ECOLOGY OF WINTERING CANADA GEESE IN THE
GREATER CHICAGO METROPOLITAN AREA

BY

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THESIS

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ABSTRACT

Canada geese (*Branta canadensis*) breed in subarctic and temperate areas of North

America, but both populations typically winter in temperate regions of the northern United

States. During winter, Canada geese are increasingly using urban areas, but data are lacking on

habitat use and selection, movements, potential thermal benefits of selected habitats, and survival

of Canada geese during late autumn and winter in urban areas. I captured Canada geese during

November–February 2014–2016 in the Greater Chicago Metropolitan Area (GCMA) in

northeastern, Illinois, USA and fitted 41 geese with solar-powered GPS transmitters. Neck

collar-mounted transmitters operated on the cellular phone network and collected hourly

locations ($n = 39,392$). Canada geese selected green spaces (59.8%) in greater proportion than

available (14%), but I also documented geese using novel habitats such as rooftops and rail yards

(i.e., industrial urban; 11.3%). Habitat use shifted away from green spaces (36%) to industrial

urban habitats (10.4%), riverine (12.8%), and deep-water habitats (37.8%) as temperatures

decreased below the lower critical limit for Canada geese (i.e., temperature at which increased

thermoregulatory costs are incurred to maintain core body temperature). During periods when

temperature decreased and snow depth increased geese increasingly used industrial urban

habitats. Both snow depth and minimum daily temperatures were associated with decreased

movement distances within habitats. Movements by Canada geese within rail yard ($\bar{x} = 224.0$ m,

SE = 13.0) and green space habitats ($\bar{x} = 145.6$ m, SE = 3.4) were the longest for any habitat

type, while movements by geese in deep-water habitats ($\bar{x} = 85.7$ m, SE = 3) and rooftop habitats

($\bar{x} = 52.9$ m, SE = 5.5) were the shortest. When temperatures were below the lower critical

temperature (-6 °C) Canada geese transitioned from deep-water to green space habitat in greater

proportion than all other possible transitions between habitat types. Proportion of use of green

space habitat increased during diurnal hours. Both deep-water and riverine habitats had greater proportional use during earlier morning hours than later in the day. Conversely, proportional use increased from midday to early evening in industrial urban habitat where proportional use increased during midday to early evening. All habitats had similar daily low temperatures, deep-water (+3.5 $^{\circ}$C) and industrial urban habitat (+3.2 $^{\circ}$C) did have warmer daily high temperatures than green space. The majority of transmittered Canada geese (85%) wintering in the GCMA never migrated south and no geese made foraging flights outside of the GCMA to agricultural fields. Winter survival was 100% for Canada geese remaining in the GCMA and 48% for geese that left the GCMA, with all mortality due to hunting. Since geese did not make foraging flights to agricultural fields, hunting may not be a viable option to reduce urban populations or change movement patterns during winter. Future research should test targeted harassment at industrial urban habitats, such as rooftops and deep-water habitats to see if Canada geese could be forced to leave urban areas.

DEDICATION

This thesis would not have been possible if it were not for all the sacrifices of my beautiful wife Sheena, daughter Una, and amazing dog Gunner throughout the years. You have opened my eyes to a completely new world I never thought possible and continually push me to be my best while following my dreams. I love you all from the bottom of my heart.

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CHAPTER 1: HABITAT SELECTION OF CANADA GEESE IN AN URBAN ENVIRONMENT DURING WINTER

1.1 ABSTRACT

Canada geese (*Branta canadensis*) breed in subarctic and temperate areas of North America, but both populations typically winter in temperate regions of the northern United States. During winter, Canada geese are increasingly using urban areas, but data are lacking on habitat use and selection and survival during late autumn and winter in urban areas. I captured Canada geese during November–February 2014–2016 and fitted 41 geese with solar-powered GPS transmitters that were affixed to neck collars. Transmitters operated on the cellular phone network and collected hourly locations ($n = 39,392$). Canada geese selected green spaces (59.8%) in greater proportion than available (14%), but I also documented geese using novel habitats such as rooftops and rail yards (i.e., industrial urban; 11.3%). Habitat use shifted away from green spaces (36%) to industrial urban habitats (10.4%), riverine (12.8%), and deep-water habitats (37.8%) as temperatures decreased below the lower critical limit for Canada geese (i.e., temperature at which increased thermoregulatory costs are incurred to maintain core body temperature). The majority of transmittered Canada geese (85%) wintering in the GCMA never migrated south and no geese made foraging flights outside of the urban areas to agricultural fields. Winter survival was 100% for Canada geese remaining in the GCMA and 48% for geese that left the GCMA, with all mortality due to hunting. During periods when temperature decreased and snow depth increased geese increasingly used industrial urban areas (i.e., rooftops and rail yards), which may increase risk for collisions with aircraft nearby Midway International Airport. Since Canada geese did not make foraging flights to agricultural fields, hunting may not be a viable option to reduce urban populations or change movement patterns during winter and

targeted harassment at industrial urban, green space, and deep-water habitats may force geese to leave urban areas and subsequently allow the population to be more effectively managed through hunting.

1.2 INTRODUCTION

Waterfowl select habitats during non-breeding periods (e.g., migration, winter) that provide the resources required to maintain a favorable energy balance over time as well as maximize survival (Baldassarre and Bolen 2006). Urban areas provide the necessary resources needed for survival, but they often require waterfowl to use novel habitats and behave differently than individuals using traditional habitats (Marzluff 2001, Zuckerberg et al. 2011). Urban areas at the northern extent of wintering ranges provide resources (e.g., green spaces, waste from agricultural refining operations, thermal cover, etc), sanctuary from hunting and other predators, and reduced energy expenditure associated with migrating (Conover and Chasko 1985, Guthery et al. 2005, Anderies et al. 2007, Zuckerberg et al. 2011). Use of urban areas by Canada geese has been shown to increase clutch size, nest success, and annual survival compared to rural areas (Raveling 1981, Paine et al. 2003, Balkcom 2010). Additionally, subarctic-breeding Canada geese have shifted their winter range northward (Gates et al. 2001, Scribner et al. 2003). Specifically, the Mississippi Valley population of sub-arctic breeding Canada geese (*B.c. interior*) have shifted their wintering range northward from southern Illinois and northwest Kentucky to northern Illinois and southern Wisconsin (Craven et al. 1986, Gates et al. 2001, AGJV 2013). Migrating Canada geese may join with geese in urban areas creating large concentrations, which can create conflicts with humans (Conover and Chasko 1985, Smith et al. 1999)

Wildlife populations have traditionally been managed through hunting; hunting can keep populations in balance with available resources, maintain current population levels, or remove

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nuisance animals with an end goal of reducing the population (Witmer and Whittaker 2001).

Local regulations in urban areas that limit hunting, public perception, and mixing of different

Canada goose populations with different management objectives can create challenges (Coluccy

et al. 2001, Unites States Fish and Wildlife Service 2015). Due to differences in population sizes

and trajectories of temperate-breeding (increasing populations; *B.c. maxima*) and migratory

populations of subarctic-breeding (stable or decreasing populations; *B.c. interior*) Canada geese,

hunting season structure is set to allow liberal harvest of temperate-breeding populations while

minimizing over harvest of subarctic-breeding populations (Scribner et al. 2003, United States

Fish and Wildlife Service 2015). However, hunting is not permitted in many urban areas and

limited data are available to determine susceptibility of geese using urban areas during winter to

hunting mortality when geese migrate south following cold-weather events, make foraging

flights to agricultural fields, or are displaced by already abundant numbers of geese using a

limited number of available habitats.

Management of Canada geese in urban areas is particularly important because large

populations or dense concentrations of Canada geese can pose threats to humans, including

contamination of water sources (Allan et al, 1995), aggressive behavior towards humans (Smith

et al. 1999), disease transmission (Smith et al. 1999, Kullas et al, 2002), and strikes with aircraft

(Dolbeer et al. 2000). Canada geese are the largest bird commonly struck by aircraft in North

America and because of their size and flocking behavior were responsible for 1,403 recorded

bird strikes to civil aircrafts from 1990 to 2012 (Dolbeer and Eschenfelder 2003, Dunning 2008,

Dolbeer et al. 2014). Noteworthy goose-aircraft strikes include a $190 million U.S. Air Force

aircraft, which resulted in the death of 24 airmen (Dolbeer et al. 2000, Richardson and West

2000), and U.S. Airways Flight 1549 that crash-landed in the Hudson River in New York after

striking multiple subarctic-breeding Canada geese (Marra et al. 2009). Thus, Canada geese can pose risks to human health and safety in urban areas, especially during winter when large flocks congregate around limited resources.

I studied the ecology of Canada geese wintering in or migrating through a large urban area during late autumn and winter to better understand habitat use and selection, survival within and outside of the urban areas, and vulnerability to hunting and other potential management strategies. Specifically, my objectives were to: (1) determine the areas in which geese spent the majority of their time (i.e., 50% utilization distribution-core use areas) and the extent of area commonly used by geese (i.e., 95% utilization distribution), (2) identify habitat use and selection, (3) estimate survival within and outside of urban areas and identify cause of mortality (e.g., hunting), and (4) describe phenology of Canada geese within and nearby the Greater Chicago Metropolitan Area during autumn and winter as it relates to the hunting season. I expected that Canada geese would use large green spaces and deep-water areas near warm-water discharges for roosting and conduct daily feeding flights out of the urban areas to agricultural fields for foraging (Conover and Chasko 1985, Havera 1999, Smith et al. 1999). I expected that survival of Canada geese in the urban area would be greater than rural areas because of increased risk of predation (i.e., hunting; Balkom 2010).

1.3 METHODS AND MATERIALS

Study Area

Canada geese were captured in the Greater Chicago Metropolitan Area (GCMA; 915 km^2) located in northeastern Illinois, USA (Fig 1.1) during late autumn and winter. The GCMA included portions of three counties (Cook, Du Page, and Will). The GCMA is heavily urbanized, but did have agricultural fields present within the GCMA boundaries (United States Department

of Agriculture 2015). The GCMA averages 43 days annually below freezing, with 7 days below

-18 °C. November has an average high of 9 °C and a low of 0 °C, December has an average high

temperature is 2 °C with a low of -6 °C, January has an average is a high of 0 °C and a low of -9

°C, and February has an average high of 2 °C and low of -7 °C (NOAA 2015*a*). Chicago

averages approximately 93 cm of snowfall annually (NOAA 2015*a*). The GCMA has an

estimated temperate-breeding Canada goose population exceeding 30,000 individuals (Paine et

al. 2003) and a human population of 9.4 million, including the city of Chicago and surrounding

suburbs (United States Census Bureau 2013).

Field Methods

During 13 November 2014 through 28 February 2015 and 14 November 2015 through 29

February 2016, I captured and attached transmitters to 41 Canada geese within the GCMA. I

focused my capture efforts at sites nearby Midway International Airport (41º47'6.5"N,

87º45'6"W) such as large parks, cemeteries, and the Stickney Water Reclamation Plant because

of their available habitat and increased risk of goose-aircraft collisions when Canada geese

concentrated at these locations throughout the fall and winter months (Fig 1.2). Standard

waterfowl capture techniques (e.g., rocket nets and cannon nets) could not be used in most urban

areas, so cast nets and small animal net guns (Wildlife Capture Services, Flagstaff, Arizona,

USA) were used for most capture attempts. After a Canada goose was captured, I determined

sex and age using cloacal inversion and feather characteristics and then obtained morphological

measurements (i.e., mass, skull length, culmen length, tarsus length; Moser and Rolley 1990,

Moser et al. 1991) as potential indicators of body condition. All length measurements were

taken using a caliper (nearest 0.1 mm) and mass was obtained using a Rapala mini digital scale

(nearest 0.01 km). An aluminum tarsal band and a GPS transmitter affixed to a white plastic

waterfowl neck collar with black alphanumeric codes was then placed on each goose prior to release (Castelli and Trost 1996, Coluccy et al. 2002, Caswell et al. 2012).

Transmitters ($n = 10$ in 2014–2015 and $n = 31$ in 2015–2016) were deployed during four times periods each year (mid November, early December and mid December, and early January) to account for temporal variation and across seven different capture locations to account for spatial variation (Table 1.1). Transmitters recovered from hunters ($n = 3$) were redeployed during the late February (Table 1.1). Transmitters included solar-powered GPS units from Cellular Tracking Technologies in Somerset, Pennsylvania, USA, and operated on the Global System for Mobile communications network and were configured to acquire a GPS location once per hour. Generation 2 models were used during 2014–2015 ($\bar{x} = 69.7$ grams, SE = 0.2) and Generation 3 transmitters were used during 2015–2016 ($\bar{x} = 62.2$ grams, SE = 0.2). Transmitters were < 2% of the body mass of Canada geese ($\bar{x} = 4,713$ grams, SE =10.6) and all Canada geese were captured and handled using the approved methods detailed by the University of Illinois Institutional Animal Care and Use Committee (Protocol # 14155).

Data Analysis

I removed locations from the day of capture from analysis, except for survival analysis, to minimize potential influences on movements and habitat use. Transmitters required a once-weekly cellular connection to program their duty cycle to the standardized rate of 1 location/hour for the entire day and upload locations to an accessible database. Depending on deployment, some transmitters did not link properly so data from transmitters with less than 10 days of data collection were removed from analysis ($n = 1$ in 2014–2015 and $n = 4$ in 2015–2016). Locations with only one satellite fix or with a horizontal dilution of precision value above 5 were removed because GPS coordinates were either not obtained or they had extremely low accuracy (Cellular

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Tracking Technologies 2015). All analyses were performed using R Version 3.1.3 (R Core

Team 2015).

To determine spatial habitat use, I used a dynamic Brownian Bridge Movement Model

(dBBMM) to estimate the 50% and 95% utilization distribution (UD; km^2) using the

adehabitatHR, rgdall, and move packages (Calenge 2006, Bivand 2015, Kranstauber and Smolla

2015). I estimated 50% utilization distributions (hereafter, core use areas) to target specific areas

used by Canada geese during winter where management actions may need to focus and the 95%

UD to represent total spatial use of Canada geese during winter. A dBBMM is a more

appropriate method to estimate spatial habitat use than home range or kernel density estimates

because it incorporates the temporal structure of the locations to estimate potential trajectories of

the segments between those locations using a maximum likelihood function (Horne et al. 2007,

Kranstauber et al. 2012). The dBBMM also provides a more accurate estimate than home range

analysis for systematically collected data because the locations are not independent (Burt 1943,

Worton 1989, Fieberg et al. 2010). If a Canada goose emigrated (i.e., did not return during the

remainder of the year) from the GCMA, all locations from migration date forward were removed

from 50% core use area and 95% UD analysis. Data collected from winter 2014–2015 were

limited due to transmitter battery recharging issues with Generation 2 models (n = 9 transmitters,

$\bar{x}$ = 10.5 locations/transmitter/day, SE = 2.9, range 2.0–26.4) compared to winter 2015–2016

when Generation 3 models provided increased battery life and efficiency (n = 27 transmitters, $\bar{x}$

= 20.8 locations/transmitter/day, SE = 0.4, range 15.4–23.3). Time between locations was

greater for Generation 2 models in 2014–2015 ($\bar{x}$ = 274.1 min, SE = 75.2) than Generation 3

models in 2015–2016 ($\bar{x}$ = 70.1 min, SE = 1.3). All locations obtained from 15 November–28

February of both years (n = 3,496 in 2014–2015 and n = 35,896 in 2015–2016) were used to

calculate 50% core use areas and 95% UD estimates. I also classified the autumn and winter

period into three distinct periods using feeding flight and activity data from Raveling et al.

(1972); early winter (15 November–31 December), mid winter (1 January–31 January), and late

winter (1 February–28 February).   I used mean imputation to fill in missing data for time period

analysis, which simultaneously retained important 50% core use area and 95% UD information

(Zar 2010). Transmitters ($n = 6$) from 2014–2015 that were present in the GCMA during

2015–2016 were not used for analysis during the second year because of limited locations with

poor temporal spacing (i.e., weeks between locations) and low accuracy. I removed one location

from analysis (Museum of Science and Industry) due to a limited sample size of Canada geese (n

$= 2$). In separate linear mixed models using the lme function in the nlme package (Pinheiro et al.

2016) I analyzed the response variables of 50% core use areas and 95% UD against the predictor

variable of time period (i.e., early, mid-, and late winter) with location of capture and year as

random effects. Statistical significance for all analyses was inferred if $P \leq 0.05$. Mean 95% UD

were plotted by location for visual representation of variation across locations.

To identify habitat use and selection, I plotted all locations of Canada geese ($n = 39,392$)

on Google Earth Pro using the rgdall and adehabitatLT packages (Calenge 2006, Bivand 2015).

Habitats were classified as green space, riverine, deep-water, industrial urban, or residential

using available aerial imagery and ancillary information. Green spaces were typically large

parks, cemeteries, and other large grass areas that contained a mixture of ponds, trees and shrubs,

large sports fields, and golf courses within their boundaries (Table 1.2). I also included small

grass lawns and areas between buildings in the green space habitat. Riverine habitat consisted of

the Des Plaines and Calumet Rivers. Deep-water habitats were defined as the Chicago Sanitary

and Ship Canal, which had steep concrete walls and warm water discharges along the canal

corridor, and the Stickney Water Reclamation Plant, which was a mixture of gravel embankments and grass near deep-water settling ponds ($n = 96$). Deep-water habitat remained ice-free throughout the entire winter due to constant moving water within the settling ponds and warm-water discharge and barge traffic within the canal. Industrial urban habitats were defined as rooftops, which were typically large flat industrial buildings and retail stores, and adjacent rail yards composed of large complex series of railroad tracks where railcars were loaded, unloaded, and stored. Residential habitats were typically houses and developments, parking lots, and miscellaneous other land uses occurring in residential areas. To determine availability of the aforementioned use areas within the GCMA, I used a random number generator to create 500 locations within the study area and then classified each location using the same methods as was used for habitat use locations. I compared habitat use and availability across the entire autumn and winter period for both years and when the temperature dropped below the theoretical lower critical temperature (LCT) for Canada geese (Batt et al. 1992). The LCT is estimated using the resting metabolic rate and is the point where the ambient temperature is below the thermoneutral zone and heat is required to maintain body temperature, typically through metabolizing endogenous reserves. I am using the theoretical LCT of -6 °C for Canada geese as my threshold with knowledge that this is not a discrete threshold and that the LCT varies by individual through a complex interplay of physiological and behavioral adaptations. Additionally, I compared use across the 3 time periods (early, mid-, late winter). I conducted a Chi-squared test to compare proportional habitat use against proportion of availability for years (including all locations and below LCT) and across the time periods setting statistical significance for all analyses at $P < 0.05$ (Campbell 2007, Richardson 2011). Phenology of spring and fall migration dates was determined once a goose either left or entered the GCMA.

To address habitat use and selection, I used the resource selection function (RSF) with an exponential link to estimate $w(x)$, which is the proportion of used locations with characteristics x, divided by the proportion of available locations with characteristics x (McDonlad 2013). When $w(x) > 1$, the habitat type is selected and Canada geese are not in that location by random chance. When $w(x) = 1$, presence in a habitat is random, and when $w(x) < 1$ Canada geese are avoiding these habitat types. I determined habitat use by taking all locations ($n = 39,392$) and creating a table of counts of Canada geese in habitat types and I then generated available habitat points (1 per used location) as a random draw, with replacement, from the sample of 500 random habitat locations used to generate habitat availability. This action doubled the dataset providing 78,784 locations used to estimate the RSF $w(x)$. I then classified used locations and available locations belonging to the aforementioned 5 different habitat types and assumed that there was no change in urban habitat across years. I expected the relationship between habitat use and snow depth and minimum daily temperature to be curvilinear. Using the RSF, I analyzed habitat use as a function of habitat type (i.e., green space, riverine, deep-water, industrial urban, and residential), time of day (i.e., diurnal or nocturnal), and snow depth (cm). In a separate RSF analysis, I analyzed habitat use as a function of habitat type, time of day, and minimum daily temperature (°C) (Manly et al. 2007, McDonald 2013, Nielson and Sawyer 2013). The diurnal time period was set at 0500–1900 to account for crepuscular movements and the nocturnal time period was 1901–0459. I expected that there would be a threshold in both snow depth and minimum daily temperature so I used a quadratic term. I also expected the affect of snow depth and time of day (i.e., nocturnal or diurnal) to vary in habitat types and that is why I used an interaction term. Covariates of daily snow depth and daily minimum temperature were used because of their correlation with Canada goose activity patterns and weather data were obtained from the weather

station at Midway International Airport (Raveling et al. 1972, Weather Underground 2016). I

plotted the parameter estimates to make predictions of RSF $w(x)$ (relative probability of a

Canada goose using a particular habitat) within the range of minimum daily temperatures and

snow depth data (Neter et al. 1996). I ran a smoothing factor for the plots to interpolate the

predicted RSF $w(x)$ between large gaps in snow depth data.

