

**The Autumn Migration of the Canada Warbler in Kespukwitk
(Southwest Nova Scotia)**

A Listening Together Research Report

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Abstract

Background

The Nova Scotia government has designated the Canada Warbler as an endangered species in the province. It is a neotropical migrant with Nova Scotia as its easternmost breeding range in Canada, and Central America and South America as its winter range. There are very few studies on the migration of this species, leaving a gap in understanding its connectivity requirements between breeding and winter residency.

Methods

Citizen scientists deployed eleven acoustic stations in Kespukwitk (Southwest Nova Scotia) using the AudioMoth, a low-cost autonomous recording unit. Analysis of recordings included both bioacoustics software and manual scanning. Weather data using the HYSPLIT model, atmospheric soundings, wind maps, and weather radar provided insights into the migratory movements of the Canada Warblers in Kespukwitk.

Results

The acoustic monitoring stations detected significant numbers of Canada Warbler night flight calls (NFCs) on the western shore of Kespukwitk but very few calls on the southern and southeastern coasts. An area straddling the border of the Municipalities of Yarmouth and Clare had a very high concentration of NFCs. The peak migration of Canada Warblers occurred during the second and third weeks of August. However, the peak NFCs along the Bay of Fundy coast occurred in the last week of August. There was significant evidence that these Bay of Fundy peaks consisted of birds from Quebec, New Brunswick, and Maine.

Conclusions

Emerging acoustic technologies combined with citizen science provide non-invasive methods to study migratory birds daily in a large region, in various habitats, and during a whole season. A comparison of the data from this study compared to eBird data suggests that Kespukwitk may be a region of continental significance in the connectivity of breeding and wintering habitats of the Canada Warbler. Protecting the migration habitats of the Canada Warbler in Kespukwitk must be an urgent priority and should be fully incorporated into the provincial Recovery Plan for this species.

Introduction

This study contributes to understanding the migration habitat and migratory connectivity of the Canada Warbler. It uses bioacoustics to describe the distribution of this species in the province of Nova Scotia, Canada, where it is an "endangered species" (Nova Scotia Department of Lands and Forestry 2021).

There are few studies of the migration habitat of the Canada Warbler. Reitsma et al. (2020) provide a summary of the literature. The studies of migratory connectivity in this species are minimal ((Roberto-Charron et al. 2020; Cárdenas-Ortiz, Bayly, Colorado Z, and Hobson 2017; Bégin-Marchand et al. 2022). Understanding the threats to this species in its breeding, migration, and wintering habitats and how they are connected will be essential to the survival of this species.

Background

Nova Scotia is the easternmost breeding range of the Canada Warbler (see Figure

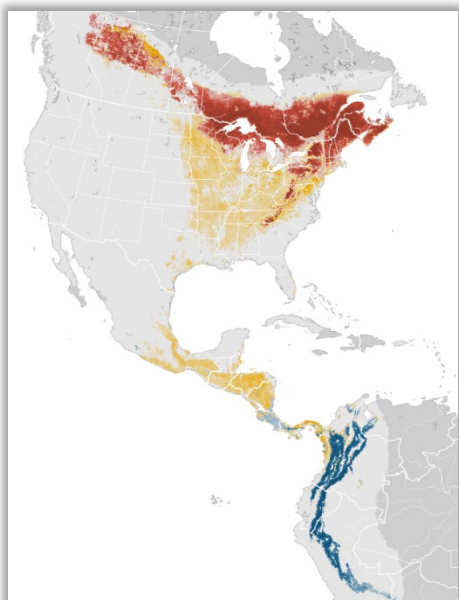


Figure 1: Range of the Canada Warbler (eBird 2023) Red=Breeding, Yellow=Migration, Blue=Winter

1). It is a neotropical migrant that spends the winter in Central and South America and is one of the last migratory birds to arrive in Nova Scotia in the spring.

The estimated population size of the Canada Warbler in Canada is between 2 and 10.4 million birds, or about 80% of the North American population. From 1970 to 2019, the population declined by 51%. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) ranked the species as "Threatened" in 2008. The long-term decline began to slow in 2003, and numbers have increased steadily since 2012. Thus its status was

upgraded to "Special Concern" in 2020. However, the declines appear to be ongoing in the Maritime Provinces (COSEWIC 2020).

Spring migration in Nova Scotia begins in the third week of May, leading to peak numbers detected on the breeding grounds by the second week of June (eBird 2017). In the Maritime provinces, the Canada Warbler breeds in moist habitats such as beaver ponds, cedar swamps, and forested wetlands with a dense, deciduous shrub layer and understory. In Nova Scotia, it shows a preference for wet sites with cinnamon fern, speckled alder, and other deciduous shrubs associated with sphagnum (Stewart 2015; Nova Scotia Department of Lands and Forestry 2021). It is most common in Nova Scotia in higher elevations of the western, central, and eastern mainland (See Figure 2).

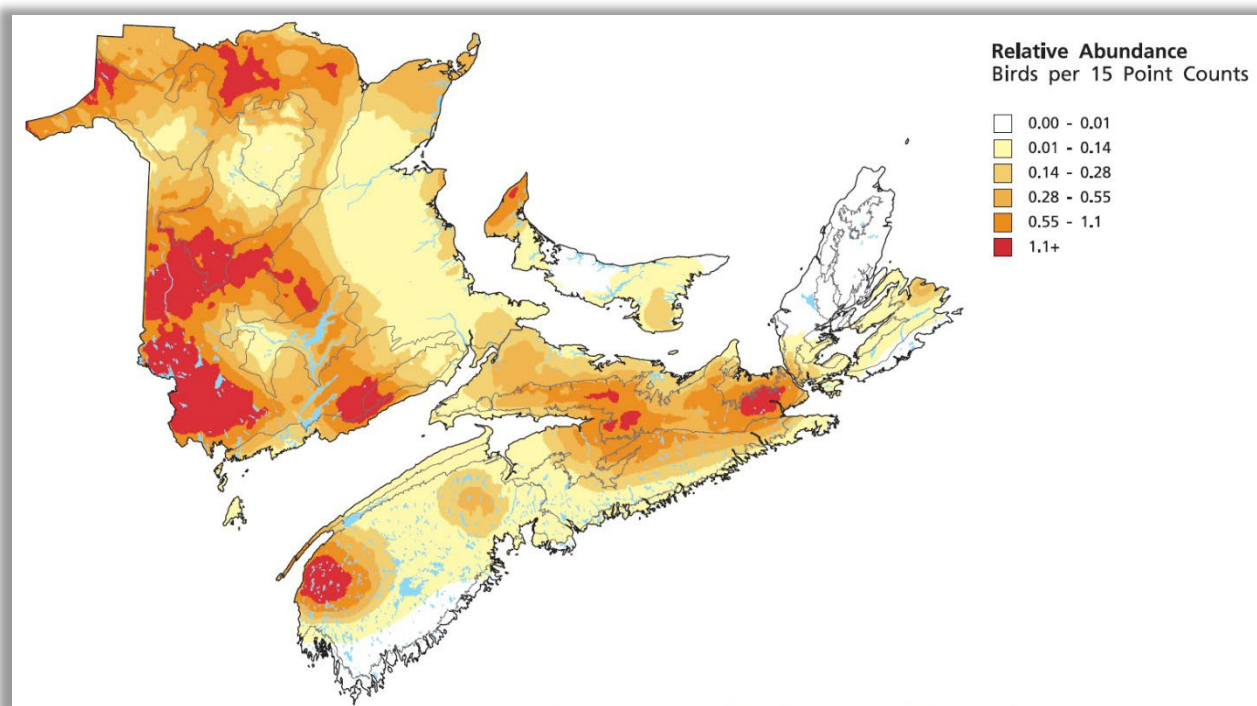


Figure 2: Relative Abundance of the Canada Warbler in the Maritime Provinces (Stewart 2015)

Threats to the Canada Warbler in its breeding territory are overbrowsing of the understory, habitat fragmentation from forestry practices, and drainage of forested wetlands for residential, agricultural, and industrial development.

