bioacoustic unit

How to Most Effectively Use Autonomous Recording Units When Data are Processed by Human Listeners

Erin Bayne, Michelle Knaggs, and Péter Sólymos

(Knight, 2017)

Bioacoustic Unit

The Bioacoustic Unit is a collaboration between the Bayne Lab at the University of Alberta and the Alberta Biodiversity Monitoring Institute . The Bioacoustic Unit is the authority on best practices for using acoustic technology in the province and a leader in the application of wildlife acoustic data to environmental management and research needs. In addition, our team is actively engaged in research to enhance our methodologies and advance our tools to better understand our natural acoustic environment. Clients regularly partner with us to assist with their wildlife monitoring needs. Our involvement varies from client to client and spans the full range of services from simply providing information to conducting a full research project on their behalf.

Our services include:

Listening

We can collect the data you need, or help you do it yourself. We provide 'how to' protocols that will guide you through the process of deploying, programming, and retrieving your audio data. Or, let us do it for you!

Analyzing

We have a team of expert taxonomists that will translate your audio recordings into species identifications. In addition, our researchers have developed automatic recognizers that quickly process audio files to detect multiple species of conservation concern. We encourage all clients to contribute their data to our publicly available data set. However, we understand that some clients may be bound by confidentiality issues that preclude this. The Bioacoustic Unit is therefore flexible in how raw data is disseminated.

Reporting

Once the audio recordings have been translated into species identifications, we will prepare a report that fully describes the results. Each report will be accompanied by the full data set of species identifications.

Discovering

We are committed to providing leading edge bioacoustics services. As such, we're always striving for excellence and innovation. Check out our current bioacoustic research to learn more about where we're headed in the field!

For further information please visit: http://bioacoustic.abmi.ca/




Overview

Increasingly, ecologists are turning to audio recording units (hereafter ARUs) as a means to count vocalizing species. ARUs provide a number of benefits relative to human observers conducting acoustic wildlife surveys. In particular, the extended duration of time that an ARU can be placed for is particularly useful. However, the challenge of using the data from ARUs left out for extended periods is how to get the most information out of the vast amount of data that is being collected. The Bioacoustic Unit is actively researching automated classification and computer scanning for species as a means for processing recordings. However, the complexity of the audio signal in most recordings from natural environments means that there are many false positives and false negatives still occurring via automated recognition processes. As such, many ecologists feel uncertain about relying solely on such an approach. Instead, many ecologists using ARUs are interested in how to get information from audio recordings via human listening, in an effort to maximize the information content and minimize listening costs.

A review of the literature on studies using ARUs indicates a wide variety of protocols in terms of the amount of time an ARU is placed in the environment, the recording schedules used, and the way the resulting recording is processed in the lab to detect the species present. Many ecologists have used duration of ARU counts and techniques similar to those used by people when conducting surveys in the field. Presumably, these decisions are based on trying to keep data consistent with historically collected information. However, whether such approaches optimize the information content that is available from ARU recordings remains poorly understood. Past literature trying to optimize point count methods for human based surveys has emphasized the trade-off between travel time between stations, time spent at a station, and the number of times a station should be visited. ARUs provide much greater flexibility in terms of what is possible when creating a sampling design because many of these constraints no longer exist. Instead, the biggest constraint is the amount of time available to listen to recordings and to handle the large amounts of data that an ARU can provide.

How to optimize a listening schedule for ARU data likely depends on the type of information that a user wants to collect. Maximizing the detection of the entire species pool at a single location may have different requirements than estimating occupancy or density for a single species. Thus, understanding the relative trade-offs between different duration point counts, methods of correcting for detection error, conversion of ARU data to point counts, and the number of repeated samples that need to be extracted for an ARU placed at a single station for an extended period of time are all key questions.

The objective of this report is to address some of these questions using a variety of datasets where multiple recordings from ARUs placed in the same area have been listened to for extended periods. The structure of the report is a series of questions with a methods and results specific to the question. A general conclusion is presented at the end of the report based on the answers to these various questions and a discussion of next steps for settling on a standardized protocol for ARU listening.

Table of Contents

How to Most Effectively Use Autonomous Recording Units When Data are Processed by Human Listeners

Q1: What proportion of species richness from a 10-minute point count can be detected in a shorter duration point count?

Does listening to data in the same recording sequentially or non-sequentially increase efficiency?

For these questions, we used a dataset that has detections of 193 different species of mammals, birds, and amphibians. These species were detected from 3689 10-minute long point counts done at 872 stations across the province of Alberta. For passerines, this data was reduced to 462 stations for surveys done between 5 and 11 AM from late May to late June. Data were collected from automated recording units deployed for varying lengths of time at various times of the year. The number of recordings listened to at each station ranged from 2 to 217. The variation in the number of recordings stems from different objectives for each project. Here, the only requirement to be included was the point count had to be 10-minutes long, and all species had to be identified. Data were listened to by a series of experienced listeners who entered data directly into a database while listening to recordings and viewing a spectrogram. The database requires listeners to record species and individuals in 1-minute increments. In other words, the listeners did a series of 1-minute sequential point counts where each individual of each species was recorded in each 1-minute interval for the entire 10-minute period. The listener recorded the time in seconds when each individual was heard in each 1-minute sub-interval (see http://bioacoustic.abmi.ca/ for more information on protocols and our database).

We calculated the total number of species recorded in each 10-minute point count. The proportion of the cumulative species detected per point count was calculated for the first minute, the first two minutes, the first three minutes etc. We then calculated the average and standard deviation of the proportion of species detected for each "shorter duration" point count. To assess if listening to sequential 1-minute segments was more or less efficient in terms of detecting the entire species pool in each recording, we also computed

(Retrieved from: http://bioacoustic.abmi.ca/)

the proportion of the cumulative species detected per point count for the first & last minute combined, for the first, middle, and last minute combined, and for altering minutes. These were compared to the first 2, first 3, and first 5 minutes. A generalized linear model with a random effect for recording identity was used to test if sequential versus non-sequential listening resulted in a greater proportion of the cumulative species detected being observed while controlling for the duration of the point count.

