






Behavioral responses of Canada geese to winter harassment in the context of human-wildlife conflicts

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Abstract

Wildlife harassment (i.e., intentional disturbance by humans) is a common nonlethal management approach employed to reduce human-wildlife conflicts, but effectiveness is often undocumented or uncertain. We evaluated the effect of harassment on Canada goose (*Branta canadensis*) behavior in an urban area during winter. Winter can be a challenging period for waterfowl given limited food availability and greater thermoregulatory costs; thus, we expected that harassment in winter may be more effective than during other portions of

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the year. We used GPS transmitters equipped with accelerometers to evaluate the effects of harassment, weather conditions, and breeding origin location on goose movements, land cover use, emigration, survival, and behavior. Harassment caused geese to leave the harassment site more often (3.5 times) than on days when not harassed, but geese returned quickly after harassment (1.9 times) than without harassment. Harassment of geese affected specific goose behaviors (foraging, resting, flying, and alert), but effects of harassment were relatively small compared to the effects of weather conditions. Changes in land cover use were impacted by weather conditions, independent of harassment. Our findings suggest that harassment was ineffective at significantly changing site use or behaviors of geese and repeated harassment had diminishing returns. Geese moved to specific land cover resources that serve as sanctuaries (e.g., open waterbodies) during periods of extreme cold to engage in energetically conservative behaviors (i.e., resting). Harassing geese in areas that provide sanctuary during extreme cold periods or the use of lethal management in coordination with targeted harassment may be more effective than harassment alone in urban areas.

KEYWORDS

accelerometer, behavior, *Branta canadensis*, Canada goose, foraging, Illinois, urban wildlife, wildlife damage

Human disturbance can adversely affect wildlife by altering behavioral time budgets (Beale and Monaghan 2004, Atkins et al. 2017), increasing energetic costs as animals flee (Bélanger and Bédard 1990, Nolet et al. 2016), displacing animals from high-quality habitat resources (Seamans and Gosser 2016), and imposing sublethal effects on fitness and reproduction (Féret et al. 2003, Beale and Monaghan 2004, Beale 2007). Human disturbance has been used to reduce human-wildlife conflicts by intentionally altering animal behavior and distribution (Kloppers et al. 2005). Intentional disturbance (hereafter referred to as harassment) has included use of pyrotechnics to disrupt double-crested cormorant (*Phalacrocorax auratus*) roosts near aquaculture operations (Tobin et al. 2002), noise-making cannons to scare birds away from crops and airports (Seamans and Gosser 2016), falcons to scare/kill geese around golf courses (Atkins et al. 2017), and other applications (Bishop et al. 2003). Although many studies have investigated the effectiveness of harassment in terms of accomplishing management goals (York et al. 2000, Sherman and Barras 2004, Holevinski et al. 2007), few have examined how harassment affects the behavior of targeted animals (but see Nolet et al. 2016, Atkins et al. 2017).

For harassment to influence the behavior of a targeted animal, animals must perceive harassment as a threat of injury or death. Animals generally respond to human disturbance as if it were a predation risk as many species have evolved with hunting by humans or have evolved responses to generalized predator behaviors such as direct

approach (Frid and Dill 2002, Beale and Monaghan 2004). One of the underlying principles of nonlethal harassment is that it increases the perceived risk at a site, manipulating behaviors in a way that makes the cost of staying at that site greater than the costs of moving to a new site (Lima et al. 1985, Frid and Dill 2002, Kloppers et al. 2005). However, animals may become habituated to disturbance, reducing the energetic cost to respond to harassment (Conomy et al. 1998, Baudains and Lloyd 2007). Even if animals perceive harassment as a predation risk, the cost of moving elsewhere may outweigh the perceived risk. Decisions to move involves weighing the conditions of the site (i.e., resource availability versus perceived risk) as well as condition at alternative sites (Frid and Dill 2002, Hagy et al. 2017). Harsh winter weather also has potential to limit resource availabilities and affect behaviors of animals as they cope with increased thermoregulatory costs. Thus, the factors affecting response to harassment are interrelated with climatic conditions, as these conditions impact the resources available, particularly in winter when resources may be limited.

Canada geese (*Branta canadensis*) are one of the most conspicuous wildlife species in urban areas across North America and parts of Europe (Groepner et al. 2008, Fox 2019, Groom et al. 2020). The adaptability of Canada geese to city and suburban landscapes has contributed to population increases and brought about human-wildlife conflicts on the ground and in the air (Conover and Chasko 1985, Paine et al. 2003). Canada geese are associated with conflicts in urban areas including aggression towards people when nesting (Photo S1, available online in Supporting Information), fecal and feather deposition leading to decreased aesthetic values of greenspaces, and risks to air traffic (Smith et al. 1999). More than 1,854 recorded goose-aircraft strikes from 1990–2018 are attributed to Canada geese (Dolbeer and Eschenfelder 2003, Dolbeer et al. 2021). Large, open turf lawns and waterbodies in city parks can support large concentrations of geese throughout the winter in areas that may pose a risk to air traffic (Askren et al. 2019). The Chicago area supports a large breeding population of Canada geese that remain as residents in winter. During winter, the local breeding population is bolstered by geese from more northern breeding areas, matching or exceeding those breeding locally.

Harassment is a common tool used by wildlife managers to reduce human–goose conflicts in urban areas but is often ineffective at achieving management goals (Smith et al. 1999, Sherman and Barras 2004, Holevinski et al. 2007, Dorr et al. 2010). Few studies have examined the effects of harassment on behavior during winter, during which many species of geese exhibit reduced survival rates (Gates et al. 2001, Massey et al. 2020). Many species of waterfowl including Canada geese (Joyner et al. 1984, Gates et al. 2001) exhibit decline in endogenous nutrient reserves over the winter period (Loesch et al. 1992, Massey et al. 2020). Changes in endogenous reserves is likely a facultative strategy that balances the costs of maintaining endogenous nutrient reserves with the energetics needs to survive winter (Gates et al. 2001). The loss in endogenous nutrient reserves in Canada geese is influenced by limited food availability, decreased food quality, and increased costs of thermoregulation during cold periods (Joyner et al. 1984, Loesch et al. 1992, Gates et al. 2001). Geese in Chicago do not leave urban areas to access high-energy, agricultural grains (Dorak et al. 2017), remaining in areas where available forage is limited to low-quality turf grasses (Conover and Chasko 1985, Conover 1991, Petrie et al. 1998). Conserving energy by altering behaviors is necessary for Canada geese to maintain a neutral or positive energy balance during extreme cold periods in urban areas, where nutrient rich food resources are limited (Biebach 1996). Thus, harassment during these extreme cold periods may have a greater effect on urban-wintering Canada goose behavior and movement.

