Spatial Ecology of the Common Nighthawk (*Chordeiles minor*) in the Halifax Backlands

by

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Abstract

Located in southern Halifax, NS, the Halifax Backlands is a suburban wilderness that is home to a diversity of species and ecosystems, including the Common Nighthawk (*Chordeiles minor*). The Common Nighthawk is a migratory aerial insectivore that is classified as Special Concern under Canada's Species at Risk Act. This study aimed to determine the spatial distribution of Common Nighthawks within the Halifax Backlands and investigate the influence of environmental characteristics on this distribution. Furthermore, seasonal and diurnal trends in Common Nighthawk activity were examined. Between May and September of 2024, Common Nighthawks were sampled in the Halifax Backlands using Autonomous Recording Units (ARUs) and visual surveys. Auditory recordings were analyzed using BirdNET. Auditory detections were plotted to visualize seasonal and diurnal trends in activity. Using location data collected during visual surveys, kernel density analysis was performed to ascertain spatial distribution. The importance of environmental variables on nighthawk spatial distribution was analyzed using a generalized linear model (GLM). The study found that Common Nighthawk activity was greatest in the northern portion of the Backlands, and that prey abundance, elevation, and bare ground were all influential in this distribution. Activity varied across the season, beginning in late-May, peaking in July, and ending in mid-September. Diurnal trends in activity showed similar trends spatially and seasonally, with peaks in activity during sunset and an hour before sunrise. Results of the study are important for improving understanding of the spatial ecology of Common Nighthawks in Atlantic Canada, and can inform future monitoring and conservation strategies in the Halifax Backlands.

List of Abbreviations

AIC	Akaike Information Criterion
ARU	Autonomous Recording Unit
BMP	Beneficial Management Practice
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DEM	Digital Elevation Model
DSM	Digital Surface Model
ECCC	Environment and Climate Change Canada
FN	False Negative
FP	False Positive
GLM	Generalized Linear Model
h	Hour
ha	Hectare
HRM	Halifax Regional Municipality
km	Kilometre
m	Metre
min	Minute
NS	Nova Scotia
PID	Point Identification
s	Second
TN	True Negative
TP	True Positive
UTM	Universal Transverse Mercator
ZID	Zone Identification

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1.0 Introduction

Across the globe, human activity is causing biodiversity to decline at a staggering rate (Ceballos et al. 2015). In recent decades, species extinctions have accelerated, with losses great enough to qualify as a sixth mass extinction (Ceballos et al. 2015; Pereira et al. 2024). Since 1970, populations of vertebrates have declined by about 50% on average, largely due to human activity (Leung et al. 2020).

Amongst bird species, declines in aerial insectivores have been disproportionately high (Nebel et al. 2010). In North America, this trend is particularly prominent in species that inhabit the northeast, as well as for birds that migrate long distances (Nebel et al. 2010). Documented drivers of aerial insectivore decline include decreased insect abundance, destruction of habitat, agricultural intensification, and climate change (Spiller and Dettmers 2019). Given their connection to insect abundance, declines in aerial insectivores may be particularly important in indicating larger changes in ecosystems and trophic structures (Nebel et al. 2010; Kelly et al. 2013). This study examines the spatial ecology of a threatened aerial insectivore, the Common Nighthawk (*Chordeiles minor*), across a 1,350 ha suburban wilderness in Atlantic Canada, the Halifax Backlands.

1.1 The Common Nighthawk

Common Nighthawks are a migratory aerial insectivore with extensive breeding range throughout North and Central America, and wintering grounds in South America (COSEWIC 2018). They typically arrive in Canada in May to early-June and depart between mid-August to Mid-September (COSEWIC 2018). During this time, they can be found within every province and territory except Nunavut (COSEWIC 2018). Considered a crepuscular species, Common Nighthawks are most active in the hours surrounding dawn and dusk, making them more difficult to observe than diurnal birds (English et al. 2017; Hannah et al. 2022).

1.1.1 Conservation Status

Within Canada, the Common Nighthawk is considered a Species at Risk (SAR) and is listed as 'Special Concern' under Schedule 1 of the Species at Risk Act (SARA) (COSEWIC 2018). Common Nighthawks in Canada have experienced a 68% decline in population between 1970 and 2018, putting the average annual decline at 2.35% during this period (COSEWIC 2018). However, the rate of decline halved to 1.16% between 2005 and 2016 (COSEWIC 2018). Previously listed as 'Threatened', Common Nighthawks were downlisted in 2018 due to the slowing population decline and evidence of ample habitat in the boreal forest (COSEWIC 2018). Provincially, the Nova Scotian population of Common Nighthawks are also classified as a SAR and are listed as 'Threatened' under the province's Endangered Species Act (NS Department of Lands and Forestry 2021).

Declines in large aerial insects are likely the preeminent driver of Common Nighthawk population decline (NS Department of Lands and Forestry 2021). Globally, of the 77,435 insect species assessed by the IUCN between 1996 and 2020, 23.47% were found to be threatened by extinction, resulting in reduced prey availability to insectivores (Raghavendra et al. 2022). Other threats to Common Nighthawks include fire suppression and loss of breeding habitat (NS Department of Lands and Forestry 2021). Over recent decades, fire suppression has reduced the open areas that Common Nighthawks prefer for breeding (NS Department of Lands and Forestry

2021). Moreover, encroachment by urban development may also be contributing to loss of breeding habitat (Valiela and Martinetto 2007).

1.1.2 Nesting Habitat & Territoriality

Common Nighthawks are a ground-nesting species that nest in a variety of landscapes, including grasslands, open pine forests, barrens, and gravel rooftops (Newberry and Swanson 2018; Knight 2021). Nesting habitat is typically open with high amounts of bare ground (Knight 2021). Due to this preference for bare ground, post-disturbance landscapes are also frequently used as nesting grounds, including clearcuts, abandoned dirt roads, and postfire areas (Farrell et al. 2017 ; Knight et al. 2021).

During their breeding season, individual male Common Nighthawks have exclusive territories that encircle their nest site (Knight et al. 2022). Although the specific resource being guarded by males is uncertain, it has been suggested that territorial displays may be performed in defense of nests or female Common Nighthawks (Knight et al. 2022). Territories are often irregularly shaped and show minimal spatial overlap between males (Armstrong 1965; Knight et al. 2022). Studies have estimated territories to average between 10.2 - 10.5 ha, and range from 1.1 - 26.8 ha (Armstrong 1965; Knight et al. 2022). Furthermore, Common Nighthawks show high interannual fidelity of territory, though precise nest locations may shift between years (Ng et al. 2018; Knight et al. 2022).

1.1.3 Foraging

Common Nighthawks have an ‘on the wing’ foraging strategy, which they use to feed on aerial insects over 5 mm in length (Brigham and Barclay 1995; Knight et al. 2018). Their diet typically consists of the insect orders Coleoptera, Trichoptera, Lepidoptera, and Hymenoptera, though insect prey preference has been found to vary spatially and seasonally (Brigham 1990; Danielle Todd et al. 1998; Knight et al. 2018). It has also been suggested that Common Nighthawk foraging niches are partitioned between sexes, with females feeding lower to the ground and on more coleopterans than males (Knight et al. 2018).

1.1.4 Vocal & Non-Vocal Sounds

The most common sound produced by Common Nighthawks is a nasal 'peent', which is a far-carrying mid-frequency vocalization (3-5 kHz; Hannah et al. 2022). Peents may be produced for conspecific communication, and are most frequently made during foraging and courtship displays (Hannah et al. 2022).

Male Common Nighthawks also produce a non-vocal wing-boom, which is typically accompanied by a peent during territorial displays and in proximity of their nest site (Roth and Gwilym 2001; Knight et al. 2022). Wing-booms are a mechanical noise, created by flexing the primary feathers during an aerial dive, and can be heard over long distances due to their low frequency (0.4-1.0 kHz; Hannah et al. 2022). Research has shown that male Common Nighthawks are unlikely to perform wing-booms outside of their exclusive territory, and that within their territory, the relative probability of wing-booms increases with proximity to their nest (Knight et al. 2022). As such, location of wing-booms can be used to estimate both nest sites and exclusive breeding territory (Knight et al. 2022).

1.2 The Halifax Backlands

The Halifax Backlands, hereafter the Backlands, is approximately 1,350 hectares of suburban wilderness located within Halifax Regional Municipality (HRM), Nova Scotia (NS), Canada (Hill and Patriquin 2014). As shown in Figure 1, the Backlands is composed of a variety of land-use types, including both public and private lands. Publicly accessible lands include HRM parklands, NS Nature Trust lands, and provincial Crown lands (HRM 2024; NS Department of Natural Resources and Renewables 2024; NS Nature Trust 2024). Due to the Backlands' expansive wilderness and close proximity to urban and residential areas, there are extensive trail networks within the area that attract hikers and cyclists (The Backlands Coalition 2023b).

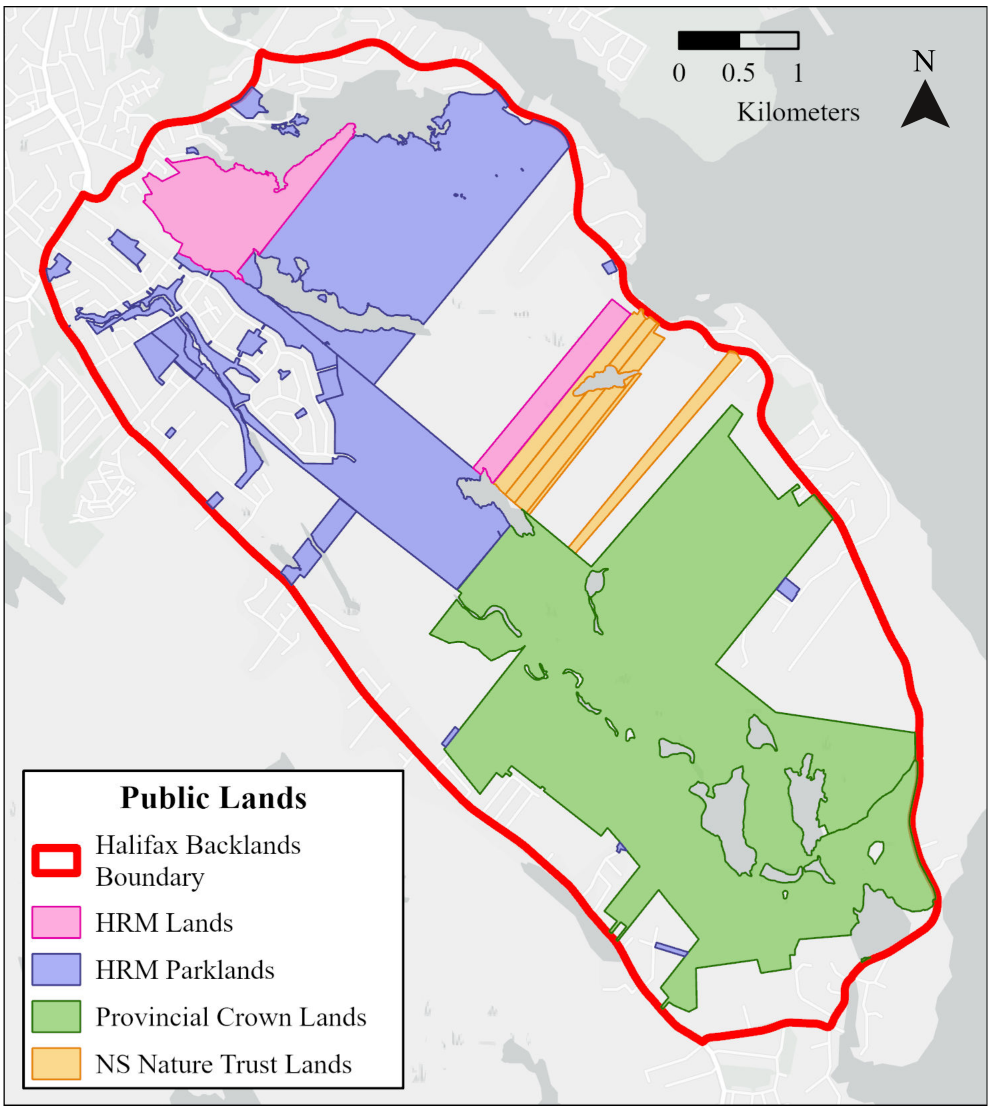

Figure 1. Map of the publicly accessible land types within the Halifax Backlands (HRM 2024; NS Department of Natural Resources and Renewables 2024; NS Nature Trust 2024).

A rich diversity of ecosystems is found within the Backlands, including wetlands, dense forests, and open barrens (Hill and Patriquin 2014). Perhaps most notable is the fire dependent Jack Pine-Broom Crowberry Barrens ecosystem, which is both globally rare and has high conservation significance (Hill and Patriquin 2014). Furthermore, many SAR have been observed within the Backlands, including plant species such as the Golden Heather (*Hudsonia ericoides*) and Mountain Sandwort (*Mononeuria groenlandica)*, and bird species such as the Rusty Blackbird (*Euphagus carolinus*), Chimney Swift (*Chaetura pelagica*), and Common Nighthawk (*Chordeiles minor*; The Backlands Coalition 2023a).

Common Nighthawks have historically been observed feeding and nesting within the Backlands by local naturalists (The Backlands Coalition 2024a). Due to its open landscape, the barrens found within the Backlands are thought to provide ideal breeding habitat for Common Nighthawks (Hill and Patriquin 2014; COSEWIC 2018). Furthermore, the numerous wetlands within the area may offer desirable foraging grounds (Hill and Patriquin 2014; COSEWIC 2018).

The Backlands Coalition is an organization composed of various community and conservation groups dedicated to the management, study, and preservation of the Backlands wilderness (The Backlands Coalition 2024b). Constituent groups include the Williams Lake Conservation Company, McIntosh Run Watershed Association, and Halifax Field Naturalists, amongst others (The Backlands Coalition 2024b). Due to their conservation aims, the Backlands Coalition is highly interested in the monitoring and conservation of SAR that inhabit the area.

1.3 Motivation

An improved understanding of the Common Nighthawk population within the Halifax Backlands could support both conservation of this species and the Backlands wilderness more broadly. Within the Backlands Coalition, a group of volunteers known as the 'Bird Team' works towards monitoring, conserving, and educating the public on bird species in the Backlands. In recent years, the Bird Team has conducted surveys and educational outreach on Common Nighthawks and intends to continue doing so. As such, further study of this population is valuable to inform future monitoring and conservation strategies.

Furthermore, protected areas within the Backlands wilderness are currently limited, with only 120 ha, including the NS Nature Trust Lands and HRM Parklands, receiving formal protection (Figure 1; The Backlands Coalition 2025). Due to this, the Backlands Coalition has outlined one of their primary aims as seeking formal protection for as much of the undeveloped lands as possible, with the purpose of conserving important species and ecosystems (The Backlands Coalition 2025). Through gaining understanding of a SAR population that calls the Backlands home, this research may not only support conservation of Common Nighthawks, but conservation of the Backlands wilderness as well.

1.4 Research Objectives & Hypotheses

Through analysis of passively collected bioacoustic data, spatially mapped field observations, and habitat characteristics, this project aimed to discern the spatial and temporal characteristics of the Common Nighthawk population within the Halifax Backlands. Four central research objectives were investigated:

1. Document the seasonal and diurnal trends in Common Nighthawk vocalizations within the Halifax Backlands.
2. Determine the spatial distribution of Common Nighthawk activity within the Halifax Backlands.
3. Investigate the influence of environmental characteristics, including habitat and insect abundance, on the spatial distribution of Common Nighthawk activity within the Halifax Backlands.
4. Develop recommendations for future conservation and monitoring of Common Nighthawks in the Halifax Backlands.