We found 49.8% of all the species detected in the entire 10-minute period were detected in the first minute. By 5-minutes, 79.2% of all the species had been detected. The shorter the point count, the lower the proportion of total species detected (x^2=2940.3, P < 0.001). The variation in proportion of species detected based on random sampling was highest in the first minute and declined thereafter (Figure 1). When listening to the data sequentially (i.e. first 2, 3, or 5 minutes) a smaller proportion of the cumulative number of species found in the entire 10-minute period were detected relative to using the first-last, first-middle-last, and alternating minutes from the 10-minute period (x^2=369.6, P < 0.001). On average, 5.7% more of the total species pool from the 10-minute period was found by listening non-sequentially to each 10-minute point count, although the interaction between point count duration and whether or not the data were listened to sequentially was also significant (Figure 2: x^2=6.7, P = 0.04).

The results for passerines during the breeding season were similar for duration (x^2=451.2, P < 0.001). However, in the first minute 60.1% of all passerine species are detected and by 5 minutes it is 85.9%. Whether or not you listen sequentially matters less for passerines, but 3.1% more of the total species pool will be observed on average if you listen non-sequentially (x^2=30.0, P < 0.001). The interaction between point count duration and whether or not the data was listened to sequentially was not significant for passerines alone (x^2=0.05, P = 0.97).

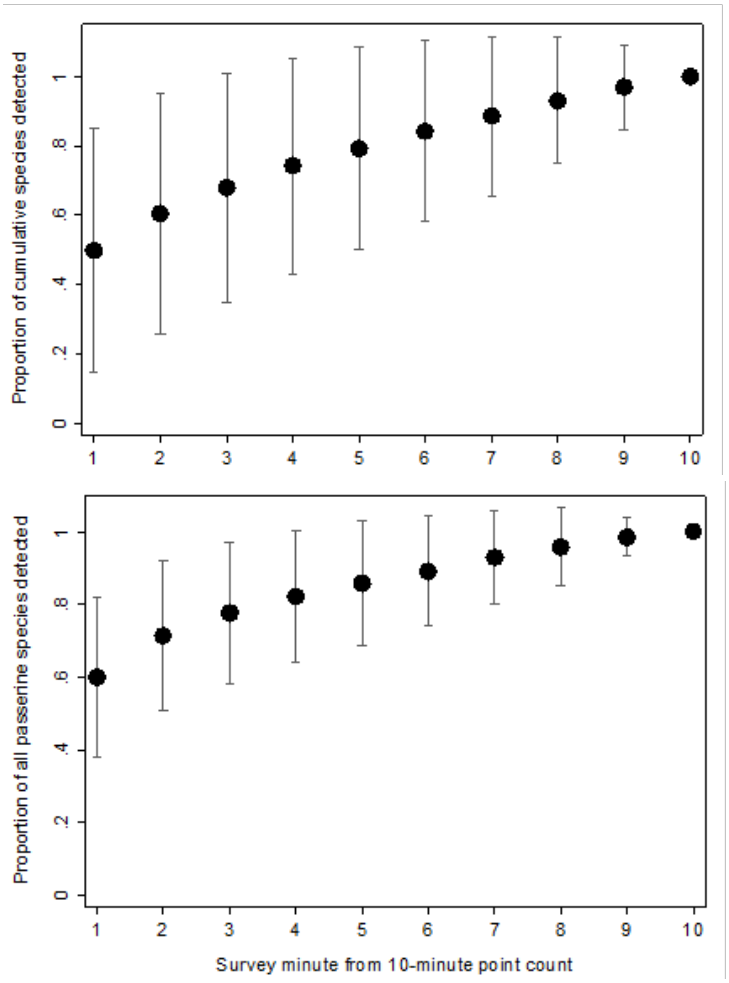
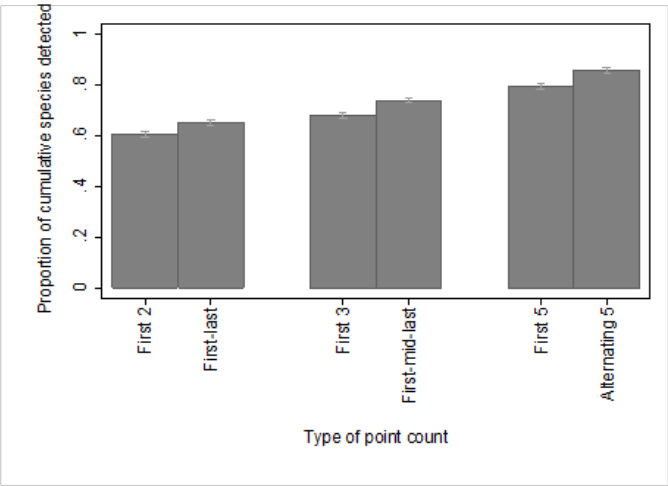


Figure 1. Proportion of cumulative number of species detected per 10-minute point count found during each minute of the entire 10-minute duration. Error bars are ± 1 standard deviation. (TOP) All species from any taxa at any time of year or day; (BOTTOM) Only passerines from 5 to 11 AM between the last week of May and the last week of June.



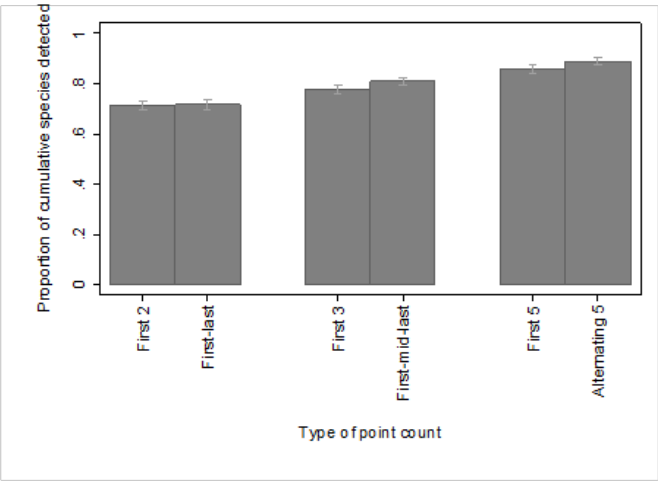


Figure 2. Proportion of cumulative number of species detected per 10-minute point count found during the first 2 minutes compared to the first & last minute of the same 10-minute period, first 3 minutes compared to first-middle-last minute of the same 10-minute period, and first 5 minutes compared to alternating minutes of the same 10-minute period. Error bars are 95% confidence intervals. (TOP) All species from any taxa at any time of year; (BOTTOM) Passerines only during the last week of May to the end of June.

