Spatial Distribution of Leach's Storm-petrel (*Hydrobates leucorhous*) on Bonaventure Island, Québec

by

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Abstract

Leach's Storm-petrel (*Hydrobates leucorhous*) populations are declining across their range, yet little is known about their breeding distribution on Bonaventure Island, Québec. I used autonomous recording units (ARUs) and spatial interpolation to assess their distribution across the island. Results indicate that call densities were highest in the northeastern region of the island, where forest regeneration and low human visitation occur. The southern and western regions had low call detections likely due to human activity and predator presence. The northern section, bordering the location of the highest call detections, was deemed inaccessible. These findings are a first step to investigating a nesting population of Leach's Storm-petrel on Bonaventure Island. The next steps include the identification of active burrows, predator management considerations, and additional monitoring. Further research is required to assess population viability and determine whether observed habitat use reflects a response to predation pressure or an undocumented breeding site.

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List of Symbols, Nomenclature, or Abbreviations

ARU – Autonomous Recording Unit

dB - Decibels

EST – Eastern Standard Time

GPS – Global Positioning System

IDP – Inverse Distance Power

IDW – Inverse Distance Weight

IUCN – International Union for Conservation of Nature

MSD – Mean Signed Deviation

SÉPAQ – Société des Établissements de Plein air du Québec

SD – Secure Digital

SM – Song Meter

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Introduction

Seabird ecology and vulnerabilities

Seabirds are top marine predators and serve as biological indicator species of marine environment health (Furness, 1997). These long-lived species spend most of their lives at sea but return to land to nest in colonies during the breeding season (Nelson, 1979). Throughout the breeding season, they regularly return to the ocean to feed themselves and their young, making them highly dependent on marine ecosystems throughout their life cycle (Diamond & Devlin, 2003; Nelson, 1979)**.** As such, changes in lower trophic levels and anthropogenic pressures (e.g., overexploitation of their prey and marine pollution) can impact their population numbers and breeding success (Furness, 1997; Parsons et al., 2008). Additionally, seabirds face threats from artificial light attraction (Montevecchi, 2006; Reed et al., 1985), interactions with offshore infrastructure such as coastal oil and gas platforms (Ronconi et al., 2015), and ongoing changes to the ocean's climate (Montevecchi et al., 2013).

Seabirds face significant threats not only at sea, but also at their breeding colonies, where they are particularly vulnerable. Smaller seabirds, such a Leach's Storm-petrels *(Hydrobates leucorhous),* are often targeted by avian predators. Gulls (*Larus spp.*) and owls (*Strigidae spp.*) have been documented preying on seabird colonies, sometimes causing substantial population declines (Bond et al., 2023a; Hoeg et al., 2021; Pollet et al., 2023; Pollet & Shutler, 2019(a); Stenhouse et al., 2000). Additionally, many seabirds evolved in predator-free environments and lack anti-predator defense behaviours. As a result, they experience severe population declines when exposed to threats from introduced mammalian predators (Bicknell et al., 2009; Buxton et al., 2016; Moors & Atkinson, 1984; Rodríguez et al., 2022). Historically, the introduction of mammalian predators to seabird colonies has led to devastating population declines, and for certain species, such as storm-petrels, it remains one of the greatest threats to their declining populations (McClelland et al., 2008; Pollet et al., 2023).

Leach's Storm-petrels Globally

Globally, seabirds are among the most threatened bird groups. Of the 346 seabird species, 97 (28%) are classified as globally threatened (Croxall et al., 2012), meaning they are listed as critically endangered, endangered, vulnerable, or near threatened by the International Union for Conservation of Nature (IUCN). Among them, Leach's Storm-petrel is listed as vulnerable, considered as being at high risk of extinction in the wild (IUCN Species Survival Council, 2000), under the IUCN Red List (BirdLife International, 2018). This small, pelagic seabird belongs to the order Procellariiformes (Ambagis, 2004; Rennie et al., 2020) and is widely distributed throughout the Northern Hemisphere. It nests on islands in both the Atlantic and Pacific Oceans (Pollet et al., 2021; Rennie et al., 2020) and is sexually monomorphic, with a darkish-brown and gray body, a distinguishable white rump patch, a forked tail, and long angled wings (Pollet et al., 2021). In Atlantic Canada, Leach's Storm-petrels breed from southern Labrador to the mouth of the Bay of Fundy, including the Gulf of St. Lawrence, and islands along Quebec's north shore (Pollet et al., 2021). As of 2018, the global population of Leach's

Storm-petrel is estimated to range between 6.7 to 8.3 million breeding pairs, with 40-48% breeding within the Atlantic Basin (BirdLife International, 2018; Pollet et al., 2021). The largest breeding colony in the Atlantic is on Baccalieu Island, Newfoundland, with an estimated 1.95 million breeding pairs (Wilhelm et al., 2020).

Leach's Storm-petrels on Bonaventure Island

Several smaller populations (<100 pairs) of Leach's Storm-petrel are scattered throughout the Gulf of St. Lawrence and along Quebec's north shore (Pollet et al., 2021). Similar to the populations throughout the Atlantic basin, these populations are declining or have experienced regional extirpation (Environment and Climate Change Canada, 2021; Pollet et al., 2021). In Québec's Gaspé Peninsula, Bonaventure Island is believed to host the only remaining population of Leach's Storm-petrel in the region. Early censuses recorded small numbers of nesting pairs, with 10 pairs observed in 1979 and 21 in 1989. However, a 2004 census found no active burrows or individuals on the island (Cotter & Rail, 2007). Despite these findings, nocturnal call playback surveys conducted in 2005, 2007, and 2008 confirmed their presence on the island (personal communication J.F. Rail).

In 2012, la Société des Établissements de Plein Air du Québec (SÉPAQ) conducted additional nocturnal surveys and detected four individuals (Côté, 2012). Between 2016 and 2021 (excluding 2020), SÉPAQ continued these efforts, completing one nocturnal survey in both 2016 and 2017, three surveys in 2018, and two surveys in both 2019 and 2021 (unpublished data, SÉPAQ 2024). Across these surveys, the number of detections has remained relatively consistent, with individuals typically observed near the eastern cliffs and behind the Northern Gannet (*Morus bassanus*) colony on the eastern tip of the island. These confirmed observations informed the placement of transects for ground surveys I conducted in June 2023 (see preliminary field component in methodology section). However, due to the island's size, the species' nocturnal behaviour, and its likely small population, obtaining an accurate estimate of the breeding population remains challenging.

Surveying for Leach's Storm-petrels

Traditional nocturnal surveys involve researchers conducting auditory or visual point counts during peak vocal activity periods at night. These methods require field crews to be physically present in possible nesting location, often in rugged terrain, under low-visibility conditions and with prior approval from the island's governing authorities. Additionally, these surveys are constrained by weather conditions, requiring low wind speeds (<19km/h) and little to no precipitation. Adverse weather conditions not only reduce the detectability of vocalizations due to increase background noise but may also suppress seabird calling behaviour altogether. On Bonaventure Island, there are limited windows of suitable weather and restricted entry, access is reliant on tourist boats and permission for nighttime access, which further constrain these types of surveys.

Given these limitations, passive acoustic monitoring offers an alternative for surveying nocturnal and cryptic seabird species. Autonomous recording units (ARUs) provide a low-disturbance and efficient means of collecting long-term data by continuously recording vocalizations throughout the breeding season (Buxton & Jones, 2012; Robb & Mullarney, 2008). The use of ARUs has been particularly effective in detecting burrow-nesting seabirds, whose vocal activity peaks at night and often serves as the most reliable indicator of presence (Buxton et al., 2013; Buxton & Jones, 2012; Robb & Mullarney, 2008). Given the uncertainty around the population status of Leach's Storm-petrels on

Bonaventure Island, acoustic monitoring represents a valuable tool for assessing their presence and may help inform conservation efforts.

Given the small population size of Leach's Storm-petrels on Bonaventure Island, their global and regional population downward trend (Pollet et al., 2023; Wilhelm et al., 2020) and the presence of mammalian predators such as red foxes (*Vulpes vulpes*) and rodents (*Rodentia spp*.), this colony faces a heightened risk of regional extirpation (Bicknell et al., 2009; Dias et al., 2019; Hilton & Cuthbert, 2010; Pollet et al., 2023). Their lack of anti-predator defenses, combined with their low annual fecundity, makes them particularly vulnerable to depredation (Nelson, 1979; Pollet et al., 2021). Understanding the distribution and abundance of this population is therefore critical for assessing its viability and to inform future conservation efforts.

Project objective

The original objective of this study was to assess the status of the Leach's Storm-petrel population on Bonaventure Island by identifying active burrows, estimating burrow density, reproductive success, and predation risk. This would have involved locating and monitoring active nests through targeted searches, estimating chick survival over time, and deploying motion sensor trail cameras to document predator presence and activity near known nesting sites.

However, because no active burrows were found during the 2023 and 2024 field seasons, the scope and focus of the study were revised and aimed to assess the spatial distribution of Leach's Storm-petrel call activity on Bonaventure Island using call densities recorded by ARUs. By deploying ARUs at a number of coastal locations on Bonaventure Island, I assessed the presence and relative activity levels of Leach's Storm-petrels based on their vocalization densities, allowing for a more comprehensive understanding of their activity behaviour. This revised approach provides valuable insights into the current status of this at-risk species on Bonaventure Island, contributes to ongoing monitoring efforts in the region, and supports decision-makers in managing and developing mitigation strategies for the species on Bonaventure Island.

Methodology

Study Site

The study was conducted on Bonaventure Island (48.5042 °N, -64.1572 °W), located approximately 3.3 km off the coast of Percé, Québec, Canada and is part of Bonaventure Island and Percé Rock National Park. The island spans 4.6 km^2 and features gradually sloped terrain on the west side of the island, with the remaining shorelines dominated by steep cliffs. Bonaventure Island hosts a diverse complex of habitats. A large portion of the island consists of mixed-wood forest dominated by balsam fir (*Abies balsamea*), eastern white cedar (*Thuja occidentalis*), and white birch (*Betula papyrifera*; Bourdages & Lavoie, 2011). The western side of the island, once a small fishing settlement, includes old agricultural fields, historic homes, and a dock. Some of the fields are still maintained or mowed by SÉPAQ grounds staff, however, the majority have been taken over by native shrubs such as *Amelanchier spp*., red osier dogwood (*Cornus stolonifera*), fire cherry (*Prunus pensylvanica*), willow (*Salix spp*), and invasive plant species; Bourdages & Lavoie, 2011). In addition, the island hosts a variety of *pteridophyte* (fern) forests, hiking trails, and hosts one of the largest Northern Gannet colonies in the world (Mowbray, 2020). The region experiences a temperate maritime climate, with an annual average temperature of 15 °C and frequent wind and fog during the summer months, coinciding with the breeding season of species on the island and tourism. Thousands of tourists visit the island every summer to visit Bonaventure Island for the scenic views, hiking trails, historic settlement, geologic formations, and seabird colonies.

Preliminary Field Component

In June 2023, a team of four individuals (including myself) visited Bonaventure Island to conduct preliminary ground surveys in search of active Leach's Storm-petrel burrows. Focusing on three key areas where Leach's Storm-petrel had been heard calling and where carcasses had been found by SÉPAQ staff and researchers in 2022-2023 (unpublished data, SÉPAQ 2024; Figure 1), the team surveyed the areas using line transects and quadrats. Following methods outlined in Pollet & Shutler (2019b), the team surveyed, in each area, five 3 m x 3 m quadrats along each of four 150 m-long transect lines (one quadrat every 30 m), that ran from a point near the shoreline towards the center of the island, with the first quadrat placed at the transect's starting point. Each area with distinct start and end points. The first area, waslocated in the northeast portion of the island, and it featured transects beginning at or as close as safely possible to the cliff edge and extending inland. The second section was near the observation tower (located between SM1-1970 and SM4-3666; Figures 4, 8 & 9) at the main Northern Gannet colony, with transects starting at the gannet colony's edge and running inland. The third section was in the mixed-wood forest south of the Northern Gannet colony, where transects began at the transition zone between cliff/meadow and forested habitats, extending inland (Figure 1, Appendix B).