We sought to determine how harassment affected 1) movement and departure from the harassment site, 2) the use of multiple land cover types, 3) behavioral time budgets, and 4) survival. We expected Canada geese would leave the site more frequently, for longer periods, have greater daily movement distances, and spend more time in alert behavior and less time in foraging behavior when harassed. We expected that harsh weather conditions might increase the effect of harassment on these behaviors and that movement and behavior of local and nonlocal breeding geese would differ due to differences in habituation. In addition, we investigated if our

actions achieved the ultimate management goal of causing geese to avoid the harassment site and disperse from the broader area.

STUDY AREA

Our study area consisted of the south and central portions of Chicago, Illinois, USA, and surrounding metropolitan area in Cook County (Figure 1). Our study area includes Midway International Airport (41°47'6.5"N, 87°45'6"W), a major commercial airline hub with thousands of flights landing and departing daily (Chicago Department of Aviation 2020). The Greater Chicago Metropolitan Area has a human population of 9.4 million, including the city of Chicago and surrounding suburbs (United States Census Bureau 2012). The area consists of dense residential areas, commercial buildings, factories, large railyards, cemeteries, lawns, and parks. The area is interspersed with rivers, ponds, and other waterbodies throughout. The Greater Chicago Metropolitan Area has a Canada goose breeding population exceeding 30,000 individuals (Paine et al. 2003) that is supplemented by geese from more northern breeding areas in winter (Dorak et al. 2017). During our study, the mean daily low temperature was -5.7°C (min-max = -30.6 – 10.0°C), mean daily max temperature was 2.2°C (min-max = -23.3 – 21.1°C), and mean snow depth was 2.6 cm (0–30.0 cm).

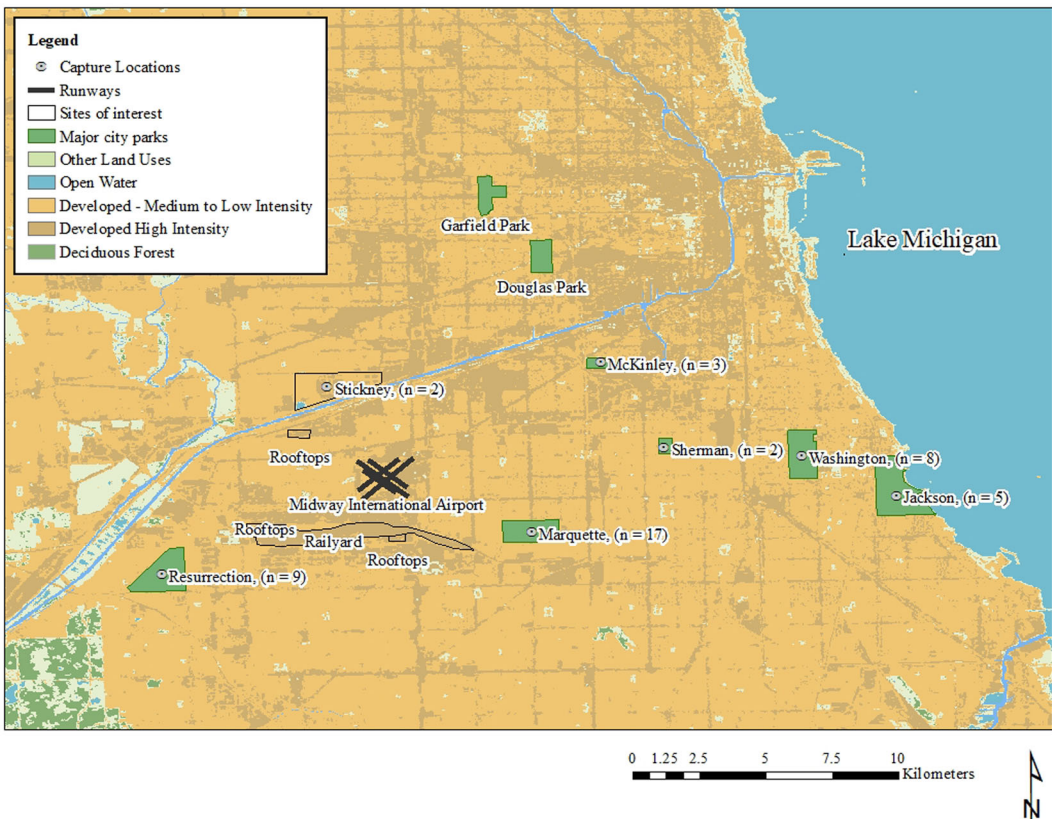


FIGURE 1 Map of the study area in Chicago, Illinois, USA, sites of interest relevant to our project, and capture locations of Canada geese (*Branta canadensis*) transmitted during winters of 2016–2018.

METHODS

We captured and deployed transmitters on Canada geese ($n = 47$) from 14 November 2015 through 16 November 2018 at parks, cemeteries, housing complexes, and water treatment plants (Figure 1). Of those 47 transmitters, 18 were active in both winters of the study resulting in 65 goose/winter seasons for analysis. Canada geese were captured using MagNet small animal net-guns (Wildlife Capture Services, Flagstaff, AZ, USA). We attached an aluminum leg band and either a Cellular Tracking Technologies (CTT) Global Positioning System, Global System for Mobile Communication transmitter ($n = 44$; GPS-GSM, Somerset, PA, USA) attached to alphanumeric neck collars (Spinner Plastics, Springfield, IL, USA) or an Ornitela GPS-GSM transmitter ($n = 3$, OrniTrack-N44, Vilnius, Lithuania) on captured Canada geese.