The Canada Warbler is one of the earliest neotropical migrants to leave Nova Scotia for its autumn migration. It has the shortest documented occupancy of a breeding site of any bird with a post-nuptial moult, 62 days for females and 72 for males at an Alberta location (Flockhart 2007). Bégin-Marchand et al. (2022) report up to a 90-day residency of Canada Warblers in the Saguenay region of Quebec. Kearney (2019a) detected post-breeding nocturnal movements in Nova Scotia as early as 26 July, indicating a residency in the vicinity of 60-70 days. According to eBird (2017), migration in Nova Scotia begins in the second week of August, peaks the following week, and ends by the third week of September, with stragglers into mid-October.

Only a few studies have examined the migration routes and stopover habitats of the Canada Warbler in the autumn. Using radio-telemetry, Bégin-Marchand et al. (2022) tracked eight birds from the Saguenay region of Québec migrating through the Great Lakes region, the Great Appalachian Valley, and the Atlantic Coast.

Using light-level geolocators, Roberto-Charron et al. (2020) tracked the migration routes of 18 Canada Warblers from their breeding territory in Alberta, Manitoba, and New Hampshire. The study documented the convergence of migratory routes around a migration barrier, with 78% of the tracked birds funnelling into a narrow geographic space on the western side of the Gulf of Mexico. The remainder travelled over water to the Yucatan. The study also showed that Canada Warblers originating in New Hampshire predominately followed an Atlantic coastal route before veering westward to Texas. During the first leg of their journey, these birds would have encountered extensive urban and deforested areas. The authors suggest this fact may partially explain lower survival rates in the most eastern populations. At the same time, the authors point out the importance of stopover habitats on the east shore of Mexico and Central America.

Cárdenas-Ortiz et al. (2017), using constant-effort mist-netting in two stopover locations in Northern Columbia, confirmed that Canada Warblers migrate through Central America rather than crossing the Caribbean Sea. Their lack of recoveries of

banded birds during the autumn season suggested the possibility that Canada Warblers have a one-day stopover followed by short flight migration strategy.

Threats to the Canada Warbler during migration are the loss of forested wetlands and other wet habitats along migration corridors due to urban, agricultural, and industrial development and collision with tall buildings and other structures (COSEWIC 2020). Studies indicate that the Canada Warbler is disproportionately more vulnerable to collision than other species (Loss, Will, Loss, and Marra 2014).

González-Prieto et al. (2016), using staple hydrogen isotope values in feathers, found moderately strong migratory connectivity in breeding and wintering areas in the Canada Warbler. Distinct populations were largely segregated into specific basins and valleys in Columbia. Less than 300 kilometres separated these populations, while their breeding range spans more than 3000 kilometres. Birds originating from Western Canada wintered predominately in the Western Andes, while Eastern Canadian populations were in the Eastern Andes. The most intense deforestation for agriculture and grazing is in the Eastern Andes and may be related to the steeper declines in the eastern breeding populations of the species. The most significant threats to Canada Warblers in their winter range are deforestation for extending agricultural and grazing lands and converting shade-grown coffee plantations to sun-grown plantations.

Nocturnal Migration Monitoring in Nova Scotia (2011-2019)

Kearney (2018, 2019b) conducted passive acoustic monitoring at sixteen locations in mainland Nova Scotia between 2011 and 2019. Twelve locations were part of pre-and post-construction environmental assessments at wind energy facilities. The other four sites were part of a long-term bird migration study in the region. Monitoring took place in both the spring and fall, from mid-April to the first week of June and from early August to the third week of October. The hours of operation were from civil sunset, when the sun is six degrees below the horizon, to civil sunrise when the sun is again six degrees below the horizon.

The autonomous recording units at wind energy facilities were the Song Meter 2 by Wildlife Acoustics and an Old Bird microphone and laptop computer at the migration research sites. As determined by side-by-side comparisons, the Old Bird detected 1.5 to 2 times the number of night flight calls compared to the Song Meter 2.

Figure 3 shows the total seasonal night flight calls (NFCs) of Canada Warblers during the autumn.

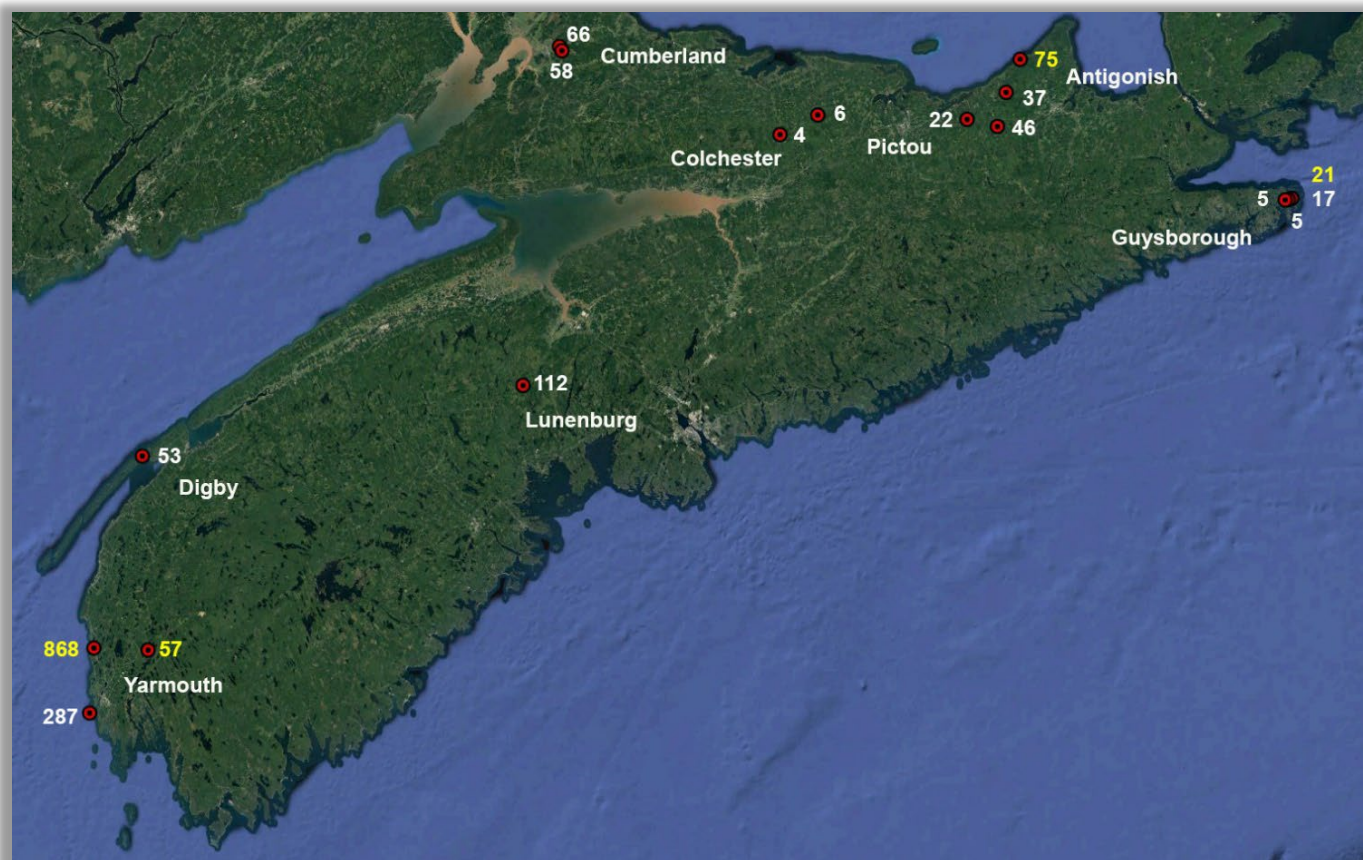


Figure 3: Total Canada Warbler NFCs by County during the Autumn 2011-2018.
Results from Song Meter 2 in white and Old Bird in yellow.

