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Short Communication

Insights on post-breeding movements from a northeastern population of Canada Warblers (*Cardellina canadensis*)

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ABSTRACT. The study of migratory songbird transition periods, such as the post-breeding period, is complex because birds undertake different types of movements that vary in space and time. Nonetheless, it is important to understand the extent and duration of the territory and specific sites use to identify human activities likely to affect the species' survival. Individuals from different regional populations may exhibit specific movements during the various phases of their annual cycle, and therefore conservation actions must be adapted. We studied a population of Canada Warblers (*Cardellina canadensis*) from the Saguenay region of Quebec, Canada, in the northeastern part of the species' breeding range. We used a coordinated radio-telemetry network (Motus) to determine the residence time within the breeding territory, dates and times of departure, and early fall migration routes of 18 adult birds. We expected individuals to leave by mid-August and to migrate through the eastern flyway, along the Atlantic Coast. Six tracked individuals remained on their breeding territory until early September, corresponding to a residence time of approximately 90 days. These individuals left just after sunset on their day of departure. Twelve individuals departed earlier, and in the daytime, before the end of August; their earlier departure was likely for a purpose other than migration. Nine individuals were detected outside their breeding territory along the Atlantic migratory flyway: four migrated through the Great Lakes region, one in the Great Appalachian Valley, three along the Atlantic Coast or coastal plain, and one with an undetermined route. Our results suggest that adult Canada Warblers remain in the Saguenay region longer than expected, and that, although some individuals remain close to their breeding territory during the post-breeding period, others may use surrounding territories prior to initiating their fall migration. Our results will allow regional conservation managers to recommend that regional industry postpone the timing of certain activities that could negatively affect the species' survival. Our study highlights the importance of fine-scale studies focused on specific periods of migratory songbird annual cycles to fill important knowledge gaps for understanding of the ecology of their species.

Aperçu des déplacements post-nuptiaux de Parulines du Canada (*Cardellina canadensis*) issues d'une population du nord-est du pays

RÉSUMÉ. L'étude des périodes de transition de passereaux migrateurs, comme la période post-nuptiale, est complexe car les oiseaux entreprennent différents types de déplacements qui varient dans l'espace et le temps. Néanmoins, il est important de comprendre l'étendue et la durée de l'utilisation du territoire et de sites spécifiques pour qu'on puisse déterminer quelles activités humaines sont susceptibles d'affecter la survie de l'espèce. Les individus de différentes populations régionales peuvent présenter des déplacements spécifiques au cours des diverses étapes de leur cycle annuel, et les activités de conservation doivent donc être adaptées. Nous avons étudié une population de Parulines du Canada (*Cardellina canadensis*) de la région du Saguenay au Québec, Canada, située dans la partie nord-est de l'aire de nidification de l'espèce. Nous avons utilisé un réseau coordonné de radiotélémétrie (Motus) pour déterminer le temps de résidence dans le territoire de nidification, les dates et les heures de départ, et les routes de migration au début de l'automne de 18 oiseaux adultes. Nous nous attendions à ce que les individus quittent à la mi-août et migrent par la voie de migration de l'est, le long de la côte atlantique. Six individus sont restés sur leur territoire de nidification jusqu'à début septembre, soit un temps de résidence d'environ 90 jours. Ces individus ont quitté juste après le coucher du soleil le jour de leur départ. Douze individus sont partis plus tôt, et de jour, avant la fin du mois d'août; leur départ précoce avait sans doute un but autre que la migration. Neuf individus ont été détectés en dehors de leur territoire de nidification le long de la voie de migration de l'Atlantique : quatre ont migré par la région des Grands Lacs, un dans la vallée des Appalaches, trois le long de la côte atlantique ou de la plaine côtière, et un dont nous n'avons pu déterminer l'itinéraire. Nos résultats indiquent que les Parulines du Canada adultes restent dans la région du Saguenay plus longtemps que prévu et que, bien que certains individus restent à proximité de leur territoire de nidification pendant la période postnuptiale, d'autres peuvent utiliser des territoires environnants avant d'entreprendre leur migration automnale. Nos résultats vont permettre aux gestionnaires de la conservation de recommander à l'industrie régionale de reporter le moment d'activités qui pourraient nuire à la survie de l'espèce. Nous soulignons l'importance de mener des études à l'échelle fine visant des périodes spécifiques du cycle annuel des passereaux migrateurs afin de combler les lacunes importantes dans la compréhension de l'écologie de ceux-ci.

Key Words: *migration routes; Motus; neotropical migrants; radio-telemetry; residence time*

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INTRODUCTION

Knowledge of the spatial distribution and behavior of migratory birds at every stage of their annual cycle is crucial for protecting these bird populations (Sillett and Holmes 2002, Faaborg et al. 2010). The transition between breeding and wintering periods is difficult to study because the birds are not necessarily faithful to a specific territory, e.g., for adult birds, the nesting territory during the breeding period. On breeding grounds, after leaving the nest, many species of songbirds, both adults and juveniles, exhibit movements that may vary in terms of distance, timing, and orientation before beginning their fall migration (Brown and Taylor 2015, Wiegardt et al. 2017, Berrigan 2018). For example, during the post-fledging dispersal, some Blackpoll Warblers (*Setophaga striata*) have been shown to travel more than 200 km before initiating migration (Brown and Taylor 2015). For regional conservation, it is important to understand the extent of the territory use of a species and the duration that birds remain on a given territory; this knowledge can lead to preventing or postponing activities likely to disturb the species or destroy its habitat (Calvert et al. 2013). At a broader scale, every piece of information collected during transition periods of different populations improves our understanding of the movements of the species throughout its range and annual cycle. We can therefore improve our assessment of the threats affecting individuals or populations, thereby favoring the species' survival. For example, after initiating their fall migration, birds travel toward their wintering grounds and may encounter individuals from other populations along their journey. The tracking of individual migration routes from various populations can identify geographic bottlenecks likely to affect the birds' survival (Bayly et al. 2018, Tonra et al. 2019, Knight et al. 2021).