We programmed transmitters to record GPS fixes every hour and uploaded data via the GSM network at least 3 times per week. We included only daylight locations (i.e., 30 min before and after sunrise) using the `suncalc` package (Thieurmel and Elmarhraoui 2019) in Program R (R Core Team 2021). We excluded locations with a horizontal dilution of precision >4 , to reduce location error, and excluded locations collected at <30 min to maintain consistent intervals and not bias comparisons of movement distance (Rowcliffe et al. 2012).

We compared movements and behavior of all geese located in the study area as well as geese located in major city parks or greenspaces where harassment did ($n = 1$) and did not occur ($n = 7$; Figure 1). Harassment was conducted by United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service, Wildlife Services employees during 4 December 2017 to 3 March 2018 and 7 December 2018 to 1 March 2019 at Marquette Park (41.7686° , -87.7032°). Marquette Park is 127.5 ha and consists of a mix of waterbodies, sports fields, forested areas, and open turf lawn (Photo S2, available online in Supporting Information). We chose Marquette Park as our harassment site due to its proximity to Midway International Airport (2.7 km at the nearest points) and previous work demonstrating movements associated with the park conflicted with air traffic using Midway International Airport (Askren et al. 2019). The schedule of harassment varied dependent on USDA personnel work schedule but typically involved 2 site visits for approximately 2 hours each day, >5 days a week, during which all geese located within the site were harassed. Multiple harassments occurred during each site visit, resulting in transmittered geese being harassed >2 times a day. Geese were harassed by approaching them on foot or an all-terrain vehicle and by clacking 5 cm \times 10 cm lumber boards together, until all or most of the flock flushed and left the vicinity (i.e., that half of the park). At each harassment event, Wildlife Services personnel recorded time, location, and observations of geese present (e.g., observation of transmitters, number of geese observed).

Statistical methods

Departures and movement distances

We used general linear mixed effects models to test the effects of harassment (was or was not harassed that day), use of the harassed site (did or did not use), breeding region (local or nonlocal), average daily temperature, and average daily snow depth on daily movement distance with individual ID as a random effect in Program R (Bates et al. 2014; Table 1). We assigned geese as associated with the harassed site if $>10\%$ of their locations occurred there in order to quantify effects of behaviors outside of the site boundaries. We classified the breeding region of individuals as local or nonlocal based on their locations during the first 2 weeks of May in previous or subsequent springs. At this time of year, most Canada geese breeding in northern regions have emigrated the study area and reached their breeding destination but geese from all breeding regions have not left on molt migration (Luukkonen et al. 2008). In addition, we investigated the interactive effects of harassment on individuals from different breeding regions (Table 1).

We classified a goose as harassed if an individual's GPS location occurred within the harassment site and within 30 min (both before and after) of harassment occurring and determined the land cover type (Evans 2021). We then

TABLE 1 List of generalized linear mixed effects models included in analyses of aspects of Canada goose (*Branta canadensis*) movement and behavior relative to harassment at an urban park in Chicago, Illinois, USA, during 2017–2019.

Independent	Fixed effect	Error distribution	Time scale	Data subset
Departures and movement distances				
Departure	Day of harassment	Binomial (logit)	Hour	Individuals-Harass site
Return time	Harassment	Gaussian (log)	Hour	Individuals-Harass site
Distances moved	Associated with harassed site/not	Gaussian (log)	Day	All transmitters
	Day of harassment	Gaussian (log)	Day	Individuals-Harass site
	Breeding region	Gaussian (log)	Day	All transmitters
	Harassment	Gaussian (log)	Hour	All transmitters
	Harassment	Gaussian (log)	Day	All transmitters
	No. of park departures	Breeding Region	Poisson (log)	Day
	Breeding region*Harassment	Poisson (log)	Day	Individuals-Harass site
Land cover use				
% Locations in parks	Harassment	Binomial (logit)	Day	All
% Water, % Developed, % Greenspace	Average daily temperature	Binomial (logit)	Day	All
	Average snow depth	Binomial (logit)	Day	All
Behavioral time budgets				
% Alert, % Feed, % Fly, % Rest	Day of harassment	Binomial (logit)	Day	Individuals-Harass site
	Harassed site-in/out	Binomial (logit)	Hour	All
	Day of harassment	Binomial (logit)	Day	Locations-Harassed site
	Average daily temperature	Binomial (logit)	Day	All
	Average snow depth	Binomial (logit)	Day	All
	Harassment*Average daily temperature	Binomial (logit)	Day	Individuals-Harass site
	Harassment*Average snow depth	Binomial (logit)	Day	Individuals-Harass site

used this variable to quantify if an individual was harassed in a given day to compare effects on daily movements of only geese associated with the harassed site. We also included day of harassment as a variable, if harassment occurred in a given day regardless if an individual was affected or not. We calculated distance moved as the Euclidean distance between one location to the following location and daily distance moved as the summed distances between sequential diurnal points.

Land cover use

We calculated the daily proportion of GPS locations that occurred in specific biologically-relevant land cover types (e.g., park, rooftop). We reclassified data from Open Street Maps (OpenStreetMap Contributors 2019, planet.openstreetmap.org, accessed 15 November 2019) and manually digitized areas of missing data using high

resolution aerial imagery (~1 m; Cook County Geographic Information Systems, <https://hub.arcgis.com/datasets/>, accessed 3 September 2020). We checked accuracy and desired land cover classifications by visually comparing the classified land cover type to aerial imagery at 100 random locations in Cook County. We grouped land covers into 3 generalized classes; greenspaces, water bodies, and developed. We used binomial GLMERs to model the effects of harassment, breeding region, temperature, snow depth, and week of season, with individual ID as a random effect, on daily proportion of time in parks and in different land cover types (Bates et al. 2014). We downloaded daily average temperature and snow depth from the National Centers for Environmental Information for the weather station at Midway International Airport within our study area (www.ncdc.noaa.gov/cdo-web/datatools/records; accessed 3 September 2020). We modeled the effects of average daily temperature and average daily snow depth on time budgets of geese during daylight hours using GLMMs with a logit link and binomial error distribution (Bates et al. 2014).