1.4.1 Hypotheses

This study will investigate eight environmental variables as potential drivers of Common Nighthawk activity in the Backlands. These variables represent habitat characteristics, weather effects, or prey availability, which are of interest due to their implications to monitoring and conservation strategies. Prey availability or important habitat characteristics could help to inform efforts in biodiversity conservation or land protections, while weather may be relevant to monitoring protocols.

High prey abundance is hypothesized to increase Common Nighthawk activity. Common Nighthawks are aerial insectivores that feed while in flight (Knight et al. 2018), and show greatest preference the large aerial insects from the orders Coleoptera, Trichoptera, Lepidoptera, and Hymenoptera (Brigham 1990; Danielle Todd et al. 1998; Knight et al. 2018).

Increasing elevation is hypothesized to increase Common Nighthawk activity. Although a relationship between elevation and Common Nighthawk presence is currently poorly documented in the literature, field observations of Common Nighthawks in the Backlands suggest that this population may show preference for higher elevation habitats.

Bare ground is hypothesized to increase Common Nighthawk activity. Bare ground is known to be important for Common Nighthawk habitat, particularly for nesting grounds (Knight 2021).

The presence of nearby open water and wetlands is hypothesized to increase Common Nighthawk activity. It has been suggested that water bodies may provide desirable foraging habitat for Common Nighthawks (Ouellet 1974).

High windspeeds and precipitation are both hypothesized to decrease detected Common Nighthawk activity. During migratory flights, lighter winds are associated with higher observations of Common Nighthawks (Kolbe et al. 2024). Furthermore, high windspeed and precipitation can affect sound attenuation, reducing the ability for Common Nighthawks to be detected during sampling (Knight 2021).

Presence of a post-wildfire landscape is hypothesized to increase Common Nighthawk activity. Past studies have shown a preference by Common Nighthawks for post-disturbance habitats, including areas affecting by wildfire (Farrell et al. 2019; Knight 2021).

2.0 Methods

2.1 Study Area

Field sampling was conducted in the Halifax Backlands between 15 May - 17 September 2024. Sampling was constrained to publicly accessible lands, including the provincial Crown Lands, HRM parklands, and land held by NS Nature Trust (Figure 1). As such, the sampled study area consists of 880 ha of contiguous publicly accessible lands within the Halifax Backlands (Figure 2).

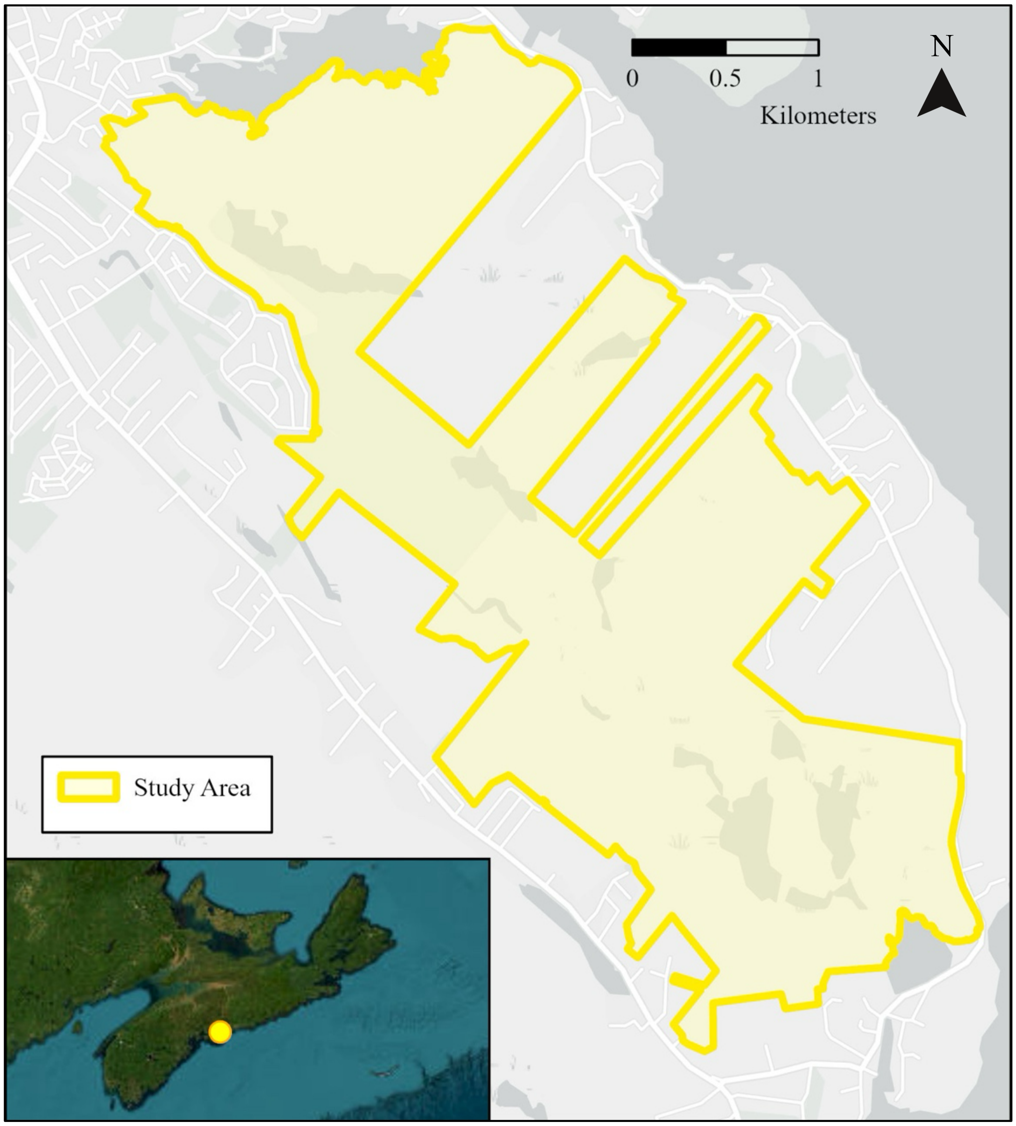

Figure 2. Spatial extent and location of the study area.

2.2 Field Data Collection

2.2.1 Autonomous Recording Units

Autonomous Recording Units (ARUs) provide a method of passive bioacoustic monitoring that can be used to research or monitor species which make distinct vocal or non-vocal sounds (Shonfield and Bayne 2017). In recent years, ARUs have become an increasingly popular method for avian monitoring and research by offering an affordable and efficient way to collect acoustic data over time (Bota et al. 2023). Data collected by ARUs is not subject to biases in traditional field monitoring, such as differences between observers (Shonfield and Bayne 2017). Given their cryptic nature, crepuscular activity, and distinctive and far-carrying sounds, Common Nighthawks are an ideal species for passive acoustic monitoring (Knight 2021).

Between mid-May to mid-September of 2024, six ARUs were deployed at various sites across the study area to sample for auditory indicators of Common Nighthawk activity (Figure 3, Table 1). AudioMoth recorders from Open Acoustic Devices were housed within IPX7 waterproof cases. Three of these ARUs were placed at season-long sites, where they sampled for the duration of the study. The other three ARUs were placed at 18 short-term sites, which were each sampled for 2-week periods between mid-May to late-August. Sampling was conducted at the short-term sites with the objective of obtaining broader insight on the spatial distribution of Common Nighthawk activity in the Backlands, while the season-long sites allowed us to investigate seasonal variation in Common Nighthawk activity.

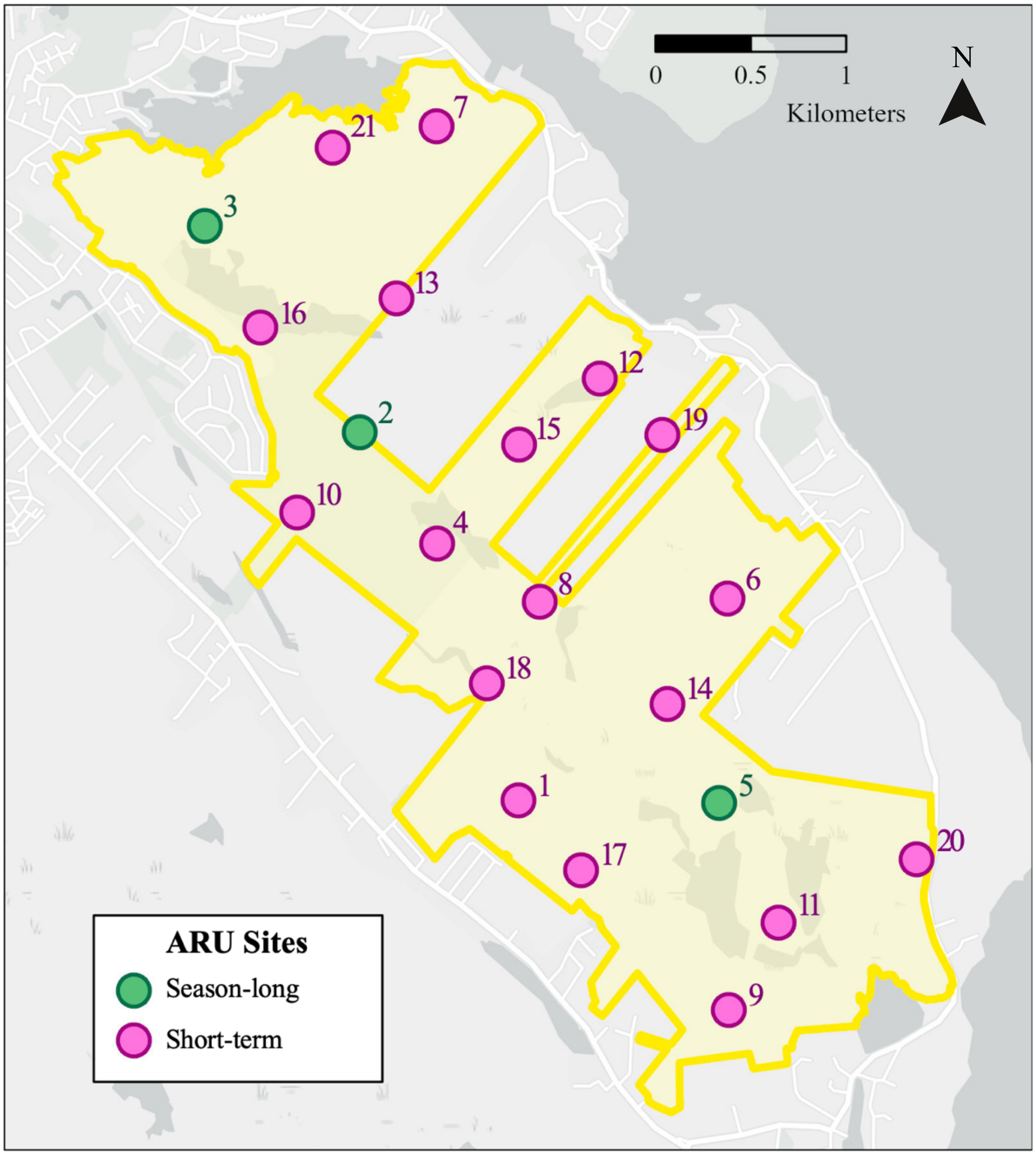

Figure 3. Locations of season-long and short-term ARU sites (Table 1). Numbers indicate the site code.

Table 1. List of ARU sites. All UTM coordinates correspond to zone 20N. Sampling periods occurred in 2024.

Site	UTM E	UTM N	Selection Method	Site Type	Sampling Period
1 - Orange Jelly	454005	4937192	Selected	Short-term	15 May - 14 June
2 - Spar	453171	4939119	Selected	Season-long	15 May - 17 September
3 - Shaw	452356	4940202	Selected	Season-long	21 May - 10 September
4 - Flat Lake	453577	4938539	Selected	Short-term	21 May - 14 June
5 - Middle Earth	455057	4937180	Selected	Season-long	21 May - 17 September
6 - Piggy Mountain	455101	4938250	Selected	Short-term	21 May - 14 June
7 - Oak Lane	453574	4940721	Random	Short-term	14 June - 28 June
8 - Duck Pond	454114	4938232	Random	Short-term	14 June - 28 June
9 - Nora	455106	4936096	Random	Short-term	14 June - 28 June
10 - Osprey	452840	4938700	Random	Short-term	28 June - 12 July
11 - Pine Island	455369	4936553	Random	Short-term	28 June - 12 July
12 - Purcells Pond	454430	4939400	Random	Short-term	28 June - 12 July
13 - Blue Jay	453362	4939822	Random	Short-term	12 July - 26 July
14 - Ghost Pine	454785	4937698	Random	Short-term	12 July - 26 July
15 - New Horizons	454008	4939057	Random	Short-term	12 July - 26 July
16 - Colpitt	452647	4939668	Random	Short-term	26 July - 9 August
17 - Casper	454332	4936826	Random	Short-term	26 July - 9 August
18 - Pond Hopper	452824	4937814	Random	Short-term	26 July - 8 Augus
19 - Sightline	454758	4939105	Random	Short-term	8 August - 23 August
20 - Blackberry	456093	4936884	Random	Short-term	9 August - 23 August
21 - Rock Garden	453027	4940609	Random	Short-term	9 August - 23 August

To align with diurnal patterns in Common Nighthawk activity, initial recording windows were scheduled for 2 h before and 2 h after both sunrise and sunset. During these recording windows, ARUs would rotate between 10 mins of recording and 10 mins off. As such, two 4 h recording windows per day would yield 240 min of recordings per ARU. However, in mid-June, the recording windows were expanded to further capture Common Nighthawk activity that had been observed during nighttime hours. The new recording window consisted of 2.5 h before sunrise to 2 h after and 2 h before sunset to 2.5 h after. Using the same 10 mins on, 10 mins off interval, the two 4.5 h recording windows per day yielded 280 mins of recordings per ARU. The expanded recording window was maintained throughout the remaining duration of the study, from mid-June to mid-September.

ARU site locations were determined using both stratified-random and non-random methods. Within the study area, six initial site locations were chosen for either having high expected Common Nighthawk activity or being points of interest to Backlands Coalition members. ARUs were deployed at these sites in mid-May and sampled for two weeks. After this period, recordings were collected and processed with Chirpity to determine relative Common Nighthawk activity between sites (Kirkland 2025). Chirpity is a software that is streamlined for simple and efficient processing of audio files to identify bird calls, including the Common Nighthawk (Kirkland 2025). The sites Spar, Shaw, and Middle Earth were selected as the season-long sites due to their high, moderate, and low relative Common Nighthawk activity respectively, as well as their broad spatial coverage across the study area. ARUs from the remaining three sites were retrieved for use at the short-term sites.

Locations for the remaining 15 short-term sites were determined using a stratified-random method. To ensure even spatial spread of sites, the study area was partitioned into three zones of equal area and five points were randomly generated within each zone. Points were generated in ArcGIS using the 'Create Random Points' tool, with a minimum allowed distance of 500 m from all other points. This minimum distance was selected to prevent overlap in audio range of ARUs, based on a conservatively high range estimate of 250 m. During each 2-week sampling interval, only one of these sites was sampled per zone. ARUs were deployed within

150 m of random points, with specific location being selected according to the factors described below.

When deploying ARUs, consideration was taken to minimize auditory disturbance to recordings while maximizing auditory range. ARUs were always mounted on conifer trees, and preference was taken for conifer stands which could optimally buffer wind. To further reduce auditory wind disturbance, ARUs were positioned to face in the direction of prevailing winds and away from leafy shrubs and deciduous trees that could produce undesirable rustling noise. An example of a mounted ARU is presented in Figure 4.

Figure 4. Example of mounted ARU. Image captured on 11 July 2024 at site Middle Earth.

