RFCx Arbimon Pattern Matching Analysis for Bird Song Recognition

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Introduction

What is Arbimon?

RFCx (Rainforest Connection) Arbimon is a Bio-acoustics analysis platform that allows biologists and ecologists to analyse audio data collected with autonomous recording units (ARUs) such as AudioMoth and SongMeter (LeBien *et al*., 2020). Multiple types of analyses are featured in their web interface, including pattern matching, soundscape analysis, and a random forest model analysis. Here, I focus on the use of pattern matching analysis withing the program. It is characterized by Arbimon as object recognition using a cross correlation analysis to identify presence of similar patterns in other audio files (https://support.rfcx.org/article/71-what-is-arbimon).

There are three ways of analysing recordings with RFCx Arbimon. The purpose of this document is to provide users with a detailed protocol focused on the Pattern Matching analysis for bird vocalizations.

1) Pattern Matching Analysis (PM)

The Pattern Matching algorithm is used for species-specific identification by matching species templates (a selected call or song from targeted species with a strong signal, but that does not overlap with other sounds) with a-priori identified calls withing the chosen recordings (https://support.rfcx.org/article/34-pattern-matching-template). This is done by matching vocalization patterns from spectrograms on a temporal/frequency scale (https://support.rfcx.org/article/4-pattern-matching).

This technique is especially useful for species with songs that are easily distinguished and have little variation. Species with common call types (e.g., chips or trills) are more prone to be confounded by the pattern matching analysis. Moreover, species with a large variety of calls (e.g., Blue Jay) may require a larger number of individual pattern matching analyses based on various templates.

Pattern matching analyses are useful for efficient measures of abundance for key species of interest (e.g., species at risk). Because each template must be created manually, quantifying the total biodiversity for a large number of recordings would be time consuming and less efficient, especially since it would require listening to a high percentage of the audio files in order to detect all the species present. However, it is possible to look for specific species in the recordings by using species-call templates from other resources (e.g., Xeno-Canto; www.xeno-canto.org) (Campos-Cerqueira, 2021).

For more information and questions, visit https://support.rfcx.org/.

2) Analyze Recordings with Random Forest Model (RFM)

The Random Forest Model (RFM) is an algorithm based on a combination of classification methods and statistics (Breiman, 2001; Pang, 2017). To create a random forest model, recordings validated with the presence and absence of key species are set with a vector (the similarity measure between the template and the spectrogram of the recording) (https://support.rfcx.org/category/35-random-forest-model). The RFM is then trained with this dataset to create an algorithm capable of accurate predictions of presence or absence of targeted species for a large number of recordings (Bravo *et al*., 2017).

3) Soundscape Recording Analysis

Soundscapes are the visualizations of all acoustic frequencies from the environment (e.g., fauna, rain, wind) and can be visualized in different temporal and spatial scales (e.g., date, time, altitude) (https://support.rfcx.org/article/32-soundscapes). Soundscape analysis is a way of comparing acoustic information from a variety of sites for a large number of species at once (Deichmann *et al*., 2017). It is also a tool to help determine how species richness and vocalizations vary with distance from the recording device (Deichmann *et al*., 2017).

Why use Arbimon?

RFCx Arbimon aims to create the largest shareable Audio Ark of rainforest sounds and eco-data to allow users to browse through acoustic data collected worldwide with the aim of supporting rainforest protection (*Rainforest Connection*, 2021). Their mission is to collect real-time data that is crucial to the protection of ecosystems as it allows scientists to compare eco-data over months and years to further understand the global changes occurring at a high rate (*Rainforest Connection,* 2021)

RFCx Arbimon is a free, speedy and user-friendly resource that allows validation from citizen scientists to add credibility. This program also facilitates ecological statistical analyses by exporting the results of audio analysis done in Arbimon to statistical software (e.g., RStudio) (Gibb *et al*., ND). Having this resource available to citizen science allows scientists worldwide to create change in their environment and promotes ecological and resource conservation (Deichmann, 2018).

On top of bio-acoustic monitoring, RFCx Arbimon supports the prevention of illegal deforestation and animal poaching by sharing eco-data to help negotiate higher protection of areas at risk of deforestation, and by showing patterns of activity releasing of poaching in protected areas (Deichmann, 2018).

For more information, see https://rfcx.org/our_work.

Methods

The Pattern Matching analysis is completed in six relatively simple steps (View tutorial for more complete instructions: https://support.rfcx.org/article/4-pattern-matching).

1) Create playlists:

The first step is to create Playlists under "*data*", by filtering through sites, dates, time, and more. Pattern matching runs faster for smaller playlists, and the same templates can be used to analyse an unlimited number of playlists.

2) Add to species list:

Species of interest must be added to the project species list under "*Data/Species*". Additional species may be added at any given time, but they must be included in the list before creating a corresponding template.

3) Visualize recordings:

By clicking the tab "*Visualizer*", the recordings can be listened to and visualized based on the playlists previously created. Every recording in the playlist is laid out in a list on the left sidebar on the visualizer page. Spectrograms can be examined by zooming in and out on both the frequency scale and the time scale. Visualizing recordings on Arbimon can be slow and may require high speed internet to load the spectrograms of selected audio files.

4) Create templates:

Segments of audio can be isolated by clicking on "*Templates (Pattern matching analysis)"* in the left sidebar. Species templates should be in a tight frame, with as little overlapping noise as possible. The templates are then manually associated to any given species from the list previously created.

