SURVIVAL AND ROOST SELECTION OF EASTERN WILD TURKEYS IN THEIR NORTHERN RANGE

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Abstract

Survival and roost selection of eastern wild turkeys in their northern range

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Understanding habitat needs of a species is critical, especially for species reintroduced to an area or expanding their range. I evaluated roost tree selection and survival probability of GPS-tagged eastern wild turkeys (*Meleagris gallopavo silvestris*) from 2017–2020 and 2022 in Peterborough County, Ontario, Canada. Fine-scale roost tree selection was associated with larger trees, with microclimate factors such as wind speed, temperature, and precipitation having little to no influence. Turkeys showed high annual survival probabilities relative to other northern regions of their range, but survival was not influenced by proximity of roost tree to a building. The behaviour of roosting in an elevated perch helps turkeys avoid ground-dwelling predators, but specific selection of one tree versus another has little additional benefit to survival. Turkeys appear to survive well in a landscape that is a mix of agricultural and urban, with forest patches intact for roosting habitat.

Key words: Eastern wild turkey, *Meleagris gallopavo silvestris*, roost sites, microclimate, survival, habitat

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Chapter One

General Introduction

Understanding how animals use resources within their habitats is critical for wildlife management and conservation. The resources that animals use can influence survival and reproduction, ultimately affecting population dynamics. Animals select resources that allow them to gain and conserve energy and avoid predation (Fretwell and Lucas 1969, Lima et al. 2005). Although resource selection is a common focus of wildlife research and management (Johnson 1980, Manly 1993), how animals choose resources for periods of rest can be easily overlooked in favour of investigating resource use during periods of activity (Lima et al. 2005, Moe et al. 2007).

Multiple explanations may account for why animals select certain resting sites. Two explanations that are commonly proposed are the predator avoidance theory (Gilliam and Fraser 1987, Lima and Dill 1990, McLoughlin et al. 2005) and the energy balance theory (Klappstein et al. 2022, Papastamatiou et al. 2024). Under the predator avoidance theory, animals select resting sites that reduce their risk of predation, especially during longer periods of rest, such as sleeping (Lima et al. 2005, Dhondt et al. 2010). Sites may have lower predator abundance (Masse et al. 2013, Harmange et al. 2021); conceal the animal from predators, such as through camouflage (Troscianko et al. 2016, Stevens et al. 2017) or through visual obstruction (Spears et al. 2007, Wam et al. 2012); or limit the predator's ability to access the animal (Fisher et al. 2004, Schrader and Müller 2009, Lambertucci and Ruggiero 2013).

A second explanation is that animals select rest sites that allow them to optimize their energy balance (Chapman 1989, Dias et al. 2006). Optimizing energy balance includes both acquiring sufficient energy and expending minimal energy (McNab 1974, 2012, Walsberg 1983). This is demonstrated by European starlings (*Sturnus vulgaris*), which select roost sites near abundant food sources. When food in these areas becomes scarce, they decrease or abandon their use of these roosts (Morrison and Caccamise 1985, 1990). Another way in which individuals can reduce energetic costs at rest sites is by selecting sites that are favourable for thermoregulation. For example, some species of grouse (family Phasianidae) are better able to conserve energy in winter by roosting under the insulative cover of deep, powdery snow (Marjakangas et al. 1984, Thompson and Fritzell 1988). Other animals select shaded or damp sites to help them avoid overheating when resting during periods of extreme heat (Williams et al. 1999, Verzuh et al. 2021, 2023). Often, both predator avoidance and energy balance simultaneously influence an animal's selection of a rest site (Bock et al. 2013, Markham et al. 2016, Nelson et al. 2022).

Roosting, the behaviour of settling down to sleep, is important for the wild turkey (*Meleagris gallopavo*), a large-bodied, non-migratory bird with a wide geographic range in North America. When turkeys are active during the day, they forage on the ground in fields, pastures, and open woodlands (Vander Haegen et al. 1989, Dickson 1992, Niedzielski and Bowman 2016). Though turkeys are more likely to travel on foot, they fly up to tree branches where they roost for the night. Turkeys exhibit communal roosting, meaning that a flock of turkeys will roost together, although not necessarily all in the same tree (Boeker and Scott 1969, Rumble 1992). Turkeys prefer roosting in large, tall trees (e.g., Kilpatrick et al. 1988, Nguyen et al. 2004, Thompson et al. 2009, Adey et al. 2023). These trees typically have sturdy, elevated branches that are well off the ground and provide a structurally sound perch (Boeker and Scott 1969, Mackey 1984), making it difficult for ground-dwelling mammalian predators, such as coyotes (*Canis latrans*) and red foxes (*Vulpes vulpes*), to access them (Weatherhead 1983, Adey et al. 2023).

Some studies report that turkeys prefer roost trees closer to water (Boeker and Scott 1969, Kilpatrick et al. 1988, Chamberlain et al. 2000), but it is less clear whether turkeys prefer roost trees closer to food sources. This may be because sources of food can be ephemeral and more spatially variable compared to water sources, making them more difficult to define on the landscape. However, turkeys are known to access supplemental food such as spilled bird seed from bird feeders, and waste grain found in manure piles or on the ground at farms (Vander Haegen et al. 1989, Kane et al. 2007). There is evidence of turkeys using roost trees located near livestock farms and other buildings (Thompson et al. 2009, Adey et al. 2023), especially during winter when deep snow can limit natural food sources. During these times, supplemental food found near buildings can help turkeys gain sufficient energy, which greatly reduces the risk of starvation (Wright et al. 1996, Kane et al. 2007, Lavoie et al. 2017). The ability to maximize access to food while minimizing the energy expenditure associated with moving to the food may therefore influence roost tree selection.

Another way in which energy balance could be influenced by roost tree selection is through selecting trees with a favourable microclimate. Although turkeys communally roost, they do not huddle closely while roosting (McRoberts et al. 2020), so they receive no thermoregulatory benefits associated with huddling behaviour (Beauchamp 1999, Paquet et al. 2016). It may therefore be beneficial for turkeys to select trees that offer thermoregulatory benefits. Studies involving other bird species demonstrate that the lower wind speeds measured at roost trees compared to open sites help birds conserve energy by reducing convective heat loss (Kelty and Lustick 1977, Walsberg and King 1980, Walsberg 1986, Thompson and Fritzell 1988). Existing research on microclimate conditions at wild turkey roost trees is lacking, although there is evidence to suggest that turkeys alter their behaviour and habitat selection to shelter from adverse weather. Gonnerman et al. (2022) found that turkeys in Maine increasingly prefer coniferous-dominated forests as snow depth and wind chill increase during winter, suggesting they gain thermoregulatory benefits by roosting in coniferous forests.

Knowledge of how roost site selection affects survival is important for wild turkey conservation and management. A comprehensive understanding of factors affecting survival is necessary for wild turkeys because they are a game species and have been reintroduced to many regions within their range. As a species with economic and cultural significance, turkeys have had a complex history with humans. Prior to European colonization of North America, turkeys were considered a bird of open woodlands (i.e., moderate to low tree densities and interspersed clearings), but their populations declined when settlers began clearing forests and overharvesting turkeys (Glover 1948, McRoberts et al. 2020). By the early 1900s, turkeys were extirpated from areas within their range, including eastern and midwestern regions of the United States of America and southern regions of Canada, the latter of which represented the northernmost extent of the turkey’s range (Dickson 1992, McRoberts et al. 2020). After being absent from the affected regions for decades, turkeys were reintroduced through a series of trap-and-transfer programs that started in the 1970s and ended in the early 2000s (Holbrook 1957, Cardoza 1993, OMNR 2007). Today, turkeys are present on human-modified landscapes, often occupying mosaics of forest, open country and agricultural land, and urban areas (Rioux et al. 2009, Pollentier et al. 2014, Baici and Bowman 2023).

Ontario, Canada, represents a region in the northern part of the eastern wild turkey's (*M. g. silvestris*) range where populations were reintroduced. Reintroductions in Ontario began in 1984 and continued to 2005 (OMNR 2007). The contemporary distribution of turkeys in Ontario extends farther north than their historic range limit, although population densities tend to be lower in the northernmost areas (Baici and Bowman 2023). In these regions, turkeys are challenged by cold, snowy winters, during which natural food is less abundant (Nguyen et al. 2003, Niedzielski and Bowman 2015). However, milder winters and the increasing conversion of forested land to agricultural and urban areas may improve turkey survival, allowing turkeys to continue expanding their range northward (Baici and Bowman 2023). Although current turkey populations are considered well-established in Ontario, monitoring wild turkey survival and population growth remains a priority. This is particularly important because turkey populations in some areas have declined since peaking in the early 2000s (Tapley et al. 2011, Chamberlain et al. 2022). Although the reasons for these declines are not fully understood, increasing predator abundance and loss of suitable habitat (for foraging, nesting, and roosting) may be contributing factors (Casalena et al. 2015, Tyl et al. 2023). For example, clearing woodlands for urban development or for conversion to monoculture row crops can reduce the quality and quantity of habitat for wild turkeys.

My thesis builds upon previous research on wild turkeys in Ontario by addressing questions raised in other studies. For example, Adey et al. (2023) investigated roost tree selection in Ontario, including whether microclimate differed among roost trees. The authors found that temperatures in roost trees may differ from ambient temperatures, depending on the season and whether the tree was coniferous or deciduous (Adey et al. 2023). The authors stated the importance of continued research on microclimate at roost sites, including investigating the role of wind speed in roost site selection (Adey et al. 2023). Additionally, Adey et al. (2023) found that winter roost trees were closer to buildings than non-roost trees, supporting Baici and Bowman's (2023) finding that building density contributed strongly to their model of wild turkey distribution in Ontario. Baici and Bowman (2023) also suggested that turkey population densities differed within different regions of Ontario, and that this has implications for turkey survival and management. Estimating survival is a key parameter in understanding variation in turkey population density. Only two studies to date have estimated annual survival rates for turkeys in Ontario (Nguyen et al. 2003, Niedzielski and Bowman 2015), and both of these studies focused on female turkeys in regions of Ontario where Baici and Bowman (2023) suggest that turkey densities may be lower than in other regions of the province. My study includes an evaluation of annual survival for male and female turkeys in Peterborough County, a region where turkey densities appear to be higher compared to other parts of Ontario (Baici and Bowman 2023). An increase in population density sometimes results in decreasing survival estimates due to density-dependent regulation (Lieske et al. 2000, Festa-Bianchet et al. 2003). This density-dependent effect on survival rates may warrant different strategies for managing turkey populations. As well, my study differs from Adey et al. (2023) in that it compares microclimate at a greater number of roost and non-roost trees and includes wind speed and precipitation as additional measures of microclimate.

There are three main objectives to my research. First, I seek to understand the importance of microclimate in roost tree selection for a large-bodied bird that cannot easily shelter in tree cavities or dense foliage like smaller-bodied birds and does not migrate to avoid harsh conditions. Second, I will estimate annual survival rates for wild turkeys in a region of Ontario where population densities are thought to be high, which has not yet been done. Finally, I will connect these two objectives by asking whether proximity of roost trees to buildings influences survival probability. I used fine-scale location data collected from GPS transmitters worn by turkeys that were captured, tagged, and tracked in Peterborough County from 2017—2020 and 2022 to inform my research on roost use and survival. This research is described in chapter two and three of my thesis. In chapter two, I test for differences in microclimate at turkey roost trees in comparison with nearby non-roost trees and an open non-forested site. In chapter three I estimate annual survival rates and test whether turkeys improve their survival probability by roosting close to buildings, where they may find supplemental food and face lower predation risk. My fourth chapter is a summary and synthesis of my findings from chapters two and three, as well as a discussion of implications for future research and management of wild turkeys in Ontario.

Chapter Two

Wild turkey roost selection is more consistently associated with tree traits than microclimate

ABSTRACT

Animals must cope with a range of climatic conditions across seasons, and they can accomplish this is by selecting habitats that are favourable for thermoregulation. Sheltering from environmental conditions can be particularly important for reducing energetic costs when animals are inactive, but the influence of microclimate on fine-scale selection of sleeping sites is often unclear. We compared microclimate at eastern wild turkey (*Meleagris gallopavo silvestris*) roost trees and nearby non-roost trees during summer and winter in southern Ontario, Canada, near the northern part of the turkeys' range. During both winter and summer, overnight air temperature and wind speeds at turkey roost trees were similar to those at nearby non-roost trees. In summer, however, there was slightly less accumulated precipitation at roost trees compared to non-roost trees. Our findings suggest that although roost trees may occasionally provide thermoregulatory benefits related to slight differences in microclimate (especially compared to open sites), turkeys' choice of specific roost trees within a woodland is more likely influenced by proximate signals related to tree characteristics. Our study highlights the importance of forests with large trees as roosting habitat for wild turkeys, particularly in agricultural landscapes within the northern part of their range.

2.1 INTRODUCTION

In temperate regions, animals must cope with large seasonal changes in climate. For these animals, the ability to reduce energetic costs in different climatic conditions can be important for survival (Cooper 2002, Broggi et al. 2004, Swanson 2010). This is particularly relevant for endothermic species, which must allocate additional energy towards thermoregulation when environmental conditions become increasingly warm or cold (McNab 1974, 2012, Dutenhoffer and Swanson 1996, Swanson 2010, Rezende and Bacigalupe 2015). To reduce the costs of thermoregulation, endotherms display various adaptations. Some adaptations are physical, such as denser pelages or plumages grown in winter to insulate against the cold (Marchand 2013, Beltran et al. 2018). Other adaptations are behavioural, such as moving to shaded or damp areas during hot summer days to reduce overheating (Long et al. 2014, Beever et al. 2017, Verzuh et al. 2021).

Habitat selection is a behavioural adaptation animals can use to help thermoregulate in regions with varying climates. Habitat selection exists at a range of spatial scales, from coarse to fine (Johnson 1980, Boyce 2006). At a coarse scale, animals may select habitats favourable for thermoregulation within their home range, although the number of examples remains limited, at least in birds. For example, red knots (*Calidris canutus*) and great knots (*Calidris tenuirostris*) in tropical northwest Australia use habitat with wet substrate for daytime roosts to reduce overheating, even though risk of predation might be lower in other habitat types (Rogers et al. 2006). At a finer scale, animals may select microhabitats favourable for thermoregulation within their broader habitats. For example, Rio Grande wild turkeys (*Meleagris gallopavo* *intermedia*) in Oklahoma reduce their movement and select sites with tall vegetation during the hottest times of the day, even when sites with tall vegetation are rare on the landscape (Rakowski et al. 2019). Similarly, greater prairie chickens (*Tympanuchus cupido*) select sites that have greater vegetation cover and are therefore cooler during the hottest times of the day (Londe et al. 2021).

Habitat selection as an adaptive behaviour for thermoregulation may be particularly important during periods of inactivity or rest, such as when sleeping. While sleeping, animals are more limited in their ability to behaviourally thermoregulate because they cannot easily move to a warmer or colder location. There is evidence that animals select microhabitats for sleeping that reduce energetic costs of thermoregulation and provide shelter from environmental conditions. For example, some species of grouse (family Phasianidae) roost under the insulative cover of deep snow, allowing them to better conserve energy compared to roosting above the snow (Marjakangas et al. 1984, Thompson and Fritzell 1988). If sufficient snow cover is not available, they roost in dense vegetation (Pekins et al. 1991, Swenson and Olsson 1991) and avoid sites in low-lying areas where cool air settles (Whitaker and Stauffer 2003). Greater hoopoe-larks (*Alaemon alaudipes*) in the Arabian Desert rest in burrows made by Egyptian spiny-tailed lizards (*Uromastyx aegyptia*) during the hottest times of the day because the burrows are cooler than above-ground sites (Williams et al. 1999). As a final example, Andean condors (*Vultur gryphus*) in northwest Patagonia roost on cliffs that face away from prevailing winds and receive lower accumulations of wind-blown snow, improving their ability to stay warm in cold conditions (Lambertucci and Ruggiero 2013).

The wild turkey (*Meleagris gallopavo*) is a large, wide-ranging non-migratory species in North America whose habitat selection can differ depending on whether they are active or inactive. Turkeys are active during the day, when they forage on the ground in pastures, fields, and open woodlands (Vander Haegen et al. 1989, Dickson 1992, Niedzielski and Bowman 2016). At night, turkeys move into trees to roost on branches. A roost site may comprise of a single tree that one turkey is using at night, or in the case of flocks, multiple trees located close together that the turkeys use. It is common for a flock of turkeys to distribute themselves among several trees at a roost site (Boeker and Scott 1969, Rumble 1992, K. Martin, *personal observation*). Although multiple turkeys may use the same tree at one time, they do not huddle closely (McRoberts et al. 2020, K. Martin, *personal observation*). As a result, turkeys do not gain any thermoregulatory benefits associated with huddling behaviour (Beauchamp 1999, Paquet et al. 2016).

There are multiple factors that appear to influence selection of roost trees by wild turkeys. Though the species of tree may differ depending on geographic region, there is abundant evidence that turkeys prefer roosting in large, tall trees (e.g., Kilpatrick et al. 1988, Nguyen et al. 2004, Thompson et al. 2009, Adey et al. 2023). Larger trees may provide better protection from predators (Weatherhead 1983, Adey et al. 2023) and may have branch structure better suited for roosting turkeys (Boeker and Scott 1969, Mackey 1984, Thompson et al. 2009). Access to food and water may also be important. For instance, some studies show a preference for roost trees closer to water (Boeker and Scott 1969, Kilpatrick et al. 1988, Chamberlain et al. 2000), but this is not always the case (Nguyen et al. 2004) and may only be important for frequently used “hub” roosts (Adey et al. 2023). Turkeys exhibit some flexibility in their roost sites and may shift to roost sites that are closer to reliable food sources (Adey et al. 2023). For example, turkeys may roost near livestock operations more frequently in winter (Thompson et al. 2009, Adey et al. 2023), allowing them convenient access to waste grain at a time of year when snow limits access to naturally occurring foods (Nguyen et al. 2004, Kane et al. 2007, Gonnerman et al. 2022).