During ARU deployment, UTM coordinates were collected using a Garmin eTrex GPS, and photos of the mounted ARU and surrounding environment were captured. All data was recorded on a data sheet, which is presented in Appendix A.

2.2.2 Observational Surveys

Between mid-June and late-August 2024, visual observation surveys were performed at 38 sites across the study area to corroborate and expand upon data collected by ARUs. Surveys were conducted to obtain counts of Common Nighthawks, map their locations, and observe their behaviour. Surveys were 15 min in duration and conducted within a window of 45 min before to 30 min after sunset. This window was selected to maximize both potential activity and visibility of Common Nighthawks. Observers remained stationary and quiet while surveying, both listening for peents and wing-booms, and using binoculars to visually locate Common Nighthawks. A maximum of two surveys were conducted per evening, and only if weather was favorable for aerial Common Nighthawk activity. Unfavorable weather was defined as having precipitation or wind speeds exceeding 14 km/h.

During surveys, information on behaviour, peents and wing-booms, age, and location of each observed Common Nighthawk was collected and recorded on a data sheet (Appendix B). Location was recorded at onset of observation and was measured by taking the bearing and distance to each Common Nighthawk using a compass and laser range finder. If in flight, the distance was taken to the point on the ground estimated to be directly below the Common Nighthawk. Additionally, weather characteristics such as wind speed, humidity, and temperature were measured using a Kestrel 3500 Wind Meter. UTM coordinates were collected using a Garmin eTrex GPS. Details on the location, sampling date and time, and count of Common Nighthawk observations for each survey is presented in Appendix C.

Selection of visual observation survey sites was determined using a stratified-random method. To ensure even spatial spread of survey sites, the study area was partitioned into six zones of equal area. In each zone, 10 random points were generated using the ‘Create Random

Points' tool in ArcGIS and were spaced a minimum of 250 m apart. Within each zone, points were randomly assigned an identification number (PID), 1 - 10; and zones were assigned identification numbers (ZIDs), 1 - 6, corresponding to decreasing latitude. Although only six sites per zone were sampled, the additional random points were generated in case some sites were inaccessible.

To minimize seasonal effects, the order of survey site sampling followed both PID and ZID sequentially, ensuring an even spatial spread of sites across the sampling season. If a point was deemed inaccessible, a nearby unsampled point with the lowest PID was sampled instead. The precise survey site was determined in the field, by finding an accessible location within 100 m of the point with good visibility. In total, six sites per zone were sampled (Figure 5). Two additional sites were sampled in zone 2, but data from these sites were discarded to avoid spatial bias introduced by oversampling of the zone.

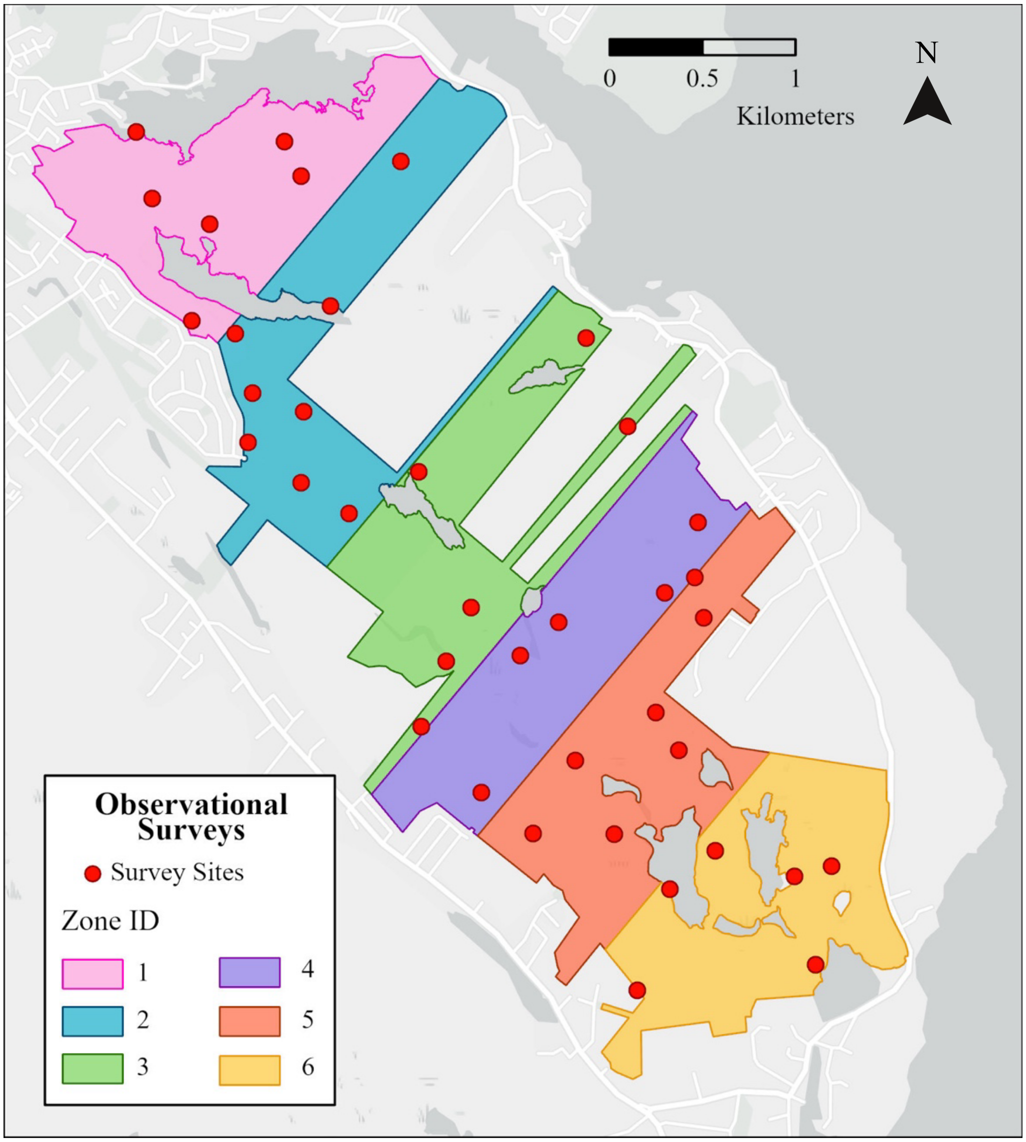

Figure 5. Observational survey sites and zones.

Spatial tools in ArcGIS were used to calculate Common Nighthawk locations from survey observation data. The ‘Bearing Distance to Line’ tool was used to generate lines extending from each survey site, using the the bearing and distance of observed Common Nighthawks. The end vertex of each line was extracted using the ‘Feature Vertices to Points’ tool, which represented the location of each observed Common Nighthawk.

2.2.3 Aerial Insect Sampling

To quantify insect prey availability to the Common Nighthawk population, a co-located study conducted aerial insect sampling in concurrence with ARU sampling at all study sites (Herold 2025). Using Pennsylvania-style light traps, order-specific biomass of nocturnal insects was collected. Light traps were deployed at sunset, and were collected the following morning at sunrise. Sampling was conducted once at each short-term site and bi-weekly at season-long sites. A comprehensive description of the insect sampling methodology can be found in "Aerial Insect Populations in the Halifax Backlands and Prey Availability to the Common Nighthawk (*Chordeiles minor*)" (Herold 2025).

2.3 Data Analysis

2.3.1 Processing Audio Recordings

The large amount of recordings collected by ARUs poses a challenge for manual processing. To address this issue, tools such as BirdNET have recently been developed to enable fast and accurate processing of large audio datasets for the purpose of avian monitoring (Kahl et al. 2021). BirdNET is a deep artificial neural learning network which can detect and classify vocalizations of over 3,000 bird species, including the Common Nighthawk (Kahl et al. 2021; Wood et al. 2022).

Audio recordings collected by ARUs were processed using BirdNET software to detect Common Nighthawk peents (Figure 6). Wing-booms were also present in the audio recordings; however, BirdNET's base model is not currently trained to detect them. The default parameters were applied in BirdNET, including no overlap of prediction segments, a sensitivity of 1, and a confidence score threshold of 0.5.

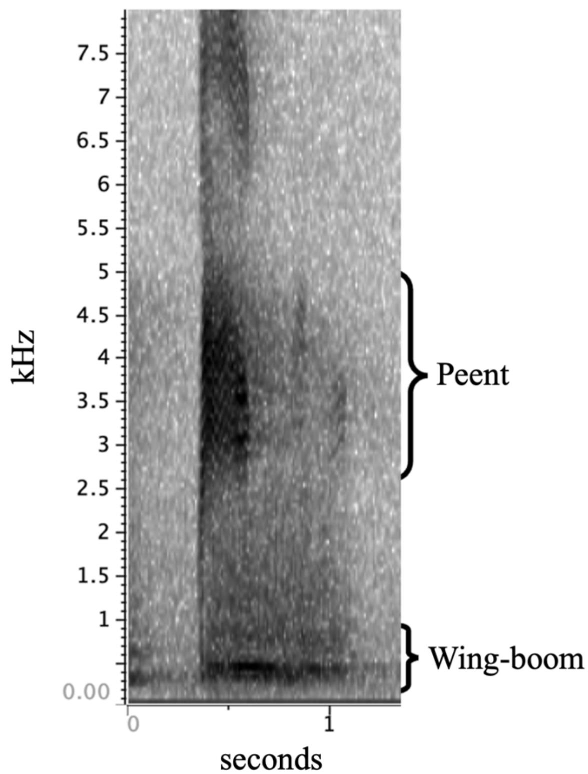

Figure 6. Spectrogram of Common Nighthawk vocal peent and non-vocal wing-boom with sound frequency (kHz) on the y-axis and time (s) on the x-axis.

BirdNET works by dividing audio recordings into 3 s segments and determining if the species of interest can be detected within that segment (Bota et al. 2023). As such, a Common Nighthawk detection can be defined as the presence of a peent within a 3 s segment of the audio recording. For analysis, the sum of detections was calculated for each 10 min recording.

2.3.2 Assessing Performance of the BirdNET Classifier

The accuracy of detections was manually evaluated for BirdNET's Common Nighthawk classifier. Performance of the classifier was determined as per the methodology described by Knight et al. (2017) and investigated two metrics: precision and recall.

A subset of 45 recordings were randomly selected from the 2024 sampling season and manually assessed for peents. Recordings were assessed in the software Raven Lite. Data for each 3 s segment of the recording was compiled into confusion matrices based on two factors: (i) if BirdNET detected a Common Nighthawk peent, and (ii) if the segment actually contained a peent. Within the confusion matrices were four possibilities: true-positive (TP), true-negative (TN), false-positive (FP), and false-negative (FN) (Figure 7) (Knight et al. 2017).

<table>
<tr><td colspan="2"></td><td colspan="2">Actual Value</td></tr>
<tr><td colspan="2"></td><td>Positive</td><td>Negative</td></tr>
<tr><td rowspan="2">BirdNET Detection Value</td><td>Positive</td><td>True Positive (TP): Common Nighthawk was detected by BirdNET and was actually present.</td><td>False Positive (FP): Common Nighthawk was detected by BirdNET but was not present.</td></tr>
<tr><td>Negative</td><td>False Negative (FN): Common Nighthawk was not detected by BirdNET but was actually present.</td><td>True Negative (TN): Common Nighthawk was not detected by BirdNET and was not present.</td></tr>
</table>

Figure 7. Confusion matrix of definitions used for assessment of classifier performance (Knight et al. 2017).

Recall can be understood as the proportion of segments that BirdNET accurately identified as containing peents, from the total number of segments that actually contained peents (Knight et al. 2017). As such, recall can be considered a measure of the BirdNET classifier's sensitivity (Knight et al. 2017), and was calculated using the following equation:

$$Recall = TP / (TP + FN)$$

Precision can be understood as the proportion of segments that BirdNET accurately identified as containing peents, from the total number of segments that BirdNET identified as containing peents (Knight et al. 2017). As such, precision can be considered a measure of the BirdNET classifier's accuracy (Knight et al. 2017), and was calculated using the following equation:

$$Precision = TP / (TP + FP)$$

2.3.3 Seasonal & Diurnal Trends

Seasonal trends in Common Nighthawk activity were analyzed using detection data from the three season-long sites. These sites were used because their consistent temporal coverage allowed for the separation of seasonal effects from spatial variation. In contrast, the short sampling duration of the short-term sites confounded seasonal and spatial effects, making them unsuitable for this analysis.

At each season-long site, detections were summed by date. For consistency throughout the season, only detections from recordings taken within a 4 hr window around sunrise or sunset were used. Data was plotted to visualize seasonal trends in Common Nighthawk peents.

Diurnal trends in Common Nighthawk activity were also analyzed using detection data from recordings at the three season-long sites. Depending on recording start time, recordings were binned by either time relative to sunrise or sunset, and averages were calculated. Data were plotted to visualize how diurnal trends varied both seasonally and spatially.

2.3.4 Spatial Distribution

Data from both ARU recordings and the observational surveys were analyzed to ascertain the spatial distribution of Common Nighthawks within the study area. Locations of Common Nighthawk sightings collected during observational surveys were analyzed in ArcGIS using kernel density analysis. A search radius of 750 m was applied to account for the high mobility of Common Nighthawks observed during surveys.

The average number of detections per recording was calculated for each ARU site. For consistency throughout the season, only recordings taken within a 4 hr window around sunrise or sunset were included. Furthermore, bias on Common Nighthawk activity caused by weather was reduced by using only a subset of recordings, which were determined using precipitation and average windspeed data collected hourly from the Shearwater RCS (ECCC 2024). Weather parameters mirrored the observational survey sampling protocol, with only recordings during hours containing no precipitation and an average windspeed below 14 km/h being used. Once the subset of detection data was derived, the mean average of detections per recording was calculated, and a log+1 transformation was applied to account for outliers. This data was then mapped to visualize spatial trends in Common Nighthawk activity.

2.3.5 Modelling

The influence of environmental characteristics on average Common Nighthawk detections at each ARU site were analyzed using a generalized linear model (GLM). All covariates included in the model represent environmental characteristics that are expected to affect the activity and distribution of Common Nighthawks. Metrics were derived from either (i) data collected in the field, (ii) LiDAR data, (iii) spatial datasets made available by the NS Department of Natural Resources and Renewables or Environment and Climate Change Canada (ECCC), or (iv) spatial datasets made available by members of the Backlands Coalition. The environmental characteristics included in the model were aerial insect biomass, elevation, vegetation height, open water and wetland, average windspeed, total precipitation, and proximity to post-fire landscape.

Aerial insect prey abundance was measured as dry biomass of the insect orders Coleoptera, Trichoptera, Lepidoptera, and aerial Hymenoptera collected by the light traps at each site (Herold 2025). These insect orders were selected for being preferred prey items to the Common Nighthawk (Brigham 1990; Danielle Todd et al. 1998; Knight et al. 2018). To further reflect prey preferences, only insects measuring >5 mm in length were included (Brigham and Barclay 1995).

LiDAR data were used to derive elevation and three measures of vegetation height. This data consisted of a 1 m spatial resolution digital elevation model (DEM) and a digital surface model (DSM) collected in 2018, which was obtained from Halifax Open Data (Halifax Data, Mapping & Analytics Hub 2018). Mean elevation around each site was calculated in ArcGIS using the 'Zonal Statistics as Table' tool. A radius of 250 m was used for this calculation, as this is the estimated auditory range of the ARUs.