Total NFCs were the highest in the extreme southwest of the mainland and the lowest in the north and northeast. These results suggested that Canada Warbler migration in the autumn follows a broad front from northeast to southwest (Richardson 1972), with aggregation occurring at the edge of a water barrier, the Gulf of Maine. The following study seeks to gain a greater understanding of this migration pattern.

Methods – A Community-based Approach

In 2019, a partnership of environmental and Mi'kmaw organizations and university and government researchers formed Listening Together, a project to engage citizens in biodiversity conservation through bioacoustics. The project was situated in Kespukwitk, one of the seven traditional districts of the Mi'kmaq and encompassed Southwest Nova Scotia. Listening Together had funding from the Canada Fund for Nature through its Priority Place Program.

Listening Together focused on species at risk, and the concentration of migrating Canada Warblers in the district's southwest corner made it an obvious candidate for acoustic study. In August 2020, volunteers deployed autonomous recording units at eleven coastal locations in Kespukwitk.

As a low-cost, small-sized, low-energy detector, the AudioMoth (see Figure 4)



Figure 4: AudioMoth (photo by Alix d'Entremont)

has revolutionized community-based acoustic monitoring of natural resources (Hill et al. 2018). The participants placed the AudioMoth in zip-lock freezer bags and attached them to a tree or stump. The devices recorded from 2230-2400, 0300-0430, and 0630-0800 hours daily from 1 August to 7 September. The 90-minute

evening recording targeted departing migrants. The pre-dawn recording represents arriving migrants, while the dawn recording includes arrivals and birds already in the area.

BirdVoxDetect, a Python-based application, extracted bird vocalizations from the audio recordings (Lostanlen et al. 2019). Kearney visually scanned all the detections to find the night flight calls (NFCs) of the Canada Warbler. It is important to note that nocturnal migrants often produce NFCs in the morning during the migration season.

The spectrogram of the Canada Warbler's NFC is one of the most distinct among nocturnal migrants (See Figure 5). Positive detections included partial or weak spectrograms if the "cup" and "tail" of the call were visible.

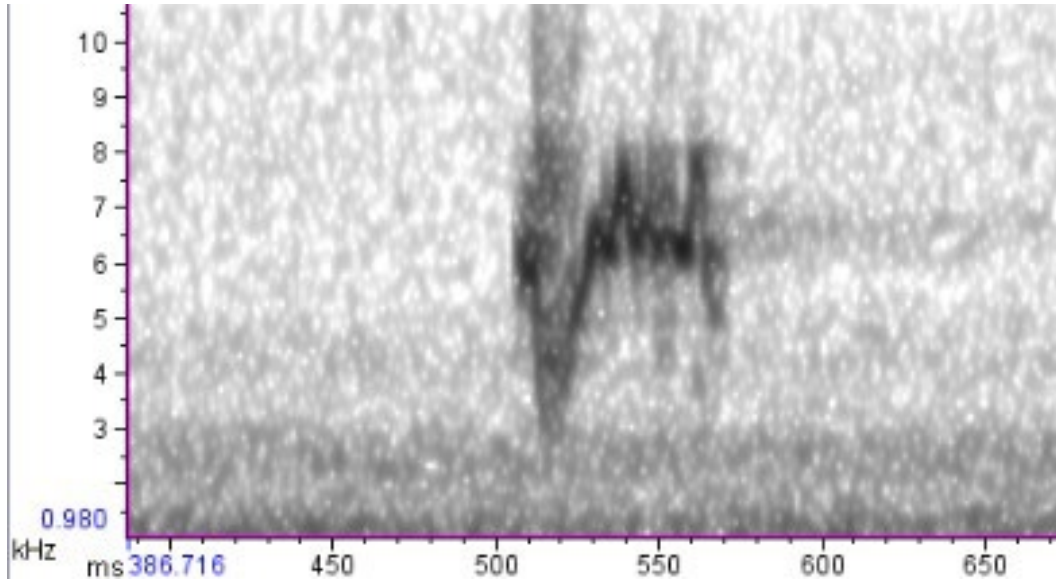


Figure 5: Spectrogram of Canada Warbler Night Flight Call (*photo by John Kearney*)

Two monitoring stations, Green Island and Bon Portage Island, were close to a gull colony where BirdVoxDetect produced tens of thousands of detections for each 90-minute recording interval. In these two situations, Kearney created a Canada Warbler detector in Raven Pro (Center for Conservation Bioacoustics 2014), resulting in fewer false positives. In any recording period that Raven Pro produced a positive detection, a visual scan was made of the whole period. The sound quality was insufficient to analyze one site, Coffin Island accurately.

In 2021 and 2022, Listening Together began acoustic monitoring of critical migration habitats for all species in Kespukwitk with additional funding from the Protected Areas and Ecosystem Branch of Nova Scotia Environment and Climate Change and the Nova Scotia Crown Share Land Legacy Trust. This study included nine additional monitoring stations and followed a similar methodology with a start date of 8 August and an end date of 17 October. Recordings made from 8 August to 7 September were comparable to the 2020 recordings. Instead of plastic bags, the

AudioMoths were in a weather-protective case and mounted on a 2-metre stake above a plexiglass plate (See Figure 6). The plate created a pressure zone that amplified the sound going to the microphone. Due to the cone on the case surrounding the microphone opening, there is no loss, and even a gain, of volume compared to the AudioMoth in a zip-lock plastic bag (Lapp 2021).



Figure 6: AudioMoth in Weather-Protective Case over Plexiglass Plate (Photo by Alix d'Entremont)

In 2021-2022, the pre-dawn period was 2.5 hours before civil dawn (the sun is 6 degrees below the horizon), with morning recordings of 10 minutes beginning at sunrise, 0.5 hours after sunrise, and 1 hour after sunrise. The evening period started at 2100 hours and ended at 2400 hours.

In addition, the recording analysis in 2021-2022 included only one of every five days. Thus, the study presented results in calls per hour when comparing 2020-2022.

Various meteorological instruments provided data to estimate the flight headings and movements of migrating Canada Warblers in 2020 (see results for details).

Results

Figure 7 maps the Canada Warbler night flight calls (NFCs) at ten acoustic stations during the 2020 migration season.



Figure 7: Total Canada Warbler NFCs during the 2020 Migration Season by Acoustic Station

The map shows NFCs concentrated along the western shore of Kespukwitk. The numbers steadily increased from Cape Split (outside Kespukwitk) to Sandyland Ponds, from 61 to 263. The southern and southeastern shores had very few NFCs, ranging from

1 to 13 per station. Table 1 lists the number of NFCs by station with the estimated number of individual birds these calls represent. A call more than one minute apart from another denoted a unique bird.

		Estimated
	Total	Total
Station	NFCs	Individuals
Cape Split	61	34
Victoria Beach	75	56
Central Grove	97	81
Sandyland Ponds	263	187
Green Island	1	1
John's Island	13	10
Pubnico Point	4	4
Bon Portage Island	2	2
Baccaro	3	3
Keji Seaside	1	1
Total	520	379

Table 1: Total NFCs and Estimated Individual Birds in 2020 by Station

Table 2 shows the distribution of NFCs by daily recording periods.