The Canada Warbler (*Cardellina canadensis*) is a neotropical migrant, and most of the Canadian population nests in eastern Canada (Reitsma et al. 2020). It is listed as threatened under the Species at Risk Act of Canada (Government of Canada 2021), and the long-term Breeding Bird Survey trends for the species show strong declines in the eastern part of the species' range in Canada (Smith et al. 2017). This bird is known to spend relatively little time on its breeding grounds, being one of the last warblers to arrive and among the first to depart (Francis and Cooke 1986, Flockhart 2007, Reitsma et al. 2020). In Quebec, at the northern part of its breeding range, the Canada Warbler generally begins its nesting period in early June (laying period) and ends it by late July; the nestlings usually fledge by late July (Rousseu and Drolet 2017). From late July until the end of October, the Canada Warbler enters its post-breeding and early migration periods (Reitsma et al. 2020). A recent study involving light-level geolocators determined migratory departure dates and routes for populations in the western (Alberta), central (Manitoba), and southeastern (New Hampshire) sectors of the species' breeding range (Roberto-Charron et al. 2020). Individuals from Alberta left between early and mid-August, those from Manitoba departed between mid- and late August, and individuals from New Hampshire left in mid-August (Roberto-Charron et al. 2020). Light-level geolocators have coarse spatial and temporal resolution, however, and do not provide accurate information on the post-breeding movement behavior at finer scales (Fudickar et al. 2012). Canada Warblers in eastern Canada adopt an overland fall migration route along the Atlantic flyway, following the Atlantic Coast and then the coast of the Gulf of Mexico, rather than flying across the Gulf of Mexico and across the Caribbean islands (Cárdenas-Ortiz et al. 2017, Roberto-Charron et al. 2020). It is unclear, however, whether most populations within the eastern breeding range adopt this same migration route.

In this study, we opted to use radio-telemetry to track the movement behavior of individuals from a population in the northeastern part of the Canada Warbler's breeding range. We aimed to determine the residence time on the breeding grounds in Quebec (Canada), including the departure date and departure time from the breeding territory, and confirm the fall migration routes used by Canada Warblers. From the work of Roberto-Charron et al. (2020), we expected the Canada Warblers from our study region to adopt a similar behavior during their early stages of fall migration to that of individuals from the New Hampshire population. Thus, we expected individuals to leave for migration around mid-August and migrate along the Atlantic Coast of northeastern North America.

METHODS

Study site

The study was conducted in the Forêt d'enseignement et de recherche Simoncouche (FERS, 48°13′53″ N, 71°15′03′ W, 27 km²; Fig. 1) in the Saguenay region of Quebec, Canada. The study area, in the northeastern part of the breeding range of the Canada Warbler, lies within the southern limit of the balsam fir–white birch boreal forest bioclimatic domain (Saucier et al. 2003). Forest stands in the study area have a dense canopy and are dominated by trembling aspen (*Populus tremuloides*), white birch (*Betula papyrifera*), and balsam fir (*Abies balsamea*). Understory vegetation is characterized by mountain maple (*Acer spicatum*), beaked hazelnut (*Corylus cornuta*), and white birch and balsam fir saplings.

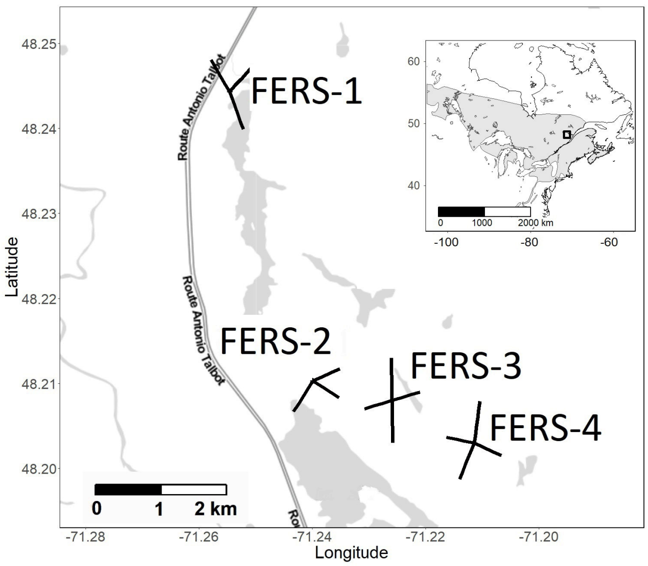
Capture and tagging

We captured Canada Warblers between 15 and 26 June 2017, i.e., during the nesting period, using mist nets and the playback of conspecific songs and calls. Mist nets were located generally along forest roads and were opened between 0550 and 1100 hours. We banded individuals with aluminum bands and determined age and sex using body plumage (Pyle 1997). We tagged individuals with a Lotek NTQB-2 radio-telemetry digitally coded nano-transmitter using a figure eight–shaped harness made of elastic nylon thread (Rappole and Tipton 1991, Streby et al. 2015). Combined, the transmitter and harness for each bird weighed about 0.45 g, representing less than 5% of the average body mass of tagged birds (10.29 ± 0.39 g [mean and SD]), which had no effect on mass change or the annual survival of another neotropical migrant species, the Bicknell's Thrush (*Catharus bicknelli*; Townsend et al. 2012).

