the analysis for each season (post-molt I 2008 [16 Jul-31 Oct], post-molt II [1 Nov-31 Jan], breeding/nesting [1 Feb-31 May], and post-molt I 2009). All data were collected in and around Greensboro, North Carolina, 2008-2009.

Season	No. of Sites	No. of Geese Resighted	Resightings (*m*)	Resightings (*u*)
Post-Molt I 2008	57	654	3,994	3,950
Post-Molt II	61	465	1,613	3,184
Breeding/Nesting	65	424	1,548	2,585
Post-Molt I 2009	58	351	1,521	3,891

Table 2.2 Movement estimates (km) for females (σ(f)) and males (σ(m)), estimated proportion of male population (ϕ), baseline encounter probability (p_0), estimated number of marked geese in the state-space (m), total abundance (N; marked and unmarked), and total density (D, individuals/km^2) for post-molt I 2008 (16 Jul-31 Oct), post-molt II (1 Nov-31 Jan), breeding/nesting (1 Feb-31 May), and post-molt I 2009. Bayesian Confidence Intervals are the 2.5 and 97.5% quantiles of the posterior distributions. All data were collected in and around Greensboro, North Carolina, 2008-2009.

	Mean	SE	2.50%	97.50%
Post-Molt I (2008)				
σ(f)	1.29	0.02	1.26	1.32
σ(m)	1.06	0.02	1.02	1.11
ϕ	0.36	0.02	0.32	0.39
p_0	0.19	0.00	0.18	0.19
m	740	3.24	733	746
N	5756	90.68	5577	5932
D	13.76	0.19	13.38	14.14

Table 2.2 Continued

Post-Molt II				
σ(f)	0.78	0.02	0.74	0.82
σ(m)	1.30	0.02	1.26	1.34
ϕ	0.53	0.02	0.49	0.57
p_0	0.18	0.00	0.17	0.19
m	729	8.79	711	745
N	6833	157.80	6532	7150
D	16.02	0.34	15.37	16.70
Breeding/Nesting				
σ(f)	0.92	0.02	0.88	0.97
σ(m)	1.31	0.02	1.27	1.35
ϕ	0.55	0.02	0.51	0.59
p_0	0.16	0.00	0.15	0.17
m	660	10.16	639	679
N	4579	106.54	4371	4787
D	11.10	0.23	10.64	11.55

Table 2.2 Continued

Post-Molt I (2009)				
σ(f)	0.89	0.02	0.85	0.93
σ(m)	1.58	0.03	1.53	1.63
ϕ	0.51	0.02	0.47	0.55
p_0	0.15	0.00	0.15	0.16
m	639	14.51	610	667
N	4613	117.36	4388	4845
D	11.13	0.26	10.63	11.64

Table 2.3 Mean home range radii estimates (km) derived from the movement parameter σ of the spatial mark-resight model. The estimates are categorized by sex and season (post-molt I 2008 [16 Jul-31 Oct], post-molt II [1 Nov-31 Jan], breeding/nesting [1 Feb-31 May], and post-molt I 2009). All data were collected in and around Greensboro, North Carolina, 2008-2009.

	Post-Molt I (2008)	Post-Molt II	Breeding/Nesting	Post-Molt I (2009)
Female	3.15	1.90	2.26	2.18
Male	2.60	3.18	3.20	3.86