5) Run pattern matching job:

Once templates have been created for the key species, Pattern Matching jobs can be run under "*Analysis/Pattern Matching"*, simply by clicking on the "+" icon, adding the desired template with any playlists, and selecting a threshold level. The tab "Jobs" allows the user to see the progress being made by the automated pattern matching analysis. Running a job takes less than a minute for a small playlist (~300 minutes of audio), and just a few minutes for a larger playlist (~1200). The default settings allows a single match per recording (the one with the highest score), but this can be adjusted to the desired number of detections per sample.

6) Adjust threshold or select out false positives:

The RFCx Arbimon threshold assigns a similarity or correlation between the template and audio data. Results with regions of interest (ROIs) higher than the correlation threshold are marked as potential presence of the species assigned to the template (Campos-Cerqueira *et al*., 2021).

The results of the pattern matching jobs need to be reviewed to select out the false positives. Low thresholds (e.g., 0.1) are useful to capture song variations that lead to very few false negatives, but it will also gather a higher percentage or false positives. The higher the threshold, the lower the likelihood of false positives (LeBien *et al*., 2020).

For more information visit https://doi.org/10.1016/j.ecoinf.2020.101113 (page 4).

Software testing

This study was possible due to the naturalists and citizen scientists who collected the data on a volunteer basis. Fifteen participants in the Listening Together project conducted point counts and deployed ARUs (AudioMoths) in different parts of Nova Scotia. These volunteers are Nova Scotia Bird Society members or other naturalists with skills in identifying bird songs and calls. The AudioMoths distributed to the participants were funded by Environment and Climate Change Canada and the Wildlife Division of the Nova Scotia Department of Lands and Forests.

I tested the RFCx Arbimon software using 1,220 recordings from three of the seven study sites where AudioMoths were deployed for breeding bird surveys in stands of Eastern Hemlock in Nova Scotia. The species of interest for this study were the Black-throated green warbler (BTNW), the Ovenbird (OVEN), the Blue-headed vireo (BHVI), the Red-eyed vireo (REVI) and the Blackburnian warbler (BLBW).

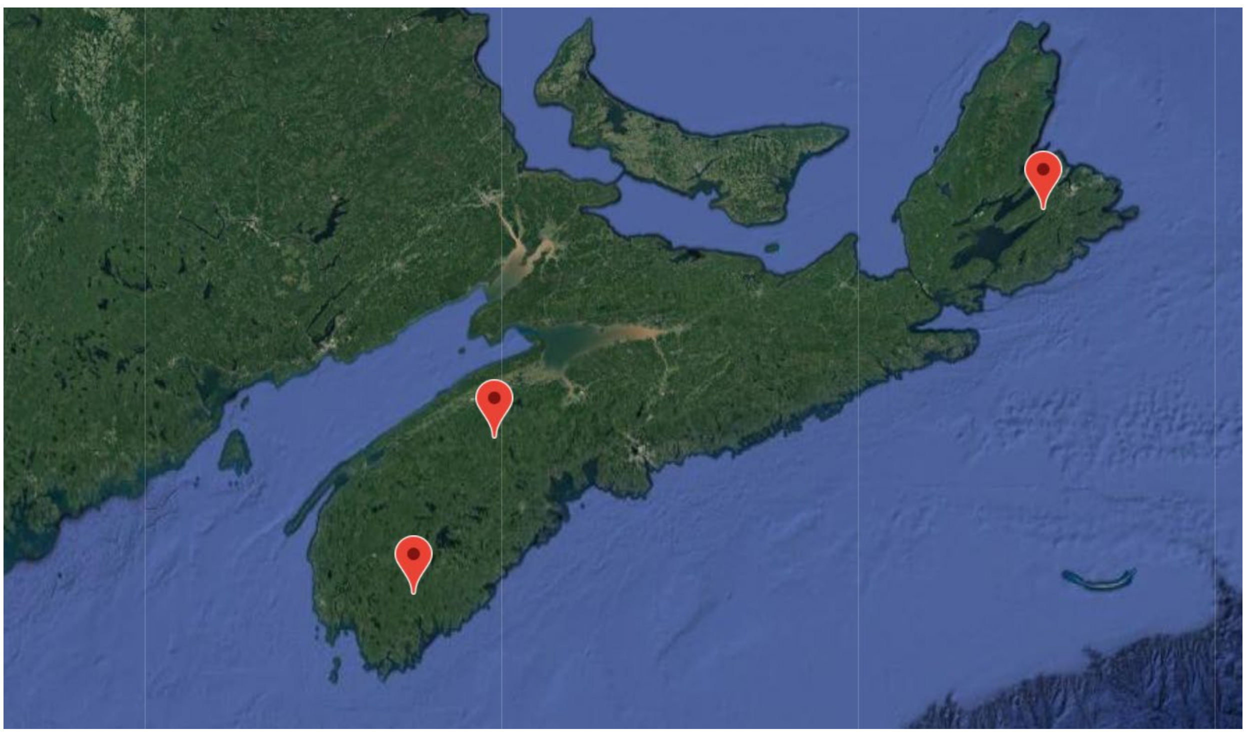

Figure 1. The three study sites (from West to East: Polly Poddy Rock Road, Armstrong Lake road, Bourinot Road) from the 2020 Hemlock breeding bird surveys.

The breeding bird surveys done at the three study sites were not conducted during the same dates throughout the season. Recordings were captured at Polly Poddy Rock Road from June 11 to June 24, at Armstrong Lake road from June 9 to June 18, and at Bourinot Road between June 18 to July 4.

Abundance

One approach to pattern matching is to use a low threshold (e.g., 0.1), and then validate or reject the pattern matching results based on presence or absence of the corresponding species (Campos-Cerqueira *et al*., 2021; LeBien *et al*., 2020). This approach is time consuming, especially for large playlists, as it requires a thorough verification of a high number of false positives. However, if revised accurately, it provides precise data with fewer false negatives (Campos-Cerqueira *et al*., 2021; LeBien *et al*., 2020).