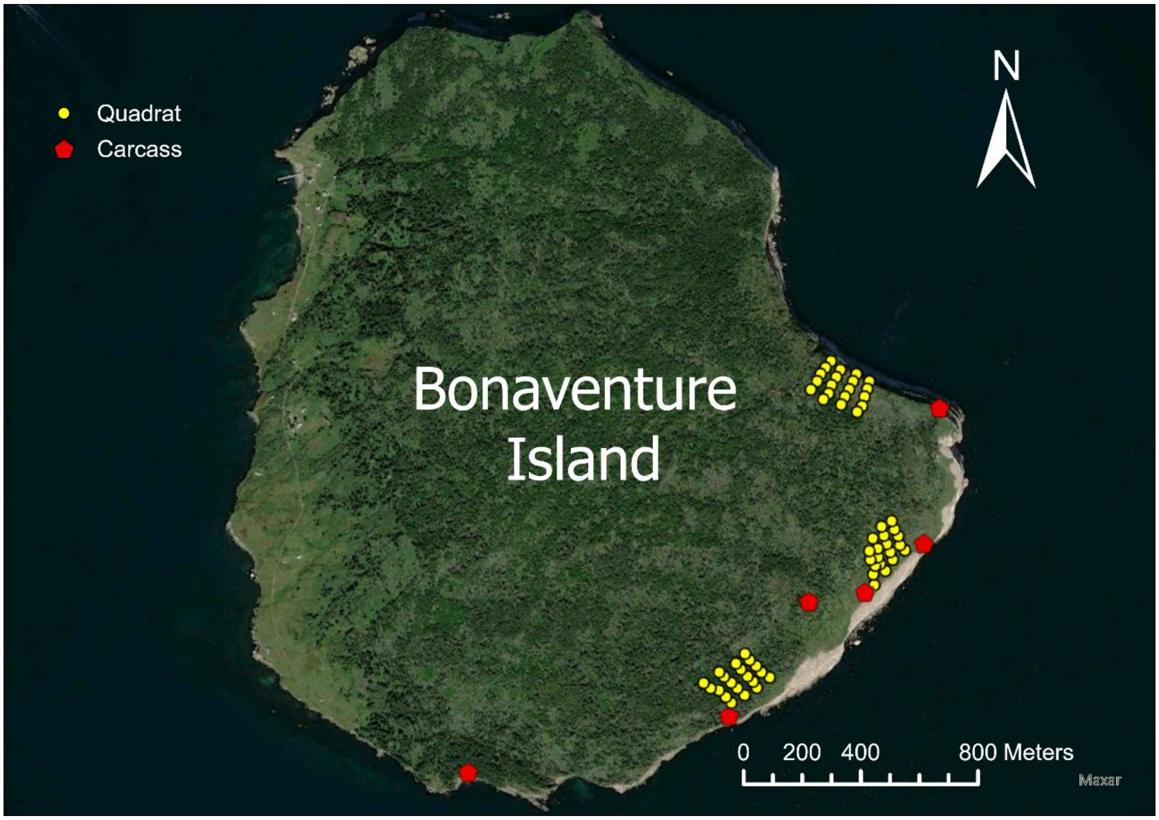

Figure 1. Map of Bonaventure Island, Québec, showing 3 m x 3 m quadrat locations (yellow circles) and Leach's Storm-petrel carcass locations (red pentagon) found by SÉPAQ during 2022-2023.

Autonomous Recording Unit (ARU) Deployment and Retrieval

In September 2023, 14 ARUs were deployed along the island's coast, positioned between 0 m - 300 m inland from the intertidal zone. Units were fixed to trees or wooden stakes with screws or zip-ties (Figure 2). The ARUs were spaced 150 m to 750 m apart, depending on habitat and accessibility (excluding the northern part of the island that was inaccessible; Figure 4). I deployed two Song Meter (SM) models of ARUs, from Wildlife Acoustics Inc. (Maynard Massachusetts, USA): four SM2+ and ten SM1 units. Each ARU was configured using the Song Meter Configuration Utility 3.2.4 to record from 23:00 to 04:00 Eastern Standard Time (EST), alternating between 15 minutes of recording and 15 minutes of pause to accommodate the nocturnal calling behaviour of Leach's Storm-petrels (Buxton et al., 2013) and projected battery life. All ARUs used an audio sample rate of 16 kHz and microphone gain of +12 (default settings). The sample rate and gain settings coincide with Leach's Storm-petrel calls that fall within 0 and 12 kHz. Each unit was equipped with two 32 GB Secure Digital (SD) cards and four D Cell batteries. The SM2+ models were programmed to automatically shut down on October 25th, 2023, and to reactivate on May 1st, 2024. In contrast, the SM1 lacked this functionality and were set to record continuously until battery depletion. This late-season 2023 deployment was designed to explore whether Leach's Storm-petrels could be detected in the fall just prior to and during fledgling.

Figure 2. Examples of SM1 (Right) and SM2+ (Left) Song Meter models deployment in September 2023. ARUs were either screwed into stakes in the ground or on trees where possible.

In May 2024, the batteries and SD cards of each SM1 and SM2 were retrieved and replaced, ensuring recordings would continue through autumn 2024, for a total of four months of recording. Additionally, nine AudioMoth 1.2 (Open Acoustics Devices, University of Southampton, UK) ARUs and two SM4 models from Wildlife Acoustics Inc. (Maynard Massachusetts, USA) were deployed using zip-ties for the SM4, and with a Velcro strap to attach to tree limbs for the AudioMoths (Figure 3). Both additional units (SM4 and AudioMoth) followed the same recording schedule and time zone settings as the initial deployment in 2023. However, both the SM4 and AudioMoth units recorded at a higher audio sample rate of 48 kHz (default). The AudioMoth units were deployed with 64 GB micro-SD cards and powered by four AA lithium batteries, while the SM4 units used a 64 GB SD card and a 128 GB SD card, powered by 4 D cell batteries. Four of the original ten SM1 units were found to be malfunctioning and were subsequently replaced with SM4 models. Locations of all SM and AudioMoth units are shown in Figure 4. See Appendix A for a summary of each unit's location, deployment and retrieval dates, and recording nights. All SM units were retrieved from the island during September 14-15, 2024; AudioMoths were retrieved by Park staff on August 30th, 2024. Recordings from

Figure 3. Examples of the deployment of AudioMoth and SM4 ARU models. The AudioMoth (left) is attached to a tree limb with a Velcro strap. The SM4 model (right) is attached to the tree using zip-ties.

all ARUs were uploaded to a laptop and all Leach's Storm-petrel calls counted using Raven Pro 1.6.5. software (see data analysis section for specifics).

To evaluate the hearing radius of each model of ARU used in my project, I played Leach's Storm-petrel calls with a Bluetooth loudspeaker (Wonderboom 3 by Ultimate Ears) at 108 dB, and noted whether or not the sound was recorded by an placed at each of six controlled distances at six controlled distances (i.e., 25, 50, 75, 100, 150, and 200 meters) from the loudspeaker. A TechResource model 33-2050, (Intertan, Barrie, Canada) sound meter, operating at a C weighting function, was used to determine the sound levels of the loudspeaker. It was calibrated using a Rion model NC-73 sound level calibrator, (Rion, Tokyo, Japan). In pre- and post-season calibrations, the sound level meter was accurate to within +/- 1 dB. Recordings were immediately uploaded and analyzed manually. The trials showed that each separate unit detect calls up until 150 m if the source level is 108 dB re 20 µPa at 1 m. Due to an error in programming and

Figure 3. Locations of all ARU units on Bonaventure Island following the deployments in September 2023 and May 2024. Song Meters denoted with green circles and AudioMoths with blue circles.

recording schedule, AudioMoth ARUs did not provide consistent data compared to the SMs (see Appendix A) and were only used to test model predictions (see "Model Error Comparison" below).

Predator Monitoring – Trail Camera Deployment and Retrieval

In May 2024, eight motion-activated trail cameras were deployed across Bonaventure Island (Figure 5). Seven of the cameras were Spypoint Force-Pro models, and the eighth a Reconyx Hyperfire I. Each camera was equipped with eight AA batteries and a 32 GB SD card and was configured to capture three consecutive photos per trigger event. Cameras were strategically placed along closed trails and game trails to maximize the likelihood of detecting mammalian predators (i.e. red fox, rodents). Each unit was mounted at approximately 60-90 cm above the ground and angled downward to optimize ground coverage. To minimize the number of non-target captures (i.e., humans), two cameras were relocated in June 2024 before closed trails were reopened, one of which (CAM4) was moved twice (once in mid-June and once in late-June). All cameras remained active throughout the summer and were retrieved in September 2024. The collected images were manually reviewed and categorized by species detected, detection count, observed behaviour, and time and date of the trigger event.

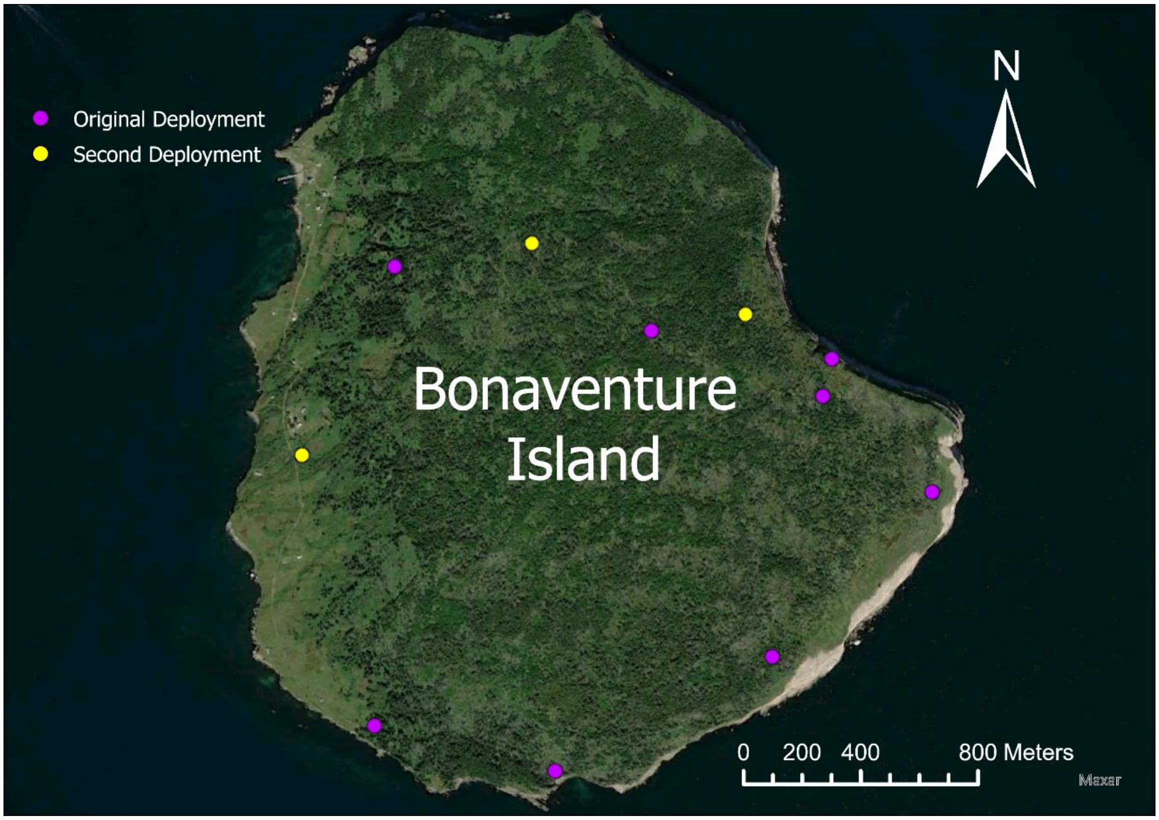

Figure 4. Locations of motion sensor trail cameras on Bonaventure Island. The original deployments (May 2024) are shown in purple and secondary deployments (June 2024) were needed as trails opened to the public and are shown in yellow.

Nocturnal Surveys

Nocturnal call playback surveys were conducted from mid-June to mid-July 2024, when Leach's Storm-petrel adults should be laying and incubating eggs and adult activity is at a maximum (Environment and Climate Change Canada, 2021; Pollet et al., 2014; Pollet et al., 2021; Wilbur, 1969). The goal of these surveys was to verify the presence of Leach's Storm-petrels (flying or grounded birds) and helped direct where targeted ground searches would occur. Surveys were conducted in areas with historic sightings (i.e., SÉPAQ nocturnal survey data) of Leach's Storm-petrel and locations where ARUs had detected calls. A total of eleven nocturnal survey points were chosen throughout the island (Figure 6). Once arrived at a survey location, one minute was spent listening for

Leach's Storm-petrel calling. If nothing was heard or observed, a combination of chatter and purr calls (i.e., 2-minutes of chatter and 1-minute of purr) were played using a Bluetooth loudspeaker (Wonderboom 3 by Ultimate Ears) at 108 dB, followed by one minute of listening before heading to the next location. The eleven survey locations (Figure 6) were surveyed between 23:00 to 03:00 over three consecutive nights when possible (Table 5). Ambient noise can significantly hinder vocalization detection, and Leach's Storm-petrel are generally less active during brighter moon phases as a means of predator avoidance (Ambagis, 2004; Watanuki, 1986). Two series of nocturnal surveys were conducted. The first round of surveys proceeded smoothly under optimal weather conditions (i.e., winds <19 km/h, little to no precipitation) over three consecutive nights. However, the second round had to be split up due to adverse weather conditions (see Table 5 for survey dates). When Leach's Storm-petrel calls were heard or individuals observed, the loudspeaker was immediately turned off to minimize the risk of predation or attracting birds from the open ocean. A 5-minute point count survey was then conducted, during which two thermal imaging cameras (Zeiss DTI 4/50 and FLIR C5) were used to locate both flying and grounded birds. Observers recorded the approximate distance from the survey locations, the birds' flight paths (e.g., "flying east to west"), and the number of individuals seen or heard calling.

Figure 5. Nocturnal survey point locations (grey squares) for Leach's Storm-petrel call-playback surveys conducted on Bonaventure Island, Québec, between June-July 2024.