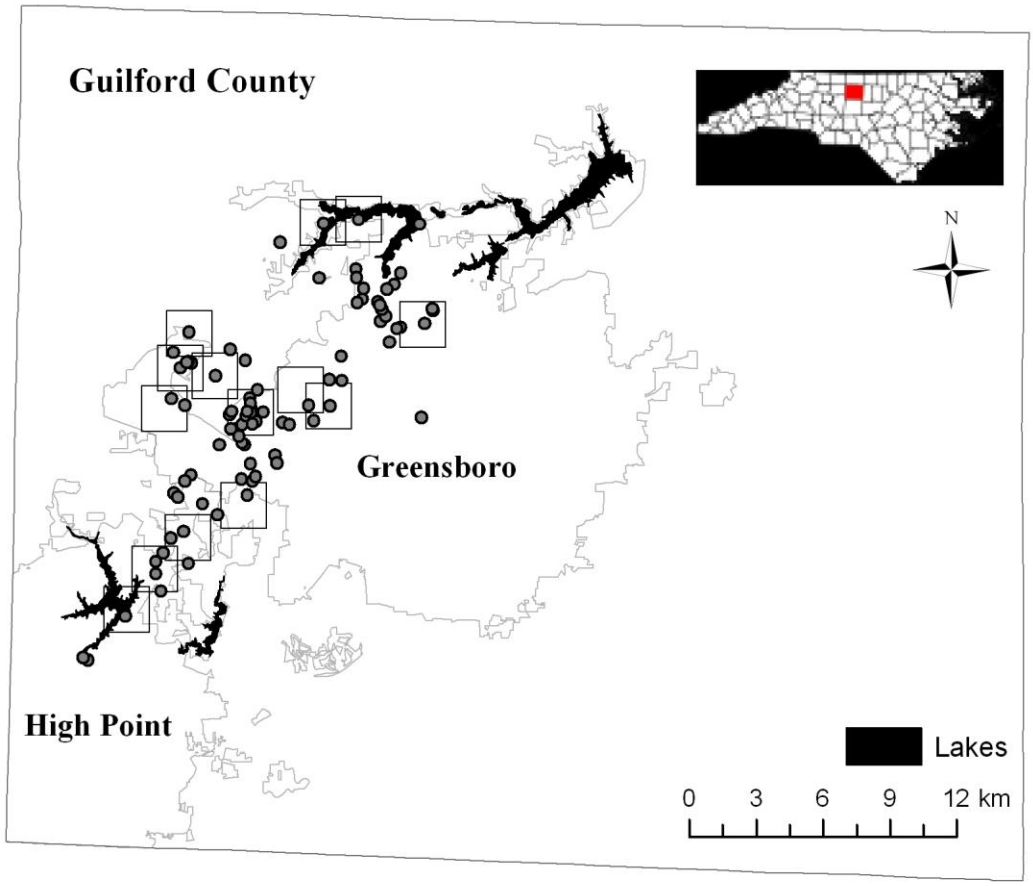

Figure 2.1 Fourteen Canada goose banding sites (□) and 87 resighting locations (•) distributed in and around Greensboro, North Carolina, 2008-2009.

Characterization of *Campylobacter* from Resident Canada Geese in an Urban Environment (Previously Published in Journal of Wildlife Diseases 49: 1-9)

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ABSTRACT: Waterfowl are natural reservoirs for zoonotic pathogens, and abundant resident (non-migratory) Canada Geese (*Branta canadensis*) in urban and suburban environments pose the potential for transmission of *Campylobacter* through human contact with fecal deposits and contaminated water. In June 2008 and July 2009, we collected 318 fecal samples from resident Canada Geese at 21 locations in and around Greensboro, North Carolina to test for *Campylobacter*. All campylobacters were *C. jejuni* and prevalence in 2008 and 2009 was 5.0% and 16.0%, respectively. Prevalence of *C. jejuni*-positive sampling sites was 21% (3/14) and 40% (6/15) in 2008 and 2009, respectively. All *C. jejuni* isolates were susceptible to a panel of six antimicrobial agents (tetracycline, streptomycin, erythromycin, kanamycin, nalidixic acid, and ciprofloxacin). We used pulsed-field gel electrophoresis and *fla*-typing to identify several strain types among these isolates. Multilocus sequence typing of representative isolates revealed six sequence types, of which two (ST-3708 and ST-4368) were new, two (ST-702 and ST-4080) were detected previously among *C. jejuni* from geese, and two (ST-991 and ST-4071) were first reported in *C. jejuni* from an environmental water source and a human case of illness, respectively. These results indicate a diverse population of antibiotic-susceptible *C. jejuni* in resident Canada Geese in and around Greensboro, North Carolina and suggest a need for additional assessment of the public health risk associated with resident Canada Geese in urban and suburban areas.
Key words: Branta canadensis, *Campylobacter*, *C. jejuni*, resident Canada Geese, strain types, waterfowl, zoonotic disease

INTRODUCTION

Resident (non-migratory) Canada Goose (*Branta canadensis*) populations have grown in

urban areas in North America, primarily because of increased availability of resources (e.g., open areas of grass and water) and lack of natural predators (McCoy, 2000). In 2008, the number of resident Canada Geese in the United States was estimated to be 4 million, 4 times the estimate in 1990 (Dolbeer et al., 2009). Increases in resident goose populations and the presence of fecal material may enhance the potential for transmission of infectious agents between geese and humans. Recreational areas (e.g., parks, corporate landscapes, golf courses) provide excellent habitats for geese, resulting in increased human-goose interactions. *Campylobacter* and other zoonotic pathogens can reside in the intestinal tract of birds (Aydin et al., 2001; Abulreesh et al., 2006; Van Dyke et al., 2010), and large amounts of feces (typically >0.45 kg of feces per day) produced by Canada Geese at recreational sites may constitute human health hazards (Kassa et al., 2001).