Despite research on factors influencing roost tree selection by wild turkeys, there remain gaps in our knowledge. For instance, there is little research on whether microclimate influences selection of roost trees by turkeys. There may be differences in temperature, wind speed, or precipitation at one tree compared to another, and turkeys could gain thermoregulatory benefits by selecting to roost in certain trees. Such differences do appear to exist at broader scales, such as between two habitat types. For example, wind speeds are lower in the shelter of forests compared to open areas (Walsberg and King 1980, Buttemer 1985, De Frenne et al. 2021), reducing convective heat loss and helping birds conserve energy (Kelty and Lustick 1977, Walsberg 1986, Thompson and Fritzell 1988, Høyvik Hilde et al. 2016). Turkeys appear to shelter from adverse weather, such as high winds and deep snow, by using forested habitat. As an example, turkeys in Maine show an increasing preference for coniferous-dominated forests with increasing snow depth and wind chill during winter (Gonnerman et al. 2022). Turkeys show this pattern when stationary during the day, but also at night, suggesting that they obtain thermoregulatory benefits by roosting in forested areas compared with resting in open areas (Gonnerman et al. 2022).

Such differences in microclimate may exist at finer scales, too, such as between two trees within a forest. For example, Pekins et al. (1991) found that wind speeds were lower at subalpine fir trees (*Abies lasiocarpa*) used by blue grouse (dusky grouse; *Dendragapus obscurus)* at night compared to Douglas fir (*Pseudotsuga menziesii*) which was used during the day. As well, Adey et al. (2023) compared temperature at a single coniferous and single deciduous roost tree used by turkeys and found that, in summer, mean overnight temperature at the roost trees was slightly warmer than ambient temperature, and the deciduous tree was warmer than the coniferous tree. In winter, however, the temperatures were similar regardless of tree type and ambient conditions. Although Adey et al. (2023) sampled only two roost trees and no non-roost trees, the findings suggest that, in some contexts, microclimate may differ among trees used by turkeys. Adey et al. (2023) highlighted that there is a lack of information about effects of microclimate on wild turkey roost selection.

Microclimate differences at roost trees may be particularly relevant for turkeys at the northern part of their range, where survival can be challenging during cold, snowy winters (Nguyen et al. 2004, Niedzielski and Bowman 2015, MacDonald et al. 2016, Lavoie et al. 2021). Turkeys sometimes make seasonal switches among roost trees (Bakner et al. 2022, Adey et al. 2023) and it is possible their choices reflect differing microclimates. Turkeys may seek out roost trees in winter that offer better protection from snow and wind, therefore reducing energetic costs. Summer climates in the northern part of the turkey’s range are not known to strongly influence survival, other than for ground-nesting hens who may be particularly vulnerable to predators during rainy conditions (Roberts and Porter 1998). However, there can still be energetic costs associated with rain exposure at the roost (Wilson et al. 2004), and turkeys may select roost trees that offer protection from heavy rainfall.

Our goal was to test for differences in microclimate at wild turkey roost trees compared to both nearby non-roost trees and to an open non-forested site, addressing the gap in knowledge about microclimate identified by Adey et al. (2023). We hypothesized that turkeys prefer to roost in trees that offer thermoregulatory benefits. We therefore predicted that roost trees in the forest would have lower wind speeds and lower amounts of snow accumulation in winter, and lower amounts of rainfall in summer compared to an open non-forested site. At a finer scale, we expected that compared to non-roost trees in the forest, roost trees would have lower wind speeds and lower amounts of snow accumulation in winter, and lower amounts of rainfall in summer.

We did not anticipate differences in temperature at roost and non-roost trees in either season. This is because although forest canopies can be warmer than ambient temperatures at night, there is less variation in temperature within forest canopies (Denyer et al. 2006, Sharmin et al. 2023). The roost and non-roost trees we compared were within forest stands, rather than isolated in open settings, and we therefore expected little variation in temperature among trees. We also did not anticipate differences in wind speeds at roost and non-roost trees in summer because the presence of foliage on both coniferous and deciduous trees would likely produce similarly low wind speeds throughout a forest (Chen et al. 1995, Grimmond et al. 2000). We used GPS transmitters affixed to individual turkeys to identify roost locations. We then collected microclimate data at multiple roost and non-roost trees during summer and winter.

2.2 METHODS

Study Area

Our study area was located within 30 km of Peterborough, Ontario, Canada (approximately 44.4° N, 78.3° W), within the northern portion of the eastern wild turkey's (*M. g. silvestris*) current range. Turkeys were reintroduced to the area beginning in the mid to late 1980s (OMNR 2007) and current populations are well-established (Baici and Bowman 2023). The landscape is predominantly agricultural fields and pasture, but also features hedgerows, mixed forest, and wetlands. Wild turkeys in our study area experience different weather conditions in the summer and winter seasons. For example, from 2017–2022 in our study area, the daily mean and maximum daily temperatures for summer (June to August) were 19.6 °C and 26.4 °C, respectively (Environment and Climate Change Canada 2023); and the daily mean and minimum temperatures for winter (December to February) were -5.8 °C and -10.9 °C, respectively (Environment and Climate Change Canada 2023). Additionally, during December to February 2017–2022, the average amount of snow on the ground each month ranged from 0–42.7 cm, with an average of 16 cm (Ontario Ministry of Natural Resources and Forestry 2023).

Turkey Trapping and Tracking

To identify roost locations, we tracked the movement of individual wild turkeys. We trapped turkeys between January and March in 2017, 2018, and 2022. We trapped turkeys during winter because that is when they typically form larger flocks (Healy and

Powell 1999) and are more likely to visit bait piles due to reduced availability of natural food (Roberts et al. 1995, Kane et al. 2007). We trapped turkeys at five locations identified from driving surveys (Baici and Bowman 2023) and where landowners allowed permission. We baited trap locations with piles of dried and whole cracked corn to attract turkeys, then used rocket nets (Grubb 1988) to catch turkeys at the bait piles. Across trapping years (2017, 2018, 2022), we captured turkeys during a total of 15 trapping sessions.

After capture, we placed turkeys in large cardboard boxes (National Wild Turkey Federation, Edgefield, South Carolina) and processed them on site to minimize time spent captive. For each turkey, we recorded sex, age, mass, and morphological measurements (length of wing, tail, tarsus; and, if applicable, beard). We then fitted an aluminum leg band for identification and a GPS transmitter tag (model PinPoint VHF-3600L, Lotek Wireless Inc., Newmarket, Ontario). Tags weighed 85 g and were only fitted to turkeys where the tag was less than 3% of the turkey's mass. We attached the tags using a backpack-style harness (Norman et al. 1997), a method frequently used with turkeys (e.g., Chamberlain et al. 2000, Niedzielski and Bowman 2016, Baici and Bowman 2023). The tags collected locations at various schedules. Tags deployed in 2017 and 2022 collected locations every 4 hours and 15 minutes; whereas those deployed in 2018 collected hourly locations between 06:30 and 22:30, with additional locations taken at 24:00 (midnight) and 04:00. These schedules allowed the tags to capture both daytime and nighttime locations. Capture and handling methods comply to the Trent University Animal Care Committee protocols #24653, and #27862.

Identifying Roost Sites

We identified roosting locations from the location data collected by the tags from 2017–2019 and 2022. We filtered the location data to include only the locations obtained from 24:00–4:00, to capture a single location per turkey per night. We assumed that the turkey would have been roosting at this time. We filtered locations further based on time of year, focusing on summer and winter because these seasons have the most contrasting weather conditions in our study area. We defined "summer" locations as those collected between June 1 and August 31, and "winter" locations as those collected between December 1 and February 28. We excluded locations from female turkeys during June and July because female turkeys nest during this time and would not be expected to roost in trees. Our summer roosting location data was from 35 turkeys (17 females and 18 males), while our winter roosting location data was from 47 turkeys (27 females and 20 males).

We observed during preliminary analysis that the turkey roosting locations were clustered. This pattern can likely be explained in two ways. First, the GPS tags had some spatial error, estimated by Adey et al. (2023) to be ±19.9 m from the true location of the tag. This could result in a cluster of locations appearing on the map even if the tagged turkey was using the same tree for each of those nights. Second, turkey roost sites are sometimes comprised of multiple roost trees in close proximity to each other (Boeker and Scott 1969, Thompson et al. 2009). For both these reasons, it was useful to first identify which roosting locations should be grouped together in a cluster, and then identify the centre of each site to represent a roost tree. First, we identified clusters of roosting locations using a defined distance density-based clustering tool in ArcGIS

Pro (Esri Inc. 2022). We used a minimum of five locations within a 15 m search distance to define clusters of summer roosting locations, whereas we used a minimum of three locations within a 15 m search distance to define clusters of winter roosting locations. This accounted for our observation of turkeys using fewer roost sites in winter and allowed us to maintain a similar roost sample size for summer and winter. The 15 m search distance ensured the edges of individual clusters were separated from each other by at least 15 m. Additionally, this distance accounted for the estimated ±19.9 m spatial error of the GPS tags (Adey et al. 2023). From this spatial analysis, we identified 49 clusters of summer roosting locations and 45 clusters of winter roosting locations. Second, we identified the centre of each cluster using the summarize center and dispersion tool in ArcGIS Pro (Esri Inc. 2022). We allowed these central coordinates to represent a roost tree for each cluster of turkey roosting locations, and we later visited these coordinates to gather evidence of roost use and to collect data related to tree characteristics and microclimate.

Data Collection

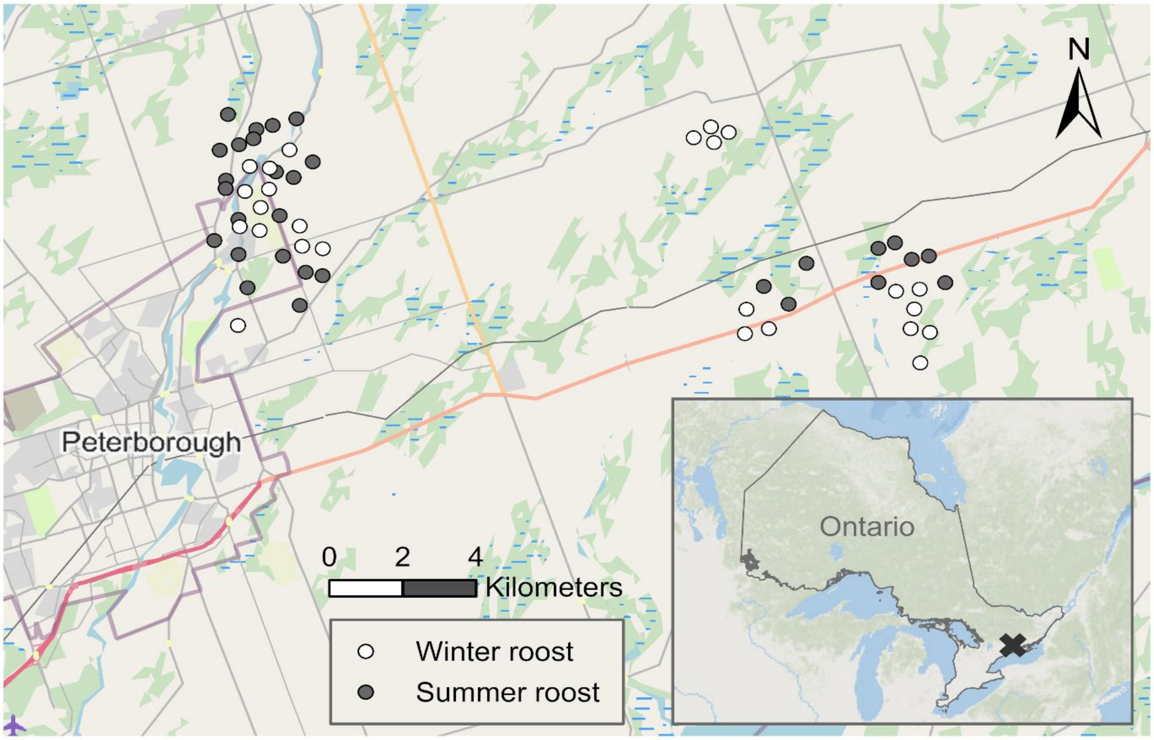
The representative roost trees we identified through spatial analysis were based on location data collected from GPS-tagged turkeys in 2017—2019 and 2022. In 2022 and 2023, we collected microclimate data at these trees to test our hypothesis that turkeys select roost trees that have a favourable microclimate. We assumed that trees within our study area would have changed little between 2017 and 2023, meaning that measurements we took in 2022 and 2023 would be representative of the tree’s characteristics dating back to 2017. Turkeys in our study area continued to re-use many of these same roost trees throughout the period of our study. In addition to microclimate measurements, we also collected data on tree type (coniferous or deciduous) and diameter at breast height (DBH; as a proxy for tree size), as there is evidence that these factors are important for turkey roost tree selection (Thompson et al. 2009, Adey et al. 2023). As such, we wanted to include tree characteristics in our analysis.

We collected data at pairs of roost and non-roost trees. For each pair, we first located the representative roost tree based on the central coordinates of the clusters we identified through spatial analysis. Upon arriving at the central coordinate, we selected the nearest tree that had evidence of recent use (turkey droppings and/or feathers) to represent the roost tree. There were some sites where, upon navigating to the central coordinate, we found no evidence of recent use for any nearby tree. We still included these sites because the GPS tag data from 2017–2019 indicated use by turkeys, and evidence of use was confirmed previously for a subset of these sites by Adey et al. (2023). For these sites, we used the nearest tree that had a DBH of at least 20 cm. We set 20 cm as our threshold for minimum DBH for both roost and non-roost trees, since this was the minimum roost tree size previously identified within the study region (Adey et al. 2023).

To compare roost and non-roost trees, we paired each roost tree with a nearby non-roost tree. Non-roost trees represented trees that were available but had no evidence of roosting turkeys. We selected non-roost trees by walking 50 m north of the roost tree and selecting the nearest tree with a DBH greater than 20 cm. This tree represented a non-roost tree that was available to turkeys but not apparently used. When a suitable tree was not available, we randomly selected a different cardinal or intercardinal direction and walked 50 m in that direction (in a single case it was necessary to walk 100 m to find a non-roost tree). There were three instances in which the largest available non-roost trees had a DBH slightly smaller than 20 cm (18 cm for two trees and 19.5 cm for one tree). At the non-roost tree, we replicated the process of measuring tree characteristics.

For each pair of roost and non-roost trees, we recorded whether the tree was coniferous or deciduous and we measured diameter at breast height (1.3 m above ground) using a DBH tape in centimeters (cm). Next, we set up a single portable weather station (Supporting Information) at each roost and non-roost tree to measure microclimate variables (wind speed (± 0.1 m/s), air temperature (± 0.5 °C), and accumulated precipitation (± 0.5 mL)). Using a throw weight and line (Notch Equipment, Greensboro, North Carolina; Weaver Leather, Millersburg, Ohio), we positioned a pulley and rope over a branch and hoisted the weather station just below the branch. The portable weather station was comprised of a platform approximately 0.5 m wide with a Kestrel 5000 Environmental Meter and wind vane attachment (Kestrel Instruments, Boothwyn, Pennsylvania). We programmed the Kestrel 5000 to record a measurement of wind speed and air temperature every half-hour. We recorded the height of the weather station based on a rope hanging from the bottom of the weather station and marked with tape at 0.25 m intervals. We used a minimum height of 5 m for weather stations, since turkeys typically roost in trees where the lowest branch is at least 3 m above the ground (Boeker and Scott 1969, Mackey 1984, Perlichek et al. 2009, Adey et al. 2023), although there was one occasion on which a weather station was set at 4.25 m due to dense branches above. Lastly, we set a 9.46- or 11.36-litre (10- or 12-quarts) metal pail (Behrens Manufacturing, Winona, Minnesota), on the ground below the weather station, but offset 1 m in the direction opposite from the tree trunk, to collect precipitation. A summary of roost and non-roost tree pairings is available in the Supporting Information.

Most roost trees were located on privately-owned property, and due to restricted access at some properties we only collected data at a subset of sites. We added four incidental winter roost trees observed during winter 2023. Although these four trees were not used by GPS-tagged turkeys, we confirmed recent use based on observations of turkey droppings below the trees. We therefore collected data at 25 winter roost trees between December 1, 2022, and March 27, 2023, and at 30 summer roost trees between June 1 and September 25, 2023 (Figure 1; see also Supporting Information). We measured each pair of roost and non-roost trees for three to five nights at a time before moving equipment to the next pair, as we did not have enough equipment to measure all pairs simultaneously. More specifically, data collection at each pair of roost and non-roost trees spanned three to four nights during the winter sampling period and three to five nights during the summer sampling period. We therefore collected microclimate data for a total of 77 nights in winter and 100 nights in summer.



Main basemap: Esri OpenStreetMap project. Inset basemap: Esri, GEBCO, NOAA, National Geographic, Garmin, TomTom Geonames.org, and other contributors. Inset Ontario boundary: Statistics Canada

Figure 1. Map of winter (white dots; December–February) and summer (grey dots; June–August) turkey roost sites sampled in our study area. Sites were identified based on clusters of nocturnal locations obtained from GPS-tagged eastern wild turkeys (*Meleagris gallopavo silvestris*; n = 25 sites for winter, n = 30 sites for summer) in 2017–2019 and 2022 in Peterborough County, Ontario, Canada. Roost locations that appeared overlapping at the map's current scale were adjusted to display with an offset.

Non-forested Site

To test whether differences in microclimate occur at a coarser scale, we set up a weather station at a single non-forested site. The non-forested site was a tree in a hedgerow with surrounding agricultural fields, and we maintained this same location for both the summer and winter sampling periods. More specifically, the weather station was hung from the branch of a basswood (*Tilia americana*) at a height of 6 m above the ground. The nearest and farthest roost trees were 0.45 and 18.5 km, respectively, from the non-forested site.

Data Analysis

We calculated nightly values for wind and temperature at each roost and non-roost tree, as well as the non-forested tree, from the measurements taken every 30 minutes between 21:00 and 06:00. We used this period because we expected that turkeys would typically be roosting between these hours. We calculated mean and maximum overnight wind speed, mean temperature, minimum temperature (winter only) and maximum temperature (summer only). Accumulated precipitation was determined by totaling the precipitation over the nights the weather station was stationed at the site. In winter, we melted snow precipitation and measured its volume. Three summer roost trees and one summer non-roost tree were missing precipitation data because the pail tipped over post-deployment. For these trees, we used imputation to substitute the missing values in our dataset. We randomly generated values to assign to the precipitation variable for these trees, but we specified that values come from a Poisson distribution to align more closely with the distribution of measured precipitation data. This has been identified as an acceptable method to preserve sample size, maintain statistical power, and reduce potential bias in models (van der Heijden et al. 2006, Nakagawa and Freckleton 2008).

