Using Vocal Behaviour to Reform the Conservation of Canada Warblers (*Wilsonia canadensis*)

Honours Candidate: Gregory Cummings

Thesis Supervisor: Cindy Staicer

ENVS 4902 Course Coordinator: Daniel Rainham

Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Overview

The Canada Warbler (*Wilsonia canadensis*) is a declining neotropical migratory songbird that breeds in Canada and the USA and winters in South America. Between 1968 and 2007, its abundance declined an estimated 4.5% per year, which corresponds to an 85% species decline over the 38-year period (Savignac, 2008). In Nova Scotia, the population is estimated to have declined 20% per year from 1997-2007 (Savignac, 2008).

The causes for the decline of the Canada Warbler are not entirely known (Savignac, 2008). However, it is thought that habitat loss and degradation to both the breeding grounds and wintering habitat have a major influence (Lambert and Faccio, 2005; Reitsma et al., 2010). Canada Warbler breeding habitat includes a wide range of mixed coniferous and deciduous forest. However, Canada Warblers are most often found near open water or in a moist, wet mixed coniferous and deciduous forest with a highly developed understory (Reitsma et al., 2010). This habitat is threatened in the eastern breeding range from conversion of swamp forests and urban development (Savignac, 2008). The western breeding range is threatened from the clearing of boreal mixed-wooded forest for agriculture and industrial development (Savignac, 2008).

Canada Warbler wintering habitat includes the dense undergrowth of cloud and rain forests and the submontane region of the Andes (Savignac, 2008). They also prefer semi-open areas such as coffee plantations and hedge rows (Reitsma et al., 2010). The Canada Warbler, among other migratory songbirds of conservation concern, relies heavily on Andean habitat for the majority of its wintering sites (Bakermans et al., 2009). However, 90% to 95% of the

northern Andean primary forest has been deforested or cleared for agriculture, fuel wood and illegal drugs (Henderson et al., 1991; Davis et al., 1997). Pipeline and road development also contribute to habitat loss (Davis et al., 1997).

After thirty years of steady population decline, the Canada Warbler is a now considered species of international conservation concern (Reitsma et al., 2010). It was designated as a Highest Priority Landbird in Bird Conservation Region 14 (Atlantic Northern Region) by the North American Bird Conservation Initiative (Dettmers, 2003), and was listed as a species of Continental Importance in the Northern Forest Region by Partners in Flight (Rich et al., 2004). In March 2010, the species was listed as Threatened on Schedule 1 of Canada's Species at Risk Act (SARA). About 85% of the population breeds in Canada (Rich et al., 2004), which gives this country a high responsibility for the conservation of Canada Warblers.

The majority of current population estimates come from the North America Breeding Bird Survey (BBS) (Savignac, 2008) which is an international survey project between the United States Geological Survey and the Canadian Wildlife Service. The BBS consists of volunteers who survey more than 3,000 roadside routes once each year. Volunteers record every bird heard or seen within a three minute period at 50 stops along a 39.4 km route (Sauer et al., 1994). Although long-term commitment is required for BBS volunteers (Canadian Wildlife Service, 2009), not all volunteers have the same knowledge and hearing ability required to make accurate counts (Sauer et al., 1994). Furthermore, Partners in Flight estimates that the BBS only adequately covers 34.6% of the Canada Warbler population (Savignac, 2008).

No quantitative analysis of Canada Warbler vocalizations has been published; however an ongoing Canada Warbler breeding ecology study has been underway at Canaan, New

Hampshire, USA since 2003. Leonard Reitsma and colleagues have been collecting long-term data on habitat selection, nesting success, mate and site fidelity for a population of uniquely color-banded Canada Warblers. A study of the vocal behaviour of this population was initiated in May 2010 by Dalhousie graduate student Alana Demko. Preliminary results from Demko's study were available for comparison with my results.

1.2 Purpose of Study

Due to enormous declines in population sizes, a species-specific song-based monitoring program is required to identify critical Canada Warbler habitat. This is the first step towards creating a recovery strategy. A song-based monitoring program would produce more accurate population estimates than BBS surveys because population numbers would be determined by characteristics of individual males Canada Warbler songs. Therefore differences in vocal behavior with respect to breeding status, time of day or season would be taken into consideration instead of just counting the number of Canada Warblers heard in a three minute interval at one point during the breeding season.

1.3 Research Question

My research aims to answer several questions relevant to developing a song-based monitoring program for the Canada Warbler. These questions are: (1) Does detectability differ with time of day and time of season? Detectability refers to the ability to detect or locate Canada Warblers based on temporal changes in their singing behaviour. It is important to determine if detectability differs with time of day and time of season because it would allow Canada Warbler populations to be estimated more accurately even if they may not be singing at a particular time of day or time of season. (2) Does singing behaviour change with pairing status? Singing

behaviour or vocal behaviour refers to the temporal, structural and frequency characteristics of male Canada Warbler songs. If singing behaviour does change, we can determine if Canada Warblers are paired and when they are fledging young. This knowledge is very important in monitoring population dynamics. (3) Does a male have more than one song in his repertoire and are his songs individually distinct? This is important because the number of types of songs a bird sings may influence population size estimates. If males have individually distinct songs, we can track birds through the season or from one season to the next. (4) Is the vocal behaviour of Nova Scotia birds the same as those in New Hampshire that are being intensively studied? If the vocal behaviour is similar between the two populations, we may be able to extrapolate conclusions regarding their vocal behavior to other areas in their breeding range. We could also apply results of the more detailed NH study to the populations in Nova Scotia.

1.4 Implications of Research

This research intends to further the knowledge of Canada Warbler vocal behaviour. By comparing a Nova Scotia Canada Warbler population with Canada Warbler data being collected in New Hampshire, I hope to find similarities between vocal behaviour which could then be used for comparison between other populations in other parts of Canada or the United States. This research will also promote less intrusive monitoring by focusing on vocal behaviour to asses individual identity and breeding status.