Q2: Is a greater proportion of a species pool sampled with more shorter point counts or fewer longer point counts?

To assess if conducting shorter duration point counts at more times of the day and year resulted in a greater proportion of the total species pool detected we randomly sampled from 100 to 3600 1-minute point counts from the dataset in question 1. We used the first minute within each point count for this random sample. With each of the 1000 random samples, we computed the proportion of the total species detected in the entire dataset. We repeated this sampling for 2-minute point counts (50 to 1800 point counts), 3 (33 to 1200 point counts), 5 (10 to 720 point counts), and 10-minute point counts (1 to 360 point counts). We then compared the proportion of the species detected for an equivalent cumulative time of observation. In other words, we compared a randomly sampled 10-minute point count to two 5- minute point counts, to three 3-minute point counts, five 2-minute point counts, and ten 1-minute point counts. We calculated the proportion of species detected across a range of cumulative times to see how quickly and how close each duration of point count was to the cumulative species detected in the entire dataset.

We found that a larger proportion of all the species detected in our dataset (n = 193) were found with more, shorter duration point counts than with fewer, longer duration point counts. For example, at 1000 minutes of cumulative observation we found that 1000 1-minute point counts detected 68.5% of the cumulative number of species in the entire dataset vs. an equivalent cumulative effort with 100 10-minute point counts, where only 34.1% of the species were detected. Increasing the duration of a point count with a proportional reduction in the number of point counts completed, always resulted in a smaller

proportion of the total species pool detected (Figure 3 - TOP).

The same pattern was observed with only passerines between the end of May and the end of June during diurnal sampling periods (Figure 3 – BOTTOM) although it the rate of species accumulation was slowing more rapidly for passerines using 1-minute surveys than for all species.

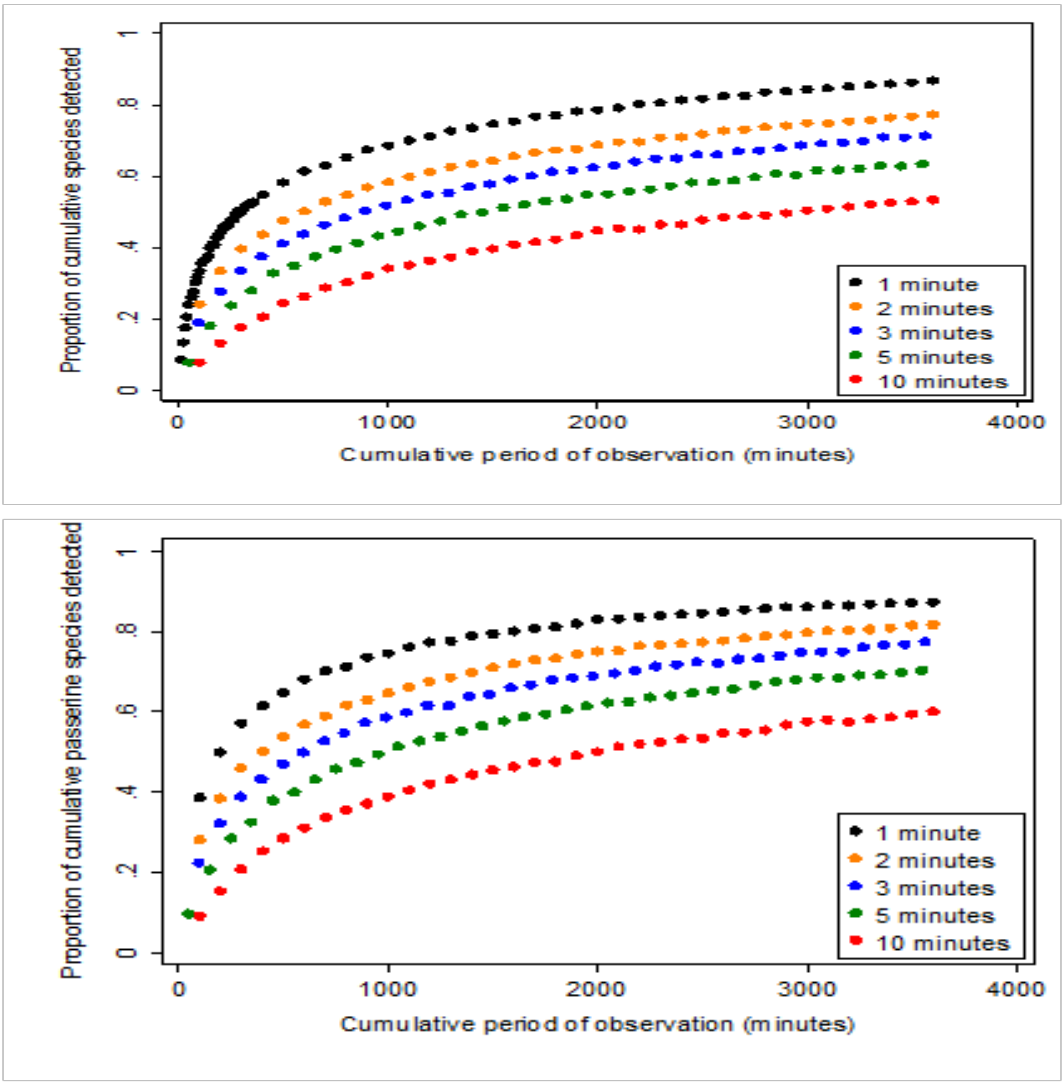


Figure 3. Proportion of cumulative number of species detected using different lengths of point counts (1-10 minutes) but sampling an equivalent cumulative period of time using the different point count length (i.e. fifty 1-minute point counts is equivalent to five 10-minute point counts). (TOP) The entire species pool available to be sampled was 193 and was located in 36890 minutes of processed recordings. Error bars not included for clarity. All species from any taxa. (BOTTOM) Passerines only during late May to late June with a total species pool of 96.

Q3: How does number and order of subsamples within a recording influence calling rates?

The results from questions 1 & 2 indicate that shorter duration point counts at various times of day and year are more effective than longer duration point counts at maximizing the number of species observed. However, species richness is not the only desired outcome of conducting point counts. Accuracy of abundance estimates is also a major concern for most users. It is now established that many individuals are missed during a typical point count and this has led to a number of approaches for correcting for the individuals missed via time to removal or detection error approaches (i.e. occupancy and n-mixture approaches). Most of these approaches rely on some form of repeated sampling where the occurrence of individuals is identified as being observed in particular time intervals.

