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Using novel spatial mark–resight techniques to monitor resident Canada geese in a suburban environment

M. Elizabeth Rutledge[A,C], *Rahel Sollmann*[A], *Brian E. Washburn*[B], *Christopher E. Moorman*[A] *and Christopher S. DePerno*[A]

[A]Fisheries, Wildlife, and Conservation Biology Program, Department of Forestry and Environmental Resources, Campus Box 7646, North Carolina State University, Raleigh, North Carolina 27695, USA.
[B]U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center, Sandusky, Ohio, USA.
[C]Corresponding author. Email: merutled@ncsu.edu

Abstract

Context. 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.

Aims. Accordingly, baseline demographic estimates for goose populations are needed to help better understand the ecology of Canada geese in suburban areas.

Methods. As a basis for monitoring efforts, we estimated densities of adult resident Canada geese in a suburban environment by using a novel spatial mark–resight method. We resighted 763 neck- and leg-banded resident Canada geese two to three times per week in and around Greensboro, North Carolina, over an 18-month period (June 2008 – December 2009). We estimated the density, detection probabilities, proportion of male geese in the population, and the movements and home-range radii of the geese by season ((post-molt I 2008 (16 July – 31 October), post-molt II 2008/2009 (1 November – 31 January), breeding and nesting 2009 (1 February – 31 May), and post-molt I 2009). Additionally, we used estimates of the number of marked individuals to quantify apparent monthly survival.

Key results. Goose densities varied by season, ranging from 11.10 individuals per km^2 (s.e. = 0.23) in breeding/nesting to 16.02 individuals per km^2 (s.e. = 0.34) in post-molt II. The 95% bivariate normal home-range radii ranged from 2.60 to 3.86 km for males and from 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 (s.e. = 0.005) to 0.995 (s.e. = 0.002).

Conclusions. By using spatial mark–resight models, we determined that Canada goose density estimates varied seasonally. Nevertheless, the seasonal changes in density are reflective of the seasonal changes in behaviour and physiological requirements of geese.

Implications. Although defining the state–space of spatial mark–resight models requires careful consideration, the technique represents a promising new tool to estimate and monitor the density of free-ranging wildlife. Spatial mark–resight methods provide managers with statistically robust population estimates and allow insight into animal space use without the need to employ more costly methods (e.g. telemetry). Also, when repeated across seasons or other biologically important time periods, spatial mark–resight modelling techniques allow for inference about apparent survival.

Additional keywords: *Branta canadensis*, density estimation, goose movements, home range, survival, urbanisation.

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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 as a result of adequate habitat and decreased predation and hunting in urban and suburban environments (Balkcom 2010; Rutledge 2013). Consequently, between 1990 and 2009, the number of resident Canada geese in the United States increased from an estimated two and a half million to more than five million birds (Dolbeer 2011). The presence and movement of Canada geese across landscapes may contribute to 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) might be an appropriate alternative to estimate resident goose population sizes and movement characteristics when telemetry studies are unavailable as a result of financial or logistical constraints. Mark–resight models account for imperfect detection of individuals and are less invasive than are traditional capture–recapture methods. In mark–resight studies, researchers mark a random subset of individuals from the population and, subsequently, obtain non-invasive 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 modelling (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*. 2013*a*, 2013*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 densities, detection rates, proportion of male geese in the population, apparent survival, movements, and home-range radii of resident Canada geese during four 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 behaviour, which could be a promising approach for monitoring Canada geese in suburban environments.

Materials and methods

The study was conducted in and around the city of Greensboro, which is located in Guilford County, North Carolina. Greensboro encompassed nearly 344 km^2 and had ~277 000 human residents in 2012 (City of Greensboro North Carolina Demographics 2013). Our study area contained a suburban airport (Piedmont Triad International Airport) and numerous retention ponds and open-grass areas frequented by resident Canada geese. The study site centre was located at 36°06′16″N, 79°56′07″W.

Marking and resighting Canada geese

From June 2008 until December 2009, we resighted neck- and leg-banded resident Canada geese in the Greensboro, North Carolina, area (Fig. 1). The geese were marked over a 3-day period (16–18 June 2008) 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 (US Fish and Wildlife Service (USFWS) 2012). 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, USA) with a distinctive four-character α-numeric code and a US Fish and Wildlife Service aluminum band (size 8; US Geological Survey Bird Banding Laboratory, 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 two to three 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. 1). In addition to recording marked individuals, we recorded the number of unmarked geese during each sampling event.

Closed population spatial capture–recapture model

We analysed 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 centre, s_i, and that all s_i are independently distributed across the state space (S) according to a random uniform distribution. The state space is an area that includes the resighting grid and is sizable enough to include all individuals potentially exposed to sampling. Resighting locations included but were not limited to parks, golf courses and corporate and residential ponds. When each individual can be recorded only once at a given site on a given occasion, the observed data (0 or 1) of individual i at resighting location 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 resighting location j to the individual's activity centre s_i, d_{ij},. Under a Gaussian (or half-normal) encounter model, $p_{ij} = p_0 \times \exp(-d_{ij}^2/2\sigma^2)$, where p_0 is the baseline resighting probability at $d_{ij} = 0$ and σ is the scale parameter of the half-normal function, which is related to the home-range radius of the sampled individuals (Reppucci *et al*. 2011, see also below). Because of this relationship, we colloquially refer to σ as the 'movement parameter'.