Three measures of vegetation height were derived from the LiDAR DEM and DSM using ArcGIS. Before processing, areas of open water were removed from the DEM and DSM to avoiding biasing the data. First, canopy height was estimated by subtracting the DSM values from the DEM values using the 'Raster Calculator' tool (ArcMap 2021). Mean canopy height within a 250 m radius of each site was then calculated using the 'Zonal Statistics as Table' tool. Next, two measures of bare ground were estimated from the canopy height data. Bare ground was defined as either (i) area where canopy height was less than 0.15 m, or (ii) area where canopy height was less than 0.3 m. Both measures of bare ground were calculated as the proportion of bare ground within a 250 m radius of each site. Due to the high correlation between these three variables, only one was selected to be included as a covariate in the model. This selection process is described later in this section.

A metric of open water and wetlands was derived in ArcGIS using two datasets made available by the NS Department of Natural Resources and Renewables. First, polygons of open water and wetlands estimated from satellite imagery were extracted from the NS Forest Inventory dataset (NS Department of Natural Resources and Renewables 2021). Second, areas where depth to water table was less than or equal to 0.5 m were extracted from the NS Wet Areas Mapping dataset (NS Department of Natural Resources and Renewables 2012). These two datasets were joined using the ‘Merge’ and ‘Dissolve’ tools, to create an overall estimate of open water and wetlands in the Backlands. The metric was calculated as the proportion of open water and wetlands within a 250 m radius of each site.

Average windspeed and total precipitation were determined using hourly weather data collected at the Shearwater RCS weather station (ECCC 2024). Only weather data collected within two hours of sunrise or sunset were included. The mean average hourly windspeed was calculated for the two-week sampling period at each site. Similarly, the total precipitation was also calculated for the two-week sampling period at each site.

In 2009, a major wildfire burned a large extent of the Halifax Backlands (CBC News 2009). A map of the extent of the area burned during this fire, provided by David Patriquin (personal communication, 2025), was used to determine proximity to post-fire landscape for each site. The map was georeferenced in ArcGIS, and a polygon was drawn around the areas marked as burned. Each site was then classified as either ‘inside’ or ‘outside’ the burned area and included as a categorical variable for the model.

The response variable, average daily Common Nighthawk detections, was calculated for each short-term site across its two-week sampling period. Data from the season-long sites were also incorporated by randomly selecting a single two-week sampling period, referred to as a 'session', that aligned with the sampling schedule of the short-term sites. A different session was selected for each season-long site to avoid overrepresenting any sessions in the model. A log+1 transformation was then applied to the average daily Common Nighthawk detections to achieve a normal distribution of values.

Two temporal variables were also derived, month and session number. Month was determined by the central date within each sampling session. The temporal factor used in the final model was selected as per the covariate selection process described below.

To select between highly related variables, candidate covariates were individually tested in separate GLMs fitted with a Gaussian family and compared using Akaike Information Criterion (AIC) values. First, each measure of vegetation height was evaluated by fitting a GLM, and the model with the lowest AIC was selected. The same process was used to compare temporal factors. After selecting the candidate covariates, a correlation matrix was constructed to confirm the absence of strong collinearity among the explanatory variables.

Once all covariates were selected, the final model was determined using an iterative backward elimination process, where non-explanatory variables were removed based on AIC reduction. The initial GLM included all eight candidate covariates. In each iteration, the least explanatory covariate was then removed, and the model was refitted. This process was repeated until no further reduction in AIC was achieved, at which point the best fit model was identified.

3.0 Results

3.1 Field Observations

During the 36 observational surveys conducted between 12 June - 24 August 2024, a total of 55 visual observations of Common Nighthawks were recorded (Figure 8a). Additionally, wing-booming behaviour was visually observed at 13 locations (Figure 8b). When also including aural-only observations, when Common Nighthawks were heard but not seen, a total of 81 observations were recorded, as well as 15 observations of wing-booming. Maps displaying the additional aural-only observations alongside visual observations are presented in Appendix D.

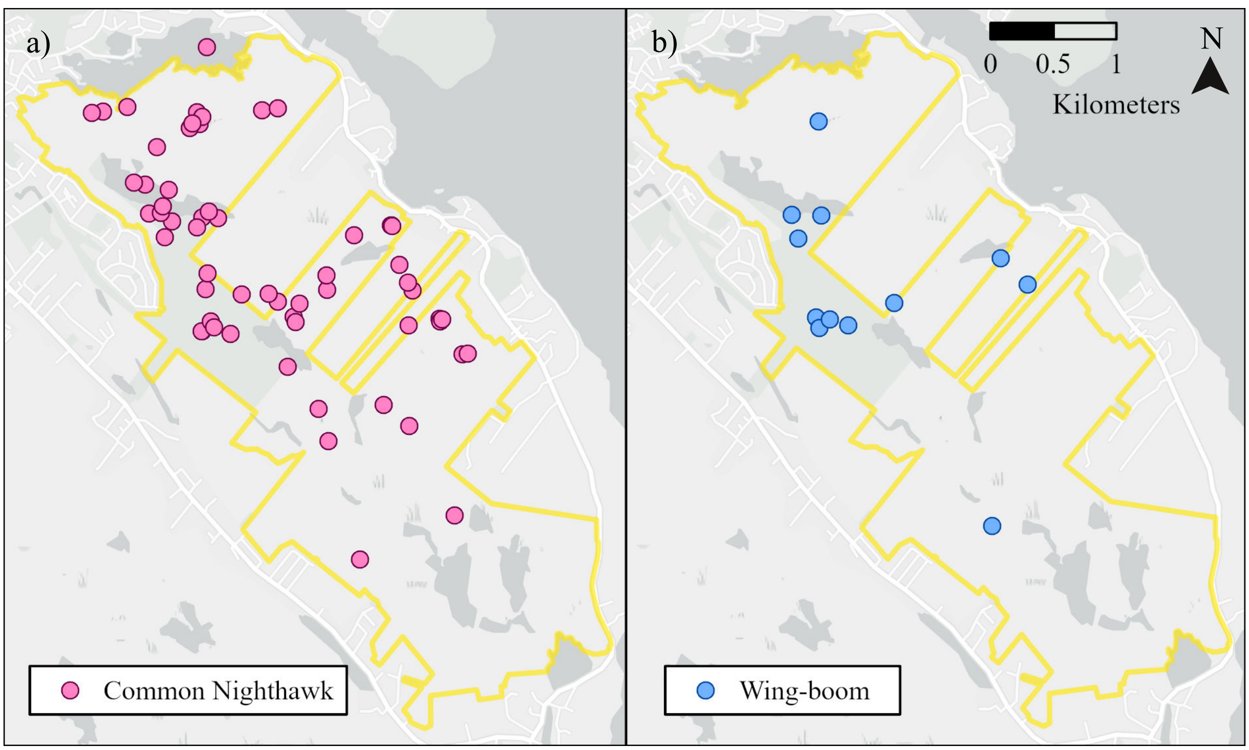

Figure 8. Locations of a) Common Nighthawk and b) wing-boom observations collected during observational surveys.

3.2 Performance of the BirdNET Classifier

Across the 45 10 min recordings that were manually assessed, 10 recordings and 543 3 s segments were identified as containing Common Nighthawk peents. Of the 543 segments, 330 were true positives, zero were false positives, and 213 were false negatives. As there were no instances of false positives identified, overall precision of the BirdNET Common Nighthawk classifier was found to be 100%. Recall was estimated to be 61%, indicating that over half of all segments containing peents were correctly identified by BirdNET's Common Nighthawk classifier.

3.3 Seasonal & Diurnal Trends in Activity

Trends in Common Nighthawk activity across the duration of the sampling season are presented in Figure 9. At all three season-long sites, Common Nighthawk activity was highest in mid-July through to early August, with less activity overall in May and June. Consistently, Spar saw the highest detection rate (mean: 444.16 per day, ± 35.40), followed by Shaw with an intermediate detection rate (mean: 82.42 per day, ± 8.78), and Middle Earth with a comparatively low detection rate (mean: 1.54 per day, ± 0.58).

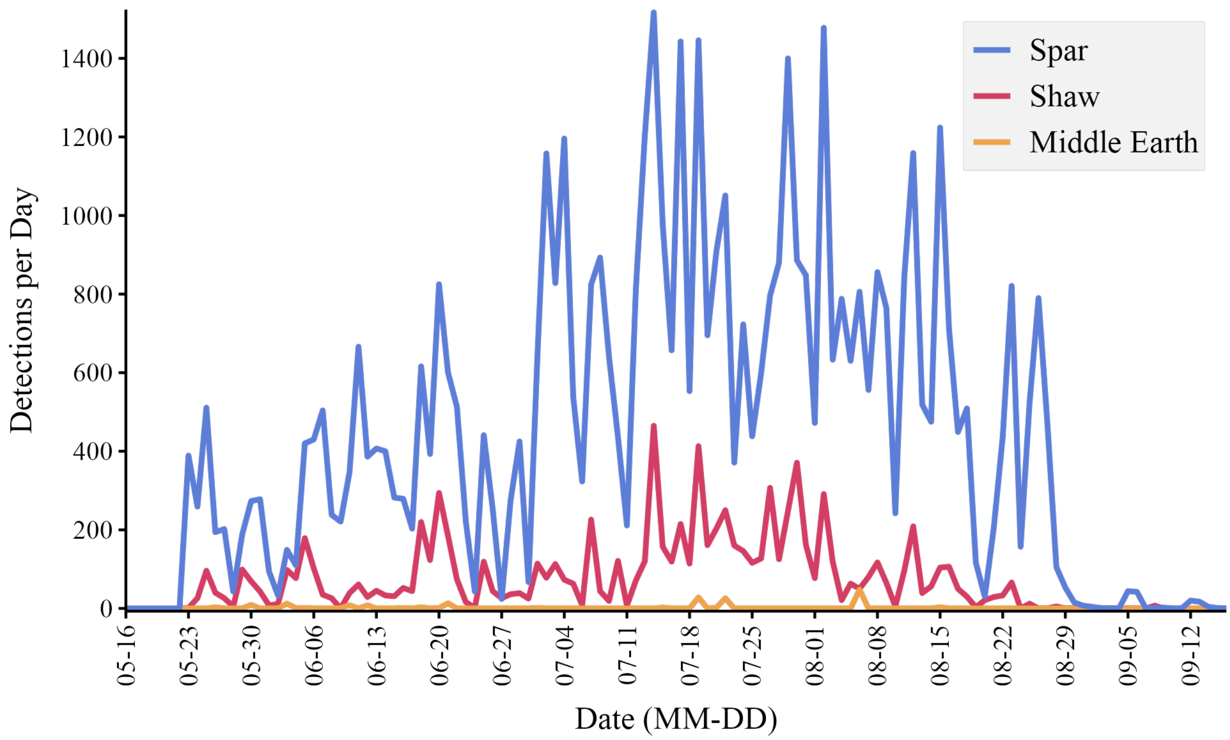

Figure 9. Seasonal trends in Common Nighthawk activity at the three season-long sites. Detections per day are the sum of BirdNET detections from 240 min of recordings at each site.

During the 2024 breeding season, Common Nighthawks were first detected in the Halifax Backlands on 23 May and remained until 15 September (Figure 9). However, most Common Nighthawks departed the area in late August, as illustrated by a rapid decline in activity at all three sites.

Diurnal trends in Common Nighthawk activity between 22 June - 31 August 2024 at the three season long sites are presented in Figure 10. Although differing in magnitude, diurnal activity is shown to follow similar patterns at site Spar and Shaw. At both sites, activity peaks at sunset and about an hour before sunrise, with activity around sunset being slightly greater. At site Middle Earth however, dawn activity is very low, and dusk activity is shown to peak an hour before sunset.

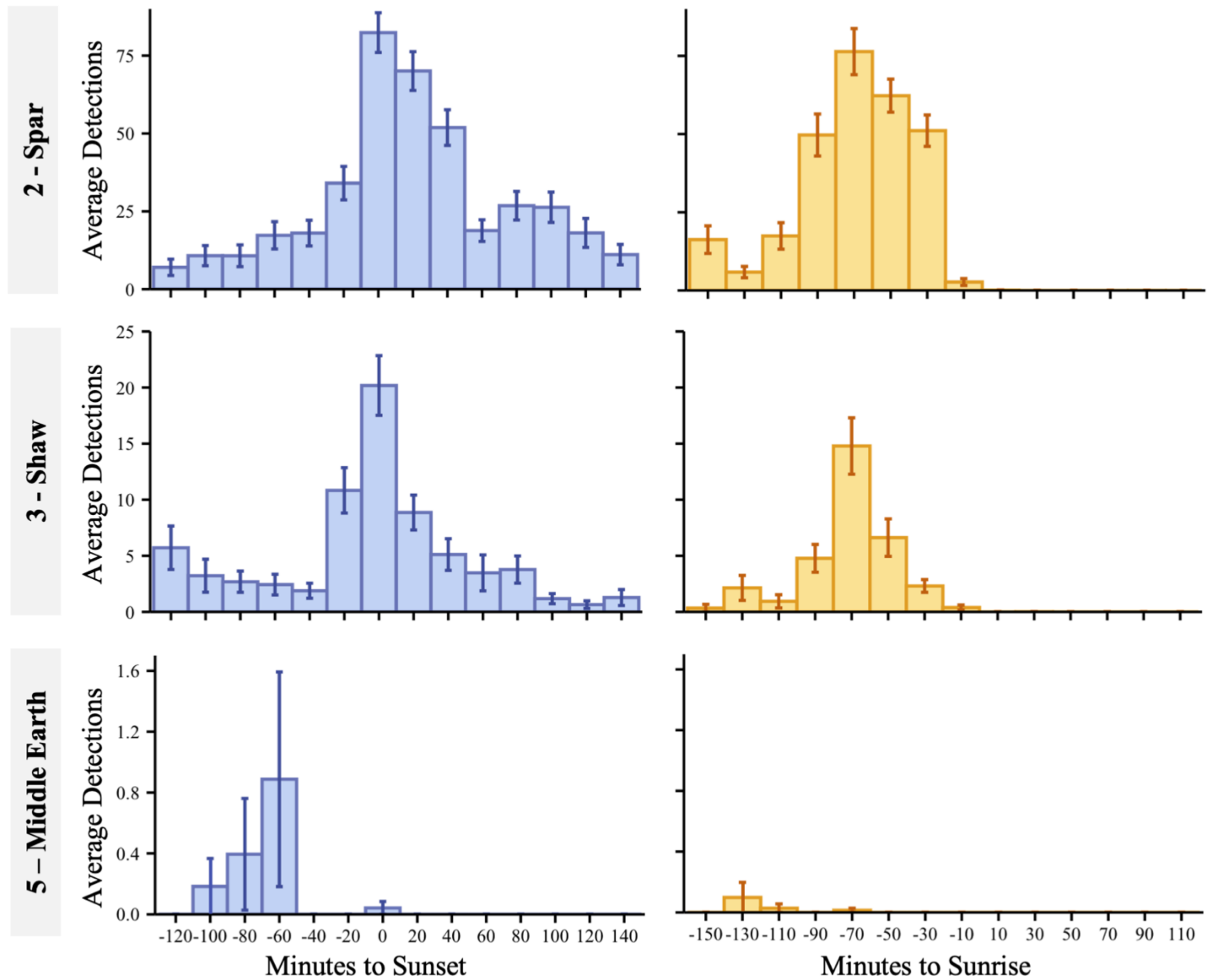

Figure 10. Diurnal trends in Common Nighthawk activity across season-long sites. Recordings captured between June 22-August 31, 2024. Error bars represent standard error. Note the y-axis scale is different between sites.

Diurnal trends in Common Nighthawk activity during each month of the sampling season are presented in Figure 11. Insufficient detection data was available to present diurnal trends in September. Diurnal activity displays similar trends across months. Notably, activity during the two hours prior to sunset was considerably higher during July than any other month.