Telemetry tracking

All transmitters were assigned the same radio frequency (166.38 MHz) and had a burst interval of 19.9 seconds. Each transmitter battery had an estimated lifespan of 106 days. We set up four receiving towers at FERS, and each tower had a series of receiving antennas with different orientations to cover the entire FERS area (Fig. 1). We tagged birds between 0.2 and 1.8 km from a receiving tower. The estimated detection range varied between antenna types. Under optimal conditions, these ranges were 3 to 5 km for

Fig. 1. Study area (Forêt d'enseignement et de recherche Simoncouche [FERS], Québec, Canada) showing the location of the four Motus radio-telemetry receiving towers and the orientation of their respective antennas. The gray zone represents the Canada Warbler's (*Cardellina canadensis*) breeding range.



the 3-element Yagi antennas (FERS-3, FERS-4) and about 15 km for the 9-element Yagi antennas (FERS-1, FERS-2; Taylor et al. 2017). All receiving towers were active during the peak-nesting and post-breeding periods; the exception was FERS-1, which was activated 19 July. We also activated a mobile receiver composed of an omnidirectional antenna (detection range approx. 0.5–1 km) fixed on the roof of a vehicle. We then performed 10 mobile surveys in July along forest roads within FERS to detect tagged individuals beyond the detection range of the receiving towers' arrays. The mobile receiver also allowed us to detect potentially lost transmitters, i.e., transmitters that had fallen from the bird. We did not perform surveys to assess the breeding activity of the tagged birds. Data beyond FERS were accessed through a coordinated radio-telemetry network (Taylor et al. 2017). In total, 514 receiving towers were active in the Americas between 1 June and 31 December 2017 (www.motus.org). In accordance with recommendations in the Motus R book for data analysis (Crewe et al. 2018), we examined every possible detection of an individual and retained only sequences having three or more consecutive detections.

Departure classification

To ensure that individuals had not been killed or lost their transmitters, we examined, for each individual, variability in signal strength over time for the four receiving towers located within FERS from the day the tag was deployed to the last detection at FERS. We assumed that individuals presenting a constant signal strength over time, i.e., suggesting no movement, were associated with lost transmitters or mortality within the radio-telemetry array's detection range, and we excluded these individuals from further analysis. Individuals that were only detected during the mobile surveys were also excluded from the analysis because the bird's activity, according to the variation in signal strength, could not be confirmed by a fixed receiving tower. The detection range of the radio-telemetry array is variable depending on a bird's behavior and activity (Crewe et al. 2019). As previously shown in other studies using a radio-telemetry array, a migratory departure flight pattern is identified by a sudden spike of the signal followed by a decrease in strength (Mills et al. 2011, Mitchell et al. 2012, 2015, Woodworth et al. 2015), suggesting a sustained flight at a higher altitude and above the canopy, likely related to migratory departure. For birds moving, foraging, or departing within the forest or through the understory, the variation in signal strength does not exhibit such a pattern; hence, it is not indicative of a definite migratory departure. Therefore, we classified the last signals received at FERS either as an "explicit departure," having the previously mentioned signal pattern, or as an "ambiguous departure," where there was signal loss but no characteristic migratory departure signal pattern. For both types of departure, we assumed that the last date with a detection by one of the four fixed receiver towers at FERS was the "departure date" from FERS. For that date, we determined the departure time as the time of the last detection, and we used this variable to calculate the number of hours preceding or following sunset (hereafter, "departure time") that the departure took place. We obtained sunset times using the suncalc R package (Agafonkin and Thieurmel 2018).

Statistical analysis

We expected that the distribution of departure dates and departure times would be asymmetrical. To estimate the mean departure date and mean departure times for explicit and ambiguous departures separately, we used a bootstrapping method and drew a new sample (with replacement from the original sample) of observations equal to the number of empirical observations in each departure classification group. We then repeated this sampling method 10,000 times and calculated the mean and 95% confidence interval (CI) for each departure classification group (Efron 1987). We also performed the same method with explicit and ambiguous departures combined to test whether there was an effect of including ambiguous departures in determining the departure phenology. Including all departure types regardless of the variation of the signal strength might reveal other types of behavior unrelated to migration but might also bias the estimated residence time. We also performed a randomization test to compare the difference between the mean departure dates and departure times between explicit and ambiguous departures. We drew, without replacement, a sample equal to the sample size of the explicit departure classification group from our original sample, both explicit and ambiguous departures combined, and assigned the departure classification "explicit" to this sample and assigned "ambiguous" to the remaining data. We calculated the difference between both means, repeated this method 10,000 times, and calculated the probability of the value equal to the empirical difference between the means of both groups.

Detection beyond FERS

The automated radio-telemetry array did not allow us to determine the ground speed of individual birds between receiving towers because not all sequential detections of birds between separate towers took place during the same evening, i.e., after being detected on one tower, birds often stopped over or rested somewhere prior to being detected at another tower. Also, movements between separate towers are not necessarily linear, which can bias estimates of the distance travelled. Instead, we derived a mean migration rate (km/day) for each transition between two receiving towers outside FERS by calculating the shortest distance (great circle distance) between both towers and the time elapsed between the detection having the strongest signal at each tower. In the case of detections from multiple receiving towers on a given day (starting at sunrise), we calculated the total distance and time travelled during that day to avoid simultaneous detections by two receiving towers, which would result in unlikely migration speeds. For receiving towers beyond FERS, we assigned a migration rate of 0 km/h when a bird was detected at the same receiving tower for two or more consecutive days, i.e., the next morning or later, and we assumed that the bird did not migrate during that period. Last, we evaluated Cook's distance plots to assess the presence of potential influential outliers in our estimates of migration rate between successive signal detections (threshold = 1).