Calling rate is one approach used to correct for the availability of a species to be detected. Calling rate is a function of how the data are collected. Little has been done to test what influence this has on various statistical corrections like time-of-detection, removal modelling or occupancy. In the dataset from question 1, we use the proportion of 1-minute sub-samples where the species was detected within the total point count length as an estimator of calling rate. A generalized linear model with a random effect for species identity nested within recording identity was then used to test how duration influenced estimates of calling rate and how calling rate was influenced by using sequential versus non-sequential listening to the same recording. Sequential means we listened to X number of 1-minute segments in a row while non-sequential means we listened to X number of 1-minute segments from the 10-minute recording but from different sections of the overall recording. Again, we used the data described in question 1.

Figure 4 shows that the average singing rates across all species and across all passerine species is higher when estimated using sequential recording periods. The magnitude of this effect differs depending on the duration of the point count, as the interaction between duration and whether or not the data were processed sequentially was significant for both groups (all $P < 0.001$).

This result indicates that singing rate estimates are not independent when measured sequentially. Presumably, this occurs because individuals of a species tend to sing or remain silent in bouts. These bouts and whether or not one occurs during the period of observation, have the potential to strongly influence the estimate of singing rate and any abundance corrections based on this technique. This has implications for how occupancy and n-mixture estimates as well as removal modelling based on the time when each individual is first observed are estimated. All of these approaches assume the periods of observation that are used to determine detection histories are independent which does not seem to be the case using these data. Wright et al. (2016) found that the goodness of fit and the accuracy of occupancy models were often reduced under serially correlated calling behaviours, and suggested there were implications of Markovian singing rates on other models that adjust for detection probability on the accuracy of habitat assessment, trend, and most importantly density.

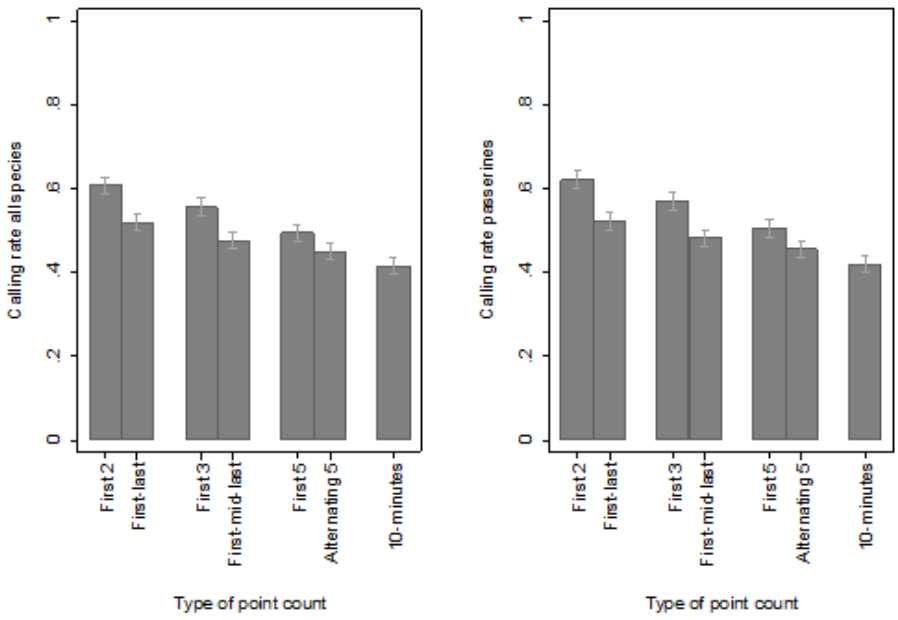


Figure 4. Average calling rate by duration and whether or not sub-intervals were sequential. This analysis controls for ARU location and species identity. LEFT – All species. RIGHT – passerines only. Error bars are 95% confidence intervals. Calling rate is the proportion of 1-minute intervals within a particular duration of point count (2 minutes, 3 minutes, 5 minutes, or 10 minutes) where the species was heard.

Q4: Is serial autocorrelation an issue?

An assumption of occupancy models is that the repeat visits are independent of one another. As shown in question 3, using different minutes within a ten-minute period influences the likelihood they are observed. This suggests some degree of temporal autocorrelation within the same ten minute period. The assumption of independence in occupancy studies requires that if a species was observed in visit 1, it should not be any more likely to be observed again in visit 2 relative to another visit later in time (i.e. visit 1 vs. visit 10 should have same chance of observed species both times as visit 1 vs. visit 10). A series of analyses were done using a runs test to assess the validity of this assumption using different sampling designs. A runs test looks for patterns of serial temporal autocorrelation over visits. In other words, it looks for series of repeated 1's or repeated 0's that are more consistent than would be expected due to chance.

The first analysis used all 3-minute surveys described in question 6. In brief, 12-14 3-minute surveys were done over a period of a month at 150 stations. We calculated whether serial autocorrelation was significant at each station for each species. On average, the runs test indicated serial autocorrelation was not a problem for most species. The proportion of stations where the runs test was significant and demonstrated serial autocorrelation ranged from 0.02 to 0.5 for different species with an average number of significant runs controlling for species of 0.15 (Figure 5)

The runs test has greater statistical power the longer the run. Simulations indicated that no series of detections could have significant serial autocorrelation with this test if there are less than 5 visits. Thus, with these data it is impossible to test whether the probability of a run occurring differs depending on whether the four 3-minute point counts are done in the same day, on different days within a week, or on different days within a month.

Using each 1-minute segment as a point count, we looked at whether the runs test was significant for the whole season. In this approach the average number of significant runs within a station controlling for species jumped to an average of 0.5 (range from 0.07 to 0.95). This analysis takes a couple of days to run for each iteration. We are currently processing it in a daily series, weekly series, and monthly series using the 1-minute point counts to see how serial autocorrelation changes.