We performed statistical analysis in R (R Core Team 2022) to compare tree characteristics and microclimate at roost and non-roost trees. To estimate whether turkeys select roost trees depending on tree characteristics or microclimate variables, we used matched case-control conditional logistic regression models from the ‘survival’ package (Therneau et al. 2024). We stratified the analysis based on the pairs of roost and non-roost trees.

Before the analysis, we used a correlation matrix to assess collinearity among our variables. For the winter dataset, mean and maximum overnight wind speed were correlated (coefficient = 0.92, n = 154), as were mean and minimum overnight temperature (coefficient = 0.99, n = 154). Additionally, the height of the weather station was correlated with mean and maximum wind speed (coefficients = 0.36 and 0.41, respectively; n = 154) and with tree use (coefficient = 0.46, n = 154). The correlation with tree use suggests that we were able to set up the weather stations higher in roost trees compared to non-roost trees. This was not intentional, as we always attempted to set the weather station as high as possible in the tree. Instead, this observed difference likely reflects how roost trees tended to have a more open branching structure, which often allowed the weather station to be set higher above the ground. For the summer dataset, mean and maximum overnight wind speed were correlated (coefficient = 0.90, n = 200), as were mean and maximum overnight temperature (coefficient = 0.92, n = 200). Weather station height was not correlated with wind speed but was somewhat correlated with roost use (coefficient = 0.28, n = 200) in the summer dataset, though to a lesser extent than in the winter dataset. In both datasets, all other variable pairings had correlation coefficients less than 0.4.

We compared a set of conditional logistic regression models for both the winter and summer datasets (Table 1). In all models, we used a binary response variable of whether a tree was a roost tree (1) or a non-roost tree (0). Both the summer and winter sets contained three models: a “means model”, which used mean overnight wind speed, mean overnight temperature, and total accumulated precipitation as fixed effects, and weather station height as an interaction term with wind speed; an “extremes model”, which used maximum overnight wind speed, minimum (winter) or maximum (summer) overnight temperature, and total accumulated precipitation as fixed effects, and weather station height as an interaction term with wind speed; and a “trees model”, which used tree type and DBH as fixed effects. Using a “means model” and “extremes model” allowed us to keep correlated variables (mean and maximum wind speed; and mean and maximum or minimum overnight temperature) separate. Adding weather station height as an interaction term helped account for the correlation between weather station height and wind speed, especially in the winter dataset. We used pair ID to define how roost and non-roost trees were be matched, since each roost and non-roost tree in a pair was measured on the same nights and located 50 m apart. We scaled our fixed effect variables using the scale function in base R (R Core Team 2022) prior to using them in the models. This function calculates the mean and standard deviation for a variable, then scales each observation by first subtracting the mean and then dividing by the standard deviation. We calculated Akaike’s Information Criterion (AICc) using the “AICcmodavg” package (Mazerolle 2023) to evaluate which model best explained winter and summer roost tree selection by wild turkeys.

We used a linear regression from the ‘stats’ package (R Core Team 2022) to test for differences in microclimate at forested sites and the single non-forested site. This evaluation considers potential differences in microclimate at a coarser scale than our comparison of roost and nearby non-roost trees. We used a linear regression rather than binomial model because we were comparing multiple forested sites with a single non-forested site. In our model, each data point represented a single night of sampling. The independent variable was the microclimate recorded at a single non-forested site, which was a tree in a hedgerow with surrounding agricultural fields. We maintained this same location for both the summer and winter sampling periods due to limitations in locating and accessing additional non-forested sites. The dependent variable in our model was the microclimate recorded at a forested site, which was represented by the roost trees, with each roost tree contributing data for three to five nights. It is therefore important to note that there was both temporal and spatial variation (to an extent) in data from the forested sites, but only temporal variation in data from the non-forested site. We used permutation tests as a non-parametric approach to address the lack of independence associated with sampling the same non-forested site each night. We used a custom method in base R (R Core Team 2022) to permute the microclimate values for the forested sites 999 times, then evaluated the proportion of permuted coefficients greater than the coefficient produced in the original linear model. This allowed us to test whether a relationship we detected between microclimates at forested sites and the non-forested site was due to actual differences in microclimate rather than the repeated sampling of the non-forested site.

Table 1. Variables tested in relation to likelihood of eastern wild turkeys (*Meleagris gallopavo silvestris*) using a tree for roosting**.** Roost trees were used by turkeys in southern Ontario, Canada, between the years of 2017-2019 and 2022. Variables were measured from December 1, 2022, to March 27, 2023, for winter sites (n = 25, sampling each site for 3–4 nights); and from June 1 to September 25, 2023, for summer sites (n = 30, sampling each site for 3–5 nights).

Variable	Description	Predicted Direction of Relationship	
		Summer	Winter
Temperature	1. *Mean overnight*: mean ambient temperature recorded at the tree between 21:00 and 6:00 (°C, continuous).	none	+
	2. *Minimum overnight*: coldest ambient temperature recorded at the tree between 21:00 and 6:00 (°C, continuous).	N/A	-
	3. *Maximum overnight*: warmest ambient temperature recorded at the tree between 21:00 and 6:00 (°C, continuous).	none	N/A
Wind Speed	1. *Mean overnight*: mean wind speed recorded at the tree between 21:00 and 6:00 (m/s, continuous).	-	-
	2. *Maximum overnight*: maximum wind speed recorded at the tree between 21:00 and 6:00 (m/s, continuous).	-	-
Precipitation	*Total accumulated:* precipitation that accumulated at the tree over the sampling period (ranged from 3-5 days; mL, continuous).	-	-
Tree Characteristics	*Tree Type*: whether the tree was coniferous or deciduous (factor).	no preference	coniferous preferred
	Tree DBH: The diameter at breast height (DBH) of the tree (cm, continuous).	+	+

2.3 RESULTS

Overall, there were minimal differences in microclimate at wild turkey roost trees and nearby non-roost trees during both winter and summer (see Tables A2 and A3 in Supporting Information). In summer, the mean volume of total accumulated precipitation was higher at non-roost trees compared to roost trees by approximately 139 mL and was a significant predictor of roost tree selection in the summer microclimate models. In winter, the mean volume of total accumulated precipitation was only a little (approximately 28 mL) higher at non-roost trees compared to roost trees, and it was not a significant predictor of roost tree use. Overnight temperatures and wind speeds were not significant predictors of roost tree selection and did not differ strongly between roost and non-roost trees. To illustrate, mean and minimum overnight temperatures at roost and non-roost trees were within 0.2 °C of each other in both winter and summer. As well, during both summer and winter, mean and maximum overnight wind speeds at roost and non-roost trees were within 0.1 m/s of each other, though overnight wind speeds were generally low.

During both seasons, wild turkeys roosted in trees that had a larger DBH than non-roost trees, and in summer they were also more likely to roost in deciduous trees (Figure 2). In winter, mean DBH of roost trees (48.5 ± 2.0 cm) was approximately 50% larger than that of non-roost trees (32.4 ± 1.2 cm). In summer, mean DBH of roost trees (60.3 ± 4.0 cm) was almost 85% larger than that of non-roost trees (32.6 ± 1.5 cm). Interestingly, mean DBH of winter roost trees was 19.7% smaller than that of summer roost trees. In both seasons, most roost and non-roost trees were deciduous. However, coniferous trees comprised a greater proportion of roost trees in winter (28%) compared to in summer (6.7%). In comparing tree type for roost and non-roost trees, we observed that the numbers of deciduous and coniferous trees were similar in winter for both roost and non-roost categories (Figure 3; see also Supporting Information). In summer, however, there were six more (27% more) roost trees than non-roost trees that were deciduous, and the opposite pattern was observed for coniferous trees (Figure 3; see also Supporting Information).

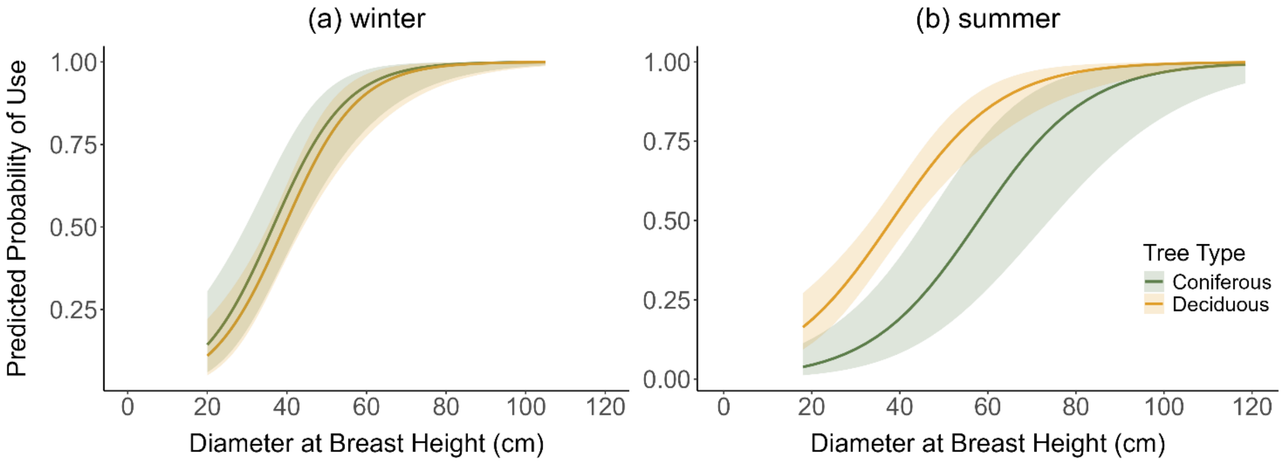


Figure 2. Predicted probability of use (± 95% confidence interval) based on tree type and diameter at breast height (DBH) at a) winter (n = 25) and b) summer (n = 30) eastern wild turkey (*Meleagris gallopavo silvestris*) roost trees. Roost trees were located within the study area in southern Ontario, Canada; and variables were measured from December 1, 2022, to March 27, 2023, for winter sites; and from June 1 to September 25, 2023, for summer sites. Note that trees < 20 cm DBH were deemed not suitable for roosting due to their small size.

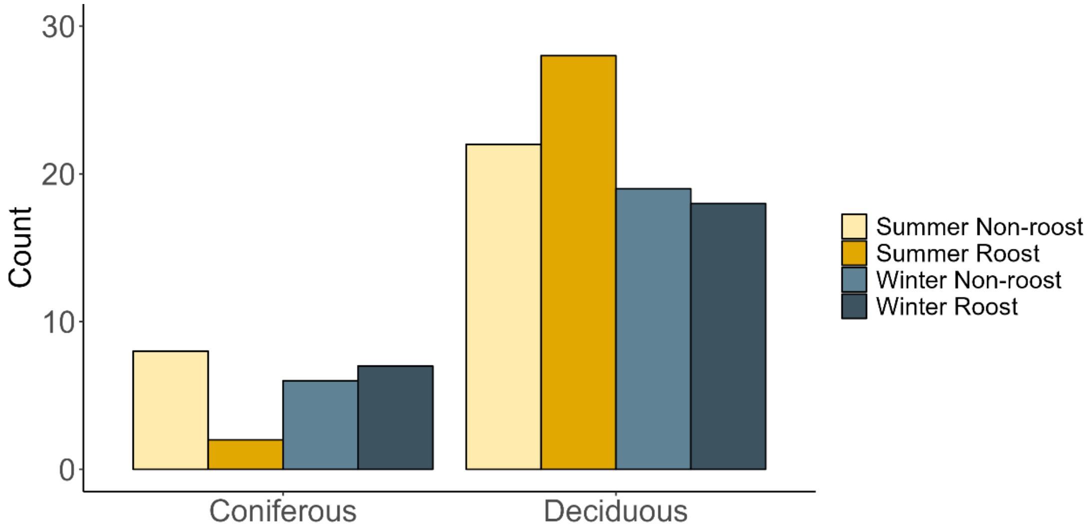


Figure 3. Counts of coniferous and deciduous roost and non-roost trees sampled in winter (n = 25 each for roost and non-roost) and summer (n = 30 each for roost and non-roost). Roost trees were used by GPS-tagged eastern wild turkeys (*Meleagris gallopavo silvestris*) in 2017– 2019 and 2022 in Peterborough County, Ontario, Canada.

Our model comparisons indicated the “trees model” best fit both our winter (Table 2, AICc = 85.31) and summer (Table 2, AICc = 39.02) data. In this model, DBH was a significant predictor for both winter and summer roost trees (Table 3). Additionally, tree type was a significant predictor, but only for summer roost trees (Table 3). Summer roost trees were more likely to be deciduous rather than coniferous. The microclimate “extremes model” only slightly outperformed the “means model”, but their results were nearly identical (Table 2). Total accumulated precipitation was a significant predictor of both winter and summer roost trees (Table 4), which supported our prediction that turkeys would select roost trees that provide better shelter from precipitation. Maximum overnight wind speed was a significant predictor for summer roost trees but not winter roost trees, with wind speeds being slightly higher at summer roost trees compared to non-roost trees (Table 4). However, overnight wind speeds were generally low, and there was little variation in wind speeds within pairs of roost and non-roost trees. Additionally, the microclimate models were poorly supported overall (Table 2), suggesting that that microclimate factors are less influential than tree characteristics in predicting roost tree selection.

Table 2. Comparison of three models (two microclimate models, one tree model, and one null model) describing selection of roost trees used by eastern wild turkeys (*Meleagris gallopavo silvestris*) in southern Ontario, Canada, separated by season (winter n = 25 sites, summer n = 30 sites). The microclimate models consisted of nightly temperature and wind speed, and accumulated precipitation over 3–5 nights at each pair of roost and non-roost trees. The tree models consisted of tree type and tree diameter. Bold indicates the top model.

		K	AICc	Delta AICc	AICc Wt	Cumulative Weight	Log Likelihood
Winter	**Trees model**	**2**	**85.31**	**0.00**	**1**	**1**	**-40.62**
	Microclimate extremes model	3	154.20	68.89	0	1	-74.02
	Microclimate means model	3	154.30	68.99	0	1	-74.07
Summer	**Trees model**	**2**	**39.02**	**0.00**	**1**	**1**	**-17.48**
	Microclimate extremes model	3	149.91	110.59	0	1	-91.40
	Microclimate means model	3	149.99	112.35	0	1	-91.44

Table 3. The "trees model", which compares two characteristics of pairs of eastern wild turkey (*Meleagris gallopavo silvestris*) roost trees and non-roost trees (n = 25 pairs in winter, n = 30 pairs in summer), as determined from a conditional logistic regression model which compared pairs of roost and non-roost trees. Bold indicates significant characteristics.

		Roost		Non-roost					
		Mean	± SE	Mean	± SE	Z-value	p-value	Coeff.	± SE
Winter	**DBH (cm)**	**48.47**	**2.00**	**32.38**	**1.20**	**5.00**	**p < 0.001**	**0.19**	**0.04**
	Tree Type (coniferous 0 deciduous 1)	0.71	0.05	0.75	0.05	-0.64	0.525	-0.48	0.75
Summer	**DBH (cm)**	**60.29**	**3.97**	**32.64**	**1.54**	**4.78**	**p < 0.001**	**0.46**	**0.10**
	Tree Type (coniferous 0 deciduous 1)	**0.94**	**0.02**	**0.74**	**0.04**	**3.37**	**p < 0.001**	**5.19**	**1.54**

Table 4. The "extremes model", which compares microclimate characteristics of pairs of eastern wild turkey (*Meleagris gallopavo silvestris*) roost trees and non-roost trees (n = 25 pairs in winter, n = 30 pairs in summer), as determined from a conditional logistic regression model which compared pairs of roost and non-roost trees. Bold indicates significant characteristics. Note that only the results of the "extremes model" are shown here, but the "means model" had similar results.

		Roost		Non-roost					
		Mean	± SE	Mean	± SE	Z-value	p-value	Coeff.	± SE
Winter	Min. Overnight Temperature (°C)	-5.0	0.7	-5.2	0.7	0.07	0.95	0.02	0.25
	Max. Overnight Wind Speed (m/s)	1.5	0.2	1.4	0.2	0.57	0.57	0.12	0.20
	Total Accumulated Precipitation (mL)	**202.08**	**27.0**	**229.64**	**28.4**	**-2.42**	**0.016**	**-1.51**	**0.63**
Summer	Max. Overnight Temperature (°C)	19.1	0.3	18.9	0.3	0.10	0.92	0.03	0.26
	Max. Overnight Wind Speed (m/s)	**0.5**	**0.1**	**0.2**	**0.1**	**3.00**	**0.003**	**2.10**	**0.25**
	Total Accumulated Precipitation (mL)	**218.2**	**47.8**	**356.8**	**60.2**	**-2.92**	**0.004**	**-0.86**	**0.29**

In comparing microclimates at winter and summer roost trees with a non-forested tree, our linear models suggested that there are differences in wind speeds in winter, and differences in total accumulated precipitation in both seasons. Our linear models suggested that mean (Figure 4) and maximum overnight wind speeds were lower at roost trees compared to the non-forested site in winter. More specifically, the slopes of these models indicated that for every 1 m/s increase in mean and maximum wind speeds at the non-forested site, wind speeds at roost trees increased by 0.37 ± 0.08 m/s and 0.43 ± 0.08 m/s, respectively, at roost trees (Table 5). These models, however, had only a moderate fit to the data (mean overnight wind speed R^2 = 0.25; maximum overnight wind speed R^2 = 0.28; see Table 5). In summer, mean (Figure 4) and maximum overnight wind speeds were again lower at roost trees compared to the non-forested site, but wind speeds were consistently low during summer and our linear models therefore poorly fit the data (mean overnight wind speed $R^2 = 0.00$; maximum overnight wind speed $R^2 = 0.02$, see Table 5).