Campylobacter is one of the leading bacterial causes of human gastroenteritis, with 0.8 million cases annually in the United States (Scallan et al., 2011). Human gastroenteritis can be accompanied by severe autoimmune sequelae, including Guillain-Barré syndrome and Reiter's syndrome (Nachamkin et al., 1998; Skirrow and Blaser, 2000; Gillespie et al., 2002). Approximately 85% of human cases are due to *C. jejuni,* with the majority of the remainder involving *C. coli* (Friedman et al., 2000; Gillespie et al., 2002). *Campylobacter* can colonize (typically without symptoms) a large range of animal hosts, and contamination of poultry by this pathogen is considered a leading risk factor for human illness (Rosenquist et al., 2003).

The role of wildlife in human *Campylobacter* infections remains poorly characterized (Petersen et al., 2001; Hepworth et al., 2011; Jokinen et al., 2011). *C. jejuni* has been recovered from healthy waterfowl (Pacha et al., 1988, Fallacara et al., 2001, 2004; Abulreesh

et al., 2006; Van Dyke et al., 2010), but genotyping has failed to yield clear links to human campylobacteriosis (Fallacara et al., 2001, 2004; Wahlström et al., 2003; Abulreesh et al., 2006). However, in 1994 and 1995, large outbreaks of campylobacteriosis (approximately 1,000 people) in Norway were attributed to drinking water sources contaminated with *C. jejuni* from the feces of Pink-Footed Geese (*Anser brachyrhynchus*) (Varslot et al., 1996). In 2008, an outbreak of human campylobacteriosis in Alaska was attributed to peas contaminated with *C. jejuni* from feces of Sandhill Cranes (*Grus canadensis*) (Gardner et al., 2011).

Canada Geese have been recognized as contributors to water contamination and potential reservoirs for several pathogens, including *Campylobacter* (Pacha et al., 1988; Feare et al. 1999; Converse et al., 2001; Fallacara et al., 2001; Kassa et al., 2001; Van Dyke et al., 2010; Jokinen et al., 2011). However, the phenomenon of large resident populations of Canada Geese in urban and suburban settings in the United States is relatively recent, and limited data are available on prevalence and strain types of *Campylobacter* from these populations. Therefore, in the summer of 2008 and 2009, we determined prevalence of *Campylobacter* from a resident Canada Goose population at several urban and suburban sites in and around Greensboro, North Carolina. Additionally, we determined antimicrobial susceptibility of campylobacters and determined strain types via a combination of three strain typing tools.

MATERIALS AND METHODS

We collected fresh fecal samples from resident Canada Geese at 14 sites in 2008 and 15 sites in 2009 in and around Greensboro, North Carolina (36°4´48´´N, 79°56´59´´W) between 16-18 June 2008 (n=218) and on 27 July 2009 (n=100) (Fig. 1). The geese were considered

resident because only resident individuals are present in the region from March to August (USFWS 2011). Sample collection sites included local lakes, parks, fields, corporate landscapes, golf courses, and residential areas (Table 1; Fig. 1). The sites sampled and variability in the number of samples per site (5-45) reflected the number of geese present at each site during the sampling visit. We collected freshly voided fecal samples (based on wet appearance of the sample and direct observation of fecal droppings deposited by the birds) using a sterile tongue depressor, placed the samples in individual plastic bags, and stored them on ice in the field. The majority of samples (98%; 313/318) were collected on grass adjacent to water. Within 24h of collection, we took the fecal samples to the laboratory and stored them at 4°C until processing.

Isolation of *Campylobacter*

To isolate *Campylobacter, w*e plated fecal material (0.1 g) from each sample directly onto blood-free modified charcoal cefoperazone desoxycholate agar (CCDA; Oxoid, Hampshire, UK). We incubated the cultures at 42°C for 48 h in a microaerobic environment generated by a GasPak EZ Campy sachet (Becton, Dickinson and Co., Sparks, MD). We subcultured putative *Campylobacter* colonies on tryptic soy agar with 5% sheep blood (SBA; Remel, Lenexa, KS) until a pure culture was obtained. We characterized one colony from each of the *Campylobacter*-positive samples from 2008 and, when possible, selected two colonies from each of the 2009 positive samples.

Determination of *Campylobacter* species and antimicrobial susceptibility profiles

We determined the species of each purified *Campylobacter* isolate by polymerase chain reaction (PCR) (Smith et al., 2004) and tested the isolates for resistance against a panel of

antibiotics including tetracycline, streptomycin, erythromycin, kanamycin, nalidixic acid, and ciprofloxacin using the agar dilution method in serial 2-fold dilutions (Gu et al., 2009). Breakpoint values (ug/ml), previously described by Gu et al., 2009, included (ciprofloxacin, ≥4; erythromycin, ≥8; kanamycin, ≥64; nalidixic acid, ≥32; streptomycin, ≥64; tetracycline, ≥16).