Pattern matching analyses to examine abundance were conducted for the Black-throated green warbler (BTNW) by using thresholds of 0.1, 0.2 and 0.3. A binomial distribution was done in *RStudio* to compute the probability of observing false positives based on the threshold used. This was completed in order to determine the proper use of this method in future studies, as well as to determine the appropriate correlation threshold for accuracy and efficiency.

Presence/absence

If the presence or absence of a species is of interest rather than the abundance, the filter "best match per site per day" can be used to show only the result with the highest correlation to the template. By using this filter, along with a threshold of 0.1, false negatives are avoided, and presence/absence can readily be determined because fewer false positives need to be examined (Campos-Cerqueira *et al*., 2021). The approach is efficient when one has a large sample size (e.g., when playlists contain numerous recordings).

Confounding songs

When species have confounding songs, pattern matching may prove problematic. I explored these issues by examining how pattern matching worked with the Red-eyed vireo (REVI) and the Blue-headed vireo (BHVI) – two species with quite similar songs. The Pattern matching analysis does not accurately differentiate the REVI song from the BHVI. The BHVI has a distinct phrase in its song that does not appear in the REVI song. To separate the two species, a template was created with this short phrase indicated in red in the spectrogram below (**Figure 2**), from the online resource Dendroica (https://www.natureinstruct.org/dendroica/). This template is simple and easy to detect. Therefore, the threshold was set at 0.3 to limit the number of false positives.

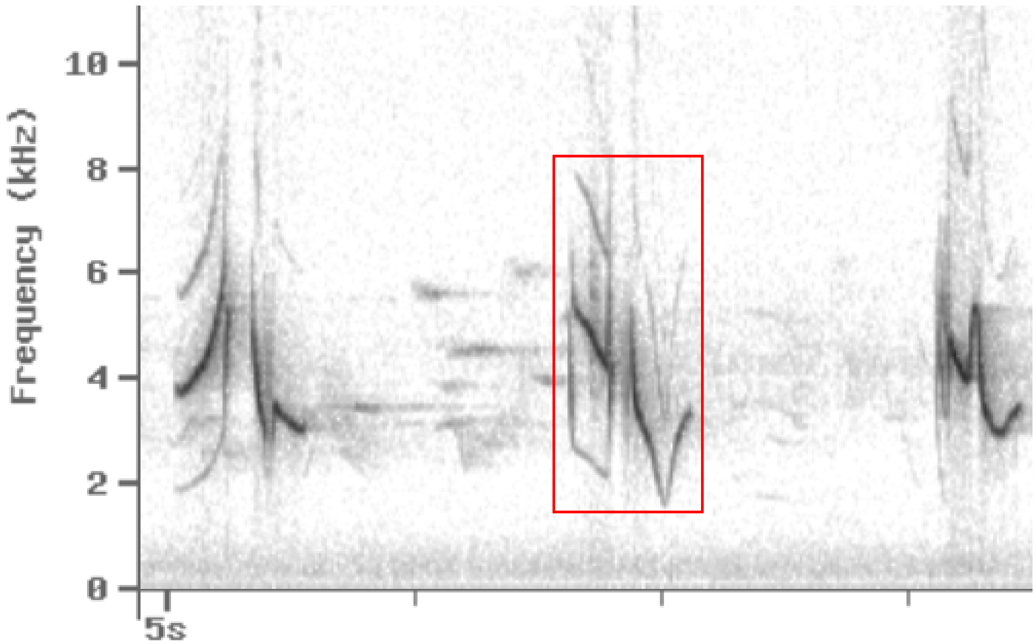

Figure 2. Spectrogram of the BHVI call used as a template for pattern matching analyses.

Because the REVI does not have a unique phrase like the BHVI, a larger portion of their song was used as a template. For this to work, the threshold must be set to 0.1 to allow room for variation. This method requires extensive verification by the listener as the differences between the songs of the BHVI and the REVI can be difficult to identify audibly. As shown below in **Figure 3**, it is not possible to visually differentiate the BHVI and the REVI from these results of the pattern matching analysis. However, the recordings can be visualized one by one by clicking on the icon in the bottom left of a square. Only the presence/absence by day and site was examined for the REVI to facilitate the verification effort.

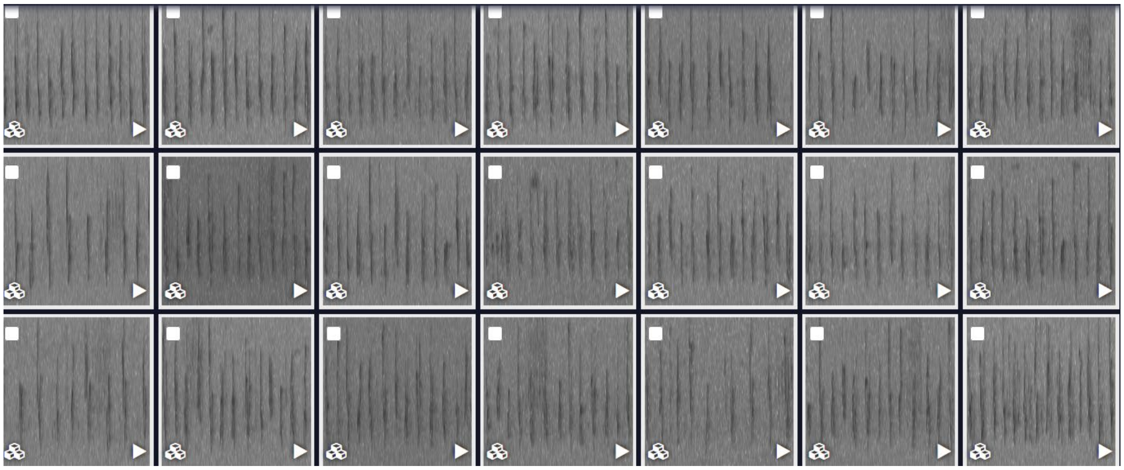

Figure 3. Example of pattern matching analysis results for the REVI.