Targeted Ground Searches

Between June 18 to July 15, 2024, targeted ground searches were conducted on 11 separate days, with survey efforts ranging from five to eight hours per day. These searches aimed to locate active Leach's Storm-petrel burrows in areas where acoustic detections or nocturnal surveys had indicated calling activity. A total of nine distinct search areas were selected based on these detections (Figure 7).

Surveys were conducted by teams of two to five individuals walking linear transects, spaced approximately three to five meters apart to ensure complete visual coverage of the ground. Each transect originated from a fixed location such as the main hiking trails or the Northern gannet colony and extended inland. Team members moved slowly and scanned the ground by displacing vegetation cover for signs of burrow-nesting activity. These signs included burrow entrances, feathers, feces, carcasses, and characteristic Leach's Storm-petrel odours. When signs were located, grubbing was attempted by gently reaching into the burrow to feel for nesting birds, chicks, or eggs.

All survey routes were recorded using Global Positioning System (GPS)-enabled smartphones and the Avenza Maps app (version 5.4.226). Tracks were saved in real time and georeferenced for later review and mapping (Figure 7).

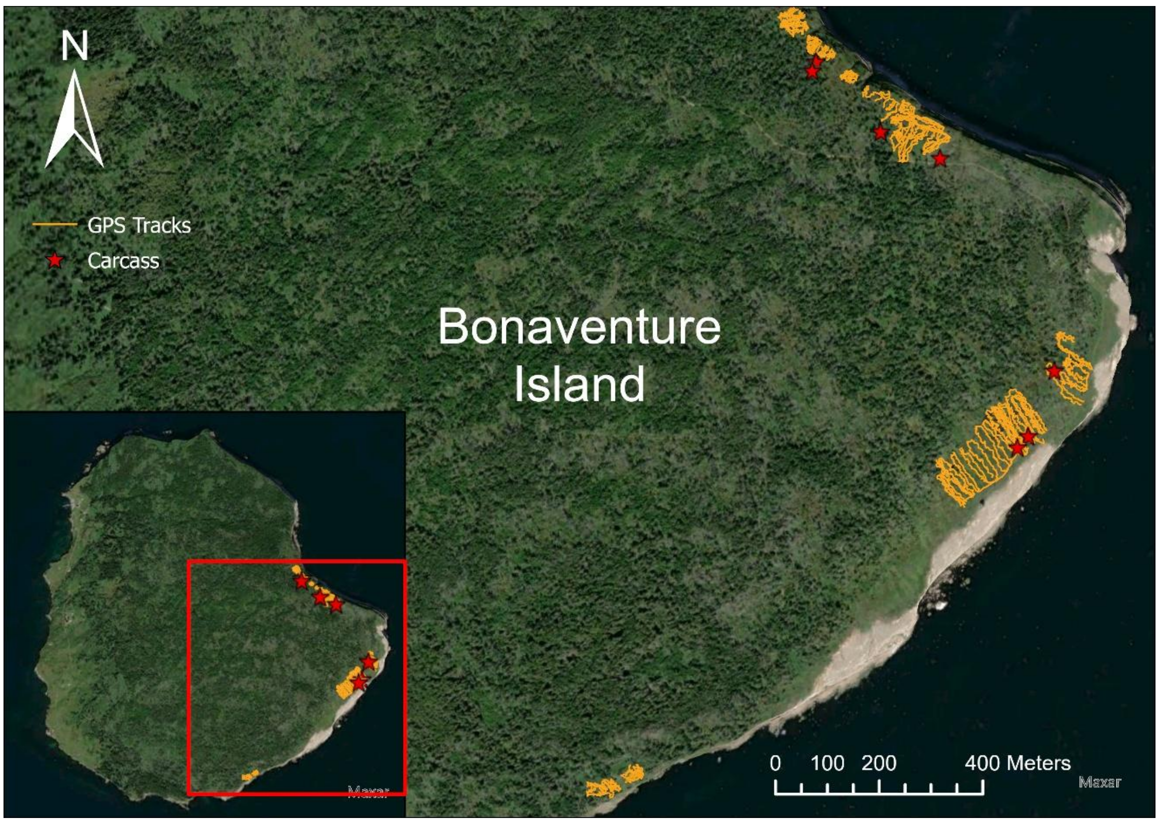

Figure 6. Targeted ground searches across 11 days for Leach's Storm-petrel burrows on Bonaventure Island in 2024, shown as orange GPS tracks. Leach's Storm-petrel carcasses discovered during these searches are marked with red stars.

Data Analysis

All recordings were analyzed using Raven Pro 1.6.5, a software tool designed for detecting and categorizing auditory vocalizations. A total of 3,784 hours of audio data collected in 2023-2024 were processed using an automated learning detection program powered by BirdNET (Kahl et al., 2021), integrated within Raven Pro 1.6.5. This program was specifically filtered to detect only Leach's Storm-petrel chatter and purr calls, with parameters set to identify calls within the zero to twelve kHz frequency range, which is the typical range for Leach's Storm-petrel call frequency. This method significantly streamlined the analysis compared to manual spectrogram processing. A detection accuracy threshold of 70% or higher was applied, meaning that only detections that matched the spectrogram template of a known Leach's Storm-petrel call with at least 70% similarity were retained. This threshold helped to optimize detection efficiency and data quality, while diminishing the number of false positive detections.

To evaluate the false positive rate, 75 detections from the automated learning detector were manually verified for each SM ARU model (SM1, SM2+, and SM4), with 25 detections selected from June, July, and August, respectively. To account for differences in recording effort among ARUs, the total number of calls detected at each ARU was divided by the number of recording nights. This produced a standardized metric "Detections per Night".

Spatial Interpolation

Proportional Call Density Circle Map

To help visualize Leach's Storm-petrels activity recorded by the ARUs on Bonaventure Island, I created a proportional circle map. In this type of map, the size of each circle is scaled to represent the number of calls detected per night at each ARU location. This provides a clear visual summary of relative call frequency where ARUs were deployed across the island. Data were processed and manipulated using R packages "*sf*" and "*dplyr*" (Pebesma, 2018; Wickham et al., 2023). The map was generated using R packages “ggplot2”, “*ggspatial*”, and “*scales*” (Dunnington, 2023; Wickham, 2016; Wickham, Pedersen, et al., 2023). Because this map presents raw detection data from each ARU, it serves as a tool for interpreting the spatial interpolation results.

Spatial Distribution of Leach’s Storm-petrels Using an Inverse Distance Weight Analysis

To interpolate Leach’s Storm-petrel call activity across the island, an Inverse Distance Weighting (IDW) analysis was performed using detections per night from the Song Meters only. IDW is a spatial interpolation technique that estimates values at unsampled locations based on the principle that values at points closer together are more similar than those farther apart (Lu & Wong, 2008). The analysis assigns higher weights to nearby ARUs and lower weights to distant ones, using a function of distance to generate a continuous prediction of call densities across the study area. This allows the prediction of potential calling hotspots even in areas that may have been missed by ARU recordings. The compiled spatial data was manipulated in RStudio (2024.09.1+394) using r packages “*raster*”, “*sf*”, “*sp*”, and “*stars*” (Hijmans, 2024b; Pebesma, 2018, 2023; Pebesma & Bivand, 2005). IDW interpolations were performed using the r package “*gstat*” (Pebesma, 2004). A spatial area representing potential Leach’s Storm-petrel nesting habitat was defined as a 300 m inland zone from the island’s coastline. This was done by adding zero-detection points 300 m inland from each ARU to reflect Leach’s Storm-petrels preference for nesting around coastal, shallow soiled habitats (Harris, 1974; Vermeer et al., 1988) and simulate habitat unsuitability in interior or inland zones that would fall beyond their expected nesting ranges. Within the spatial area a 50 m x 50 m resolution grid using the r package “*scales*” (Wickham et al., 2023) was applied to interpolate values and visualize spatial variation.

The inverse power parameter (IDP) was set to 5. This parameter controls how quickly the influence of a recorded point diminishes with distance, with higher values placing greater weight on nearby points. A value of 5 was chosen to prioritize strong local influence and minimize smoothing over large distances, given the size of the island, number of ARUs and the patchiness of Leach’s Storm-petrel call activity. However, it’s important to note that IDP selection influences interpolation outcomes, with lower IDP producing a more generalized distribution, and higher IDP creating localized peaks.

To help visualize interpolated call densities, spatial outputs were mapped using r packages “*ggplot2*” and “*geosphere*” (Hijmans, 2024a; Wickham, 2016).

Model Error Comparison

To assess the reliability of the IDW interpolation, I generated predicted values from the IDW using the R package “*gstat*” (Pebesma, 2004) and compared them with detections per night from the AudioMoth units (where partial data were available). While not all AudioMoths yielded usable data, those with partial recordings provided a point of comparison for evaluating the spatial predictions. To assess whether prediction error was biased either high or low (i.e., whether IDW over- or under- estimated call rates), I computed mean signed deviation (MSD) using the following formula:

$$MSD = \frac{1}{n}\sum_{i-1}^{n} Calls\ Detected\ per\ Night\ - Predicted\ Calls\ per\ Night$$

Predictions were considered accurate when MSD was close to zero, whereas large discrepancies indicated an underestimation or overestimate of call detections. To facilitate visualization, I used R packages "*knitr*" and "*kableExtra*" (Xie, 2014; Zhu, 2024) to create a structured comparison table.

Results

Preliminary Field Component

Prior to the June 2023 field visit, SÉPAQ staff and other researchers documented six Leach's Storm-petrel carcasses on Bonaventure Island (Figure 1). In response, a preliminary field survey was conducted to assess Leach's Storm-petrel activity and locate potential active burrows, with targeted searches focused on areas where the carcasses had been found and where SÉPAQ had previously observed their presence. Despite these efforts, no burrows or individuals were found during the trip. The absence of observed individuals and active burrows prompted a shift in focus toward the use of ARUs to help identify potential nesting areas and monitor Leach's Storm-petrel activity on the island.

ARUs were deployed in September 2023 to capture late-season call activity from individuals that may have remained in burrows into the fall. However, no Leach's Storm-petrel calls were detected during this period. This absence of fall vocalizations contributed to the decision to end ARU recording schedules earlier, at the end of August, for the 2024 season to better align with the species' peak breeding and vocal activity period.

Acoustic Recording Detections

During the 2024 breeding season, the 16 Song Meters (Table 1) recorded a total of 2,832.5 hours of audio over 1,133 recording nights. A total of 28,627 (ranging between 0-

13,877 per recording unit) Leach's Storm-petrel calls were detected using Raven Pro Software and 48% of these were detected at one Song Meter located on the northeast side of the island (SM4-18217; Table 1, Figure 4).

Table 1. Locations, total call detections, recording nights, and detections per night for 16 Song Meters deployed on Bonaventure Island, Québec, during the 2024 breeding season.

Unit Number	Latitude	Longitude	Calls Detected	Recording Nights	Detections per Night
SM1-071	48.4991	-64.1535	1,071	69	15.52
SM1-097	48.4958	-64.1475	331	82	4.04
SM1-177	48.4844	-64.1665	1	73	0.01
SM1-179	48.4873	-64.1534	84	76	1.11
SM1-182	48.4871	-64.1733	0	68	0.00
SM1-953	48.4915	-64.1761	1	71	0.01
SM1-970	48.4902	-64.1494	2,045	74	27.64
SM1-973	48.4841	-64.1594	0	76	0.00
SM2-8339	48.4964	-64.1494	327	67	4.88
SM2-8365	48.4850	-64.1573	652	73	8.93
SM4-1274	48.4983	-64.1764	0	50	0.00
SM4-1313	48.4946	-64.1457	142	80	1.78
SM4-18217	48.5010	-64.1540	13,877	99	140.17
SM4-3666	48.4916	-64.1467	3,548	95	37.35
SM4-3700	48.5038	-64.1737	7	95	0.07
SM4-7192	48.4976	-64.1519	6,541	80	81.76
TOTAL	**-**	**-**	**28,627**	**1,228**	**323.27**
AVERAGE	**-**	**-**	**1,789.19**	**76.75**	**23.31**

Detections from AudioMoth units were not included in the total number and analysis due to the inconsistent programming and recording throughout the field season. Few to no calls were detected on the western side of the island (Figure 8 & 9). Standardized detection rates, expressed as "Detections per night", varied across locations (range 0-140.17) and the overall average detections per night across all Song Meters was 20.20 ± 18.90 (95% CI) per recording unit (Table 1). False positives were assessed by manually listening to selections of recordings from each SM ARU model. In all cases, I found no false positives (i.e., average accuracy of 100% across all months) when using an accuracy threshold of 70% or higher (Table 2). As this study focuses on the presence of Leach's Storm-petrels and not their absence, no false negative verifications were conducted.

Table 2. Manual verification for false positives from Leach's Storm-petrel calls detected at Bonaventure Island in 2024 by the automated learning detector. The verification confirmed 100% accuracy in identifying Leach's Storm-petrel calls with a detector parameter confidence threshold of 70% or higher.