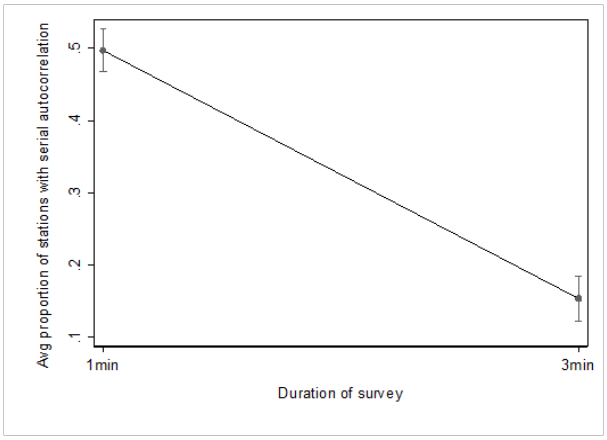


Figure 5. Average number (95% CI) of significant runs per species that demonstrated evidence of serial autocorrelation. Three minute point counts separated by longer time periods showed less evidence of serial autocorrelation than 1 minute point counts that occurred in blocks of time (i.e. three sequential 1-minute point counts followed by long time gap).

Q5: Is there value in sampling repeatedly at the same location relative to going to new places when assessing gamma richness?

As part of a separate project funded by Environment and Climate Change Canada we were provided a dataset of 36 ARU stations from a wetland complex in southern Ontario from 2016. This dataset had a minimum of 180 minutes of data from 1-minute samples for a period of 6 weeks (late May to early July) with 3-6 surveys done per day on days with good weather. Both day and night surveys were done in a systematic way across the entire survey period. We used this data because it provides the best dataset to assess this question as the ARUs were clustered over a relatively constrained spatial extent.

We created a sampling that randomly selected 1, 2, 3… to 36 stations from the entire region. The program then randomly selected 1, 2, 3… to 36 recordings from the randomly selected stations. This was done 100 times. For each combination of number of stations and number of recordings, the cumulative number of species observed was recorded. These data were then ln-transformed and used in an ordinary least squares regression to assess the rate of change in the cumulative number of species (ln-transformed) as a function of the number of recordings (ln-transformed) and number of stations (ln-transformed).

The cumulative number of species observed as a function of number of recordings (ln-transformed) and number of stations (ln-transformed) had an $r^2 = 0.94$. The rate of change was steeper for the number of stations (ln-transformed) than for the number of recordings (ln-transformed, Table 1). The variance explained (r^2)

by number of stations (ln-transformed) when run as a univariate model was 0.46 while the number of visits (ln-transformed) was 0.48. This indicates that both variables strongly influence the cumulative number of species (ln-transformed) observed but that increasing the number of stations increases the cumulative number of species observed more than increasing the number of recordings per station. Figure 6 shows the mean cumulative species richness as a function of the ratio of recordings to the number of stations. In this figure, 1.52 ± 0.70 (SD) fewer species are found cumulatively when the ratio of recordings to stations is higher, controlling for total number of surveys done.

While cumulatively more species are observed by going to a new station versus listening to more recordings from the same station, the difference is not that large. Given the substantially larger costs involved in going to a new location rather than leaving an ARU out for a longer period of time it seems prudent based on this analysis to leave ARUs out for an extended period of time versus simply recording once at a single station. Given that the cumulative species curve does not plateau, ARUs will continue to observed new species as they are left out for longer periods just as moving to new locations within the same study area will although at a somewhat lower rate.

Table 1. Model coefficients to predict the ln – cumulative number of species observed as a function of the ln – number of recordings listened and the ln- number of stations visited.

Variable	Value	Lower 95% CI	Upper 95% CI
Constant	2.2478	2.2437	2.2519
Ln-Recordings	0.2747	0.2738	0.2756
Ln-Stations	0.3046	0.3037	0.3056

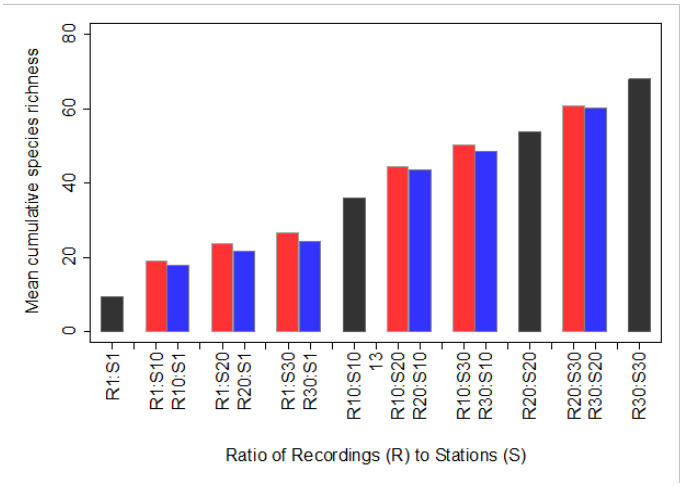


Figure 6. Mean cumulative species richness as a function of the ratio of recordings (R) to the number of stations (S). Black bars indicate an equal ratio of recordings to stations, red bars indicate fewer recordings processed than the number of stations visited, and blue bars are more recordings processed than the number of stations visited. The total sample size increases from left to right on the graph (range 1R:1S to 30R:30S).

Q6: Is the proportion of stations where a species is observed different if you sample for a day, a week or a month with approximately equal effort?

Questions 1 to 5 highlight the value of short duration point counts done over multiple periods. However, the question that remains unanswered is 'could similar results be achieved by recording and listening to multiple recordings from the same day versus a week versus a month?' Addressing this question would allow one to determine when it is more useful to move ARUs rather than leave them in place in order to increase spatial replication.

To address this question we created a dataset from boreal Alberta, the Edehzhie region of NWT, and the northern boreal forest of Ontario. We listened to data for 150 stations (50 in each region with ten 3-minute recordings per station). However, in this analysis we used only 137 stations as 13 stations had < 3 recordings per day because of equipment failure. At the 137 stations, recordings were processed, to get 3-5 recordings per week. At the same stations, we also listened to enough recordings to get 3 to 5 weeks of data where one recording was available per week between the last week of May and the last week of June. For the within day recordings, the times sampled were between sunrise and 10 AM. The weekly and monthly recordings were done between sunrise and 7 AM.

The proportion of the stations where each species was observed was used as the response variable in a generalized linear mixed model. The goal of the GLMM was to determine if the proportion of stations where the species was observed varied between repeated surveys done on single day, individual days within a single week, each week for a month using one survey per week, and across all point counts done for the entire season. The random effect in this case was species identity. This analysis was done once including all species and once for passerines only.