Results

BTNW

Pattern matching analyses with correlation thresholds of 0.1 through 0.3 for BTNW showed fluctuation in the percentage of false positives between the study sites. All of the detections at Armstrong Lake road were false positives, regardless of the threshold. All the detections with ROIs above 0.3 were at Bourinot Road, with no false positives. The percentage of false positives dropped by 51% between the scores 0.1 to 0.2 for Bourinot Road but did not change for the other two sites. In total, between June 9th to July 4th there were 89 BTNW detected at the Bourinot Road site and 40 at the Polly Poddy Rock Road site. No BTNW were validated as present at the Armstrong Lake road site (**Table 1**).

Table 1. Total number of matches, presence and absence of BTNW at the three study sites based on the correlation threshold used for the pattern matching analysis.

Species	Sites	Threshold	Total matches	Presence	Absence	% False positive
BTNW	Bourinot Rd	0.1	410	89	321	78
		0.2	105	77	28	27
		0.3	54	54	0	0
	Poly Poddy Rock Rd	0.1	326	40	286	88
		0.2	76	9	67	88
		0.3	0	0	0	0
	Armstrong Rd	0.1	230	0	230	100
		0.2	118	0	118	100
		0.3	1	0	1	100

A binomial distribution for the BTNW was done to determine the turning point from a majority of absence to a majority of presence based on ROIs. The figure below (**Figure 4**) shows a slow increase in presence between scores of 0.1 and 0.2, and a rapid increase between 0.2 and 0.4. The curve reaches a plateau around a score of 0.45, meaning that every detection beyond that point is validated as present. The far-right point with a score of 1.0 represents the template used for this pattern matching analysis.

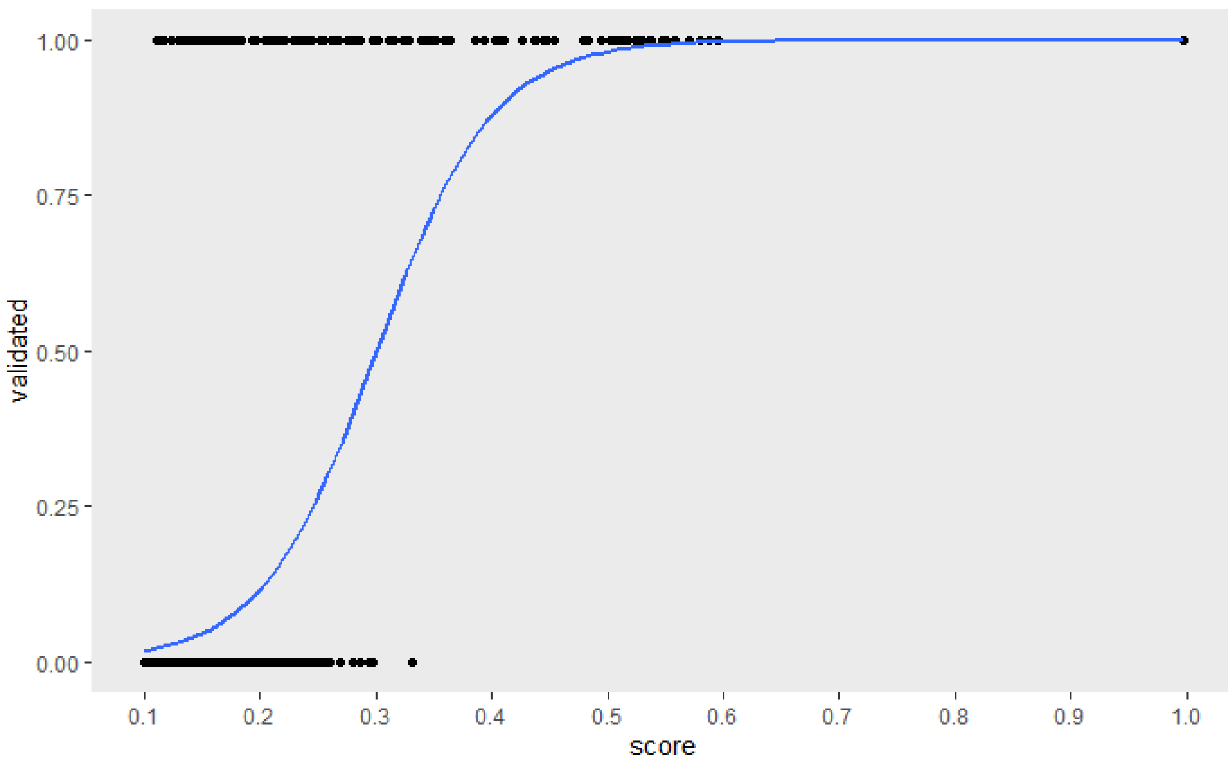

Figure 4. Binomial distribution of presence (1.00) and absence (0.00) of BTNW based on the given score from the pattern matching analysis.

No BTNW were present at Armstrong Lake road between June 9th and 18th. The highest abundance of BTNW was recorded at Bourinot Road on June 28th. The peak of BTNW abundance at Polly Poddy Rock Road was on June 16th.