Winter survival (S) with 95% confidence intervals (CI) was calculated using the Known-

Fate model in Program MARK because transmitters provided fine-scale data and status (i.e.,

alive or dead) of all Canada geese ($n = 41$) was known (Cooch and White 2016). I assumed that

all transmittered Canada geese were mutually exclusive and because of spatial variation in

transmitter deployment, I used a staggered entry design with paired entries with "0" in the first

position to indicate a Canada goose was not transmittered yet and "1" in the first position for

individuals that were transmittered. The second position in the pair was "0" if the Canada goose

survived to the end of the interval or "1" if it died sometime during the interval. I broke down

time intervals into weeks ($n = 15$) and then grouped them into the 3 time periods (i.e., early, mid-

, late winter). A body condition index (BCI) was developed by regressing the residuals from an

ordinary least-squares regression of massagainst an index of body size (Devries et al. 2008). The

body size index was calculated by running a principal component analysis of all structural

morphological measurements (skull, culmen, and tarsus) obtained at capture with the prcomp

function in Program R and the first principal component (PC1) was used as the index of body

size (Arsnoe et al. 2011). I created 6 models to evaluate the effects of BCI, group (remained in

GCMA or migrated from GCMA), and time period on survival and ranked models using

Akaike's information criterion adjusted for a small sample size (AIC$_c$; Burnham and Anderson

2002). I summed model weights (w_i) of top models to determine relative variable importance.

1.4 RESULTS

Neither the 50% core use areas ($\bar{x} = 0.7$ km^2, SE = 0.3, $F_{1,95} = 1.3$, $P = 0.26$) nor the 95% UD ($\bar{x} = 24.5$ km^2, SE = 5.2, $F_{1,95} = 0.37$, $P = 0.54$) of Canada geese ($n = 36$) varied by time period (Figure 1.3). Canada geese selected green space (59.8%), deep-water (15.2%), industrial urban (11.3%), and riverine (8.1%) habitats in greater proportion than their availability ($P \leq 0.05$) (Table 1.3). When temperatures were below the LCT, Canada geese increased use of deep-water (+245.6%) and riverine habitats (+158.0%) while decreasing their use of green space (-60.2%; Table 1.3). Green space was selected more than any other habitat and used in disproportion to available green space during the early winter time period (80.4%), but selection of green space declined during mid winter (52.2%) and late winter (52.8%; $P < 0.01$; Table 1.4). Canada geese increased use of deep-water habitat throughout the time periods from 0.7% in early winter to 41.7% during mid winter and 37.5% in late winter (Table 1.4). Similarly, increased use of industrial urban habitats was observed from early winter (6.8%) to mid winter (11.3%) and late winter (14.2%; Table 1.4).

Snow depth ($F_{1, 78,728} = 119.23$, $P < 0.01$), minimum daily temperature ($F_{1, 78,728} = 183.56$, $P < 0.01$), time of day ($F_{1, 78,728} = 9.19$, $P < 0.01$), and all interactions ($P < 0.01$) affected habitat use. The resource selection function (RSF) $w(x)$ was above 1 for every habitat type except residential indicating that Canada geese selected green space, industrial urban, riverine, and deep-water habitats, but avoided residential habitats (Figures 1.4–1.13). As snow depth increased the RSF $w(x)$ increased for industrial urban, riverine, and deep-water habitats, while use of green space decreased (Figure 1.4, Figure 1.5, Figure 1.7, Figure 1.8). Residential habitat had the lowest RSF $w(x)$ that was near "0" across almost all snow depths and minimum daily temperature ($^{\circ}$C) ranges (Figure 1.6, Figure 1.11). Canada geese selected riverine and deep-

water habitats more often during nocturnal than diurnal periods (Figure 1.4, Figure 1.7, and Figure 1.12). As minimum daily temperature (^oC) decreased, the RSF $w(x)$ increased for riverine and deep-water habitats. Industrial urban habitats had an increase in RSF $w(x)$ as temperature decreased, but then selection peaked and started to decrease towards "1" at -5 ^oC (Figure 1.13). Green space use declined as temperature decreased and approached $w(x) = 1$ near -20 ^oC indicating that use was almost by chance (Figure 1.5).

Winter survival was 100% for Canada geese using the GCMA ($n = 35$) and 48% (95% CI range = 16% to 82%; $n = 6$) for geese that emigrated from the GCMA. Weekly survival for emigrating Canada geese was 95% (95% CI range = 86% to 98%). Time period affected survival for Canada geese that left the GCMA with an estimated weekly survival of 100% for early winter, 85% (95% CI range = 62% to 95%) during the mid winter, and 100% for late winter. I documented three direct mortalities, all from hunting during the mid-winter time period. Mortalities occurred 8 days (range 2–16) after the Canada geese emigrated from the GCMA. Hunting mortalities occurred in northwest Indiana, southwest Illinois, and northwest Tennessee. BCI was related negatively to survival, but confidence intervals overlapped zero indicating no true effect. The top two models for survival analysis ($\sum w_i = 0.9$) included time period (Table 1.5). All Canada geese that migrated from the GCMA died during the mid winter time period, a time period that corresponds to the hunting season in the region.

The majority of Canada geese (85%) fitted with transmitters never migrated south from the GCMA. During 2014–2015, only 3 Canada geese left the GCMA. One Canada goose left on 30 November 2014 and 2 left on 4 January 2015. During 2015–2016, only 3 of the 31 Canada geese emigrated from the GCMA to more southern latitudes, 1 left on 30 December 2015 and 2 left on 13 January 2016.

In 2015, Canada geese ($n = 7$) initiated spring migration on 11 March through 16 March 2015, while 2 geese remained in the GCMA for the breeding season. Spring migration initiated earlier in 2016 when Canada geese ($n = 15$) started northward from 20 February through 1 April 2016. Fourteen Canada geese remained within the GCMA during the breeding portion of the annual cycle in 2016. Canada geese showed high site fidelity to the GCMA. All Canada geese with active transmitters from 2014–2015 ($n = 7$) were present within the GCMA during the autumn of 2015. Return flights to the GCMA ranged from May through November in 2015.

1.5 DISCUSSION

Canada geese in the GCMA had relatively small core use areas (Rutledge et al. 2015), remained within urban areas and did not make flights to agricultural fields within or outside of the GCMA where they might have been subjected to hunting mortality, high survival and made use of novel habitats within highly urbanized areas such as rooftops, rail yards, water treatment facilities, and warm-water discharges along rivers and the canal. Canada geese in the GCMA tended to have relatively small 50% core use areas, which predominately included green spaces, and 95% UD were similar to the home range estimate of 25 km^2 produced by Groepper et al. (2008). Although agricultural fields were present within and nearby the GCMA Canada geese did not make foraging flights and apparently did not require waste grain in agricultural fields for survival. Possibly Canada geese entered the winter at with abundant fat reserves to minimize the need for feeding flights and instead choose to minimized energy expenditure by remaining within the GCMA throughout winter. For example, male Canada geese were approximately 500 g heavier and females were 700 g heavier than geese captured during winter near Rochester, Minnesota (McLandress and Raveling 1981; Appendix Table A.1). Additionally, Canada geese in the GCMA were larger than wintering geese from southern Illinois and east-central Wisconsin

(Gates e al. 2001). Moreover, Canada geese increased use of these industrial urban habitats as snow depth increased and temperature decreased suggesting there may be thermal or survival benefits from selecting these areas. While I know of no other published accounts of Canada geese extensively using rooftops and rail yards in winter, I expect they are taking advantage of the relative safety of the urban landscape.

Canada geese used a mix of habitats in the GCMA, including many areas not previously reported as primary habitats (e.g., rooftops, rail yards, wastewater treatment facilities). Large green spaces were selected across all time periods, even when temperatures were below the LCT for Canada geese, and likely provide necessary food and water resources needed by geese even during winter. Although the LCT may have been affected by a complex interplay of physiological and behavioral mechanisms resulting in variation between individuals and habitats, I believe the LCT I selected represented an approximate temperature threshold which could have influenced thermoregulatory costs of Canada geese in the GCMA during winter. During winter weather events when snow depth increased and temperatures decreased, Canada geese reduced their use of green spaces and increased use of industrial urban habitats (i.e., rooftops, rail yards, and the canal; Figures 1.4–1.13). This change may be in response to availability of roost areas and forage within green spaces becoming limited due to ice coverage and increased snow depth. Canada geese may change to novel urban habitats for thermal benefits, sanctuary, food resources (see Chapter 2). For example during these cold periods, spilled grain may have been available in rail yards. Industrial rooftops may have provided thermoregulatory benefits and sanctuary from disturbances and predators, and deep-water habitat may have provided open water for roost locations. Once temperature increased and snow depth decreased, Canada geese increased proportional use of green spaces. The difference in use of green space between the 2 years may

be due to the weather extremes. The winter during 2014–2015 was 2 °C colder and had 32 cm

more snow accumulation than an average winter for the GCMA compared to 2015–2016 that

was 3 °C warmer with 30 cm less snow than average (NOAA 2015*b*, 2016). Harsh winter

conditions during 2014–2015 may have affected the ability of Canada geese to roost on water

sources in green spaces and reduced the availability of grass for foraging making geese utilize

novel urban habitats at a higher frequency.

   High survival of Canada geese in the GCMA relative to other published estimates during

autumn and winter suggests that urban habitats provide sanctuary and other resources needed for

survival north of historic wintering ranges (Balkcom 2010). Typically, survival rates for Canada

geese are lower during winter months at more northern latitudes than I observed within the

GCMA (72–98%; Hestbeck and Malecki 1989). Unlike Groepper et al. (2008), a study

conducted in another urban landscape, Canada geese that wintered in the GCMA never occupied

locations that permitted hunting and all geese had their entire 95% UD within city limits.

   The majority of transmittered Canada geese (85%) never migrated south of the GCMA

during winter and no geese made daily feeding flights to agricultural fields unlike results

reported by Groepper et al. (2008). Canada geese could be shifting their foraging efforts and

exploiting different types of available food resources within urban areas, similar in shifts seen by

Atlantic brant (*Branta bernicla hrota*; Ladin et al. 2011). The most compelling reason for

Canada geese not leaving the GCMA may be the lack of predation risk. Similarly, Balkcom

(2010) indicated high seasonal survival (95.8%) in urban areas of Georgia, USA. I suspect that

Canada geese are continually adapting to changing climate and landscapes in North America by

shifting wintering ranges northward and utilizing nontraditional habitats within urban areas,

which provide sanctuary conditions.

Autumn migration of Canada geese returning to the GCMA occurred earlier than other studies in the Midwest (Wege and Raveling 1983). Approximately 50% of Canada geese returned to the GCMA prior to open hunting seasons. Arriving during times when hunting pressure is limited allowed Canada geese to reach urban areas and remain within the city limits during autumn and winter when hunting seasons were open. Canada geese that did migrate from the GCMA during the winter did so during portions of the year when Canada goose hunting seasons were open in Illinois and surrounding states making geese susceptible to predation via hunting, ultimately lowering their survival estimates. Increased hunting pressure outside of urban environments likely creates a strong selection pressure for Canada geese to remain in urban environments, especially when novel urban habitat types may provide necessary resources for survival (Lima and Dill 1990).

1.6 MANAGEMENT IMPLICATIONS

Management of Canada geese in urban areas should focus on harassment during extreme winter weather conditions to reduce the risk of goose-aircraft collisions. Canada geese can mitigate the extreme weather events by taking advantage of novel urban habitats at the northern edge of their wintering range and increase survival. I suspect that Canada geese wintering in northern locations, such as the GCMA, are pushing their thermoregulatory limits, especially during harsh winter conditions. While no transmittered Canada geese died during the study within the GCMA, I found several goose carcasses on rooftops after extreme weather conditions. Harassment of Canada geese at these nontraditional habitats during cold periods may "push" geese to the point where they have to choose to either migrate out of the area, to locations where hunting is permissible, or potentially risk death due to increased energy demands and exposure to the elements. Currently much of the harassment and management of Canada geese within the

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GCMA is focused on the breeding season (Smith et al. 1999, Scribner et al. 2003), and I suggest there is an opportunity to effectively manage geese in urban areas in winter. Additional research is needed to better understand response of Canada geese to harassment in urban areas and understand thermoregulatory balance in these areas.

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1.8 TABLES AND FIGURES

Table 1.1. Dates and number of Canada geese (*Branta canadensis*) captured and transmittered during autumn and winter 2014–2016 in the Greater Chicago Metropolitan Area, Illinois, USA.

Location	2014–2015				2015–2016			
	November 13–31	December 1–15	January 15–31	February 15–28	November 14–31	December 1–15	January 1–15	February 15–29
Marquette Park			1		2	1		
McKinley Park	1					3	5	
Museum of Science and Industry	1				1		1	1*
Resurrection Cemetery		1	1		1	3	1	
Sherman Park	1	1			1	2		
Stickney Water Reclamation Plant			2	1*	1		3	1*
Washington Park					1	1	2	
Total	3	2	4	1	7	10	12	2

*Transmitters recovered from hunters and then redeployed

Table 1.2. Percentage of available habitat compared to all GPS locations in each habitat type used by Canada geese (*Branta canadensis*) and the percentage of habitat use when temperature was below the lower critical temperature (LCT; -6 ⁰C) for Canada geese in the Greater Chicago Metropolitan Area, Illinois, USA, during 2014–2016.

Location	Total Area (km^2)	Surface Water (km^2)	Description
Marquette Park	1.25	0.16	Contains sports fields, 9-hole golf course, trees and shrubs, lagoon
McKinley Park	0.28	0.03	Contains sports fields, trees and shrubs, and pond with islands
Museum of Science and Industry	1.95	0.33	Contains sports fields, 18-hole golf course, trees and shrubs, a lagoon and harbors, bordered to the east by Lake Michigan
Resurrection Cemetery	1.18	0.02	Contains ponds, large buildings, headstones, trees and shrubs
Sherman Park	0.25	0.05	Contains sports fields, trees and shrubs, and a lagoon

Table 1.3. Percentage of available habitat compared to all GPS locations in each habitat type used by Canada geese (*Branta canadensis*) and the percentage of habitat use when temperature was below the lower critical temperature (LCT; -6 ⁰C) for Canada geese in the Greater Chicago Metropolitan Area, Illinois, USA, during 2014–2016.

Habitat	Available	2014–2015		2015–2016		Total	
		All Locations	Below LCT	All Locations	Below LCT	All Locations	Below LCT
Green Space	14.0%	30.1%[a]	18.4%[a]	62.7%[a]	40.8%[a]	59.8%[a]	36.0%[a]
Riverine	2.2%	14.1%[a]	15.6%[a]	7.6%[a]	12.0%[a]	8.1%[a]	12.8%[a]
Deep Water	1.0%	20.9%[a]	29.6%[a]	14.6%[a]	40.1%[a]	15.2%[a]	37.8%[a]
Industrial Urban	8.0%	30.6%[a]	32.3%[a]	9.4%	4.4%[a]	11.3%[a]	10.4%
Residential	74.8%	4.3%[a]	4.1%[a]	5.7%[a]	2.7%[a]	5.6%[a]	3.0%[a]
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

[a] Designates proportional habitat use that was determined to significantly ($P \leq 0.05$) differ from proportion of habitat available based on Chi-squared tests.

Table 1.4. Percentage of available habitat compared to percentage of GPS locations in each habitat type used by Canada geese (*Branta canadensis*) for all locations and when temperature was below the lower critical temperature (LCT; -6 ⁰C) for Canada geese during the 3 time periods in the Greater Chicago Metropolitan Area, Illinois, USA, during 2014–2016.

Habitat	Available	Early Winter		Mid Winter		Late Winter	
		All Locations	Below LCT	All Locations	Below LCT	All Locations	Below LCT
Green Space	14.0%	80.4% [a]	84.7% [a]	52.2% [a]	38.7% [a]	52.8% [a]	30.6% [a]
Riverine	2.2%	3.5%	7.3% [a]	11.4% [a]	11.8% [a]	8.4% [a]	14.0% [a]
Deep Water	1.0%	1.9%	0.7%	21.8% [a]	41.7% [a]	18.2% [a]	37.5% [a]
Industrial Urban	8.0%	6.8%	0.3% [a]	11.3% [a]	6.2%	14.2% [a]	14.2% [a]
Residential	74.8%	7.4% [a]	7.0% [a]	3.3% [a]	1.6% [a]	6.4% [a]	3.7% [a]
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

[a] Designates proportional habitat use that was determined to significantly (P ≤ 0.05) differ from proportion of habitat available based on Chi-squared tests.

Table 1.5. Results of linear models evaluating the effects of period (early winter, mid winter, late winter), group (stayed or emigrated from the Greater Chicago Metropolitan Area), and body condition index (BCI) on survival (S) of Canada geese (*Branta canadensis*) captured and transmittered during autumn and winter 2014–2016 in the Greater Chicago Metropolitan Area, Illinois, USA with Akaike's Information Criterion adjusted for sample size AIC_c with number of parameters (k), difference in AIC_c with top model (ΔAIC_c), model weight (w_i), and deviance.