Our linear models comparing accumulated precipitation at roost trees and the non-forested site suggested that less precipitation accumulated at the roost trees compared to the non-forested site (Figure 5). Our linear model predicted that, in winter, every 1 mL increase in accumulated precipitation at the non-forested site corresponded with an increase of about half as much at roost trees (0.56 ± 0.07 mL, $R^2 = 0.45$, see Table 5). The difference was smaller for accumulated precipitation in summer, with a predicted increase of 0.81 ± 0.04 mL at roost trees for every 1 mL increase at the non-forested site ($R^2 = 0.86$; see Table 5). Unlike wind speeds and total accumulated precipitation, mean (Figure 6) and maximum or minimum overnight temperatures did not differ between roost trees and non-forested trees. Slopes for the relationship between air temperatures at roost trees and the non-forested site were approximately 1 for both the winter models and summer models (Table 4).

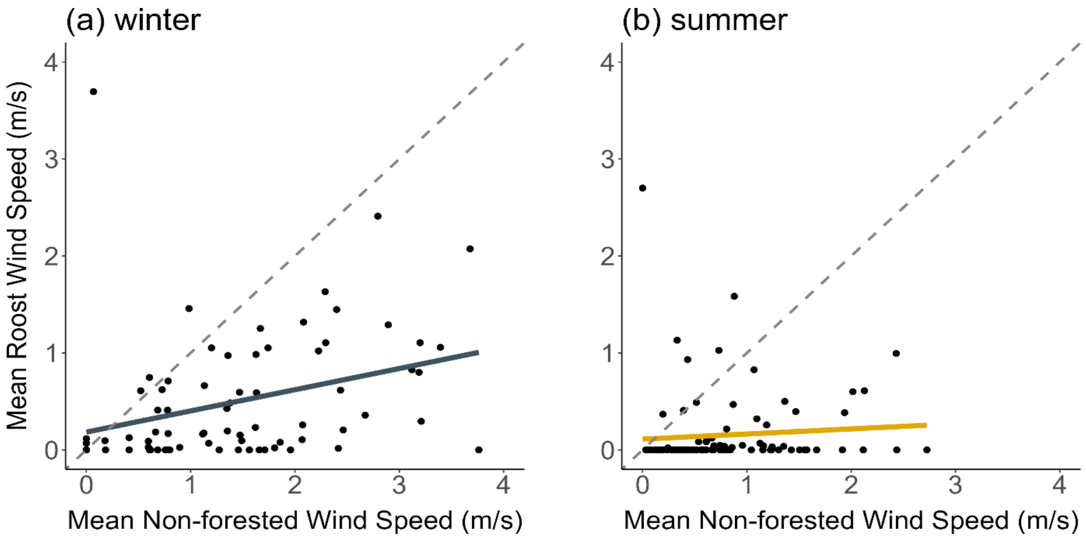


Figure 4. Regression plots of the relationship between mean overnight wind speed at a) winter (n = 25) and b) summer (n = 30) eastern wild turkey (*Meleagris gallopavo silvestris*) roost trees and a single non-forested tree located within the study area in southern Ontario, Canada**.** Variables were measured from December 1, 2022, to March 27, 2023, for winter sites; and from June 1 to September 25, 2023, for summer sites.

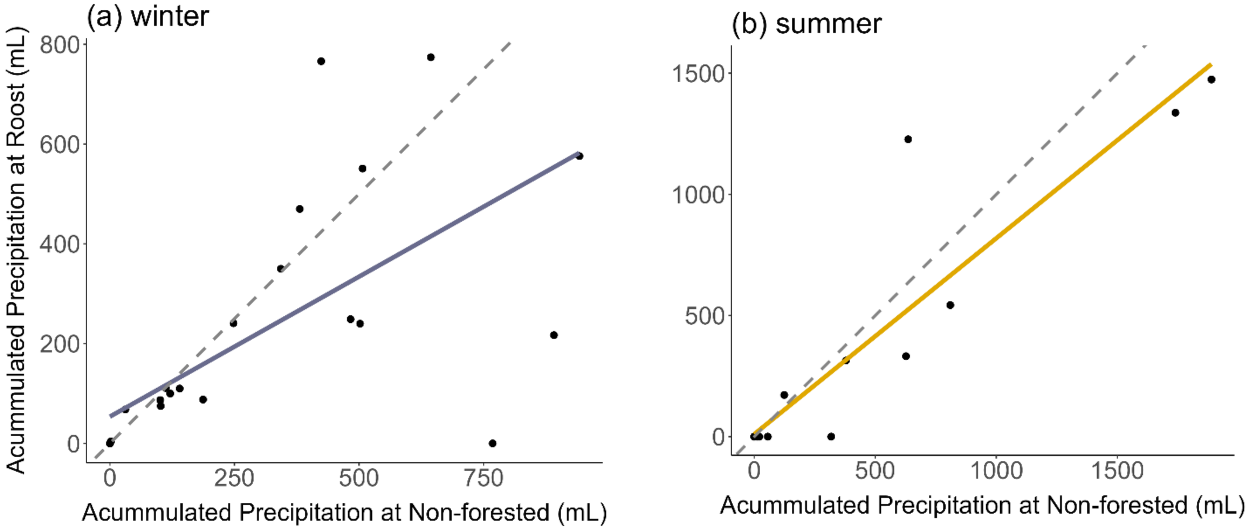


Figure 5. Regression plots of the relationship between mean accumulated precipitation at a) winter (n = 25) and b) summer (n = 30) eastern wild turkey (Meleagris gallopavo silvestris) roost trees and a single non-forested tree located within the study area in southern Ontario, Canada. Variables were measured from December 1, 2022, to March 27, 2023, for winter sites; and from June 1 to September 25, 2023, for summer sites.

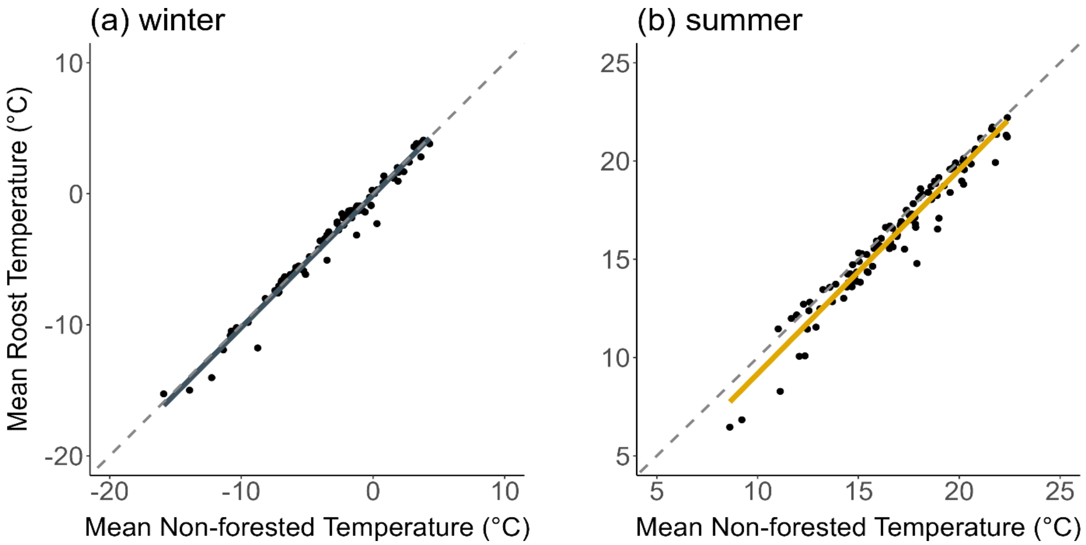


Figure 6. Regression plots of the relationship between mean overnight temperature at a) winter (n = 25) and b) summer (n = 30) eastern wild turkey (*Meleagris gallopavo silvestris*) roost trees and a single non-forested tree located within the study area in southern Ontario, Canada. Variables were measured from December 1, 2022, to March 27, 2023, for winter sites; and from June 1 to September 25, 2023, for summer sites.

Table 5. Results from bivariate linear regression models comparing microclimate at a single non-forested tree with a set of roost trees (n = 25 in winter, n = 30 in summer) used by eastern wild turkeys (*Meleagris gallopavo silvestris*) in southern Ontario, Canada. Microclimate data were collected from December 1, 2022, to March 27, 2023 for winter, and June 1, 2023, to September 25, 2023 for summer.

			Slope	SE	R^2	Permutation p-value*
Winter	Temperature	Mean overnight (°C)	1.01	0.10	0.98	0.16
		Minimum overnight (°C)	1.02	0.02	0.98	0.30
	Wind Speed	Mean overnight (m/s)	0.37	0.08	0.25	0.51
		Maximum overnight (m/s)	0.43	0.08	0.28	0.98
	Precipitation	Total accumulated (mL)	0.56	0.07	0.45	0.59
Summer	Temperature	Mean overnight (°C)	1.03	0.02	0.95	0.97
		Maximum overnight (°C)	1.00	0.03	0.94	0.18
	Wind Speed	Mean overnight (m/s)	0.05	0.06	0.00	0.22
		Maximum overnight (m/s)	0.12	0.10	0.02	0.72
	Precipitation	Total accumulated (mL)	0.81	0.04	0.86	0.84

* p-values calculated from permutation (999 permutations), indicating the proportion of permuted coefficients more extreme than the Slope estimated in the model.

2.4 DISCUSSION

Our study investigated roost tree selection for a large, non-migratory bird in temperate North America at both a fine tree-level scale and a coarse scale. Our hypothesis that turkeys select roost trees that offer thermoregulatory benefits compared to nearby trees was not supported by our results. We compared a set of microclimate variables (air temperature, wind speed, and accumulated precipitation) at pairs of wild turkey roost trees and nearby non-roost trees. During both summer and winter, microclimates were similar at roost and non-roost trees, and our microclimate models were poor predictors of roost tree selection. At the fine tree-level scale, tree size predicted roost trees used during both winter and summer, with a preference for large-diameter trees. Additionally, tree type predicted summer roost trees, with a preference for deciduous trees.

Our finding that tree size predicted roost tree selection in both summer and winter is consistent with many existing studies (e.g., Boeker and Scott 1969, Kilpatrick et al. 1988, Thompson et al. 2009, Adey et al. 2023). Turkeys may prefer larger trees because larger trees typically have sturdier branches and a more favourable branching pattern. Turkeys have been observed using large, open-branched trees elsewhere in their range, such as Ponderosa pine (*Pinus ponderosa*) in South Dakota (Rumble 1992) and Arizona (Boeker and Scott 1969). Within our study area, sugar maples (*Acer saccharum*) are abundant on the landscape and were frequently used as roost trees. As they age, sugar maples use new wood to thicken existing branches and the trunk, and the crown widens disproportionately as tree height increases (King 1986, Pederson

2010, MacFarlane and Kane 2017). The resulting trees may offer sturdy branches with space in between, allowing turkeys to access branches more easily for roosting. Our models suggested that turkeys showed little preference towards coniferous or deciduous trees during winter, but in summer they may show a preference towards deciduous trees. The absence of a clear preference for coniferous or deciduous trees in winter may result from turkeys preferring roost trees closest to food sources. For example, Adey et al. (2023) evaluated the locations of turkey roost trees in much of the same study area and found that winter roosts were closer to buildings compared to summer roosts and year-round roosts. During winter, we observed some turkeys frequenting coniferous roost trees near a livestock operation, where they fed on waste grain, and other turkeys frequenting deciduous roost trees near a house, where they fed on birdseed. Access to a reliable and convenient food source could help turkeys deal with increased energy demands in winter (Haroldson et al. 1998, Coup and Pekins 1999).

When we investigated microclimate at a fine scale, we found that total accumulated precipitation differed at roost and non-roost trees in both winter and summer, with slightly less precipitation at roost trees. Our microclimate models, though they did not fit the data as well as the tree characteristics models, suggested that turkeys select roost trees where less precipitation accumulates over time. It is possible that selecting roosts sheltered from precipitation helps turkeys reduce metabolic costs associated with warming their body after heat loss due to evaporation (McCafferty et al 2001, Wilson et al 2004). Though we predicted lower wind speeds at winter roost trees compared to non-roost trees, we found wind speeds did not differ significantly in winter.

Contrary to our prediction, we found that wind speeds differed during summer, with our models suggesting turkeys roosting in trees where overnight wind speeds were higher. However, in both seasons the overnight wind speeds were typically low, meaning there was little variation for turkeys to select for or against when choosing a roost tree. The apparent selection for higher wind speeds at summer roost trees may be related to other factors, rather than turkeys actively selecting trees based on wind speeds. For example, summer roost trees were often large, mature deciduous trees with longer branch segments and more open space among branches. This contrasts with some of the non-roost trees, which were younger, smaller, and had longer twigs. Wind speeds may be slightly higher in these open spaces among the branches, which could be why our models predicted higher wind speeds at roost trees. However, turkeys may be selecting these trees not because of the wind speed, but because the trees are easy to access (i.e., fly into and move from one branch to another).

In our study, the distance between roost and non-roost trees was 50 m, and it is possible that the microclimate variables we measured do not vary on this spatial scale. The concept of microclimate can be applied to a range of spatial and temporal scales (De Frenne et al. 2021). Wind speed, for example, can decline sharply within 30 m of moving past the forest edge and into the forest (Chen et al. 1995). Many of the roost and non-roost trees we measured were in forest interiors rather than edges, and wind speeds may therefore have been comparably low at roost and non-roost trees. Similarly, differences in air temperature can be scale dependent, with greater differences among habitats than within habitats (Ziter et al. 2019, De Frenne et al. 2021). Interestingly, however, Adey et al. (2023) found that, during summer, mean overnight air temperatures were slightly warmer at a single deciduous roost tree compared to a single coniferous roost tree within our study area. We extended this analysis by evaluating multiple roost and non-roost trees, and although we found that turkeys preferred roosting in deciduous trees during summer, temperature did not predict selection of roost trees. Though there may be small differences in temperature in summer, selection of deciduous trees in summer appears to be driven by factors other than microclimate.

When we compared microclimate at a coarser scale, we saw differences in wind speed during winter but not during summer. On any given night during winter in our study, wind speeds were, on average, lower at roost trees compared to a tree in a non-forested site. Although our linear models were only a moderate fit to the data, our results are consistent with other research showing that wind speeds tend to be lower within forests (De Frenne et al. 2021), particularly within tree canopies (Wuyts et al. 2008). Additionally, other studies demonstrate that birds roosting in forests experience lower wind speeds than they would in open habitats (Buttemer 1985, Pekins et al. 1991). Studies using operative temperature models have built upon this concept by demonstrating that convective heat loss is reduced for birds roosting in forests, allowing birds to stay warmer and reduce energy expenditure (Walsberg and King 1980, Kelty and Lustick 1977, Walsberg 1986, Thompson and Fritzell 1988). Combined with the results of these other studies, our findings suggest that turkeys select roost trees in forested areas to reduce their thermoregulatory costs, especially on cold, windy nights.

We saw small differences in accumulated precipitation at roost trees compared to the non-forested tree. Turkeys may experience reduced precipitation by roosting in forested areas, especially if they are in the lower canopy, where upper branches can intercept and redistribute some precipitation (Schmidt and Gluns 1991, Koivusalo and Kokkonen 2002, Levia et al. 2011). However, we use caution in making conclusions about precipitation based on our results because our linear model suggested that precipitation at forested sites is variable and may be influenced by multiple factors. Additionally, our method for measuring accumulated precipitation was less accurate than our method for measuring wind speed and air temperature. We measured the total amount of precipitation collected in pails placed on the ground below the roost trees. It would be more accurate to collect precipitation within the tree canopy, as turkeys roost on branches in the canopy rather than on the ground below the tree. As well, it would be more accurate to use a data logger rain gauge that would allow estimates of rainfall per night, rather than measuring accumulated precipitation over multiple nights.

Interestingly, we saw no differences in mean overnight ambient temperature when comparing roost trees with the tree at a non-forested site. This contrasts with evidence of forests maintaining warmer microclimates overnight compared to open areas due to canopy cover reducing radiative heat loss (De Frenne et al. 2019, 2021). The lack of temperature differences in our study could be explained by the characteristics of the forests where roost trees were located. The forests in our study area tend to be isolated due to surrounding agricultural or developed land, and temperature differences are reduced in fragmented forests (Latimer and Zuckerberg 2017). Additionally, most forests in our study area contain high proportions of deciduous trees, and in winter deciduous trees lose their leaves. The lack of canopy cover during winter reduces the heat-trapping ability of forests at night (De Frenne et al. 2019).

We acknowledge that our results may have been affected by our study design and equipment. For example, we collected microclimate data at a single non-forested tree for the entire duration of both the winter and summer sampling periods. An alternative design would be to assign a non-forested tree for every pair of roost and non-roost tree. Additionally, edge effects can influence microclimate variables within a forest (Wuyts et al. 2008, Latimer and Zuckerberg 2017), and it could be informative to also evaluate each roost and non-roost tree's distance to the forest edge.

Turkeys will use branches at various levels of a tree canopy, and our results more accurately reflect conditions experienced by turkeys using lower branches. This is because we were rarely able to throw our lines and set our weather stations in the upper branches. This is important to note because we found a moderate positive correlation between wind speed and height of the weather station in winter. We did not observe this correlation in summer, possibly because wind speeds were consistently low. This correlation between wind speed and height of the weather station is supported by research identifying differences in wind speed and turbulence depending on height below or within the canopy (Samson and Hunt 2012, Moon et al. 2019). It is therefore possible that the upper branches of trees have a different microclimate than the lower ones, at least in relation to wind speed. Future studies may attempt to measure microclimate at both upper and lower levels of tree canopies when comparing roost trees with non-roost trees.

Wild turkeys in our study area appear less likely to experience thermal stress in summer compared to winter. In summer, maximum overnight temperatures recorded in our study never exceeded 26.4 °C, which is well below the 35 °C above which wild turkeys show signs of heat stress (Buchholz 1996). In winter, however, roosting turkeys are frequently exposed to temperatures less than 11 °C, below which turkeys are reported to experience an increase in metabolic costs related to thermoregulation (Gray and Prince 1988, Haroldson et al. 1998). Mean overnight temperature recorded during winter in our study was around -3.4 °C, and minimum overnight temperature was, on average, around -4.9 °C. Additionally, there were several nights when both the mean and minimum overnight temperatures were around -10 °C or colder. The presence of wind on some of these nights would further compound the coldness perceived by roosting turkeys due to convective cooling (Walsberg 1983). To cope with this increase in metabolic needs during cold conditions, turkeys can increase their consumption of food (Haroldson et al. 1998). Turkeys often find food in proximity to human development (e.g., bird feeders at houses, or waste grain and cattle manure at farms), and reliance on these food sources can greatly increase their ability to survive in winter in northern parts of their range (Vander Haegen et al. 1989, Kane et al. 2007). In our study area, turkeys often select winter roost trees that are close to buildings (Adey et al. 2023), and sometimes feed on waste grain at livestock operations or birdseed at bird feeders. Turkeys may be more flexible with their choice of roost tree (e.g., willing to use coniferous and deciduous trees) if the roost tree is located near food.