1.5 Relevance to Environmental Science

This research is relevant to environmental science because it focuses on the conservation of a species at risk. The particular population I studied was found along a rail road that has been converted to a trail in the Halifax metro area. The area around the trail is currently threatened by

urban development. By gathering data on the Canada Warbler, I hope to contribute to the conservation of the species by helping to lay the foundation for a song-based monitoring program that will help identify critical breeding habitat and ensure it is protected from urban development, degradation, habitat loss and other disturbances.

2.0 Literature Review

The purpose of this literature review is to summarize the scientific literature on the Canada Warbler and issues related to developing a monitoring program for this species. In particular, attention is given to aspects of Canada Warbler vocal behaviour and habitat use that is relevant to this study. The review provides background information on the ecology of Canada Warblers, population estimates and status designations, aspects of singing behaviour that influence population monitoring, and current studies on Canada Warbler vocal behaviour.

2.1 Ecology of Canada Warblers

The Canada Warbler is a neotropical migrant wood warbler in the family Parulidae. It is one of the most understudied North American wood warblers, as there are only a few studies documenting the ecology of the species. The Canada Warbler breeds in Canada and the northeastern United States. The Canadian range extends from the Maritimes to British Colombia, including portions of all provinces and territories except Nunavut and Newfoundland and Labrador (Savignac, 2008). The American range includes the Great Lakes region and northeastern New England, extending south through the Appalachian Mountains including western Maryland, western Virginia, and southeast Kentucky to northern Georgia (Savignac, 2008; Reitsma et al., 2010). An estimated 85% of the breeding range is in Canada even though

the majority of published studies on Canada Warbler breeding ecology have taken place in its USA range (Rich et al., 2004).

As with many wood warblers, breeding ecology is directly influenced by habitat selection and forest type. Early studies found Canada Warbler foraging behaviour concentrated in shrubs and low tree branches at heights of 3 to 5 m (Sabo and Holmes, 1983; Sodhi and Paszkowski, 1995). More recently, Chace et al. (2009) found that Canada Warblers occupied breeding sites in a variety of forest types including northern hardwoods, red maple-cedar swamps, lowland spruce-fir forests, cedar-fir swamps, and oak-hickory forests. They reported that high densities of shrubs and saplings, such as those associated with disturbed forests or forested wetlands, provided suitable cover and favorable foraging structure. Canada Warblers selected areas with high shrub densities and emergent trees characterized by denser shrub foliage between 2.0 and 2.5 m above ground, lower canopies, and higher numbers of perch sites (Hallworth et al., 2008a). Shrub density appears to influence breeding success directly as females prefer males whose territories contain high densities of shrubs.

Since Canada Warblers select several different habitat types, forest practices may have implications for reproductive success. Early community-level studies found Canada Warblers prefer early regenerating forests 6 to 20 years after clear-cutting (Titterington et al., 1979; Hagan et al., 1997). Hallworth et al. (2008b) measured differences in breeding success between a young forest stand following a timber harvest and an unharvested red maple swamp. Site fidelity and breeding success were similar between the two areas, indicating that forestry practices may provide suitable habitat for Canada Warblers. Reitsma et al. (2008) found similar results when they compared breeding success in red maple swamps and post-harvest forests. Although habitat created by forest practices may be short-lived at the stand level, it could be maintained at the

landscape level by rotation of partial or clear cut harvests (Lambert and Faccio, 2005). Since extensive clear-cutting can degrade forests ecosystems, future studies should seek to identify minimum cut sizes for Canada Warbler habitat (Lambert and Faccio, 2005).

Migration dynamics is another understudied aspect of Canada Warbler ecology. Canada Warblers are typically one of the latest birds to arrive to the breeding grounds and one of the earliest to leave (Reitsma et al., 2010). Flockhart (2007) published a study that focused on the migration of Canada Warblers in northern Alberta. In comparing migration timings of Canada Warbler individuals to those of other locally breeding wood warblers, he found that male and female Canada Warblers had the shortest breeding site occupancy (72 days for the male, 62 days for the female) for any bird with a post-nuptial molt. Flockhart suggested the short breeding season may impose energetic constraints that influence breeding, molt, and survival of Canada Warblers.

The Canada Warbler wintering range in South America includes Colombia, Venezuela, Peru, Ecuador, and Brazil (Reitsma et al., 2010). To date, no studies have focused on the ecology of the Canada Warbler in its wintering range. Only a few surveys of neotropical migrant habitat use or studies focusing on other neotropical migrants have included observations on wintering Canada Warblers. One such study, which focused on Cerulean Warbler *(Dendroica cerulean)* use of shade coffee plantations in Venezuela, recorded 325 detections of 17 species (including the Canada Warbler) of neotropical migrants using shade coffee plantations for habitat (Bakermans et al., 2009). Use of the coffee plantation was significantly higher than use of neighbouring primary forest habitat as only 114 detections of 15 species of neotropical migrants were recorded in the primary forest. This study also found improved body condition in individuals of 3 of the species found in the plantation (Cerulean and Tennessee Warblers and

American Redstart) compared to individuals found in the primary forest. Thus shade coffee plantations can provide important habitat for neotropical migrants in an area that is experiencing major deforestation (Henderson et al., 1991).

2.2 Population Estimates and Status Designations

There are currently several organizations that collect data to monitor population trends of all species of land birds. These organizations include: Étude des populations des oiseaux du Québec, Ontario Breeding Bird Atlas, Ontario Forest Bird Monitoring Program, Canadian Migration Monitoring Network, Canadian Breeding Bird (Mapping) Census Database, Project for the Prediction of Bird Presence and Density for Quebec, National Boreal Bird-Habitat Modeling Project, and the North American Breeding Bird Survey (BBS). The best estimates for Canada Warblers come from the BBS because it covers a significant portion of the bird's breeding range and has reasonable precision for detecting significant changes in abundance (Savignac, 2008). Abundances of Canada Warblers have been recorded for over 40 years with data collected by the BBS. The BBS has been recording Canada Warbler population status since 1966 in eastern USA and 1968 in western USA and Canada (Sauer et al., 2008). Data from the BBS is used to develop management plans for regional conservation initiatives such as Partners in Flight (Sauer et al., 2003).