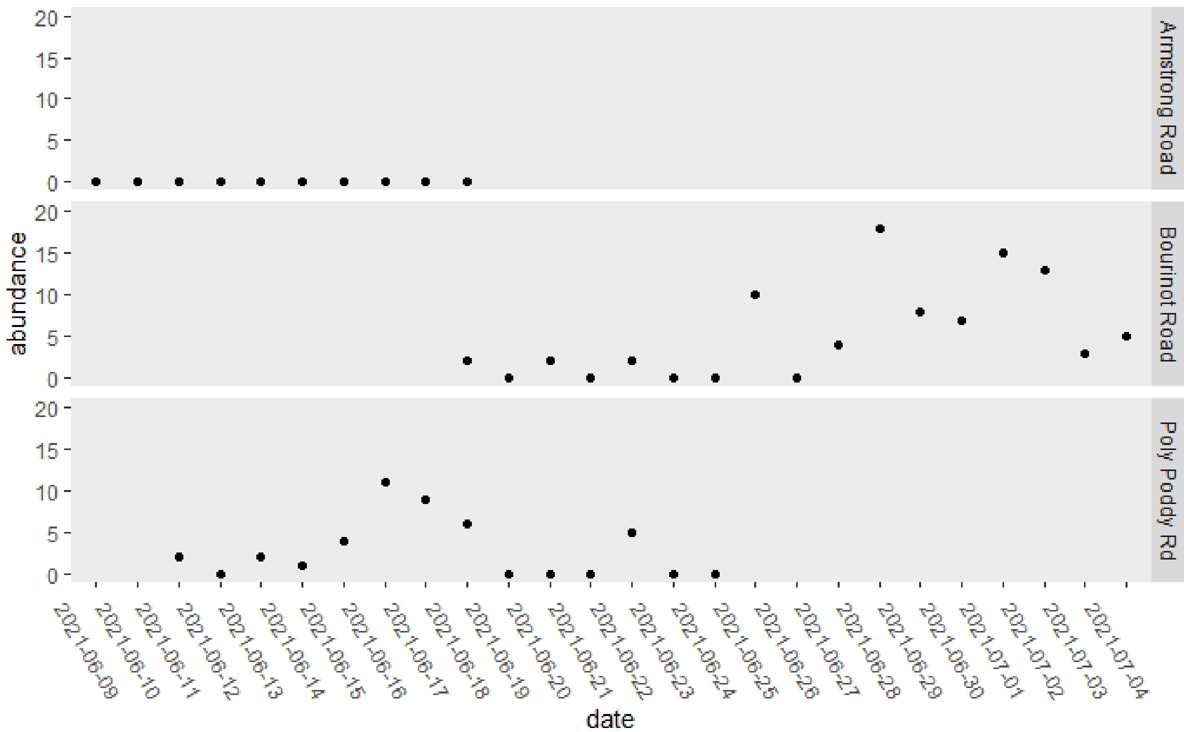

Figure 5. BTNW abundance at each of the study sites based on the date of detection corresponding to the OVEN template.

OVEN

The pattern matching analysis for the Ovenbird detected 295 potential matches with a threshold of 0.3. 191 of those detections were validated as present, 98 as absent, and 6 were left unvalidated (presence undetermined). The site Polly Poddy Rock Road counts for 77% of the absence or false positives (**Table 2**).

Table 2. Number of present, absent and unvalidated Ovenbirds at the three study sites between June 9th 2020 and July 4th 2020 based on the detections of pattern matching analysis using a correlation threshold of 0.3.

Species	Site	Present	Absent	Unvalidated	Total
OVEN	Armstrong Lake road	62	16	3	
	Bourinot Road	110	7	1	
	Polly Poddy Rock Road	19	75	2	
Total =		191	98	6	**295**

A binomial distribution for the detections of Ovenbirds shows a plateau around a score of 0.4. Only 25% of detections were validated as present with a score of 0.3 but increased rapidly between 0.3 and 0.4.