Wild turkeys are managed as a game bird in Ontario, Canada. They were extirpated from the province in the early 20th century, and their reintroduction to the province in the 1990s –2000s is considered a success (OMNR 2007). However, monitoring this species remains important to ensure populations are stable (Baici and Bowman 2023). Turkeys have adjusted well to the vast amounts of land that has been cleared for agriculture in Ontario, Canada (OMNR 2007), but our findings show that forested habitat is still important for providing roost trees. Mature forests in particular are likely to contain large, old trees that turkeys prefer for roosting. As well, forests may offer a slightly more favourable microclimate compared to open habitat during cold, windy winter nights. Even small agricultural or urban woodlots can be a source of roost trees, and therefore are worth conserving.

Our study represents one of the few studies to date that compares a set of microclimate variables at individual roost and non-roost trees within a forested habitat for a large, non-migratory bird in temperate North America (but see Pekins et al. 1991, and Whitaker and Stauffer 2003). Our work adds to the comprehensive existing literature comparing microclimate variables between open and forested habitats (e.g., Walsberg 1986, Thompson and Fritzell 1988, Gonnerman et al. 2022). We demonstrate that within forested habitats microclimate may not differ significantly among individual trees. Turkeys in our study area may therefore select roost trees based on size and proximity to food sources. As such, the availability of large, old, accessible roost trees within patches of forests should be considered when managing populations of wild turkeys.

Chapter Three

Survival of wild turkeys and the effect of roosting near buildings

ABSTRACT

Animals living in developed landscapes can improve their probability of survival by exploiting supplemental food sources and reducing predation risk. One such animal that thrives in contemporary landscapes within its range is the eastern wild turkey (*Meleagris gallopavo silvestris*), which often lives in agricultural and semi-urban areas. As a game species, understanding the survival of wild turkeys is important, especially now that turkey populations are declining in some regions. We evaluated survival, causes of mortality, and the effect of roosting near buildings (an index of proximity to supplemental food sources) for 23 male and 28 female turkeys tracked using GPS transmitters from February 2017 to February 2020 in Ontario, Canada. Annual survival estimates differed for our three study years, with lowest survival in 2017–2018 at 0.55 (95% CI: 0.37–0.83) and highest survival in 2018–2019 at 0.92 (95% CI: 0.82–1.0). Over three years, nine turkeys of both sexes died of natural causes and five male turkeys were harvested. Most turkeys had within their home range a roost tree that was less than 150 m away from the nearest building, but this proximity had no effect on survival. Sex and body mass also had no effect on survival probability. Our annual survival estimates were higher than those reported from other northern regions, potentially due to access to supplemental food and lower snow accumulation in our study area.

3.1 INTRODUCTION

When managing wildlife populations, it is important to understand survival rates, causes of mortality, and factors affecting risk of mortality (Williams et al. 2002, Murray 2006, Conde et al. 2019). Understanding survival is particularly important for species that are influenced by human activities, such as those that live in heavily altered landscapes (McLellan et al. 1999, Evans et al. 2015, Hill et al. 2020) and those that are subject to harvesting (Rolland et al. 2010, Servanty et al. 2011, Slabach et al. 2018, Wightman et al. 2024). Similarly, assessing survival is important for monitoring the success of populations that have been reintroduced to a region (Bertolero et al. 2007, Armstrong and Seddon 2008, Schaub et al. 2009, McCarthy et al. 2012). Wildlife managers may also be interested in estimating survival for populations near the periphery of the species' range (Pitt et al. 2008, Niedzielski and Bowman 2015, Lewis et al. 2023), as population demographics can be more variable in these areas (Sexton et al. 2009). Consequently, analyzing survival of animals remains a fundamental method in wildlife conservation and management.

One species that is managed across its wide geographic range is the wild turkey (*Meleagris gallopavo*). The wild turkey is a large non-migratory game bird native to North America and well-known for its cultural and economic significance. Wild turkey populations began to decline during European colonization of North America because of habitat changes and overharvest, and by the early 1900s, wild turkeys had been extirpated from regions where they were once abundant (Dickson 1992, McRoberts et al. 2020). Trap-and-transfer programs beginning in the 1970s and often ending in the early 2000s were integral to restoring wild turkey populations (Holbrook 1957, Cardoza

1993, OMNR 2007, Chamberlain et al. 2022). Once considered a bird of open woodlands (Glover 1948, Healy 1990), turkeys have adjusted to the contemporary landscapes within their range, many of which include a patchwork of forests, agricultural lands, and even urban areas (Rioux et al. 2009, Pollentier et al. 2014b, Baici and Bowman 2023). As a result, turkey populations increased after reintroduction efforts, although contemporary populations in many locations appear to have declined since then (Tapley et al. 2011, Chamberlain et al. 2022). The reasons for these declines are not fully understood, though there is evidence to suggest that survival and reproductive success of adult female turkeys strongly affect population dynamics (Roberts et al. 1995, Pollentier et al. 2014a, Tyl et al. 2023) and therefore may be linked to range-wide population declines (Londe et al. 2023). Although the factors linked to survival and reproductive success are not fully understood, increasing predator abundance and loss of suitable habitat are likely contributors (Casalena et al. 2015, Tyl et al. 2023). In some regions, declines may be an effect of populations stabilizing due to density-dependent factors (Hartman 1994, Newton 1998, Nummi and Saari 2003, Boyce 2018) or even differences in the methods used to estimate population sizes (Healy and Powell 1999, Anderson 2001, Baici and Bowman 2023). Even if populations have stabilized over the long term, it is still typical for turkey populations sizes to fluctuate from one year to the next (Roberts et al. 1995), often as a result of hen and poult survival (Miller et al. 1998, Roberts and Porter 1998, Kane et al. 2007, Niedzielski and Bowman 2015) or changes in harvest pressure (Humberg et al. 2009, Norman et al. 2022, Wightman et al. 2024). It therefore remains important to monitor population sizes for wild turkeys, especially in the context of setting harvest quotas (Little et al. 2016, Chamberlain et al. 2022, Wightman et al. 2024).

Given the wide geographic range of turkeys and their importance as a game bird, there is substantial literature that estimates and evaluates wild turkey survival. This is particularly relevant for the eastern wild turkey (*M. g. silvestris*), which is the most wide-ranging subspecies of wild turkey. Annual survival rates estimated in the last 50 years for eastern wild turkeys range from 0.22 to 0.78, with a mean of 0.50 (Table 6, Figure 7). Turkey survival rates are influenced by both anthropogenic factors such as harvest (Humberg et al. 2009, Norman et al. 2022, Wightman et al. 2024) and agriculture (Porter et al. 1980, Vander Haegen et al. 1989, Roberts et al. 1995, Kane et al. 2007); and natural factors such as predation (e.g., Pollentier et al. 2014b, Little et al. 2016) and climate (Wright et al. 1996, Kane et al. 2007). There can also be inter-annual variation in survival, especially when comparing male and female turkeys. Although male and female turkeys of all ages are at risk of predation, mammalian predators such as coyotes (*Canis latrans*) represent a major natural cause of mortality for nesting hens during spring and summer (Wright et al. 1996, Miller et al. 1998, Pollentier et al. 2014b). Hens nest on the ground and are especially vulnerable to predators during rainy nesting seasons when predators may more easily use olfactory cues to find nesting hens (Roberts and Porter 1998). Male turkeys often have lower survival during spring and fall, as these seasons coincide with legal hunting periods (Norman et al. 2022, Wightman et al. 2024). Hens may also experience lower survival during fall in jurisdictions where hens are included in the legal fall hunt (Porter et al. 1983, Wright et al. 1996). Additionally, turkey populations near the northern edge of their range experience additional pressure from climate, resulting in lower estimated annual and winter survival rates (Table 6, Figure 7). At these higher latitudes, cold, snowy winters can reduce turkeys' access to food, increase energetic demands, and make turkeys more vulnerable to predators (Nguyen et al. 2003, Kane et al. 2007, Niedzielski and Bowman 2015).

Survival of individual wild turkeys can be influenced by resource use. For example, turkeys that have access to supplemental food from bird feeders or agricultural sources (e.g., waste grain and cattle manure) in winter have higher survival than those that do not (Vander Haegen et al. 1989, Kane et al. 2007). Additionally, turkeys tend to have smaller home range sizes when they have access to supplemental food sources, especially during times of year when natural food sources are limited on the landscape (Niedzielski and Bowman 2016, Baici and Bowman 2023). Another way survival can be affected by resource use is through the selection of roost sites. For instance, hens and their broods are better able to survive once poults are old enough to switch from ground roosting to tree roosting, as tree roosting limits access by predators (Chamberlain et al. 2020). Predator avoidance is understood to be a major reason why turkeys roost in trees at night rather than on the ground (e.g., Gonnerman et al. 2022, Adey et al. 2023). Indeed, some of the most common predators of turkeys, such as coyotes and red foxes (*Vulpes vulpes*) (Hubbard et al. 1999, Niedzielski and Bowman 2015, Little et al. 2016), would have great difficulty climbing a roost tree. Turkeys may therefore be able to improve their probability of survival by selecting roost trees that are near supplemental food sources and are in areas with low predator density.

Table 6. Estimates of annual survival probability for eastern wild turkeys (*Meleagris gallopavo silvestris*) reported from within their range and near the northern edge of their range in the United States and Canada. Studies are listed in order from northernmost to southernmost.

Study	Location	Year(s)	Sample	Estimate	95% CI
Nguyen et al. 2003	Ontario	1999–2000	17 females	0.529	0.356–0.702
		2000–01	1 female	0.067	0.000–0.195
Kane et al. 2007	Minnesota	2002	11 females with supplemental food	0.273	0.144–0.402
			6 females without supplemental food	0.219	0.082–0.356
Niedzielski and Bowman 2015	Ontario	2012–13	45 females	0.37	0.25–0.55
Current study	Ontario	2017–18	15 females, 18 males	0.55	0.37–0.83
		2018–19	18 females, 15 males	0.92	0.82–1.0
		2019–20	12 females, 4 males	0.63	0.37–1.0
Pollentier et al. 2014b	Wisconsin	2010–11	62 females in forested site	0.450	0.30–0.597
			52 females in open site	0.707	0.603–0.811
		2011–12	42 females in forested site	0.279	0.095–0.463
			42 females in open site	0.651	0.563–0.739
Wright et al. 1996	Wisconsin	1988–89	64 females	0.470	0.386–0.554
		1989–90	52 females	0.448	0.358–0.538
		1990–91	75 females	0.431	0.357–0.505
		1991–92	38 females	0.628	0.506–0.750
		1992–93	21 females	0.660	0.495–0.825
Roberts et al. 1995	New York	1990–91	48 females	0.505	0.340–0.670
		1991–92	52 females	0.556	0.423–0.689

		1992–93	72 females	0.428	0.312–0.544
		1993–94	57 females	0.477	0.297–0.657
Hubbard et al. 1999	Iowa	1993–94	45 females	0.759	0.643–0.875
		1994–95	53 females	0.674	0.554–0.794
		1995–96	73 females	0.594	0.484–0.704
Humberg et al. 2009	Indiana	2003–04	11 females	0.800	0.535–1.000
			14 males	0.214	0.047–0.381
		2004–05	17 females	0.755	0.534–0.976
			15 males	0.300	0.100–0.500
Kurzejeski et al. 1987	Missouri	1984–85	60 females	0.435	0.291–0.57
Norman et al. 2022*	Virginia	2004–07	308 males	0.70	0.65–0.75
	West Virginia	2004–07	274 males	0.66	0.60–0.72
Wightman et al. 2024*	Georgia, Louisiana, North Carolina, South Carolina	2014–22	387 adult males	0.54	0.49–0.59
			162 juvenile males	0.86	0.81–0.92
Miller et al. 1998	Mississippi	1984–85	19 females	0.770	0.720–0.820
		1985–86	27 females	0.755	0.719–0.791
		1986–87	28 females	0.382	0.343–0.421
		1987–88	22 females	0.224	0.183–0.265
		1988–89	43 females	0.551	0.524–0.578
		1989–90	40 females	0.343	0.318–0.368
		1990–91	22 females	0.634	0.577–0.691
		1991–92	15 females	0.772	0.700–0.844
		1992–93	19 females	0.307	0.249–0.365
		1993–94	13 females	0.378	0.296–0.460
		1994–95	13 females	0.474	0.395–0.553
Little et al. 2016*	Georgia	2010–13	126 females	0.55	0.44–0.67

* Annual estimates not reported for individual study years

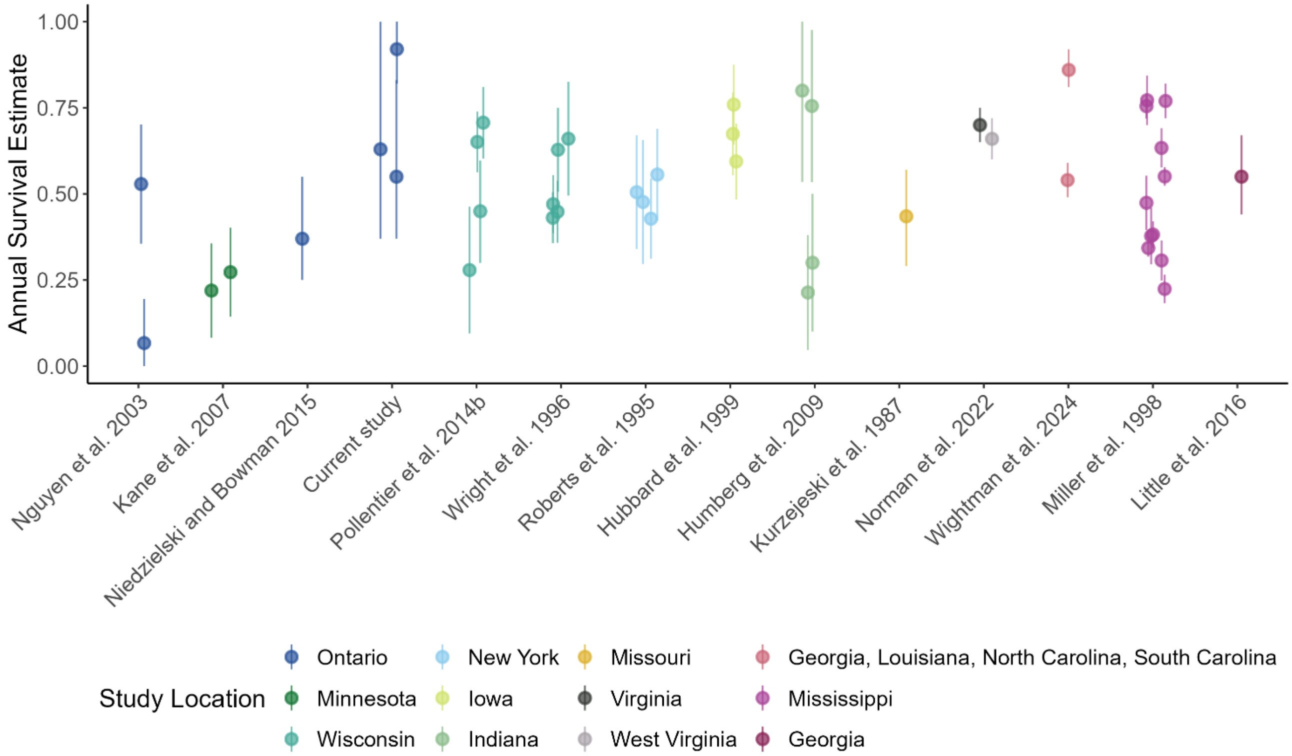


Figure 7. Estimates (with 95% confidence interval) of annual survival probability for eastern wild turkeys (*Meleagris gallopavo silvestris*) reported from within their range and near the northern edge of their range in the United States and Canada. Studies are arranged from left to right in order from northernmost to southernmost.

While there is extensive literature on wild turkey survival and selection of roost trees, studies that combine both topics are needed to better inform management both for turkeys and their habitat. For example, Adey et al. (2023) found that roost trees used by turkeys in winter were located closer to buildings compared to roost trees used at other times of the year and suggested that supplemental food sources are often associated with buildings. However, it is not known whether roosting near buildings influenced survival. Aside from providing access to supplemental food, roosting near buildings may also reduce risk of predation. Human activity centred around buildings can make buildings a hotspot for disturbance stimuli like the sound or sight of vehicles, farm machinery, and humans themselves (Frid and Dill 2002). There is mounting evidence that both mesopredators (Haswell et al. 2017, Nickel et al. 2020) and large carnivores (Muhly et al. 2011, Valeix et al. 2012, Smith et al. 2017) avoid such hotspots of human-caused disturbances. Major mammalian predators of adult wild turkeys may therefore be less likely to hunt turkeys that are roosting in trees close to buildings.

The aim of our study was to identify factors affecting survival for male and female wild turkeys near the northern edge of their range in a region of Ontario, Canada where survival has not yet been evaluated. Specifically, our first objective was to estimate annual survival rates for turkeys. We hypothesized that survival is affected by the challenges associated with cold, snowy winters in the north. We therefore predicted that annual survival rates would be similar to those in other northern areas of the turkeys' range but lower than those in the southern core. Our second objective was to compare sources of mortality for turkeys, focusing on human-caused mortality and natural causes of mortality. We hypothesized that turkeys would be at risk from both natural predators and humans due to our study site's location in a predominantly agricultural landscape that includes woodlots, homes, and farms, with an urban area nearby. We predicted that both human-caused and natural sources of mortality would therefore contribute similarly to mortality for this population of turkeys. Finally, our third objective was to investigate factors influencing annual survival. We hypothesized that proximity to humans, as indexed by the distance between roost tree and nearest building, influences survival because buildings can be a source for supplemental food and can deter predators. Our prediction followed that turkeys with shorter distances between any one roost tree and the nearest building would have higher estimates of annual survival than those that roosted farther away. As well, we hypothesized that there are minimal differences in survival due to sex and mass. We expected males and females to have similar annual survival estimates because, although females have higher risk of mortality during nesting season, males face higher risk of mortality from harvest during the spring and fall (though females can be harvested during fall in some jurisdictions). Although body mass can contribute to survival when food availability is low, we expect that turkeys roost near supplemental food sources, which allows them to access food and avoid starvation. We answered our research questions by combining turkey home range data from Baici and Bowman (2023), roost tree locations from Adey et al. (2023), and survival data from male and female turkeys that were tracked with GPS transmitters over a span of three years.