RESULTS

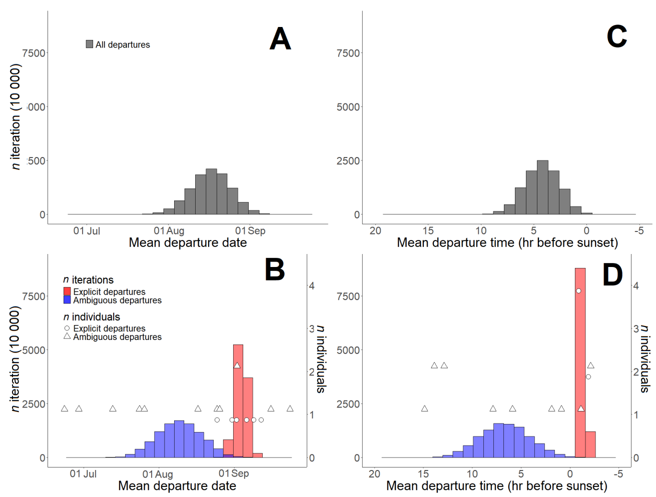
Detections at FERS

We captured 23 Canada Warblers (22 males and one female); 12 were second year (SY), 10 were after second year (ASY), and one was classified as after hatching year (AHY). After examining the graphs of signal strength over time, we included 18 individuals in our analysis: six explicit departures (2 SY, 4 ASY) and 12 ambiguous departures (7 SY, 4 ASY, 1 AHY). We excluded the remaining five individuals because of lost transmitters (n = 2, Fig. A1.1), detections exclusively during the mobile surveys (n = 2), or tag failure (i.e., more than three consecutive detections; n = 1). The departure of the only tagged female was classified as ambiguous, and this individual was not detected beyond FERS (Table A1.1). We did not test for differences between sexes and ages. Further details about individual departures are provided in Appendix 1 (Table A1.1). The individual activity patterns exhibited by the graphs of signal strength over time at FERS showed that some individuals were detected on a regular basis between the date of capture and the departure date, whereas other individuals would remain undetected for several weeks. This pattern was partly explained by the distance between the tagging location and the nearest tower, although some individuals with few detections were tagged within 0.5 km of a receiving tower (Fig. A1.2 and A1.3). We detected most individuals (17/18) during the mobile surveys with the mobile receiver, including two individuals that were detected on fewer than five days using the automated fixed radio-telemetry array over the entire study period.

Migratory departures

The earliest departure date was on 23 June 2017 (an ambiguous departure, tagged on the same day), and the latest was on 24 September 2017 (explicit departure). Two individuals left in June, three in July, five in August, and eight in September. The mean date of explicit migratory departure was 3 September (25 August to 8 September, 95% CI, n = 6) compared with 9 August for ambiguous departures (22 July to 26 August, 95% CI, n = 12; Fig. 2B). The difference between the mean departure date of both departure classification groups was 21.5 days (randomization test, p = 0.02). When both departure types were combined, the mean departure date was 16 August (1 to 30 August, 95% CI, n = 18; Fig. 2A). Further details concerning the variation of signal strength near FERS (Fig. A1.1 and A1.2) and the departure dates of the birds (Table A1.1) are provided in Appendix 1.

Fig. 2. Mean departure date for both departures combined (A) and for "explicit" and "ambiguous" departures separately (B); mean departure time both departures combined (C) and for "explicit" and "ambiguous" departures separated (D). On the left-hand y-axis, the histogram bars show results obtained after 10,000 iterations using data from 18 Canada Warblers (*Cardellina canadensis*; open symbols). The right-hand y-axis shows the six explicit departures (circles) and 12 ambiguous departures (triangles).