Long-term population declines from BBS data has allowed for the assessment of population trends and thus has led to status designations by several organizations. In December 2002, the Canada Warbler was designated as a Highest Priority Landbird in Bird Conservation Region 14 (Atlantic Northern Region) by the North American Bird Conservation Initiative (NABCI) (Dettmers, 2006). Founded in 1999, the NABCI is a USA-based coalition of

government agencies, private organizations, and bird initiatives working to ensure the long-term health of North America's native bird populations. In 2004, the Canada Warbler was listed as a species of Continental Importance in the Northern Forest Region by Partners in Flight (Rich et al., 2004). Partners in Flight was launched in 1990 in response to growing concerns about declines in the populations of many land bird species, and in order to emphasize the conservation of birds not covered by existing conservation initiatives. In April 2008, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed the Canada Warbler as Threatened (Savignac, 2008). COSEWIC was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It should be noted that the International Union for Conservation of Nature (IUCN) lists the Canada Warbler as Least Concern because the species does not meet the range size criterion (< 20,000 km^2 combined with a declining or fluctuating range size, habitat extent/quality, or population size and a small number of locations or severe fragmentation) or the population trend criterion (> 30% decline over 10 years or 3 generations) to be listed as Vulnerable (IUCN, 2010).

The Canada Warbler is now protected under federal legislation in Canada. In March 2010, the species was listed as Threatened on Schedule 1 of Canada's *Species at Risk Act* (SARA). SARA, established in June 2003, is a commitment by the federal government of Canada to protect and conserve wildlife species and their biological diversity. The Canada Warbler is currently not protected in the USA.

2.3 Aspects of Singing Behaviour that Influence Population Monitoring

Most landbird species in North America can be monitored because they vocalize spontaneously and regularly to defend a territory during the breeding season. Although not yet

documented in Canada Warblers, the time of season, the time of day and male pairing status are known to influence male birds' song rates, and thus the probability of detection during surveys. For example, male unpaired Kirtland Warblers (*Dendroica kirtlandii*) sing at their highest rate early in the morning (0630-0800) and slowly decrease throughout the day, whereas paired males sing at a more constant rate with a peak rate in mid-morning (0930-1100) (Hayes et al., 1986). Unpaired male Nightingales (*Luscinia megarhynchos*) are more detectable than paired males because they sing more actively throughout the breeding season (Amrhein et al., 2004, 2007). Detectability in Grace's Warbler (*Dendroica graciae*) is affected by pairing status, time of season and day, location in the territory, and type of social interaction affecting singing behaviour (Staicer, 1989).

Wood-warblers with two kinds of singing behaviour can also influence detectability. Singing behaviour of unpaired male American Redstarts (*Setophaga ruticilla*) are known to significantly differ from paired males in three ways (Staicer et al., 2006). Unpaired males sing a single song almost exclusively, use only one mode (Repeat) after sunrise whereas paired males sing in two different modes (Repeat and Serial), and sing Repeat mode at a higher rate and with a more regular cadence than paired males (Staicer et al., 2006). Use of repeat mode makes unpaired American Redstarts more detectable than and also distinguishable from paired males (Staicer et al., 2006). Male Hooded Warblers (*Wilsonia citrina),* a close relative to the Canada Warbler, tend to use Repeat mode before pairing, and Mixed mode, where multiple songs are sung in sequence, after pairing (Wiley et al., 1994). Singing behaviour of Canada Warblers is thought to be highly variable, with little repetition and more individual notes per song than in other warbler species (Lemon et al., 1983). This complexity is the most likely reason why Canada Warbler vocal behaviour is understudied compared to other wood warblers.

2.4 Current Canada Warbler Vocal Behaviour Studies

A Canada Warbler breeding ecology study has been underway at Canaan Town Forest and Bear Pond Natural Area near Canaan, New Hampshire, USA since 2003 under the direction of Leonard Reitsma of Plymouth State University, Plymouth, NH. Reitsma's team has been collecting long-term data on habitat selection, nesting success, and mate and site fidelity for a population of uniquely color-banded Canada Warblers (A. Demko pers. comm.). Alana Demko, an M.Sc. student at Dalhousie University is currently studying the vocal behaviour of this population. To my knowledge, this is the only current study on Canada Warbler vocal behaviour other than my own.

The only population data for Canada Warblers in the Maritimes has been collected through large-scale annual population surveys pertaining to multiple bird species such as conducted by the BBS and surveys of forest bird communities conducted in Kejimkujik National Park (e.g. Staicer, 2009). My study will be the first to document Canada Warbler vocal behaviour in Nova Scotia or anywhere in the Maritimes.

2.5 Conclusion

This review of the scientific literature contains the most relevant published studies relating to Canada Warbler vocal behaviour and habitat use. Very little information is known about the ecology and behaviour of Canada Warblers. In particular, lack of information about their vocal behaviour limits our ability to design an effective monitoring program for the species. In the next section, the Materials and Methods, the study area and subjects, methods of field data collection, statistical analysis, song and singing behaviour measurements and limitations and delimitations of the study will be explained in depth.

3.0 Materials and Methods

3.1 Study Area and Subjects

My study site was located along the Shearwater Flyer Trail (44°39'N, 63°27'W), which is part of the Cole Harbour Heritage Park in Cole Harbour, Nova Scotia, Canada. The trail consisted of a flat raised bed on former rail road tracks surrounded by a second-growth mixed-forest dominated by red maple (*Acer rubrum*), white birch (*Betula papyrifera*) and black spruce (*Picea mariana*), and a private housing development to the north of the trail. The site consisted of a 2.5 km portion of the trail beginning at the Bissett road entrance. The subjects were ten male Canada Warblers, who occupied territories on either side of the trail (see Figure 1). Territories were mapped visually, based on observed singing locations. Individual territories sometimes encompassed both sides of the trail and extended up to 200 m into the forest.

3.2 Field Data Collection

Field work took place between 27 May and 8 July 2010. A total of 10 males were sampled between 05:00 and 11:00 ADT, the period when songbird population surveys are typically conducted. Samples were recorded using an Audio-Technica cardioid microphone and a Marantz PMD-661 portable field recorder. Each male was sampled for a 30-min interval at least once per week throughout the breeding season. Samples were taken at several different times in the morning to avoid bias due to diurnal variation in song rate (Hayes et al., 1986). Males were identified at the time of sampling based on previously observed territorial boundaries and later confirmed using spectrograms (photographic display of the frequency spectrum of the song). Repertoires (number of distinct song types, including half songs and variations) were fairly unique to individual males (pers. obs.), making spectrograms useful for identification.