Recording Period				
Station	Evening	Pre-Dawn	Dawn	Total
Cape Split	11	16	34	61
Victoria Beach	30	10	35	75
Central Grove	46	46	5	97
Sandyland Ponds	174	89		263
Green Island	1			1
John's Island	12		1	13
Pubnico Point	1	2	1	4
Bon Portage Island	1	1		2
Baccaro	1	1	1	3
Keji Seaside			1	1
Total	277	165	78	520

Table 2: NFCs by Daily Recording Period in 2020 by Station

From Table 2, Cape Split and Victoria Beach had the highest number of NFCs at dawn (56% and 46%, respectively). The highest number of pre-dawn calls was at Sandyland Ponds (89 and 34%) but proportionately at Central Grove (46 and 47%). The

greatest number of evening NFCs was at Sandyland Ponds (174 or 66%). The Sandyland station also had the highest total NFCs (263).

As graphed in Figure 8, the peak date for the Canada Warbler migration in 2020 was 16 August (79 calls), with smaller peaks (more than 30 calls) on 23 and 26 August.

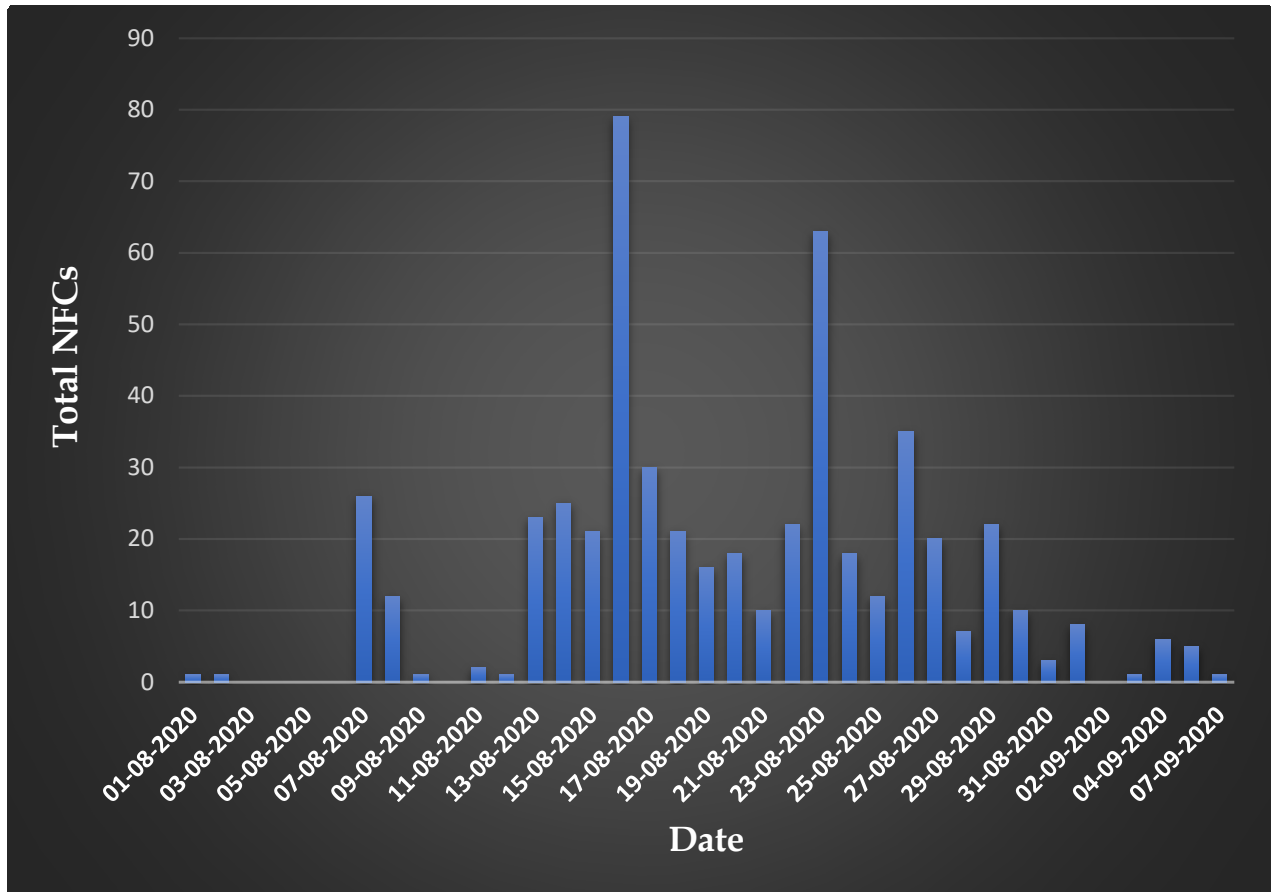


Figure 8: Total NFCs at All Stations in 2020 by Date

Table 3 shows the peak dates and numbers for the four acoustic stations on the western shore of Kespukwitk (including Cape Split). The peak date at Sandyland Ponds on 16 August corresponds to the peak date for all stations combined. The Central Grove and Victoria Beach peaks account for the second peak on 23 August for all stations. Finally, the peak at Cape Split represents most of the calls on 29 August, the last day that all calls at all stations were greater than 20. Notably, peak dates are later from south to north up the western shore, whereas total calls are greater from north to south.

Station	Peak Date	Peak Number
Cape Split	29-Aug	16
Victoria Beach	23-Aug	29
Central Grove	23-Aug	19
Sandyland Ponds	16-Aug	66

Table 3: Peak Dates and Numbers for Four Stations in 2020.

By using the NOAA HYSPLIT Model (Stein et al. 2015), atmospheric soundings (University of Wyoming 2023), weather radar (National Oceanic and Atmospheric Administration 2021) and upper air wind maps (Beccario 2023), it was possible to gain insights about the migration dynamics of the Canada Warbler in Kespukwitk.

The HYSPLIT Model provides forward and backward trajectories for a particle in the atmosphere from a given point and time. One enters the location, starting time, and tracking duration at one to three altitudes. The HYSPLIT Model provides information on the state of upper air currents and shows what options are available to birds for their migratory flights. In this case, I entered 300 metres, 600 metres, and 1,500 metres into the model and a nine-hour duration, roughly representing the time between civil sunset and civil sunrise when birds are in a migratory flight (Cooper et al. 2023).

The first run of the model was for Sandyland Ponds for the pre-dawn period on 16 August and included 35 NFCs and an estimated 23 birds. As shown in the upper panel of Figure 9, the wind flow coming from the northeast at 1,500 metres was likely the most favourable for Canada Warblers. At civil sunset, atmospheric soundings at Shearwater, Nova Scotia, the closest upper air meteorological station to the beginning of the backward trajectory, recorded a wind speed of 22 kilometres per hour from the northeast at 1,500 metres. This speed and direction would have given migrating birds a tailwind for flying to the southwest. With an estimated flying speed of 35 km/hr and a 22 km/hr wind profit, Canada Warblers, which arrived in the pre-dawn period at Sandyland Ponds, would have travelled an estimated 400 kilometres. This speed would place their starting location in northeastern Nova Scotia in Antigonish and

Guysborough Counties. The wind map for the evening of 15 August in the lower panel of Figure 9 also indicates highly favourable winds for arriving at Sandyland Ponds the following day.