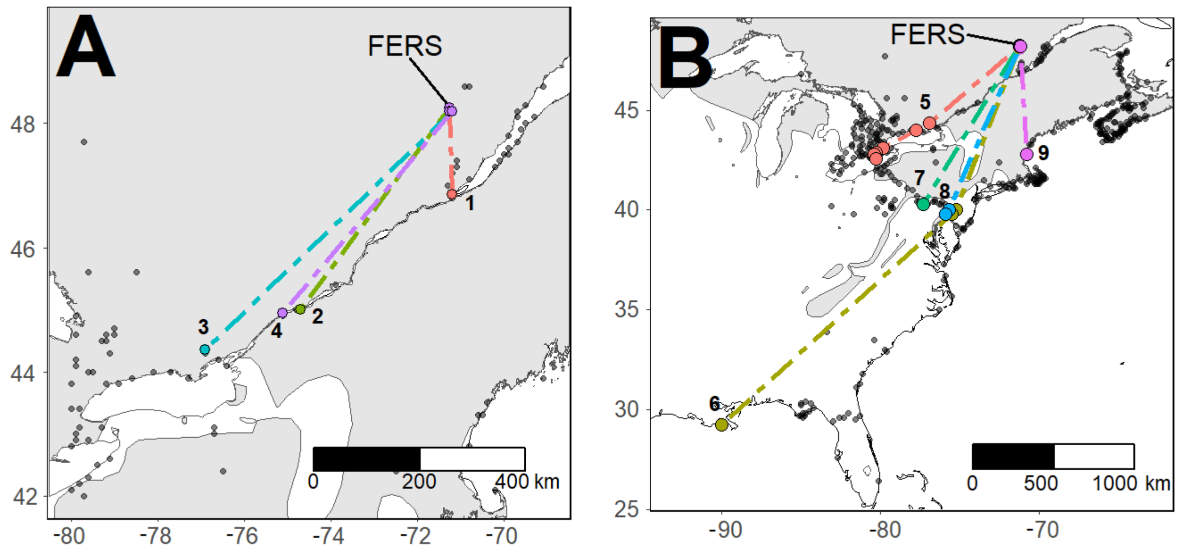


The mean departure time for explicit departures was 1.3 h after sunset (1.0 to 1.7 h after sunset, 95% CI, n = 6) compared with 6.6 h before sunset for ambiguous departures (11.4 h to 1.7 h before sunset, 95% CI, n = 12; Fig. 2D). The difference between the mean departure time of both departure classification groups was 5.5 h (randomization test, p < 0.01). When both departure types were combined, the mean departure time was 4.3 h before sunset (7.5 h to 1.2 h before sunset, 95% CI, n = 18; Fig. 2C).

Telemetry tracking of migration

A total of nine individuals were detected within the Motus radio-telemetry array outside FERS: six were from explicit departures (mean departure date = 3 Sept., mean departure time = 1.3 h after sunset) and three from ambiguous departures (mean departure date = 16 Aug., mean departure time = 5.5 h before sunset). Four individuals migrated through the Great Lakes region (individuals [ID] 2, 3, 4, and 5; Fig. 3A and 3B). One individual was detected within the Great Appalachian Valley (ID 7, Fig. 3B), three individuals reached the Atlantic Coast or the coastal plain (ID 6, 8, and 9; Fig. 3B), and one individual was detected over too short a distance to determine its route (ID 1; Fig. 3A). The southernmost detection was located near Grand Isle, Louisiana (29°15′ N, 90°00′ W) on 25 September (ID 6; Fig. 3B). During the early migration, most birds that were tracked beyond FERS, i.e., in the northeastern United States and southeastern Canada, were detected within a narrow calendar window from September 2 to 12 (Table A1.2). One individual, after departing from FERS on 1 September, was detected by seven receiving towers in Ontario

Fig. 3. Migration maps for the nine individual Canada Warblers (*Cardellina canadensis*) equipped with radio-transmitters that were subsequently detected by Motus receiving towers beyond the study site. The left panel (A) shows four individuals detected within approximately 500 km of the study site, and the right panel (B) presents the five individuals detected beyond 500 km from the study site. The applied identification number (ID) refers to the number given to the individual. Colored circles show detections at Motus receivers, and black circles are Motus receiving towers that did not detect any individual. The northernmost detection on each panel (first of the series) is the last detection within the study site. The gray zone represents the Canada Warbler's breeding range.



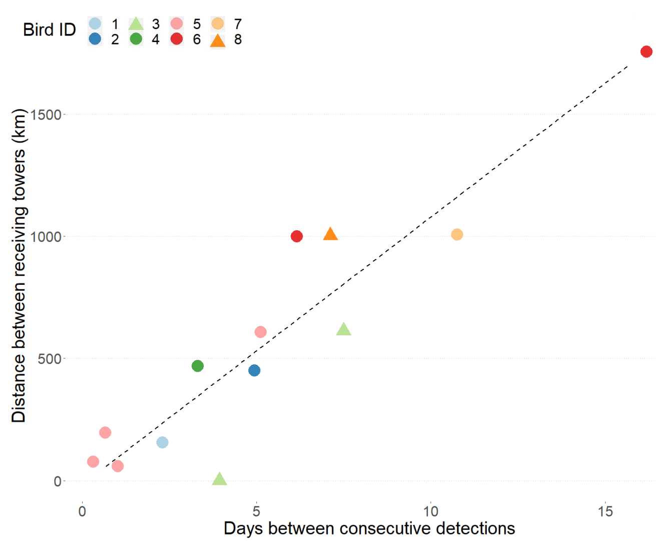
between 6 and 9 September. The tracking showed a route that crossed Lake Ontario (at least partially) and Lake Erie (ID 5; Fig. 3B). Further details concerning detections beyond FERS and the age of the detected birds are provided in Table A1.2.

The mean migration rate ranged between 0 and 184 km/day (Fig. 4). One bird's movement was an outlier (ID 9, distance = 601.9 km, time = 35.5 days, Cook's distance = 0.45; Fig. 3B); we therefore calculated the mean migration rate without this observation. Mean migration rate was 106.4 km/day for both departure types combined, 116.3 km/day (range = 65.3 to 184.8 km/day) for explicit departures, and 73.7 km/day (range = 0 to 137.2 km/day) for ambiguous departures. One bird likely remained close to Napanee, Ontario (44°21′ N 76°54′ W, approx. 600 km from FERS) given the consecutive detections at the same receiving tower 3.8 days apart (ID 3, ambiguous departure; Fig. 3A). The previously mentioned outlier (ID 9, ambiguous departure; Fig. 3B) was detected near the Atlantic Coast (approx. 600 km from FERS) 35 days after it was last recorded at FERS. One individual (ID 6, explicit departure) migrated over 1750 km from Pennsylvania to Louisiana (Fig. 3B) in 16 days (112 km/day; Fig. 4), suggesting that this bird maintained a high migration rate with few multiple-day stopovers.