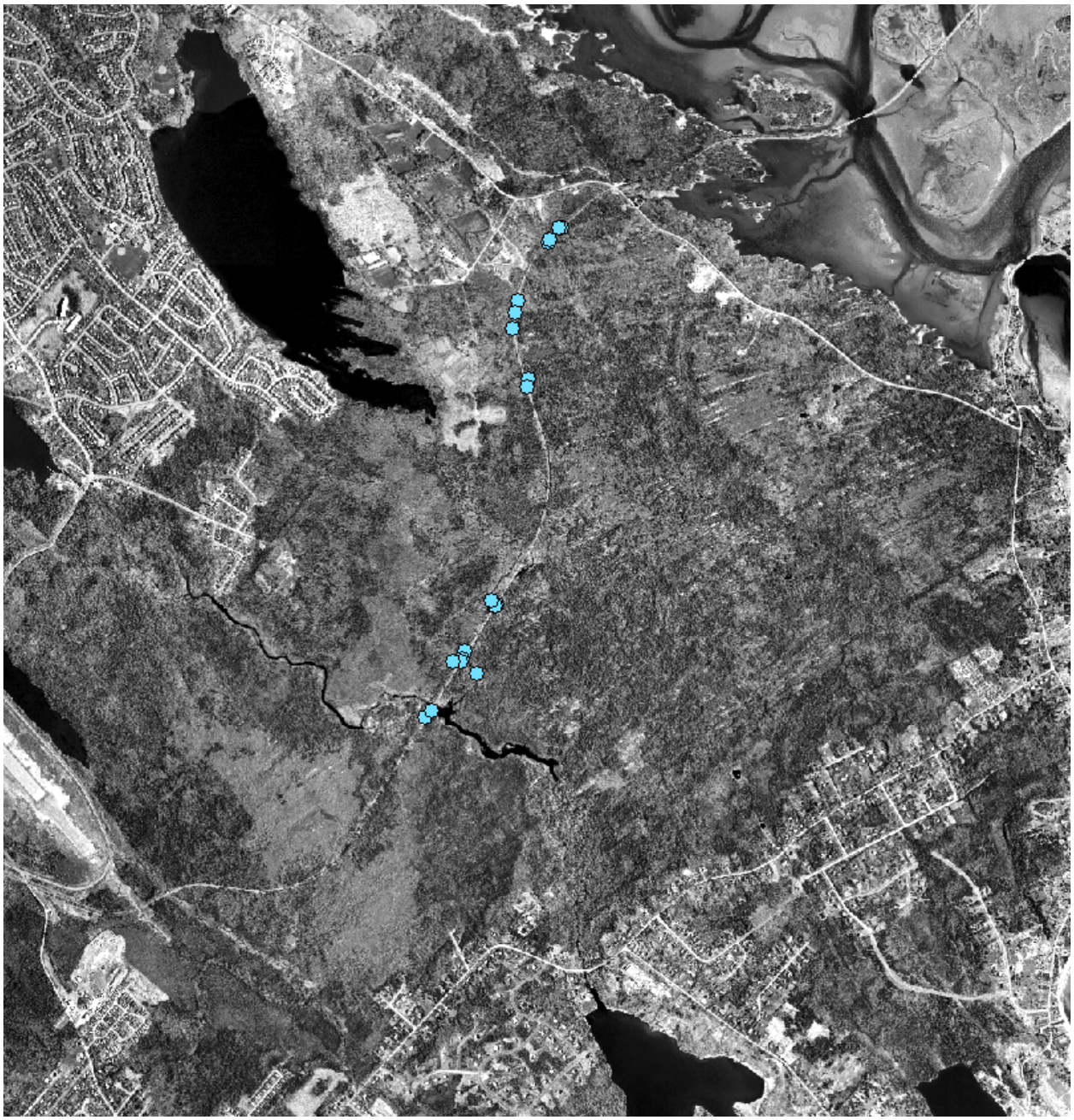

Figure 1: Map of study site with locations of male Canada Warblers. Blue dots represent GPS locations of male territories. Although more than one dot may represent the same male, larger clusters of dots generally represent multiple males.

3.3 Song and Singing Behaviour Measurements

I measured frequency, temporal and structural features of songs and chips (short notes found at the beginning of songs or in between songs) from spectrograms created by Raven Pro 1.3 sound analysis software (www.birds.cornell.edu/raven). Frequency measurements for songs and chips included maximum frequency, minimum frequency, bandwidth (maximum - minimum frequency), and peak frequency (frequency of maximum power), as these features differ among song types in other warbler species (e.g. Staicer, 1996). Temporal measurements included song duration (time between the start of the first and the end of the last note in a song), cadence (time between the start of consecutive songs), song rate (number of songs/min) and proportion of time chipping (cumulative chip time divided by total recording time). Structural features included number of notes per song, number of song types (particular series of notes in a given order), number of variants (half songs and modified song types), and repertoire size per individual (total number of song types per male).

3.4 Statistical Analysis

I used nonparametric tests to determine whether time of day and time of season affect detectability. Data were not normally distributed and sample sizes were small, so I calculated medians instead of means as a measure of central tendency. Using the statistical program SYSTAT (Wilkinson, 1987), I performed Wilcoxon signed-ranks tests to assess differences in frequency, temporal and structural features of individual males with respect to early and late time of day. I also used SYSTAT to perform Mann-Whitney *U*-tests to determine if frequency, temporal and structural features differed between early and late season. Time of day and time of season was divided to allow comparison of early and late. Early time of day recordings were

taken between 05:00 and 08:00 ADT and late time of day recordings were taken between 08:00 and 11:00 ADT. Recordings made from 27 May to 9 June were considered early season and recordings made from 10 June to July 5 were considered late season.