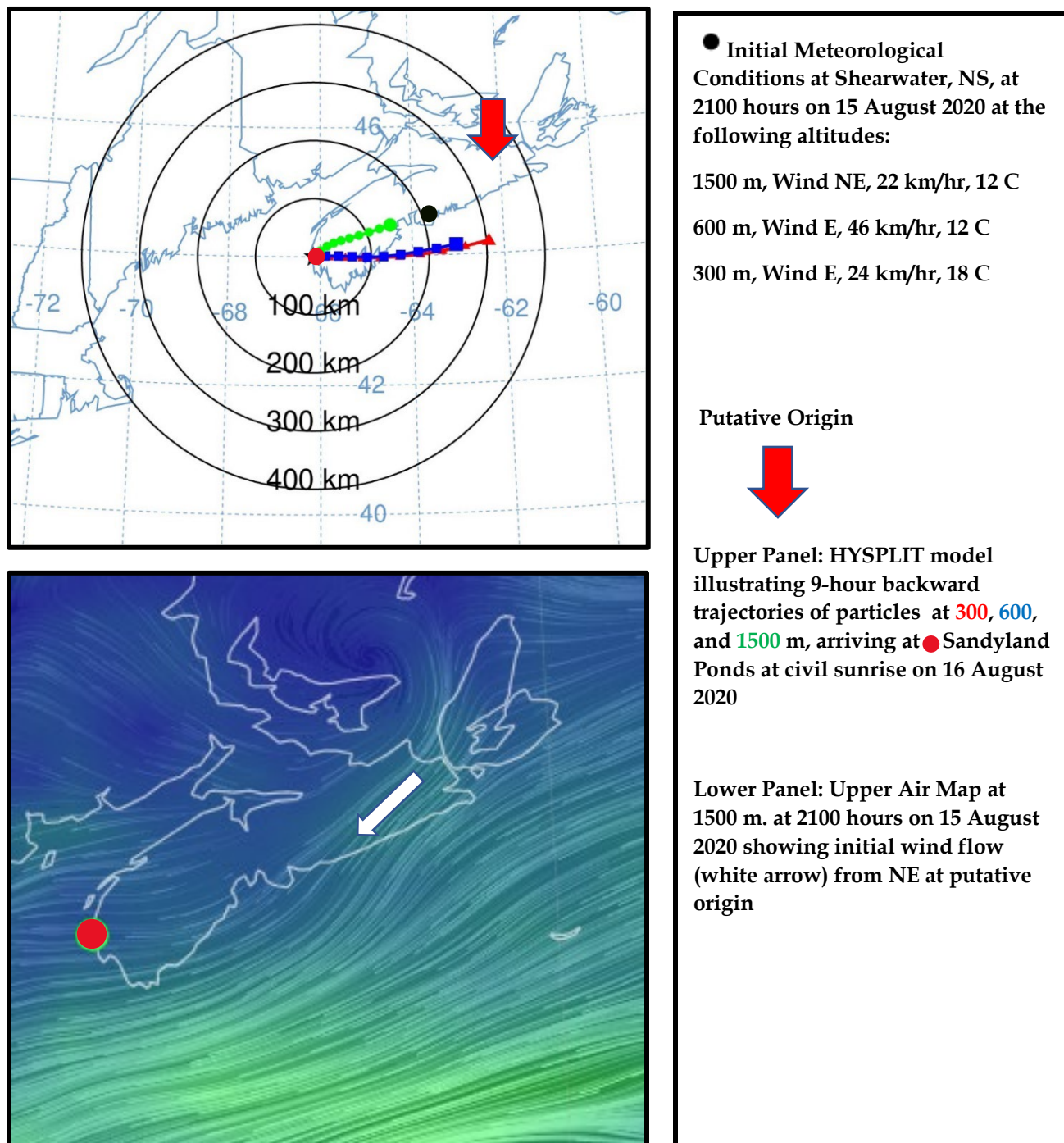


Figure 9: Putative Origin of Morning Arrivals at Sandyland Ponds on 16 August 2020

On the evening of 16 August, at or near Sandyland Ponds, Canada Warblers (31 NFCs and estimated 23 birds) departed in the evening. This flight may indicate that Canada Warblers only spent one day in stopover in the area. The upper panel of Figure 10 shows the forward trajectory of atmospheric particles at civil sunset on 16 August 2020. While all three altitudes (300 m, 600 m, and 1500 m.) appeared favourable for migratory flight, travelling at 1500 metres would have given the most significant wind profit of 28 km/hr and an estimated flight distance of over 400 kilometres.

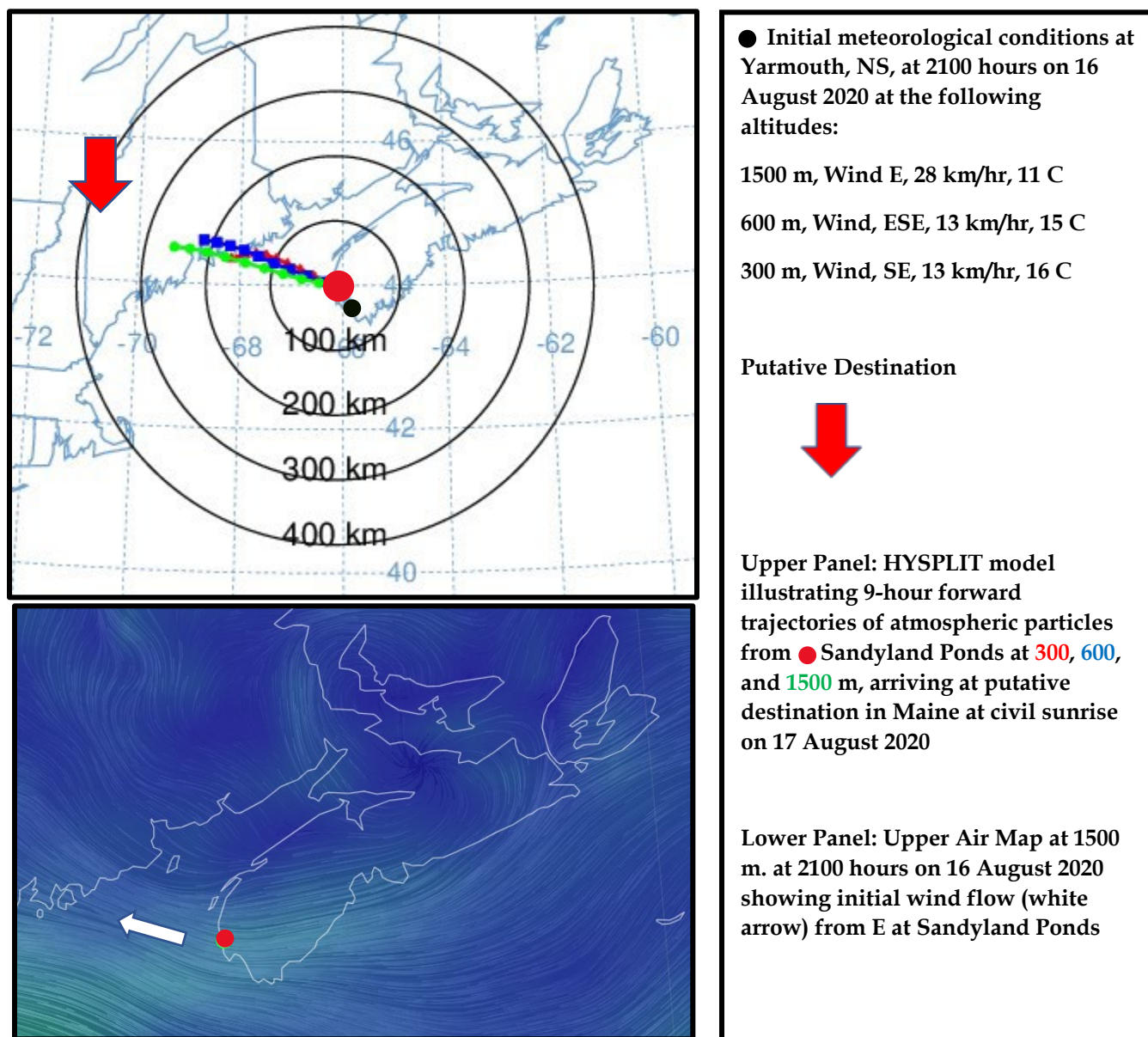


Figure 10: Putative Destination of Evening Departures from Sandyland Ponds on 16 August 2020