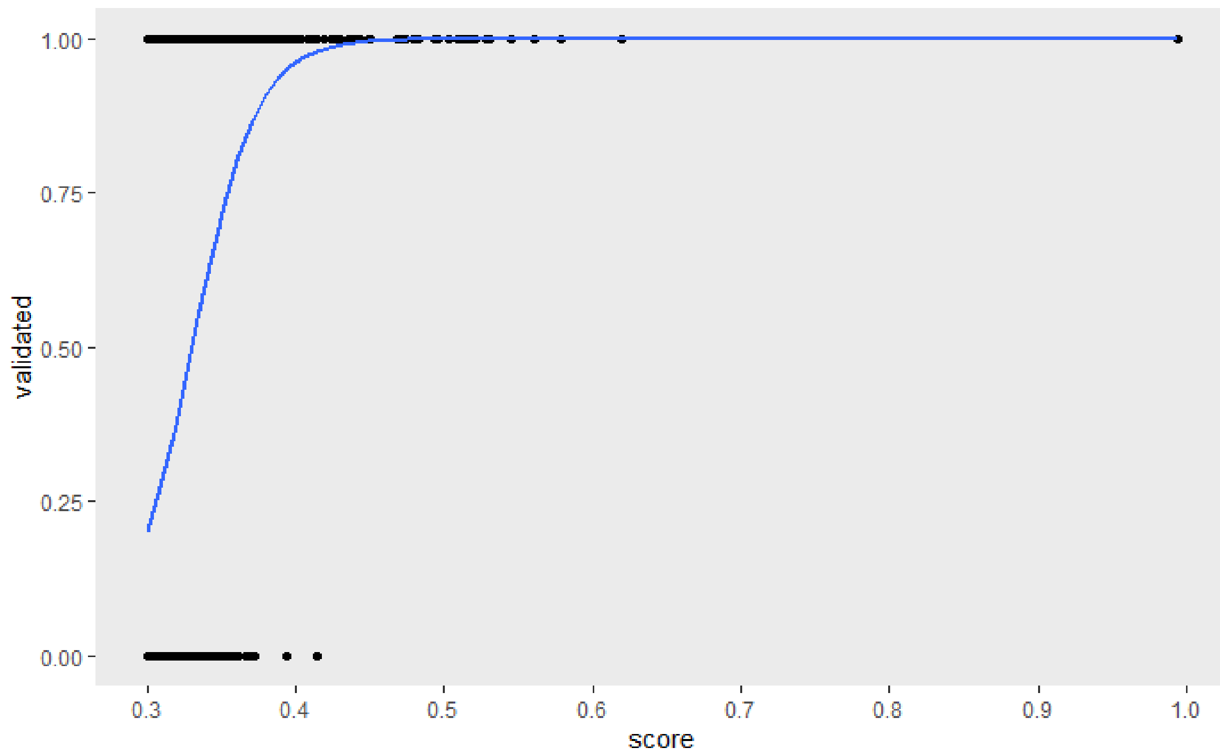

Figure 6. Binomial distribution of presence (1.00) and absence (0.00) of OVEN based on the given score from the pattern matching analysis.

The pattern matching results showed that the abundance of OVEN was highest on June 28th, 2020 at the site Bourinot Road, where 20 individuals were detected. The only day with more than 10 Ovenbirds at Polly Poddy Rock Road was June 17th. There was between 10 and 15 Ovenbirds at Armstrong Lake road on June 10th, 13th and 16th. There were no present Ovenbirds at Polly Poddy Rock Road for the first five days of surveys.

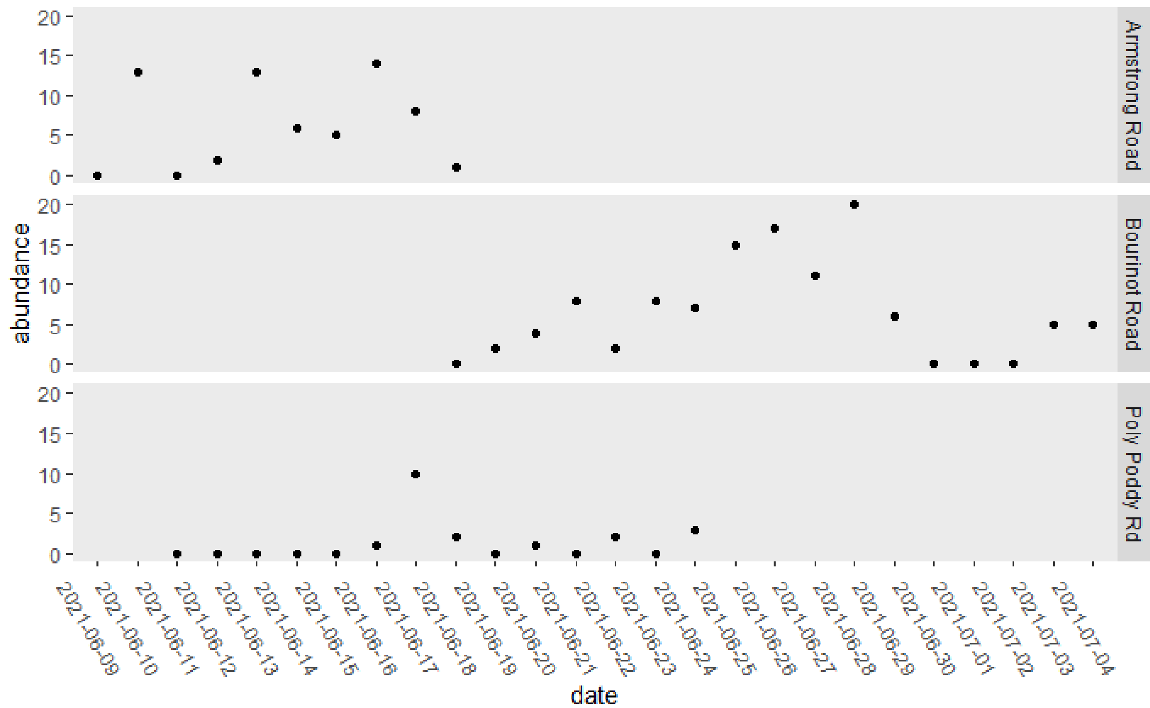

Figure 7. Ovenbird abundance at each of the study sites based on the date/time of detection corresponding to the OVEN template.

BHVI

Detecting BHVI using a short phrase unique to their species was efficient for visual validation of pattern matching results. The figure below illustrates the 21 matches out of 524 with the highest ROIs, out of which 20 were validated as presence of BHVI. These 20 matches look nearly identical and are easily distinguishable from the REVI. The threshold was set at 0.3.