Behavioral time budget

The use of accelerometer-equipped GPS transmitters allows researchers to quantify complex behavioral patterns at large spatial and temporal scales (Nathan et al. 2012, Weegman et al. 2017, VonBank et al. 2021). We used tri-axial acceleration data (hereafter ACC packets) recorded by transmitters at 10 Hz frequency for 3 sec at 15-min intervals to quantify behavioral time budgets of transmitted geese ($\bar{x} = 3,838$ ACC packets per individual, $SE = 317$). Transmitters manufactured by CTT recorded acceleration in g-force (min-max = -4-4 g) while Ornitela transmitters measured acceleration in millivolts (min-max = -2049-2049 mV). In addition, CTT measurements are unbounded making transformations to scale the 2 complex (VonBank et al. 2021), therefore we analyzed the CTT and Ornitela accelerometry data separately. We built training datasets with which to train classification models by pairing observed behaviors from video of recorded geese in the field to ACC packets that could be unambiguously classified as head-up (i.e., alert), head tucked (i.e., resting), foraging, and in-flight behaviors. We chose these 4 behaviors as they were the primary behaviors that could be differentiated using neck collar mounted accelerometers (Kölzsch et al. 2016) and are commonly recorded in other behavioral studies of geese (Bélanger and Bédard 1990). Head-up behavior included any behaviors in which a goose's neck was erect, including alert and vigilance while walking; we considered head tucked as an individual with bill tucked under a wing typical of a resting goose, foraging as active pecking or grazing, including walking with head outstretched while actively feeding, and flight as an individual actively airborne. We labeled behaviors that we did not uniquely identify including preening, drinking, swimming, or walking as other. We first calculated summary statistics for each ACC packet and translated the summarized ACC packets to instantaneous behaviors using a supervised machine learning approach and classification process (Shamoun-Baranes et al. 2012, Resheff et al. 2014, VonBank et al. 2021). Summary statistics include measures of overall acceleration among all axes, changes in acceleration in single axes, and relational measures between 2 axes following methods of Resheff et al. (2014). We used a workflow with an extreme gradient boosting algorithm in package XGboost (Chen and Guestrin 2016) to build separate classification models for CTT and Ornitela transmitters (due to their different data outputs) to predict unknown ACC packets (Shamoun-Baranes et al. 2012, Kölzsch et al. 2016, VonBank et al. 2021). We ran 100 iterations of a train-test split using 75% of the data to train and 25% of the training data to test accuracy. The accuracy of the trained, extreme gradient boosting algorithm was 89.1% for CTT and 93.8% for Ornitela transmitters (i.e., how often the observed behavior was the same as the predicted behavior). We then used the trained models to predict the probability of an unknown ACC packet belonging to each of the focal behaviors and assigned the predicted label to the behavior class that had the highest probability.

Our training dataset consisted of clean behavioral observations that represented only one of the 4 focal behaviors (alert, flight, foraging, and resting). We allowed for behaviors that could not be distinguished (e.g., preening, bathing) or ACC packets that had multiple behaviors within the 3-sec window (Kölzsch et al. 2016), based on the distribution of predictive probability. We reclassified predicted labels to other if the probability for that ACC

packet was below the 1st quartile of the probability distribution of each behavior and excluded those packets from subsequent analyses. Our other class included preening behaviors that we were unable to accurately classify and ACC packets that captured switching between more than one behavior in the 3-sec period (Kölzsch et al. 2016). We assigned predicted behaviors to the nearest GPS fix (i.e., 30 min before or after a GPS fix) via timestamps of GPS and ACC packets, which resulted in ~4 behaviors per GPS fix. We calculated the hourly proportion of alert, foraging, resting, and in-flight behaviors per hour for each transmitted goose using accelerometer data. We modeled the effects of harassment on time budgets of geese during daylight hours using GLMMs with a log link and Gaussian error distribution (Bates et al. 2014). We report predicted values of random effects, the mean random effect variance (σ^2_i) and the residual variance (τ_{00}) of the model.

Dispersal and survival

Dispersal from the study area was defined as departure from a 25-km radius from harassment site. Dispersal distance was related to the distance to agricultural dominated landscapes and the extent of Cook County where harassment and captures were conducted. We used a G-test of independence to compare the proportion of geese that dispersed by breeding regions, primarily-used parks, and the geese that had been harassed. We estimated seasonal and weekly, known-fate survival of transmitted Canada geese in Program MARK (White and Burnham 1999) implemented in package RMark (Laake and Rexstad 2009) using a staggered entry design (Pollock et al. 1989). We determined mortality during the study period based on hunter reports of harvested geese or GPS locations indicating mortality. We assumed stationary GPS locations for extended periods indicated a deceased bird, as we had no evidence of transmitter loss, and attempted to confirm all mortality. We used a G-test of independence to test if harassment explained variation in the survival of transmitted geese.

RESULTS

Of 47 geese tracked during our study, 17 remained in the study region during the breeding season while 30 emigrated from the study area and were located in other parts of the upper Midwest and Canada. We recorded 99,919 locations ($n = 47$ geese), consisting of 44,333 daytime locations and 55,586 nighttime locations. We conducted 359 harassment events during 4 Dec 2017–3 Mar 2018 and 268 harassment events during 7 Dec 2018–1 Mar 2019. An average of 25.6 (SE = 18.7) harassment events were conducted each week in 2017–2018 and 20.6 (SE = 12.3) in 2018–2019. In both years, 12 individual geese were harassed, resulting in a total 105 goose/harassment days in 2017–2018 and 123 goose/harassment days in 2018–2019.