To estimate N, the number of activity centres in S, we employ data augmentation (Royle *et al*. 2007; Royle and Dorazio 2012). Let n be the number of observed individuals. Hence, this approach is equivalent to augmenting the observed dataset with $M - n$ 'all-zero' encounter histories or 'hypothetical

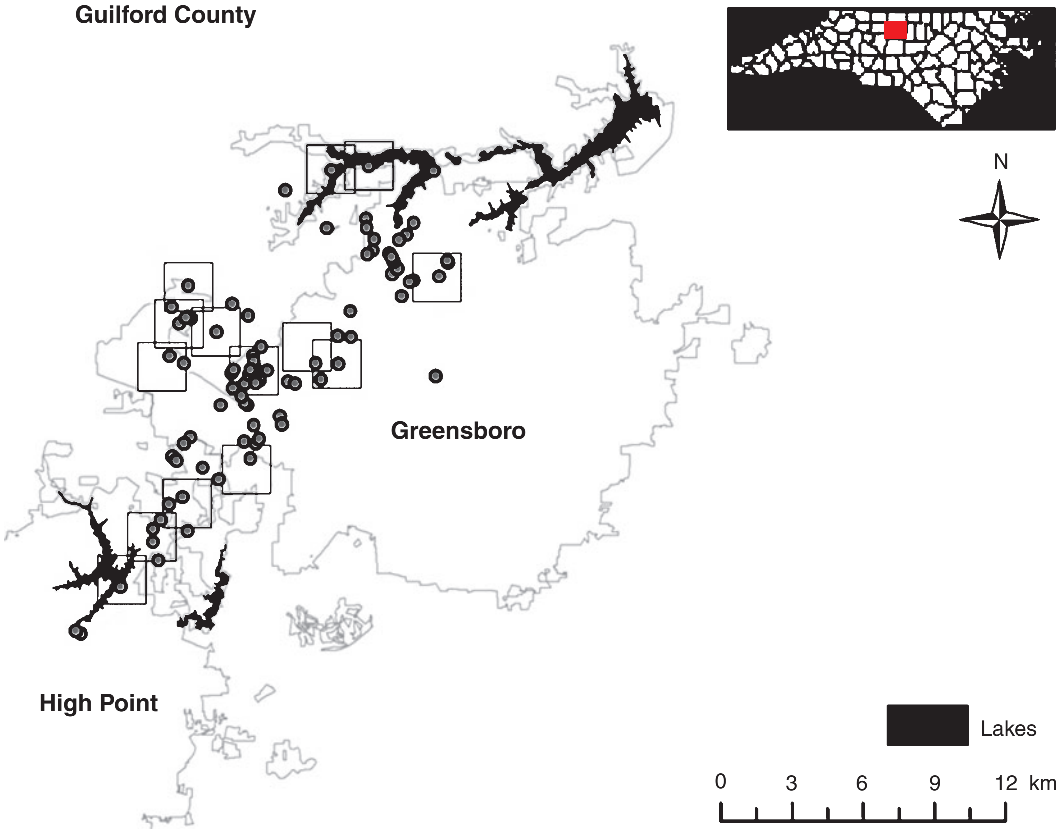

Fig. 1. Fourteen Canada goose banding sites (□) and 87 resighting locations (●) distributed in and around Greensboro, North Carolina, 2008/2009.

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 not to 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.* 2013*a*, 2013*b*). Under these circumstances, only y_{ijk} for the m marked animals are observed. For the unmarked individuals, we observe only the accumulated counts $\eta_{jk} = \sum y_{ujk,}$ 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}, as follows:

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

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 dataset of marked and unmarked individuals separately (Royle *et al.* 2014*a*). This means 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 assumed that marked geese were a random sample from the resulting state–space because (1) marking took place across the extent of the resighting array (Fig. 1), and (2) marking was undertaken 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 the following four seasons: post-molt I 2008 (16 July – 31 October), post-molt II 2008/2009 (1 November – 31 January), breeding/nesting 2009 (1 February – 31 May) and post-molt I 2009 (16 July – 31 October) and analysed seasons separately. We divided post-molt into two seasons to detect changes in density caused by the potential presence of migratory geese during the winter months. We did not analyse 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 (Rutledge 2013), thus violating the assumption of population closure.

We allowed the parameters of the detection function (σ and p_0) to differ between males and females. We were unable to confirm with certainty whether a marked goose was still alive and available for resighting at any given period, so we treated the number of marked individuals as unknown and estimated this parameter as part of the model. We originally marked 763 geese but 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 dataset and we augmented each unmarked dataset to the following sizes: post-molt I (2008): 7000; post-molt II: 7500; breeding/nesting: 5500; and post-molt I (2009): 5500. We implemented the model using a custom-made MwG sampler (see Supplementary Material to this paper) 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 5000 iterations as burn-in. We reported the posterior mean (±standard error) and 95% Bayesian credible intervals (95BCI) for all parameters.