Model	k	AICc	ΔAICc	w_i	Deviance
S(Period) +(Group)+(BCI)	4	22.5	0.0	0.5	14.4
S(Period)	3	23.0	0.5	0.4	16.9
S(Group)	2	28.2	5.7	0.0	24.1
S(Constant)	1	37.0	14.5	0.0	35.0
S(BCI)	2	37.7	15.3	0.0	33.7
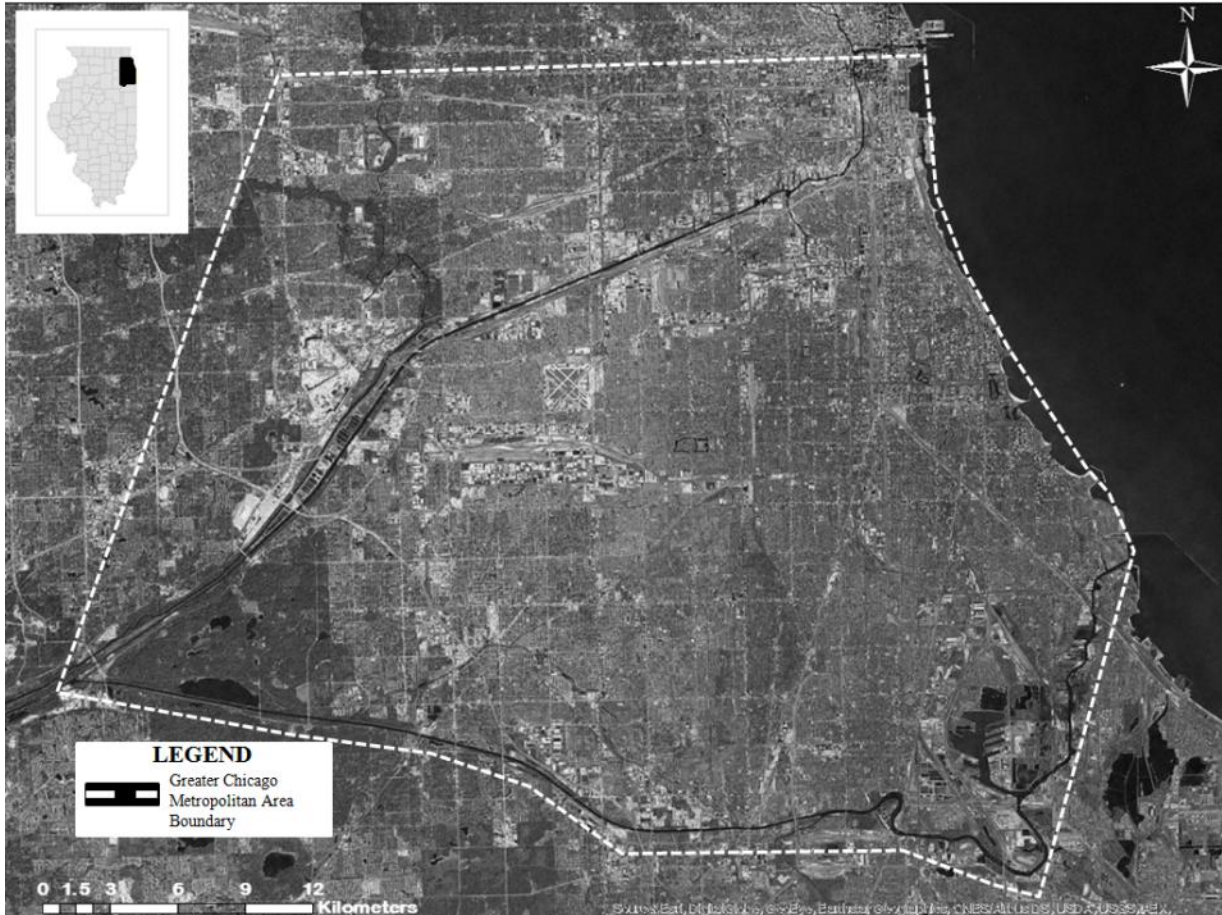
Figure 1.1. The Greater Chicago Metropolitan Area located in northeast Illinois, USA.
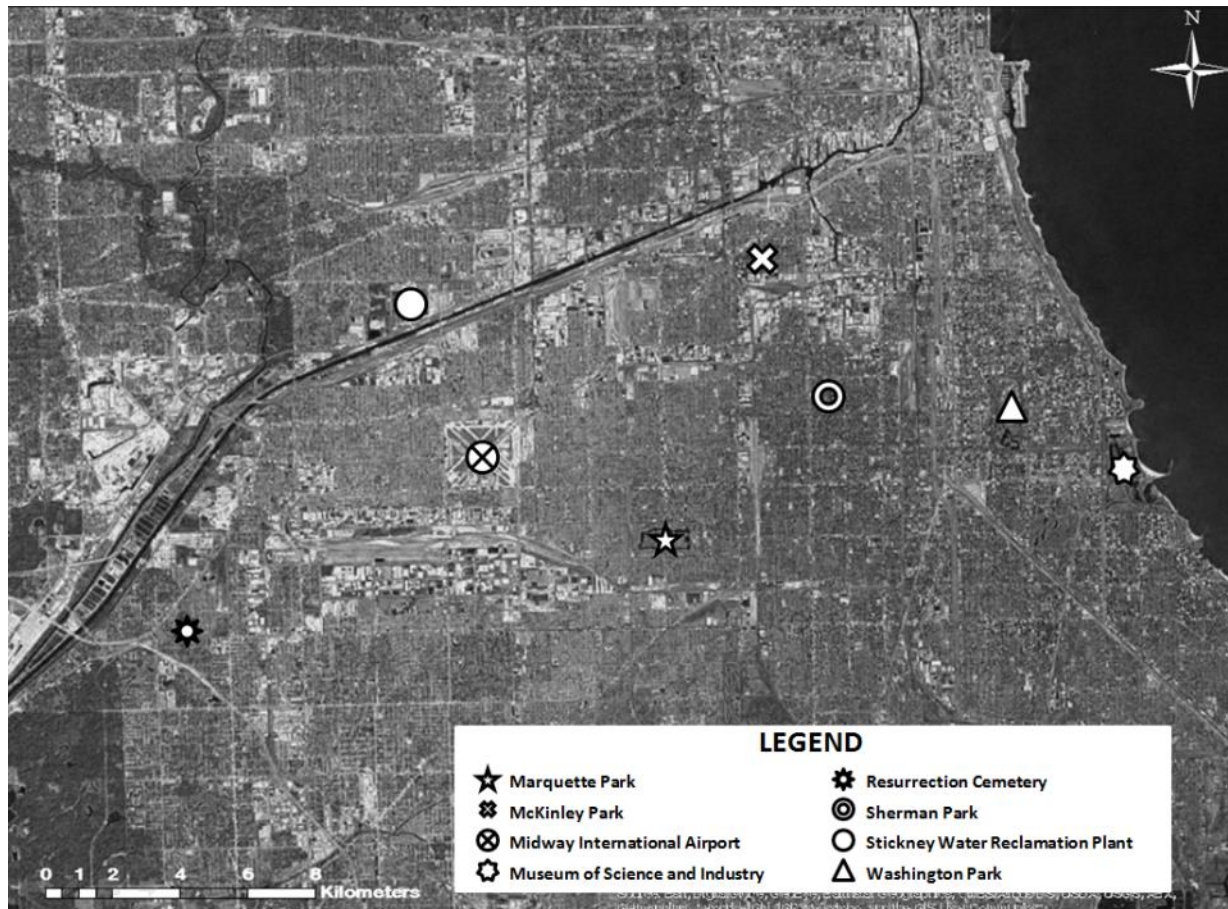
Figure 1.2. Main capture locations (*n* = 7) for Canada geese (*Branta canadensis*) in relation to Midway International Airport in the Greater Chicago Metropolitan Area, Illinois, USA.
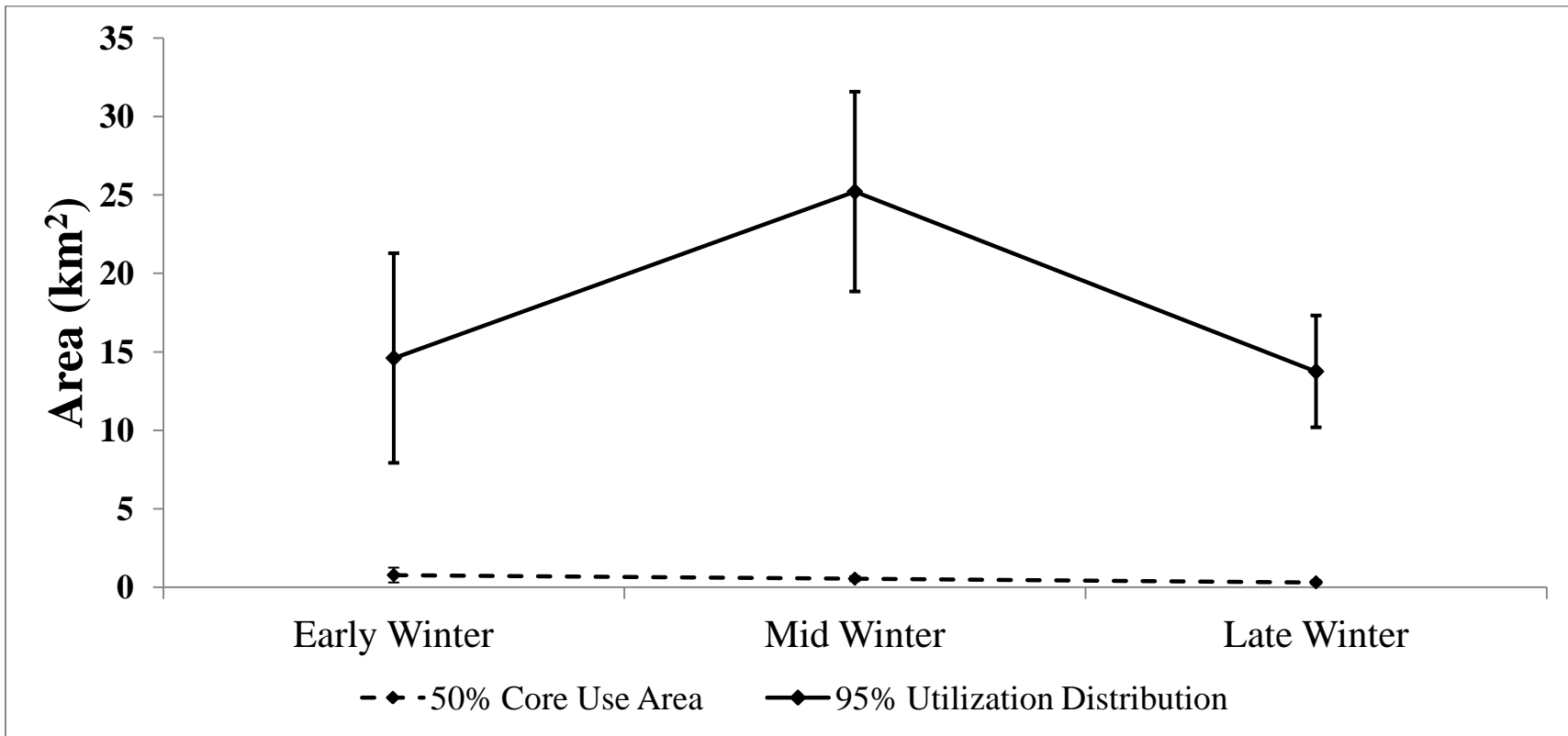
Figure 1.3. Change in 50% core use areas and 95% utilization distribution estimates with standard error bars across 3 time periods for Canada geese during autumn and winter 2014–2016 in the Greater Chicago Metropolitan Area, Illinois, USA.
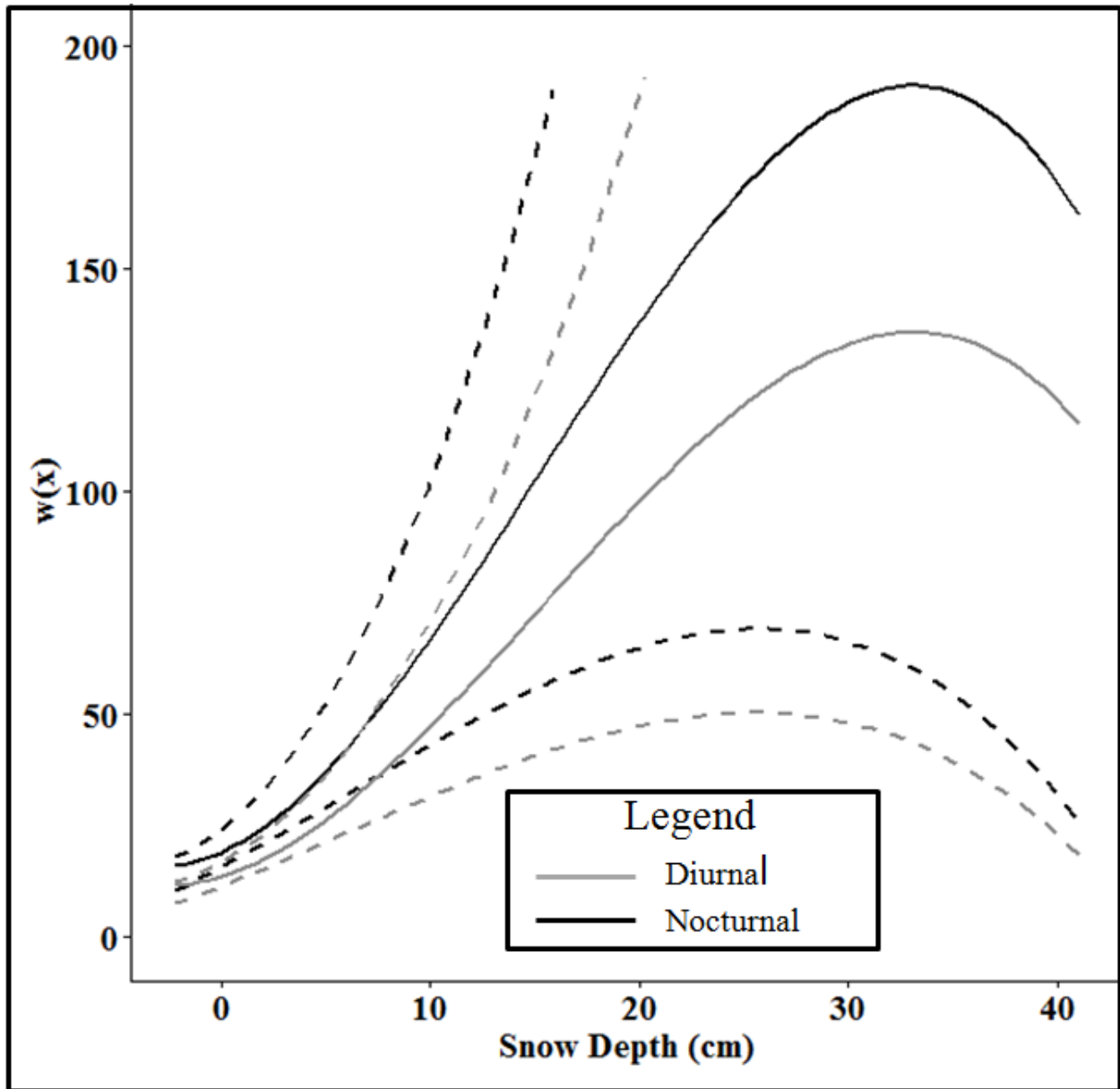
Figure 1.4. Estimated resource selection function $w(x)$ for deep-water habitat used by Canada geese (*Branta canadensis*) at varying levels of snow depth (cm) from November 2015 through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.
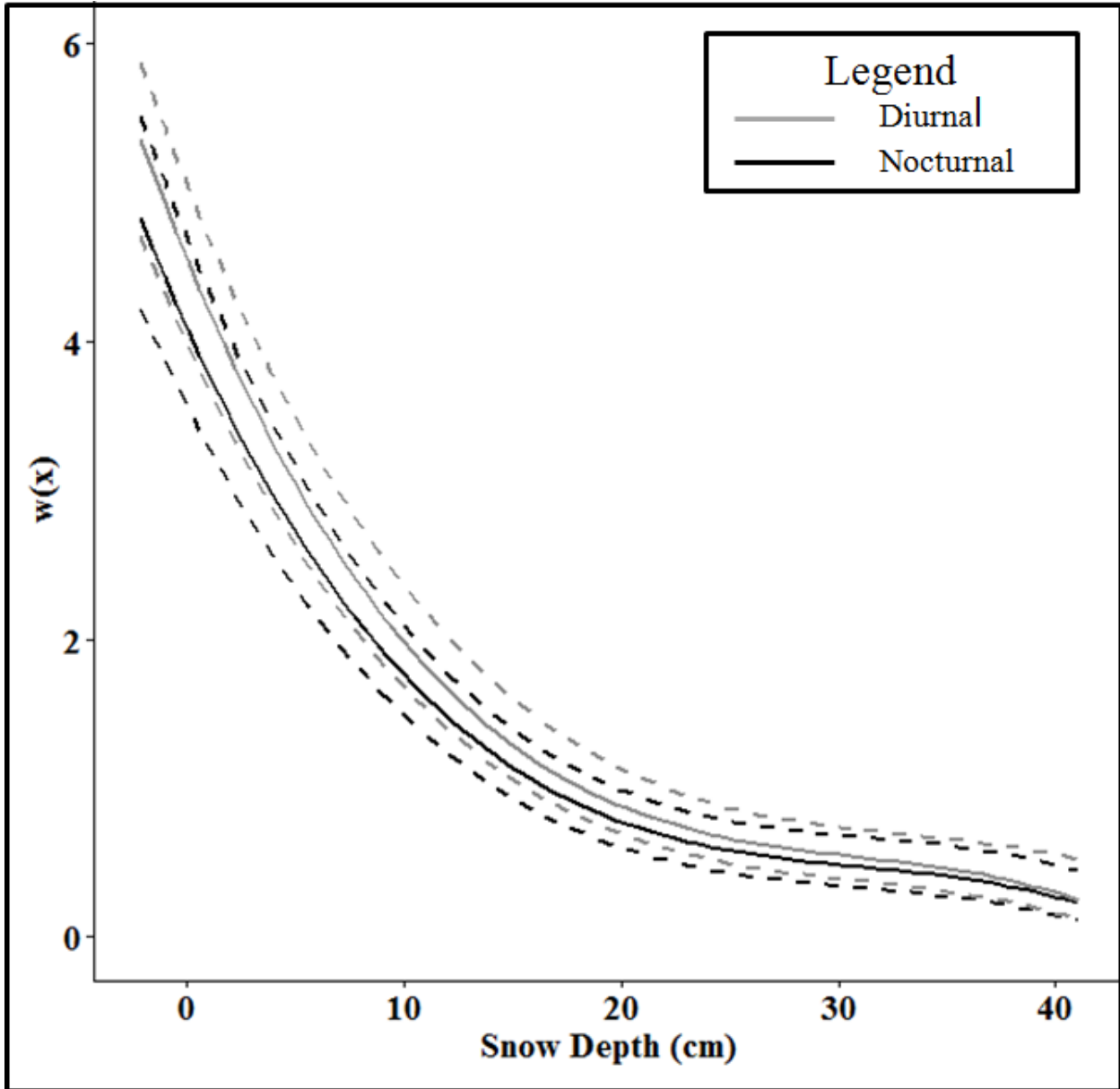
Figure 1.5. Estimated resource selection function *w*(*x*) for green space habitat used by Canada geese (*Branta canadensis*) at varying levels of snow depth (cm) from November 2015 through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.
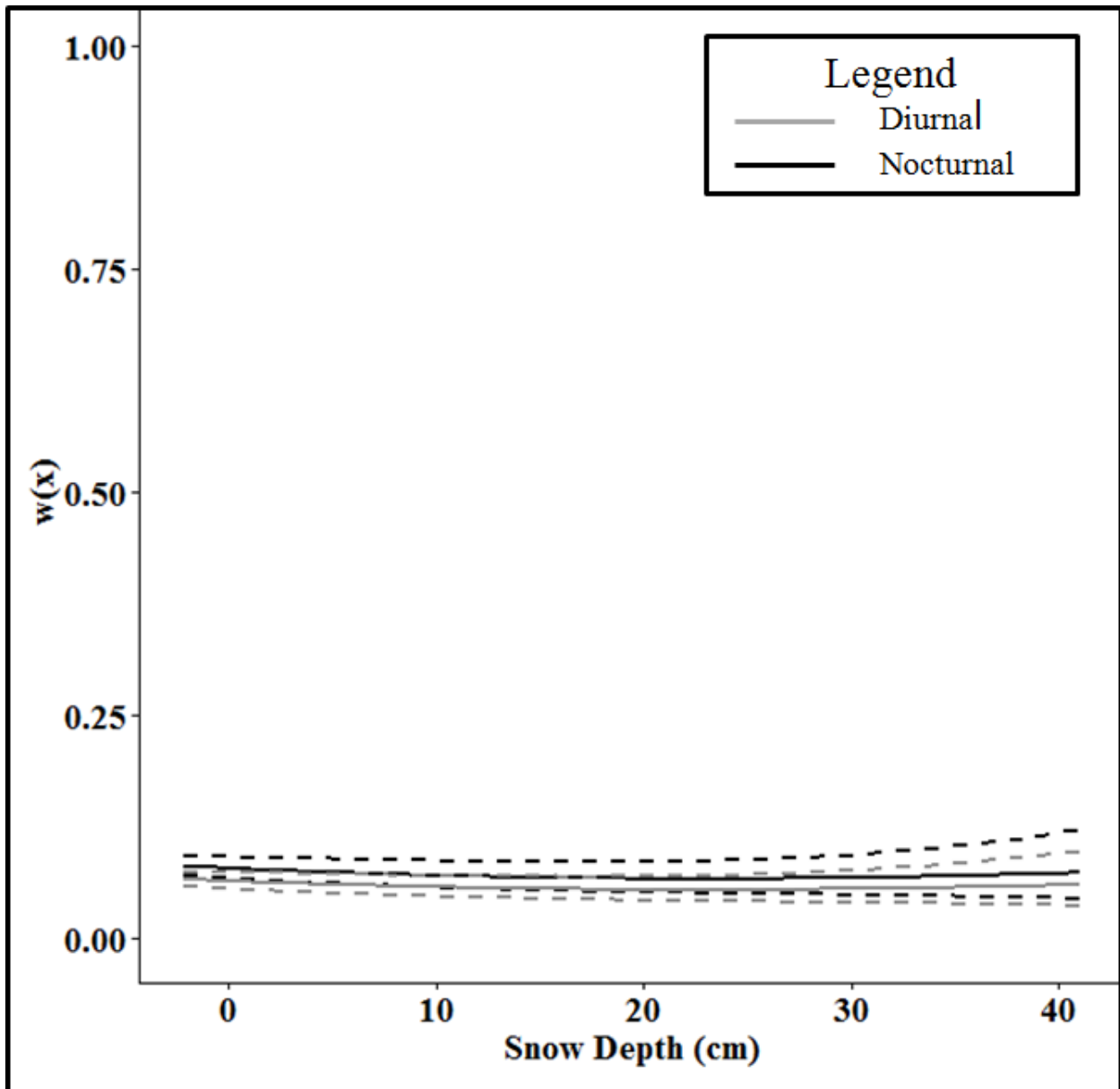
Figure 1.6. Estimated resource selection function *w*(*x*) for residential habitat used by Canada geese (*Branta canadensis*) at varying levels of snow depth (cm) from November 2015 through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.