DISCUSSION

Canada Warblers departed from their breeding territories in the Saguenay region of Quebec between the end of August and early September, later than we had expected. Radio-telemetry suggests that individuals that departed earlier in the season left FERS—assumed to be the breeding location—during the day, potentially by flying at lower altitudes or through the understory, whereas

Fig. 4. Distance (km) as a function of time (days) between consecutive detections at a given pair of receiving towers outside the study site for nine Canada Warblers (*Cardellina canadensis*). Each bird is distinguished by a different color. Those individuals having explicit departures are represented by circles and those with ambiguous departures are represented by triangles. The black line is the migration rate slope (mean = 90.3 km/day).



individuals that departed later in the season appeared to initiate a long-distance migratory flight at higher altitudes. We expected that Canada Warblers from Quebec would migrate along the Atlantic Coast; however, detections within the radio-telemetry network showed variability in the selected migration route covering territory from the Great Lakes to along the Atlantic Coast.

Assuming that birds had arrived in late May or early June (Savard and Cormier 1995, Sullivan et al. 2009) and initiated their fall migration in late August and early September, we suggest that some Canada Warblers remained in the vicinity of their breeding territory for approx. 90 days. This duration highlights that Canada Warblers had a later migratory departure date and a longer residence time than previously expected when compared with other populations within the species breeding range in Alberta (mid-August), Manitoba (early/mid-August), and New Hampshire (mid/late August; Flockhart 2007, Roberto-Charron et al. 2020).

Birds having an earlier departure date from FERS might represent floaters (Penteriani et al. 2011) or individuals that made extraterritorial movements during the breeding season (Stutchbury 1998, Reitsma et al. 2018). Earlier departures in the season might have been prompted by reproductive failure or energetic stress (Haas 1998). For example, a portion of a Black-throated Blue Warbler (*Setophaga caerulescens*) population emigrated from their initial territory located in a suboptimal habitat and immigrated to a higher quality habitat during the breeding season (Betts et al. 2008). A similar situation may have occurred in our study, because a slightly higher proportion of second-year birds, likely making their first breeding attempt, exhibited an earlier departure. However, we did not assess reproductive activity in our study, and we strongly believe that including this information in similar future projects is essential for properly inferring bird behavior. In this study, the telemetry tracking was mostly limited by the use of fixed receiving towers. Our mobile surveys with a mobile receiver were not performed on a regular basis but did allow us to detect individuals within FERS that were outside the detection range of the radio-telemetry array; this included two individuals (excluded from our analysis) that were not detected by any fixed receiving towers. Both individuals exhibited an earlier departure and were subsequently detected by other receiving stations beyond FERS. Despite an earlier departure date, their detection dates outside the breeding territory were similar to those of later-departing birds. We suggest that both individuals likely left their initial breeding territory and dispersed to other surrounding territories on the breeding grounds before initiating migration in late August. Hence, we recommend that further studies enlarge the detection coverage by using a mobile telemetry station or drones (Tremblay et al. 2017) or manual radio-telemetry receivers. Regular surveys should be conducted in nearby habitats to detect a greater number of individuals beyond the radio-telemetry array's detection range, identify potential suboptimal habitat, and document post-breeding movements at finer temporal and spatial scales.

The Canada Warblers breeding in Quebec migrated along the Atlantic flyway, a pattern similar to individuals from the New Hampshire population (Roberto-Charron et al. 2020). Moreover, some individuals from Quebec likely migrated to similar locations as individuals from the New Hampshire population, as suggested by the detections near Delaware, on the Atlantic Coast. Most of our detections during the birds' migration suggest a larger migration corridor spread between the Great Lakes region and the Atlantic Coast. Although some individuals migrate along the Atlantic Coast, the relatively few detections along the coast, despite the high density of available Motus receiving towers in this area, suggest that most of the individuals from our study did not migrate along the coastal route. Our results show some variability of migration route selection between individuals from the same breeding location. This variability may result, however, from the changing conditions along the Atlantic migratory flyway (Richardson 1978, Becciu et al. 2019). The variability of migration routes for individuals from two eastern populations (Quebec and New Hampshire) may prevent those populations from encountering temporal geographic bottlenecks, at least in the early stages of the fall migration, (Bayly et al. 2018, Buechley et al. 2018). One individual migrated along the coast of the Gulf of Mexico in Louisiana, supporting the hypothesis that Canada Warblers do not fly across the Gulf of Mexico to reach their wintering grounds (Cárdenas-Ortiz et al. 2017, Roberto-Charron et al. 2020).

The results of our study have important implications for regional recommendations to industry involved in the exploitation of natural resources, such as forest harvesting. Our results highlight a longer residence time for Canada Warblers than previously believed and that a portion of the studied population likely uses additional space surrounding their breeding territories before initiating migration. These results provide concrete examples of critical information needed by landscape managers to adapt their practices, and, for instance, delay the timing of certain activities likely to be detrimental to the species during the post-breeding period. Despite the limited sample size from one single population, we believe that all information collected at a fine-spatial scale and at the different stages of the annual cycle, in particular during transition periods such as the post-breeding and the migration periods, fills significant gaps in knowledge and improves the protection and recovery of at-risk species such as the Canada Warbler.