3.2 METHODS

Study Area

We studied eastern wild turkeys in Peterborough County in Ontario, Canada (approximately 44.4° N, 78.3° W), which is in the northern part of their current range, the edge of which tracks roughly the 49th parallel. While turkey populations are now well-established in Peterborough County and northward (Baici and Bowman 2023), the county was historically either at or just beyond the species' northernmost range limit in Ontario (OMNR 2007, Thornton 2016). Wild Turkeys were extirpated from Ontario in the early 1900s due to overharvest and habitat loss during European settlement and reintroduced across their historic range from 1984 to 2005 (OMNR 2007). Across their current range, eastern wild turkeys use landscapes comprising of a patchwork of forests (deciduous or mixed) and open areas such as fields and pastures (Dickson 1992, Pollentier et al. 2014b, Niedzielski and Bowman 2016). Turkeys have also adjusted well to human-altered landscapes such as agricultural and urban areas (OMNR 2007, , Niedzielski and Bowman 2016, Pollentier et al. 2021). Within our study area, the landscape is mainly comprised of agricultural fields (primarily corn, soybean, winter wheat, and hay) and pasture bounded by hedgerows and interspersed with patches of mixed forest and wetlands.

Turkey Trapping and Tracking

We estimated home ranges and identified roost locations by tracking the movement of individual turkeys in our study area. We trapped turkeys between January and March, 2017–2019. Trapping during winter allowed us to target more turkeys per trapping session, as turkeys tend to form larger flocks in winter (Healy and Powell 1999) and may be more likely to visit bait piles when snow cover reduces access to natural food sources (Roberts et al. 1995, Kane et al. 2007). We trapped turkeys during a total of 14 trapping sessions across 2017–2019. We trapped turkeys at five locations in Peterborough County that were first identified from driving surveys (Baici and Bowman 2023) and where landowners granted permission. We used piles of dried whole and cracked corn to attract turkeys to trap locations, where we then captured the turkeys with rocket nets (Grubb 1988).

After capture, we placed turkeys in large cardboard boxes (National Wild Turkey Federation, Edgefield, South Carolina) and completed processing on-site. Processing included weighing, sexing, taking morphological measurements, and fitting individuals with an aluminum leg band and GPS transmitter tag (model PinPoint VHF-3600L, Lotek Wireless Inc., Newmarket, Ontario). We used backpack-style harnesses (Norman et al. 1997) to attach tags, which is a method commonly used with turkeys (Chamberlain et al. 2000, Niedzielski and Bowman 2016, Yeldell et al. 2017) and only fitted the tags to turkeys if the tag mass (approximately 85 g) was less than 3% of the turkey's mass. The tags recorded GPS locations according to schedules which varied depending on the capture year and location. The schedules ranged from one location per hour to once every 4 hours and 15 minutes, allowing the tags to capture both daytime and nighttime locations. Additionally, the tags included a mortality mode sensor which activated when the turkey had not moved for 8 hours, allowing us to collect tags and investigate causes of mortality. Turkeys were tracked from 17 February 2017 to 17 February 2020. Capture and handling methods comply with the Trent University Animal Care Committee protocols #24653, and #27862.

Spatial Analysis

To understand how proximity of roost trees to buildings may influence annual turkey survival, we determined the distance from roost trees to the nearest building within each turkey's home range. We performed this analysis for a total of 38 individuals (19 females and 19 males) using GPS location data collected from the tags from 2017–2020. We first obtained roost location data from Adey et al. (2023). Adey et al. (2023) identified winter and summer roost locations from GPS-tagged turkeys in the same study area as the current study and between the years of 2017–2019. The total sample of 45 turkeys studied by Adey et al. (2023) included the 38 individuals whose home range polygons we used in our current spatial analysis. Roost locations were identified by filtering the location data to one location per turkey per night, with the nighttime period defined as 24:00–04:00 (Adey et al. 2023). Adey et al. (2023) used location data collected over the whole year, classifying winter roosts as those used from November 1 to April 30, and summer roosts as those used from May 1 to October 31. Location data from female turkeys that were nesting during summer were excluded from the roost identification process, as nesting turkeys are not expected to roost in trees. Adey et al. (2023) also confirmed roost sites by ground-truthing the locations and checking for evidence of use (e.g., the presence of feathers or fecal droppings below the roost tree). Adey et al. (2023) identified a total of 119 and 100 individual summer and winter roost trees, respectively, used by 45 tagged turkeys across 2017–2019. Across 2017–2019, the median number of times a roost tree was used (either on the same night by multiple individuals or on multiple nights by the same individual) was two for winter roost trees and three for summer roost trees.

We then obtained 95% kernel home range polygons that were calculated by Baici and Bowman (2023) for each of our 38 turkeys. Briefly, these home range polygons were estimated for winter (November 1 to March 15) and summer (May 1 to July 31) and were calculated using the ‘adehabitatHR’ package (Calenge and Fortmann-Roe 2023) in R (R Core Team 2022). Baici and Bowman (2023) used an ad-hoc approach for selecting bandwidth values, starting with 100% of the reference bandwidth (246.95) and reducing in 10% decrements until reaching the lowest bandwidth that resulted in the same number of polygons as the reference bandwidth. Only individuals that were tracked for 13 or more days were included in the current analysis to account for the influence of capture on movement and survival (Pollentier et al. 2014b, Niedzielski and Bowman 2016, Gonnerman et al. 2022). Some individuals were tracked long enough to have multiple home range polygons (e.g., winter home range polygons from two years and a summer home range polygon from one year), whereas others were tracked for a shorter period of time and only had a single home range polygon from one season. We calculated winter home range polygons for 25 individual turkeys, 13 of which had home range polygons from two winters and 12 of which had a home range polygon from one winter only. Across 2017–2019, the mean winter home range size varied from 0.06 to 6.12 km^2, with a mean of 1.29 ± 0.23 km^2. We calculated summer home range polygons for 38 individual turkeys, 33 of which had home range polygons from two summers and five of which had a home range polygon from one summer only. The mean summer home range size varied from 0.11 to 8.63 km^2, with a mean of 2.18 ± 0.31 km$^{2.}$

Although both Adey et al. (2023) and Baici and Bowman (2023) used 45 individual turkeys in their studies, we could only use 38 of these individuals in our spatial analysis of how proximity of roost trees to buildings may influence annual turkey survival. We did this because these individuals had home range polygons that overlapped with known roost tree locations. However, we were able to use all 51 GPS-tagged turkeys for analyses not involving proximity of roost trees to buildings. With these 38 individuals, we used the ‘sf’ package (Pebesma et al. 2024) in R (R Core Team 2022) to calculate the shortest distance between any roost tree and any building within each turkey’s home range polygon. Home range polygons contained multiple roost trees and buildings. However, only the distance representing the closest roost tree and building for each home range polygon was retained for analysis. We obtained location data for buildings from the “building as symbol” shapefile (Provincial Mapping Unit 2020), which displays structures that are larger than 50 m^2 but have no side greater than 30 m or 50 m in length, depending on the scale of the data. Due to these criteria, some of the larger barns were not represented in this map layer; however, a smaller building located near the barn, such as a farmhouse, was still represented.

Some turkeys were tracked long enough to have more than one home range polygon (e.g., both a winter and summer home range, and sometimes for multiple years). We used the smallest distance between roost tree and building taken from any season and any year, rather than calculating a mean value across seasons or years. We felt this approach was acceptable because it more closely aligned with the process of how we selected the shortest distance from any roost tree to any building for turkeys who only had a single home range polygon.

Survival Estimation

To estimate annual survival probability and assess the effect of covariates, we used time-to-event models using the package ‘survival’ (Therneau et al. 2024) in R (R Core Team 2022). First, we calculated annual survival probability using the Kaplan-Meier method (Kaplan and Meier 1958) with staggered entry design (Pollock et al. 1989). We defined our study period as 17 February 2017 to 17 February 2020, as these represent the first and last dates that turkeys were tracked. We divided our entire study period into three year-long periods; with year one as 17 February 2017 to 16 February 2018, year two as 17 February 2018 to 16 February 2019, and year three as 17

February 2019 to 16 February 2020. We used weeks as our units of time in the analysis, as turkeys were typically tracked on a weekly basis. Turkeys entered the study on the date that they were tagged, as this is when we began tracking them. They exited the study either on the date that they died or, for turkeys whose signals we lost, the last date we detected a signal from the turkey's tag. For individuals that were known to be alive at the end of the year-long period, we used the last day of the year-long period as the event date and censored the turkeys. We then re-entered those individuals into the next study year (Table 7).

Table 7. Number of eastern wild turkeys (*Meleagris gallopavo silvestris*) added or re-entered into the study in the Peterborough region of Ontario, Canada, for each study year from 2017–2020. Each study year began on 17 February and ends on 16 February of the following year. Turkeys were added to the study in the year that they received a GPS transmitter, and turkeys that survived to the end of one study year were re-entered into the subsequent study year.

	Year 1 2017–2018	**Year 2 2018–2019**	**Year 3 2019–2020**
Number added	33	15	3
Number re-entered	N/A	18	13
Total at risk	33	33	16
Number of known deaths	9	2	3
Number of unknown fates	6	18	11
Number known to be alive at end	18	13	2

We investigated whether there were differences in survival probability based on sex (male or female), body mass, and proximity of roost tree to nearest building using two Cox proportional hazards (CPH) models (Cox 1972). Due to small sample sizes within each year, we pooled data from the three study years when evaluating whether risk of mortality was associated with our three covariates. The first model tested the effect of proximity of roost tree to nearest building on survival and used the 38 turkeys for which we had roost tree data. The second model tested the effects of sex and body mass on survival and used the full group of 51 turkeys. CPH models assume that the hazard function remains constant over time, meaning that the effect of sex and proximity of roost tree to nearest building on probability of survival are constant over time. We tested this assumption of proportionality using the cox.zph function (Therneau et al. 2024). We estimated cause-specific mortality rates for two categories: harvest and natural. Harvest represented the only human-caused mortality events occurred during the study. Natural causes of mortality included predation, illness, starvation, and a single unknown cause. We compared the risk of harvest and natural mortality over time using a nonparametric cumulative incidence function estimator with a competing risks approach (Heisey and Patterson 2006) using the package ‘tidycmprsk’ (Sjoberg and Fei 2023) in R (R Core Team 2022).

3.3 RESULTS

We tracked 51 turkeys (28 females and 23 males) from February 2017 to February 2020. Most (31 individuals, or 60.8%) of the turkeys were adults when we began tracking them, with the remaining 21 individuals being juveniles. By the end of the three-year study period, 14 turkeys had died, 35 turkeys were of unknown status due to lost signals, and two turkeys were known to still be alive. Twelve of the juvenile turkeys were adults by the time they died or when we censored them due to a lost signal. Most turkeys were adults at the time they died, with only two individuals still being juveniles at the time they died. Over the three study years, turkeys died from both natural causes and harvest (Table 7). Although we predicted that these causes of mortality would occur in similar frequencies, we found that natural causes were more frequent. Nine turkeys of both sexes died of natural causes, with six (42.9%) of these deaths due to predation, and one death each (7.1% each) due to illness, starvation, and an unknown natural cause. The remaining five (35.7%) turkeys that died during our study were males that were harvested during legal hunting seasons.

Table 8. Causes of mortality for eastern wild turkeys (*Meleagris gallopavo silvestris*) tracked with GPS transmitters in the Peterborough region of Ontario, Canada, for each study year from 2017–20. Deaths were confirmed for 14 of 51 turkeys.

		Natural causes				**Harvest**
		Predation	Starvation	Illness	Unknown	
2017–18	Males	2	1	1	0	1
	Females	4	0	0	0	0
2018–19	Males	0	0	0	0	1
	Females	0	0	0	1	0
2019–20	Males	0	0	0	0	3
	Females	0	0	0	0	0
TOTAL	Males	2	1	1	0	5
	Females	4	0	0	1	0
	Both	6	1	1	1	5

Despite annual variation, our estimated annual survival rates were generally higher than rates estimated from elsewhere within the northern part of the wild turkey's range. Nine individuals died in the first year of the study, two in the second year, and three in the third year. Estimated annual survival was higher in 2018–2019 compared to both 2017–2018 and 2019–2020 ($\chi^2(df = 2) = 7.6$, $p = 0.02$; Figure 8). Estimated annual survival rates (95% confidence interval) in 2017–2018, 2018–2019, and 2019–2020, respectively, were 0.55 (0.37–0.83), 0.92 (0.82–1.0), and 0.63 (0.37–1.0). Deaths tended to occur within 16 weeks of tagging (Figure 8), which coincides with the approximate period of late February to late June. When we compared the risk of harvest and natural mortality over time using a cumulative incidence function estimator, we found that the rate of mortality at one year for natural causes (0.21, 95% CI: 0.11–0.38) was higher than harvest mortality (0.02, 95% CI: 0.00–0.11). At two years, however, the rate for harvest mortality increased to 0.24 (95% CI: 0.06–0.47) and was closer to the rate for natural causes, which did not change from its one-year rate.

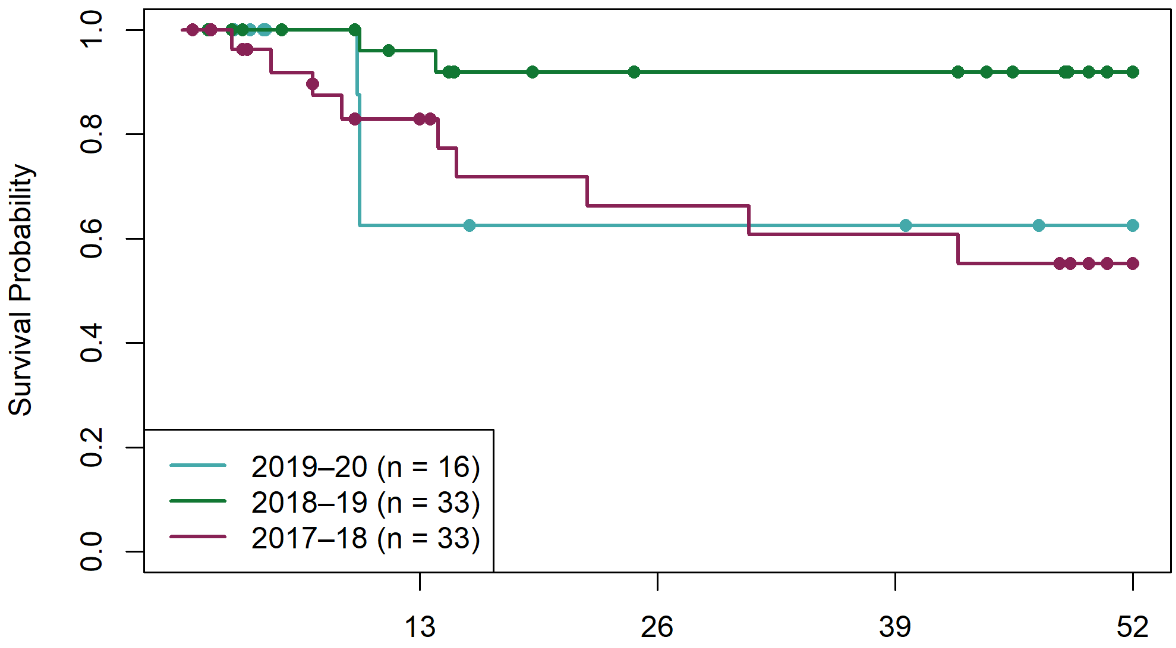


Figure 8. Kaplan-Meier annual survival estimates for eastern wild turkeys (*Meleagris gallopavo silvestris,* n = 51 individuals) radio-tracked in the Peterborough region of Ontario, Canada, from 2017–2020**.** Each study year begins on 17 February and ends on 16 February of the following year**.** Dots along the lines represent times when turkeys left the study either because they died or were censored due to a lost signal. Annual survival probability in 2018–2019 was significantly higher than in 2017–2018 and 2019–2020.

We assessed whether a set of covariates influenced risk of mortality. First, we tested whether proximity to humans had an effect and used distance between roost tree and nearest building as an index. We tested this for the subset of 38 turkeys (19 females and 19 males) whose 95% kernel home range polygons contained roost trees mapped by Adey et al. (2023). Contrary to our prediction, there was no clear effect on risk of mortality, even though roost trees were located fairly close to buildings. The median shortest distance between any roost tree and any building was 74 m and 33 (86.8%) of the 38 turkeys had a roost tree less than 150 m from the nearest building. The results of our Cox proportional hazards model indicated that risk of death does not increase significantly with each one-meter increase in distance from roost tree to nearest building (hazard ratio = 1.00, 95% CI 0.99–1.01, p = 0.70).We tested the assumption of proportional hazards and found it was not violated (p = 0.98), suggesting that the risk of mortality, as it relates to distance from roost tree to nearest building, did not change significantly over the duration of our study.

We then tested the effects of sex and mass on survival probability for the full sample of 51 turkeys (23 males, 28 females), and were unable to detect any clear effect. When we compared mortality risk for male and female turkeys, we found that the risk was 46% higher for males compared to females (hazard ratio = 1.46, 95% CI 0.26–8.07), but once again there was a high degree of uncertainty and no statistical significance (p = 0.67). Our model also predicted a 7% decrease in mortality with each 1 kg increase in turkey mass (hazard ratio = 0.93, CI 0.57–1.51), but again this was not statistically significant (p = 0.77). Again, when we tested the assumption of proportional hazards, we found it was not violated for either sex (p = 0.30) or mass (p = 0.42), suggesting that the effects of these characteristics on risk of mortality remained constant over our study duration.