Figure 1.7. Estimated resource selection function $w(x)$ for riverine habitat used by Canada geese (*Branta canadensis*) at varying levels of snow depth (cm) from November 2015 through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.

Figure 1.8. Estimated resource selection function *w(x)* for industrial urban habitat used by

Canada geese (*Branta canadensis*) at varying levels of snow depth (cm) from November 2015

through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.
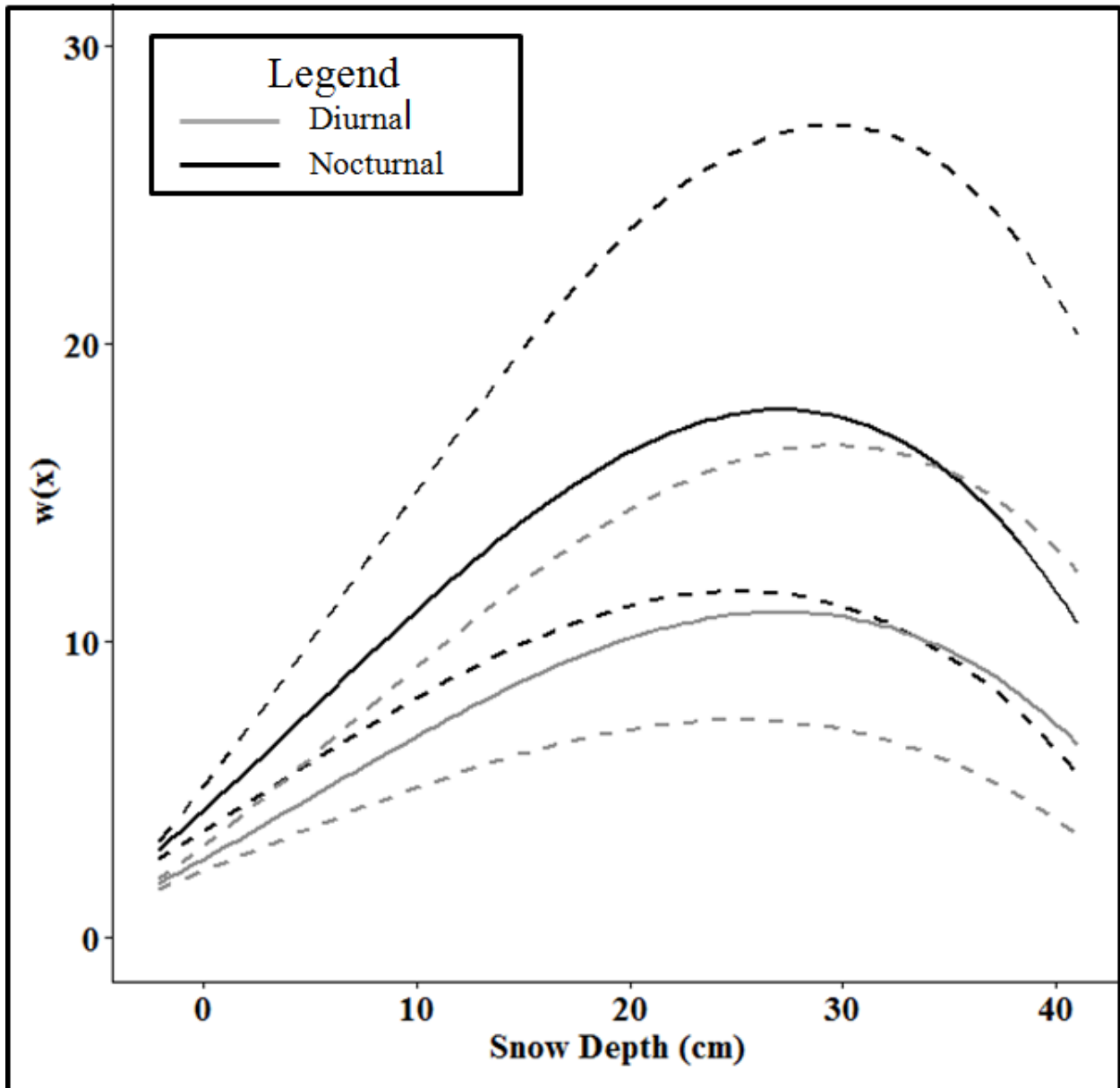
Figure 1.9. Estimated resource selection function *w*(*x*) for deep-water habitat used by Canada geese (*Branta canadensis*) at varying levels of minimum daily temperatures (°C) from November 2015 through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.

Figure 1.10. Estimated resource selection function *w*(*x*) for green space habitat used by Canada geese (*Branta canadensis*) at varying levels of minimum daily temperatures (°C) from November 2015 through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.

Figure 1.11. Estimated resource selection function *w*(*x*) for residential habitat used by Canada geese (*Branta canadensis*) at varying levels of minimum daily temperatures (°C) from November 2015 through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.
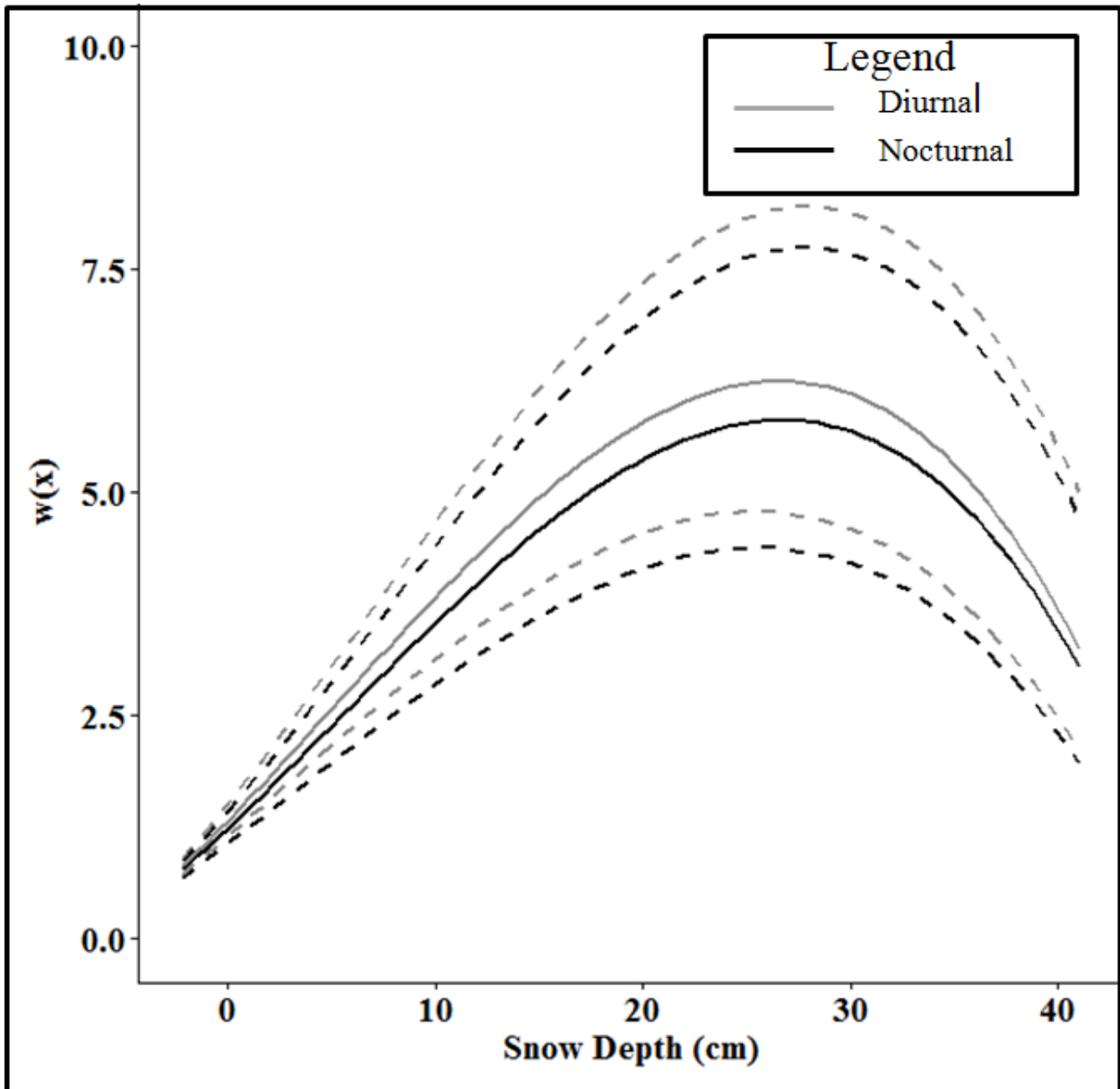
Figure 1.12. Estimated resource selection function *w*(*x*) for riverine habitat used by Canada

geese (*Branta canadensis*) at varying levels of minimum daily temperatures (°C) from November

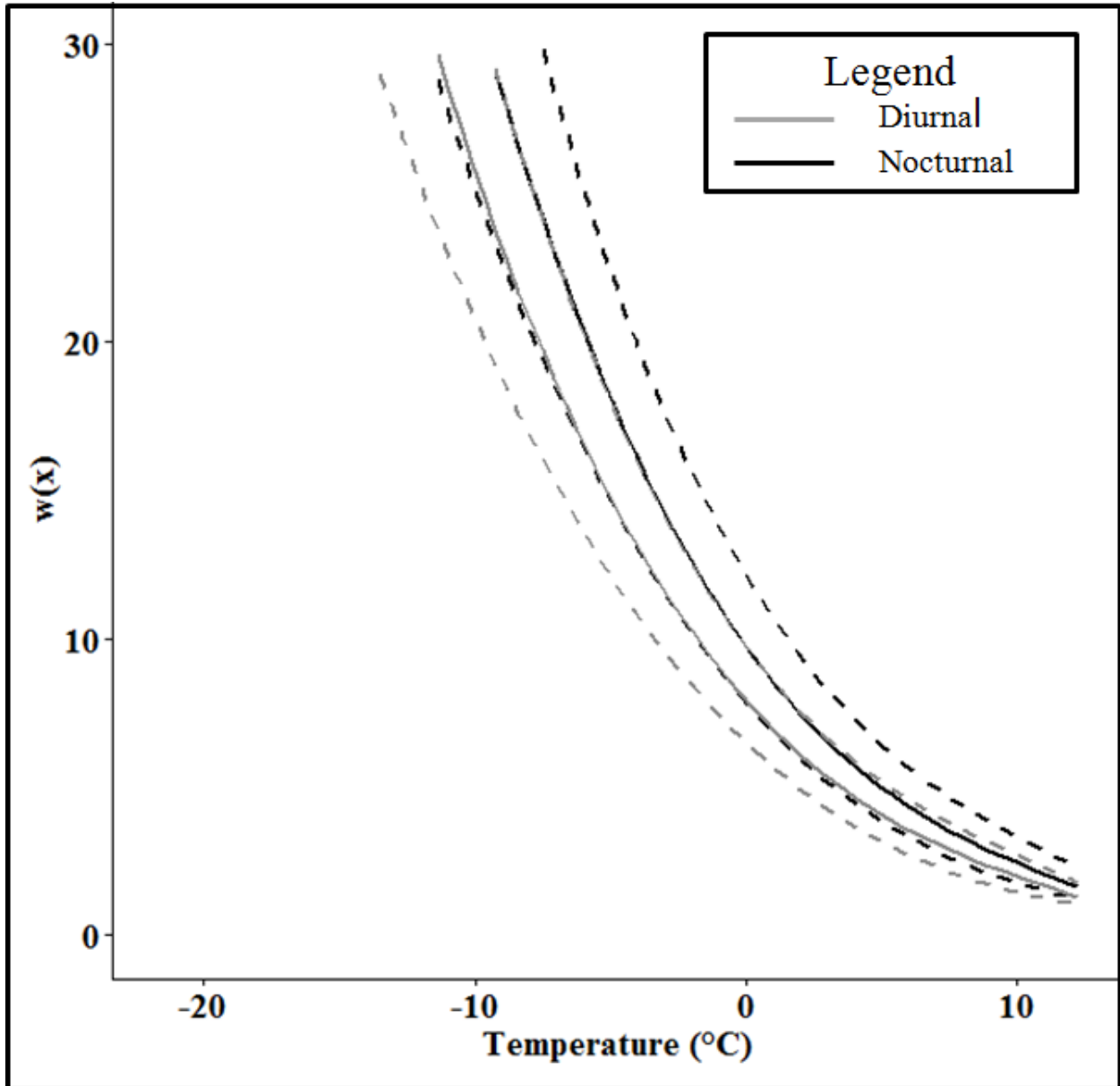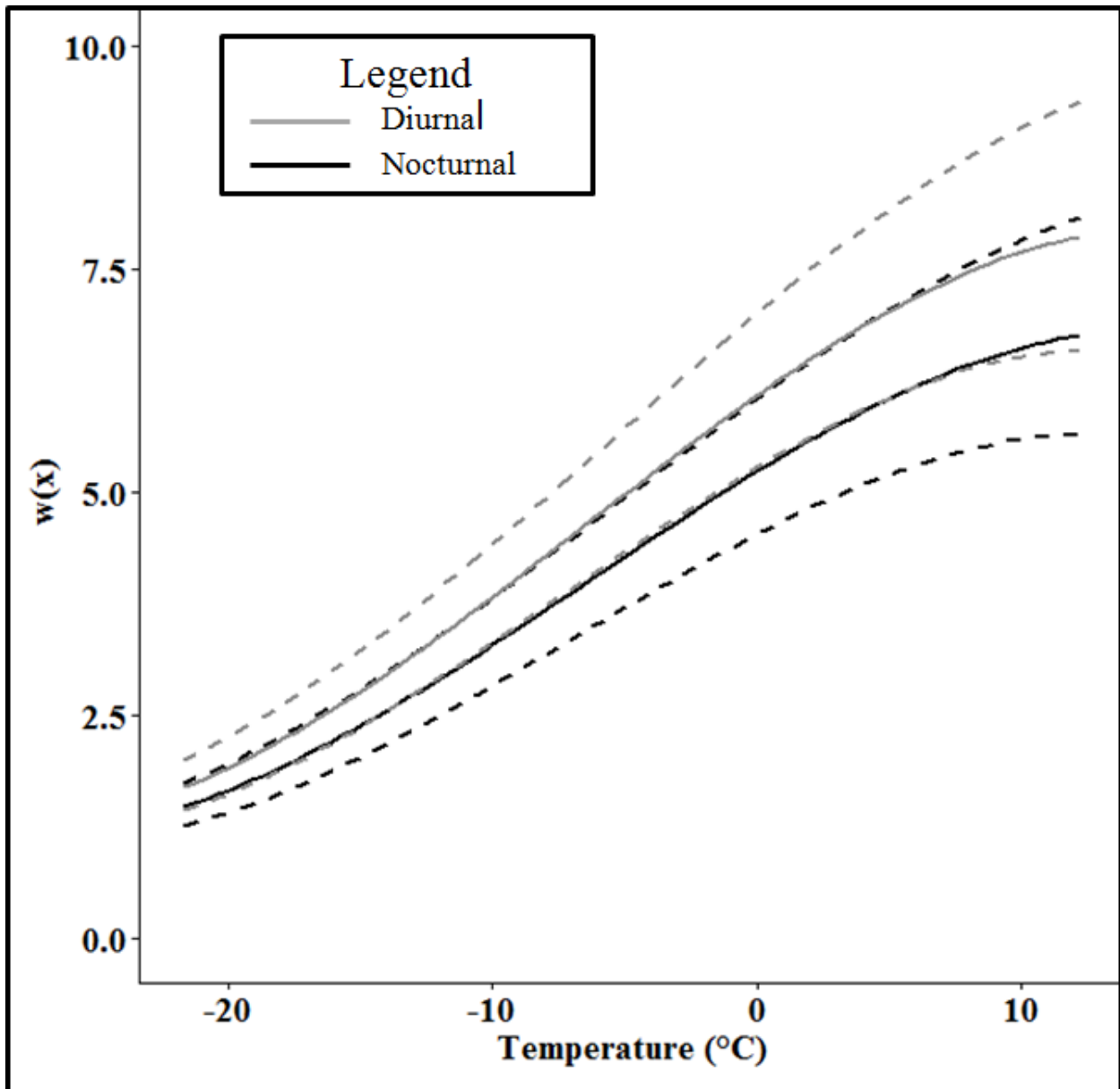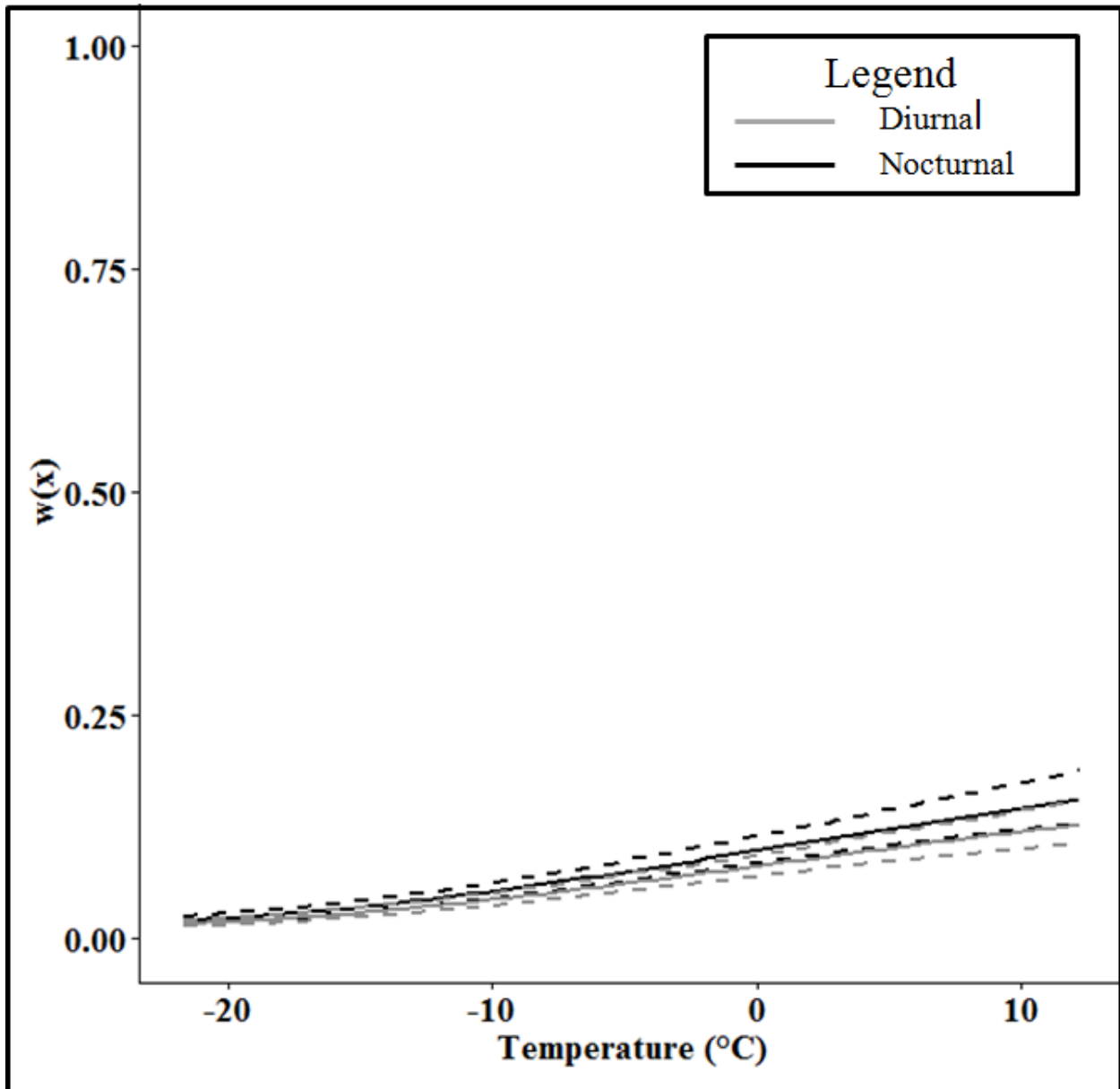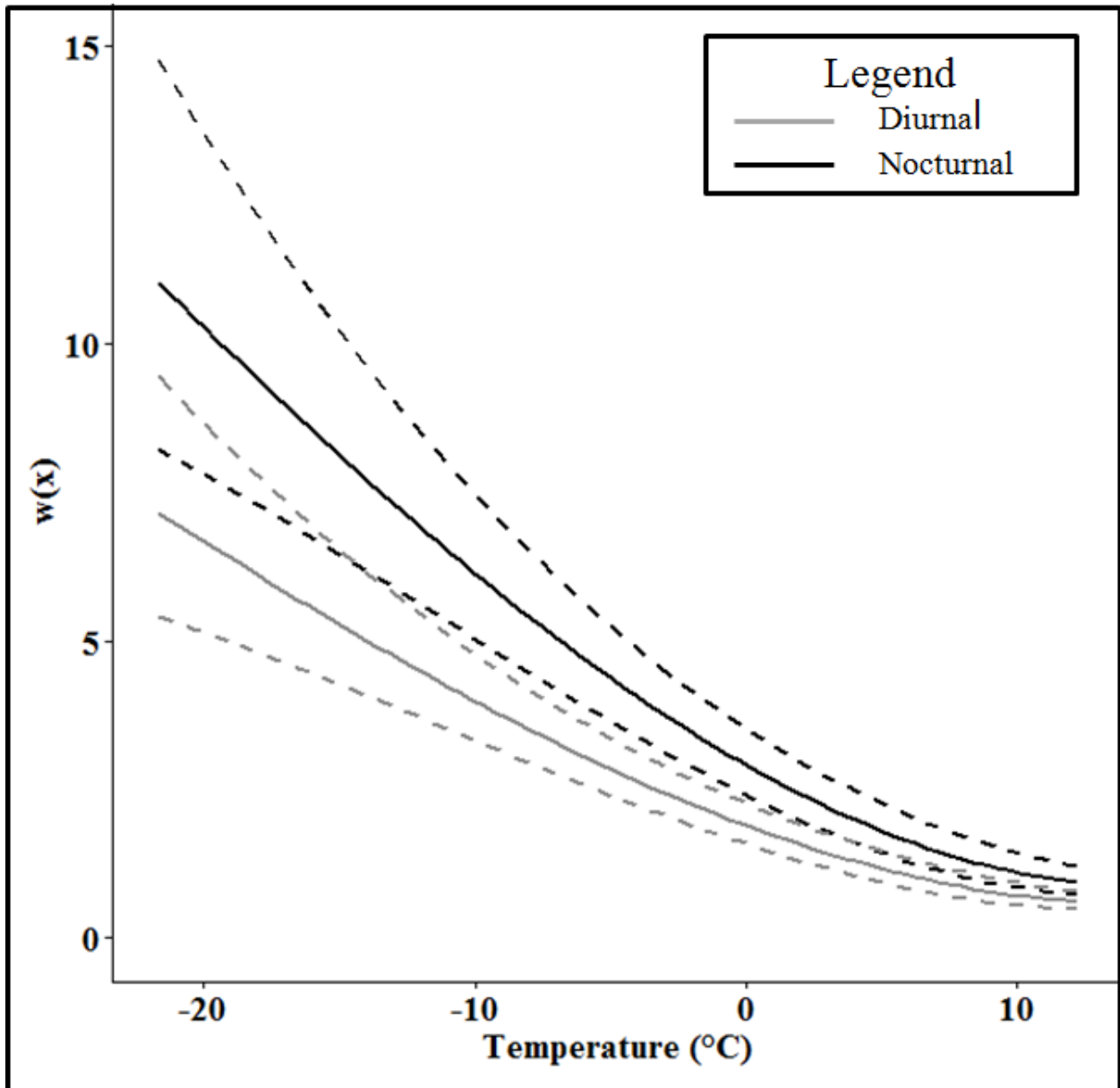2015 through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.