Departures and movement distance

The probability that a goose left the park where harassment occurred on a day when no harassment occurred in a given hour was 0.063 (SE = 0.06, $n = 19$) compared to 0.22 (SE = 0.01, $n = 19$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.49$) on days when harassment occurred. Geese that left the park following harassment returned to the location where they were harassed faster ($\bar{x} = 40.6$ hr, SE = 0.24, $n = 349$) than when not harassed (return time = 78.8 hr, SE = 0.21, $n = 146$, $t = -3.9$, $P < 0.005$, $\sigma^2_i = 3.27$, $\tau_{00} = 1.83$). The mean daily distance moved by geese in the park where harassment occurred was greater ($\bar{x} = 5,907.5$ m, SE = 1,336.6, $n = 13$) than geese in the parks without harassment ($\bar{x} = 4,040$ m, SE = 3.37, $P < 0.01$, $\sigma^2_i = 7.29$, $\tau_{00} = 0.13$). Furthermore, geese using the site where harassment occurred moved 1.61 times further on days when harassment occurred than days that it did not ($\bar{x} = 4,271$ m, SE = 1166 m versus 6,433 m, SE = 1408 m, $t = 8.64$, $P < 0.01$, $\sigma^2_i = 8.44$, $\tau_{00} = 0.06$). There was an immediate effect of harassment as the

hourly mean distance moved of harassed geese (531.7 m) was greater than the average distance moved without harassment ($\bar{x} = 429.0$ m, $t = 1.94$, $P = 0.05$, $\sigma^2_i = 2.66$, $\tau_{00} = 0.02$). The number of harassment events in a day had diminishing returns, with a negative relationship between the number of harassment events and distance moved ($t = -4.47$, $P < 0.01$, $\sigma^2_i = 1.10$, $\tau_{00} = 0.42$).

There was no difference in the mean daily distance moved of local breeding vs. non-local geese in parks without harassment ($\bar{x} = 3,969$ m, SE = 902 m vs. 4,269 m, SE = 739 m, $t = 0.55$, $P = 0.58$, $\sigma^2_i = 7.56$, $\tau_{00} = 0.16$) or with harassment ($\bar{x} = 5,864$ m, SE = 1077 m vs. 5,209 m, SE = 860 m, $t = -0.74$, $P = 0.46$, $\sigma^2_i = 9.18$, $\tau_{00} = 0.28$). Overall, geese that bred locally departed parks at similar rates (0.39 departures/day \pm 0.24) to geese that bred in other regions (0.31 departures/day \pm 0.31, $z = -0.74$, $P = 0.46$, $\sigma^2_i = 1.35$, $\tau_{00} = 0.84$). However, when harassed, local breeders departed a park more often (harassed = 1.68 departures/day \pm 0.25), on average, than geese that bred in other regions (harassed = 0.86 departures/day \pm 0.25, $z = 3.15$; $P < 0.01$, $\sigma^2_i = 1.14$, $\tau_{00} = 0.31$).

Land cover use

There was no long-term effect of harassment resulting in geese spending less time in the harassed site compared to geese in other parks during the study period ($z = -0.10$, $P = 0.92$, $\sigma^2_i = 0.12$, $\tau_{00} = 0.07$; Figure 3). During daylight hours, 57.4% (SD = 17.1) of locations occurred in greenspaces (including 21.1% [SD = 35.2] in large city parks), 14.4% (SD = 14.6) in developed land covers (including parking lots, industrial areas), and 28.4% (SD = 10.6) on waterbodies (e.g., rivers, ponds). Of locations recorded immediately following harassment (1 hr later), 71.4% remained in the harassment site, meaning they left the park but returned within the hour or simply flew to another portion of the park. Geese that left the park after harassment used commercial rooftops (23.9%, $n = 6$), railyards (20.2%, $n = 7$), other parks (16.5%, $n = 8$), water treatment ponds (12.0%, $n = 5$), and sports fields (11.0%, $n = 4$). Weather had the greatest impact on land cover use (Figure 4). Use of water ($z = -40.1$, $P < 0.01$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.25$) and developed resources decreased ($z = -9.2$, $P < 0.01$, $\sigma^2_i = 3.29$, $\tau_{00} = 3.35$) while use of greenspace increased ($z = 49.7$, $P < 0.01$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.64$) with increasing temperatures (Figure 4). Use of water ($z = -29.0$, $P < 0.01$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.25$) and developed resources increased ($z = 24.9$, $P < 0.005$, $\sigma^2_i = 3.29$, $\tau_{00} = 3.35$) and use of greenspace decreased ($z = -50.8$, $P < 0.01$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.64$) with increasing snow depth (Figure 4). As temperature declined and snow depth increased, geese tended to leave greenspace for open water, unrelated to harassment.

Behavioral time budgets

On average, geese in our study spent 31.0% (SE = 4.6%) in alert behavior, 35.0% (SE = 4.7%) in foraging behavior, 3.5% (SE = 1.5%) in resting behavior, and 20% in other behaviors.

Geese that primarily used the harassment site spent 4.7% more time in alert behavior (SE = 7%, $z = 2.8$, $P < 0.01$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.06$) and 1.6% more time in flight (SE = 20%, $z = 3.61$, $P < 0.01$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.00$) on days when harassment occurred but there was no effect on foraging ($z = -1.46$, $P = 0.14$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.25$) or resting ($z = -0.50$, $P = 0.62$, $\sigma^2_i = 3.29$, $\tau_{00} = 2.36$) behaviors. Prior to harassment, proportion of time spent in the 4 focal behaviors by geese located in the harassment site did not differ from geese in other parks, but geese in the harassment site spent more time alert and in flight and less time foraging within an hour harassment than times when harassment did not occur (Table 2). Geese spent more time in alert and resting behavior and less time foraging in waterbodies and developed land covers compared to greenspaces. We investigated the impact of temperature and snow depth on behavioral time budget, as well as the interactive effect of harassment and weather. Increasing temperature had strong positive effect on the foraging ($z = 15.82$, $P < 0.005$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.01$), moderate negative effects on alert ($z = -5.14$, $P < 0.005$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.01$) and resting ($z = -3.96$, $P < 0.005$, $\sigma^2_i = 3.29$,