For all species ($x^2 = 305.6$, $P < 0.001$) the model was statistically significant. Pairwise comparisons using a Bonferroni correction indicated that a single day of repeated surveys had the lowest average probability of observation across species and was significantly different from week, month, or season (Figure 6). The proportion of species detected within a single day and month were both significantly lower than over an entire season, which is to be expected as greater sampling effort took place over the entire season. However, week and month were not significantly different from one another. For passerines only ($x^2 = 228.1$, $P < 0.001$), the model was statistically significant. The results were identical to all species except that week vs. day did not have as great a difference as all species, although the result remained statistically significant ($z = 2.6$, $P = 0.05$).

Table 2 (Appendix) shows the observed proportion of stations where each species was observed using the different sampling designs. Note for rarer species there are cases where the species was observed using one sampling design but was not observed at all using the other sampling design. Whether or not a species was observed at any station was not statistically different between the different sampling designs ($x^2 = 0.17$, $P = 0.92$).

Figure 7 shows how the distribution of the proportion of stations where species were observed shifts as a function of the sampling design. Overall, these results suggest sampling for a period of approximately a week will result in higher estimates of species detection at a station, compared to sampling for a day. However, leaving an ARU out for a month will not result in dramatically higher estimates of occurrence. That being said, this assumes that only four 3-minute surveys will be processed in any scenario and it is likely that most people leaving ARUs out for extended periods will try to process more data than that. As demonstrated in question 7, the absolute number of species observed continues to increase with even twelve 3-minute surveys. In fact, other work we recently completed in southern Ontario indicates that species accumulation only slows at about 50 minutes and does not plateau with even 200 minutes of observation.

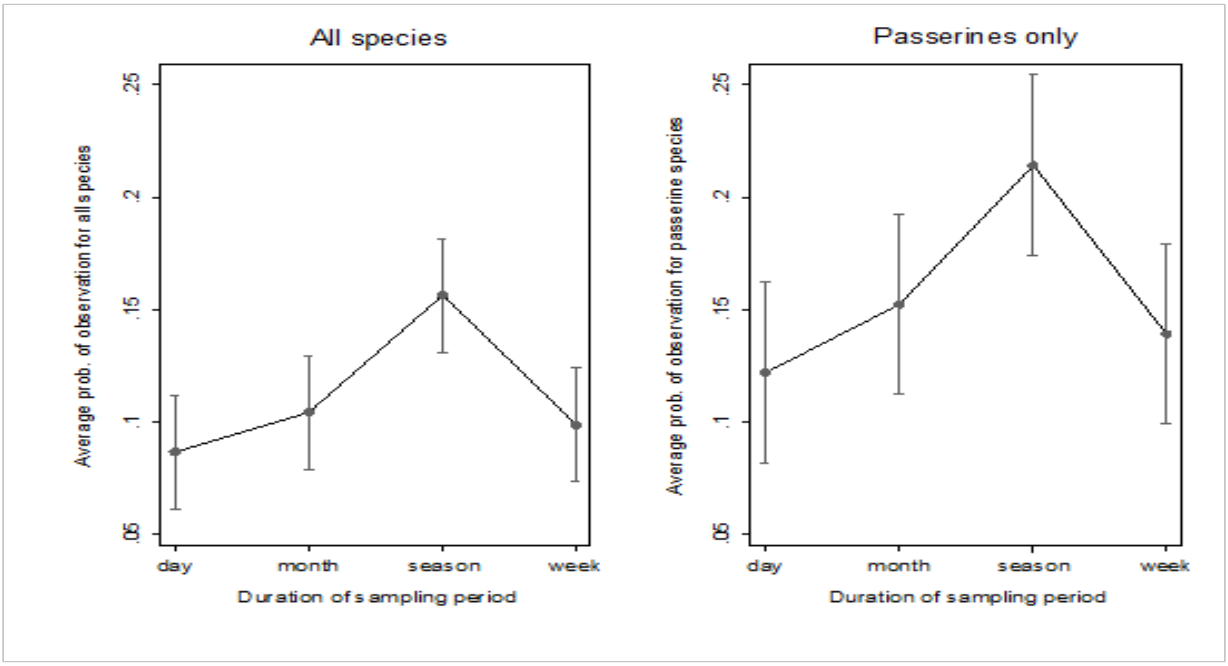


Figure 7. Average proportion of stations were species were observed (n = 137) across species using different sampling designs: 1) SEASON – entire sampling period with average 11.4 ± 1.7 (SD) of recordings processed; 2) MONTH - one recording per week was processed per 4.36 ± 0.74 weeks per station (range 3 to 5); 3) WEEK - one recording per day was processed for a single week with 3.72 ± 0.48 recordings per WEEK (range 3 to 5) ; and 4) DAY where 3.73 ± 0.46 recordings were processed per day (range 3 to 5). Error bars are 95% confidence intervals. Data are split into all species of animals and passerine birds only. In this dataset, only diurnal recordings were used.

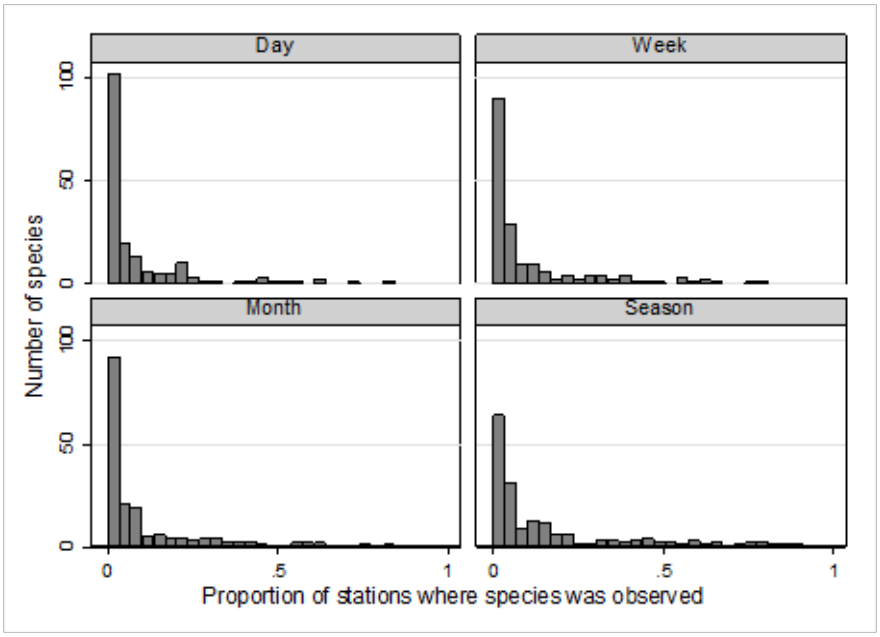


Figure 8. Histograms for each survey design (day, week, month, or season) showing the number of species that had a given proportion of stations where they were observed.