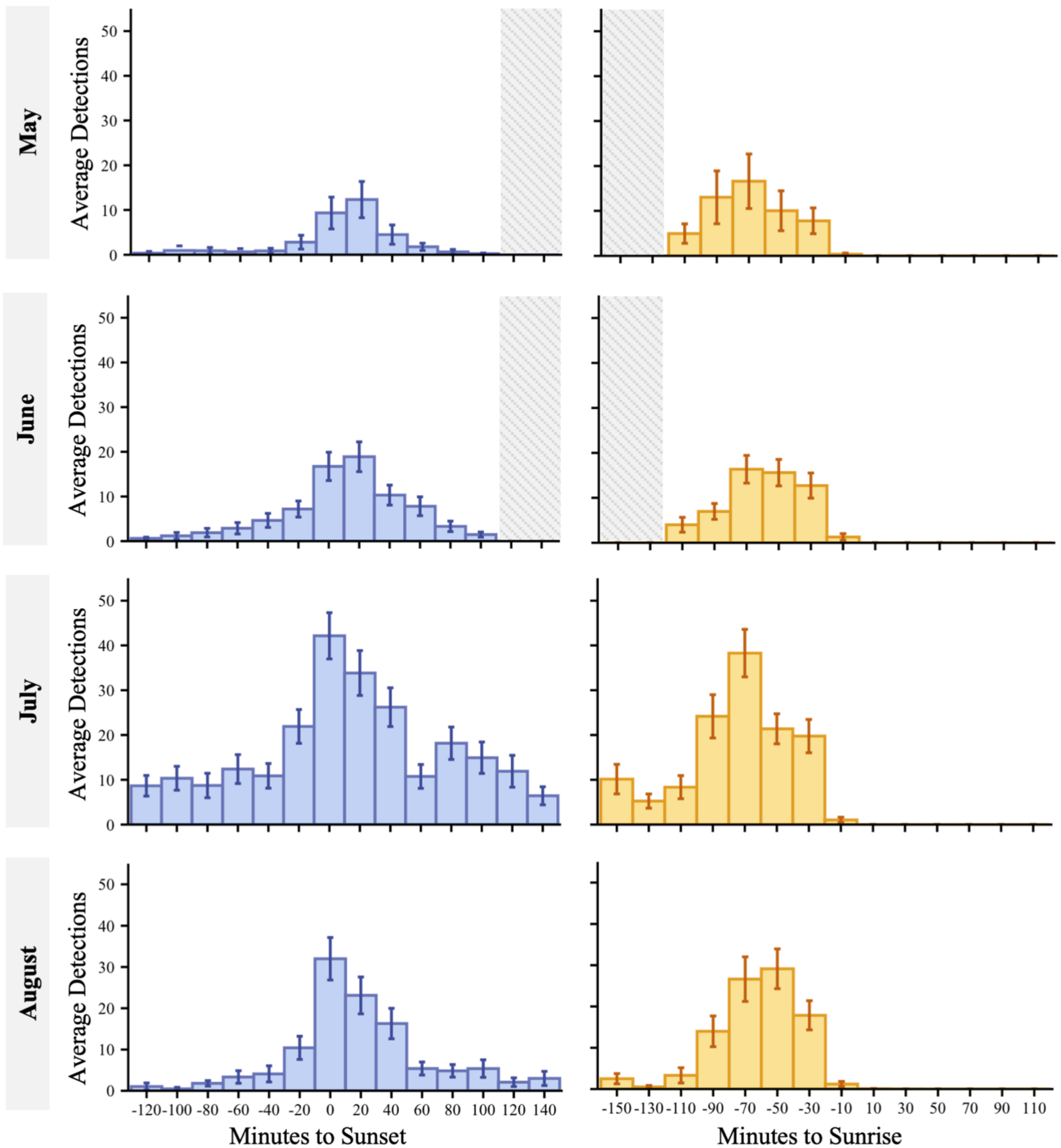

Figure 11. Diurnal trends in Common Nighthawk activity by month. Detections were averaged across the three season-long sites. Error bars represent standard error. Area greyed out where data were unavailable.

3.4 Spatial Distribution

3.4.1 Detections at Study Sites

A heat map showing the average Common Nighthawk detections per audio recording (log+1 transformed) at each study site is presented in Figure 12. Detections were found to be greatest in the northern portion of the Backlands, with the southern portion showing low Common Nighthawk vocal activity overall. In particular, the short-term site New Horizons and the season-long site Spar are located closely to each other and had the highest activity. The three sites located farthest south in the Backlands (Nora, Pine Island, and Blackberry) all had zero detections.

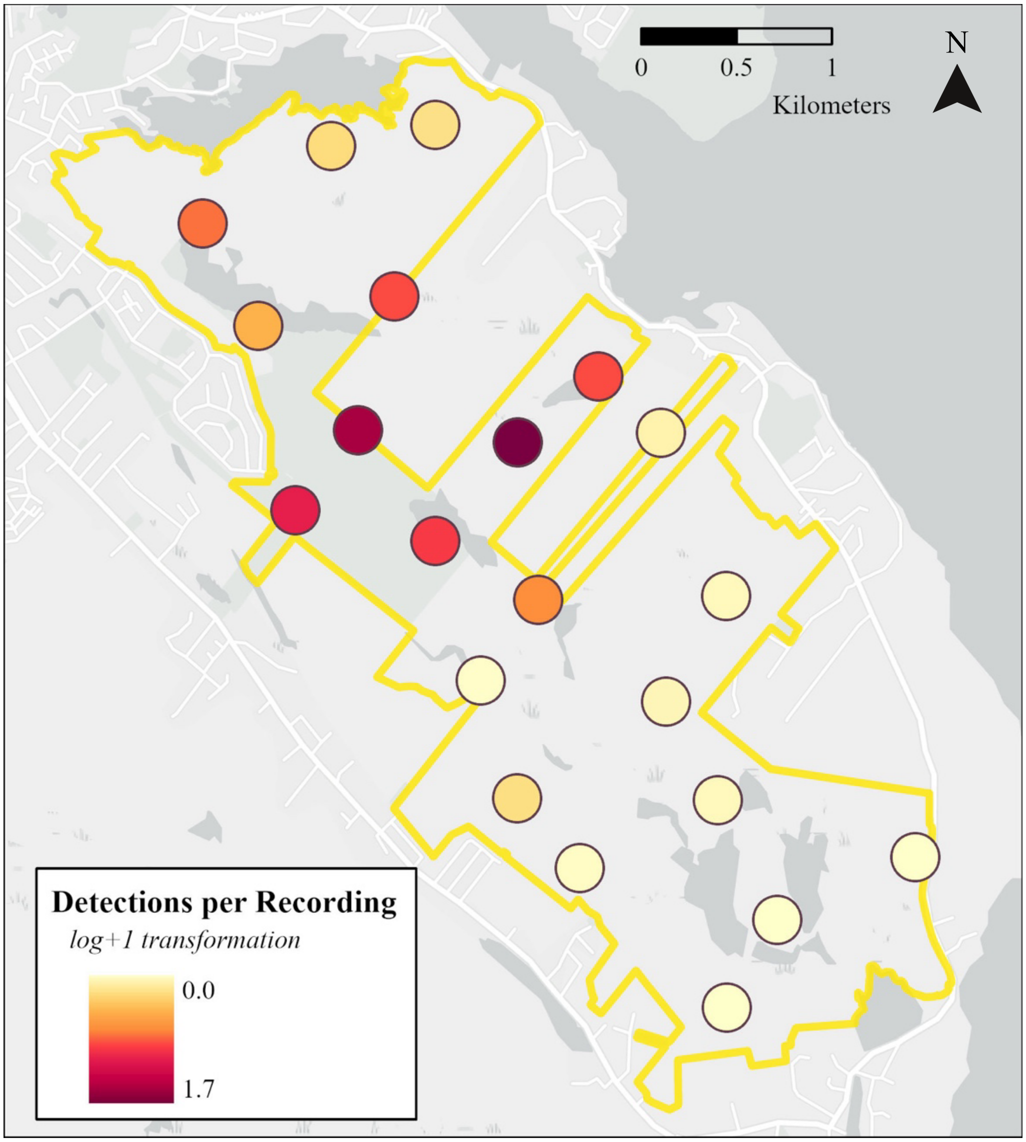

Figure 12. Average Common Nighthawk detections per recording at the study sites. A log+1 transformation has been applied to the data.

3.4.2 Kernel Density Analysis

A kernel density analysis of visual Common Nighthawk observations is presented in Figure 13. Similarly to the results for audio recordings (Figure 12), visual observations of Common Nighthawk activity were greatest in the northern portion of the Backlands, and no Common Nighthawks were observed in the southernmost portion of the Backlands.

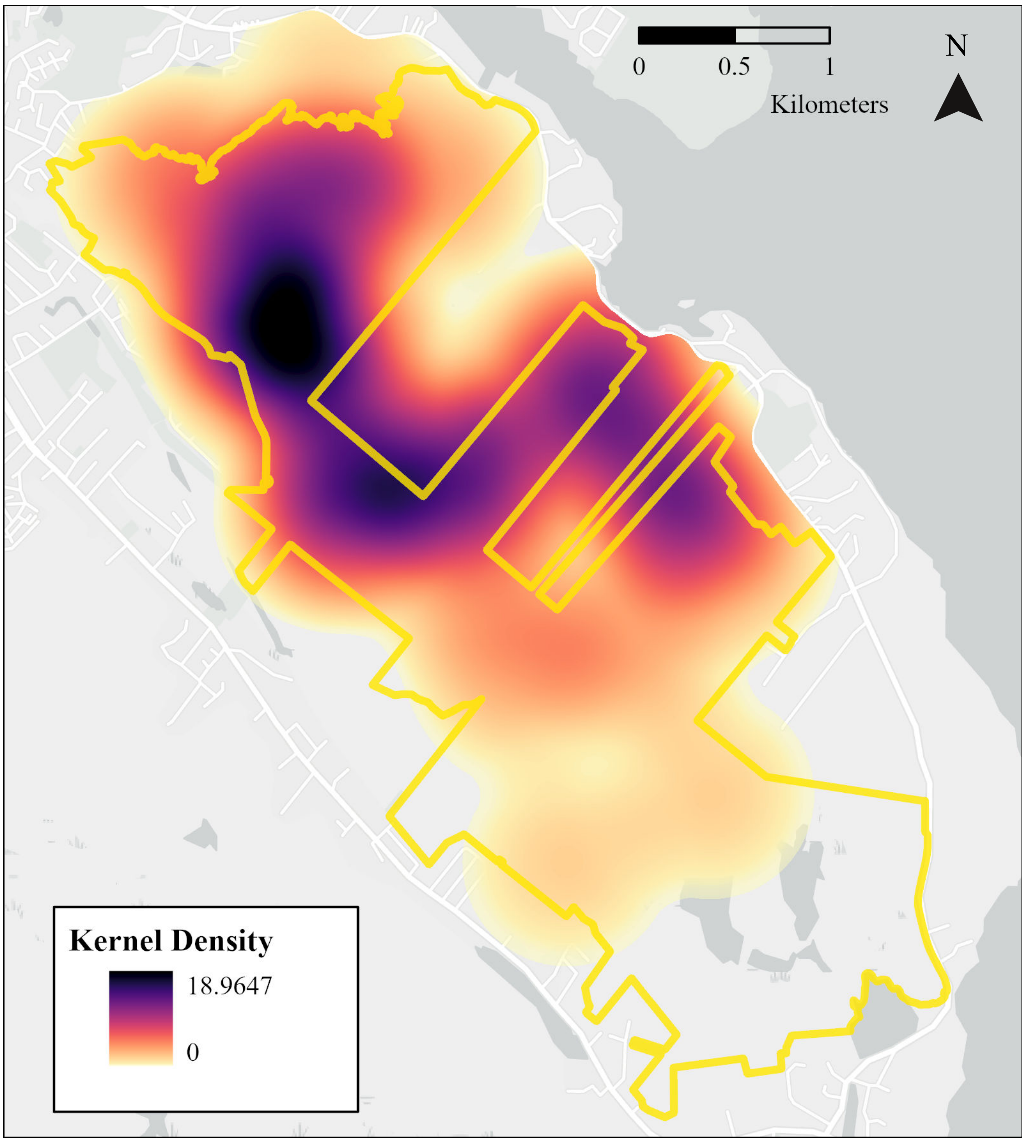

Figure 13. Kernel density analysis of Common Nighthawk observations.

3.5 Generalized Linear Model

A GLM was used to better understand the environmental drivers of Common Nighthawk abundance in the Halifax Backlands. To select between highly related covariates, models were compared using AIC (Table 2). Among the measures of vegetation height, the model including proportion of bare ground below 0.3 m yielded the lowest AIC (41.829) and was therefore selected. Similarly, when comparing temporal units, the model including month as a categorical variable outperformed the model using recording session and was therefore retained.

Table 2. Summary of GLM results for selection of covariates.

Covariate of Interest	**K**	**AIC**
Measures of vegetation height		
Proportion bare ground (below 0.15 m)	8	46.457
Mean canopy height	8	42.722
Proportion bare ground (below 0.3 m)	8	41.829
Temporal factors		
Session	8	43.757
Month	8	41.829

An iterative backward elimination process was then used to identify the most parsimonious model (Table 3). Removing open water and wetlands, wildfire zone, and total precipitation all reduced the AIC values, with Model 4 (AIC = 38.016) being the best fit model.

As presented in Table 4, this model retained five explanatory variables: month, aerial insect biomass, average windspeed, mean elevation, and proportion of bare ground.

Table 3. Results of the GLMs for determining the best fit model using an iterative backward elimination process.

Model	**Covariate removed**	**K**	**AIC**
Null Model	All covariates removed	0	61.500
Model 1	-	8	41.829
Model 2	Open water and wetlands	7	39.895
Model 3	Wildfire zone	6	38.911
Model 4	Total precipitation	5	38.016
Model 5	Average windspeed	4	42.741

Table 4. Summary of the best fit model results.

Covariate	**Coefficient**	**Standard Error**	**t-value**	**p-value**
Intercept	-2.5	0.63	-3.95	0.002
Month (July vs August)	1.58	0.39	4.04	0.001
Month (June vs August)	0.63	0.42	1.52	0.152
Insect Biomass	-0.21	0.08	-2.74	0.017
Average Windspeed	0.10	0.04	2.28	0.040
Mean Elevation	0.06	0.01	5.59	<0.001
Proportion Bare Ground	2.22	0.96	2.31	0.038

Model assumptions were assessed through diagnostic plots, including residuals vs fitted values, normal Q-Q plot, scale-location plot, and Cook's distance. Residuals were approximately normally distributed and homoscedastic, and no influential outliers were detected.

As presented in Table 4, of the environmental variables retained in the best fit model, mean elevation was found to be the most strongly explanatory (p-value<0.001). However, insect biomass (p-value=0.017), proportion of bare ground (p-value=0.038), and average windspeed (p-value=0.040) were all found to be significantly explanatory as well.

Descriptive scatterplots and boxplots of the response variable against each retained explanatory variable are presented in Figure 14. The scatterplots show a positive correlation between average daily Common Nighthawk detections (log+1 transformed) and insect biomass, mean elevation, and proportion of bare ground. However, no correlation between average windspeed and the response variable is evident. The boxplot shows average daily Common Nighthawk detections as highest in July, followed by June, and then August.