Unit ID	Calls Verified	Detector Accuracy (%)	Detection Scores (%)	False Positives
SM4-7192	75	100	74-99	0
SM1-970	75	100	70-99	0
SM2-8365	75	100	70-99	0

Spatial Distribution of Leach's Storm-petrels

The IDW spatial interpolation analysis revealed distinct spatial patterns in Leach's Storm-petrel activity on Bonaventure Island. The northeastern region exhibited the highest detection density, with moderate activity recorded near the eastern cliffs (located between SM4-18217 and SM4-1313; Figure 4) and the Northern Gannet observation tower (located between SM4-1313 and Au-63; Figure 4). By contrast, the southern and western sides of the island showed little to no activity.

When comparing predicted call detections with call detections per night from AudioMoths locations (Figure 9), my interpolation seemed to underestimate areas with large volumes of calls per night, particularly at Au-61 and Au-65 (Table 3). However, predictions for the remaining seven ARUs where very few calls were recorded were fairly accurate, with signed errors close to zero, and the overall MSD showing an overall mean signed deviation overestimate of about 15.72 calls detected per night (Table 3).

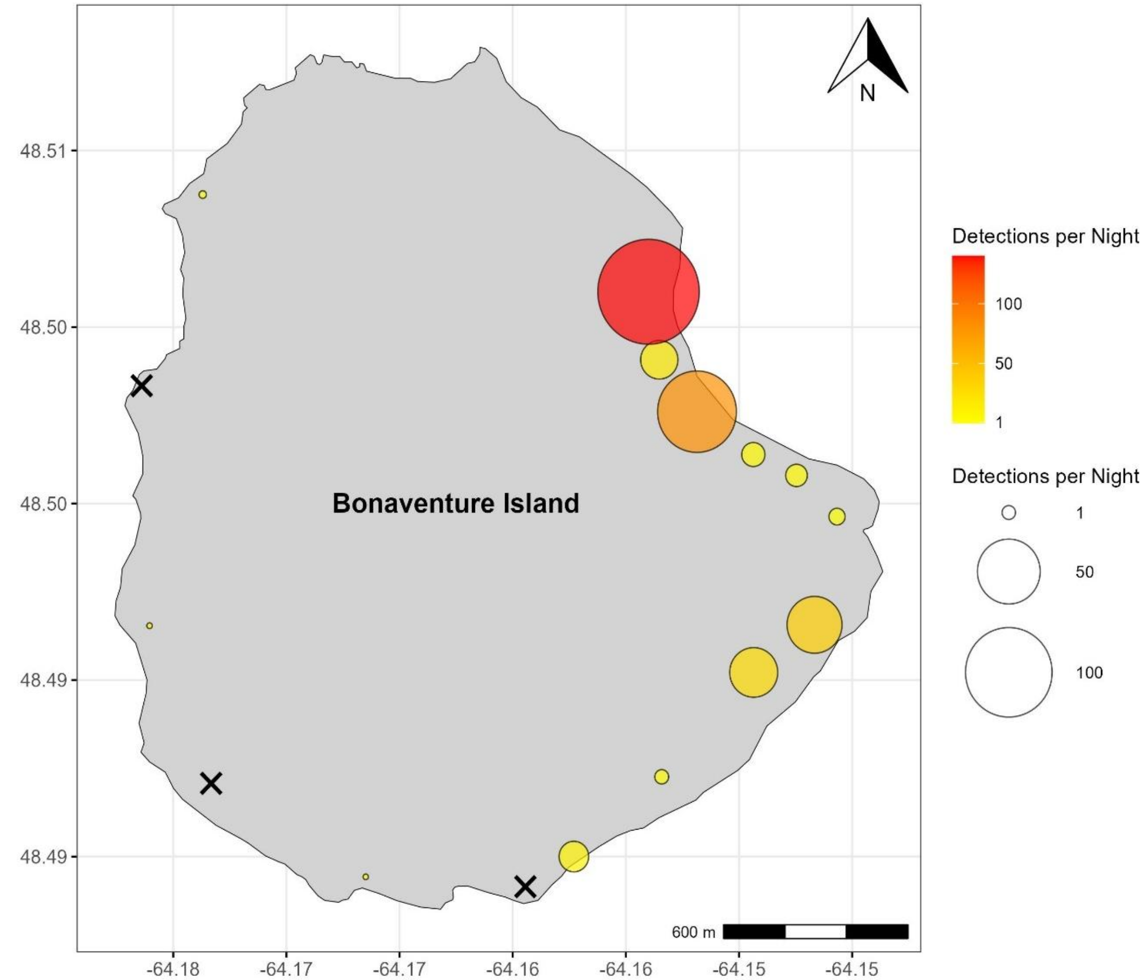

Figure 7. Map of Leach's Storm-petrel detections per night for each ARU unit deployed on Bonaventure Island during the 2024 breeding season. The size and color intensity of the circles represent call density, with larger, darker circles indicating higher detection rates and smaller, lighter circles indicating lower detection rates. Locations of ARUs with zero detections are marked with a black X.

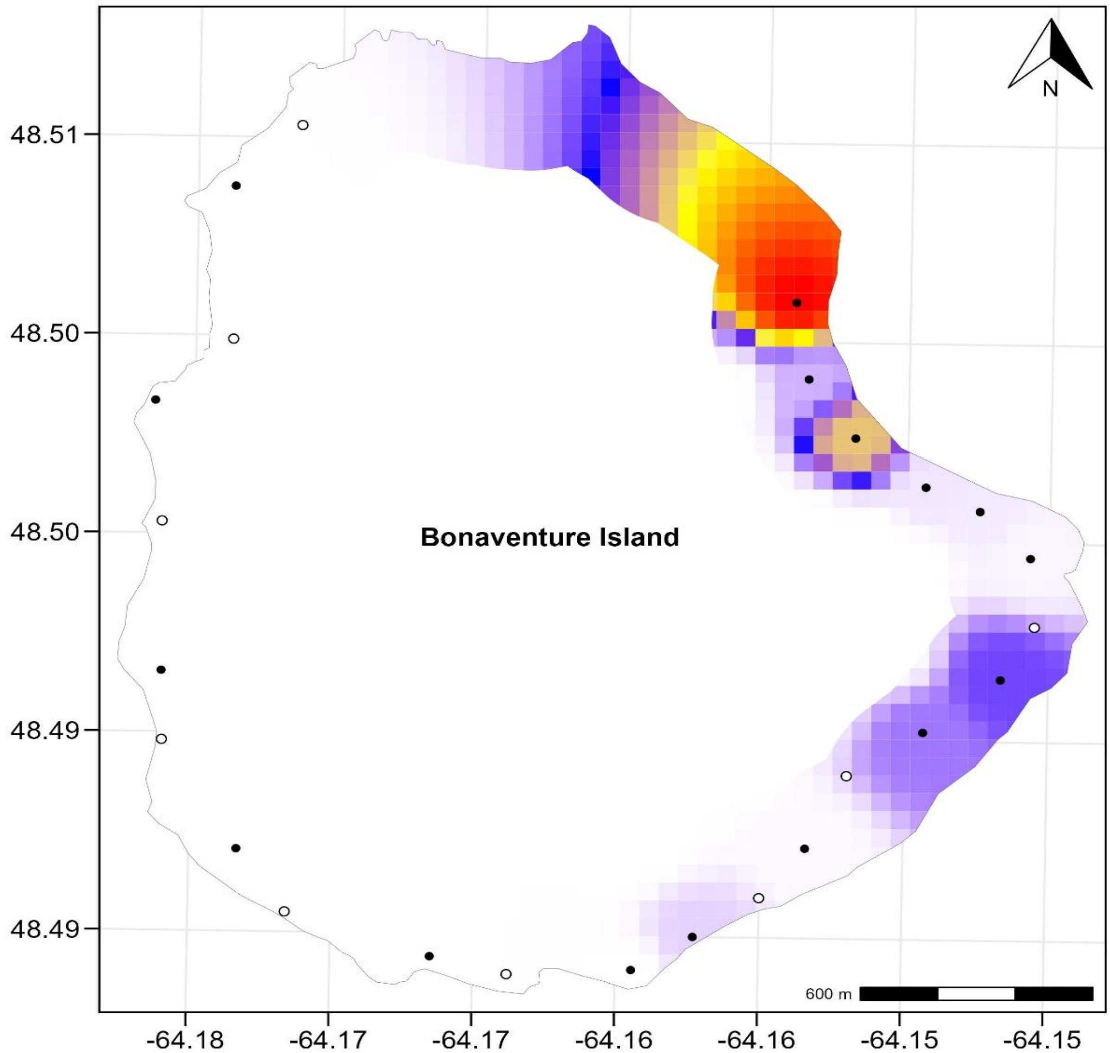

Figure 8. Spatial interpolation of Leach's Storm-petrel call detections on Bonaventure Island, Québec, during the 2024 breeding season. The map was generated using an Inverse Distance Weighting (IDW) model to estimate call density across the island. Areas with higher detection rates are shown in warmer colors (e.g., red), while areas with lower detection rates are shown in cooler colors (e.g., blue). Black dots represent Song Meter locations and white dots represent AudioMoth locations; calls detected from AudioMoths were not included in the IDW interpolation.

Table 1. Summary of mean signed deviation (MSD) for Inverse Distance Weighting (IDW) predicted calls per night and actual calls per night from nine AudioMoth ARUs deployed on Bonaventure Island, Quebec in summer 2024.

Unit Number	Calls Detected per Night	Predicted per Night	Signed Error
Au-41	0	0.12400	-0.124
Au-61	31.36	0.57000	30.79
Au-63	0	4.56000	-4.56
Au-65	114.13	0.01100	114.11
Au-64	0.167	0.00200	0.165
Au-66	0	0.00200	-0.002
Au-67	0	0.00050	-0.0005
Au-68	0.129	0.00080	0.128
Au-69	1	0.01100	0.989
		Mean Signed Deviation	**15.72**

Predator Monitoring

Motion-activated trail cameras captured a total of 11 identified species over the course of their deployment (May-September 2024), along with two unidentified species at CAM6 (Table 4). No detections were recorded at CAM5.1, and CAM8 malfunctioned, failing to capture any photos. The most frequently detected species were humans, with over 13,000 recordings of individuals in more than 7,000 photos at CAM7, CAM5, and CAM4.2. These high detection rates reflect heavy tourist and park staff traffic, particularly on active trails and around park infrastructure. Among wildlife detections, Snowshoe Hare (*Lepus americanus*) was the most frequently recorded species, with 67 detections across multiple cameras (Table 4). Three species identified as potential Leach's Storm-petrel predators were also recorded (Table 4), these include: 1) Red Fox, detected at six camera locations, with a total of 22 observations; 2) Deer Mouse (*Peromyscus maniculatus*) observed only at CAM4, with 15 detections; 3) Northern harrier (*Circus hudsonius*) detected at CAM1 and CAM4.2, with a total of four observations. Other species recorded included forest birds that are unlikely to pose a direct threat to Leach's Storm-petrels (Table 4).

Table 2. Total number of species observed from motion-activated trail cameras. (Cameras CAM5 and CAM7 are not displayed as they only captured photos of humans. Cameras CAM5.1 and CAM8 did not capture any photos.)

Species	Camera ID						
	CAM1	**CAM2**	**CAM3**	**CAM4**	**CAM4.2**	**CAM6**	**Grand Total**
American Robin		2		5			7
Gray Catbird				1			1
Least Flycatcher				3			3
Deer Mouse				15			15
Northern Harrier	2				2		4
Red Fox	2	8	5	1	2	4	22
Rodent				1			1
Savannah Sparrow					1		1
Snowshoe Hare	8	23	3		1	32	67
Song Sparrow				4			4
Swainson's Thrush				1			1
Unknown Species						8	
Grand Total	**12**	**33**	**8**	**31**	**6**	**44**	**134**

Nocturnal Surveys

Leach's Storm-petrel activity was detected at nine of the 11 nocturnal survey points, with no activity recorded at NS-10 and NS-11 (Figure 6). A total of 92 individual sightings of at least seven individual birds were detected (Table 5). It is difficult to differentiate individuals from survey location to survey location, and it is probable some individuals may have been detected and counted multiple times. The highest activity occurred during the second round of surveys, particularly on the night of June 27-28, with 21 detections recorded throughout the whole survey.

Table 3. Counts of individual Leach's Storm-petrels observed or heard during nocturnal surveys on Bonaventure Island, Québec, in 2024. The table summarizes the total number of individuals detected at each survey location across two survey rounds.

Survey Point	Leach's Storm-petrel Nocturnal Survey Detections						Total per Survey Point
	Round 1			Round 2			
	Jun 20-21	Jun 21-22	Jun 22-23	Jun 27-28	Jun 28-29	July 1-2	
NS-01	0	2	7	0	2	4	15
NS-02	2	4	2	2	2	5	17
NS-03	0	2	1	7	4	1	15
NS-04	0	2	1	4	2	2	11
NS-05	0	2	5	2	2	6	17
NS-06	0	0	1	4	0	1	6
NS-07	1	0	1	2	0	1	5
NS-08	0	0	0	0	5	0	5
NS-09	0	0	0	0	1	0	1
NS-10	0	0	0	0	0	0	0
NS-11	0	0	0	0	0	0	0
Total per Night	3	12	18	21	18	20	92

Notably, nocturnal survey points NS-01 through NS-05, all located along the eastern coast of the island, showed relatively high numbers of Leach's Storm-petrel sightings compared to NS-06 through NS-11. For example, NS-02 and NS-05 each recorded 17 detections, while other eastern points like NS-01, NS-03, and NS-05 had similarly elevated detection rates (Table 5), suggesting greater activity in this region.