Q 7: Do detection rates vary as a function of whether you repeatedly sample within a day, within a week, or within a month? How does this influence the number of visits to ensure with 95% certainty a species is absent?

The concept of detection error is fundamental to understanding how repeated surveys from ARUs can and should be used. If detection error is high then estimates of occupancy and/or n-mixture counts that correct for detection will tend to be greater than naïve measures. Ideally, detection rates would be similar between sampling designs as this would suggest that the underlying assumptions from these methods are consistent and would result in consistent occupancy measures regardless of the sampling design. Based on the dataset described in question 5, we computed the proportion of visits where each species was observed using the different sampling designs (day, week, month, and season). Only those ARU stations where the species was known to occur within that sampling design were used.

We examined detection rates for each species using a binomial mixed model regression with species as the random effect. Controlling for species, we found significant differences in average detection rates between the various sampling designs ($x^2 = 945.4$, $P < 0.001$: Figure 8). Pairwise comparisons with a Bonferroni correction were significant in all cases although day versus week showed the smallest difference ($P = 0.03$). Seasonal detection rates were the lowest on average. Overall, these results suggest that closure (the assumption that the species of interest is always within the sampling area during the period of observation) probably plays a role in the estimation of detection rates as the greater number of repeat visits, and the longer the duration between different repeat samples , the more detection rate decreased. With more repeat visits and a longer duration of time between different repeat samples, the more detection rate decreased

Table 3 (Appendix) shows the detection for each species using the different sampling designs (sorted from highest to lowest). We also computed the number of visits required to ensure that you have a 95% certainty the species was present versus absent for that particular sampling design. The number of repeat visits required, based on observed detection rates, was computed using methods described in (Slwiknski, Powell, Koper, Giovanni, & Schatt, 2016). Specifically, if the probability of failing to detect a species is $d= (1-P)x$, where d is the desired detection rate, P is the detection probability, and x is the number of visits, then one can solve for values of x that achieve the desired detection rate (here d=5% for 95% confidence).

For example, the White-throated Sparrow only required two 3-minute point counts in any sampling design to determine if the species was present versus absent. In other words, detection rates were consistent across sampling designs. In contrast, the Brown Creeper would require 27 visits across the season, 14 visits across the month, 10 across a week, and 5 within a day to ensure the species could be deemed present versus absent. Across species, the average number of visits required to have 95% confidence in species occupancy were 15, 8, 6 and 5 for SEASON, MONTH, WEEK and DAY revisit designs respectively. If lower confidence is acceptable, then the number of required visits is somewhat less; for example 90% confidence would require 12, 6, 5 and 4 visits

for SEASON, MONTH, WEEK and DAY revisit designs respectively on average. The difference suggests that the assumption of closure is more likely to be violated over longer periods. Importantly, the interpretation of occupancy or n-mixture models likely differs between the sampling designs. Occupancy models are most effective at estimating the density of birds in a "super-population" which has been defined as the number of individuals with territories/ home ranges that overlap some sampling area over the period of the surveys. Typically, occupancy models try to revisit stations over the entire sampling period of interest to provide a super-population estimate over an extended period (i.e. entire breeding season). Using a day or week as a sampling design, we suggest the definition of the super-population and what is estimated may be different than if you use a month or season. We argue the DAY sampling design is likely estimating the size of the local super-population during that period of time (i.e. that DAY or WEEK). Since the size of the super-population likely changes over the entire breeding season, what this data means is open to different interpretations.

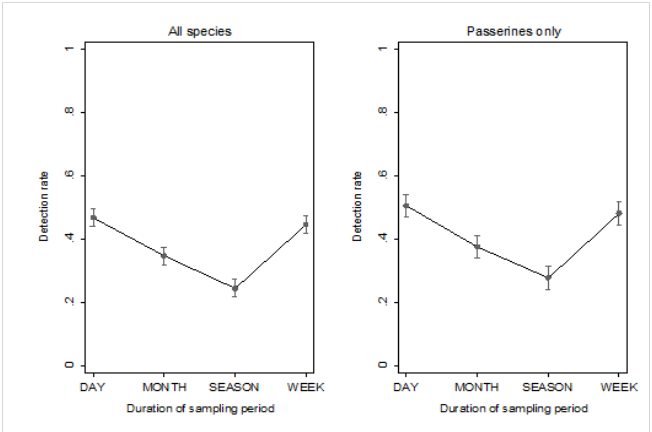


Figure 9. Average detection rate across species with 95% confidence intervals for different sampling designs. Detection rate was the average proportion of visits at a station where the species was observed, for those stations where the species was known to occur. Data are split into all species of animals and passerine birds only. In this dataset, only diurnal recordings were used between the last week of May and the last week of June.

Potentially, controlling for the dates and times of day when DAY or WEEK sampling occurs could provide a similar occupancy or n-mixture estimate to MONTH and SEASON but this requires further investigation.

Q8: Does the absolute number of species observed and proportion of the total species pool observed change as a function of whether sampling occurs within a day, week, or month?

The results in question 4 strongly suggest that species richness increases with more sampling effort, whether spatial or temporal sampling. In that particular dataset, surveys were conducted using all species in a diverse area dominated by wetlands. Whether wetlands, which presumably are more variable in space and time than forests, are indicative of how species accumulate in other habitats is not well understood. In addition, whether passerines, which tend to be more territorial and thus more likely to meet the assumption of closure, show the same pattern requires more investigation.

Using the data described in question 5, we evaluated how the absolute number of species accumulated using the different sampling designs. We also evaluated what proportion of species from the entire sampling season were detected using a DAY, WEEK, or MONTH of sampling with equivalent effort differentially spread out across the season.