TABLE 2 Mean proportion (\pm SE) of alert, foraging, resting, flight, and other/unclassified behaviors in Canada geese (*Branta canadensis*) relative to harassment at an urban park in Chicago, Illinois, USA, during 2017–2019. Statistical differences from the Harassment site–Not harassed occurred to Parks without harassment, and the Harassment site–Hour after harassed to Harassment site–Not harassed occurred based on binomial, generalized linear mixed effects models denoted by $\bullet < 0.1$, $* < 0.05$. Greenspaces–Not parks consisted of any area of vegetation not contained in city parks (ex. golf courses, cemeteries), Manmade include any constructed surfaces (ex. rooftops, parking lots, industrial areas), and waterbodies are any area of open water (ex. ponds, rivers, wetlands).

	Hourly-In parks			Hourly-Land cover types		
	Parks without harassment	Harassment site–Not harassed	Harassment site–Hour after harassed	Greenspaces–Not parks	Manmade	Waterbodies
Alert	27.3 (± 5.0)	24.0 (± 6.7)	30.1 (± 7.8)*	23.2 (± 3.9)	33.8 (± 4.9)	42.7 (± 5.1)
Feeding	44.4 (± 5.6)	40.6 (± 7.5)	37.8 (± 7.8)*	47.6 (± 4.7)	25.7 (± 4.2)	18.5 (± 3.6)
Resting	6.7 (± 3.0)	16.4 (± 6.9)	13.1 (± 6.7)	7.2 (± 2.7)	14.8 (± 4.4)	14.1 (± 4.0)
Flight	4.0 (± 1.9)	2.3 (± 1.8)	4.2 (± 2.7)*	4.2 (± 1.7)	3.5 (± 1.6)	2.2 (± 1.1)

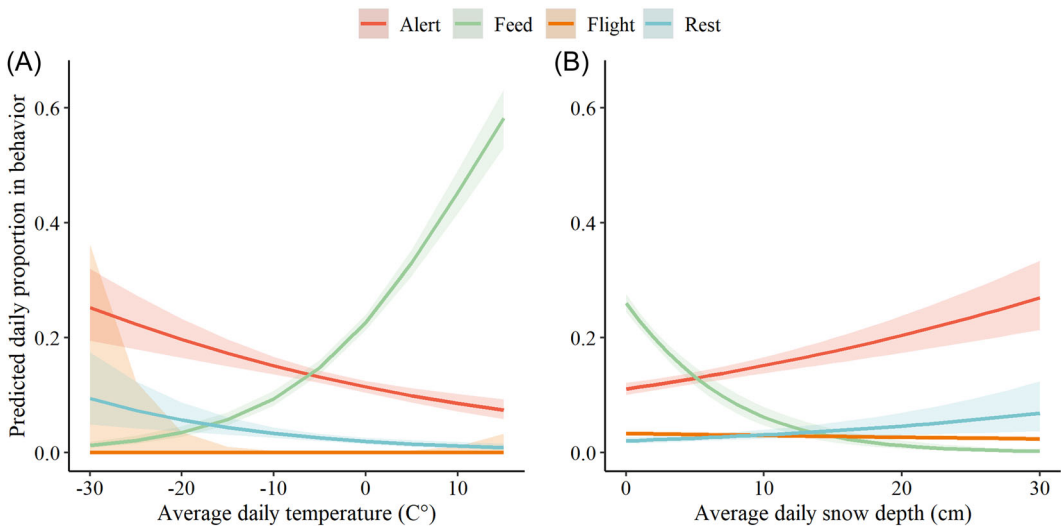


FIGURE 2 The effect of temperature (A) and snow depth (B) on daily proportion of time spent in alert ($n = 51,689$), foraging ($n = 58,767$), flight ($n = 5,813$), and resting behaviors ($n = 17,688$) by Canada geese (*Branta canadensis*) in the Chicago area of Illinois, USA, during 1 December–1 March during 2017–2018 and 2018–2019.

$\tau_{00} = 0.19$), and no effect on flight ($z = -0.16$, $P = 0.87$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.01$; Figure 2) behaviors. Snow depth had similar but inverse effects on foraging ($z = -11.03$, $P < 0.005$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.01$), alert ($z = 6.17$, $P < 0.005$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.00$), and resting ($z = 3.34$, $P < 0.005$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.18$) behaviors, but it differed in its effect on flight ($z = -5.16$, $P < 0.005$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.19$; Figure 2). For geese that used the harassment site, there was an interactive effect of harassment and temperature on alert ($z = 2.63$, $P = 0.008$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.01$) and foraging behaviors ($z = -2.21$, $P = 0.03$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.12$), but not resting behavior ($z = -0.45$, $P = 0.66$, $\sigma^2_i = 3.29$, $\tau_{00} = 1.85$) or flight ($z = 0.00$, $P = 1.0$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.01$). Likewise, there was an interactive effect of harassment and snow depth on foraging behavior ($z = -102.95$, $P < 0.005$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.10$) but not alert ($z = -0.72$, $P = 0.47$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.01$), resting ($z = 0.11$, $P = 0.92$, $\sigma^2_i = 3.29$, $\tau_{00} = 1.80$), or flight behaviors ($z = 0.00$, $P = 1.0$, $\sigma^2_i = 3.29$, $\tau_{00} = 0.01$).