Figure 1.13. Estimated resource selection function *w*(*x*) for industrial urban habitat used by Canada geese (*Branta canadensis*) at varying levels of minimum daily temperatures (°C) from November 2015 through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.
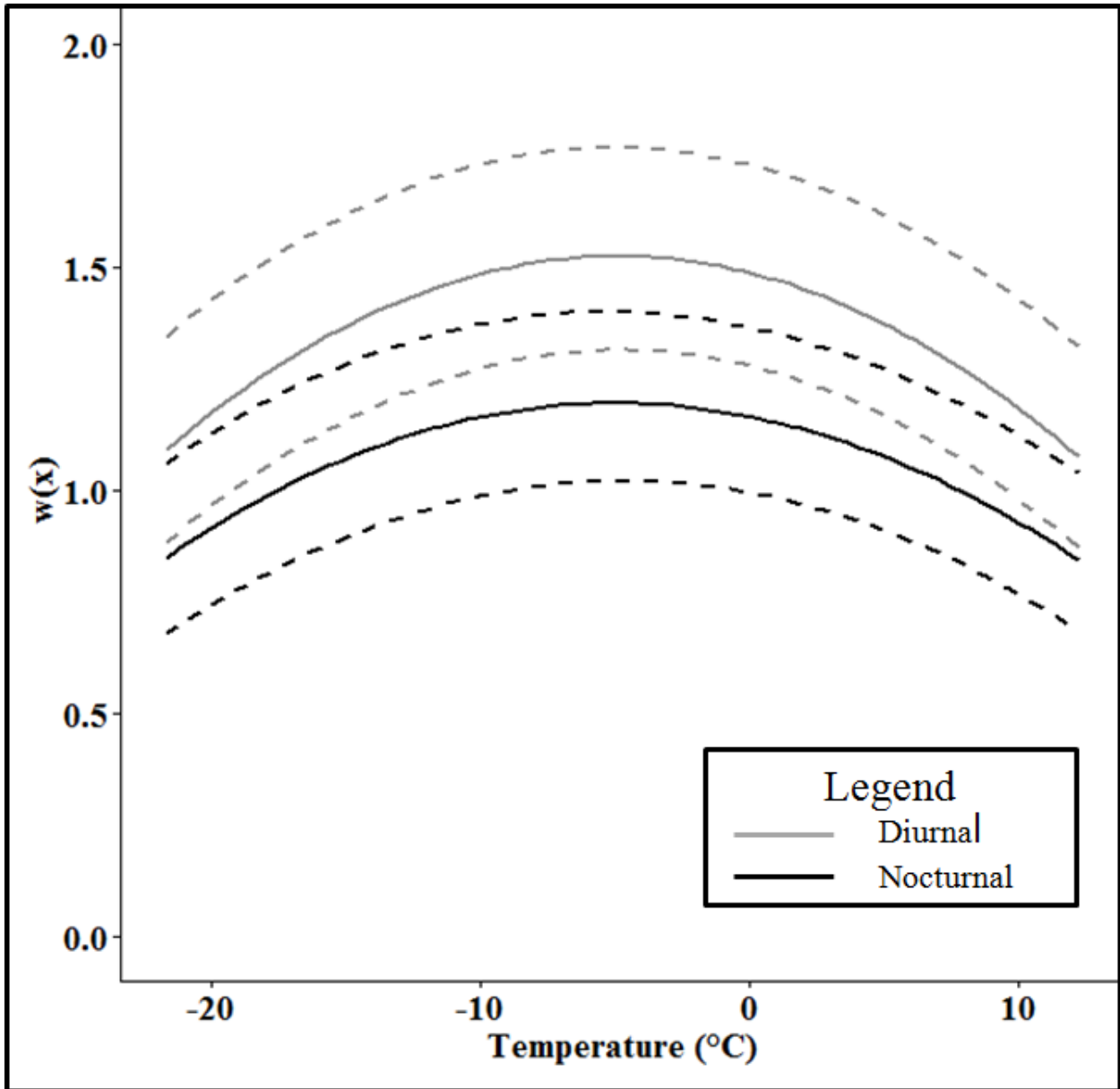
CHAPTER 2: HOW DO CANADA GEESE ALTER THEIR BEHAVIOUR TO ALLOW FOR SURVIVAL NORTH OF HISTORIC WINTERING GROUNDS?

2.1 ABSTRACT

The winter distribution of birds is typically correlated with minimum temperature isotherms, but some individuals can overcome thermoregulatory limits though behavioral adaptations and utilization of urban areas. I investigated factors affecting habitat use and movements, as well as thermal benefits of habitats selected by Canada geese (*Branta canadensis*) during late autumn and winter in the Greater Chicago Metropolitan Area (GCMA) in northeastern, Illinois, USA. I captured Canada geese during November–February 2014–2016 and fitted 41 geese with solar-powered GPS transmitters that were affixed to neck collars. Transmitters operated on the cellular phone network and were programmed to collect hourly locations ($n = 35,896$). I investigated the movement of Canada geese both within and between six habitats (i.e., green space, rail yards, residential, riverine, rooftops, and deep-water). Although I found that rooftops and deep-water habitats had greater maximum daily temperatures, there was no difference in the minimum daily temperatures, providing limited support for their selection as thermal refugia in the winter. When temperatures were warmer than the lower critical temperature (LCT; -6 ⁰C) Canada geese typically moved between green spaces and rooftops; however, when temperatures were below the LCT, geese moved from green spaces to deep-water habitats. Canada geese appear to be using multiple urban habitats to mitigate the effects of wintering at northern latitudes where thermoregulatory costs may be high. First, Canada geese used habitats that had slightly warmer maximum daily temperatures; second, geese used habitats where disturbance was likely minimal such as deep-water and rooftop habitats. Finally, Canada geese used novel habitats such as rail yards where they likely forage on spilled

agricultural grain from railcars and use of these nontraditional habitats in urban areas allows

Canada geese to winter in more northerly areas than historically.

2.2 INTRODUCTION

The winter distributions of most birds appear to be driven by effects of multiple and

interacting environmental factors (Brown 1984, Brown et al. 1995, Canterbury 2002). Typically,

the northern boundaries of birds in winter correlate with average minimum temperature

isotherms (Root 1988*a*, *b*). Winter weather increases energy demands at the same time that

available resources become limited for most species (Charles and Harold 1966, Rising and

Hudson 1974, Baldassarre and Bolen 2006). Distributions of winter ranges of birds can be

affected by changes in available food or thermal refugia (Cotton 2003, Pearson and Dawson

2003). However, waste grain in agricultural fields can increase food availability during late

autumn and winter and urban areas may provide thermal refugia that allows birds to maintain

energy balances in more northerly areas than they have used historically (Jokimäki et al. 1996,

Baldassarre and Bolen 2006, La Sorte and Thompson 2007).

A number of behavioral mechanisms may allow species to overcome factors limiting

their northern distributions and expand their wintering ranges. For example, nine-banded

armadillos (*Dasypus novemcinctus*) expanded their range north during over the past several

decades through selection of thermally beneficial den sites and behavioral adaptations to forage

during periods more thermally beneficial and remain sedentary during periods of colder

temperatures (Bond et al. 2000, Eichler and Gaudin 2011). Adaptations of birds to

supplementary food resources (i.e., bird feeders) have been found to expand avian winter ranges

northward (Siriwardena et al. 2007, Zuckerberg et al. 2011). Grey-headed flying-fox (*Pteropus

poliocephalus*) have expanded their winter range by utilizing urban areas that provide warmer

winter conditions than rural areas (Parris and Hazell 2005). Behavioral adaptations through the

use of additional food resources (e.g., bird feeders, agricultural waste), use of thermal refugia

(e.g., warm-water discharges), and a reduction in energy expenditure (e.g., limited movements

during times when not thermally beneficial) have facilitated northward expansion of many

species to areas where they would not have been able to survive previously (Calder and King

1974, Prince and Zuckerberg 2015, Williams et al. 2015).

The Eastern Prairie Population of Canada geese (*Branta canadensis interior*), which nests

in Manitoba along Hudson Bay, historically wintered in Texas, Louisiana, and Arkansas, but has

shifted their wintering range northward to include Missouri and southern Illinois (Sheaffer et al.

2004). Similarly, the Mississippi Valley Population of sub-arctic breeding Canada geese (*B. c.

interior*) have shifted their wintering range northward from Mississippi and Arkansas to southern

Illinois and northwest Kentucky and then again to northern Illinois and southern Wisconsin

(Reeves at al. 1968, Craven et al. 1986, Gates et al. 2001). Lefebvre and Raveling (1967)

estimated maximum thermal stress for temperate-breeding Canada geese (*B. c. maxima*) and

determined the northern limit during winter to be Rochester, Minnesota, USA. Currently,

temperate-breeding Canada geese have expanded their range and now include year-round

residency in portions of southern Ontario and Manitoba (Baldassarre 2014). Canada geese are

wintering north of their historic winter distribution, but it is unclear how geese are able to

negotiate the extreme winter conditions and why northward shifts are beneficial.

I studied Canada geese in northeast Illinois, USA to understand the factors that may

influence habitat selection and movements at northern latitudes during winter. Specifically, my

objectives were to determine: (1) if urban habitats provided a thermal refugia for Canada geese,

(2) how weather affected movement distances within different urban habitats, and (3) transitions

between particular habitats when temperatures were above and below the lower critical temperature. I further discuss the behaviors that may have allowed Canada geese to winter north of their traditional wintering grounds and the benefits of wintering in an urban landscape.

2.3 METHODS AND MATERIALS

Study Area

Canada geese were captured in the Greater Chicago Metropolitan Area (GCMA; 915 km^2) located in northeastern Illinois, USA (Fig 2.1) during late autumn and winter. The GCMA is located in portions of three counties (Cook, Du Page, and Will) and is a heavily urbanized landscape with little agriculture present (United States Department of Agriculture 2015). The GCMA averages 43 days annually below freezing, with 7 days below -18 °C. November has an average high of 9 °C and a low of 0 °C, December has an average high temperature is 2 °C with a low of -6 °C, January has an average is a high of 0 °C and a low of -9 °C, and February has an average high of 2 °C and low of -7 °C (NOAA 2015). Chicago averages approximately 93 cm of snowfall annually (NOAA 2015).

Field Methods

During 13 November 2014 through 28 February 2015 and14 November 2015 through 29 February 2016, I captured and transmittered 41 Canada geese within the GCMA. I focused my capture efforts at large parks, cemeteries, and the Stickney Water Reclamation Plant because of their available habitat and concentrations of Canada geese (Fig 2.2). Standard waterfowl capture techniques (e.g., rocket nets and cannon nets) could not be used at most sites due to the dense urban area so cast nets and small animal net guns (Wildlife Capture Services, Flagstaff, Arizona, USA) were used for most capture attempts.

Transmitters ($n = 10$ in 2014–2015 and $n = 31$ in 2015–2016) were deployed during four time periods each year (i.e., mid November, early December and mid December, and early January) to account for temporal variation and across seven different capture locations to account for spatial variation (Table 2.1). Transmitters recovered from hunters ($n = 3$) were redeployed during the latter part of the field seasons (Table 2.1). Transmitters included solar-powered GPS units from Cellular Tracking Technologies in Somerset, Pennsylvania, USA, and operated on the Global System for Mobile communications network and were configured to acquire a GPS location once per hour. Generation 2 models were used during 2014–2015 ($\bar{x} = 69.7$ grams, SE = 0.2) and Generation 3 transmitters were used during 2015–2016 ($\bar{x} = 62.2$ grams, SE = 0.2). Transmitters were < 2% of the body mass of Canada geese ($\bar{x} = 4{,}713$ grams, SE =10.6) and all Canada geese were captured and handled using the approved methods detailed by the University of Illinois Institutional Animal Care and Use Committee (Protocol # 14155).

Using transmitter locations from 2014–2015, I identified 10 sites that were used throughout all portions of the autumn and winter by Canada geese. During 2015–2016, I used these sites to record ambient temperature and wind speed to understand thermal benefits of used sites. I deployed iButton temperature loggers (model DS1921G-F5#; Maxim Integrated, San Jose, CA) in green spaces ($n = 7$), rooftops ($n = 2$), and deep-water habitat (Stickney Water Reclamation Plant) to record ambient temperatures (ºC) (Hubbart et al. 2005). Restricted access prohibited the deployment of iButtons at rail yards. I deployed anemometers (model PCE-WL 1; PCE Americas Inc, Jupiter, FL) at green spaces ($n = 2$), rooftops ($n = 3$), and deep-water habitat approximately 15 cm off the ground or rooftop to record wind speeds. iButtons and anemometers were programmed to obtain hourly recordings and were deployed in specific locations used by Canada geese from 18 November 2015 through 29 February 2016.

Data Analysis

I removed locations from the day of capture from analysis to minimize potential influences on movements and habitat use. Transmitters required a once-weekly cellular connection to program their duty cycle to the standardized rate of 1 location/hour for the entire day and upload locations to an accessible database. Depending on deployment, some transmitters did not link properly so data from transmitters with less than 10 days of data collection were removed from analysis (4 in 2015–2016) because data were not collected in the same scale as other transmitters. Locations with only one satellite fix or with a horizontal dilution of precision value above 5 were removed because GPS coordinates were either not obtained or they had extremely low accuracy (CTT 2015). All analyses were performed using R Version 3.1.3 (www.R-project.org, accessed 15 July 2016). Statistical significance for all analyses was set at $P \leq 0.05$.

I defined a movement as the distance (m) between subsequent hourly GPS locations. Transmitters used for movement analysis were Generation 3 models that operated with high efficiency ($n =27$ transmitters, $\bar{x} = 20.8$ locations/transmitter/day, SE = 0.4, range 15.4–23.3) and obtained locations on average close to the hourly setting ($\bar{x} = 70.1$ min, SE = 1.3). To analyze movements and classify habitat types, I plotted all locations of Canada geese ($n = 35,896$) on Google Earth Pro and measured distance moved between hourly locations using the rgdall and adehabitatLT packages (Calenge 2006, Bivand 2015).

Habitats were classified as green space, rail yards, residential, riverine, rooftops, and deep-water using available aerial imagery and ancillary information. Green spaces were typically large parks, cemeteries, and other large grass areas that contained a mixture of ponds, trees and shrubs, large sports fields, and golf courses within their boundaries (Table 2.2). I also

included small grass lawns and areas between buildings in the green space habitat. Rail yard

habitat was composed of large complex series of railroad tracks where railcars were loaded,

unloaded, and stored. Residential habitats were typically houses and developments, parking lots,

streets, and miscellaneous other land uses occurring in residential areas. Riverine habitat

consisted of the Des Plaines and Calumet rivers. Rooftop habitats were typically large flat

industrial warehouse facilities or retail stores. Deep-water habitats were defined as the Chicago

Sanitary and Ship Canal, which had steep concrete walls and warm water discharges along the

canal corridor, and the Stickney Water Reclamation Plant, which was a mixture of gravel

embankments and grass near deep-water settling ponds ($n = 96$). Deep-water habitat stayed open

throughout the entire winter due to constant moving water within the settling ponds and warm-

water discharge and barge traffic within the canal.

I removed distance measurements that were not from subsequent hourly locations (i.e.,

more than two hours between locations). Transitional movements ($n = 3,264$) between habitat

types were also removed to provide data consisting of only movements within habitats for

analysis. I conducted a Fisher's exact test to determine if transitional movements were greater

between habitat types, both above and below the lower critical temperature (LCT), than by

random chance. The LCT is estimated using the resting metabolic rate and is the point where the

ambient temperature is below the thermoneutral zone and heat is required to maintain body

temperature, typically through metabolizing endogenous reserves. I used the theoretical LCT of

-6 ⁰C for Canada geese, but I acknowledge that this is not a discrete threshold and that the LCT

varies by individual through a complex interplay of physiological and behavioral adaptations

(Batt et al. 1992). I calculated maximum daily movement distance (m) as the longest distance

between subsequent hourly GPS locations for each day. I used a generalized linear model to test

for the effects of snow depth, minimum daily temperature, and their interactions on maximum

daily movement distance using the glm function in the nlme package (Pinheiro et al. 2016). In a

separate generalized linear model, I modeled movement distances as a function of independent

variables habitat, snow depth (cm), time of day (i.e., diurnal or nocturnal), LCT (i.e., above or

below the LCT), and their interaction. Transformations ($\log_{10}$ [x+1]) were used to normalize

movement distance parameters. The diurnal time period was set at 0500–1900 to account for

crepuscular movements and the nocturnal time period was 1901–0459. Covariates of daily snow

depth and daily minimum temperature were used because of their correlation with Canada goose

activity patterns (Raveling et al. 1972). I analyzed movements within habitats and transitional

movements to understand possible energy expenditure since increased movements distances

require increased energy expenditure (Bowlin et al. 2005, Couturier et al. 2010, Jachowski and

Singh 2015). Mean movements above and below the LCT were plotted by hour for visual

representation of variation across the day. The non-significant predictor variables and

interactions were removed from models by using partial sums of squares until only significant

associations remained (Crawley 2005).