***Campylobacter* strain typing**

To identify *Campylobacter* strain types among the isolates, we used *fla*-typing, pulsed-field gel electrophoresis (PFGE), and multilocus sequence typing (MLST). For *fla*-typing, we amplified the *fla*A gene with the polymerase chain reaction (PCR) using primers *fla*AF (ATGGGATTTCGTATTAACAC) and *fla*AR (CTGTAGTAATCTTAAAACATTTTG) (Smith et al., 2004). Digestion of the PCR product with DdeI, separation of the fragments, and analysis of the resulting image was conducted using BioNumerics (version 4.6; Applied Maths) (Smith et al., 2004). We performed cluster analysis using the band-based Dice coefficient with a lane optimization of 2.0% and band tolerance of 2.0% to identify genetic relatedness among strain types.

We performed PFGE using SmaI (Gu et al., 2009) and for cluster analysis we used the band-based Dice coefficient with a lane optimization of 1.5% and band tolerance of 1.5%. We generated a dendrogram (Fig. 2) using the unweighted-pair group method with arithmetic averages (UPGMA). To determine the allele profile and sequence type (ST), we performed MLST as described (Gu et al., 2009; Miller et al., 2006). The amplified products were sequenced by Genewiz, Inc. (Germantown, MD). The sequences were analyzed using BioEdit (version 7.0, BioEdit sequence Alignment Editor) and analyzed against the *C.*

jejuni/*C. coli* MLST database (http://pubmlst.org/*Campylobacter*) (Jolley and Maiden, 2010).

RESULTS

We isolated *Campylobacter* at three of the 14 (21%) sites in 2008 and six of the 15 (40%) sites in 2009. In 2008, fecal samples from the 'Golf Course' had putative *Campylobacter*, but the organisms failed to grow upon subculture and could not be confirmed. In 2009, samples from this same site yielded typical *Campylobacter* cultures (Table 1). Of the eight locations sampled in both years, two yielded *Campylobacter* each year. Of the remaining six sites sampled both in 2008 and 2009, four were negative in both years and two were positive for *Campylobacter* only in 2009 (Table 1).

We isolated *Campylobacter* from 10 of 218 (5%) fecal samples in 2008 and 16 of 100 (16%) samples in 2009 (Table 1). Prevalence of *Campylobacter*-positive samples varied among the sites, from 7% (1/15) to 80% (4/5). A residential neighborhood site, 'Residential 1', had the highest prevalence of *Campylobacter* each year (34% and 80%, respectively). In 2008, isolates from two sites accounted for 90% (9/10) of those obtained. These same two sites contributed 39% of the isolates obtained the following year. We obtained positive samples from four additional sites in 2009, three of which had not been surveyed in 2008 (Table 1).

All *Campylobacter* isolates were identified as *C. jejuni*. Although some variation in the antibiotic minimum inhibitory concentrations (MIC) was noted among the isolates, the MIC was below the resistance breakpoint value for each compound (Gu et al., 2009). Genomic fingerprinting of the *C. jejuni* isolates by *fla*-typing and PFGE indicated that in the majority (78%) of the *Campylobacter*-positive sites the Canada Geese were colonized by a single

strain of *C. jejuni* at a given time. Only two sites yielded two strain types each, both in 2009. Although the Canada Goose populations from these two sites had a mixture of *C. jejuni* strain types, the two isolates from the same sample always had the same *fla* and PFGE profiles (Fig. 2).

Strain types detected among isolates in 2008 were distinct from those of *C. jejuni* isolates from 2009. In 2008, we identified three strain fingerprints: one in *C. jejuni* from 'Corporate 2' and 'Residential 1' (one isolate each), a closely related type (identical *fla* types and a single-band difference with PFGE) in four isolates from 'Residential 1', and a third strain type in all four 'Corporate 10' isolates. Although all strain types from 2008 could be distinguished by *fla*-PFGE from 2009 samples, there were pronounced similarities between the 'Residential 1' isolates from 2008 and half of the isolates from the same site in 2009. These 'Residential 1' isolates from 2008 and 2009 shared the same *fla* type and had closely related PFGE profiles, differing only in the size of the largest band. Clearly distinct *fla* and PFGE profiles were exhibited by the remaining four isolates from 'Residential 1' in 2008 (Fig. 2).