Using Zeiss DTI 4/50 and FLIR C5 thermal imaging cameras, 12 thermal video recordings of Leach's Storm-petrels were captured. Stills of the videos were extracted to illustrate Leach's Storm-petrel nocturnal activity (Appendix C).

Targeted Ground Searches

Despite systematic efforts over two field seasons across nine search areas, no active Leach's Storm-petrel burrows were located. However, signs of potential nesting activity, such as feathers and carcasses, were observed in several areas, particularly those with higher acoustic detections or nocturnal survey observations. Throughout the 2024 field season, a total of seven carcasses were found (Figure 7) during the targeted ground searches or while walking between nocturnal survey point locations.

Discussion

Leach's Storm-petrel Distribution on Bonaventure Island

This study aimed to assess the spatial distribution of Leach's Storm-petrel on Bonaventure Island using ARUs, ground searches, and nocturnal playback surveys. The results indicate a high level of call density and nocturnal detections in the northeastern part of the island, with additional detections near the eastern cliffs and behind the Northern Gannet colony observation tower. The presence of Leach's Storm-petrels near the cliffs and behind the observation tower has been well documented by SÉPAQ in recent years. However, the previously undocumented call activity in the northeastern part of the island suggests either an overlooked or newly established nesting area that deserves further investigation. While the IDW analysis showed a moderate to low overall call density predictability, particularly for areas with high call rates, my results indicate a potential area of high calling density closest to the northeastern ARU (SM4-18217) that should be investigated. However, it is possible that call rates in this area may be inflated as the next closest alternative ARU location for the interpolation to draw upon was located at the far western end of the island. This spatial gap may have caused the interpolation to rely too heavily on data from SM4-18217, potentially overestimating call density in the area.

The detection of Leach's Storm-petrel calls in the northeastern forested area was unexpected and could indicate a shift in areas od Leach's Storm-petrel activity. Leach's

Storm-petrels tend to be associated with sparsely vegetated coastal and shallow soiled areas (Harris, 1974; Vermeer et al., 1988). However, the northeastern area of the island is dominated by sparse mixed-wood forests, which may offer enough open space for flight while also offering concealment from predators. Additionally, this region runs adjacent to large cliffs to the northeast, which could serve as a natural barrier against ground-based predators and provide a means of escape. Previous studies have indicated that Leach's Storm-petrels may select nesting sites based on habitat availability, predator pressure, and proximity to foraging areas (Stenhouse & Montevecchi, 2000; Vermeer et al., 1988; Wilhelm et al., 2015; Wilhelm et al., 2020). Further research is needed to determine whether this northeastern expansion is a shift in their distribution as a response to increased predation and human activity or more simply that SÉPAQ and other researchers have not previously documented this aspect of their habitat use on Bonaventure Island.

Leach's Storm-petrel Absence in the Southern and Western Island Regions

The lack of call activity in the southern and western parts of the island are consistent with past surveys (unpublished data, SÉPAQ 2024; Côté, 2012; Cotter & Rail, 2007). This absence may be due to a number of reasons. <u>Habitat Suitability</u>: The southern region of Bonaventure Island is dominated by dense coniferous stands, which may impede flight maneuverability and limit burrow excavation opportunities in this region. <u>Human Disturbance</u>: The western region of Bonaventure Island is heavily influenced by park infrastructure, historic settlements, interpretive displays, and popular hiking trails. These contribute to high levels of human activity, which may cause Leach's Storm-petrels to avoid these areas or abandon nests due to frequent disturbances (Blackmer et al., 2004; Pollet et al., 2023). <u>Predator Presence</u>: Ground-dwelling predators, such as foxes and rodents, tend to concentrate in areas with high food availability (e.g., scavenging near the gannet colony for foxes, and human food sources for rodents). Leach's Storm-petrels may actively avoid these predator-dense zones, leading to lower nesting densities in those areas (Miles et al., 2013; Stenhouse, 1998; Watanuki, 1986). Additionally, areas that are more open can increase their vulnerability to predation by Great Black-backed (*Larus marinus*) and Herring gulls (*L. argentatus*) (Bond et al., 2023b; Stenhouse et al., 2000; Veitch et al., 2016), both of which are known to nest on Bonaventure Island (personal observation, Eric Pollard 2024).

Although direct evidence of predator-prey interactions was not observed, the deployment of trail cameras during this study captured images of red foxes, rodents, and snowshoe hares near known Leach's Storm-petrel activity areas. These finding provide important confirmation of mammalian presence in Leach's Storm-petrel habitats and contribute to the understanding of predator pressure on the island. As such, the use of motion sensor cameras should be included in long-term monitoring programs to help identify predator hotspots and evaluate whether there is a need for management strategies. Future studies could expand on this work by assessing predator distribution and abundance across the island and determining the degree to which predator presence impacts nesting activity and reproductive success.

Access Constraints to the Northern Island Region

Survey efforts were limited in the island's northern section due to extensive blowdown likely caused from past hurricane-force winds, and subsequent dense forest regeneration, which hindered movement and visibility of field crews. In addition, steep cliffs, and unstable, loose undercut grassy terrain made access unsafe, ultimately leading to the decision to exclude this area from the study. However, this region's isolation from human activity and presumed inaccessibility to mammalian predators suggest it may be an important refuge for Leach's Storm-petrel.

Future research should prioritize this northern region by using passive monitoring techniques, such as ARUs and motion sensor trail cameras, which are well-suited for collecting long-term data in areas that are difficult to access regularly. To do this effectively and safely, coordination with SÉPAQ staff for safety, logistical planning, and equipment retrieval will be essential. A combination of remote imagery and ground truthing could help identify the safest and least disruptive access routes. In some areas, temporary trails may be required to improve accessibility. However, these changes to the landscape could inadvertently facilitate access for mammalian predators and require careful consideration. Targeted efforts in this region could provide data on Leach's Storm-petrel activity and predator presence in what may represent the most suitable habitat for the species on Bonaventure Island.

Minimum Population Estimate

While a robust population estimate is difficult to achieve, it is possible to propose a minimum estimate based on survey findings. At least seven unique individuals were observed during nocturnal surveys in 2024. Additionally, three to seven carcasses have been found annually by SÉPAQ or throughout my field seasons on the island, which likely underrepresents actual mortality numbers. These observations suggest a minimum presence of 10 individuals on the island, however, breeding status of these individuals is unknown. Furthermore, 10 ARUs detected Leach's Storm-petrels along the eastern side of the island (Figure 8 & 9), although it is unlikely all 10 locations serve as breeding sites, there is the possibility that some nesting activities are occurring. While conservative, these estimates highlight the importance of continued monitoring and suggest that a small breeding population on Bonaventure Island is possible.

Traditional Surveys vs ARU monitoring

Nocturnal surveys conducted during the 2024 breeding season confirm the continued presence of Leach's Storm-petrels (Table 5 & Appendix C), with a total 92 individual bird sightings or a minimum of seven individuals detected per survey location. This confirms the presence of Leach's Storm-petrel on Bonaventure Island. Whether or not petrels are nesting remains uncertain.

Compared to traditional nocturnal surveys, ARUs provide a more comprehensive, non-invasive method for monitoring cryptic seabird species. When properly configured, ARUs can record continuously throughout the entire breeding season and offer higher detection probabilities than traditional nocturnal point-count or playback surveys (Buxton et al., 2013; Buxton & Jones, 2012; Orben et al., 2019; Shonfield & Bayne, 2017). ARUs have been successfully used to monitor colony population trends, estimate population size, and assess burrow occupancy for various seabird species, including Leach's Storm-petrels (Buxton & Jones, 2012; Oppel et al., 2014; Orben et al., 2019; Pérez-Granados & Traba, 2021). However, it is important to note that these population estimates typically rely on pre-existing knowledge of burrow density and known nesting locations to calibrate call rates with population size. In the absence of these ground-truthed data, interpreting call counts alone as population estimates is potentially misleading, as calling rates can vary by individual behaviour, colony density, time of night, and breeding status (Oppel et al., 2014). Accurately distinguishing individual birds based on call structure alone remains a significant challenge, often requiring in-depth bioacoustics knowledge and detailed manual verification. As such, individual-level acoustic analyses should be conducted by researchers with specialized expertise in sound analysis and vocalization pattern recognition.

In this study, ARUs proved valuable for documenting species presence and spatial patterns of calling activity. However, the nine AudioMoth units deployed on Bonaventure Island were improperly configured, resulting in inconsistent recording timing and durations when compared to SM units, limiting their use to assessing the results from the interpolation. Moreover, while the ARUs had an approximate detection range of 150 m under optimal conditions, this range is reduced by dense vegetation, terrain, and background noise. These environmental factors, combined with uneven spacing of ARUs, likely influenced call detection rates and may have introduced biases in the IDW spatial interpolation. Given the differences in spacing between ARUs and their acoustic detection limits, some areas of higher or lower call density could have been under or over estimated.

Despite these limitations, the spatial interpolation outputs of the IDW analysis (Figure 9) complemented the raw ARU detections (Figure 8) by providing estimates of call activity across unsampled areas of the island. While ARU detections provide valuable location-based information, IDW interpolation helps visualize spatial trends and identify areas of higher or lower call density. Future applications of ARUs should aim to refine unit spacing, ensure proper configuration across all devices, and incorporate concurrent ground-truthing to support more robust population trends.

Predator Monitoring and Trail Camera Insights

Although Leach's Storm-petrel reproductive success and detailed predation surveys were not completed due to the absence of confirmed burrows, trail cameras captured images of known predators including rodents and foxes. Additionally, snowshoe hares were observed near Leach's Storm-petrel activity areas (Table 4; Figure 6, 8, & 9). Hares are known to alter vegetation habitat structures and indirectly affect seabird nesting habitat quality (Hipfner et al., 2010; Wheelwright, 2016). Motion-triggered cameras are effective for passively monitoring cryptic species (Bondi et al., 2010; Lamelas-López & Salgado, 2021; Pickerell et al., 2013; Rendall et al., 2014), and the use of these cameras may be the most cost-effective way to monitor the presence of mammalian predators on the island. Collaboration with island restoration and seabird conservation groups could support predator management efforts, drawing from successful Canadian and global examples (e.g., Baker et al., 2020; Courchamp et al., 2003; Rauzon, 2008; Scopel, 2017; Spatz et al., 2022; Wheelwright, 2016).

Long-term Monitoring and Conservation Recommendations

The observation of Leach's Storm-petrels on Bonaventure Island is encouraging and suggest their continued presence on the island. Continued research and monitoring are important to fully understand their distribution, breeding status, and population trends. To support conservation efforts, the following actions are recommended.

1. Locating Active Burrows: Continue using grubbing, call playback, and thermal imagery technology, and employ GPS tagging to identify active burrow locations, particularly in unexplored areas of the island. Locating active nests will help assess population size, monitor reproductive success, and direct protective measures.

2. Burrow Protection and Enhancement: Consider predator-exclusion fencing, artificial burrows, or translocations, which have been successful with other seabird species (Bourgeois et al., 2015; Fromant et al., 2020; Priddel & Carlile, 1995; Ringma et al., 2020; Sutherland et al., 2014; Young et al., 2018). These measures can increase nesting success by reducing predation risk and enhancing suitable habitat.

3. Comprehensive Predator Assessment: Conduct a full evaluation of both mammalian and avian predators to understand the pressures affecting Leach's Storm-petrel populations and their reproductive success on the island. Identifying key predator species, their estimated numbers, and activity patterns will help inform management actions to mitigate their threats against Leach's Storm-petrels.

Study Limitations

This study faced several logistical challenges that limited the scope of data collection. Bonaventure Island's large size and dense vegetation made locating active burrows particularly difficult, especially given the cryptic and nocturnal nature of Leach's Storm-petrels. The dense undergrowth in many areas of the island required extensive effort to navigate and survey effectively. Additionally, several ARUs were not properly configured, which limited their inclusion in some of the final analyses. Future work would benefit from joint troubleshooting or technical setup prior to deployment to ensure data quality and maximum recording coverage. Burrow searches were constrained by limited personnel capacity, which reduced the extent of the areas that could be covered. Collaborations involving more personnel or volunteers may help increase search efforts in future field seasons. Despite these limitations, the study successfully documented key areas of Leach's Storm-petrel activity and highlighted promising areas for future research.

Conclusion

This study provides important insight into the areas of high Leach's Storm-petrel activity on Bonaventure Island. The detections in the northeastern region suggest previously undocumented or shifting activity, highlighting the importance of long-term monitoring for this cryptic, nocturnal seabird. However, the population remains small and faces multiple threats both at sea and on the island. Without conservation measures, particularly those addressing predation, human disturbance, and habitat protection, this population is at risk of local extirpation. Ongoing collaboration between researchers, park managers, and conservation organizations, along with the implementation of standardized monitoring and active management strategies, will be essential to ensure the persistence of this population and contribute to broad seabird conservation efforts across Atlantic Canada.