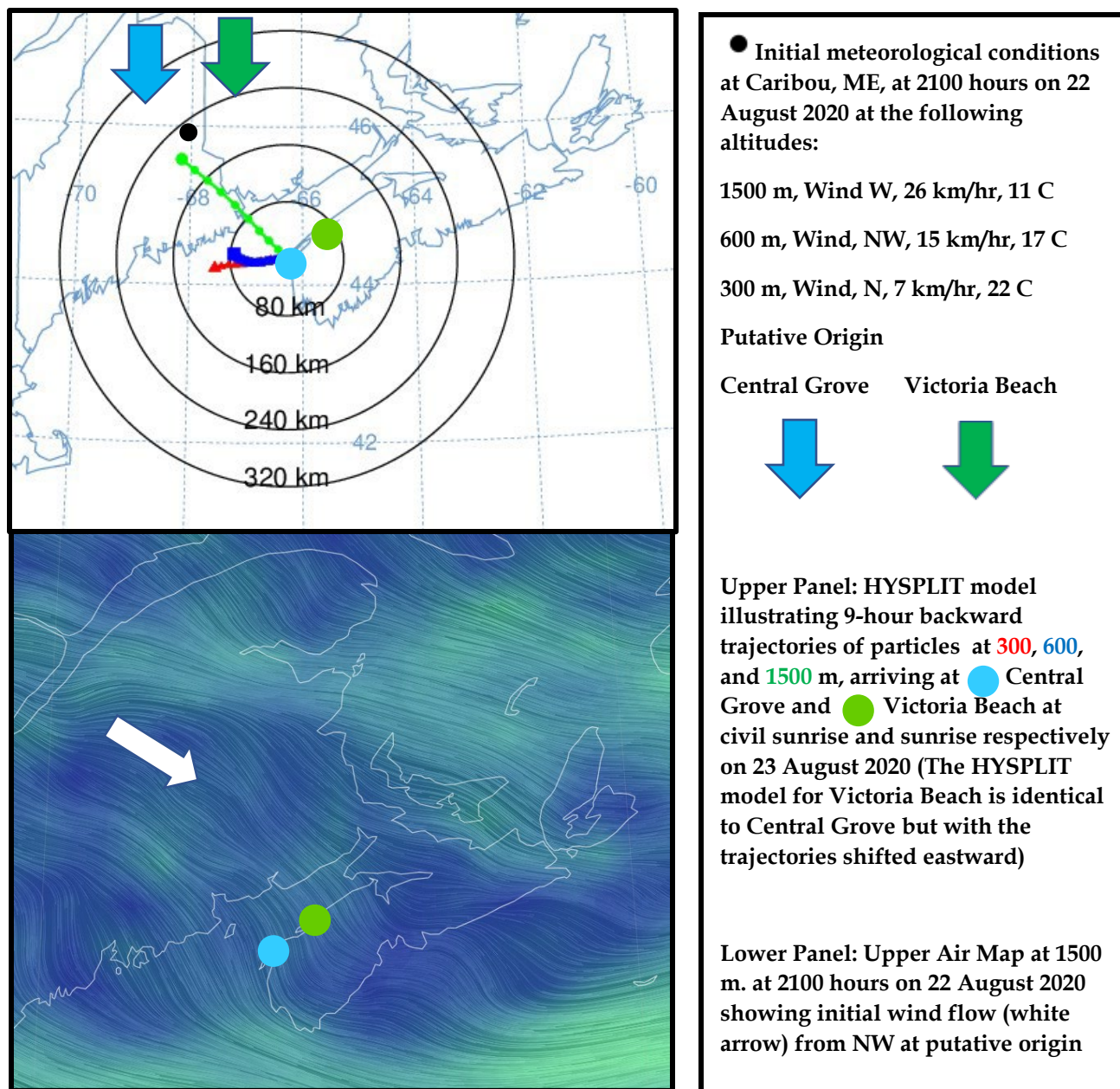


Figure 11: Putative Origin of Morning Arrivals at Central Grove and Victoria Beach on 23 August 2020

During the pre-dawn at Central Grove and sunrise at Victoria Beach on 23 August, the acoustic stations detected 17 and 25 NFCs and an estimated 13 and 11 birds, respectively. The backward trajectory of atmospheric particles at Central Grove at civil

dawn indicated a wind flow from the west and northwest at the three altitudes in the HTSPLIT Model, as shown in the upper panel of Figure 11. The trajectories at Victoria Beach (not shown in the upper panel) were almost identical but shifted eastward. The soundings station at Caribou, Maine, indicated winds from the west, northwest, and north at the 1,500 m, 600 m, and 300 m altitudes. Wind speeds at these altitudes were 26 km/hr, 15 km/hr, and 7 km/hr, respectively. As seen in the lower panel of Figure 11, wind direction and speeds were variable but showed a strong flow from the northwest overall. The weather radar at Caribou, Maine, indicated a moderate migration with the highest density of echoes north of the radar early in the night and south of the station later in the night (National Oceanic and Atmospheric Administration 2021). The radial velocity of the echoes indicated that birds were flying south during the whole night. While it is difficult to estimate the wind profit, 15 km/hr profit along with the flight speed of the warbler would give a putative origin of northern Maine and northwest New Brunswick about 350 kilometres from their dawn location.

The most significant movement of Canada Warblers at Cape Split occurred at dawn on 29 August when an AudioMoth detected 16 NFCs representing an estimated six birds. Figure 12 shows that moderate to strong NW winds dominated the preceding night. The upper panel in Figure 12 indicates that winds at 600 metres could have brought passive atmospheric particles 300 kilometres from northern New Brunswick. Combined with the flight speed their flight speed, the birds could have potentially travelled 700 kilometres from as far away as the Gaspé or the Lower North Shore of Quebec. The lower panel of Figure 12 demonstrates the intensity of the northwest winds in the Maritime Provinces. The fact that the Canada Warblers arrived at dawn further supports a passage over the upper Bay of Fundy. Typically, NFCs detected at sunrise and up to three hours after dawn indicate birds found themselves over the ocean at civil sunrise and gained altitude to reorient their flight toward the closest land, usually the end of a peninsula and other promontories, like Cape Split and Victoria Beach.