Seven isolates (11957, 12022, 12156-1, 12184-2, 12188-1, 12189-1, and 12215-2) representative of distinct *fla*-PFGE profiles were analyzed by MLST. With the exception of 12215-2 and 12188-1, which were both of ST-4080 and had highly similar (92% identity) *fla* and PFGE profiles (Fig. 2), each of the other five isolates had different STs which also belonged to different clonal complexes. Notably, STs 3707 and 4368 were newly identified in this study.

DISCUSSION

In this study, resident Canada Geese shed *C. jejuni*. Although previous surveys provided evidence for the potential of Canada Geese to serve as reservoirs for *Campylobacter* (Pacha et al., 1988; Aydin et al., 2001; Wahlström et al., 2003; Van Dyke et al., 2010), limited data are available on *Campylobacter* strain types, genetic diversity, and antimicrobial susceptibility of *C. jejuni* from urban and suburban sites. In the current study, the focus was on *C. jejuni* and *C. coli*, as these are the *Campylobacter* species primarily responsible for human disease (Friedman et al., 2000; Gillespie et al., 2002).

We detected a prevalence of *C. jejuni* similar to that reported for migratory Canada Geese (5%) (Pacha et al., 1988) but significantly lower than the 50% prevalence from birds in metropolitan parks in central Ohio (Fallacara et al., 2001). Also, our data revealed relatively low frequency of *C. jejuni*-positive samples from several of the *C. jejuni*-positive sites, despite close proximity of the individual geese and the observed abundance of fecal droppings. It is possible that colonization was transitory or that bacteria in the droppings were rapidly inactivated by dehydration and UV light.

Season, size and extent of mobility of groups of Canada Geese, and vicinity to other sources of *Campylobacter* may account for the difference in prevalence observed between the current study and previous results (Fallacara et al., 2001). Furthermore, the cross-sectional nature of the study allowed us to survey a number of different groups of geese at a variety of sites but prevented us from assessing the temporal persistence of colonization status or of strain types. Our results indicate that for several sites data from one year could not predict prevalence or strain types for the following year. However, for the two sites that

were *C. jejuni*-positive in 2008 and 2009, isolates from 'Residential 1' in 2008 were highly similar to some of the isolates from the same site in 2009. The limited difference (the size of the largest SmaI fragment) could reflect genetic differentiation as the bacteria amplified in the birds.

Thermophilic campylobacters were not isolated from several sites, including four of those surveyed in 2008 and 2009. The reasons for *C. jejuni* being isolated from birds at some sites but not others are not clear and may reflect attributes of the feeding grounds at those sites or the extent of commingling with other individuals. Longitudinal studies are needed to assess the duration of *C. jejuni*-positive or *C. jejuni*-negative status in a given population.

Similar to previous reports, all campylobacters isolated were *C. jejuni* and were susceptible to a panel of antibiotics (Fallacara et al., 2001, 2004). A study of river water and waterfowl in Canada revealed that *C. jejuni* was the most frequently isolated *Campylobacter* species and also described recovery of *C. lari* from fecal samples of Canada Geese (Van Dyke et al., 2010). The isolation methods we employed were optimized for the recovery of thermophilic campylobacters (*C. jejuni*, *C. coli*, *C. lari*); therefore, we were unable to exclude the presence of other *Campylobacter* species. Furthermore, prevalence data were based on direct plating on selective media and higher prevalence may have been detected had selective enrichments been used. The choice for direct plating was made to allow unbiased strain recovery, as certain strains may outcompete others during selective enrichment protocols (Harder and Dijkhuizen, 1982; Dunbar et al., 1997).

The *fla*-PFGE and MLST data indicated that a diverse collection of strains colonized the Canada Geese surveyed in this study. The sharing of water sources and adjacent land by

multiple groups of resident Canada Geese would be expected to promote transmission of *Campylobacter* among geese and may account for ST-4080 becoming disseminated among several sites in 2009. The resident Canada Geese sampled moved freely among the sites and bodies of water in the area (M. E. Rutledge, unpublished data) and *Campylobacter* may spread from one group of Canada Geese to individuals in other locations as birds move between foraging and roosting sites (Kassa et al., 2001). However, our study shows strain homogeneity within each sampled group which may support a lack of mixing among the geese or with other avian sources of *Campylobacter*.