To compare daily temperatures among habitat types I used a general linear model with

the lme function in package nlme package (Pinheiro et al. 2016) with mean daily temperature

($^\circ$C) as my dependent variable and habitat type as an independent variable and ID (data logger)

as a random effect. I conducted similar linear mixed effects models for minimum and maximum

daily temperature. I used a similar linear model to determine if mean and maximum wind speed

(km/h) varied by habitat type with ID (data logger) as a random effect. I removed one location

from my wind analysis due to constantly being knocked over and blown off the rooftop (last

recorded wind speed that day was 78.9 km/h), which resulted in large gaps (i.e., months) of

53

missing entries in the dataset. I conducted a post hoc Tukey's HSD test for significant results (α = 0.05) to simultaneously test for differences in the means (Zar 2010).

2.4 RESULTS

Habitats did not differ in daily minimum temperature ($F_{6,\ 927} = 0.11$, $P = 0.90$), but they did have different daily maximum temperature ($F_{6,\ 927} = 5.9$, $P = 0.04$). The maximum daily temperatures were 3.15 °C (SE = 1.1; $P = 0.01$) and 3.54 °C (SE = 1.4, $P = 0.04$) warmer at rooftops and deep-water locations respectively than green space. Both rooftop and deep-water habitats had higher maximum daily temperatures for every month when compared to green space, although the difference was greater later in the winter (Figure 2.3). Both mean daily wind speeds ($F_{2,\ 515} = 79.7$, $P = 0.01$) and maximum daily wind speeds ($F_{2,\ 515} = 66.7$, $P = 0.01$) varied by habitat (Figure 2.4). The mean daily wind speeds were 13.6 km/h (SE = 1.1, $P < 0.01$) greater on rooftops than green space and deep-water habitat had mean wind speeds 6.5 km/h (SE = 1.3, $P < 0.01$) greater than green space. Rooftops had mean daily wind speeds of 7.1 km/h (SE = 1.3, $P < 0.01$) greater than deep-water habitats. Maximum daily wind speeds were 22.9 km/h (SE = 2.0, $P < 0.01$) greater at rooftops than green space habitats and deep-water habitats had maximum wind speeds 12.1 km/h (SE = 2.4, $P < 0.01$) greater than green space. The wind speeds on rooftops were 10.7 km/h (SE = 2.4, $P < 0.01$) greater than at deep-water habitats.

Movement distance differed by habitat type ($F_{4,\ 32,172} = 168.1$, $P < 0.01$), temperature ($F_{1,\ 32,175} = 603.2$, $P < 0.01$), snow depth ($F_{1,\ 32,175} = 203.9$, $P < 0.01$), and time of day ($F_{1,\ 32,175} = 3,690$, $P < 0.01$; Figure 2.5). Movement distances for Canada geese were shorter when temperature was below the LCT, as snow depth increased geese made shorter movements, and geese made shorter movements during the nocturnal period. Movements by Canada geese within rail yard ($\bar{x} = 224.0$ m, SE = 13.0) and green space habitats ($\bar{x} = 145.6$ m, SE = 3.4) were the

longest for any habitat type, while movements by geese in deep-water habitats ($\bar{x}$ = 85.7 m, SE = 3) and rooftop habitats ($\bar{x}$ = 52.9 m, SE = 5.5) were the shortest (Table 2.3). In general, Canada geese moved 2 to 4 times farther in rail yards and green space than in deep-water and rooftop habitats (Table 2.3).

Canada geese were more likely to move between certain habitats and these habitats changed when temperatures were above and below the LCT. When the temperature was below the LCT, the only habitat transition that occurred more often than random was to green spaces from deep-water and vice versa (G^{adj} = 23.39, $P < 0.01$; Table 2.4). When the temperature was above the LCT, there were more movements between green space and rail yards than would be expected by chance (G^{adj} = 6.86, $P < 0.01$; Table 2.4). The mean movements for all transition flights between habitats was 1554.4 m (SE = 30.4).

The proportion of locations in green space was highest during diurnal hours (i.e., 0500–1900) and overall Canada geese used green space most (Figure 2.6). Both deep-water and riverine habitats had a spike in proportional use during early morning, but use decreased throughout the day. Proportional use of rail yards increased during early afternoon while use of residential habitat was consistent throughout the day (Figure 2.6). There were two peaks in movement distances during crepuscular periods (i.e., early morning and late evening), and the timing of these movements also varied depending if the temperature was above or below the LCT (Figure 2.7). The mean maximum daily movement of individuals across all habitats was 2,009.3 m (SE = 74.6) with the longest movement within the GCMA being 19,998 m.

2.5 DISCUSSION

Wintering ranges of Canada geese in the Mississippi Flyway have shifted northward and use of urban areas in northern latitudes appears to be a strategy for increasing survival. There

might be a strong selection pressure on migratory Canada geese to winter at more northerly latitudes to minimize spring migration flight distances resulting in minimized energy expenditure and arrival to nesting grounds at a more opportune time to secure preferred nest sites (Alerstam and Lindstrom 1990). Canada geese appear to be utilizing a new strategy to winter at these northern clines through the use of nontraditional habitats occurring within urban areas (Chapter 1). During the autumn and winter 2014–2016, 66.7% of transmittered geese used novel urban habitats (rooftops and rail yards) and the ability of Canada geese to use these nontraditional habitats in urban areas likely allows them to maintain a positive energy balance and may even increase survival (Chapter 1). The ability of Canada geese to survive in these urban landscapes appears due to the ability to find potentially warmer habitats where costs of thermoregulation are within tolerable ranges, locate food sources (e.g., grass in green spaces, spilled grain in rail yards), and use disturbance free areas for loafing (e.g., rooftops).

There appear to be limited thermal benefits for selected habitats; I found no difference in daily low temperatures between habitats used by Canada geese, but data are limited to only sites that are being used by Canada geese. The maximum daily temperature was greater on rooftops and at deep-water habitats, but these habitats also had the greatest amount of wind. Green space had the lowest wind speed for all habitat types due to trees and buildings acting as wind blocks. Canada geese moved to deep-water habitats when temperatures were below the LCT, but given how the low temperatures in the green spaces were nearly the same as the deep-water habitats the thermal benefits of rooftops and deep-water habitats is likely limited. Shifts in habitat use may also be link to decreased open water in green spaces as ice coverage forces Canada geese to find alternative roost locations. The warmer temperatures on rooftops are likely the result of solar radiation as nearly all the rooftops used by Canada geese were black. Black rooftops and deep-

water habitats absorbing solar radiation during the day would account for the warmer maximum temperatures, but no difference in the low temperatures at night (Figure 2.8).

Canada geese exhibited the greatest within-habitat movement distances in rail yards and green space. I commonly observed Canada geese in these habitats actively foraging. The rail yards contained spilled agricultural grains and the Canada geese were typically observed moving around the rail yards foraging for spilled corn or other items (Figure 2.9). The shortest movement distances were found in deep-water and rooftop habitats suggesting that these habitats are used primarily for roosting. Reduced movements in deep-water and rooftop habitats minimize energy expenditure. I observed Canada geese typically loafing or sleeping in these habitats (Figure 2.10). Deep-water and rooftops likely provided a safe location in the urban landscape for Canada geese to conserve energy. While one would expect Canada geese to use deep-water habitat, the rooftop is a novel habitat for waterfowl that provide a safe, disturbance-free location to conserve energy compared to green space and residential habitats that contain many disturbances such as walking humans, dogs, cats, cars and coyotes (Brown 2007).

Other studies of Canada geese have found that weather events impact the movement behavior of geese. Raveling et al. (1972) noticed significant declines in movements and activity of Canada geese when temperatures were below -6 $^\circ$C. Similarly, I observed limited transitional flights between habitats and reduced movement distances within habitat types used by geese within the GCMA below the same temperature. Flight is the most energetically demanding activity for birds during the non-breeding portion of the year and studies of a closely related species brant (*Branta bernicla*) in Great Britain found that when disturbances occurred the average time of flight increased sevenfold (Alerstam 1991, Korschgen and Dahlgren 1992). I

speculate that Canada geese wintering in the GCMA limit their movements as a strategy to limit energy expenditure and associated nutrient intake requirements.

Snow cover also has a large impact on behavior as it can limit food and habitat availability (Jorde et al. 1983, Schummer et al. 2010). I found that as snow accumulation increased there were shorter movements (Appendix; Figure A.2). However, in the second year of the study when the movement data were collected, snow accumulation was below average (National Oceanic and Atmospheric Administration 2016). During the initial year of the study, anecdotal observations supported the finding in year 2 that increases in snow depth were associated with reduced activity. Further research in years with average snow fall could help determine if other novel habitats are used in times of deep snow accumulation.

Canada geese in the urban landscape appear to require several different habitats and their use of habitats differs with temperature. In general, green space is the most used habitat regardless of temperature, but when temperatures are above the LCT, Canada geese most often moved between rail yards and green space. When temperatures are below the LCT, Canada geese move between deep-water and green spaces. Approximately 31% of all transitional movements when the temperature is below the LCT were to at deep-water habitats. My data suggest that Canada geese foraged in green spaces and rail yards and then moved to deep-water habitats to loaf and potentially take advantage thermal benefits.

During winter in the GCMA Canada geese have adapted a strategy of using nontraditional urban habitats with thermal benefits and that provide sanctuary from predation to maximize survival. Although food resources in urban areas may be limited or of low value, Canada geese are apparently minimizing movements and energy expenditure by remaining within small areas of the GCMA. Canada geese may have adopted a strategy of building fat

reserves during autumn for use during winter, which allows Canada geese to modify their

behavior and select habitat with minimal disturbance, instead of areas with high-energy forage or

make flights to agricultural fields containing forage. Hunting seasons in the autumn and winter

in North America are a significant source of mortality for Canada geese and the ability to use

habitats in urban areas where generally there are regulations against hunting may allow geese to

locate a safe refuge. The fact that urban areas are generally free of hunting pressure and appear

to have the various habitats need by Canada geese suggests that geese will continue to use and

potentially expand their use of urban landscapes in winter.

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2.7 TABLES AND FIGURES

Table 2.1. Dates and number of Canada geese (*Branta canadensis*) captured and transmittered during autumn and winter 2014–2016

in the Greater Chicago Metropolitan Area, Illinois, USA.

Location	2014–2015				2015–2016			
	November 13–31	December 1–15	January 15–31	February 15–28	November 14–31	December 1–15	January 1–15	February 15–29
Marquette Park			1		2	1		
McKinley Park	1					3	5	
Museum of Science and Industry	1				1		1	1*
Resurrection Cemetery		1	1		1	3	1	
Sherman Park	1	1			1	2		
Stickney Water Reclamation Plant			2	1*	1		3	1*
Washington Park					1	1	2	
Total	3	2	4	1	7	10	12	2

*Transmitters recovered from hunters and then redeployed

Table 2.2. Percentage of available habitat compared to all GPS locations in each habitat type used by Canada geese (*Branta canadensis*) and the percentage of habitat use when temperature was below the lower critical temperature (LCT; -6 ⁰C) for Canada geese in the Greater Chicago Metropolitan Area, Illinois, USA, during 2014–2016.

Location	Total Area (km^2)	Surface Water (km^2)	Description
Marquette Park	1.25	0.16	Contains sports fields, 9-hole golf course, trees and shrubs, lagoon
McKinley Park	0.28	0.03	Contains sports fields, trees and shrubs, and pond with islands
Museum of Science and Industry	1.95	0.33	Contains sports fields, 18-hole golf course, trees and shrubs, a lagoon and harbors, bordered to the east by Lake Michigan
Resurrection Cemetery	1.18	0.02	Contains ponds, large buildings, headstones, trees and shrubs
Sherman Park	0.25	0.05	Contains sports fields, trees and shrubs, and a lagoon

Table 2.3. Mean movement distance (m) between hourly GPS locations with standard error (SE) within each habitat type when temperature is below the lower critical temperature (LCT; -6 ^{o}C), for the entire temperature range, and when above the LCT for Canada geese (*Branta canadensis*) in the Greater Chicago Metropolitan Area, Illinois, USA, from 15 November 2015 through 28 February 2016.

Location	Below LCT		All Temperatures		Above LCT	
	$\overline{x}$	SE	$\overline{x}$	SE	$\overline{x}$	SE
Deep Water	69.8	3.7	85.7	3.0	101.6	4.8
Green Space	103.6	8.6	145.6	3.4	151.0	3.7
Rail Yards	152.1	28.6	224.0	13.0	230.9	14.0
Residential	62.4	23.1	117.9	11.8	121.1	12.4
Riverine	70.0	8.1	95.1	7.9	105.3	10.6
Rooftops	69.3	18.3	52.9	5.5	51.6	5.8

Table 2.4. Percent of transitional movements between habitat types when temperatures were <u>below</u> the Lower Critical Temperature (LCT; -6 °C) for Canada geese (*Branta canadensis*) wintering in the Greater Chicago Metropolitan Area, Illinois, USA, from 15 November 2015 through 28 February 2016. The departure habitats are on the vertical axis and destination habits are on the horizontal axis ($n = 636$ transitions).

		Destination					
		Deep Water	Green Space	Rail Yards	Residential	Riverine	Rooftops
Starting Location	Deep Water		22.6%[a]	2.4%	6.3%	0.6%	0.9%
	Green Space	18.4%[a]		3.8%	2.7%	5.7%	1.3%
	Rail Yards	2.7%	2.7%		0.5%	0.5%	1.3%
	Residential	7.5%	3.1%	0.8%		0.9%	0.2%
	Riverine	0.9%	6.4%	0.3%	1.4%		0.2%
	Rooftops	1.6%	2.7%	1.6%	0.2%	0.0%	

[a] Designates proportion of transitional flights that occur more often than by chance based on Fisher's exact test ($P \leq 0.05$).

Table 2.5. Percent of transitional movements between habitat types when temperatures were <u>above</u> the lower critical temperature (LCT; -6 °C) for Canada geese (*Branta canadensis*) while in the Greater Chicago Metropolitan Area, Illinois, USA, from 15 November 2015 through 28 February 2016. The departure habitats are on the vertical axis and destination habits are on the horizontal axis (*n* = 2,628 transitions).

		Destination					
		Deep Water	Green Space	Rail Yards	Residential	Riverine	Rooftops
Starting Location	Deep Water		8.6%	1.1%	2.1%	0.2%	1.1%
	Green Space	8.3%		10.4%[a]	7.5%	4.9%	4.9%
	Rail Yards	2.1%	8.6%		2.1%	0.2%	3.7%
	Residential	2.2%	7.0%	2.2%		2.4%	1.5%
	Riverine	0.2%	5.6%	0.3%	1.3%		0.2%
	Rooftops	1.0%	7.0%	1.7%	1.2%	0.5%	

[a] Designates proportion of transitional flights that occur more often than by chance based on Fisher's exact test (P ≤ 0.05).