Bibliography

Ambagis, J. (2004). A comparison of census and monitoring techniques for Leach's Storm Petrel. *Waterbirds*, *27*(2), Article 2. https://doi.org/10.1675/1524-4695(2004)027[0211:ACOCAM]2.0.CO;2

Baker, C. M., Plein, M., Shaikh, R., & Bode, M. (2020). Simultaneous invasive alien predator eradication delivers the best outcomes for protected island species. *Biological Invasions*, *22*(3), 1085–1095. https://doi.org/10.1007/s10530-019-02161-z

Bicknell, T. W. J., Reid, J. B., & Votier, S. C. (2009). Probable predation of Leach's Storm-petrel *Oceanodroma leucorhoa* eggs by St Kilda Field Mice *Apodemus sylvaticus hirtensis*. *Bird Study*, *56*(3), 419–422. https://doi.org/ 10.1080/ 00063650903216618

BirdLife International. (2018). *The IUCN red list of threatenedsSpecies*. *Hydraoabtes Leucorhous*. The IUCN red list of threatened species 2018: E.T132438298A132438484. https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T132438298A132438484.en

Blackmer, A. L., Ackerman, J. T., & Nevitt, G. A. (2004). Effects of investigator disturbance on hatching success and nest-site fidelity in a long-lived seabird, Leach's storm-petrel. *Biological Conservation*, *116*(1), 141–148. https:// doi.org/10.1016/S0006-3207(03)00185-X

Bond, A. L., Wilhelm, S. I., Pirie-Hay, D. W., Robertson, G. J., Pollet, I. L., & Arany, J. L. (2023a). Quantifying gull predation in a declining Leach's Storm-petrel

(*Hydrobates leucorhous*) colony. *Avian Conservation and Ecology*, *18*(1). https://doi.org/10.5751/ACE-02388-180105

Bond, A. L., Wilhelm, S. I., Pirie-Hay, D. W., Robertson, G. J., Pollet, I. L., & Arany, J. L. (2023b). Quantifying gull predation in a declining Leach's Storm-petrel (*Hydrobates leucorhous*) colony. *Avian Conservation and Ecology*, *18*(1). https://doi.org/10.5751/ACE-02388-180105

Bondi, N., White, J., Stevens, M., & Cooke, R. (2010). A comparison of the effectiveness of camera trapping and live trapping for sampling terrestrial small-mammal communities. *Wildlife Research*, *37*, 456–465. https://doi.org/10.1071/WR10046

Bourdages, M., & Lavoie, C. (2011). Plant introduction and extirpation in a small island park: Natural and anthropogenic rates. *Écoscience*, *18*(2), 89–97. https://doi.org/10.2980/18-2-3388

Bourgeois, K., Dromzée, S., & Vidal, E. (2015). Are artificial burrows efficient conservation tools for seabirds? A case study of two sympatric shearwaters on neighbouring islands and guidelines for improvement. *Biological Conservation*, *191*, 282–290. https://doi.org/10.1016/j.biocon.2015.07.002

Buxton, R. T., & Jones, I. L. (2012). Measuring nocturnal seabird activity and status using acoustic recording devices: Applications for island restoration. *Journal of Field Ornithology*, *83*(1), Article 1. https://doi.org/10.1111/j.1557-9263.2011.00355.x

Buxton, R. T., Major, H. L., Jones, I. L., & Williams, J. C. (2013). Examining patterns in nocturnal seabird activity and recovery across the Western Aleutian Islands, Alaska, using automated acoustic recording. *The Auk*, *130*(2), 331–341. https://doi.org/10.1525/auk.2013.12134

Côté, J. (2012). *Inventaire partiel de l'océanite cul-blanc à l'île Bonaventure*. Parc national de l'Île-Bonaventure-et-du-rocher-Percé.

Cotter, R., & Rail, J.-F. (2007). Third census of seabird populations of the Gaspé Peninsula, Québec, 2002. *The Canadian Field-Naturalist*, *121*(3), Article 3. https://doi.org/10.22621/cfn.v121i3.475

Courchamp, F., Chapuis, J.-L., & Pascal, M. (2003). Mammal invaders on islands: Impact, control and control impact. *Biological Reviews*, *78*(3), 347–383. https://doi.org/10.1017/S1464793102006061

Croxall, J. P., Butchart, S. H. M., Lascelles, B., Stattersfield, A. J., Sullivan, B., Symes, A., & Taylor, P. (2012). Seabird conservation status, threats and priority actions: A global assessment. *Bird Conservation International*, *22*(1), 1–34. https://doi.org/10.1017/S0959270912000020

Diamond, A. W., & Devlin, C. M. (2003). *Seabirds as Indicators of Changes in Marine Ecosystems: Ecological Monitoring on Machias Seal Island*. *88*, 153–175.

Dias, M. P., Martin, R., Pearmain, E. J., Burfield, I. J., Small, C., Phillips, R. A., Yates, O., Lascelles, B., Borboroglu, P. G., & Croxall, J. P. (2019). Threats to seabirds: A global assessment. *Biological Conservation*, *237*, 525–537. https://doi.org/10.1016/j.biocon.2019.06.033

Dunnington, D. (2023). *ggspatial: Spatial data framework for ggplot2*. https://CRAN.R-project.org/package=ggspatial. Accessed: March 28, 2025.

eBird. (2025). *eBird: An online database of bird distribution and abundance. eBird, Cornell Lab of Ornithology, Ithaca, New York.* http://www.ebird.org. Accessed: April 24, 2025.

Environment and Climate Change Canada. (2021, October 12). *Leach's Storm-Petrel (Atlantic population) (Oceanodroma leucorhoa): COSEWIC assessment and status report 2020* [Featured articles]. https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/cosewic-assessments-status-reports/leachs-storm-petrel-2020.html

Fromant, Aymeric., Miskelly, C. M., Arnould, J. P. Y., & Bost, C.-A. (2020). Artificial burrows as a tool for long-term studies of diving petrels. *Polar Biology*, *43*(5), 435–442. https://doi.org/10.1007/s00300-020-02645-y

Furness, R. (1997). Seabirds as monitors of the marine environment. *ICES Journal of Marine Science*, *54*(4), Article 4. https://doi.org/10.1006/jmsc.1997.0243

Harris, S. W. (1974). Status, chronology, and ecology of nesting Storm Petrels in northwestern California. *The Condor*, *76*(3), 249–261. https://doi.org/10.2307/1366338

Hijmans, R. (2024a). geosphere: spherical trigonometry. https://CRAN.R-project.org/package=geosphere. Accessed: March 28, 2025.

Hijmans, R. (2024b). Raster: geographic data analysis and modeling. https://CRAN.R-project.org/package=raster. Accessed: March 28, 2025.

Hilton, G. M., & Cuthbert, R. J. (2010). Review article: The catastrophic impact of invasive mammalian predators on birds of the UK Overseas Territories: a review and synthesis. *Ibis*, *152*(3), 443–458. https://doi.org/10.1111/j.1474-919X.2010.01031.x

Hipfner, J. M., Lemon, M. J. F., & Rodway, M. S. (2010). Introduced mammals, vegetation changes and seabird conservation on the Scott Islands, British Columbia, Canada. *Bird Conservation International*, *20*(3), 295–305. https://doi.org/10.1017/S0959270910000043

Hoeg, R., Shutler, D., & Pollet, I. L. (2021). Levels of predation at two Leach's Storm-petrel *Hydrobates Leucorhous* breeding colonies. *Marine Ornithology*, *49*, 119-125. https://doi.org/10.5038/2074-1235.49.1.1407

International Union for Conservation of Nature - Species Survival Council. 2000. IUCN red list criteria and categories. IUCN, Gland, Switzerland. 3.1(2).

Kahl, S., Wood, C. M., Eibl, M., & Klinck, H. (2021). BirdNET: A deep learning solution for avian diversity monitoring. *Ecological Informatics*, *61*, 101236. https://doi.org/10.1016/j.ecoinf.2021.101236

Lamelas-López, L., & Salgado, I. (2021). Applying camera traps to detect and monitor introduced mammals on oceanic islands. *Oryx*, *55*(2), 181–188. https://doi.org/10.1017/S0030605319001364

Lu, G. Y., & Wong, D. W. (2008). An adaptive inverse-distance weighting spatial interpolation technique. *Computers & Geosciences*, *34*(9), 1044–1055. https://doi.org/10.1016/j.cageo.2007.07.010

McClelland, G., Jones, I. L., Lavers, J. L., & Sato, F. (2008). Breeding biology of Tristram's Storm-petrel *Oceanodroma Tristrami* at french frigate shoals and

Laysan Island, northwest Hawaiian Islands. *Marine Ornithology*, *36*, 175–181. https://doi.org/10.5038/2074-1235.36.2.787

Miles, W. T. S., Parsons, M., Close, A. J., Luxmoore, R., & Furness, R. W. (2013). Predator-avoidance behaviour in a nocturnal petrel exposed to a novel predator. *Ibis*, *155*(1), 16–31. https://doi.org/10.1111/ibi.12007

Montevecchi, B., Chardine, J., Rail, J.-F., Garthe, S., Pelletier, D., Regular, P., Burke, C., Hedd, A., McFarlane Tranquilla, L., Bennett, S., Mooney, C., Power, K., Power, T., Hogan, H., Daoust, P.-Y., Lawson, J., Rogers, L., Wilhelm, S., Montevecchi, M., & Lang, A. (2013). Extreme event in a changing ocean climate: Warm-water perturbation of 2012 influences breeding gannets and other marine animals in the Northwest Atlantic and Gulf of St Lawrence. *The Osprey*, *44*, 14–19.

Montevecchi, W. (2006). *Ecological consequences of artificial night lighting*. Island Press. Washington, DC, USA. 94-113.

Nelson, B. (1979). *Seabirds their biology and ecology*. A&W Publishers Inc. New York.

Orben, R. A., Fleishman, A. B., Borker, A. L., Bridgeland, W., Gladics, A. J., Porquez, J., Sanzenbacher, P., Stephensen, S. W., Swift, R., McKown, M. W., & Suryan, R. M. (2019). Comparing imaging, acoustics, and radar to monitor Leach's storm-petrel colonies. *PeerJ*, *7*, e6721. https://doi.org/10.7717/peerj.6721

Parsons, M., Mitchell, I., Butler, A., Ratcliffe, N., Frederiksen, M., Foster, S., & Reid, J. B. (2008). Seabirds as indicators of the marine environment. *ICES Journal of Marine Science*, *65*(8), Article 8. https://doi.org/10.1093/icesjms/fsn155

Pebesma, E. (2004). Multivariable geostatistics in S: The GSTAT package. *Computers & Geosciences*, *30*(7), 683–961. https://doi.org/DOI:10.1016/j.cageo.2004.03.012

Pebesma, E. (2018). Simple features for R: standardized support for spatial vector data. *The R Journal*, *10*(1), 439–446. https://doi.org/10.32614/RJ-2018-009

Pebesma, E. (2023). *Spatial data science: with applications in R*. Chapman and Hall/CRC. https://doi.org/10.1201/9780429459016

Pebesma, E., & Bivand, R. (2005). *Classes and methods for spatial data in R* (Vol. 5). https://CRAN.R-project.org/doc/Rnews/

Pérez-Granados, C., & Traba, J. (2021). Estimating bird density using passive acoustic monitoring: A review of methods and suggestions for further research. *Ibis*, *163*(3), 765–783. https://doi.org/10.1111/ibi.12944

Pickerell, G., O'Donnell, C., Wilson, D., & Seddon, P. (2013). How can we detect introduced mammalian predators in non-forest habitats? A comparison of techniques. *New Zealand Journal of Ecology*, *38*, 86–102. https://doi.org/10.20417/nzjecol.38.1.7.