With the exception of one sequence type (ST-4071, clonal complex ST-1034), which was detected in *C. jejuni* from a case of human campylobacteriosis in Canada, the strain types of *C. jejuni* from the Canada Geese were not previously encountered among human clinical cases or among *C. jejuni* from food animals. The predominant sequence types, ST-4080 and ST-702, were previously identified among *C. jejuni* from Canada Geese, while ST-991 (clonal complex ST-692) was previously identified in *C. jejuni* from environmental water. Isolates of *C. jejuni* from water and wildlife appear to comprise a distinct clade with limited representation among human isolates (Hepworth et al., 2011). However, testing of two *C. jejuni* strains from Canada Geese in a day-old chick colonization model indicated that both were capable of colonizing the chicks (R. M. Siletzky and S. Kathariou, unpublished), suggesting the potential of *C. jejuni* from Canada Geese to enter the poultry production system.

Due to differences in STs between resident Canada Geese and humans and the lack of antimicrobial resistance of the goose isolates, our study indicates that resident Canada Geese

may not be a substantial source of *C. jejuni* infection in humans. More research is needed to assess the hazards of sharing locations with Canada Geese, including surveillance of human and animal samples from urban and animal production environments.

Our objective and focus for this paper was to characterize *Campylobacter* in resident Canada Geese. However, *Salmonella* sampling (n=100) was conducted in 2009, but no isolates were detected. The absence of *Salmonella* is similar to results from previous studies (Hussong et al. 1979; Fallacara et al., 2001; Wahlström et al., 2003).

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LITERATURE CITED

Abulreesh, H. H., T. A. Paget, and R. Goulder. 2006. *Campylobacter* in waterfowl and aquatic environments: incidence and methods of detection. Journal of Environmental Science and Technology 40: 7122-7131.

Aydin, F., H. I. Atabay, and M. Akan. 2001. The isolation and characterization of *Campylobacter jejuni* subsp. *jejuni* from domestic geese (*Anser anser*). Journal of Applied Microbiology 90: 637-642.

Converse, K. A., M. Wolcott, D. Docherty, and R. Cole. 2001. Screening for potential human pathogens in fecal material deposited by resident Canada geese on areas of public utility. U.S. Geological Survey, Biological Resources Division, National Wildlife Health Center, Madison, Wisconsin, 16 pp.

Dolbeer, R. A., S. E. Wright, J. Weller, and M. J. Begier. 2009. Wildlife strikes to civil aircraft in the United States 1990-2008. Federal Aviation Administration, National Wildlife Strike Database Serial Report Number 15, Report of the Associate Administrator of Airports, Office of Airport Safety and Standards, Airport safety and Certification Washington, DC, 72 pp.

Dunbar, J., S. White, and L. Forney. 1997. Genetic diversity through the looking glass: effect of enrichment bias. Applied and Environmental Microbiology 63: 1326-1331.

Fallacara, D. M., C. M. Monahan, T. Y. Morishita, and R. F. Wack. 2001. Fecal shedding and antimicrobial susceptibility of selected bacterial pathogens and a survey of intestinal parasites in free-living waterfowl. Avian Diseases 45: 128-135.

_____, _____, C.M. Monahan, T.Y. Morishita, C.A. Bremer, and R. F. Wack. 2004. Survey of parasites and bacterial pathogens from free-living waterfowl in zoological settings. Avian Diseases 48: 759-767.

Feare, C. J., M. F. Sanders, R. Blasco, and J. D. Bishop. 1999. Canada goose (*Branta canadensis*) droppings as a potential source of pathogenic bacteria. Journal of the Royal Society for the Promotion of Health 119: 146-155.

Friedman, C. R., J. Neimann, H. C. Wegener, and R. V. Tauxe. 2000. Epidemiology of *Campylobacter jejuni* infections in the United States and other industrialized nations, *In Campylobacter*, 2nd Edition. I. Nachamkin and M. J. Blaser (Eds.), American Society for Microbiology, Washington, DC, pp. 121-138.

Gardner, T. J., C. Fitzgerald, C. Xavier, R. Klein, J. Pruckler, S. Stroika, and J. B. McLaughlin. 2011. Outbreak of campylobacteriosis associated with consumption of raw peas. Clinical Infectious Diseases 53: 26-32.

Gillespie, I. A., S. J. O'Brien, J. A. Frost, G. K. Adak, P. Horby, A. V. Swan, M. J. Painter, and K. R. Neal. 2002. A case-case comparison of *Campylobacter coli* and *Campylobacter jejuni* infection: a tool for generating hypotheses. Emerging Infectious Diseases 8**:** 937-942.

Gu, W., R. M. Siletzky, S. Wright, M. Islam, and S. Kathariou. 2009. Antimicrobial susceptibility profiles and strain type diversity of *Campylobacter jejuni* isolates from turkeys in eastern North Carolina. Applied and Environmental Microbiology 75: 474-482.

Harder, W., and L. Dijkhuizen. 1982. Strategies of mixed substrate utilization in microorganisms. Philosophical Transactions of the Royal Society of London Series B 297: 459-480.