3.5 Limitations / Delimitations

This study is primarily limited by its sample size. One to a few samples from ten male Canada Warblers is too small of a sample to extrapolate conclusions about their vocal behaviour for the entire population. This small sample size also prevented me from comparing differences with respect to paired and unpaired males because I did not have enough paired males for comparison. Therefore the aim of this study was to compare the vocal behaviour of these birds to those that are being studied in New Hampshire. However, the data also provides a foundation for future studies on Canada Warbler vocal behaviour in Canada and will contribute to the baseline data needed to design a monitoring program for the species.

The project will only focus on the vocal behaviour of the subjects. The initial plan also included analysis of Canada Warbler habitat use but this was omitted due to time constraints. The knowledge gained from analyzing the vocal behaviour will be more beneficial than analyzing the habitat use because less is known about the characteristics of their vocal behaviour.

4.0 Results

4.1 Pairing Status

I found one male already paired when I began collecting data on 27 May. To my knowledge, this was the only male that was paired throughout the majority of the breeding season. However, I discovered that two more males were paired by the end of the breeding

season; one on 6 July and the other on 8 July. I had stopped collecting data on 5 July so singing behaviour from these males was not assessed. Since I only had recordings of one paired male, I was unable to determine statistical differences between paired and unpaired males. However, trends in singing behavior of the one paired male were different than unpaired males. Cadence was generally more irregular and song rate was generally faster than unpaired males for daytime singing. Dawn chorus singing was similar to unpaired males.

4.2 Frequency Measurements

Chip and song frequencies for were similar among males for daytime recordings. The chip low frequency typically ranged from 2600 to 3100 Hz and the high typically ranged from 7200 to 8400 Hz. Song low frequency typically ranged from 2300 to 2600 Hz and the high typically ranged from 8000 to 9000 Hz. Dawn chorus recordings varied more with respect to chips because multiple types of chips with different frequencies were used in each recording.

Frequency measurements for chips and songs tended to remain similar throughout the day and the season for all birds sampled. The only significant difference found within the frequency measurements was between early and late time of season for the song peak frequency (see Figure 2). The peak frequency was higher in early season compared to late season (Mann Whitney *U*-test: $P = 0.042$).

4.3 Structural Features

Structural features were similar between males. Each male typically had 1 to 2 song types for daytime singing, although one male had as high as 7. The number of variants of each song type depended on the male as some males had more variants than others. The number of variants each male had depended on (1) the number of recordings of the specific male, as males

with fewer recordings typically had less variants, and (2) if a dawn chorus was recorded, as dawn chorus singing typically contained more variants than daytime recordings. These two factors also influenced repertoire size because males with more recordings and a dawn chorus recording typically had more song types. Repertoire sizes ranged from 2 to 19 distinct song types (see Table 1).

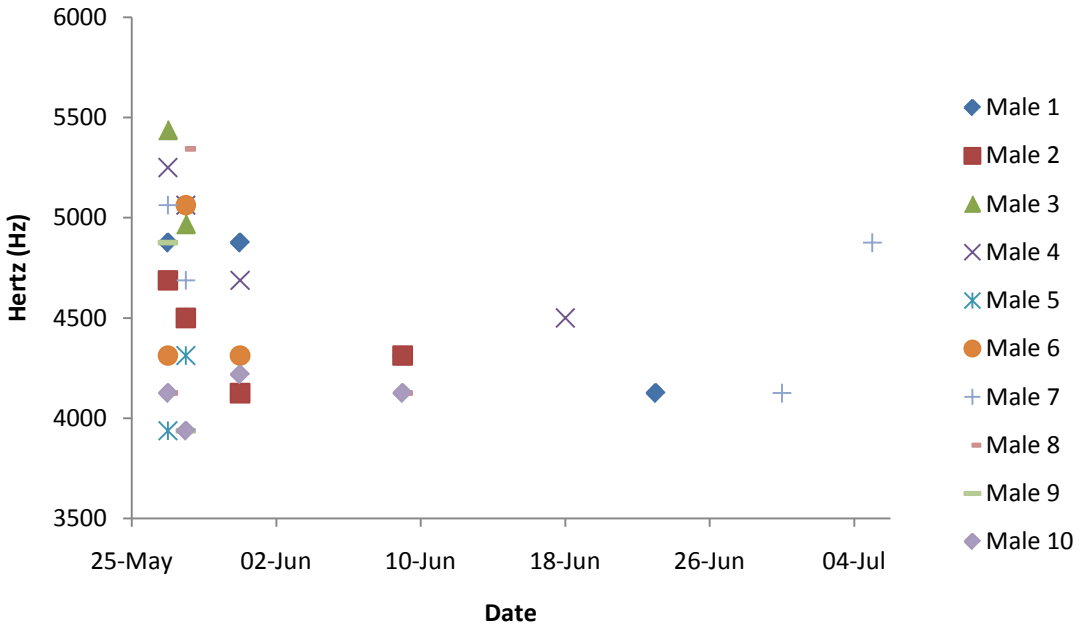

Figure 2: Song peak frequency for all recordings with respect to time of season (n = 10 males).

Table 1: Summary of repertoire measurements for all birds sampled throughout the season.

Male	Number of recordings	Number of song types (repertoire size)	Number of variants
1	6	2	48
2	4	2	13
3	2	1	1
4	5	18	112
5	2	2	10
6	3	2	16
7	5	13	19
8	4	19	38
9	2	2	16
10	4	4	12