Responses to this article can be read online at:
https://www.ace-eco.org/issues/responses.php/2013

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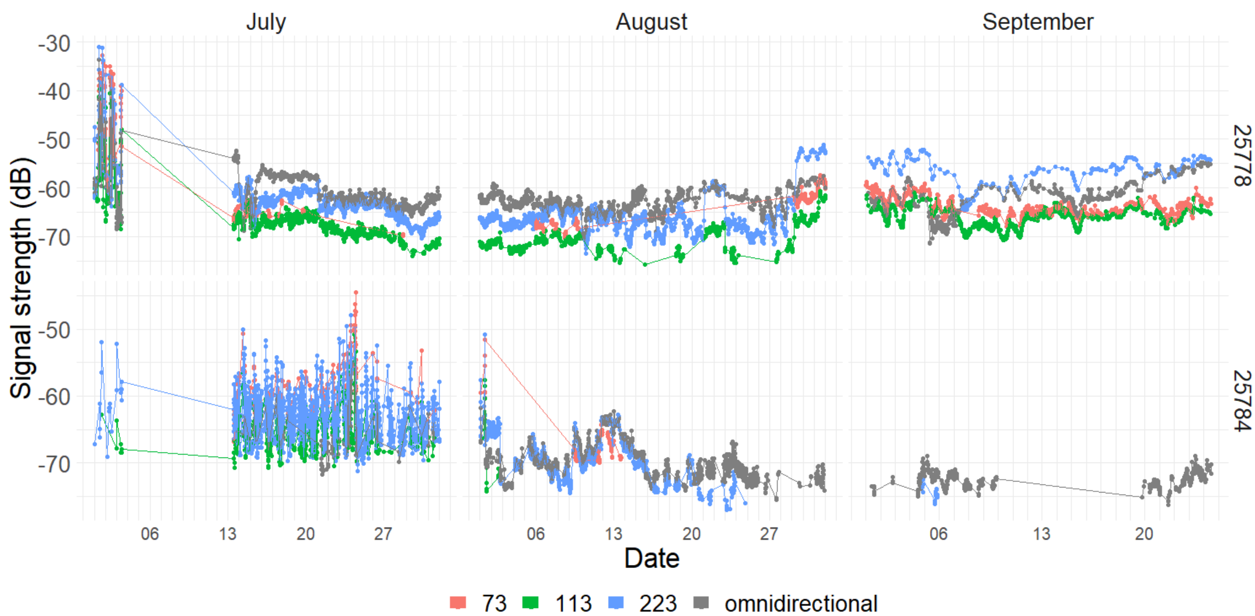
Appendix 1

Figure A1.1. Variation of the signal strength of two Canada Warblers assumed to have lost their tag, and thus removed from further analysis. The signal was detected by one receiving tower (FERS-2) with 3 Yagi 9-element antennas oriented at 73, 113 and 223 degrees, and one omnidirectional antenna. ID 25778: Signal became stable in mid-July and stops at the end of September likely due to battery lifespan. ID 25784: Signal varied daily in July and became stable by the end of August near the receiving tower (detected by the omnidirectional antenna).



Appendix 1

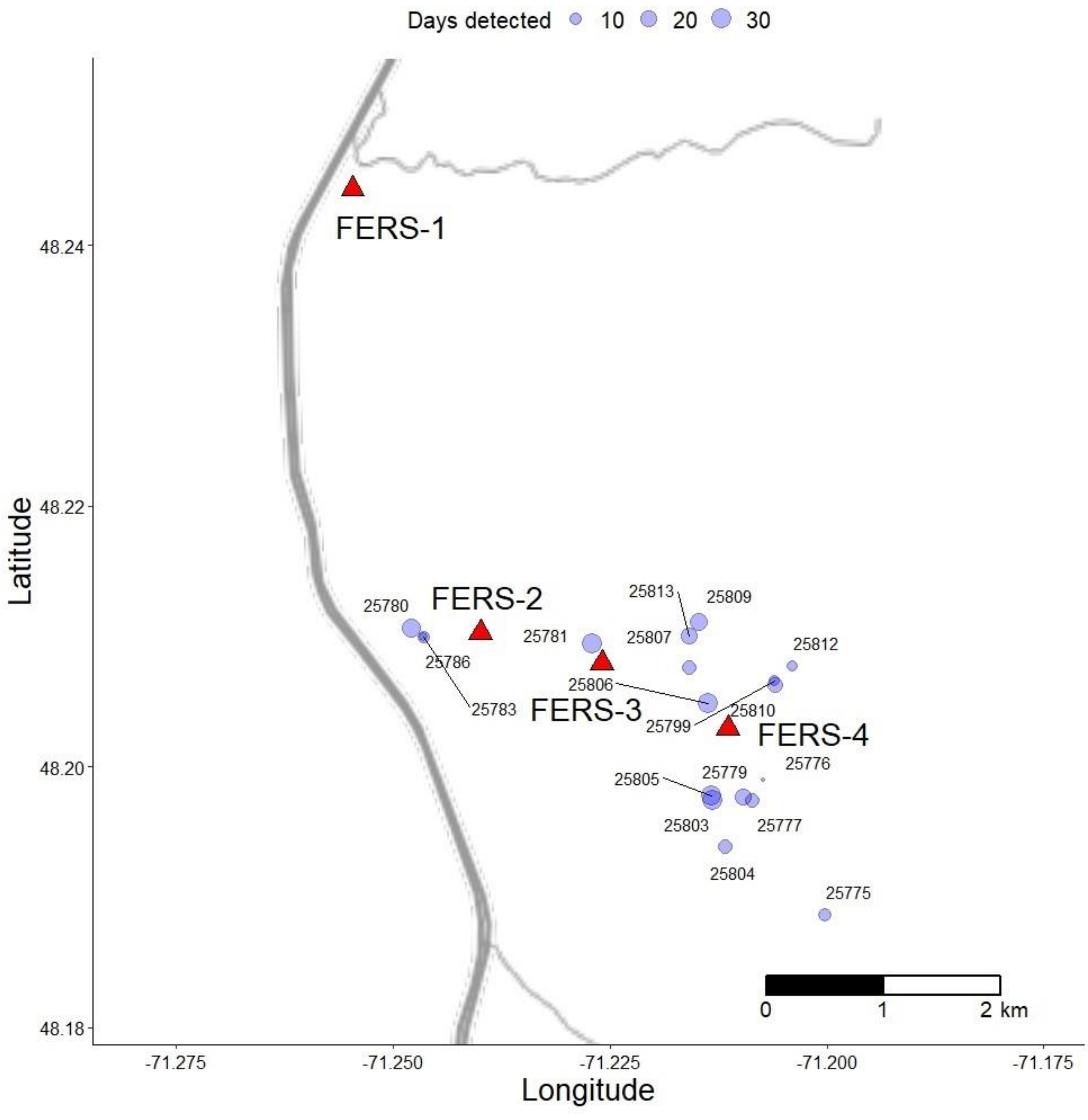
Figure A1.2. Variation of the daily maximum signal strength at every receiving tower on the study site (FERS-01, FERS-02, FERS-03, FERS-04) and from the mobile receiver, between date of capture and date of departure from the study site for 18 Canada Warblers (tag ID on the right).