Pollet, I. L., & Shutler, D. (2019a). Effects of Great Horned Owls (*Bubo virginianus*) on a Leach's Storm-Petrel (*Oceanodroma leucorhoa*) population. *The Wilson Journal of Ornithology*, *131*(1), 152–155. https://doi.org/10.1676/18-13

Pollet, I., & Shutler, D. (2019b). Leach's Storm Petrel *Oceanodroma leucorhoa* population trends on Bon Portage Island, Canada. *Seabird*, *31*, 75–83. https://doi.org/10. 61350/sbj.31.75

Pollet, I., Hedd, A., Taylor, P. D., Montevecchi, W. A., & Shutler, D. (2014). Migratory movements and wintering areas of Leach's Storm-Petrels tracked using geolocators: Migration and Wintering Areas of Leach's Storm-Petrels. *Journal of Field Ornithology*, *85*(3), 321–328. https://doi.org/10.1111/jofo.12071

Pollet, I. L., Bond, A. L., Hedd, A., Butler, R. G., & Mauck, R. (2021). Revision History—Leach's Storm-Petrel—*Hydrobates leucorhous—Birds of the World*. https://birdsoftheworld.org/bow/species/lcspet/cur/history

Pollet, I., Lenske, A., Ausems, A., Barbraud, C., Bedolla-Guzmán, Y., Bicknell, A., Bolton, M., Bond, A., Delord, K., Diamond, A., Fifield, D., Gjerdrum, C., Halpin, L., Hansen, E., Hedd, A., Hoeg, R., Major, H., Mauck, R., McClelland, G., … Mallory, M. (2023). Experts' opinions on threats to Leach's Storm-Petrels (*Hydrobates leucorhous*) across their global range. *Avian Conservation and Ecology*, *18*(1), Article 1. https://doi.org/10.5751/ACE-02370-180111

Priddel, D., & Carlile, N. (1995). An artificial nest box for burrow-nesting seabirds. *Emu - Austral Ornithology*, *95*(4), 290–294. https://doi.org/10.1071/MU9950290

Rauzon, M. J. (2008). Island restoration: Exploring the past, anticipating the future. *Marine Ornithology*, *35(2)*, 97-107. https://doi.org/10.5038/2074-1235.35.2.739

Reed, J. R., Sincock, J. L., & Hailman, J. P. (1985). Light attraction in endangered *Procellariiform* birds: reduction by shielding upward radiation. *The Auk*, *102*(2), Article 2. https://doi.org/10.2307/4086782

Rendall, A. R., Sutherland, D. R., Cooke, R., & White, J. (2014). Camera trapping: a contemporary approach to monitoring invasive rodents in high conservation priority ecosystems. *PLOS ONE*, *9*(3), e86592. https://doi.org/10.1371/journal.pone.0086592

Rennie, I. R. F., Green, D. J., Krebs, E. A., & Harfenist, A. (2020). High apparent survival of adult Leach's Storm Petrels *Oceanodroma Leucorhoa* in British Columbia. *Marine Ornithology*, *48*, 133–140. https://doi.org/10.2989/16083681.2020.1731510

Ringma, J., Barnes, M. D., & Bode, M. (2020). Australian birds could benefit from predator exclusion fencing. *Conservation Science and Practice*, *2*(4), e168. https://doi.org/10.1111/csp2.168

Robb, M., & Mullarney, K. (2008). *Petrels night and day: a sound approach guide*. sound approach. Dorset, United Kingdom.

Ronconi, R. A., Allard, K. A., & Taylor, P. D. (2015). Bird interactions with offshore oil and gas platforms: Review of impacts and monitoring techniques. *Journal of Environmental Management*, *147*, 34–45. https://doi.org/10.1016/j.jenvman.2014.07.031

Scopel, L. C. (2017). The case for lethal control of gulls on seabird colonies. *The Journal of Wildlife Management*, *81(4)*, 572-580. https://doi.org/10.1002/ jwmg.21233

Shonfield, J., & Bayne, E. M. (2017). Autonomous recording units in avian ecological research: Current use and future applications. *Avian Conservation and Ecology*, *12*(1), art14. https://doi.org/10.5751/ACE-00974-120114

Spatz, D. R., Holmes, N. D., Will, D. J., Hein, S., Carter, Z. T., Fewster, R. M., Keitt, B., Genovesi, P., Samaniego, A., Croll, D. A., Tershy, B. R., & Russell, J. C. (2022).

The global contribution of invasive vertebrate eradication as a key island restoration tool. *Scientific Reports*, *12*(1), 13391. https://doi.org/10.1038/s41598-022-14982-5

Stenhouse, I. J. (1998). Habitat utilization and breeding success of Leach's storm-petrel, *Oceanodroma leucorhoa* [Masters, Memorial University of Newfoundland]. https://research.library.mun.ca/1285/

Stenhouse, I. J., Montevecchi, W. A., & Robertson, G. J. (2000). Herring Gull *Larus argentatus* predation on Leach's Storm-Petrels *Oceanodroma leucorhoa* breeding on Great Island, Newfoundland. *Atlantic Seabirds*, *2*(1), 35–44.

Stenhouse, I., & Montevecchi, W. (2000). Habitat utilization and breeding success in Leach's Storm-Petrel: The importance of sociality. *Canadian Journal of Zoology-Revue Canadienne De Zoologie - CAN J ZOOL*, *78*, 1267–1274. https://doi.org/10.1139/cjz-78-7-1267

Sutherland, D. R., Dann, P., & Jessop, R. E. (2014). Evaluation of artificial nest sites for long-term conservation of a burrow-nesting seabird. *The Journal for Wildlife Management*, *78*(8), 1415–1424. https://doi.org/DOI:10.10002/ jwmg.783

Veitch, B. G., Robertson, G. J., Jones, I. L., & Bond, A. L. (2016). Great Black-Backed Gull (*Larus marinus*) predation on seabird populations at two colonies in eastern Canada. *Waterbirds*, *39*(1), 235–245. https://doi.org/10.1675/063.039. sp121

Vermeer, K., Devito, K., & Rankin, L. (1988). Comparison of nesting biology of Fork-Tailed and Leach's Storm-Petrels. *Colonial Waterbirds*, *11*(1), 46. https://doi.org/10.2307/1521169

Watanuki, Y. (1986). Moonlight avoidance behavior in Leach's Storm-Petrels as a defense against Slaty-Backed Gulls. *The Auk*, *103*(1), 14–22.

Wheelwright, N. T. (2016). Eradication of an ecosystem engineer. *Frontiers in Ecology and the Environment*, *14*(1), 53–54. https://doi.org/10.1002/fee.1221

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Springer-Verlag. https://ggplot2.tidyverse.org. Accessed: March 28, 2025.

Wickham, H., Francois, R., Henry, L., Muller, K., & Vaughan, D. (2023). *dplyr: a grammar of data manipulation*. https://CRAN.R-project.org/package=dplyr. Accessed: March 28, 2025.

Wickham, H., Pedersen, T., & Seidel, D. (2023). *Scale functions for visualization*. https://CRAN.R-project.org/package=scales. Accessed: March 28, 2025.

Wilbur, H. M. (1969). The breeding biology of Leach's Petrel, *Oceanodroma leucorhoa*. *The Auk*, *86*(3), 433–442. https://doi.org/10.2307/4083406

Wilhelm, S. I., Hedd, A., Robertson, G. J., Mailhiot, J., Regular, P. M., Ryan, P. C., & Elliot, R. D. (2020). The world's largest breeding colony of Leach's Storm-petrel *Hydrobates leucorhous* has declined. *Bird Conservation International*, *30*(1), Article 1. https://doi.org/10.1017/S0959270919000248

Wilhelm, S., Mailhiot, J., Arany, J., Chardine, J., Robertson, G., & Ryan, P. (2015). Update and trends of three important seabird populations in the western North Atlantic using a geographic information system approach. *Marine Ornithology, 43*, 211–222. https://doi.org/10.5751/ES-07616-200217

Xie, Y. (2014). knitr: A comprehensive tool for reproducible research in R. In V. Stodden, F. Leisch, & R. D. Peng (Eds.), *Implementing reproducible research* (1st ed., pp. 1–29). Chapman and Hall/CRC.

Young, L. C., Behnke, J. H., Vanderwerf, E. A., Raine, A. F., Kohley, C. R., Dalton, M., Mitchell, M., Tonneson, H., DeMotta, M., Wallace, G., Nevins, H., Hall, C. S., & Uyehara, K. (2018). The Nihoku Ecosystem Restoration Project: A case study in predator exclusion fencing, ecosystem restoration, and seabird translocation. *Pacific Cooperaaive Studies Unit*. http://hdl.handle.net/10125/58879

Zhu, H. (2024). *kableExtra: Construct complex table with "kable" and pipe syntax*. https://CRAN.R-project.org/package=kableExtra. Accessed: March 28, 2025.

Appendix A

Table A1. Locations of each autonomous recording unit (ARU) on Bonaventure Island and their deployment and retrieval dates, and number of recording nights per unit.

Unit Number	Model	Latitude	Longitude	Deployment	Retrieval	Recording Nights
Au-41	AM 1.2	48.48600	-64.15500	30-May-24	30-Aug-24	32
Au-61	AM 1.2	48.48910	-64.15200	30-May-24	30-Aug-24	11
Au-63	AM 1.2	48.49290	-64.14550	29-May-24	30-Aug-24	4
Au-65	AM 1.2	48.48400	-64.16380	30-May-24	30-Aug-24	16
Au-64	AM 1.2	48.49990	-64.17370	29-May-24	30-Aug-24	12
Au-66	AM 1.2	48.48550	-64.17160	29-May-24	30-Aug-24	3
Au-67	AM 1.2	48.48980	-64.17600	29-May-24	30-Aug-24	30
Au-68	AM 1.2	48.49530	-64.17610	29-May-24	14-Sep-24	31
Au-69	AM 1.2	48.50530	-64.17140	29-May-24	30-Aug-24	9
SM1-071	SM1	48.49907	-64.15353	24-Sep-23	14-Sep-24	69
SM1-097	SM1	48.49580	-64.14746	24-Sep-23	14-Sep-24	82
SM1-177	SM1	48.48442	-64.16650	23-Sep-23	15-Sep-24	73
SM1-179	SM1	48.48726	-64.15342	23-Sep-23	15-Sep-24	76
SM1-182	SM1	48.48707	-64.17333	23-Sep-23	15-Sep-24	68
SM1-953	SM1	48.49154	-64.17605	23-Sep-23	14-Sep-24	71
SM1-970	SM1	48.49022	-64.14935	24-Sep-23	14-Sep-24	74
SM1-973	SM1	48.48415	-64.15944	23-Sep-23	15-Sep-24	76
SM2-8339	SM2+	48.49639	-64.14937	24-Sep-23	14-Sep-24	67
SM2-8365	SM2+	48.48500	-64.15730	23-Sep-23	15-Sep-24	73
*SM4-1274	SM4	48.49834	-64.17640	23-Sep-23	14-Sep-24	50
*SM4-1313	SM4	48.49463	-64.14567	23-Sep-23	14-Sep-24	80
SM4-18217	SM4	48.50100	-64.15400	30-May-24	14-Sep-24	99
*SM4-3666	SM4	48.49157	-64.14667	23-Sep-23	14-Sep-24	95
*SM4-3700	SM4	48.50375	-64.17370	24-Sep-23	14-Sep-24	95
SM4-7192	SM4	48.49760	-64.15186	30-May-24	14-Sep-24	80

*Replaced malfunctioning SM1 units in spring 2024

** AudioMoth (AM)

Appendix B

Table B1. Locations of each quadrat location during the 2023 preliminary transect burrow searches on Bonaventure Island.

Quadrat ID	Latitude	Longitude	Quadrat ID	Latitude	Longitude
C1A	48.4967	-64.1502	F3A	48.4871	-64.1529
C1B	48.4965	-64.1505	F3B	48.4872	-64.1533
C1C	48.4963	-64.1507	F3C	48.4874	-64.1535
C1D	48.4960	-64.1509	F3D	48.4876	-64.1538
C1E	48.4958	-64.1511	F3E	48.4878	-64.1540
C2A	48.4964	-64.1498	F4A	48.4863	-64.1546
C2B	48.4962	-64.1500	F4B	48.4865	-64.1549
C2C	48.4959	-64.1502	F4C	48.4867	-64.1552
C2D	48.4957	-64.1503	F4D	48.4868	-64.1556
C2E	48.4955	-64.1506	F4E	48.4869	-64.1559
C3A	48.4963	-64.1491	T1A	48.4903	-64.1476
C3B	48.4960	-64.1492	T1B	48.4905	-64.1479
C3C	48.4958	-64.1494	T1C	48.4907	-64.1480
C3D	48.4956	-64.1496	T1D	48.4910	-64.1480
C3E	48.4953	-64.1498	T1E	48.4913	-64.1483
C4A	48.4960	-64.1485	T2A	48.4899	-64.1481
C4B	48.4958	-64.1486	T2B	48.4902	-64.1482
C4C	48.4956	-64.1487	T2C	48.4905	-64.1481
C4D	48.4953	-64.1488	T2D	48.4907	-64.1484
C4E	48.4951	-64.1490	T2E	48.4909	-64.1484
F1A	48.4868	-64.1535	T3A	48.4907	-64.1473
F1B	48.4870	-64.1537	T3B	48.4909	-64.1475
F1C	48.4871	-64.1539	T3C	48.4911	-64.1476
F1D	48.4873	-64.1542	T3D	48.4914	-64.1478
F1E	48.4875	-64.1545	T3E	48.4917	-64.1479
F2A	48.4865	-64.1540	T4A	48.4909	-64.1468
F2B	48.4868	-64.1544	T4B	48.4911	-64.1470
F2C	48.4869	-64.1547	T4C	48.4914	-64.1471
F2D	48.4871	-64.1550	T4D	48.4916	-64.1473
F2E	48.4873	-64.1552	T4E	48.4918	-64.1474

Appendix C

Figure C1. Leach's Storm-petrel thermal imagery photo taken on June 29 at NS-09 during the 2024 nocturnal surveys.