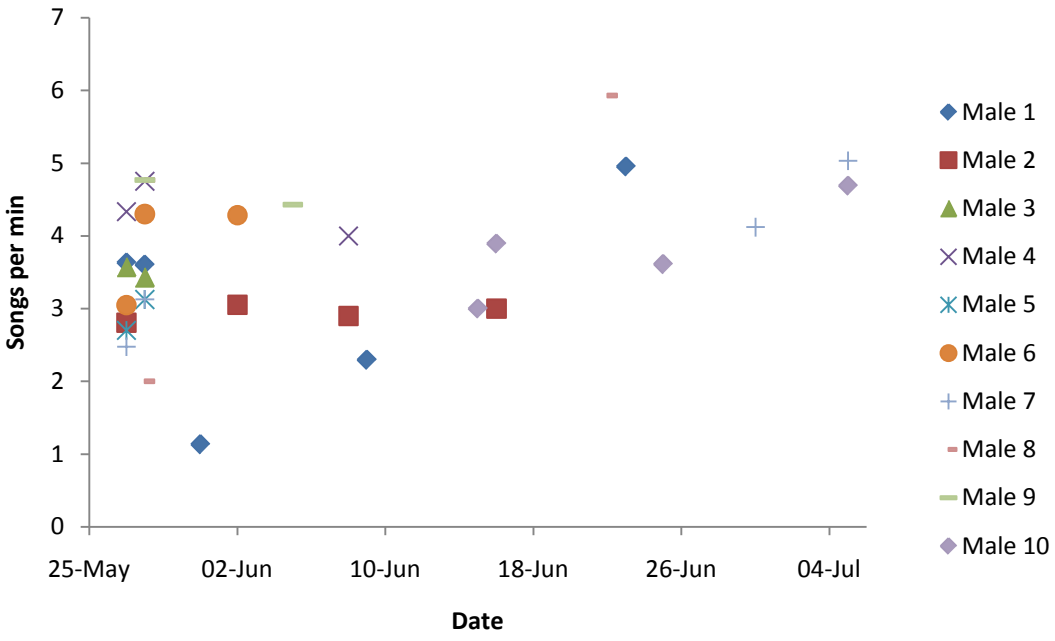

Figure 3: Song rates of all recordings with respect to time of season (*n* = 10 males).

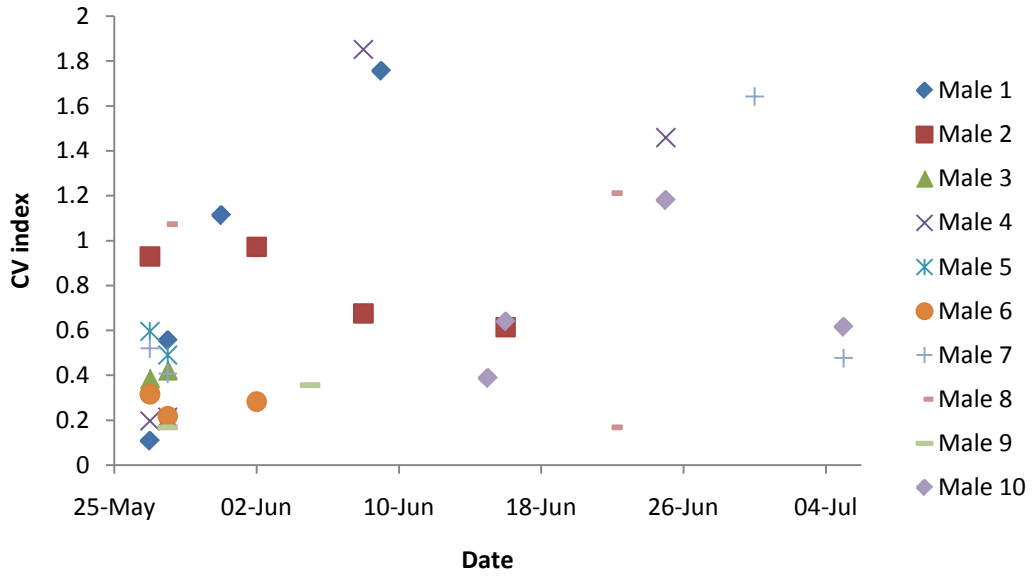

Figure 4: Coefficient of variation of the cadence for all recordings with respect to time of season (*n* = 10 males).

I found no significant differences when comparing structural features with early and late time of season and time of day (see Table 2 and Table 3 respectively). The biggest, though non-significant difference between early and late time of day was number of variants (P = 0.206). The biggest, though non-significant difference between early and late time of season was also the number of variants (P = 0.288).

Table 2: Characteristics of songs and singing behaviour for early and late season recordings. Median values are given for temporal, structural and frequency measures (n = 10 males).

Temporal Measures	Early	Late	T-statistic	p-value	
Song Rate (songs/min)	3.39	4.64	9	0.034	*
Cadence CV	0.46	1.13	3	0.005	*
Song Duration (sec)	1.17	1.17	27.5	0.953	
Proportion of time chipping (sec)	0.0011	0.0043	9	0.034	*
Structural Measures					
Number of Variants	7	9.3	18	0.288	
Number of Song Types	2	2.5	10	0.248	
Number of Notes	10	9.5	28.5	0.856	
Frequency Measures					
Chips					
Low Frequency (Hz)	2979.3	2889.6	36	0.289	
High Frequency (Hz)	7849.3	8137.2	15	0.157	
Peak Frequency (Hz)	4640.6	4312.5	36.5	0.259	
Bandwidth (Hz)	4737.9	5137.8	11	0.059	
Songs					
Low Frequency (Hz)	2497.3	2450.7	35	0.346	
High Frequency (Hz)	8509.7	8685.6	24	0.724	
Peak Frequency (Hz)	4687.5	4218.8	44	0.042	*
Bandwidth (Hz)	5943.1	6306.3	22	0.556	

*$p < 0.05$, Mann-Whitney U-tests

4.4 Temporal Features

Temporal features were the most variable features out of all that were measured for daytime recordings. Song rate ranged from 1.1 to 5.9 songs per minute, the cadence CV ranged from 0.11 to 1.85, and the proportion of time spent chipping ranged from 0 to 0.027 seconds. Temporal features were also the most varied out of all the features measured with respect to

difference in early and late season (see Table 2). I found that song rate was significantly different between early and late season (Mann Whitney *U*-test: $P = 0.034$). Figure 3 illustrates that late season had a higher song rate than early season. I found that the cadence CV was also significant between early and late season (Mann Whitney *U*-test: $P = 0.005$). Figure 4 illustrates that cadences in the late season were more variable compared to those in the early season. In addition, I found that the proportion of chipping was significantly different (Mann Whitney *U*-test: $P = 0.034$). Figure 5 illustrates that the proportion of time chipping was high in the late season compared to the early season.