Figure 2.1. The Greater Chicago Metropolitan Area located in northeast Illinois, USA.
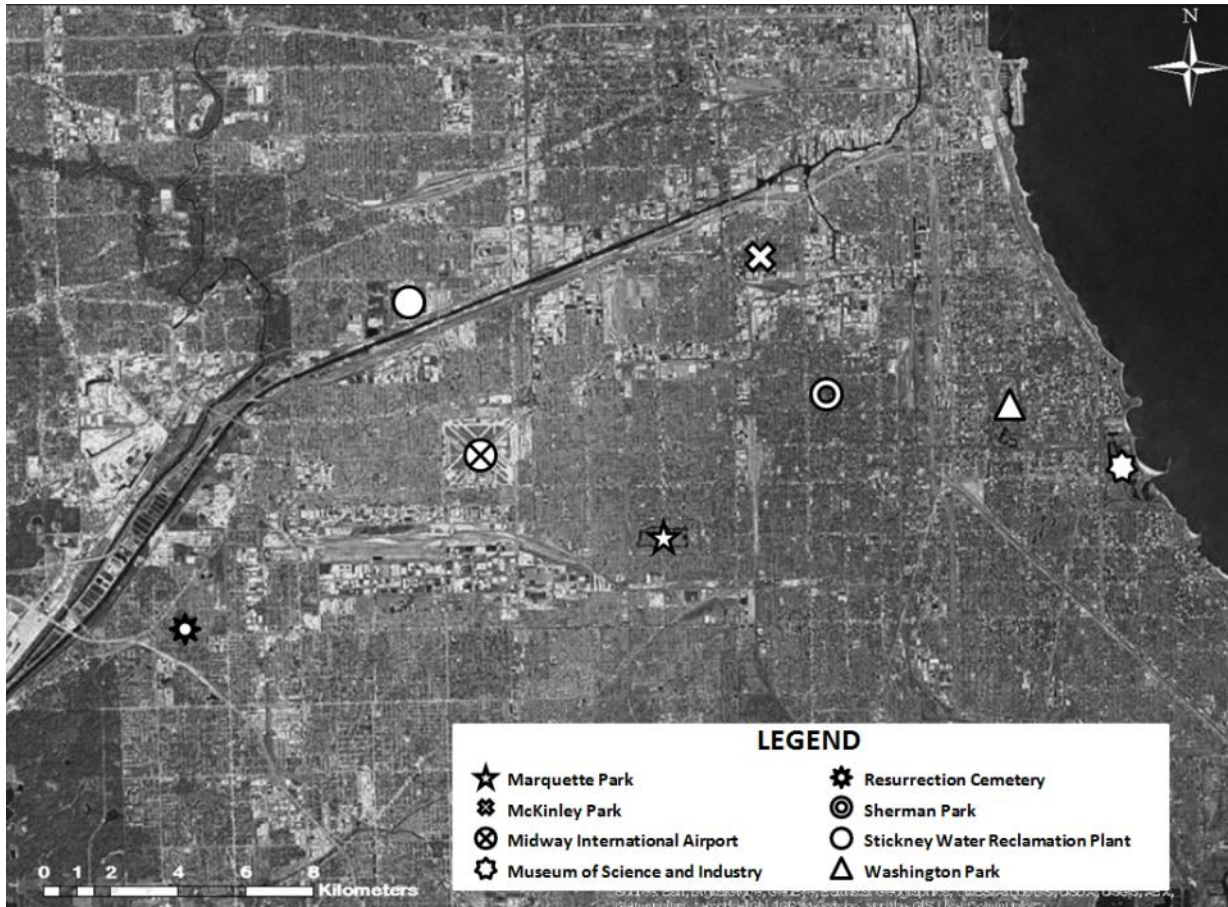
**Figure 2.2.** Main capture locations (*n* = 7) for Canada geese (*Branta canadensis*) in relation to Midway International Airport in the Greater Chicago Metropolitan Area, Illinois, USA.
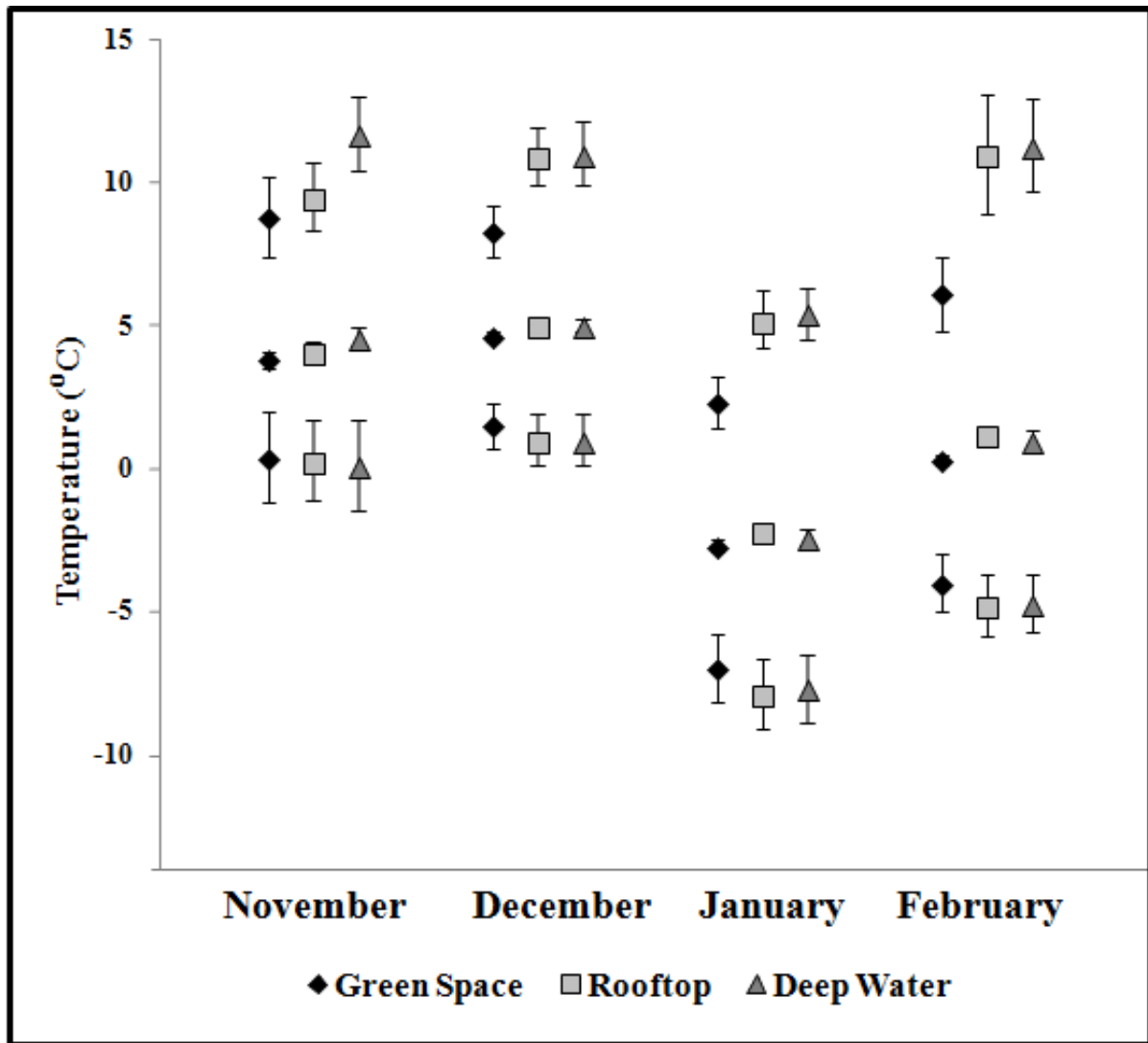
Figure 2.3. Comparison of daily high (top point), mean monthly (middle point), and daily low (bottom point) temperatures and standard errors for green space, rooftop, and deep-water habitats used by Canada geese (*Branta canadensis*) while in the Greater Chicago metropolitan Area, Illinois, USA from 18 November 2015 through 29 February 2016.
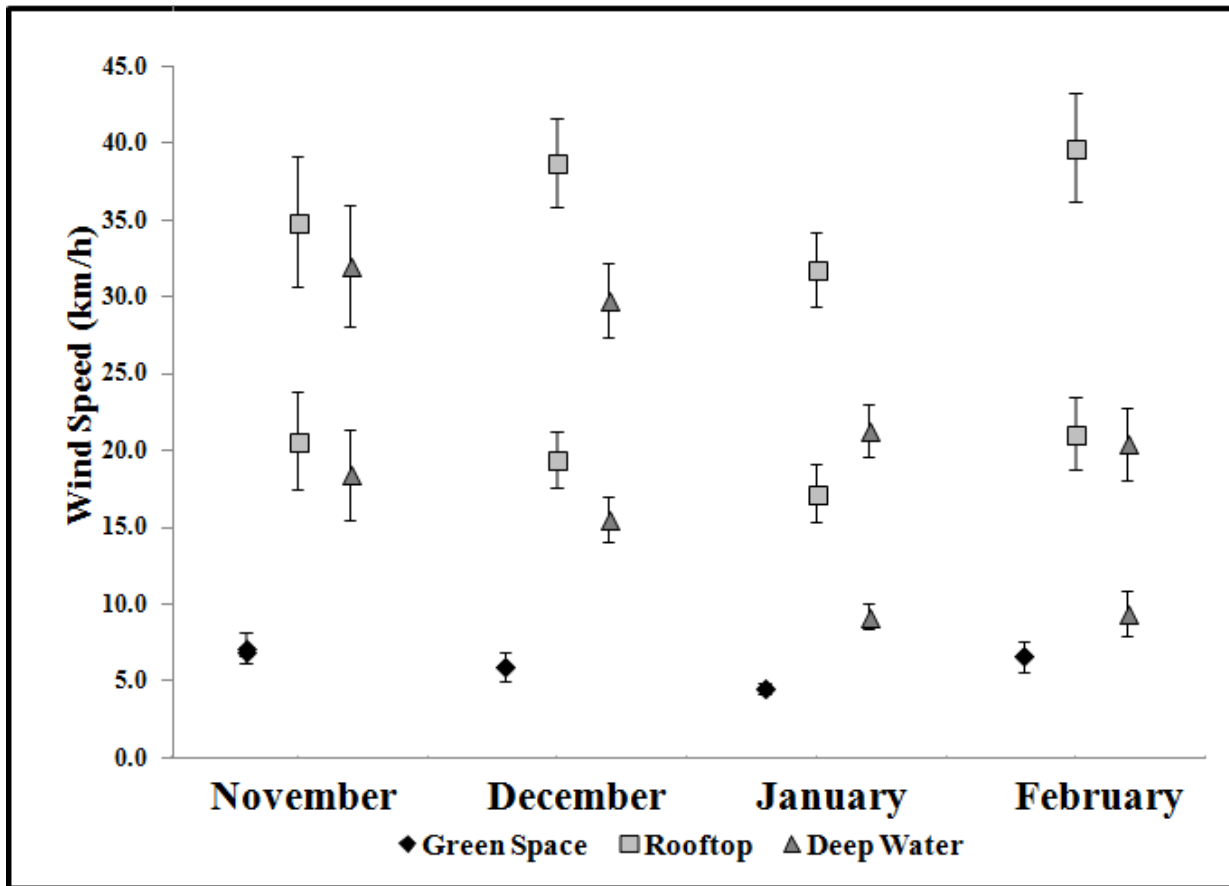
Figure 2.4. Comparison of mean monthly (bottom point) and mean maximum daily (top point) wind speeds (km/h) with standard errors for green space, rooftop, and deep-water habitats used by Canada geese (*Branta canadensis*) while in the Greater Chicago metropolitan Area, Illinois, USA from 18 November 2015 through 29 February 2016.
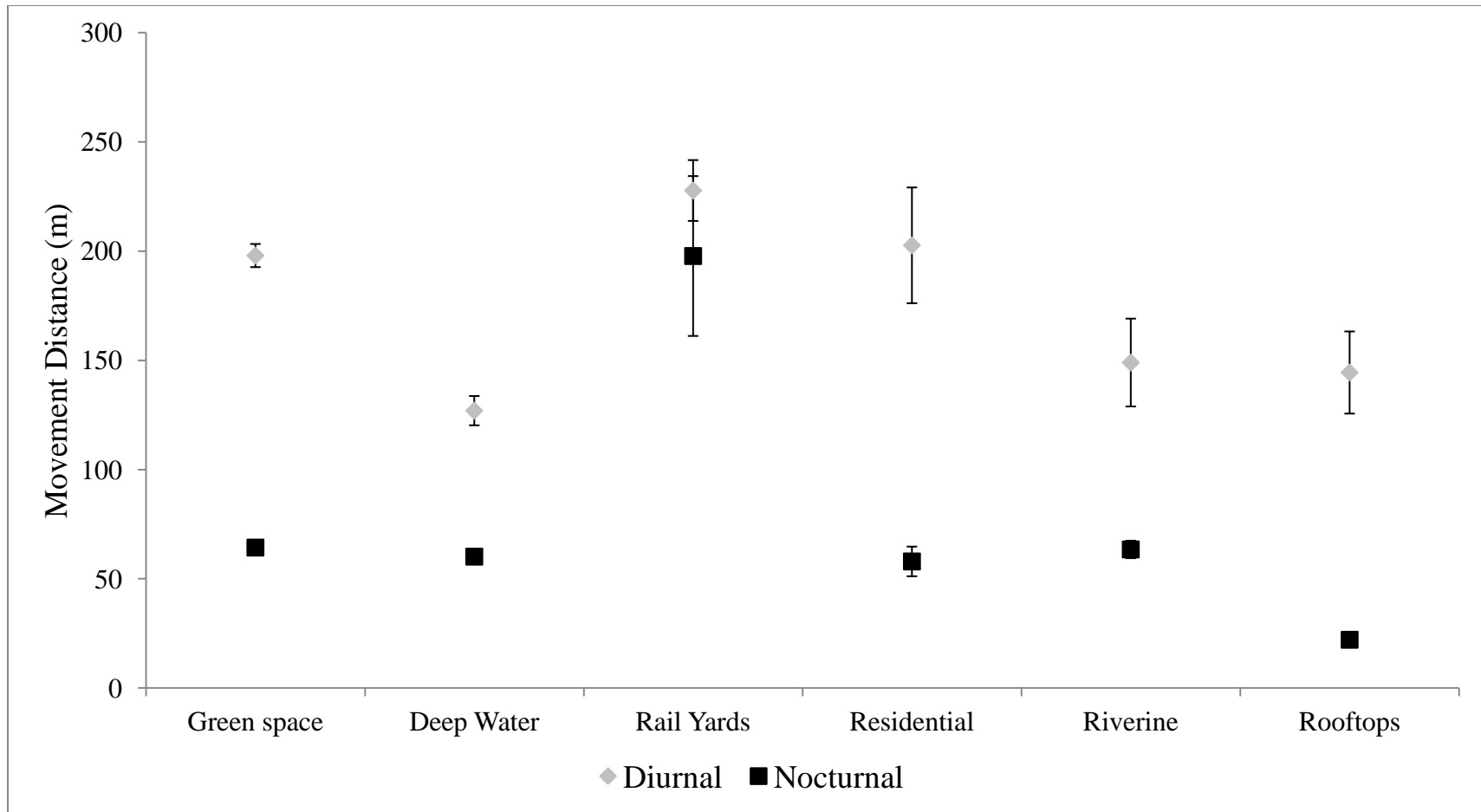
Figure 2.5. Mean movement distance (m) with standard error bars between hourly GPS locations within all habitats used during diurnal and nocturnal time periods for Canada geese (*Branta canadensis*) in the Greater Chicago Metropolitan Area, Illinois, USA from November 2015 through February 2016.

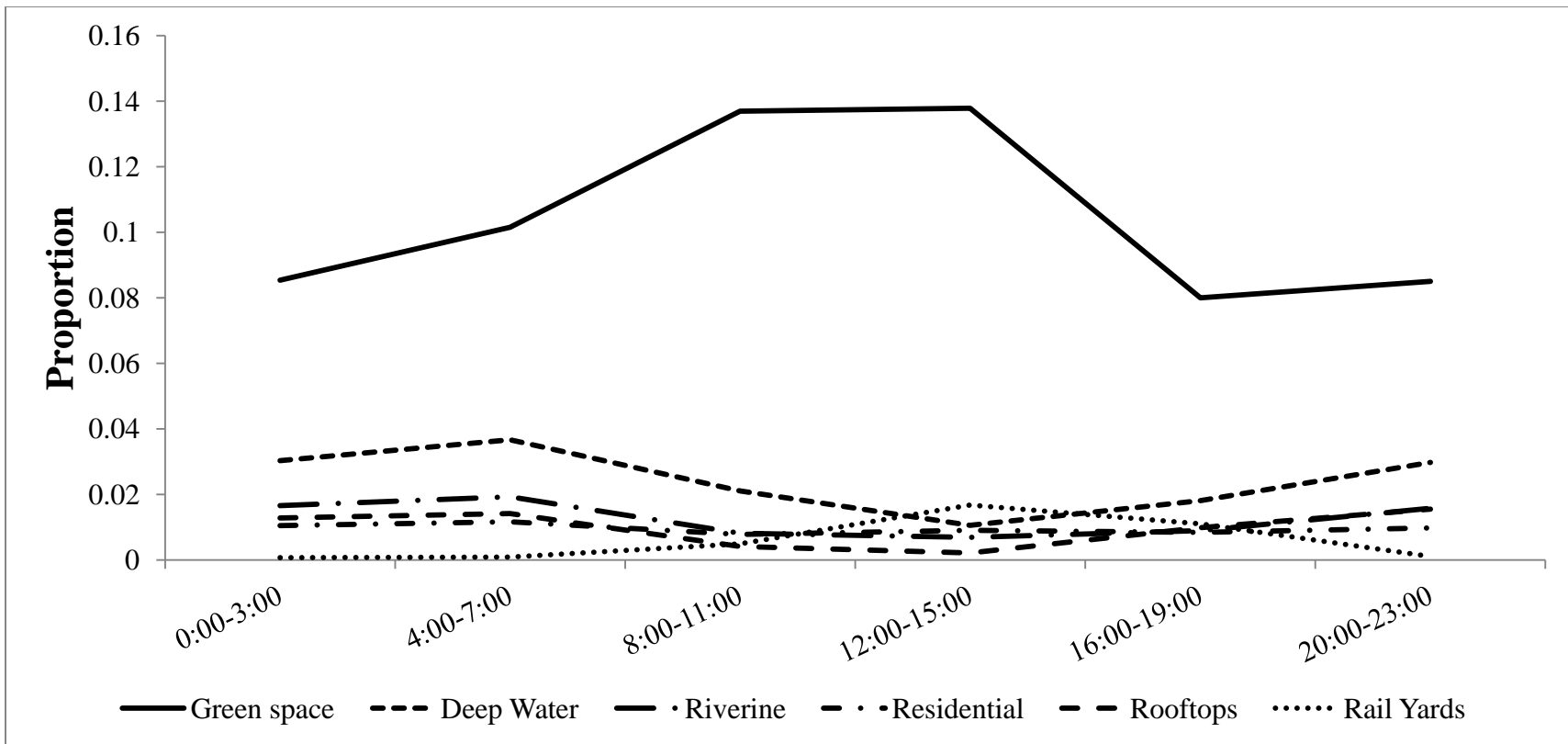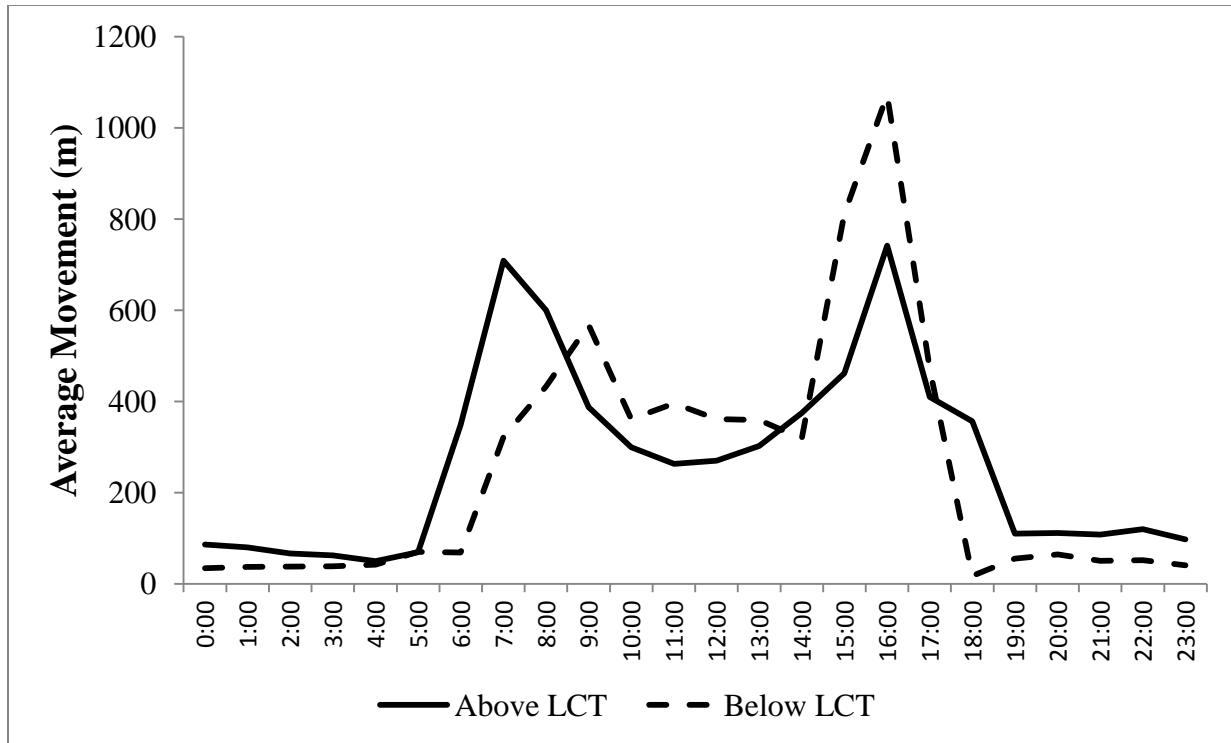**Figure 2.6.** Proportion of locations within habitat types used by Canada geese (*Branta canadensis*) diurnally while in the Greater

Chicago Metropolitan Area, Illinois, USA during autumn and winter 2015–2016.

Figure 2.7. Mean movement distance (m) diurnally for Canada geese (*Branta canadensis*) when temperatures were above and below the lower critical temperature (LCT; -6 °C) in the Greater Chicago Metropolitan Area, Illinois, USA during autumn and winter 2015–2016.
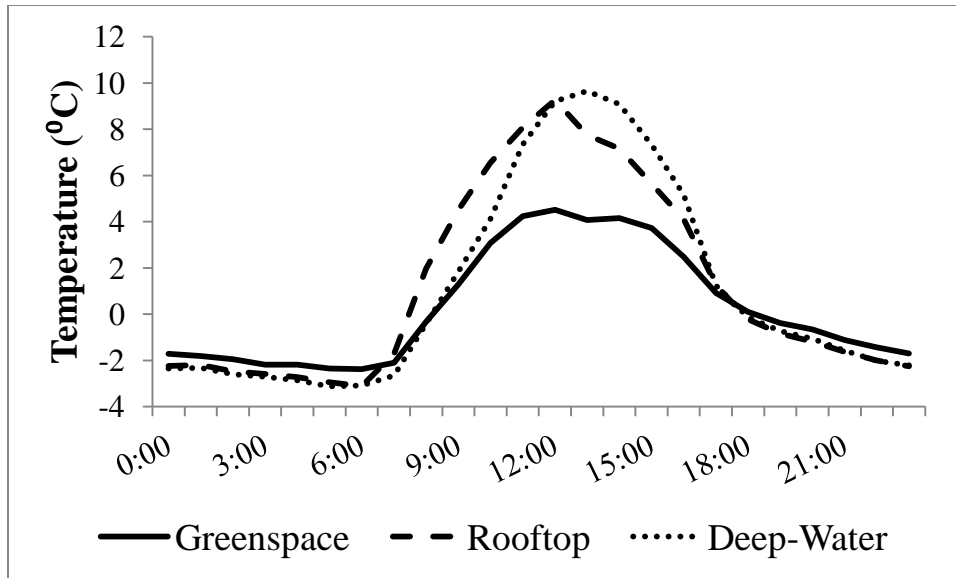
Figure 2.8. Fluctuation in daily temperatures recorded in habitats used by Canada geese (*Branta canadensis*) in the Greater Chicago Metropolitan Area, Illinois, USA during autumn and winter 2015–2016.

Figure 2.9. Canada geese foraging on agricultural waste at a rail yard in the Greater Chicago

Metropolitan Area, Illinois, USA during the winter of 2014–2015.

Figure 2.10. Canada geese loafing on a rooftop in the Greater Chicago Metropolitan Area, Illinois, USA during the winter of 2014–2015.

CHAPTER 3: SUMMARY

The winter distributions of most birds are affected by multiple and interacting environmental factors (Brown 1984, Brown et al. 1995, Canterbury 2002). Typically, the northern boundaries of winter ranges correlated with average minimum temperature isotherms (Root 1988*a*, *b*). In particular, waterfowl select habitats during non-breeding periods (e.g., migration, winter) that provide the resources required to maintain a favorable energy balance and maximize survival (Baldassarre and Bolen 2006). Urban areas provide the necessary resources for survival, but they often require waterfowl to use nontraditional habitats and adopt behaviors different than individuals using traditional habitats (Marzluff 2001, Zuckerberg et al. 2011). Urban areas at the northern extent of wintering ranges may provide food resources, sanctuary from hunting and other predators, and reduced energy expenditure associated with reduced migration distances (Conover and Chasko 1985, Guthery et al. 2005, Anderies et al. 2007, Zuckerberg et al. 2011). Use of urban areas by Canada geese has been shown to increase clutch size, nest success, and annual survival compared to rural areas (Raveling 1981, Paine et al. 2003, Balkcom 2010). Thus, there may be fitness incentives for Canada geese using urban areas during nonbreeding periods at northern extents of their wintering range.