The half-normal detection function we assumed in our model implies a bivariate normal model of space use, which allowed us to translate the scale parameter σ into a 95% home-range radius, r, using the formula $r = \sigma \times \sqrt{5.99}$ (Royle *et al.* 2014*b*).

Finally, we used the estimated number of marked geese across the four 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 mid-points of each two subsequent seasons.

Results

Of the marked geese, 44% were determined to be male and 56% were determined to be female. 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 juveniles from the sample because we would not have been able to exclude the geese from the unmarked counts, because age cannot be determined reliably on resighting. We accumulated a total of 8676 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, whereas the number of marked geese resighted decreased steadily over time (Table 1).

The SMR models indicated that geese were present at densities ranging from 11.10 individuals per km^2 (s.e. = 0.23) in breeding/nesting to 16.02 individuals per km^2 (s.e. = 0.34) in post-molt II. Estimates of σ ranged from 1.06 km (s.e. = 0.02) to 1.58 km (s.e. = 0.03) for males and from 0.78 km (s.e. = 0.02) to 1.29 km (s.e. = 0.02) for females (Table 2), and were greatest for males during post-molt I 2009, whereas estimates were greatest for females during post-molt I 2008. The corresponding 95% bivariate normal home-range radii ranged from 2.60 to 3.86 km for males and from 1.90 to 3.15 km for females (Table 3). Last, the estimates of apparent monthly survival taken from the mid-points of each two consecutive seasons (banding to post-molt I 2008: 0.995 (s.e. = 0.002), post-molt I 2008 to post-molt II: 0.995 (s.e. = 0.004), post-molt II to breeding/nesting: 0.972 (s.e. = 0.005), and breeding/nesting to post-molt I 2009: 0.994 (s.e. = 0.005)) were relatively high within the sample population.

Discussion

Using the SMR methods, we determined that the estimates of Canada goose density varied seasonally. During our study, Canada goose populations increased during the winter months, likely because of the presence of migratory Canada geese wintering in North Carolina. Goose density then decreased as breeding/nesting began and estimates were relatively similar across years for the post-molt I season. These seasonal changes in density are likely to be reflective of the seasonal changes in behaviour and physiological requirements of geese.

Estimates from the SMR analysis were largely similar to values determined during a concurrent study of 16 geese fitted with satellite telemetry harnesses. Goose home ranges, as determined by using both SMR and satellite telemetry, consistently spanned larger areas during the post-molt I season (Rutledge 2013). The mean home-range radii from SMR analysis were smaller for females than males during the post-molt II and

Table 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 July – 31 October), post-molt II (1 November – 31 January), breeding/nesting (1 February – 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	3994	3950
Post-molt II	61	465	1613	3184
Breeding/nesting	65	424	1548	2585
Post-molt I 2009	58	351	1521	3891

Table 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 per km^2) for post-molt I 2008 (16 July – 31 October), post-molt II (1 November – 31 January), breeding/nesting (1 February – 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

Parameter	Mean	s.e.	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
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
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 3. Estimates of mean home-range radii (km) derived from the movement parameter σ of the spatial mark–resight model

The estimates are categorised by sex and season (post-molt I 2008 (16 July – 31 October), post-molt II (1 November – 31 January), breeding/nesting (1 February – 31 May), and post-molt I 2009). All data were collected in and around Greensboro, North Carolina, 2008/2009

Sex	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

breeding/nesting seasons (November–May), when female geese were likely to be 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). In the present study, the mean home-range size for female geese was between 11.34 and 31.16 km^2, depending on the season. However, the mean home-range estimate of the telemetered geese (9.92 km^2; Rutledge 2013) was smaller, probably because the SMR estimates are based on the assumption that the home range is bivariate normal.

Sex of the birds and season influenced the movements of resident Canada geese. Fluctuations in density estimates, home ranges and goose movements across the landscape were likely to be related to changes in habitat quality and food availability. Interestingly, localised goose movements were concentrated around wetland areas, which are known waterfowl attractants where breeding/nesting and molting activities occur. Many of the geese in our study flew short distances to access multiple small retention ponds on a regular basis, implying that 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 of 751 geese were still alive and within the study area and the annual survival of resident Canada geese in the Greensboro area was 0.93, which is indicative of adequate goose habitat with little predation and hunting (Rutledge 2013). Similarly, a monthly survival rate of 0.94 (female geese only) and a study survival rate of 0.96 have been reported for resident Canada geese in other portions of their range (Groepper *et al*. 2008; Balkcom 2010).

When estimating 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 is the assumption that marked individuals represent a random sample, both demographically and spatially, from the state–space *S*. Ideally, *S* would be defined before individuals are marked so that marking can take place across all of *S* (Royle *et al*. 2014*a*). 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, defining *S* as the resighting area plus a 4.5-km buffer was adequate because geese were marked throughout most of the resighting area (Fig. 1) and during molt, when they are mostly immobile, giving them the chance to redistribute throughout *S* after marking. Although absolute density estimates could be 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. SMR methods provide managers with statistically robust 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 other biologically important time periods, SMR modelling 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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