Table 3: Characteristics of songs and singing behaviour for early and late time of day recordings. Median values are given for temporal, structural and frequency measurements ($n = 9$ males).

Temporal Measures	Early	Late	Z-value	p-value	
Song Rate (songs/min)	3.89	3.05	-2.429	0.015	*
Cadence CV	0.49	0.52	0.652	0.515	
Song Duration (sec)	1.18	1.17	-0.178	0.859	
Proportion of time chipping (sec)	0.0017	0.0013	0.14	0.889	
Structural Measures					
Number of Variants	8	7	-1.263	0.206	
Number of Song Types	2	2	-1	0.317	
Number of Notes	10	10	0.921	0.357	
Frequency Measures					
Chips					
Low Frequency (Hz)	2961.3	2884.3	-1.68	0.093	
High Frequency (Hz)	7884.7	7881.3	0.28	0.779	
Peak Frequency (Hz)	4406.3	4359.4	0.957	0.339	
Bandwidth (Hz)	4949.3	4999.8	0.84	0.401	
Songs					
Low Frequency (Hz)	2493.6	2427.7	-0.415	0.678	
High Frequency (Hz)	8581.2	8468.1	-0.533	0.594	
Peak Frequency (Hz)	4687.5	4500	-0.299	0.765	
Bandwidth (Hz)	6045.3	6000	-0.533	0.594	

*$p < 0.05$, Wilcoxon signed-ranks test

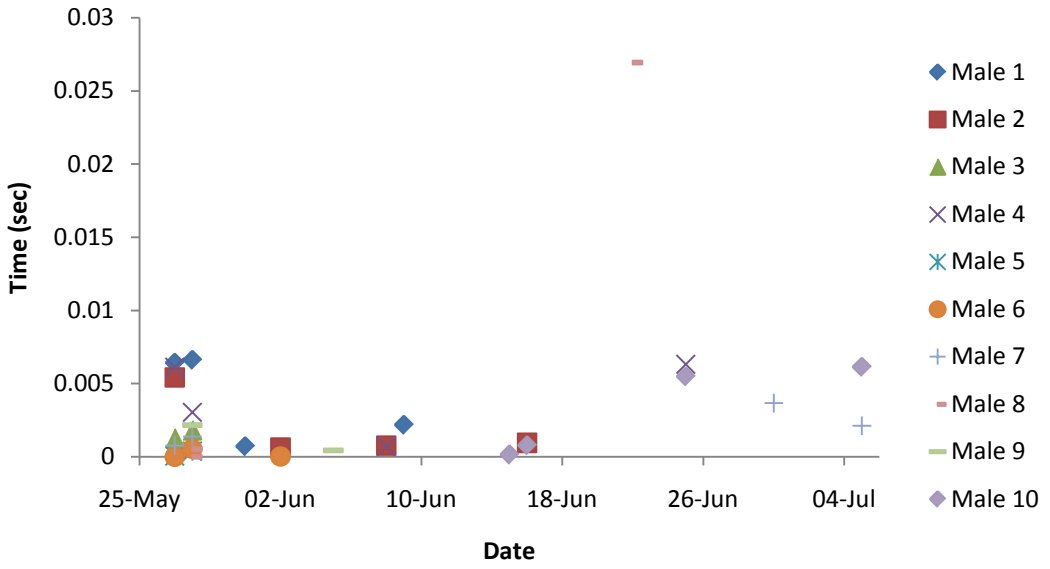

Figure 5: Proportion of time chipping for all recordings with respect to time of season (*n* = 10 males).

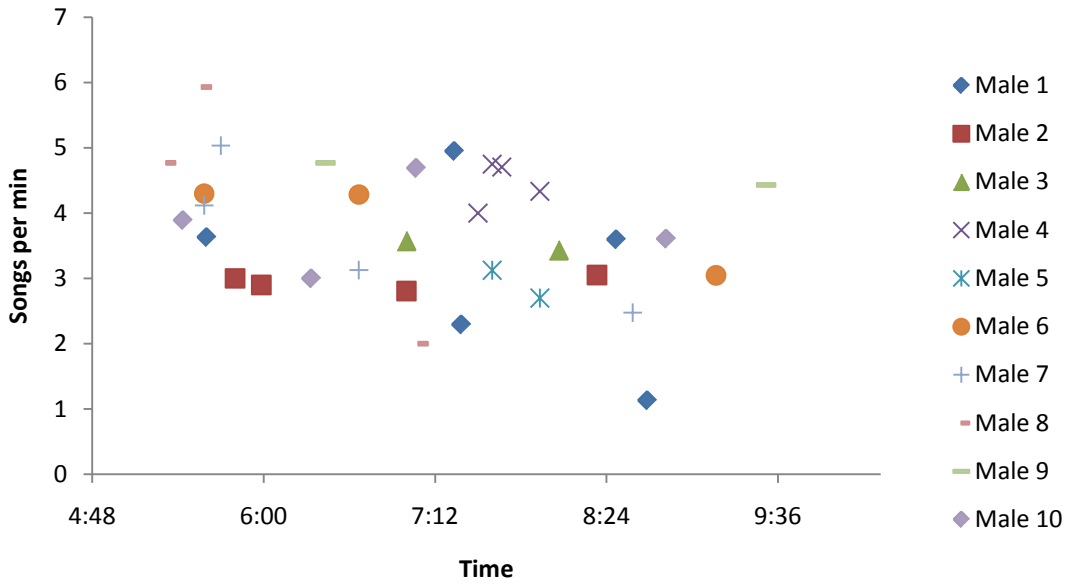

Figure 6: Song rate of all recordings with respect to time of day (ADT) (*n* = 10 males).

With respect to time of day and differences within individual males, I found that song rate was significantly different between early and late time of day (Wilcoxon signed-ranks test: *P*

= 0.015; Table 3). Figure 6 illustrates that song rate was significantly higher in early morning compared to late morning.

4.5 Dawn Chorus

Only four males were recorded at dawn however structural and temporal song features were quite varied among these males. The number of variants ranged from 7 to 104 and the number of song types ranged from 2 to 18. Proportion of time chipping ranged from 0.22 to 0.058 and song rate ranged from 4.7 to 14.2 songs per minute. Differences in song types mainly resulted from males combining aspects of multiple song types to form new ones that were repeatedly used. Three males did this for their dawn chorus singing while the other did not.