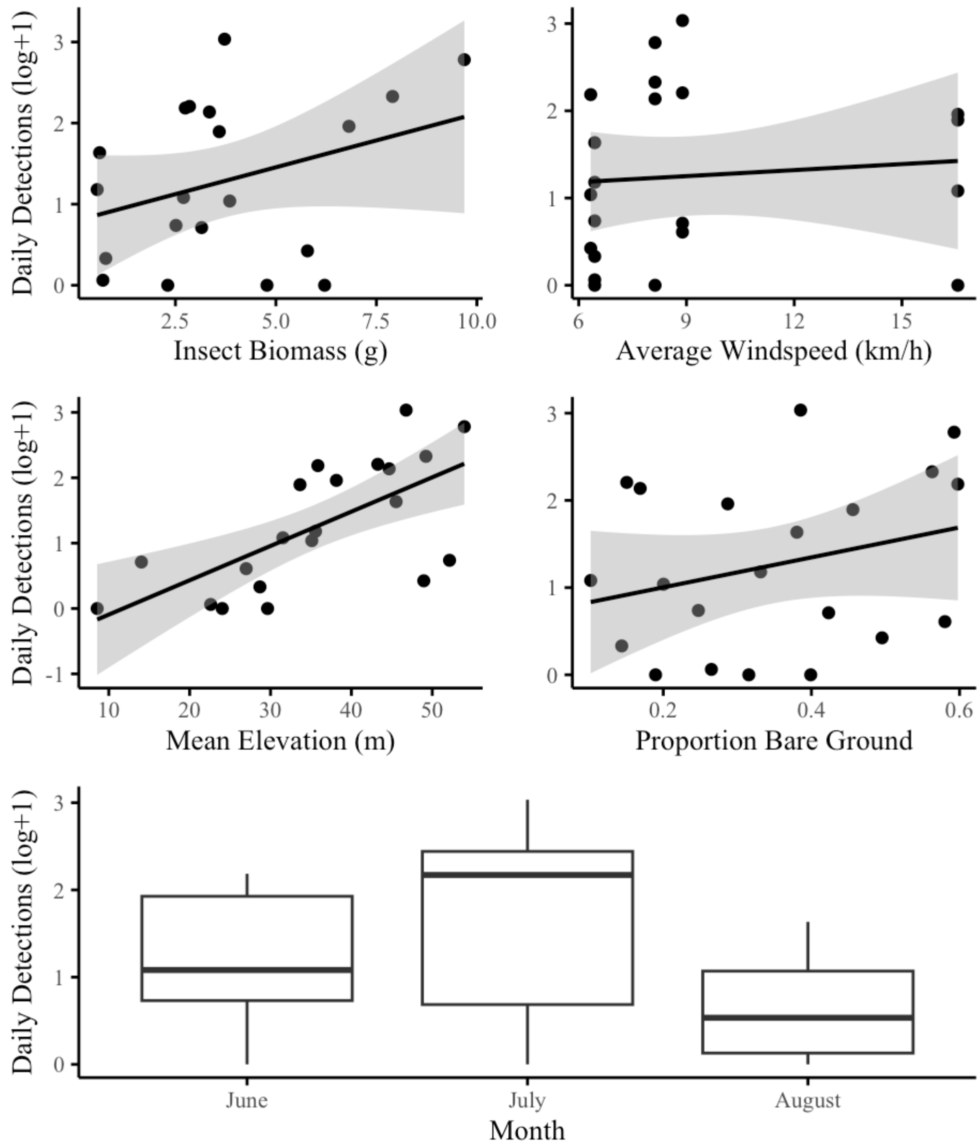

Figure 14. Descriptive plots of the response variable (log+1 of daily Common Nighthawk detections) and the five covariates retained in the best fit model.

The modeled relationships between average daily Common Nighthawk detections (log+1 transformed) and the retained explanatory variables are illustrated in Figure 15. Effect plots show the modeled relationship between each explanatory variable and Common Nighthawk activity while accounting for the effects of the other covariates.

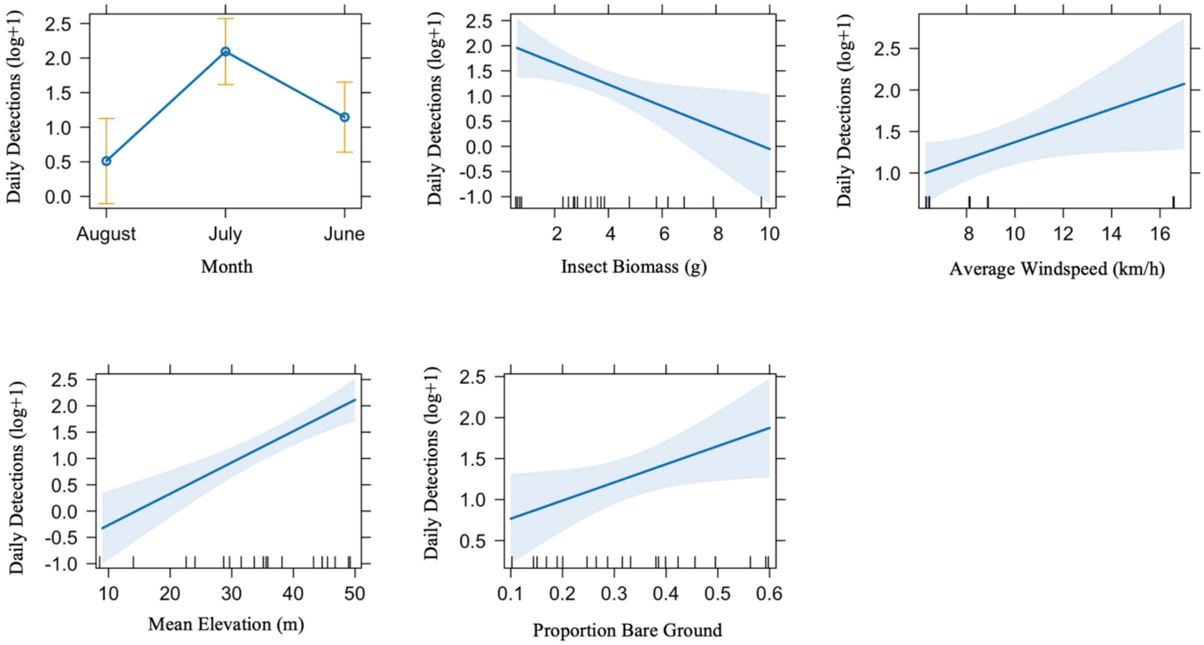

Figure 15. Effect plots for all covariates retained in the best fit model. Shaded regions represent 95% confidence intervals.

As presented in Figure 15, in the best fit model, average windspeed, mean elevation, and proportion of bare ground all showed a positive relationship with average daily Common Nighthawk detections (log+1 transformed). The effect plot for insect biomass, however, shows a negative relationship with Common Nighthawk activity. The effect plot for month shows July as having the highest detections, followed by June, then August.

When comparing between the scatterplots and boxplots presented in Figure 14, and the effect plots in Figure 15, the relationship with Common Nighthawk detections is consistent for month, mean elevation, and proportion of bare ground. For windspeed however, the model reveals a positive relationship with detections. However most notably, the relationship between insect biomass and detections changes once accounting for the effects of the other covariates, with the scatterplot indicating a positive relationship, but the effect plot indicating a negative relationship.

4.0 Discussion

This study explored the spatial ecology of Common Nighthawks within the Halifax Backlands. I found that Common Nighthawk activity was greatest in the northern portion of the Backlands, and that prey abundance, elevation, and bare ground were all influential in this distribution. Furthermore, I found that activity varied across the season, beginning in late-May, peaking in July, and then ending in mid-September. Diurnal trends in activity were found to show similar trends spatially and seasonally, with peaks in activity during sunset and an hour before sunrise.

4.1 Common Nighthawks in the Halifax Backlands

4.1.1 Seasonal Trends in Activity

During their 2024 breeding season, Common Nighthawks were first detected by the ARU located at Spar on 23 May, and remained highly active in the area until 31 August. Although late August saw a steep decline in activity, the ARU at Spar continued to detect Common Nighthawk peents until the morning of 15 September. These findings aligned with other reports of Common Nighthawk fall migration from across southern Canada, which suggest that the species departs southward between mid-August and mid-September, with the fall migration peaking in late-August (Sidler 2017; COSEWIC 2018; Ng et al. 2018). Although there is greater variation in the reported timing of Common Nighthawk arrival at breeding grounds following their spring migration, reports from across southern Canada suggest this occurs sometime between early-May to mid-June (Coady 2007; COSEWIC 2018; Ng et al. 2018). The 23 May arrival of Common Nighthawks to the Backlands falls squarely within this timeframe. Overall, these findings suggest the arrival and departure of Common Nighthawks in NS could follow similar timing to populations of Common Nighthawks along similar latitudes in North America.

I found that Common Nighthawk activity peaked in mid-July to early-August, with the highest number of detections recorded at a season-long site on 14 July, and the second highest on 2 August. Past research on Common Nighthawks in central and northern Canada found that activity peaks in the middle of their breeding season (Ng et al. 2018), however my findings show peaks in activity nearer to the end of the breeding season. This is more closely aligned with findings from another study in NS, which showed a similar peak in Common Nighthawk activity in late-July (Shaver 2023). I suggest that the increase in activity detected in mid-July may correspond with the onset of juvenile vocal activity, while the end of this high activity period likely indicates the departure of the first Common Nighthawks on their southward migration.

4.1.2 Diurnal Trends in Activity

While the peaks in activity near dawn and dusk are consistent with crepuscular behaviour, they vary somewhat from other studies on diurnal trends in Common Nighthawk activity. In a study conducted by Ng et al. (2018), the diurnal activity of Common Nighthawks in central Canada was bimodally distributed, with peaks an hour after both sunset and sunrise. Furthermore, activity was considerably lower at dusk, with the greatest activity occurring during dawn. In contrast, I found that activity in the Backlands peaked at sunset and about an hour before sunrise, and that activity at dusk was slightly higher than at dawn. Latitude has been shown to influence diurnal trends in Common Nighthawk activity (Ng et al. 2018), however this is unlikely to be the reason for these contrasting results, as both studies were conducted along similar latitudes. It is possible that variation in anthropogenic activity, including light pollution, may be a driver for the differences in diurnal trends at the study locations, however there is currently limited research to support this connection.

Notably, the diurnal trends observed at Middle Earth were considerably different than those at Shaw and Spar. While it is possible that this difference may be due to spatial effects, such as a difference between nesting and foraging grounds, it is more likely that the overall low activity of Common Nighthawks at Middle Earth made it difficult to accurately capture diurnal activity patterns.

4.1.3 Spatial Distribution

Both the ARUs and observational surveys found similar spatial distribution of Common Nighthawks, with the greatest activity occurring in the northern part of the Backlands. Although there are small inconsistencies between the findings from the ARUs and the observational surveys, these are likely due to the limitations of each sampling method. Through drawing insights from both the ARU data and the observational surveys, we can develop a clearer understanding of Common Nighthawk activity across the Backlands.

Identifying nesting areas and distinguishing them from areas only used for foraging may be valuable in informing future monitoring or conservation efforts. Although no nests were observed in the field, wing-booming typically occurs near nesting sites (Knight et al. 2022). Given the numerous observations of wing-booming near Spar, as well as the persistently high activity of Common Nighthawks at the study site, it is likely that the area around this site serves as nesting grounds.

Clusters of wing-booming observations were also present along the south shore of Colpitt Lake, and the kernel density analysis shows high activity around the area. However, the ARU placed at study site Colpitt between 26 July and 9 August 2024, had relatively low detections compared to nearby ARUs. Although these findings suggest that there may have been another nesting site in this area, they are inconclusive.

The site New Horizons had the highest recorded Common Nighthawk activity by far. This may have been due in part to its sampling period, which spanned from 12 July to 26 July 2024 and coincided with the seasonal peak in activity. However, the relatively high kernel density at the location as well as its position amongst other high activity sites supports that this site has high importance for Common Nighthawks in the Backlands. While the lack of observed wing-booms near the study site suggests that there were no nearby nesting grounds, the area around New Horizons may be highly important as foraging grounds.

4.1.4 Explanatory Factors of Activity

Four environmental variables were found to be significant drivers of Common Nighthawk activity in the GLM. The most significant variable was mean elevation within a 250 m radius of each study site, which had a $p\text{-value}<0.001$. This supported the hypothesis that elevation would have a positive relationship with Common Nighthawk activity. However, there is currently no literature linking elevation to Common Nighthawk activity, and it is unclear why this relationship exists in the Halifax Backlands.

Biomass of large aerial insects was also found to be a driver of Common Nighthawk activity in the Backlands ($p\text{-value}=0.017$). Although insect biomass showed a positive relationship with Common Nighthawk activity in the scatterplot, the model suggested that insect biomass actually had a negative effect, which does not support the hypothesis that Common Nighthawk activity will be higher in areas of high insect biomass. One interpretation of these conflicting findings are that Common Nighthawks are drawn to areas with high prey availability and are exerting top-down trophic control on the insect population in the Backlands. However, further research would be necessary to investigate this.

Another significant driver of Common Nighthawk activity was the proportion of bare ground within a 250 m radius of a study site (p-value=0.038). This supports the hypothesis that large areas of bare ground will increase Common Nighthawk activity. This finding is aligned with existing research, which suggests that bare ground is important for nesting (COSEWIC 2018; Knight 2021). Open areas associated with bare ground may also support foraging, making it easier for Common Nighthawks to maneuver and locate prey while feeding on the wing (Brigham and Barclay 1995).

Average windspeed was also found to influence Common Nighthawk activity in the model (p-value=0.040). This effect was found to be positive, which does not support the hypothesis that increasing windspeed would correspond with a decrease in Common Nighthawk activity. It is possible that for most of the season, average windspeeds may not have been high to suppress activity, while moderate windspeeds could have had a positive effect on activity. However, further research would be necessary to investigate this.

Proximity to post-fire landscape, open water and wetlands, and total precipitation all had no significant effect on Common Nighthawk activity in the model. Although existing research has established a connection between post-disturbance landscapes, such as areas burned by wildfire, and Common Nighthawk habitat, there was no evidence that Common Nighthawks had preference for areas burned by the 2009 fire in the Backlands. As such, the hypothesis that proximity to post-fire habitat would increase Common Nighthawk activity was not supported. One possible explanation comes from Farrell et al. (2019), who found that Common Nighthawks tend to prefer post-disturbance habitats that are less than 10 years old. As the wildfire occurred 15 years prior to the sampling period, the burned area may no longer exhibit the post-disturbance habitat characteristics typically associated with increased Common Nighthawk activity.

Precipitation did not have a significant effect in the model, which did not support the hypothesis that precipitation would decrease Common Nighthawk activity. This may be due to the low overall precipitation during the study period, with only two of the six sessions having any rainfall around dawn or dusk. Because the majority of sites recorded zero precipitation, there was limited variation in this variable, likely reducing its ability to explain patterns in activity.

Finally, the proportion of open water and wetlands within a 250 m radius of each site was the least explanatory covariate, a finding which did not support the hypothesis that nearby open water and wetlands would increase Common Nighthawk activity. Although research suggests that water bodies may provide desirable foraging habitat for Common Nighthawks (Ouellet 1974), it is possible that the high availability of open water and wetlands in the Backlands means that this is not an important driver for Common Nighthawk activity here.

4.2 Recommendations for Future Monitoring & Conservation

4.2.1 Future Monitoring Strategies

Continued monitoring of Common Nighthawks in the Backlands would be valuable for understanding long-term population trends and informing conservation strategies. Both sampling methods used in this study have benefits and limitations, and due to this, I suggest a mixed-method approach for future monitoring.

Given their distinctive, far-carrying sounds and crepuscular behaviour, Common Nighthawks are well-suited for monitoring using ARUs (Knight 2021). ARUs provide an efficient and repeatable method for data collection that avoids biases associated with traditional field surveys, such as differences between human observers (Shonfield and Bayne 2017). Furthermore, ARUs can be used to monitor other bird, frog, and bat species concurrently.