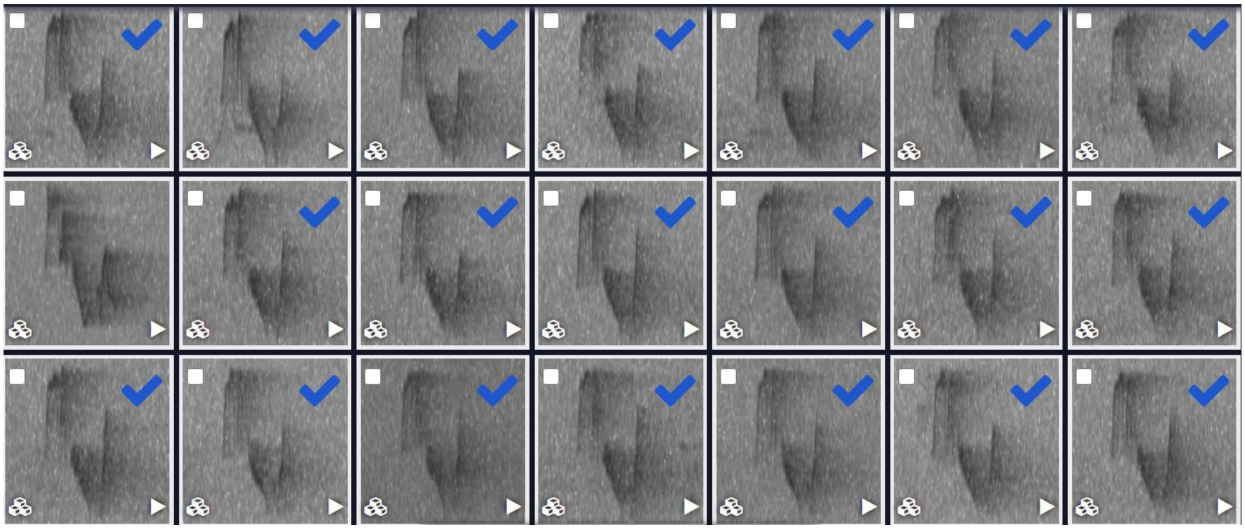

Figure 8. Some of the potential detections of BHVI in the shape of spectrograms based on a template from a single phrase that does not appear in the REVI song.

There were 524 potential matches for the three study sites combined out of which 164 were validated at present. The remaining 360 were left unvalidated. There were 21 BHVI on June 30th at Bourinot Road. No individuals were detected at Armstrong Lake road, and only two were identified at Polly Poddy Rock Road, on June 14th and 17th.

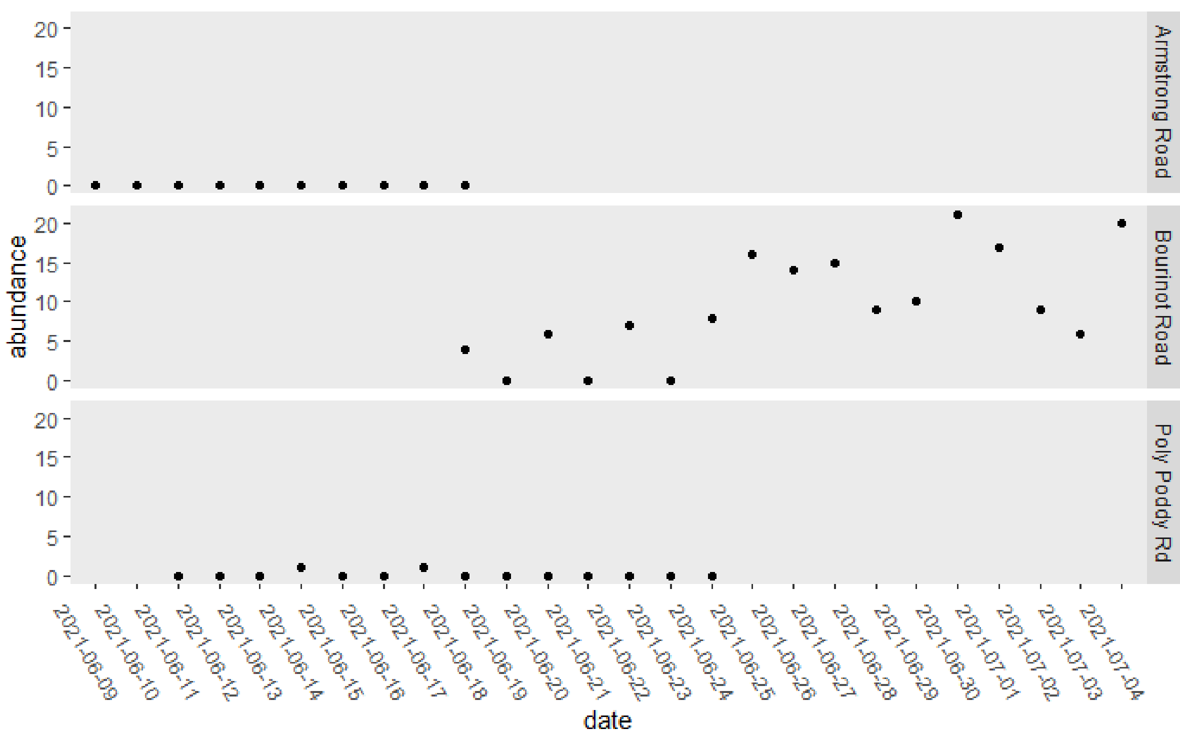

Figure 9. BHVI abundance at each of the study sites based on a pattern matching analysis corresponding to the BHVI template.

REVI

Only the presence and absence of REVI was monitored. Results show that REVI were detected at Armstrong Lake road everyday from June 9th to June 15th. REVI were only recorded at Bourinot Road on June 20th and June 22nd. Polly Poddy Rock Road showed presence of REVI during every day of breeding bird surveys.