Table 4: Characteristics of songs and singing behaviour for dawn and daytime recording. Median values are given for temporal, structural and frequency measures. (n = 10 males)*.

Temporal Measures	Dawn	Daytime
Song Rate (songs/min)	9.32	4.07
Cadence CV	1.41	0.88
Song Duration (sec)	1.29	1.13
Proportion of time chipping (sec)	0.0476	0.0031
Structural Measures		
Number of Variants	27.5	7
Number of Song Types	13.5	2
Number of Notes	9.5	9
Frequency Measures		
Chips		
Low Frequency (Hz)	2681	2998.8
High Frequency (Hz)	8237.35	8070
Peak Frequency (Hz)	4406.25	4429.7
Bandwidth (Hz)	5504.95	5070.7
Songs		
Low Frequency (Hz)	2133.8	2505.3
High Frequency (Hz)	8269.8	8520.7
Peak Frequency (Hz)	4500	4640.6
Bandwidth (Hz)	6096.7	6009.9

* Sample size was too small to achieve statistical significance as there were only 4 samples for dawn.

4.6 Dawn vs. Daytime

Most temporal and structural song features measured differed between dawn and daytime recordings (Table 4). Although trends are apparent between the two time periods, it should be noted that the sample size was too small to obtain statistical significance using the Wilcoxon signed-ranks test ($n = 4$).

5.0 Discussion

5.1 Singing Behaviour

Although I was unable to assess difference in male Canada Warbler singing behaviour with respect to breeding status, I identified several differences with respect to early and late time of day and time of season that could potentially influence population monitoring.

I found that song rate significantly decreased from early to late time of day. Although I was unable to assess differences between paired and unpaired males, all of my birds decreased their song rate throughout the morning. Likewise, unpaired male Kirtland's Warblers were found to sing most in the early morning (0630-0800), with a steady decline throughout the day (Hayes et al., 1986).

Since male birds sing for mate attraction and territory defense, song rate would be expected to decrease throughout the breeding season as males are paired (e.g. Skirvin, 1981). However, the males in my study showed the opposite trend where song rate increased throughout the breeding season. This trend could be associated with changes in singing behaviour with respect to conspecific density. Several of my samples from the late season had elevated song rates and males singing in the presence of other singing males. Not only was singing faster, but

in some cases it was more varied and had more complicated songs. Higher conspecific density has been found to lead to high song rates in other song birds (e.g. McShea and Rappole, 1997). Similarly, there is evidence that conspecific density plays a role in song rate in males currently being studied in New Hampshire (A. Demko, pers. comm.) One possibility is that Canada Warblers have two distinct singing modes as found in their close relative; the Hooded Warbler (Wiley et al., 1994).

Higher song rate in late season could also be influenced by my sample size. My sample size was small (n = 10) with respect to typical studies on song behaviour. I also had fewer recordings later in the season compared to early season (10 late, 23 early). Therefore there could be a bias towards early season measurements since there were fewer recordings to compare them to in the late season. When combined with my small sample size and unequal distribution (more recordings early season compared to late), differences in singing behaviour with respect to conspecific density could have caused male song rate to increase throughout the season since many of the (few) recordings from late season had other males present.

Increased song rate could also be attributed to changes in pairing status or breeding stages throughout the breeding season. Canada Warblers may change their singing mode when their pairing status changes, as this has been documented in many other song birds including American Redstarts (Staicer et al., 2006) and Hooded Warblers, a close relative to the Canada Warbler (Wiley et al., 1994). My study was unable to assess these changes as I was unable to confirm if or when many of my males became paired. However, the pairing status of many males in New Hampshire had been previously identified prior to Demko's study so insight into this trend could be explained further by that study (A. Demko, pers. comm.).

My study also found significant differences in peak frequency, cadence CV, and proportion of chipping between early and late season. The higher proportion of chipping found in late season coincided with the increased song rate. Males tended to chip more often due to the increased song rate because 1 to 2 chips usually preceded songs. Differences in peak frequency could be associated with the possibility of different singing modes discussed with respect to conspecific density or pairing status. Some males changed or modified song types through the season so differences in peak frequency may be associated with this. Changes in frequency between song types have been documented in other wood warbler species (e.g. Staicer, 1996). A more irregular cadence (higher CV) in late season could also be associated with differences in pairing status or conspecific density. Paired male American Redstarts are known to have a more irregular cadence than unpaired males when both are singing in repeat mode (Staicer et al., 2006).

5.2 Implications for Population Monitoring

I found differences in the detectability of males with respect to time of season and time of day. Males in my study actively sang 2 times as much in the early portion of the season compared to the late season. I obtained 23 recordings in the early season compared to only 10 recordings in the late season even through males were sampled at the same rate throughout the breeding season. Males also actively sang 2 times as much in the early portion of the day compared to the late day. I obtained 23 recordings in the early day compared to only 10 recordings in the late day even through males were sampled at the same rate throughout the day. These trends indicate that male Canada Warblers are twice as detectable in the early morning and early season than in late morning and late season. This information should be taken into

consideration for single day surveys such as the Breeding Bird Survey, and when designing a monitoring program for Canada Warblers.

5.3 Conclusion

This study assessed Canada Warbler singing behaviour with respect to time of day and time of season. A higher song rate, cadence CV, proportion of chipping and peak frequency was found in late season, and a higher song rate was found in early day. Although this study provided some baseline data for Canada Warbler singing behaviour, several aspects needs to be incorporated into future studies to advance research in Canada Warbler singing behaviour. Assessing differences between paired and unpaired males would provide more insight into male singing behaviour. I was unable to achieve this in my study because my sample size was small and to my knowledge, only one of my males was paired for the majority of the breeding season. Since the population is declining, the ability to assess differences in singing behaviour between paired and unpaired males would give a better estimate of the status of the population. Regardless, my study provides baseline data to help fill a gap in scientific knowledge in the vocal behaviour of male Canada Warblers.

6.0 References

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