In the Backlands, the study sites Spar and New Horizons recorded the highest levels of Common Nighthawk activity. As such, I recommend that future monitoring efforts continue to deploy ARUs at these sites. Furthermore, I recommend that ARUs are placed at Shaw and Middle Earth to allow for analysis of year-to-year variation in Common Nighthawk activity. Although overall activity was low at Middle Earth, continued monitoring at this site would be valuable for detecting potential changes in habitat use within the southern portion of the Backlands.

To conserve batteries, memory, and ARU deployment effort, I recommend shortening the programmed recording window to reflect diurnal patterns in Common Nighthawk activity. At dusk, ARUs should be programmed to record from 2 h before to 2 h after sunset. At dawn, a shorter recording window of 2 h before to 30 min after sunrise is recommended, as I found that activity tended to decline rapidly after sunrise. In both cases, ARUs should continue recording using a 10 min on and 10 min off schedule to balance data collection with resource efficiency.

Although conducting observational surveys requires greater effort than sampling with ARUs, it can provide valuable information that ARUs cannot capture, such as counts and behavioral observations. Based on my findings, I recommend conducting surveys during sunset, as Common Nighthawk activity was consistently high during this period, and light levels remained sufficient for visual observation.

Additionally, I recommend prioritizing the area near the Spar study site, spanning between Colpitt Lake and Flat Lake, as a key location for continued Common Nighthawk surveys. This recommendation is supported by the high level of activity recorded in the area, numerous observations of wing-booming behavior, and the site's accessibility using established trails. However, expanding surveys to other areas of the Backlands would also provide valuable insights into spatial variation in habitat use.

4.2.2 Recommendations for BMPs

A beneficial management practice (BMP) describes a practice that mitigate risks posed to bird species, with the aim of eliminating negative consequences to conservation (Government of Canada, 2023). This section outlines recommendations for BMPs to conserve Common Nighthawks in the Halifax Backlands.

Due to the Backlands' expansive wilderness and close proximity to urban and residential areas, the Backlands is a popular location for recreation, including hiking and cycling (The Backlands Coalition 2023b). The following are recommendations for recreational activity in the Backlands during the Common Nighthawk breeding season (mid-May to August):

- Remain on trails to prevent damage to nests, particularly in areas of high Common Nighthawk activity.
- Keep pets on-leash to prevent damage to nests and harassment of nesting or roosting Common Nighthawks.
- Avoid development of new trails in areas of high Common Nighthawk activity.

4.3 Limitations

4.3.1 BirdNET Classifier Performance

The BirdNET classifier was found to have a very high precision (100%), indicating that there are no concerns that it will misidentify Common Nighthawk peents. However, the recall of the classifier was only 61%, suggesting a limitation in the classifier's ability to detect all 3 s segments containing peents. I observed that recordings with peents that were more distant from the recorder or were affected by auditory disturbance such as wind or leaf rustling had the lowest recall, while recordings with peents that were loud and in short succession had comparatively high recall. As such, study sites experiencing high auditory disturbance may have detection rates that are under-representative.

4.3.2 Estimating Relative Activity

There are also limitations in using the number of detections in recordings as a measure of Common Nighthawk activity. For one, since a detection represents a peent detected within a 3 s segment of a recording, there is an absolute maximum number of detections in any given recording, which may artificially deflate Common Nighthawk activity at the site. For example, in a 10 min recording, there is a maximum of 200 detections possible. Theoretically, this means that a single Common Nighthawk producing a peent every 3 s would have the same detection rate as multiple Common Nighthawks each producing a peent every 3 s.

To address this limitation, call rate could be used as a measure of Common Nighthawk activity instead. For Common Nighthawks, call rate represents the total number of peents produced over unit time. Call rate has no theoretical maximum and could better reflect the count of vocally active Common Nighthawks in a recording. However, determining call rate requires manual analysis of recordings, which may not be feasible for projects with high volumes of acoustic data.

Another limitation of using peents as a measure of Common Nighthawk activity is that it does not reflect the activity of nearby Common Nighthawks that are not vocally active. Although Common Nighthawks usually produce peents while in flight, this is not always the case. During the observational surveys, of the 81 Common Nighthawks observed, there were two instances of aerial Common Nighthawks that did not produce any peents while being observed. While this represents a small proportion of overall activity, it is still a limitation of passive acoustic monitoring that should be considered.

4.3.3 Estimations of Spatial Distribution

Both the ARUs and the observational surveys have unique limitations associated with estimating the spatial distribution of Common Nighthawks in the Backlands. For ARUs, this includes many of the limitations pertaining to auditory detections as previously described.

The largest limitation for estimating Common Nighthawk activity at the short-term study sites is seasonal effects. Since project logistics meant that these sites could not all be sampled concurrently, it is likely that seasonal variation in Common Nighthawk activity affected detections rates at various sites. As such, study sites sampled during seasonal peaks in activity likely overrepresent Common Nighthawk activity in the area, while sites sampled during seasonal lows are likely an underrepresentation.

The observational surveys also present limitations in estimating Common Nighthawk spatial distribution. Although effort was made to have survey sites spread across the study area, environmental and temporal effects not related to Comon Nighthawk distribution likely influenced the likelihood of observing Common Nighthawks. For example, more densely forested areas had lower visibility, reducing observers' ability to detect Common Nighthawks visually. Additionally, surveys conducted at sunset may have been more likely to observe Common Nighthawks than surveys conducted even 45 min before or 30 min afterwards.

Ideally, the limitations of each sampling method can balance with the other, underscoring the value of a mixed-method approach in estimating Common Nighthawk spatial distribution across the study area.

4.3.4 Modelling

The relatively small geographic extent of the study area was another limitation of this study. This may have led to reduced heterogeneity in the environmental variables, potentially reducing the ability for the model to detect significant relationships between the covariates and Common Nighthawk activity. Additionally, spatial autocorrelation could have reduced the spatial independence of observations at each site.

Another limitation of the model was the use of summed or averaged weather variables across entire sampling sessions. This approach may have obscured short-term fluctuations in weather conditions that influence Common Nighthawk activity on finer temporal scales, potentially reducing the explanatory power of these variables.

4.4 Directions for Future Study

As previously discussed, there are limitations of using detections as a measure of Common Nighthawk activity as opposed to call rate. However, estimates of Common Nighthawk activity could be improved by establishing a connection between the detection rate and call rate. This could involve manually assessing a subset of recordings at each site to establish the average number of calls in each detected segment. Once ratios are established for each site, detection rate could be used to estimate call rate.

Another area for future research is investigating the impact of recreational activity on Common Nighthawks in the Backlands. This could include the effect of hikers and cyclists in the area, as well as domestic animals. This research would be valuable for informing conservation strategies to minimize the impacts of recreation in the Backlands on the Common Nighthawk population.

The biggest opportunity for future study would be the detection and analysis of wing-booms in the auditory recordings. Although I attempted to develop a wing-boom classifier in BirdNET, I encountered very low precision of the classifier due to the misidentification of wind. However, if a wing-boom classifier could be developed, this would be invaluable for monitoring breeding activity and identifying potential nesting areas.

4.5 Conclusion

Overall, the findings from this study indicate that Common Nighthawk activity is greatest in the northern portion of the Halifax Backlands, and that prey abundance, elevation, and bare ground all influenced this distribution. I also found that Common Nighthawk activity varied across the breeding season, beginning in late-May, peaking in July, and ceasing in mid-September. Common Nighthawk activity was found to peak around sunset and an hour before sunrise, with minimal seasonal or spatial variation.

ARUs and observational surveys were both highly effective monitoring methods. I recommend that a mixed-method approach that incorporates both passive acoustic monitoring and surveys continues to be used in the Halifax Backlands to monitor Common Nighthawks.

References

ArcMap. 2021. Estimating Forest Canopy Density and Height. https://desktop.arcgis.com/en/arcmap/latest/manage-data/las-dataset/lidar-solutions-estimating-forest-density-and-height.htm

Armstrong JT. 1965. Breeding Home Range in the Nighthawk and Other Birds: Its Evolutionary and Ecological Significance. Ecology. 46(5):619–629. doi:10.2307/1935001.

Bota G, Manzano-Rubio R, Catalán L, Gómez-Catasús J, Pérez-Granados C. 2023. Hearing to the Unseen: AudioMoth and BirdNET as a Cheap and Easy Method for Monitoring Cryptic Bird Species. Sensors. 23(16):7176. doi:10.3390/s23167176.

Brigham RM. 1990. Prey Selection by Big Brown Bats (*Eptesicus fuscus*) and Common Nighthawks (*Chordeiles minor*). American Midland Naturalist. 124(1):73. doi:10.2307/2426080.

Brigham RM, Barclay RMR. 1995. Prey Detection by Common Nighthawks: Does Vision Impose a Constraint? Ecoscience. 2(3):276–279. doi:10.1080/11956860.1995.11682294.

CBC News. 2009. Residents Flee Homes as Crews Battle Wildfire in Halifax Area. https://www.cbc.ca/news/canada/nova-scotia/residents-flee-homes-as-crews-battle-wildfire-in-halifax-area-1.835814.

Ceballos G, Ehrlich PR, Barnosky AD, García A, Pringle RM, Palmer TM. 2015. Accelerated Modern Human–Induced Species Losses: Entering the Sixth Mass Extinction. Sci Adv. 1(5):e1400253. doi:10.1126/sciadv.1400253.

Coady G. 2007. The Common Nighthawk in the Greater Toronto Area. Toronto Birds. 1(7). http://www.torontobirding.ca/toc-docs/TorontoBirds_2007-09.pdf.

COSEWIC. 2018. COSEWIC Assessment and Status Report on the Common Nighthawk (*Chordeiles minor*) in Canada 2018. Committee on the Status of Endangered Wildlife in Canada. https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/cosewic-assessments-status-reports/common-nighthawk-2018.html

Danielle Todd L, Poulin RG, Brigham RM. 1998. Diet of Common Nighthawks (*Chordeiles minor*: Caprimulgidae) Relative to Prey Abundance. The American Midland Naturalist. 139(1):20–28. doi:10.1674/0003-0031(1998)139[0020:DOCNCM]2.0.CO;2.

ECCC. 2024. Historical Data. https://climate.weather.gc.ca/historical_data/search_historic_data_e.html.

English PA, Nocera JJ, Pond BA, Green DJ. 2017. Habitat and Food Supply Across Multiple Spatial Scales Influence the Distribution and Abundance of a Nocturnal Aerial Insectivore. Landscape Ecol. 32(2):343–359. doi:10.1007/s10980-016-0454-y.

Farrell CE, Fahrig L, Mitchell G, Wilson S. 2019. Local Habitat Association Does Not Inform Landscape Management of Threatened Birds. Landscape Ecol. 34(6):1313–1327. doi:10.1007/s10980-019-00843-6.

Farrell CE, Wilson S, Mitchell G. 2017. Assessing the Relative Use of Clearcuts, Burned Stands, and Wetlands as Breeding Habitat for two Declining Aerial Insectivores in the Boreal Forest. Forest Ecology and Management. 386:62–70. doi:10.1016/j.foreco.2016.11.026.

Government of Canada. 2023. Beneficial Management Practices. https://www.canada.ca/en/environment-climate-change/services/avoiding-harm-migratory-birds/beneficial-management-practices.html.

Halifax Data, Mapping & Analytics Hub. 2018. LiDAR 2018. https://data-hrm.hub.arcgis.com/documents/3fd2ca6bc7a24bc89e0798ead2952dfa/explore.

Hannah KC, Leston LFV, Knight EC, Weeber R. 2022. In the Twilight Zone: Patterns in Common Nighthawk (*Chordeiles minor*) Acoustic Signals During the Breeding Season and Recommendations for Surveys. ACE. 17(2):art18. doi:10.5751/ACE-02241-170218.

Herold S. 2025. Aerial Insect Populations in the Halifax Backlands and Prey Availability to the Common Nighthawk (*Chordeiles mino*r). Dalhousie University.

Hill N, Patriquin D. 2014. Ecological Assessment of the Plant Communities of the Williams Lake Backlands. The Williams Lake Conservation Company. https://dalspace.library.dal.ca/items/56d67273-f64f-47cb-bd58-6731485e52e2.

HRM. 2024. HRM Parks. Halifax Data, Mapping & Analytics Hub. https://data-hrm.hub.arcgis.com/datasets/HRM::hrm-parks/about.

Kahl S, Wood CM, Eibl M, Klinck H. 2021. BirdNET: A Deep Learning Solution for Avian Diversity Monitoring. Ecological Informatics. 61:101236. doi:10.1016/j.ecoinf.2021.101236.

Kelly JF, Bridge ES, Frick WF, Chilson PB. 2013. Ecological Energetics of an Abundant Aerial Insectivore, the Purple Martin. Brigham RM, editor. PLoS ONE. 8(9):e76616. doi:10.1371/journal.pone.0076616.

Kirkland M. 2025. Chirpity: Identify Birds by Sound. https://chirpity.mattkirkland.co.uk/.

Knight EC. 2021. What does a Detection Mean? Spatial and Behavioural Context Improves the use of Passive Acoustic Monitoring for the Conservation of a Wide-Ranging Bird [Thesis]. University of Alberta. https://era.library.ualberta.ca/items/fdfd14fc-3452-424f-b321-be7eb377764b.

Knight EC, Brigham RM, Bayne EM. 2021. Specialist or Generalist? It Depends. Context-Dependent Habitat Relationships Provide Insight Into Forest Disturbance Effects for a

Boreal Bird Species. Forest Ecology and Management. 502:119720. doi:10.1016/j.foreco.2021.119720.

Knight EC, Brigham RM, Bayne EM. 2022. The Big Boom Theory: The Common Nighthawk Wing-Boom Display Delineates Exclusive Nesting Territories. Ornithology. 139(1):ukab066. doi:10.1093/ornithology/ukab066.

Knight EC, Ng JW, Mader CE, Brigham RM, Bayne EM. 2018. "An inordinate fondness for beetles": first description of Common Nighthawk (*Chordeiles minor*) diet in the boreal biome. The Wilson Journal of Ornithology. 130(2):525–531. doi:10.1676/16-219.1.

Kolbe S, Niemi G, Bracey A, Etterson M, Grinde A. 2024. Incorporating Weather in Counts and Trends of Migrating Common Nighthawks. ACE. 19(1):art9. doi:10.5751/ACE-02621-190109.

Leung B, Hargreaves AL, Greenberg DA, McGill B, Dornelas M, Freeman R. 2020. Clustered versus Catastrophic Global Vertebrate Declines. Nature. 588(7837):267–271. doi:10.1038/s41586-020-2920-6.

Nebel S, Mills A, McCracken JD, Taylor PD. 2010. Declines of Aerial Insectivores in North America Follow a Geographic Gradient. ACE. 5(2):art1. doi:10.5751/ACE-00391-050201.

Newberry GN, Swanson DL. 2018. Common Nighthawks (*Chordeiles minor*) in the Western Corn Belt: Habitat Associations and Population Effects of Grassland and Rooftop Nesting Habitat Conversion. The American Midland Naturalist. 180(2):216–232. doi:10.1674/0003-0031-180.2.216.

Ng JW, Knight EC, Scarpignato AL, Harrison A-L, Bayne EM, Marra PP. 2018. First Full Annual Cycle Tracking of a Declining Aerial Insectivorous Bird, the Common

Nighthawk (*Chordeiles minor*), Identifies Migration Routes, Nonbreeding Habitat, and Breeding Site Fidelity. Can J Zool. 96(8):869–875. doi:10.1139/cjz-2017-0098.