Appendix 1


June
July
August
September
Daily maximum signal strength (dB)
-20
-40
-60
25803
25804
25805
25806
25807
25809
25810
25812
25813
0
10
20
30
Date
FERS-01
FERS-02
FERS-03
FERS-04
Mobile

Appendix 1

Figure A1.3. Tagging location of 18 Canada Warbler (blue circles with tag ID) at Forêt d'Enseignement et de Recherche de Simoncouche (FERS), location of 4 receiving towers (red triangles) and number of days detected within the radio-telemetry array within the study site represented by the circle size.



Appendix 1

Table A1.1 Departure date of 18 Canada Warblers tracked on the study site in Quebec (48.2314, -71.2508): tag ID, sex (M = Male, F = Female), age (SY = Second-year, ASY = After Second-year, AHY = After Hatching-Year), and departure type (Explicit or Ambiguous).

Tag ID	Sex	Age	Departure date	Departure type
25803	M	SY	2017-09-02	Ambiguous
25804	M	SY	2017-09-02	Ambiguous
25805	M	ASY	2017-09-16	Ambiguous
25806	M	SY	2017-09-24	Ambiguous
25807	M	SY	2017-07-13	Ambiguous
25809	M	SY	2017-07-24	Ambiguous
25810	M	ASY	2017-09-06	Explicit
25812	M	AHY	2017-06-29	Ambiguous
25813	M	ASY	2017-06-26	Ambiguous
25775	M	ASY	2017-08-31	Explicit
25776	M	ASY	2017-06-23	Ambiguous
25777	M	ASY	2017-09-12	Explicit
25779	M	ASY	2017-08-17	Ambiguous
25780	M	SY	2017-09-02	Explicit
25781	M	SY	2017-08-25	Explicit
25783	F	SY	2017-08-25	Ambiguous
25786	M	SY	2017-07-26	Ambiguous
25799	M	ASY	2017-09-09	Explicit

Appendix 1

Table A1.2. Detections of 9 Canada Warblers tracked outside their breeding site in Quebec: bird ID, tag ID, sex (M = Male, F = Female), age (SY = Second-year, ASY = After Second-year, AHY = After Hatching-Year), Departure type (Explicit/Ambiguous), location of the detection (latitude/longitude), date, distance from last receiver and time elapsed between last detection at the preceding receiving station, i.e. from breeding site if there is only one detection outside the breeding site. The bird ID refers to different segments from the same individual and to the ID illustrated in Figure 3. The letter following the Bird ID refers to the segment measured in Figure 3.

Bird ID-track	Tag ID	Age - Sex	Departure type	Latitude	Longitude	Detection date	Distance (km)	Time (day)	Speed (km*day^{-1})
1	25777	ASY-M	Explicit	46.85	-71.20	2017-09-15	155.89	2.00	77.92
2	25799	ASY-M	Explicit	45.00	-74.80	2017-09-15	452.16	4.98	90.88
3-a	25803	SY-M	Ambiguous	44.35	-76.90	2017-09-10	612.89	7.31	83.89
3-b				44.35	-76.90	2017-09-14	0.00	3.77	0.00
4	25810	ASY-M	Explicit	44.95	-75.10	2017-09-10	468.86	3.04	154.17
5-a	25775	ASY-M	Explicit	44.35	-76.90	2017-09-06	610.15	5.36	113.81
5-b				44.00	-77.75	2017-09-07	78.25	0.68	115.83
5-c				43.10	-79.85	2017-09-08	196.83	1.06	184.94
5-d				42.90	-80.30	2017-09-09	42.87	0.91	47.23
6-a	25780	SY-M	Explicit	40.00	-75.50	2017-09-09	973.60	6.35	153.35
6-b	25780			29.25	-90.00	2017-09-25	1756.32	15.68	112.04

Appendix 1

7	25781	SY-M	Explicit	40.30	-77.30	2017-09-06	1007.07	11.01	91.47
8	25804	SY-M	Ambiguous	40.00	-75.50	2017-09-10	973.60	7.30	133.44
9	25812	AHY-M	Ambiguous	42.80	-70.80	2017-09-02	601.93	35.67	16.87