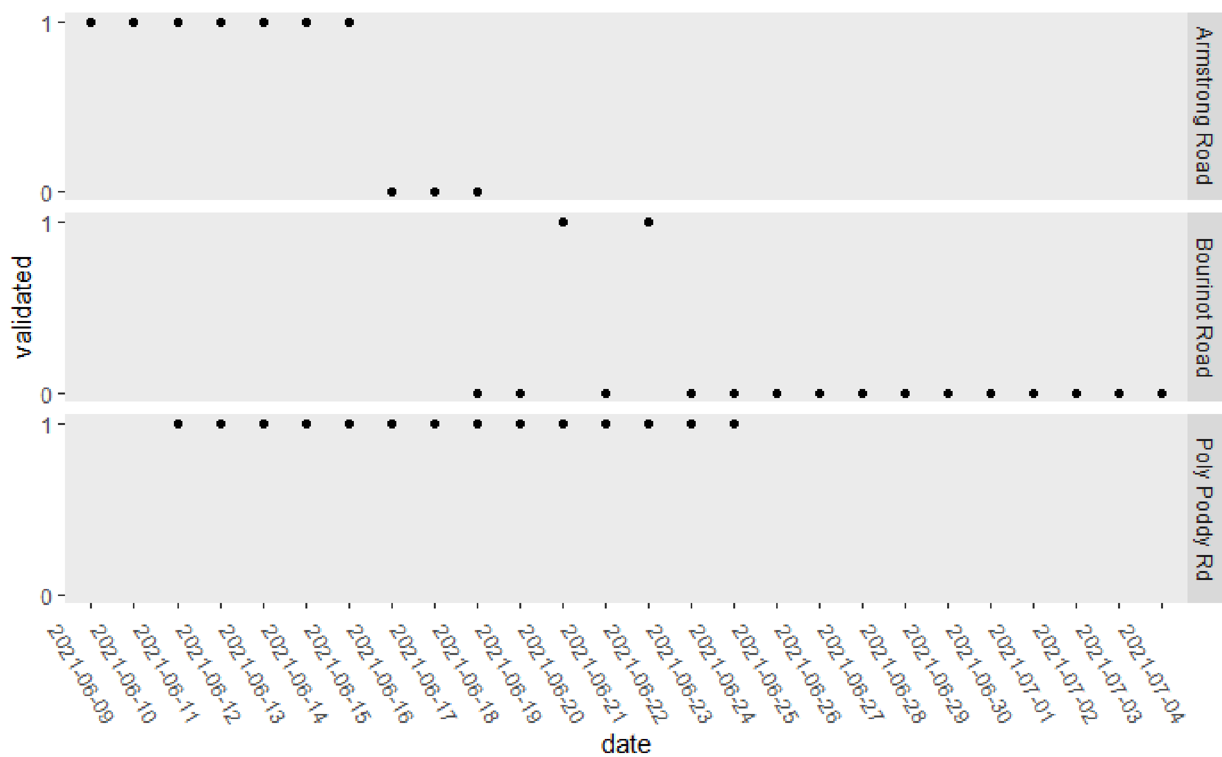

Figure 10. Presence and absence of REVI at the three study sites based on a pattern matching analysis corresponding to the REVI template.

Discussion

Based on the results from the binomial distribution of BTNW, using a threshold of 0.3 to reduce the verification effort is justifiable, as the majority of the detections with a score lower than 0.3 are false positives. The high percentage of false positives of BTNW at Polly Poddy Rock Road (**Table** 1) can most likely be explained by the muted sound of the recordings, as the recordings were not amplified to the same level as the sites Bourinot Road and Armstrong Lake road. This resulted in dimmer spectrograms that made pattern matching more difficult and less accurate. The detection scores of Polly Poddy Rock Road were in result considerably lower, mainly ranging between 0.1 and 0.2. This fluctuation can be avoided by amplifying the recordings for each site equally.

The binomial distribution of OVEN supported the statement above saying that a correlation threshold of 0.3 is justifiable, as the curve did not plateau until a score of around 0.4, meaning that accurate detections (presence) are nearly consistent starting around a score of 4.0 to 4.5 (i.e., few detections validated as absent). Therefore, a threshold of 0.3 leaves enough room for variation. Once again, the less amplified recordings of Polly Poddy Rock Road may explain the high percentage of absence of Ovenbird in the pattern matching results (**Table 2**). It is possible that the frequency of wind or rain was being picked up on the spectrogram and was confounded as an Ovenbird song, especially when the background noise muffled the frequency of other bird songs that share similar characteristics to the Ovenbird song. For example, the Northern Parula was often being picked up by the pattern matching analysis for OVEN.

Pattern matching results for the BHVI using the short single phrase template (**Figure 2**) were easier to verify than with a template containing multiple phrases of the song. However, REVI were still detected in the analyses because of the similarities between their song and the BHVI song, even when specifically choosing the phrase of the BHVI that is unique to its species. The unvalidated matches remained as such because further verification of the results would be needed to confidentially validate them as presence or absence of BHVI. To do so, it may be necessary to visualize the entire song of the individual rather than the phrase (by selecting the detections one at a time to visualize the spectrograms), as it can be difficult to differentiate the REVI from the BHVI.

Pattern matching analysis for the Blackburnian warbler (BLBW) was not conducted, because I could not find a song that was loud enough within the recordings to create a template that would pick up on other BLBW. This problem could be fixed by listening to and visualizing more recordings to find BLBW songs that are visible enough to use as a template, or by loading an existing template from another resource.

Generally speaking, RFCx Arbimon is a useful and available resource for bio-acoustic analyses and is advantageous for measuring the abundance of selected species through a series of recordings. Acoustic monitoring may be the future of ecology and conservation (Deichmann *et* al., 2018). It has already been applied to measure bird occupancy and the impacts of forest degradation (Campos-Cerqueira, M., Robinson *et al*., 2021), as well as the impacts of drought and hurricanes on bird and frog distribution (Campos-Cerqueira and Aide, 2021). Arbimon has also been used to predict habitat type and vegetation structure based on acoustic metrics (Do Nascimento *et al*., 2020), and to assess biodiversity is diverse landscapes (Furumo and Aide, 2019).

To improve this research, more time could be spend creating a variation of templates that fit different calls and songs for key species. By running multiple pattern matching analyses for the same species of interest, the likelihood of detecting all the present individuals is higher. Furthermore, having an expert or multiple scientists verify the results would add to the credibility and accuracy of the data.

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