NS Department of Lands and Forestry. 2021. Recovery Plan for the Common Nighthawk (*Chordeiles minor*) in Nova Scotia. https://novascotia.ca/natr/wildlife/species-at-risk/docs/RECOVERY_PLAN_Adopted_Common_nighthawk_10Feb21.pdf.

NS Department of Natural Resources and Renewables. 2012. Wet Areas Mapping and Flow Accumulation Channel. https://novascotia.ca/natr/forestry/gis/wamdownload.asp.

NS Department of Natural Resources and Renewables. 2021. NS Forest Inventory. https://novascotia.ca/natr/forestry/gis/forest-inventory.asp.

NS Department of Natural Resources and Renewables. 2024. Crown Land Map. https://data.novascotia.ca/Lands-Forests-and-Wildlife/Crown-Land-Map/sqec-gjbw.

NS Nature Trust. 2024. Our Conservation Lands. https://nsnt.ca/our-work/our-conservation-lands/.

Pereira HM, Martins IS, Rosa IMD, Kim H, Leadley P, Popp A, Van Vuuren DP, Hurtt G, Quoss L, Arneth A, et al. 2024. Global Trends and Scenarios for Terrestrial Biodiversity and Ecosystem Services from 1900 to 2050. Science. 384(6694):458–465. doi:10.1126/science.adn3441.

Raghavendra KV, Bhoopathi T, Gowthami R, Keerthi MC, Suroshe SS, Ramesh KB, Thammayya SK, Shivaramu S, Chander S. 2022. Insects: Biodiversity, Threat Status and Conservation Approaches. Current Science. 122(12):1374. doi:10.18520/cs/v122/i12/1374-1384.

Shaver E. 2023. Breeding Habitat Occupancy and Habitat Use of Common Nighthawks (*Chordeiles minor*) in Kespukwitk. Dalhousie University.

Shonfield J, Bayne EM. 2017. Autonomous Recording Units in Avian Ecological Research: Current Use and Future Applications. ACE. 12(1):art14. doi:10.5751/ACE-00974-120114.

Sidler A. 2017. Common Nighthawk (*Chordeiles Minor*) Habitat Associations and Activity Patterns in the Northern Boreal Forest. The University of Regina. https://www.proquest.com/docview/2482618005.

Spiller KJ, Dettmers R. 2019. Evidence for Multiple Drivers of Aerial Insectivore Declines in North America. The Condor. 121(2):duz010. doi:10.1093/condor/duz010.

The Backlands Coalition. 2023a. SAR & Priority Species List. https://backlandscoalition.ca/?page_id=5270.

The Backlands Coalition. 2023b. Trails. https://backlandscoalition.ca/?page_id=5270.

The Backlands Coalition. 2024a. Common Nighthawk. https://backlandscoalition.ca/?page_id=6350.

The Backlands Coalition. 2024b. Our Members. https://backlandscoalition.ca/?page_id=10.

The Backlands Coalition. 2025. Protected Areas. http://backlandscoalition.ca/?page_id=1439.

Valiela I, Martinetto P. 2007. Changes in Bird Abundance in Eastern North America: Urban Sprawl and Global Footprint? BioScience. 57(4):360–370. doi:10.1641/B570410.

Wood CM, Kahl S, Rahaman A, Klinck H. 2022. The Machine Learning–Powered BirdNET App Reduces Barriers to Global Bird Research by Enabling Citizen Science Participation. PLoS Biol. 20(6):e3001670. doi:10.1371/journal.pbio.3001670.

Appendix A: ARU Deployment Data Sheet

ARU Deployment Field Sheet

☐ *Scanned*
☐ *Entered*

Record #

ARU #:	Batteries: NEW / OLD	Deployed by:
Date (yy/mm/dd):		Others present:
Time (hh:mm):		

Site name:	Site Code:	Site Status: *NEW / EXISTING / MOVED*
GPS point #:	Easting (X):	Northing (Y):

Camera:	Deployment Notes:
Image Numbers:	

CONI - 2024

Appendix B: Observational Survey Data Sheet

Observation Survey Field Sheet

☐ *Scanned*
☐ *Entered*

Record #

Date (yy/mm/dd):	Sunset (hh:mm):
Sampling start (hh:mm):	Sampling end (hh:mm):

Point ID:	Easting (X):	Camera:
GPS Waypoint:	Northing (Y):	Image Numbers:

Temperature (°C):	Relative humidity (%):	# Observers:
Avg. wind speed (km/h):	Cloud cover (%):	Names:
Wind direction (°):		

Weather Notes:	Visibility (m):	Suitable nest habitat present? *YES / NO*
	N: E:	Notes:
	W: S:	

CONI Observations

Total Observed:

Present at sampling end time: *YES / NO*

ID#	Time (hh:mm)	Detection	Location (m/°)	Traits	Behaviour
	Start:	*VISUAL / AUDIO↓*	Distance:	Sex: *M / F / ?*	
	End:	*boom / peent / call*	Direction:	Age: *Adult / Juv.*	
ORN:		# booms:	Height: *Hi / Med / Lo / Grd*	*Young / ?*	
Notes:					
	Start:	*VISUAL / AUDIO↓*	Distance:	Sex: *M / F / ?*	
	End:	*boom / peent / call*	Direction:	Age: *Adult / Juv.*	
ORN:		# booms:	Height: *Hi / Med / Lo / Grd*	*Young / ?*	
Notes:					
	Start:	*VISUAL / AUDIO↓*	Distance:	Sex: *M / F / ?*	
	End:	*boom / peent / call*	Direction:	Age: *Adult / Juv.*	
ORN:		# booms:	Height: *Hi / Med / Lo / Grd*	*Young / ?*	
Notes:					
	Start:	*VISUAL / AUDIO↓*	Distance:	Sex: *M / F / ?*	
	End:	*boom / peent / call*	Direction:	Age: *Adult / Juv.*	
ORN:		# booms:	Height: *Hi / Med / Lo / Grd*	*Young / ?*	
Notes:					

Page: _____ of _____

Appendix C: Observational Survey Sites

Table A. Summary of observational survey sites. All UTM coordinates correspond to zone 20N.

Site Number	Date	Start Time	UTM E	UTM N	Common Nighthawk Count
115	June 12	20:41	452932	4940596	3
317	June 13	20:26	453800	4937804	0
401	June 13	20:57	453751	4937495	0
607	June 17	20:31	455246	4936785	0
101	June 18	19:59	453019	4940409	5
201	June 18	21:05	453557	4940487	3
414	June 19	20:30	454198	4937833	0
301	June 19	21:28	453278	4938596	4
616	June 20	20:21	454828	4936038	0
509	June 20	21:03	455185	4938038	2
502	July 3	20:30	454267	4936880	1
202	July 3	21:22	453034	4939144	5
203	July 8	20:20	452736	4938980	4
102	July 8	20:56	452218	4940289	0
604	July 9	20:32	455672	4936649	0
303	July 15	20:43	454554	4939540	3
402	July 17	20:31	454976	4938171	1
503	July 17	21:11	454927	4937530	1
109	July 22	19:59	452528	4940153	4
211	July 22	21:01	453177	4939712	5
505	July 27	20:32	454704	4936876	2
605	July 28	20:30	455874	4936704	0
404	July 30	20:30	454404	4938013	4
309	August 2	20:08	453618	4938873	5
205	August 2	20:50	453019	4938762	4
302	August 7	20:30	453969	4937946	2
213	August 8	20:09	452666	4939564	5
110	August 8	20:35	452431	4939632	3
615	August 12	20:17	455005	4936581	0
516	August 15	20:21	455139	4938254	3
408	August 16	19:52	455155	4938549	2
304	August 16	20:39	454776	4939065	3
515	August 18	19:57	454493	4937269	0
514	August 18	20:15	455052	4937326	1
413	August 18	20:28	453989	4937099	1
608	August 19	20:10	NA	NA	0
106	August 19	20:17	452134	4940646	2
218	August 21	20:20	452760	4939244	3

Appendix D: Visual and Aural Common Nighthawk Observations

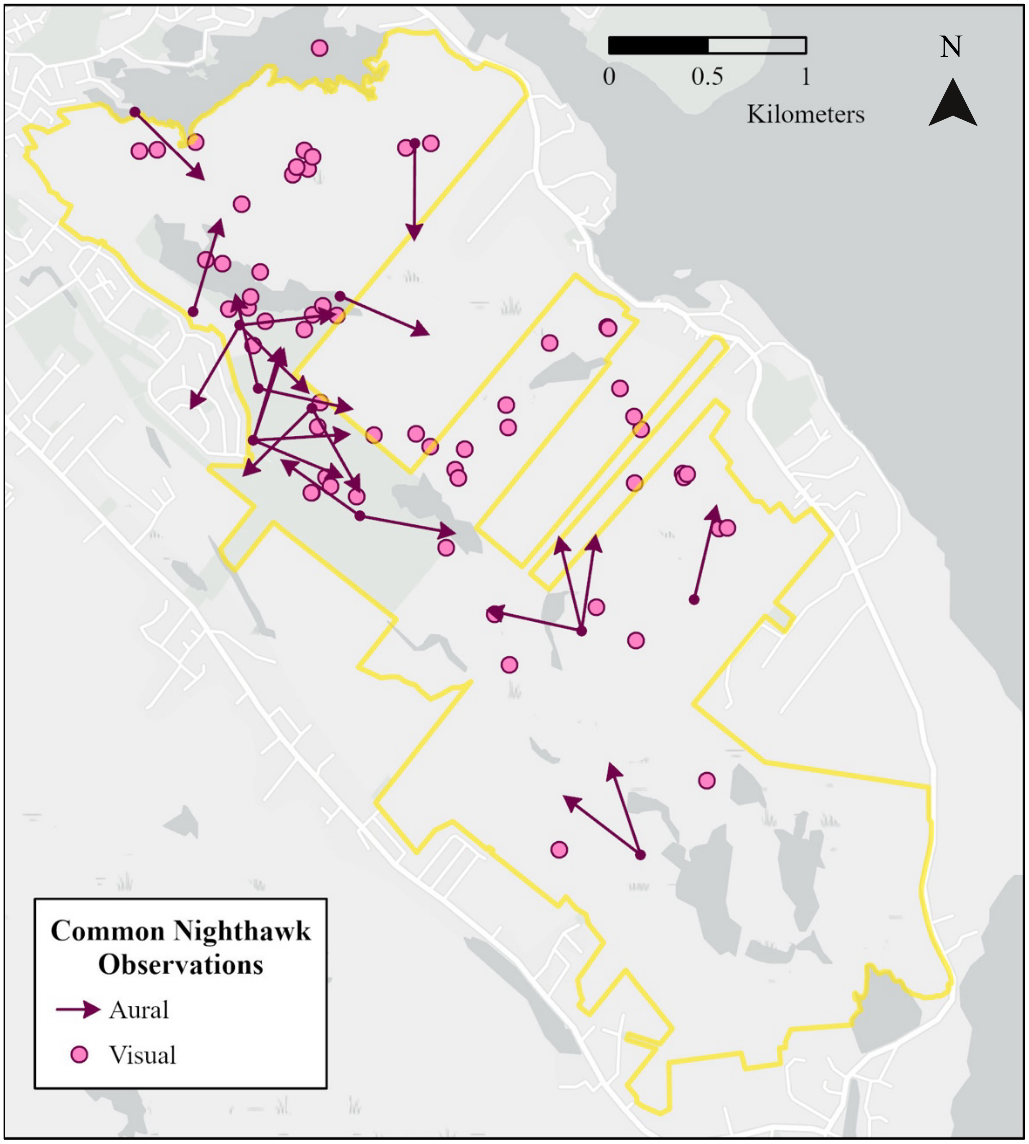

Figure B1. Common Nighthawk observations collected during observational surveys. Visual observations are indicated by point locations. Direction of aural observations are represented by arrows, with an estimated maximum auditory detection range of 500 m.

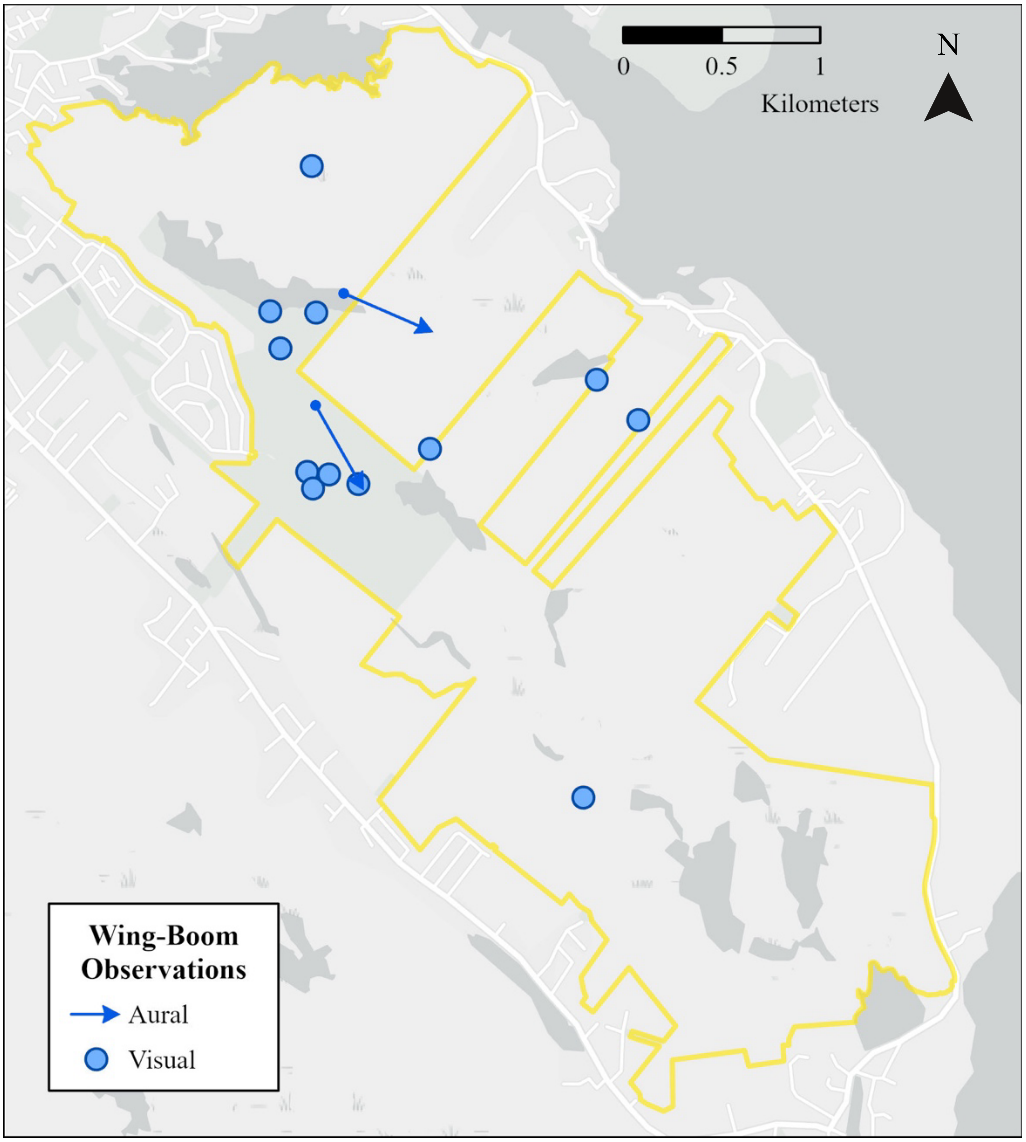

Figure B2. Wing-boom observations collected during observational surveys. Visual observations are indicated by point locations. Direction of aural observations are represented by arrows, with an estimated maximum auditory detection range of 500 m.