Hepworth, P. J., K. E. Ashelford, J. Hinds, K. A. Gould, A. A. Witney, N. J. Williams, H. Leatherbarrow, N. P. French, R. J. Birtles, C. Mendonca, N. Dorrell, B. W. Wren, P. Wigley, N. Hall, and C. Winstanley. 2011. Genomic variations define divergence of water/wildlife-associated *Campylobacter jejuni* niche specialists from common clonal complexes. Environmental Microbiology 13: 1549-1560.

Hussong, D., J. M. Damaré, R. J. Limpert, W. J. L. Sladen, R. M. Weiner, and R. R. Colwell. 1979. Microbial impact of Canada geese (*Branta canadensis*) and whistling swans (*Cygnus columbianus*) on aquatic ecosystems. Applied and Environmental Microbiology 37: 14-20.

Jokinen, C., T. A. Edge, S. Ho, W. Koning, C. Laing, W. Mauro, D. Medeiros, J. Miller, W. Robertson, E. Taboada, J. E. Thomas, E. Topp, K. Ziebell, and V. P. J. Gannon. 2011. Molecular subtypes of *Campylobacter* spp., *Salmonella enterica*, and *Escherichia coli* O157:H7 isolated from faecal and surface water samples in the Oldman River watershed, Alberta, Canada. Water Research 45: 1247-1257.

Jolley, K. A., and M. C. J. Maiden. 2010. BIGSdb: Scalable analysis of bacterial genome variation at the population level. BMC Bioinformatics 11:595.

Kassa, H., B. Harrington, and M. S. Bisesi. 2001. Risk of occupational exposure to *Cryptosporidium*, *Giardia*, and *Campylobacter* associated with the feces of Giant Canada geese. Applied Occupational and Environmental Hygiene 16: 905-909.

McCoy, N. H. 2000. Economic tools for managing impacts of urban Canada geese. USDA National Wildlife Research Center Symposia, Human Conflicts with Wildlife: Economic Considerations. University of Nebraska, Lincoln, Nebraska.

Miller, W. G., M. D. Englen, S. Kathariou, I. V. Wesley, G. Wang, L. Pittenger-Alley, R. M. Siletzky, W. Muraoka, P. J. Fedorka-Cray, and R. E. Mandrell. 2006. Identification of host-associated alleles by multilocus sequence typing of *Campylobacter coli* strains from food animals. Microbiology 152: 245-255.

Nachamkin, I., B. M. Allos, and T. Ho. 1998. *Campylobacter* species and Guillain-Barré syndrome. Clinical Microbiology Reviews 11: 555-567.

Pacha, R. E., G. W. Clark, E. A. Williams, and A. M. Carter. 1988. Migratory birds of central Washington as reservoirs of *Campylobacter jejuni*. Canadian Journal of Microbiology 34: 80-82.

Petersen, L., E. M. Nielsen, J. Engberg, S. L. W. On, and H. H. Dietz. 2001. Comparison of genotypes and serotypes of *Campylobacter jejuni* isolated from Danish wild mammals and birds and from broiler flocks and humans. Applied and Environmental Microbiology 67: 3115-3121.

Rosenquist, H., N. L. Nielsen, H. M. Sommer, B. Nørrung, and B. B. Christensen. 2003. Quantitative risk assessment of human campylobacteriosis associated with thermophilic *Campylobacter* species in chickens. International Journal of Food Microbiology 83: 87-103.

Scallan, E., R. M. Hoekstra, F. J. Angulo, R. V. Tauxe, M. A. Widdowson, S. L. Roy, J. L. Jones, and P. M. Griffin. 2011. Foodborne illness acquired in the United States--major pathogens. Emerging Infectious Diseases 17: 7-15.

Smith, K., N. Reimers, H. J. Barnes, B. C. Lee, R. Siletzky, and S. Kathariou. 2004. *Campylobacter* colonization of sibling turkey flocks reared under different management conditions. Journal of Food Protection 67: 1463-1468.

Skirrow, M. B., and M. J. Blaser. 2000. Clinical aspects of *Campylobacter* infection. *In Campylobacter*, 2nd Edition. I. Nachamkin and M. J. Blaser (Eds.), American Society for Microbiology, Washington, DC, pp. 69-88.

United States Fish and Wildlife Service (USFWS). 2011. Final Environmental Impact Statement: Resident Canada Goose Management, http://www.fws.gov/migratorybirds/CurrentBirdIssues/Management/cangeese/finaleis.htm. Accessed April 2012.