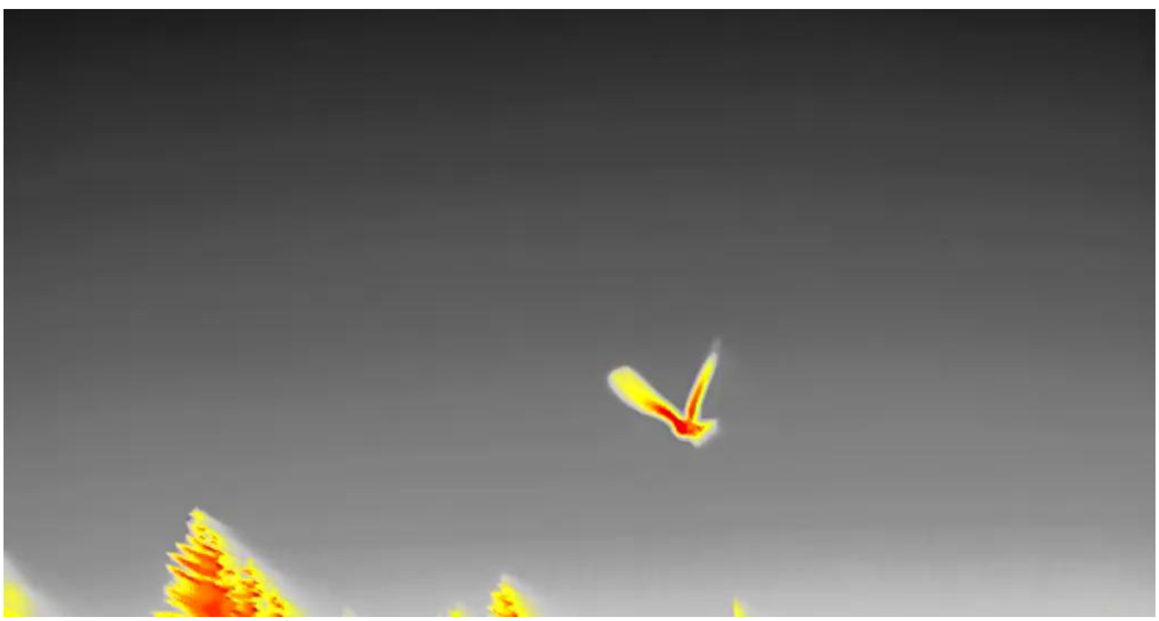

Figure C2. Leach's Storm-petrel thermal imagery photo taken on June 28 at NS-03 during the 2024 nocturnal surveys.

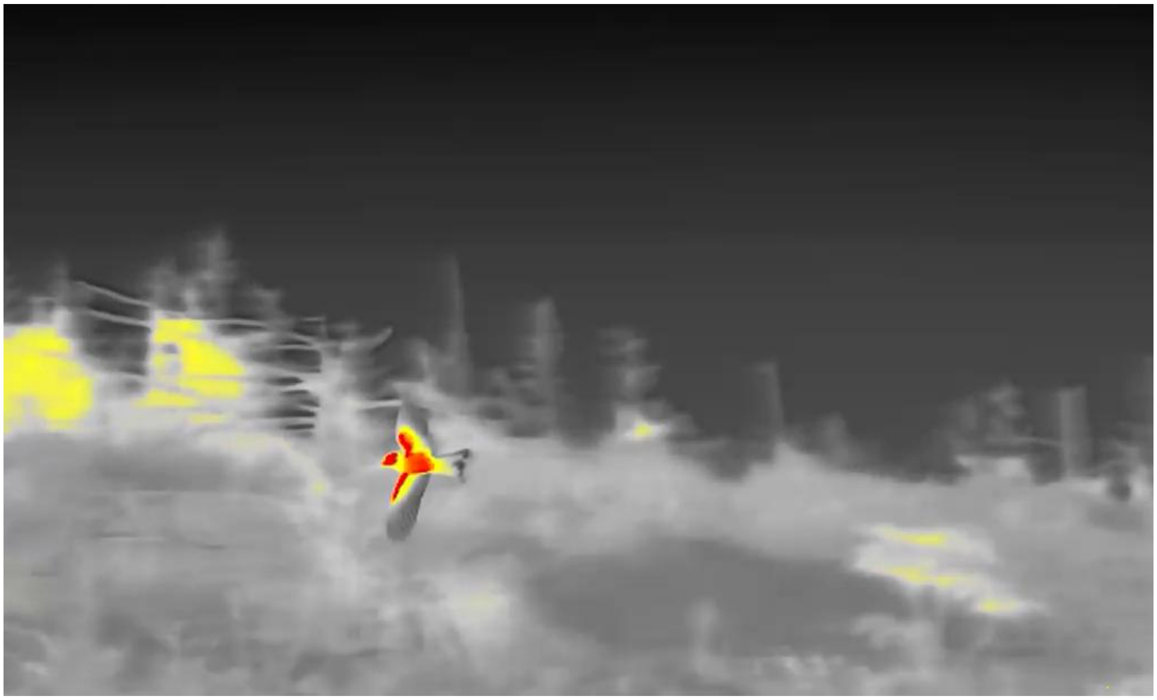

Figure C3. Leach's Storm-petrel thermal imagery photo taken on June 22 at NS-05 during the 2024 nocturnal surveys.

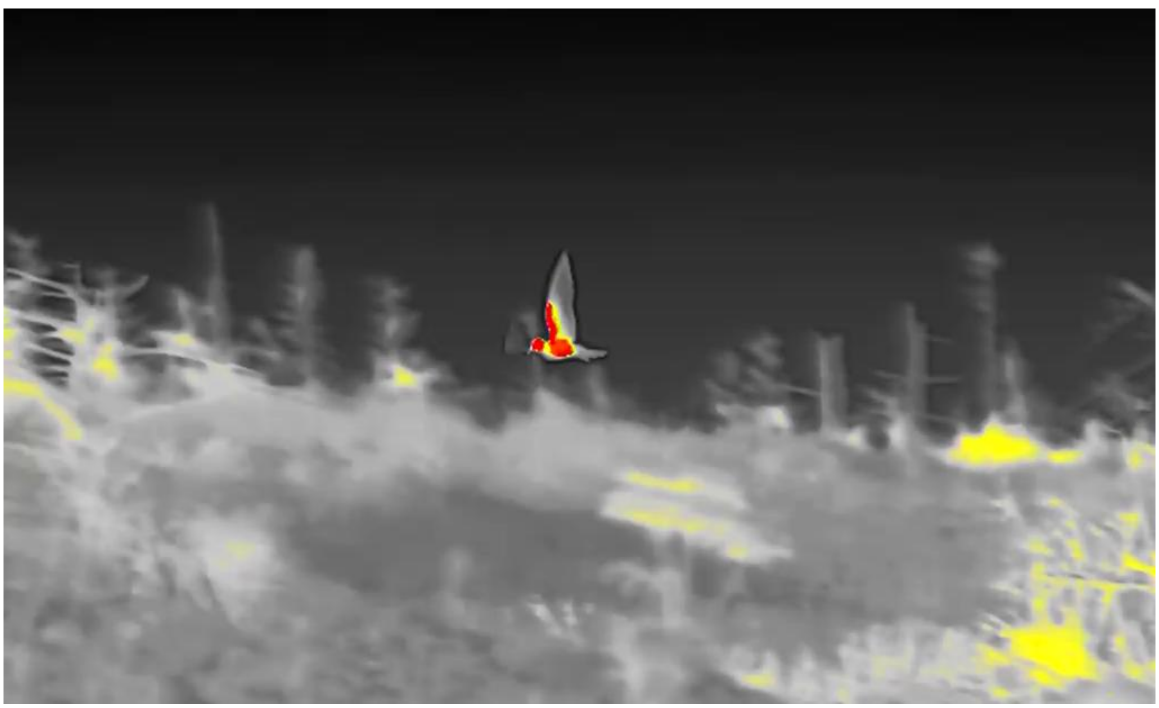

Figure C4. Leach's Storm-petrel thermal imagery photo taken on July 2 at NS-05 during the 2024 nocturnal surveys.

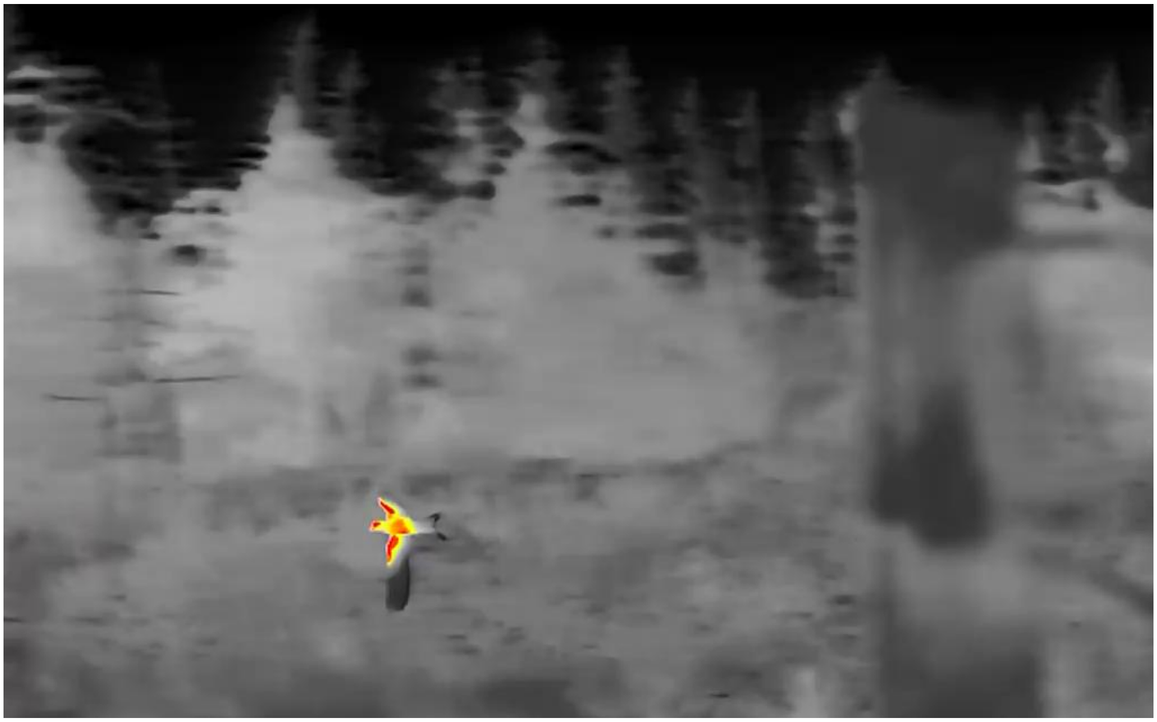

Figure C5. Leach's Storm-petrel thermal imagery photo taken on June 23 at NS-01 during the 2024 nocturnal surveys.

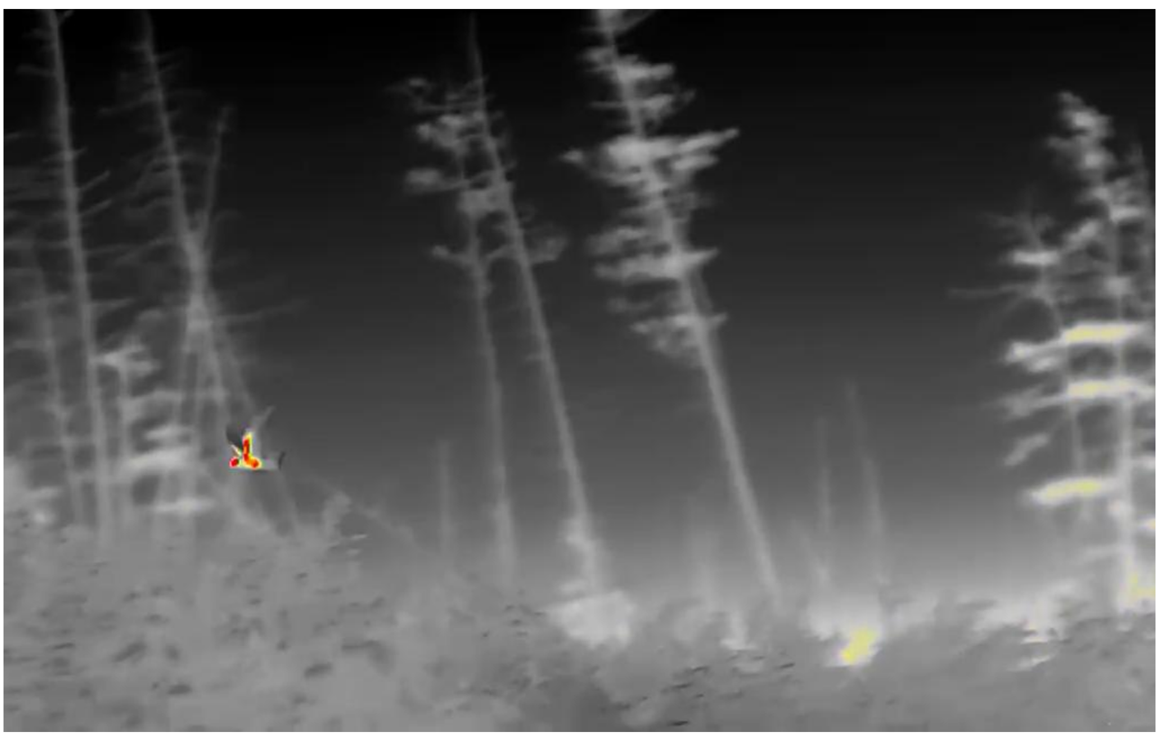

Figure C6. Leach's Storm-petrel thermal imagery photo taken on June 22 at NS-02 during the 2024 nocturnal surveys.

Curriculum Vitae

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