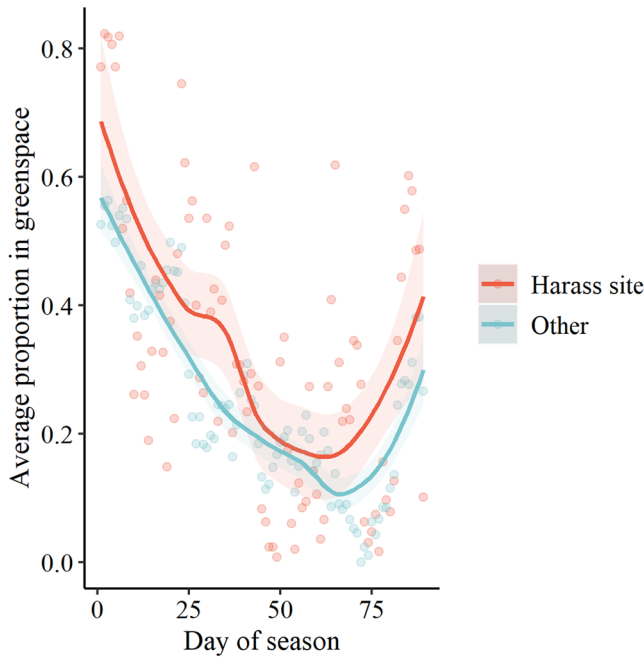


FIGURE 3 Average daily proportion of locations in the park for Canada geese (*Branta canadensis*) assigned to Marquette Park by day of season in Chicago, Illinois, USA during 1 December–1 March during 2017–2018 and 2018–2019.

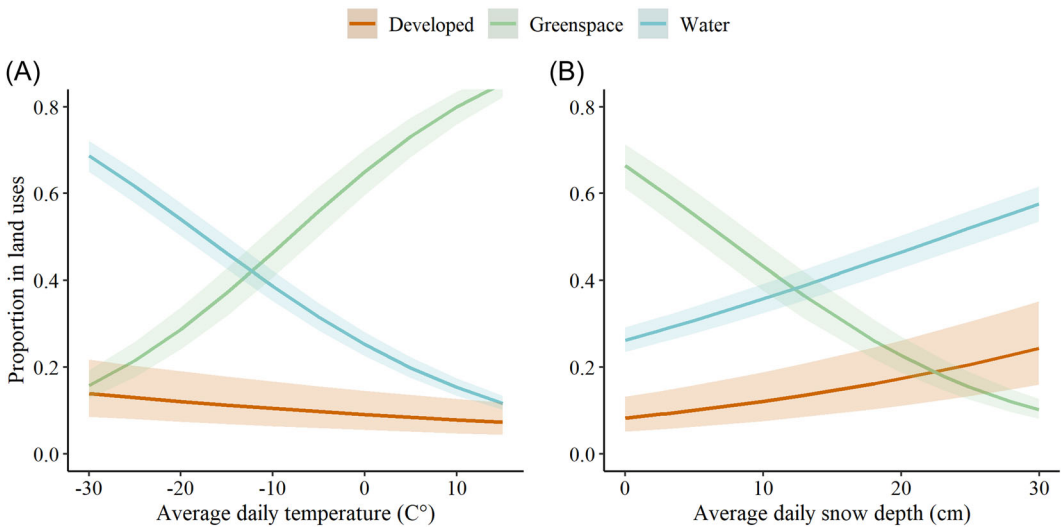


FIGURE 4 The effects of average daily temperature and average daily snow depth on proportional use of developed ($n = 9,458$), greenspaces ($n = 25,771$), and water ($n = 12,801$) land covers by Canada geese (*Branta canadensis*) in the Chicago area of Illinois, USA, during 1 December–1 March during 2017–2018 and 2018–2019.

Dispersal and survival

Most geese that wintered in the Chicago area survived ($\hat{S} = 86.2\%$, $n = 65$ geese/winter) for the duration of the study period. The proportion of geese that departed the area did not differ between seasons (2017, 6 of 34 goose/

winters; 2018, 4 of 31; $G^{\text{adj}} = 0.27$, $P = 0.60$). Local breeders left the study area during winter at a similar rate (3 of 28 goose/winters, $n = 17$) as geese from other breeding regions (7 of 37 goose/winters, $n = 30$; $G^{\text{adj}} = 0.81$, $P = 0.37$). Geese that were harassed left at a similar rate (5 of 19, $n = 13$) to geese that were not harassed (5 of 46, $n = 34$; $G^{\text{adj}} = 2.14$, $P = 0.14$). Only 5 birds died during the study and there was no difference in the percentage that died that were harassed (2 of 19) compared to those that were not harassed (3 of 46; $G^{\text{adj}} = 0.25$, $P = 0.63$). Mortality events occurred during periods of colder temperatures and deeper snow (average temperature of -5.8°C [SE = 2.28] and snow depth = 8.0 cm [SE = 3.8]) compared to the study period (1 December–1 March 2017–2019) means of -2.8°C and 3.0 cm.

DISCUSSION

Winter harassment in an urban park resulted in geese spending more time in alert and flight behaviors both at the daily and hourly scales, which was consistent with our predictions and previous studies (Nolet et al. 2016, Atkins et al. 2017). However, harassment resulted in short-term behavioral changes that may not have significantly affected energetic costs of using the site and did not accomplish the management goals of causing individuals to leave the area or avoid a specific location for more than 48 hours. We suggest the success of harassment in our study was limited by 2 broad themes. First, harassment did not affect the perceived cost of staying versus the perceived cost of leaving the site. Second, weather affected use of the harassment site and other greenspaces, regardless of harassment, indicating weather was the primary driver behind decreased use of the harassment site. Because geese left greenspaces during cold periods, our harassment did not add to the physiological stress geese experienced during extreme cold periods. The use of inaccessible locations (e.g., open waterbodies and rooftops) resulted in our inability to harass individuals during these extreme cold periods and likely provided some spatial sanctuary for the geese within the study area.