3.4 DISCUSSION

Our study evaluated annual survival for a large, non-migratory game bird, the wild turkey, near the northern edge of its range. Our hypothesis that annual survival rates for our study population would be similar to those of other northern populations but lower than those of populations within the core range was not supported. The annual survival estimates for each of our three study years ranged from 0.55 to 0.92 and were higher than those reported elsewhere in the northern extent of the turkey's range and were more similar to survival rates reported from the core of the range in the eastern United States (Table 6, Figure 8). Our second hypothesis, that risk of mortality would be similar for harvest and natural causes of death, was only partially supported by our results. Approximately two-thirds of deaths were due to natural causes, while harvest comprised of approximately one-third of deaths. Turkeys in our study had a higher probability of dying from natural causes within one year compared to harvest, though by two years the risk of dying from either cause was similar. We failed to draw any meaningful conclusions for our third hypothesis that proximity of roost trees to buildings would influence annual survival estimates. The small sample size and wide confidence intervals limited our ability to accurately detect whether mortality risk differed with distance from roost tree to nearest building. Similarly, we could not confidently identify whether body mass or sex have an effect on survival probability.

We calculated an annual survival estimate for each of our three study years and found that survival was similar in the first (2017–2018) and third (2019–2020) study year, but significantly higher in the second study year (2018–2019). Variability in survival rates among years is consistent with other studies that estimated annual wild turkey survival for multiple years (e.g., Miller et al. 1998, Humberg et al. 2009), and can be related to fluctuations in environmental conditions. For example, Miller (1998) observed the lowest annual survival rate for wild turkeys over a ten-year study period in 1987–88 (Table 6) when there was both a mast failure and an extreme drought. Indeed, lower rates of survival tend to be associated with persistent extreme conditions, such as deep snow (e.g., greater than 30 cm) and limited access to food for several days or more (Lavoie et al. 2017, Gonnerman et al. 2022). Some of the variation in our annual survival estimates may be linked to environmental conditions, but all three study years had relatively mild winters, suggesting that differences in survival among study years was likely not due to poor winter survival. It is possible that differences in annual survival were linked to our inability to determine the fate of some individuals. For example, in 2018–19 and 2019–20, 54.5% and 69.9% of turkeys, respectively, were of unknown fate at the end of the study year (Table 7). These two study years were also the years in which survival estimates were higher compared to in 2017–18 (Figure 8), when only 18.2% of turkeys were of unknown fate by the end of the study year. These individuals of unknown fate were censored rather than counted as mortalities, potentially inflating the survival estimates in 2018–19 and 2019–20.

In comparing our results with other studies from the northern part of the eastern wild turkey's range, we report relatively higher annual survival estimates (Table 6). In other northern regions, annual survival estimates ranged from a low of 0.22 (± 0.07) in Minnesota (Kane et al. 2007) to a high of 0.53 (± 0.05) in Wisconsin (Wright et al. 1996). The lower survival rates were typically associated with deep snow. For example, Kane (2007) reported low survival rates for turkeys, even when supplementary food was provided, when deep snow limited movement and access to the food. Similarly, Nguyen (2003) documented low turkey survival in a region of Ontario west of the current study region, but noted that survival was likely decreased due to the 38 days during which snow depths were greater than 25 cm. In our study, there were only two periods during which snow depths were greater than 25 cm for longer than one week: eight days in February 2017 and 11 days in February 2018 (Environment and Climate Change Canada 2023). This is unsurprising given that our study was conducted more recently than most others from the northern part of the eastern wild turkey's range, and winters in northern regions are increasingly becoming warmer and less snowy due to climate change. Had we conducted this study in the 1990s or 2000s, for example, we may have estimated lower annual survival rates more comparable to those reported by other studies in the northern part of the range. As well, many turkeys in our study area had access to supplemental food in the form of waste grain and manure piles at farms, standing corn in agricultural fields, and bird seed at bird feeders set out by community members. Therefore, the annual survival rates we estimated more closely aligned with those from studies in which supplemental food was available in winter (e.g., Roberts et al. 1995, Wright et al. 1996, Pollentier et al. 2014). Our results add additional support to the positive effect of mild winters and supplemental food on wild turkey survival at northern latitudes.

We observed most mortality events occurring within 16 weeks after tagging, coinciding with approximately late February to late June. We doubt these deaths to be a result of capture effects, as they all occurred more than two weeks post-capture. Mortality occurring more frequently during spring has been reported in other survival studies from across the turkey's range (Roberts et al. 1995, Wright et al. 1996, Pollentier et al. 2014, Little et al. 2016). One reason why we found more mortality events within this period is because turkeys typically increase their movement during spring. Females that are reproductively active search for nesting locations (Badyaev et al. 1996, Hubbard et al. 1999, Niedzielski and Bowman 2016), and males disperse from winter flocks and search for mates (Godwin et al. 1994, Holdstock et al. 2006, Chamberlain et al. 2018). Though predation risk can be higher for turkeys making larger movements, it can also be high for females that remain sedentary on the nest. Females that are nesting face increased predation risk during spring because they nest on the ground, making them more vulnerable to mammalian predators (Miller et al. 1998, Shields and Flake 2006). Even after the eggs hatch, hens roost on the ground with their poults for a period of approximately two weeks until the poults are old enough to fly and roost in trees (Roberts et al. 1995, Miller et al. 1998, Chamberlain et al. 2000). Another possible reason why more deaths occurred between late February and late June in our study is the legal spring harvest, which takes place from late April to late May in our study region. In Ontario, more turkeys are harvested during the spring harvest period compared to the fall. For example, in 2017 approximately 34 times more turkeys were harvested during spring compared to fall (MNRF 2018). As well, only males can be harvested during spring, whereas both male and females can be harvested during fall

(MNRF 2017, 2018). Therefore, male turkeys in our study area are at higher risk of mortality during spring, which is supported by our observation that all five harvest-related mortalities occurred in males during spring.

In contrast to our prediction, we found that a greater proportion of mortalities were from natural causes. Additionally, the results of our cumulative incidence function suggested that turkeys were at greater risk of death from natural causes compared to harvest within one year after we began tracking them. We expected that natural causes would be the primary cause for females (Kurzejeski et al. 1987, Wright et al. 1996, Niedzielski and Bowman 2015, Little et al. 2016), but we expected that harvest would be the main one for males as this has been shown elsewhere (Wright and Vangilder 2000, Humberg et al. 2009, Norman et al. 2022). We also expected some females to be taken in the fall harvest. As a result, we expected similar rates of natural and harvest when we pooled male and female turkeys. In our study, only male turkeys were harvested, and males were also affected by natural causes of mortality. Females were affected by natural causes, with no confirmed cases of harvest. However, it is possible that some of the censored turkeys (male or female) were harvested without their tags being reported to the Ministry of Natural Resources, leaving us unable to verify.

Our study was one of the few turkey survival studies to date that included both male and female turkeys rather than focusing on just one sex (but see Humberg et al. 2009). Despite different causes of mortality for males and females in our study, the results of our Cox proportional hazards model suggested that, overall, mortality risk (regardless of cause) was not significantly different for males and females. This differs from Humberg et al. (2009), who reported higher survival of female turkeys compared to males. It is possible that a difference in annual survival rates could become more apparent in our study if we had a larger sample size with fewer censored turkeys of unknown fate. Despite this, our findings align with existing literature demonstrating that males tend to be affected by harvest more than females, but that both sexes are affected by natural factors such as predation.

Contrary to our hypothesis, our results suggest that proximity to humans, as indexed by the distance between roost tree and nearest building, had no effect on survival probability. Most turkeys in our study had a roost tree that was less than 150 m from the nearest building, with less than a quarter had their closest roost tree more than 150 m away. We assumed that buildings were sources of supplementary food, though in reality that is not always the case. However, with many of the turkeys in our study having a roost tree within 150 m of a building, it is likely that some turkeys were able to access supplemental food associated with buildings, such as waste grain, cattle manure, and bird feeders. Access to supplemental food reduces risk of starvation (Wright et al. 1996), especially for turkeys of smaller mass (Porter et al. 1983). In our study, mass did not have a significant effect on risk of mortality, which may be linked to access to supplemental food.

It is also possible that, contrary to our hypothesis, predators may not avoid buildings in the way we expected. For example, coyotes coexist in developed areas by becoming more active from dusk to dawn, therefore reducing their interactions with humans (Gehrt et al. 2009, Thompson et al. 2021). Coyotes are a main predator of turkeys in our study site, and they may attempt to prey on a turkey moving to or from a roost tree at dusk or dawn, even if that roost tree is near a building. Many reproductively active female turkeys fall prey to predators during nesting season, when they spend approximately one and a half months roosting on the ground rather than in trees (Healy et al. 1975, Dickson 1992, McRoberts et al. 2020). Due to our small sample size, we opted to still include hens in our analysis of proximity of roost trees to buildings. However, future studies with larger sample sizes could exclude mortality events that occurred while hens were nesting or ground-roosting with poults.

We could only confirm the status of alive or dead for 16 turkeys, with the remaining 35 turkeys censored and of unknown fate due to lost transmitter signals or other reasons preventing tracking (e.g., access to privately-owned land; Table 7). As a result of this uncertainty and small sample size, it is unlikely we would detect any statistically significant relationships. Another consideration is that we assumed that turkeys would frequently use whichever roost tree in their home range was nearest to a building, and not stray far from this roost tree. However, turkeys use multiple roost trees in their home ranges, especially during spring when they are moving more within their home ranges (Hoffman 1991, Godwin et al. 1994). Turkeys in our study may have been using roost trees that were not the ones located closest to buildings, or they may have moved far from the roost tree during the day, putting the turkeys at greater risk of predation (Holdstock et al. 2006). A future study could account for this flexibility in roost use by instead measuring the distance from the nearest building to whichever roost tree was used by the turkey the night before a mortality event.

In conclusion, the annual survival rates estimated in our study were higher than estimated from elsewhere within the northern part of the eastern wild turkey’s range. Milder winters with fewer, shorter periods of deep snow may allow turkeys to access natural food sources through the winter. Additionally, our study took place on a landscape that is predominantly agricultural, with numerous farms and homes that may be sources of supplemental food for turkeys. These buildings may be present at high enough densities on the landscape that turkeys may be able to access supplemental food, regardless of which roost tree they use. Although distance between roost trees and the nearest buildings did not affect turkey survival in our study, we recognize that there are opportunities for additional research on the topic. For example, roosting near buildings may be more important for turkey populations that are at the leading edge of the species' northward expansion. As the edge of the range creeps northward, turkeys may encounter more snow in winter and sparser buildings and farmland on the landscape. Monitoring populations of wild turkeys and factors influencing survival remains useful, especially as turkeys continue to expand their range northward in a changing climate.

Chapter Four

General Discussion

The objective of my study was to investigate the role of microclimate in roost tree selection, estimate annual survival rates, and determine whether survival is influenced by proximity of roost trees to buildings for eastern wild turkeys near the northern edge of their range in Ontario, Canada. Microclimate was not a strong predictor of roost tree selection, and I found minimal differences in overnight air temperature, overnight wind speeds, and accumulated precipitation at turkey roost trees and nearby non-roost trees during both winter and summer. This suggests that microclimate does not influence fine-scale roost tree selection. Instead, fine-scale selection appears to be influenced by tree characteristics, with turkeys preferring larger trees and, in summer, deciduous trees.

I also evaluated annual survival rates for turkeys in my study area and found that the main causes of mortality for turkeys were predation and, for males, harvest. Despite this, annual survival rates were higher than those reported from elsewhere within the northern part of the wild turkey's range. Specifically, the estimated annual survival rates (95% confidence interval) in 2017–2018, 2018–2019, and 2019–2020, respectively, were 0.55 (0.37–0.83), 0.92 (0.82–1.0), and 0.63 (0.37–1.0). As well, I tested whether proximity of roost trees to buildings improved survival, possibly because buildings may be associated with supplemental food sources or reduced predation risk. Home ranges of most turkeys contained at least one roost tree that was less than 150 m from the nearest building, but proximity of roost tree to building had no significant effect on survival probability. As well, neither sex nor body mass significantly influenced survival probability.

My results suggest that in my study area, fine scale roost tree selection is not likely to influence turkey survival. While roosting behaviour itself benefits survival by keeping turkeys elevated and away from ground-based mammalian predators, the selection of one specific tree over another does not appear to have major effects on survival probability. This may be because turkeys face highest mortality risk when they are on the ground rather than when they are in a roost tree. On the ground, turkeys are vulnerable to major predators such as coyotes (Hubbard et al. 1999, Niedzielski and Bowman 2015, Little et al. 2016) and, during harvest, humans (Humberg et al. 2009, Norman et al. 2022, Wightman et al. 2024). Although turkeys may be safe from these predators while roosting, they become vulnerable during the day when they leave the roost and travel on foot, or when hens spend weeks at a time on the ground nesting (Miller et al. 1998, Shields and Flake 2006).

Although risk of starvation in winter can be greater for turkeys in the northern part of their range (Porter et al. 1983, Kane et al. 2007, Lavoie et al. 2021), the turkeys in my study were generally able to cope with winter conditions, with no starvation events occurring during winter. Turkeys likely fared relatively well during winter because the conditions during my study were relatively mild compared to other years and other regions. Similarly, the turkeys in my study live on a predominantly agricultural and urban landscape, where supplemental food may be more abundant and evenly distributed across the landscape compared to less developed landscapes. For example, most turkeys in my study had a roost tree less than 150 m from a building within their home range, although I recognize that not all buildings offer supplemental food. Turkey habitat suitability is positively associated with building density up to a certain point (Baici and Bowman 2023), and the landscape within my study area might represent a building density and level of development at which turkeys benefit. Turkey roost selection and survival probabilities may be different in less densely populated areas. In these areas, turkeys may have to travel farther to access supplemental food to avoid starvation when natural food is limited, and proximity of roost trees to supplemental food sources may be important.

Preference for larger trees is commonly seen in other studies on wild turkey roost sites (e.g., Boeker and Scott 1969, Kilpatrick et al. 1988, Thompson et al. 2009, Adey et al. 2023). Large, open-branched trees are thought to provide sturdy branches and better visibility of the surrounding area (Boeker and Scott 1969, Rumble 1992). Large trees may also be more accessible to turkeys, and I suspect that roost accessibility is an important yet understudied factor that may influence fine-scale roost tree selection. Turkeys are short-winged heavy-bodied birds, reducing their ability for agile, sustained flight (Tran et al. 2022). I observed that roost trees were often situated in areas that offered a clear path for turkeys to enter the trees. Some roost trees were located near the edges of forests, and those located deeper into the forest were often situated near a clearing or trail. At one roost site in a cedar forest, I captured trail camera images of turkeys using dead, leaning trees as ramps as they moved upwards into roost trees. There were also several roost trees in my study that were located on slopes. Slope-side roost trees have been observed in other studies (Boeker and Scott 1969, Rumble 1992, Perlichek et al. 2009) and may improve accessibility by allowing turkeys to walk upslope and fly directly to the crown of a roost tree growing downslope. There may also be a thermoregulatory benefit if the roost trees are on south-facing slopes, as they may receive morning sun sooner than roost trees on flat terrain (Renaud and Rebetez 2009). Slope steepness and aspect are two factors I did not account for in my study that may influence microclimate, but not necessarily at night. A future study may place more consideration on the role of slope in predicting roost tree selection, in addition to quantifying roost accessibility to further explore factors affecting roost tree use.

Although microclimate does not appear to influence fine-scale roost tree selection, thermoregulatory benefits may be obtained at a coarser scale, such as in the selection of roost habitat. For example, I found that wind speeds were lower for roost trees compared to a tree in an open non-forested site. Turkeys may therefore display coarser-scale selection by choosing roost trees within forests rather than isolated trees in open settings. There is also evidence to suggest that turkeys roost in forests with higher proportions of coniferous trees in winter, which may reduce their exposure to wind and snow (Gonnerman et al. 2022). In my study area there is a cedar forest which is heavily used by turkeys for roosting in winter but seldom used during summer. At the fine scale, comparing trees 50 m apart, both the roost and non-roost trees I measured within this forest were coniferous, and as a result they likely had similar microclimates. However, I may have detected microclimate differences if I had compared a coniferous tree within the forest with a tree (coniferous or deciduous) farther away in the open pasture next to the forest. Turkeys may have increased their use of this coniferous forest in winter because wind speeds were lower in this forest or perhaps because they could better conceal themselves from avian predators such as great horned owls (*Bubo virginianus*) by roosting among the leaves.

Elsewhere in my study area turkeys used deciduous trees in winter, and ultimately showed no significant selection of coniferous versus deciduous trees in winter. Sometimes roost tree selection can depend on the availability of roosting habitat across the larger landscape (Chamberlain et al. 2000, Byrne et al. 2015), which is something I did not measure in my study. Turkeys may have used deciduous trees in winter if those trees were more available on the landscape, even if they obtained fewer thermoregulatory benefits from roosting in deciduous trees. It may be beneficial in the future to measure the composition of the forest surrounding the roost tree to better understand the habitat conditions under which turkeys select one roost tree instead of another.

There is growing evidence to suggest that turkeys benefit from living in areas populated by humans (Adey et al. 2023, Baici and Bowman 2023), especially in agricultural areas where turkeys can more easily access supplemental food during winter (Porter et al. 1983, Vander Haegen et al. 1989). In my study, I assumed that buildings are sources of supplemental food, since there are many farms in my study area, as well as houses with bird feeders. However, I did not confirm the presence of supplemental food at the buildings, and it is unlikely that all buildings had supplemental food. I also did not account for agricultural fields being a source of supplemental food. For example, standing corn is sometimes left in fields to dry over winter, as a cover crop to improve soil conditions, or as a source of food for wildlife such as turkeys or white-tailed deer (*Odocoileus virginianus*). Corn is a popular cash crop in my study area and turkeys may have been roosting near fields with standing corn rather than roosting near buildings. Similarly, I assumed that buildings would be associated with reduced predation risk for turkeys, since predators such as coyotes avoid humans (Frid and Dill 2002, Gehrt et al. 2009, Thompson et al. 2021). It would be best to measure the type and abundance of predators around buildings to test this assumption. Future studies could use camera traps or winter track surveys to better understand predator activity both around the roost and at around buildings.