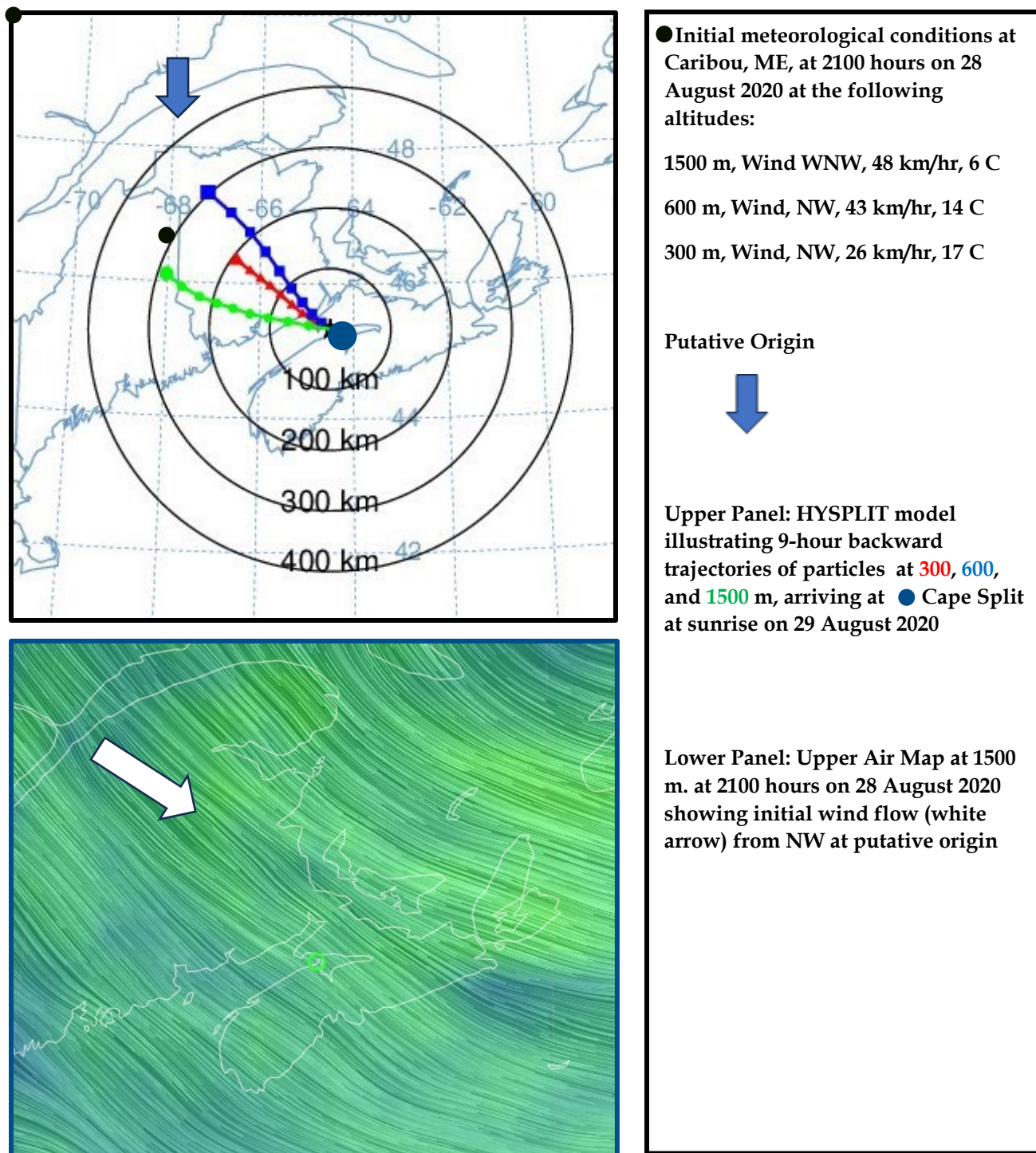


Figure 12: Putative Origin of Morning Arrivals at Cape Split on 29 August 2020

This study also demonstrates that Canada Warblers do not always select tailwinds for migratory flights. On the evening of 17 August, the station at Sandyland

Ponds detected 25 NFCs representing an estimated 15 Canada Warblers, presumably leaving the province. The winds that night were from the north at 17 km/hr. Similarly, on the evening of 27 August, the Sandyland Ponds station detected 17 NFCs, representing an estimated 12 birds, with winds from the west at 17 km/hr. A crossing to Maine that night would have encountered light winds ranging from 10 to 27 km/hr.

Overall, there were tailwinds for birds flying to New Brunswick or Maine on four nights during the migration season, and 21% of evening NFCs occurred on those nights.

Figure 13 presents the calling rates for Canada Warblers from 2020 to 2022. Since

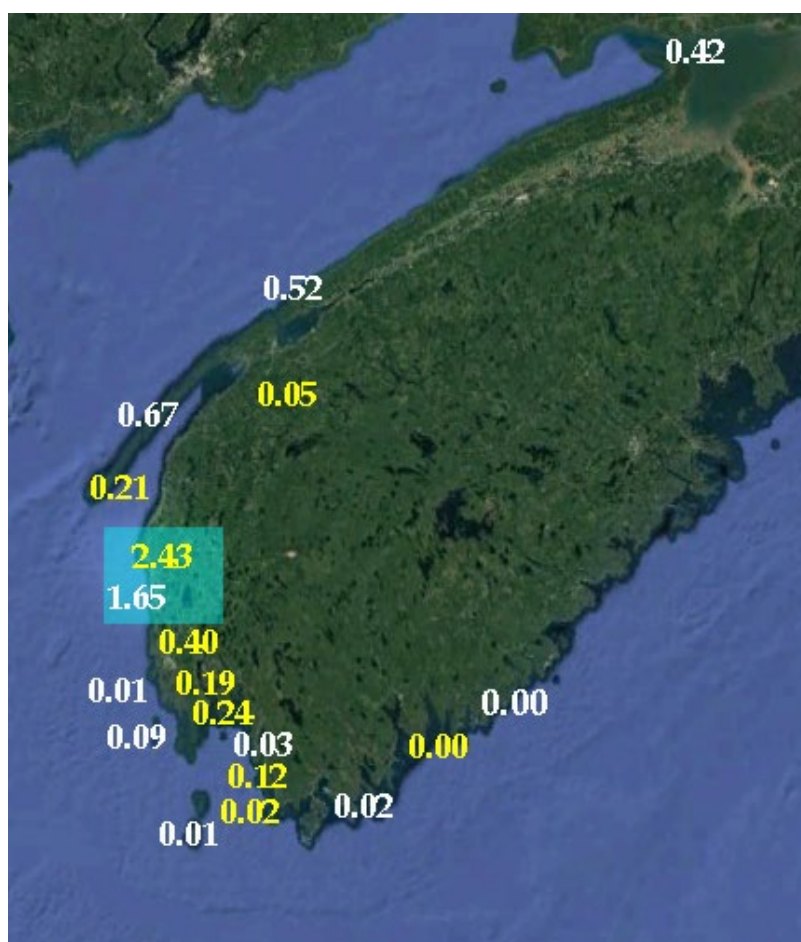


Figure 13: NFCs per Hour in 2020-2022 [Calling rates are white for 2020 and yellow for 2021-2022. The shaded area indicates the highest concentration of Canada Warblers]

the analysis in 2021 and 2022 sampled one of every five days compared to every day in 2020, the map displays the results in calling rates per hour.

The additional data from 2021-2022 confirms a similar distribution of migrating Canada Warblers compared to 2020. Higher densities occur along the west and southwest shore of Kespukwitk (Kings, Annapolis, Digby, and Yarmouth Counties) and a scarcity of warblers in the south and southeast portions (Shelburne and Queens

Counties). Notably, the highest density is in the southern part of Digby County (Municipality of Clare) and the northern area of Yarmouth County (Municipality of Yarmouth). The shaded portion of Figure 13 represents this higher-density area.

Table 4 lists the total calls at the acoustic station in the Municipality of Clare near Cape St. Marys, which had an overall calling rate of 2.43/hour. The migration on 9 August 2021 closely replicates conditions at Sandyland Ponds on 16 August 2020 with

Date	Pre-dawn	Dawn	Evening
09-Aug-2021		16	12
13-Aug-2021	2		65
18-Aug-2021			2
29-Aug-2021	1	1	3
Total	3	17	82

Table 4: Total NFCs near Cape St. Marys by Date and Recording Period

strong NE winds (this time at all altitudes) during the night of 8-9 August, giving birds from northeast Nova Scotia a strong tailwind. Similarly, light south easterlies boosted the apparent migration out of Nova Scotia on the evening of 9 August.

This migration event also suggests a one-day stopover, like in 2020. The migration pattern on 13 August 2021 replicates other departures of Canada Warblers from Nova Scotia in 2020 on nights of light crosswinds.