The effectiveness of our harassment may have been limited by the ability of geese to discern our harassment as a simple disturbance rather than a real threat of predation (Frid and Dill 2002, Atkins et al. 2017). Avian species have evolved the ability to recognize and respond to different predators according to the threat they pose (Curio et al. 1983). For harassment to increase the cost of staying at a site, it must be perceived as a real risk, and if it is, should affect changes in vigilance behavior (Atkins et al 2017). The amount of time geese spent in alert behavior was greater on days when harassment occurred and in the hour after harassment, however, these differences were small and variable. Additionally, the social behavior and flock dynamics of geese may have mitigated the behavioral effects of harassment (Atkins et al. 2019). Many species of animals share duties of watching for predators and the proportion of those spending time in vigilance behavior decreases as the number of animals increase (Cresswell and Quinn 2011, Atkins et al. 2019). Geese in our study were harassed while part of a flock (\bar{x} flock size = 99.6, min–max = 2–1,500; R. Askren, University of Arkansas, unpublished data). Because of the flock size and dynamics of geese, it is possible that we increased the amount of time spent in vigilance behavior of some individuals within a flock without affecting measurable changes to the behaviors of the entire flock or the transmitted individuals.

Similarly, habituation to human disturbance can moderate the impacts of harassment on behaviors of animals (Kloppers et al. 2005, Fox 2019). Habituation is a decreased response to stimulus and can vary temporally and spatially (Blumstein 2003). Although we didn't explicitly test for habituation to harassment, we were interested in differences in the response to harassment by geese from different breeding regions. Locally-breeding geese in our study nested in greenspaces and industrial areas within the city, exposed to human disturbance year-round. Non-local breeding geese nested where human disturbance was light or nonexistent, along Hudson Bay and southern Ontario in Canada or large marshes in rural Wisconsin. We expected that locally-breeding geese would be more tolerant of harassment compared to non-local geese. However, harassment was more effective in causing local individuals to move and leave the park compared to non-local

individuals. It might be that local geese had prior knowledge of other parks that provided the same resources as the park where harassment occurred and thus perceived little cost of relocating compared to non-local breeding geese. Differences between breeding regions in the probability of leaving following harassment suggests that habituation to general human disturbance did not have a major impact on goose movements but the perceived cost and trade-off with harassment likely did.

The ability of Canada geese to overwinter in the upper Midwest, especially in urban areas, is facilitated by their ability to buffer against periods when access to food is extremely limited, such as in deep snow cover or extreme cold temperatures (Gates et al. 2001). The ability of geese to survive the winter period, largely by using energy reserves, is well described yet the importance of these reserves for geese wintering in urban areas is unknown. Even the temporary effects of harassment on behaviors is energetically costly and likely leads to the metabolism of some endogenous reserves. Although our results did not support biologically meaningful differences in proportion of time in flight, the frequency of data collection did not capture short flights that resulted immediately after harassment. Flight is the most energetically costly behavior in flying animals (Bryant 1997), estimated to be 11.5 times more costly than resting behaviors in snow geese (*Chen caerulescens*; Bélanger and Bédard 1990). While alert behavior is not as energetically costly (3 times more so than resting; Bélanger and Bédard 1990), it does reflect missed opportunity costs, meaning that an individual must forego foraging or resting behavior. In addition, increased foraging by harassed geese in this study reflected the costs incurred by behavioral changes caused by harassment and are likely reflected in the amount of time spent foraging as geese compensate for lost energy (Nolet et al. 2016). While there was some evidence that foraging increased following harassment, the difference was likely not great enough to suggest a biological difference; that geese were working to make up energetic costs. Although we harassed geese daily, it may be that the type of harassment did not result in the behaviors that impacted the energy balance of wintering geese. Future work examining the relationship between habitat resources and the energy balance of geese wintering in urban and exurban/rural areas could shed more light on the ability to change goose behavior and achieve management objectives.

The effects of harassment on goose behaviors were likely reduced during harsh weather as geese reduced their use of greenspaces, including the harassment site. While we predicted harassment would have the greatest effects on geese during extreme cold periods, harassment in a greenspace had little effect as geese used alternative land covers during those periods. Transmitted geese spent twice as much time resting in developed land covers and waterbodies compared to greenspaces. The use of these land covers for energetically conservative behaviors is likely driven by either the thermal characteristics or disturbance levels. Dorak et al. (2017) used anemometers to record temperature and wind speed at canals and rooftops in our study area but did not find any evidence of thermal benefits of these sites. Because no thermal benefits were evident, we suggest that site use during cold periods is driven by land cover characteristics that allow geese to avoid disturbance and energetically costly behaviors. If a lack of disturbance at these resources allows geese to reduce catabolizing endogenous reserves during winter, harassment at these sites may be more effective at incurring greater energetic costs and persuading geese to disperse from those land covers and the broader area.

MANAGEMENT IMPLICATIONS

Given the lack of substantial effect of our harassment on dispersal from urban greenspaces during winter, it is likely that wildlife managers will need to focus winter harassment on different land uses or incorporate lethal management techniques in coordination with harassment to meaningfully disperse geese (Atkins et al. 2017). Although we did not examine various intensities of harassment (i.e., scariness), it is possible that nonlethal harassment using real predators (i.e., dogs, falcons) or drones mimicking aerial predators (Egan et al. 2020) may

illicit a more extreme response to harassment. Harassment or habitat manipulation at rooftops or canals and rivers that offer areas of open water are likely to be the most effective means to reduce goose abundances during winter months. The addition of lethal management, such as the use of falconry, in coordination with harassment, also has greater potential to alter the favorability of urban sites for Canada geese (Atkins et al. 2017).

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ETHICS STATEMENT

Work was conducted with all necessary permits, including institutional (University of Illinois IACUC No. 20039), Illinois state scientific (No. 6079), Chicago Parks District Scientific Research (No. 1839), Chicago Water Reclamation District (No. P-557; 17-NE 014), and federal banding permit (USGS BBL No. 23923).

DATA AVAILABILITY STATEMENT

All data used in this research will be provided upon request.

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SUPPORTING INFORMATION

Photo 1. Canada goose (*Branta canadensis*) attacking during a nest visit conducted for related research on factors influencing molt migration.

Photo 2. Flock of Canada geese (*Branta canadensis*) at sunrise on the lagoon in Marquette Park, Chicago where we conducted harassment.

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