The reintroduction of wild turkeys to their historic range is widely considered a conservation success story. Not only are turkeys present in areas from which they were once extirpated, but they are even expanding their range beyond historic limits. In Ontario, turkeys are expected to continue their northward range expansion as the climate warms and as agricultural and urban development increases in the north (Baici and Bowman 2023). Wildlife managers may therefore be tempted to assume that wild turkey populations are doing well and that they warrant less attention, but this is not the case. Turkey populations in some regions have declined in the last two decades, and even in Ontario the contemporary wild turkey population appears to be lower than the estimated 70,000 turkeys in 2007 (OMNR 2007, Baici and Bowman 2023). Although annual survival rates in my study were relatively high compared to estimates from other parts of the turkey's range, my estimate has a degree of uncertainty due to censoring many of the turkeys in my study. It can be challenging to track turkeys in a landscape comprised predominantly of privately-owned land. I do not know the fate of the large number of censored turkeys in my study, but if they in fact died it would decrease my estimates of annual survival probability. I would recommend another survival study involving more individual turkeys from more flocks, since there is less likely to be spatial overlap in resources used by individuals from different flocks.

Lastly, I would encourage continued research on the effects of climate on wild turkeys. Although microclimate did not have a significant effect on roost tree selection in my study, microclimate or, more broadly, extreme weather events may affect nesting turkeys. Nest success contributes largely to population growth (Roberts et al. 1995, Pollentier et al. 2014, Tyl et al. 2023), but female turkeys that are nesting are vulnerable to predators, habitat disturbance, and weather events (Miller et al. 1998, Roberts and Porter 1998, Shields and Flake 2006, Tyl et al. 2023). Extreme weather events are increasing in frequency and intensity due to climate change, and their effects on turkey nest success and overall survival are not fully understood. For example, heavy rainfall events may compromise nesting attempts, either directly by preventing hens from using nesting habitat (Cobb and Doerr 1997, Chamberlain et al. 2013) or indirectly through increased ability of predators to locate nesting hens using olfaction (Roberts et al. 1995, Roberts and Porter 1998). Periods of extreme heat and drought are also becoming increasingly common during spring and summer (IPCC 2023), and nesting hens may be vulnerable to overheating during prolonged heatwaves (Collier et al. 2017, Rakowski et al. 2019). Continued monitoring of wild turkeys will be critical in understanding how climate change and other environmental and human-caused pressures affect long-term sustainability of these populations.

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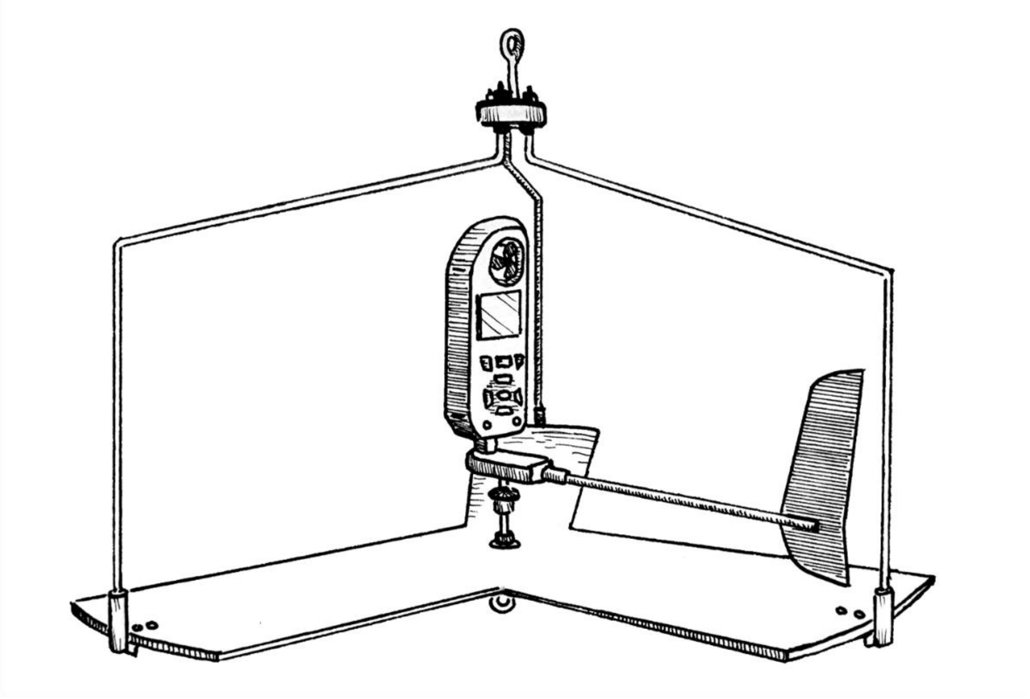
Appendix: Supporting Information



Supplementary Figure A1. Diagram showing a portable weather station, which was hung from a branch in a roost tree or non-roost tree. The weather station consists of a Kestrel 5000 Environmental Meter with wind vane attachment (Kestrel Instruments, Boothwyn, Pennsylvania) mounted onto a platform that was approximately 0.5 m in diameter. Not shown is the metal pail set on the ground below to capture precipitation. Illustration by K. Martin.

Supplementary Table A1. Summary of winter and summer fieldwork conducted for this study. All fieldwork was conducted within the study area, located within 30 km of Peterborough, Ontario, Canada.

	Winter	Summer
Sampling period	December 1, 2022 – March 27, 2023	June 1 – September 25, 2023
Number of roost and non-roost tree pairs	25 pairs	30 pairs
Distance between roost and non-roost tree	50 m, with one exception of 100 m	50 m
Number of nights weather stations were left out at each site (pair of roost and non-roost tree)	3 nights (23 sites) 4 nights (2 sites)	3 nights (22 sites) 4 nights (6 sites) 5 nights (2 sites)
Total number of nights sampled	77 nights of sampling	100 nights of sampling
Minimum number of GPS-tagged individuals recorded using any one roost tree*	1	1
Maximum number of GPS-tagged individuals recorded using any one roost tree *	16	9
Minimum number of GPS locations (from any individuals) at any one roost tree*	3	6
Maximum number of GPS locations (from any individuals) at any one roost tree*	359	220
Criteria for defining a roost tree in ArcGIS	At least 3 nocturnal locations within 15 m of each other	At least 5 nocturnal locations within 15 m of each other
Number of properties visited	10	11

* Across the period of 2017—2019 and 2022, not necessarily all on the same night.

Supplementary Table A2. Mean values (± SE) for microclimate and tree characteristics at pairs of winter roost and non-roost trees (n = 25 pairs), and at a fixed non-forested site (n = 1 tree). Roost trees were used by eastern wild turkeys (*Meleagris gallopavo silvestris*) in southern Ontario, Canada, between the months of December to February and within the years of 2017—2019 and 2022—2023. Variables for winter sites were measured from December 1, 2022, to March 27, 2023.

		Site Type	**Mean**	**SE**	**Lower 95% CI**	**Upper 95% CI**
Temperature	Mean overnight (°C)	Roost	-3.6	0.6	-4.8	-2.4
		Non-roost	-3.7	0.6	-4.9	-2.5
		Non-forested	-3.1	0.5	-4.1	-2.1
	Minimum overnight (°C)	Roost	-5.0	0.7	-6.3	-3.7
		Non-roost	-5.2	0.7	-6.5	-3.8
		Non-forested	-4.5	0.6	-5.7	-3.4
Wind speed	Mean overnight (m/s)	Roost	0.6	0.1	0.4	0.8
		Non-roost	0.5	0.1	0.4	0.7
		Non-forested	1.5	0.1	1.3	1.8
	Maximum overnight (m/s)	Roost	1.5	0.2	1.1	1.8
		Non-roost	1.4	0.2	1.0	1.7
		Non-forested	3.6	0.2	2.7	3.6
Precipitation	Total accumulated (mL)	Roost	202.08	27.0	148.3	255.9
		Non-roost	229.64	28.4	173.1	286.2
		Non-forested	275.61	33.0	210.0	341.2
Tree characteristics	Tree DBH (cm)	Roost	48.47	2.0	44.5	52.5
		Non-roost	32.38	1.2	30.0	34.8
		Non-forested	NA	NA	NA	NA
	Tree type (coniferous 0 deciduous 1)	Roost	0.71	0.05	0.61	0.82
		Non-roost	0.75	0.05	0.65	0.85
		Non-forested	NA	NA	NA	NA
Weather station set up	Height (m)	Roost	8.2	0.1	7.9	8.5
		Non-roost	6.8	0.2	6.5	7.1
		Non-forested	NA	NA	NA	NA
	Distance from trunk (m)	Roost	2.0	0.1	1.8	2.3
		Non-roost	1.6	0.1	1.3	1.8
		Non-forested	NA	NA	NA	NA

Supplementary Table A3. Mean values (± SE) for microclimate and tree characteristics at summer roost (n = 30) and non-roost (n = 30 pairs) trees, and at a fixed non-forested site (n = 1 tree). Roost trees were used by eastern wild turkeys (*Meleagris gallopavo silvestris*) in southern Ontario, Canada, between the months of June to August and within the years of 2017—2019 and in 2022. Variables for summer sites were measured from June 1 to September 25, 2023.

		Site Type	Mean	SE	Lower 95% CI	Upper 95% CI
Temperature	Mean overnight (°C)	Roost	16.2	0.3	15.6	16.9
		Non-roost	16.0	0.3	15.4	16.7
		Non-forested	16.8	0.3	16.2	17.4
	Maximum overnight (°C)	Roost	19.1	0.3	18.5	19.7
		Non-roost	18.9	0.3	18.3	19.5
		Non-forested	19.5	0.3	18.9	20.1
Wind speed	Mean overnight (m/s)	Roost	0.2	0.0	0.1	0.2
		Non-roost	0.1	0.0	0.0	0.1
		Non-forested	0.7	0.1	0.6	0.9
	Maximum overnight (m/s)	Roost	0.5	0.1	0.3	0.7
		Non-roost	0.2	0.1	0.1	0.3
		Non-forested	1.8	0.1	1.6	2.0
Precipitation	Total accumulated (mL)	Roost	218.2	47.8	123.1	313.2
		Non-roost	356.8	60.2	237.3	476.3
		Non-forested	363.5	59.2	246.1	481.0
Tree characteristics	Tree DBH (cm)	Roost	60.3	4.0	52.4	68.2
		Non-roost	32.6	1.5	29.6	35.7
		Non-forested	NA	NA	NA	NA
	Tree type (coniferous 0 deciduous 1)	Roost	0.94	0.02	0.89	0.99
		Non-roost	0.74	0.04	0.65	0.83
		Non-forested	NA	NA	NA	NA
Weather station set up	Height (m)	Roost	8.9	0.2	8.6	9.2
		Non-roost	7.7	0.2	7.3	8.2
		Non-forested	NA	NA	NA	NA
	Distance from trunk (m)	Roost	2.6	0.2	2.2	2.9
		Non-roost	2.1	0.1	1.9	2.3
		Non-forested	NA	NA	NA	NA

Supplementary Table A4. Summary of winter roost trees. Roost trees were used by GPS-tagged eastern wild turkeys (*Meleagris gallopavo silvestris*) in southern Ontario, Canada, between the months of December to February and within the years of 2017—2019 and 2022—2023. Winter sites were measured from December 1, 2022, to March 27, 2023. Number of roost events and individuals detected were unknown for four trees that were added based on incidental observation rather than location data from GPS-tagged wild turkeys.

Site	Tree Species	Tree Classification	Years Used	Number of Roost Events*	Individuals Detected at Roost*
W.A1	Basswood	Deciduous	2018	5	2
W.A2	Sugar maple	Deciduous	2018	3	2
W.C1	Sugar maple	Deciduous	2017, 2018	3	2
W.C2	Sugar maple	Deciduous	2017, 2018	4	1
W.C3	Sugar maple	Deciduous	2018	3	1
W.D1	Sugar maple	Deciduous	2018	3	1
W.D2	Sugar maple	Deciduous	2017, 2018	15	6
W.D3	Eastern white cedar	Coniferous	2018, 2022	3	2
W.D4	Eastern white cedar	Coniferous	2018, 2022	18	2
W.D5	Eastern white cedar	Coniferous	2017, 2018	5	4
W.D6	Eastern white cedar	Coniferous	2017, 2018, 2022	54	13
W.D7	Eastern white cedar	Coniferous	2017, 2018, 2022	191	16
W.E1	Sugar maple	Deciduous	2018	4	4
W.G1	Eastern white pine	Coniferous	2018	7	1
W.J1	Sugar maple	Deciduous	2017, 2018	5	1
W.J2	Eastern hemlock	Coniferous	2017, 2018	6	1
W.J3	Sugar maple	Deciduous	2018	4	1
W.K2	Bigtooth aspen	Deciduous	2017, 2018	45	5
W.K3	Bigtooth aspen	Deciduous	2017, 2018, 2019	359	11
W.L1	Black locust	Deciduous	2018, 2019	109	5
W.N1	White ash	Deciduous	2018	6	2
W.P1	Freeman's maple	Deciduous	2022	unknown	unknown
W.P2	Freeman's maple	Deciduous	2022	unknown	unknown
W.P3	Freeman's maple	Deciduous	2022	unknown	unknown
W.P4	Basswood	Deciduous	2022	unknown	unknown

* Across the period of 2017—2019 and 2022, not necessarily all on the same night.

Supplementary Table A5. Summary of summer roost trees. Roost trees were used by eastern wild turkeys (*Meleagris gallopavo silvestris*) in southern Ontario, Canada, between the months of June to August and within the years of 2017—2019 and in 2022. Variables for summer sites were measured from June 1 to September 25, 2023.

Site	Tree Species	Tree Classification	Years Used	Number of Roost Events *	Individuals Detected at Roost *
S.A1	Trembling aspen	Deciduous	2017	7	4
S.B1	Freeman's maple	Deciduous	2018	8	1
S.I1	Trembling aspen	Deciduous	2017, 2018	13	1
S.L1	Sugar maple	Deciduous	2017	17	1
S.L2	Sugar maple	Deciduous	2017, 2018	62	1
S.M1	White oak	Deciduous	2022	19	2
S.M2	Hawthorn	Deciduous	2022	37	2
S.M3	Hickory	Deciduous	2022	9	2
S.M4	Basswood	Deciduous	2022	7	2
S.M5	American elm	Deciduous	2022	40	2
S.N2	Sugar maple	Deciduous	2017	12	1
S.O1	Sugar maple	Deciduous	2022	6	2
S.O2	Eastern white pine	Coniferous	2022	7	1
S.Q1	White ash	Deciduous	2017	10	4
S.Q2	Sugar maple	Deciduous	2017	34	4
S.Q4	White ash	Deciduous	2017	21	2
S.Q5	Sugar maple	Deciduous	2017	22	4
S.Q6	Basswood	Deciduous	2017	24	4
S.R1	Sugar maple	Deciduous	2017	22	1
S.R2	Sugar maple	Deciduous	2017, 2018, 2022	107	9
S.R3	Eastern white cedar	Coniferous	2018	6	2
S.R4	Sugar maple	Deciduous	2018	196	6
S.R5	Sugar maple	Deciduous	2018	14	5
S.R6	Sugar maple	Deciduous	2018, 2022	59	5
S.U1	American elm	Deciduous	2022	16	1
S.U2	Black locust	Deciduous	2018	11	1
S.U3	Black locust	Deciduous	2018	43	5
S.W1	Sugar maple	Deciduous	2017, 2018	19	3
S.W2	Sugar maple	Deciduous	2017, 2018	220	8
S.W3	Basswood	Deciduous	2017, 2018	157	8

* Across the period of 2017—2019 and 2022, not necessarily all on the same night

Supplementary Table A6. Distance (m) from roost tree to nearest building within summer and winter home range polygons of eastern wild turkeys (*Meleagris gallopavo* silvestris; n = 38) radio-tracked in Peterborough County, Ontario, Canada. For individuals who were tracked long enough to have multiple home range polygons, the shortest distance from roost tree to building was carried forward (indicated in bold) to the survival analysis, regardless of the year or season.

Turkey ID	Year	Season	Distance (m)
46318	2017	summer	133.7
		winter	**49.3**
	2018	winter	89.3
46319	2017	summer	134.5
		winter	49.3
	2018	summer	134.5
		winter	**49.3**
46320	2017	summer	126.0
		winter	337.1
	2018	summer	**126.0**
		winter	348.4
46321	2017	summer	134.5
		winter	49.3
	2018	summer	134.5
		winter	**49.3**
46322	2017	summer	**74.1**
		winter	242.3
	2018	winter	237.5
46323	2017	summer	**134.5**
46323.2	2018	summer	418.5
		winter	**253.1**
46324	2017	summer	74.1
46324.2	2018	summer	147.0
		winter	**49.3**
46326	2017	summer	**74.1**
	2018	winter	237.5
46327	2017	summer	**74.1**
46329	2017	summer	134.5
		winter	**49.3**
46329.2	2018	summer	418.5

		winter	**191.5**
46330	2017	summer	133.7
		winter	49.3
	2018	winter	**49.3**
46331	2017	summer	133.7
		winter	**49.3**
	2018	summer	133.7
		winter	89.3
46332	2017	summer	**133.7**
46332.2	2018	summer	**84.2**
46333	2017	summer	**134.5**
46334	2017	summer	**74.1**
46338	2017	summer	147.0
		winter	303.2
	2018	summer	**147.0**
		winter	253.1
46339	2017	summer	**134.5**
46340	2017	summer	**432.8**
46371	2018	winter	253.1
	2019	winter	**49.3**
46372	2018	summer	**134.5**
46373	2018	summer	74.1
		winter	**49.3**
46374	2018	summer	84.2
		winter	191.5
	2019	winter	**49.3**
46375	2018	summer	418.5
		winter	**303.2**
46376	2018	summer	**84.2**
		winter	303.2
46379	2018	summer	**147.0**
		winter	303.2
46380	2018	summer	74.1
		winter	49.3
	2019	winter	**49.3**
46381	2018	summer	**63.8**
46382	2018	summer	**84.2**

		winter	253.1
46383	2018	summer	249.4
		winter	**49.3**
	2019	winter	253.1
46384	2018	summer	**74.1**
		winter	314.9
46718	2019	summer	**212.1**
46719	2019	winter	**49.3**
46720	2019	summer	134.5
	2020	winter	**49.3**
46721	2019	summer	**147.0**