The migration at Cape St. Marys on 9 August 2021 differs from 16 August 2020 at Sandyland Ponds in one important way. At Sandyland Ponds, the station detected the birds during the pre-dawn period compared to at dawn at Cape St. Marys. At the latter location, the station was at the edge of a shrub sphagnum bog. This wetland shares some of the characteristics of the breeding habitat of Canada Warblers. In addition, there are several large, similar bogs in the area. Thus, the NFC activity at dawn at Cape St. Marys may indicate that birds had arrived at their stopover location, while the pre-dawn birds at Sandyland Ponds were still searching for stopover habitat. Figure 14 is a photo of the bog near Cape St. Marys.



Figure 14: Photo of Shrub Sphagnum Bog near Cape St. Marys

Discussion

This study has demonstrated that the western shore of Kespukwitk is a major point of departure from the province for Canada Warblers. Five years of acoustic monitoring in this region have consistently pointed to an even further concentration of these warblers in the area straddling the Municipality of Yarmouth and the Municipality of Clare. Additional monitoring may show that this area extends from Chebogue Point to Meteghan within the same two municipalities.

The origin of these birds is undoubtedly those nesting in the interior regions of Yarmouth, Digby, Annapolis, and Queens counties of Kespukwitk (see Figure 2). However, this study has provided evidence that considerable numbers of Canada Warblers from central and northeastern Nova Scotia use this gateway by taking advantage of nocturnal tailwinds. These flights also suggest that these Canada Warblers spend only one day in a stopover in Kespukwitk. This idea is consistent with the findings of Cárdenas-Ortiz et al. (2017), which also imply a one-day stopover in northern Columbia in the autumn.

This study also offers data indicating that Canada Warblers from Quebec and the Gaspé, New Brunswick, and Maine intentionally or accidentally from wind drift stopover in Kespukwiti. In 2020, these birds from a more westerly origin appeared along the Bay of Fundy coast. It is long established that vagrants and sea arrivals, known as "reverse migrants," are frequent in this area (Mills and Laviolette 2022). However, more recent research indicates that passerines regularly circulate the Bay of Fundy and Gulf of Maine shores (Kearney 2023; Brown and Taylor 2017; Smetzer, King, and Taylor 2017; Woodworth et al. 2015). These Canada Warblers may have been travelling east to reach the coast to follow the Canada Warblers' Atlantic coast route described by Roberto-Charron et al. (2020).

This study's peak Canada Warbler migration occurred in the second and third weeks of August, mainly at the Sandyland Ponds acoustic station. The peak occurred later at Central Grove, Victoria Beach, and Cape Split. At these three stations, there was evidence of arrivals from Eastern Canada and where the distance across the ocean is less than at Sandyland Ponds. These later peaks are consistent with the findings of Bégin-Marchand et al. (2022) that peak departure dates in the Saguenay Region of Québec were in late August and early September.

Figure 15 presents all Canada Warbler eBird data submitted using the NFC protocol. Iain Raynor, a citizen scientist from Ontario, created a visualization of this data and posted it online (Rayner 2022).

The circle on the map in Nova Scotia represents NFC data from one station in the autumn of 2018 situated in the concentration area shown in Figure 13. Since acoustic monitoring is a relatively new citizen science activity, and thus data are far from comprehensive, one cannot draw major conclusions from this visualization. However, it suggests two possibilities that align with the present study's findings. First, Canada Warblers concentrate at a water barrier (the Gulf of Maine and Lake Ontario), and second, the high numbers of Canada Warblers detected in Nova Scotia in the autumn

support the evidence for the presence of birds from breeding populations from other areas of Eastern Canada.

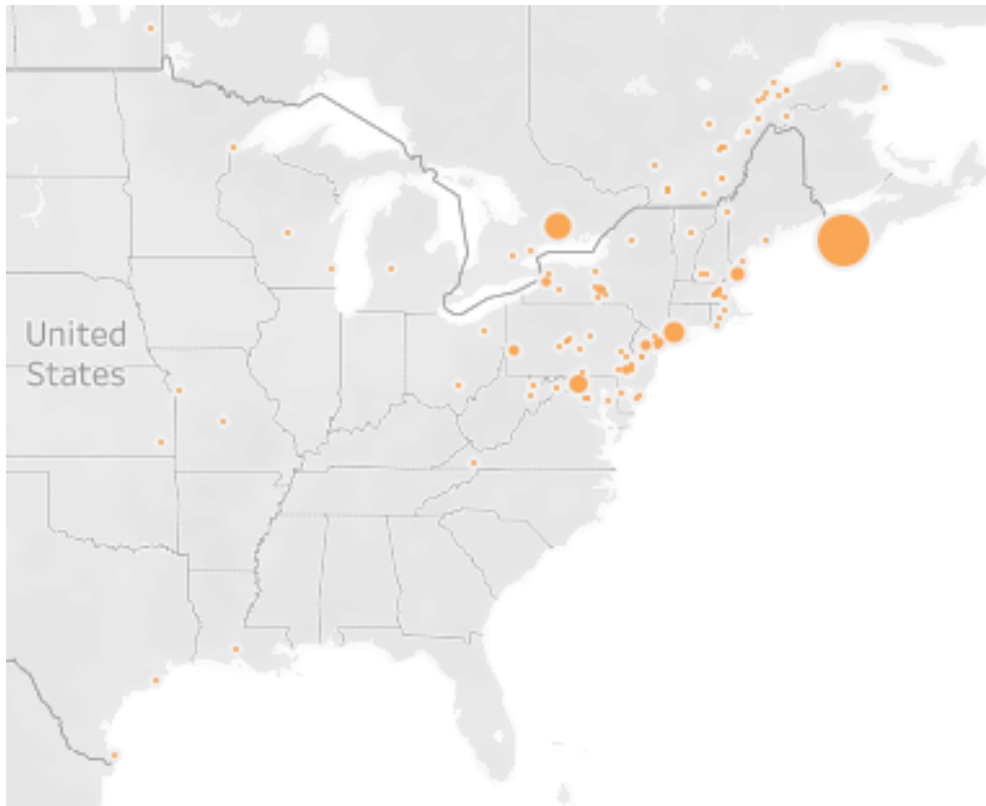


Figure 15: Visualization of all Canada Warbler NFCs Submitted to eBird Using the NFC Protocol (Rayner 2022)

Methodologically, this research has demonstrated the value of citizen science combined with emerging acoustic technologies and artificial intelligence to provide wide geographic coverage of Canada Warbler distribution during the autumn migration period. Since completing the fieldwork and analysis for this study, two classifiers aimed explicitly at NFCs are now or soon to be available (Van Doren et al. 2023; Kitzes Lab 2023). These applications will enhance both the speed and comprehensiveness of future research.

Finally, the study highlights the urgent need to update the Nova Scotia Recovery Plan for the Canada Warbler (Nova Scotia Department of Lands and Forestry 2021) to include the protection of migration habitat. This study shows where conservation

agencies should focus protection efforts. At the same time, there should be immediate follow-up research to pursue the leads this study provides for identifying this species' most important staging and stopover habitats.

Acknowledgements

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- Scott Jermey, Acadia First Nation
- Alix d'Entremont, Nova Scotia Bird Society
- Kathleen MacAulay, Nova Scotia Bird Society
- Bertin d'Eon, Nova Scotia Bird Society
- Tony Millard, Nova Scotia Bird Society
- Angie Millard, Nova Scotia Bird Society
- Paul Gould, Nova Scotia Bird Society

Phil Taylor at Acadia University wrote R-scripts to facilitate recordings analysis and batch-processed recordings using BirdVoxDetect. The Wildlife Division of the Nova Scotia Department of Natural Resources and Renewables, and the Protected Areas and Ecosystems Branch of the Nova Scotia Department of Environment and Climate Change facilitated the funding process and provided project advice and support.

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