Climate change and landscape modifications, especially large-scale expansion of agriculture, have altered wintering ranges of waterfowl. For example, subarctic-breeding Canada geese have shifted their winter range northward (Gates et al. 2001, Scribner et al. 2003). Specifically, the Mississippi Valley Population of subarctic-breeding Canada geese (*B.c. interior*) have shifted their wintering range northward from southern Illinois and northwest Kentucky to northern Illinois and southern Wisconsin (Craven et al. 1986, Gates et al. 2001, AGJV 2013). Migrating Canada geese may join with geese in urban areas creating large

concentrations, which can create conflicts with humans (Conover and Chasko 1985, Smith et al. 1999).

Large populations or dense concentrations of Canada geese can pose threats to humans, including contamination of water sources (Allan et al, 1995), aggressive behavior towards humans (Smith et al. 1999), disease transmission (Smith et al. 1999, Kullas et al, 2002), and strikes with aircraft (Dolbeer et al. 2000). Local regulations in urban areas that limit hunting, public perception, and mixing of different Canada goose populations with different management objectives can create management challenges (Coluccy et al. 2001, Unites States Fish and Wildlife Service 2015). However, hunting is not permitted in many urban areas and limited data are available to determine susceptibility of geese using urban areas during winter to hunting mortality when geese migrate south following cold-weather events, make foraging flights to agricultural fields, or are displaced by already abundant numbers of geese using a limited number of available habitats.

I captured Canada geese during November–February 2014–2016 in the Greater Chicago Metropolitan Area (GCMA) located in northeastern Illinois, USA and fitted 41 geese with solar-powered GPS transmitters. Transmitters were mounted on neck collars and operated on the cellular phone network to collect hourly locations ($n = 39,392$). Canada geese used urban areas exclusively throughout autumn and winter and did not make foraging flights to agricultural fields within or outside the GCMA. Canada geese in the GCMA tended to have relatively small 50% core use areas ($\bar{x} = 0.7$ km^2, SE = 0.3), which were predominantly in green spaces, and had 95% UD ($\bar{x} = 24.5$ km^2, SE = 5.2) similar to those reported in other urban areas (Groepper et al. 2008). Canada geese selected green spaces (59.8%) in greater proportion than availability (14%), but they were also documented using novel urban habitats such as rooftops and rail yards

(11.3%). Habitat use shifted away from green spaces (36%) to industrial urban areas (10.4%), riverine (12.8%), and deep-water habitats (37.8%) as temperatures decreased below the Lower Critical Temperature (LCT; -6 $^{\circ}$C) for Canada geese. During periods when temperature decreased and snow depth increased geese increasingly used industrial urban areas (i.e. rooftops and rail yards), which may increase risk for collisions with aircraft nearby Midway International Airport. While I know of no other published accounts of Canada geese using rooftops in winter, we expect they are taking advantage of the relative safety of the urban landscape and may be behaving similarly in other urban areas.

Both snow depth and minimum daily temperatures decreased movement distances. Movements by Canada geese within green space habitat ($\bar{x}$ = 145.6 m, SE = 3.4) were the longest for any habitat type, while movements by geese in deep-water habitats were the shortest ($\bar{x}$ = 85.7 m, SE = 3). Proportion of use of green space habitat increased during diurnal hours. Both deep-water and riverine habitats had higher proportional use during earlier morning hours and the opposite was shown in industrial urban habitat where proportional use increased during midday to early evening. Deep-water and industrial urban habitat (i.e., rooftops) consistently had warmer daily high temperatures than green space by 3.5 $^{\circ}$C and 3.2 $^{\circ}$C, respectively, but there was no difference in daily minimum temperatures among all habitat types. Green space habitat was more sheltered from the wind while deep-water habitat and industrial urban habitat exceeded green space maximum wind speeds by 12.1 km/h and 22.9 km/h, respectively. The majority of transmittered Canada geese (85%) wintering in the GCMA never migrated south and no geese made foraging flights outside of the urban areas to agricultural fields. Winter survival was 100% for Canada geese remaining in the GCMA and is the greater than published estimates for Canada geese (Balkcom 2010). Survival was 48% for geese that left the GCMA, with all

mortality due to hunting. Since Canada geese remaining within the GCMA did not make foraging flights to agricultural fields, hunting may not be a viable option to reduce urban populations or change movements patterns during winter. Targeted harassment at urban habitats apparently used for sanctuary may force geese to leave urban areas and subsequently allow the population to be more effectively managed via hunting.

During periods when temperature decreased and snow depth increased geese increasingly used industrial urban areas (i.e., rooftops and rail yards), which may be due to water within green spaces freezing and availability to forage on grasses decreasing with snow depth. Shifts in habitat use during these weather events may increase risk for collisions with aircraft nearby Midway International Airport. Most nontraditional habitats were located within a close proximity to Midway International Airport, within 4 km or less, and may be areas to concentrate harassment efforts when winter weather becomes extreme to mitigate use of these locations from geese to prevent possible goose-airplane collisions (Appendix Figure A.3). Industrial urban habitats appeared to reach a threshold for both snow depth (26 cm) and minimum daily temperature (-5 $^{\circ}$C) where the selection for this habitat started to decrease. This may provide certain weather scenarios when harassment efforts should focus on this habitat and then potential shift to other habitats such as deep-water or riverine.

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APPENDIX

Table A.1. Morphological measurements (mean and standard error) of Canada geese (*Branta canadensis*; *n* = 41) captured and fitted with transmitters in the Greater Chicago Metropolitan, Illinois, USA, during autumn and winter 2014–2016.

| Measurement	Males			Females		
	n	$\bar{x}$	*SE*	*n*	$\bar{x}$	*SE*
Mass (kg)	21	5.0	0.1	20	4.4	0.1
Skull (mm)	21	131.2	1.4	20	123.8	1.4
Culmen (mm)	21	58.6	1.1	20	55	1.0
Tarsus (mm)	21	114.7	1.4	20	108.4	1.4

Table A.2. Morphological measurements and subspecies classification using culmen length classification method provided by Moser et al. (1991) of Canada geese (*Branta canadensis; n =* 41) captured and fitted with transmitters in the Greater Chicago Metropolitan, Illinois, USA, during autumn and winter 2014–2016. Female *B.c. interior* culmen < 53 mm, Female *B.c. maxima* culmen < 56.8 mm, male *B.c. interior* > 53 mm, male *B.c. maxima* > 56.8 mm.

ID	Sex	Skull (mm)	Culmen(mm)	Tarsus(mm)	Mass (kg)	Classification
00D	M	136.0	61.5	112.1	6.0	*B.c. maxima*
01D	F	121.2	54.9	108.4	4.2	*B.c. maxima*
02D	F	121.2	50.7	98.7	4.0	*B.c. interior*
03D	M	130.0	57.4	110.8	4.5	*B.c. maxima*
57R	F	129.4	59.3	105.9	4.8	*B.c. maxima*
58R	M	135.2	57.7	125.9	5.9	*B.c. maxima*
59R	F	125.9	54.0	112.9	5.1	*B.c. maxima*
60R	M	125.8	53.2	120.9	5.1	*B.c. interior*
61R	F	130.2	57.7	117.8	4.3	*B.c. maxima*
62R	F	119.8	53.4	103.9	3.3	*B.c. maxima*
63R	F	128.4	57.4	109.8	4.2	*B.c. maxima*
64R	F	126.0	56.6	110.7	4.2	*B.c. maxima*
65R	M	109.9	43.4	101.2	3.7	*B.c. interior*
66R	M	131.9	59.8	110.2	5.0	*B.c. maxima*
67R	F	125.3	55.5	108.8	3.9	*B.c. maxima*
68R	F	117.3	51.1	107.8	3.7	*B.c. interior*
69R	M	127.5	55.6	112.8	3.9	*B.c. interior*
70R	M	129.1	60.4	108.9	4.6	*B.c. maxima*
71R	M	136.9	65.2	122.2	5.1	*B.c. maxima*
72C	F	115.8	51.9	100.2	4.1	*B.c. interior*
72R	M	131.1	60.3	111.8	5.0	*B.c. maxima*
73C	M	130.9	58.1	110.5	5.3	*B.c. maxima*
73R	M	137.4	63	122.1	4.7	*B.c. maxima*
74C	F	121.5	55.5	106.8	4.3	*B.c. maxima*
76C	M	130.9	59.8	105.1	5.3	*B.c. maxima*
76R	F	134.2	64.4	120.8	5.7	*B.c. maxima*
78C	F	108.3	43.4	99.4	3.8	*B.c. interior*
83C	F	129.1	56.5	110.9	4.5	*B.c. maxima*
84C	M	127.2	54.6	107.8	5.0	*B.c. maxima*

Table A.2. Continued

ID	Sex	Skull (mm)	Culmen(mm)	Tarsus(mm)	Mass (kg)	Classification
85C	M	132.8	58.3	118.5	5.5	*B.c. maxima*
86C	M	139.5	66.2	120.8	5.1	*B.c. maxima*
87C	M	121.9	53.8	109.0	4.7	*B.c. interior*
88C	F	117.8	50.9	99.2	4.2	*B.c. interior*
89C	M	132.7	59.8	117.4	5.2	*B.c. maxima*
90C	M	135.0	63.8	121.1	5.0	*B.c. maxima*
91C	F	122.7	54.7	105.8	5.1	*B.c. maxima*
95C	M	133.7	57.2	118.8	5.5	*B.c. maxima*
96C	F	129.2	58.2	116.5	5.6	*B.c. maxima*
97C	F	122.0	54.7	106.0	4.2	*B.c. maxima*
98C	M	139.7	62.5	120.0	5.0	*B.c. maxima*
99C	F	131.5	59.9	117.1	5.0	*B.c. maxima*
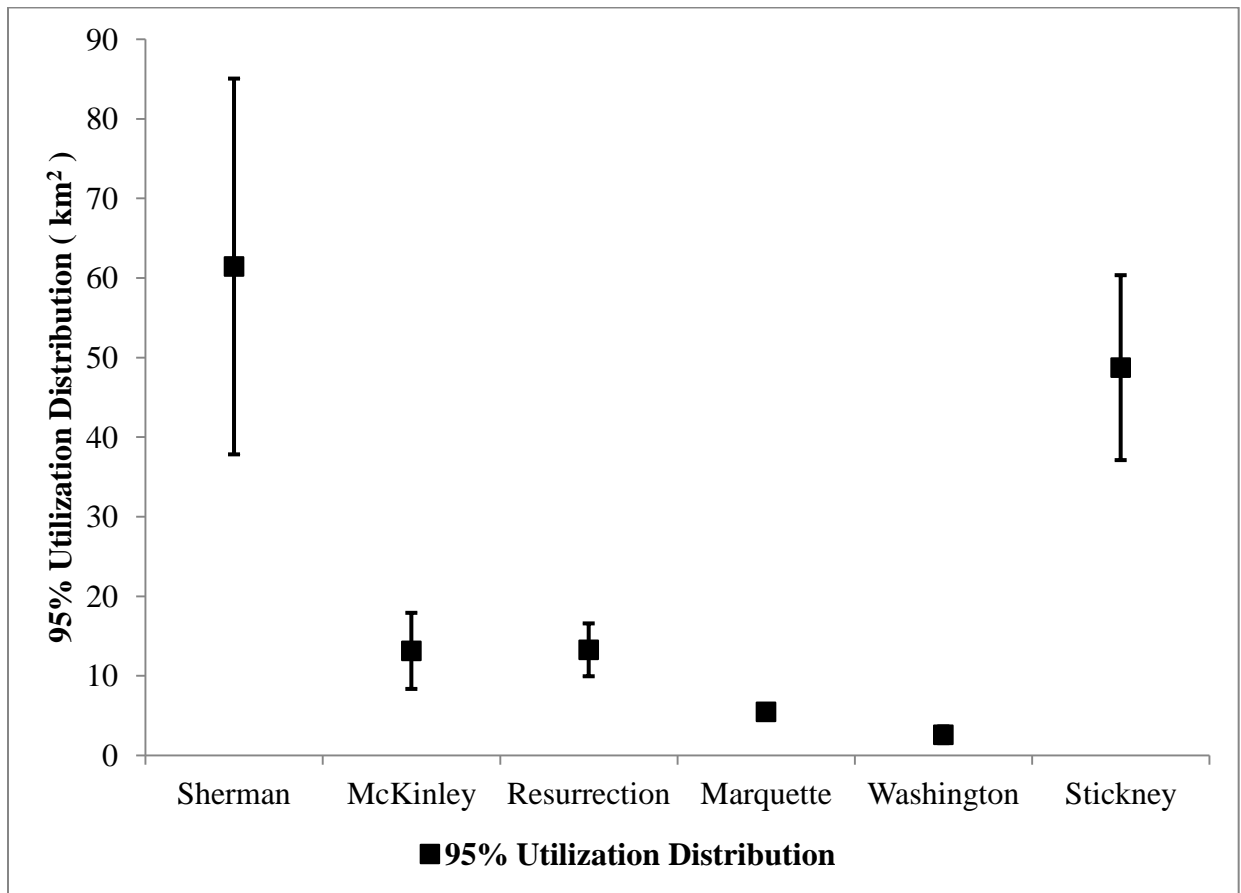
Figure A.1. Mean 95% Utilization Distribution with standard errors for Canada geese (*Branta canadensis*) by capture location (in order from smallest area km^2) in the Greater Chicago Metropolitan Area, Illinois, USA during autumn and winter 2014–2016. The Museum of Science and Industry was removed from analysis because of a low sample size (*n* = 2; Sherman Park = 0.25 km^2, McKinley Park = 0.28 km^2, Resurrection Cemetery = 1.18 km^2, Marquette Park = 1.25 km^2, Washington Park = 1.42 km^2, and Stickney Water Reclamation Plant = 1.97 km^2). Resources may have become limited at Sherman Park and lead to increased 95% utilization distribution. Stickney Water Reclamation Plant was a site where Canada geese were commonly harassed by USDA Wildlife Services in early morning hours to prevent goose-aircraft collisions and may have led to an increased 95% utilization distribution.
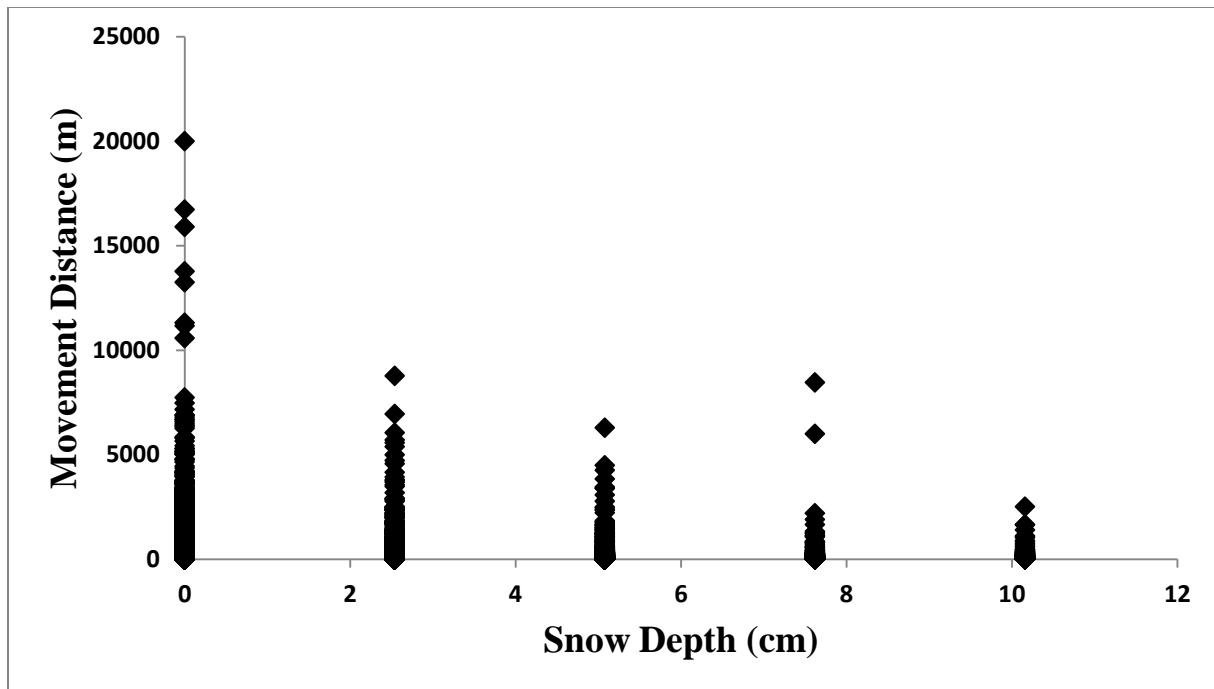
Figure A.2. Movement distances by Canada geese across snow depths from November 2015 through February 2016 in the Greater Chicago Metropolitan Area, Illinois, USA.
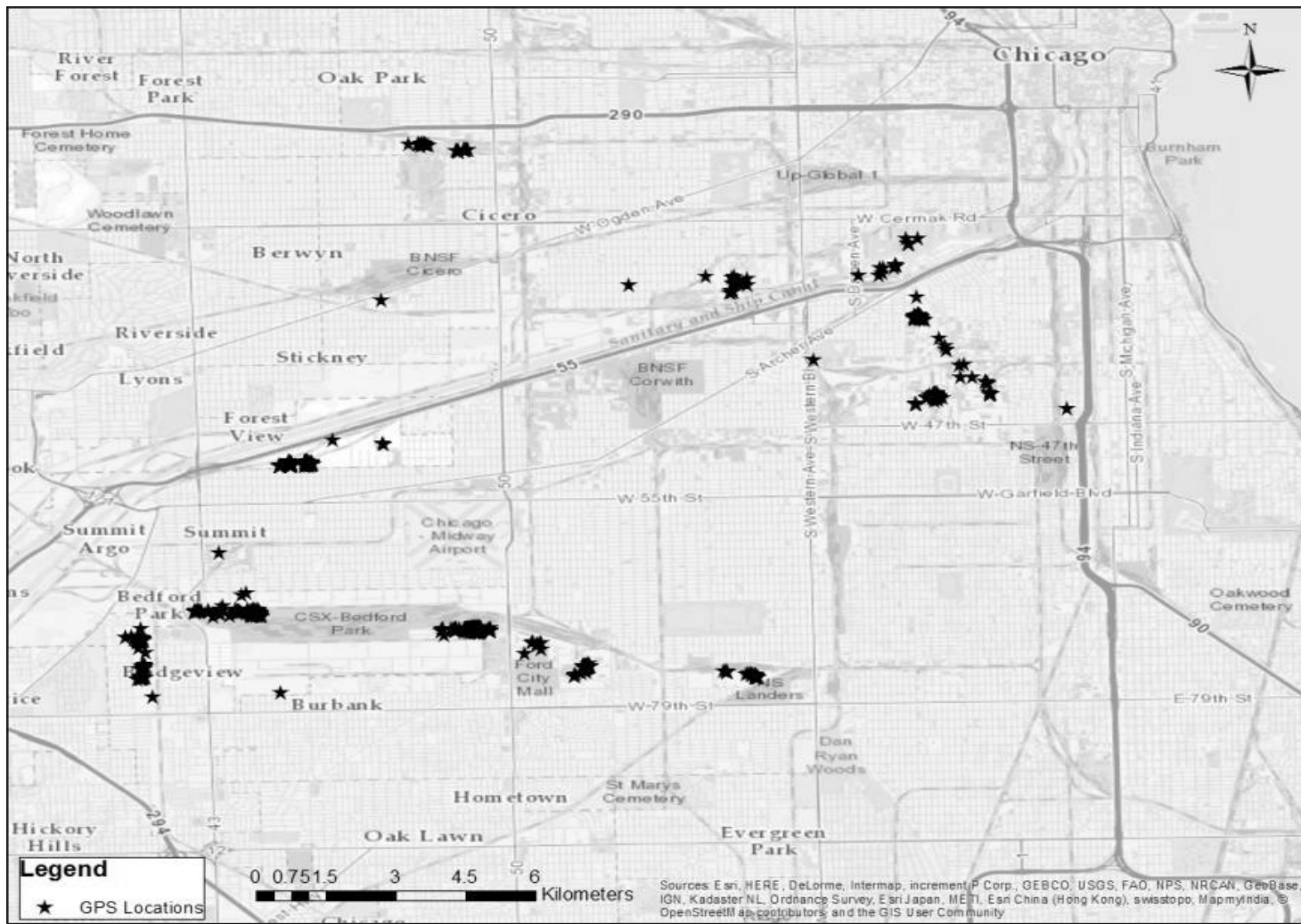
Figure A.3. GPS locations from transmittered Canada geese (*Branta canadensis*) while geese utilized rooftops during late autumn and winter 2014–2016 in the Greater Chicago Metropolitan Area, Illinois, USA.