Van Dyke, M. I., V. K. Morton, N. L. McLellan, and P. M. Huck. 2010. The occurrence of *Campylobacter* in river water and waterfowl within a watershed in southern Ontario, Canada. Journal of Applied Microbiology 109: 1053-1066.

Varslot, M., J. Resell, and I. G. Fostad. 1996. Water-borne *Campylobacter* infection—probably caused by pink-footed geese. Two outbreaks in Nord-Trøndelag, Stjørtdal in 1994 and Verdal in 1995. Tidsskrift for Den Norske Laegeforening 116: 3366-3369.

Wahlström, H., E. Tysén, E. Olsson Engvall, B. Brändström, E. Eriksson, T. Mörner, and I. Vågsholm. 2003. Survey of *Campylobacter* species, VTEC O157 and *Salmonella* species in Swedish wildlife. Veterinary Record 153: 74-80.

TABLE 1. Number of fecal samples and isolated strains of *C. jejuni* collected per site in and around Greensboro, North Carolina, 2008-2009. No fecal samples were collected at some sites during some sampling visits (-) because Canada Geese were not present. Strain relatedness is indicated with different letters (A-D).

	2008		**2009**	
Site	# Sampled	*Campylobacter* positives (strain)[a]	# Sampled	*Campylobacter* positives (strain)[a]
Corporate 1	15	0	5	0
Corporate 2	15	1 (A)	-	-
Corporate 3	-	-	5	0
Corporate 4	-	-	5	3 (C)
Corporate 5	15	0	5	0
Corporate 6	15	0	-	-
Corporate 7	15	0	5	2 (C1, D)
Corporate 8	-	-	10	3 (C)
Corporate 9	8	0	-	-
Corporate 10	15	4 (B1)	10	2 (C)
Corporate 11	6	0	-	-
Residential 1	15	5 (A)	5	4 (A1, C)
Residential 2	-	-	5	0
Golf Course	15	0[b]	5	2 (B)
Field 1	-	-	5	0
Field 2	-	-	10	0
Lake 1	15	0	-	-
Lake 2	15	0	-	-
Park 1	-	-	10	0
Park 2	9	0	5	0
Park 3	45	0	10	0
Total	**218**	**10[b]**	**100**	**16**

[a] Strain designations are based on combined SmaI and *fla* profiles and are described in Fig. 2.

[b] We were unable to confirm two putative *Campylobacter* isolates.

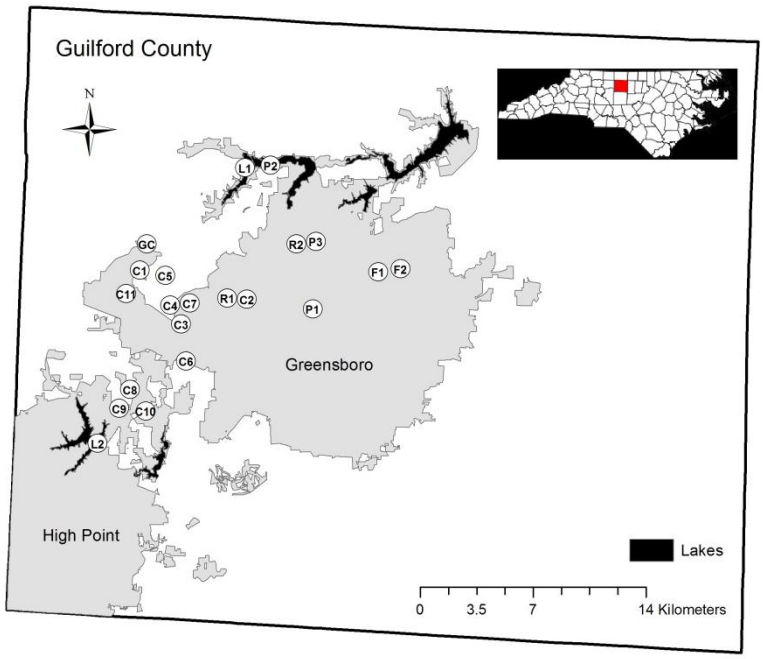

FIGURE 1. Sites (n=21) sampled for *Campylobacter* spp. in the Greensboro, North Carolina area. Site labels categorized based on sampling location; C: Corporate, F: Field, GC: Golf Course, L: Lake, P: Park, and R: Residential.

FIGURE 2. Dendrogram of Canada Goose *C. jejuni* isolates based on the combined profiles generated by PFGE using SmaI and *fla*-typing from samples collected in and around Greensboro, North Carolina, 2008-2009. Different clusters are indicated with different letters (A-D). Clusters A1, B1, C1 were closely related to A, B and C, respectively.