WEEK and MONTH showed very similar species accumulative curves while DAY and SEASON were also similar. WEEK/ MONTH accumulated species faster with more visits than DAY/ SEASON (Figure 9). This pattern was the same whether you used all species or only passerines. The consequence of this pattern is that a larger proportion of the entire species pool is observed

using WEEK or MONTH than using DAY (Figure 10). The results also show that even with 20+ 3-minutes of data over the season, not all species are observed. The species accumulation curves in these forests did not plateau and the rate at which species accumulate was still quite rapid across the range of effort available in this dataset.

By way of comparison, Figure 11 shows the results of species accumulation at the 36 southern Ontario wetlands described in question 4 at different spatial scales. In this dataset, each survey was a 1-minute sample and the slowing of the accumulation curve did not occur till about 50+ minutes of surveys and based on a ln-ln curve did not plateau. In other words, insufficient effort to locate all species occurred at the station level, while at the site and regional level there was evidence that all of the vocalizing species present may have been observed at around 180 minutes of observation.

The times described above are simply visual approximations and more work is needed to determine exact cutpoints when species accumulation curves show distinct slowing at different spatial scales and in different habitats.

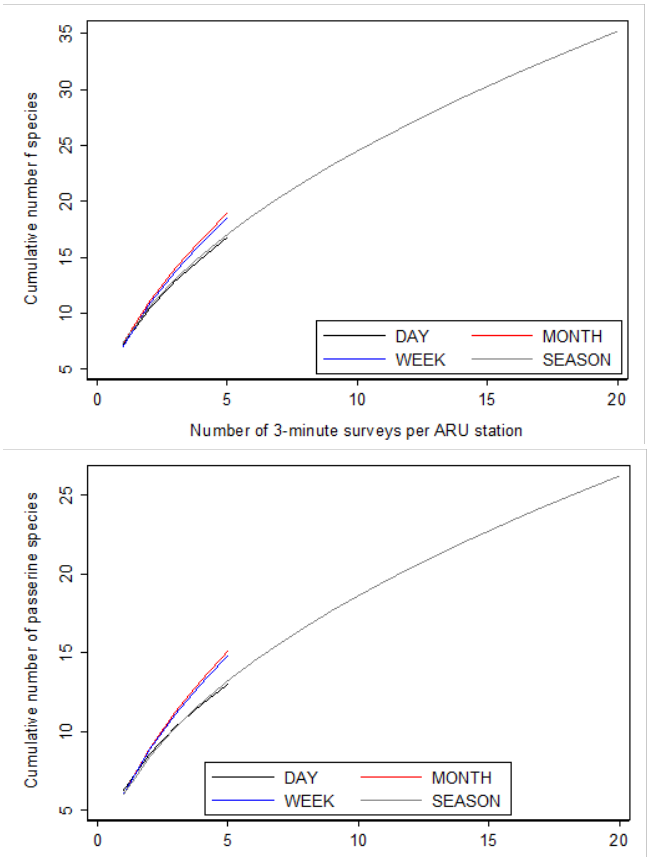


Figure 10. Species accumulative curves as a function of the number of surveys completed using different sampling designs. TOP – ALL SPECIES. BOTTOM – PASSERINES ONLY.

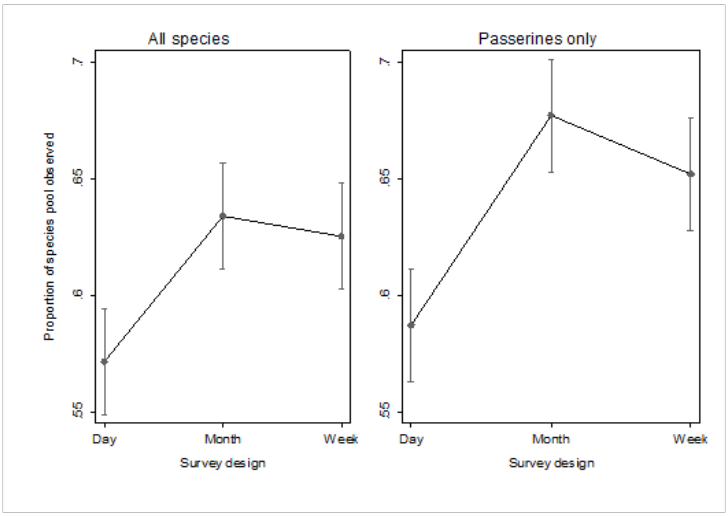


Figure 11. Proportion of total species observed over the entire season (LEFT – All species, RIGHT – Passerines only) using DAY, WEEK, or MONTHLY sampling designs.

(ABMI, 2014)

Q9: Is there a general rule about the proportion of species observed as a function of the way sampling effort is allocated?

The results from questions 4 & 7 indicate that a lot of sampling effort is required to ensure that all species are observed. They also suggest that the assumption of closure is not met for many species at the station scale. This may occur because the birds are non-territorial, and have home ranges that are of considerably larger scale than the sampling area of an ARU station. Thus, listening to many audio recordings at the same station will still have detection error for some species (i.e. it is present once but not observed) and not all species will be observed.

This observation led us to ask whether there is a rule about how sampling effort influences the proportion of the total species pool that is observed. For each station, we computed gamma richness (total number of species observed given the 12+ visits to each station over the entire season). We then randomly sampled 1,2,3…x visits to each station and computed the total number of species observed with a subsample of the total sampling effort. We converted these counts to proportion of total species pool observed at a station and proportion of the total number of visits available. We then used a mixed effects regression model to assess how proportion of species observed changed as a function of the proportion of sampling effort using a fractional polynomial function to fit the curve. This analysis was based on the data from question 5 for passerines only.

We found a ln curve provided a good fit to the data, indicating that as the proportion of the total sampling effort increases the proportion of the species pool observed

increases (Figure 12- Appendix). However, the rate slows with increasing effort. When 10, 25, 50, and 75% of the point counts done at a station are used to estimate the proportion of the cumulative species detected per station, about 36%, 59%, 78%, and 91% of species respectively, will be detected. Obviously, when all of the point counts done at a station are used then all of the species observed all of the species are detected. This does not mean that all species are detected however, as increasing effort tends to more species being observed as shown in Figure 9 and Figure 11.

To determine if these patterns were the same in different regions/ habitats we compared these curves for surveys done in boreal Alberta, boreal NWT, and boreal Ontario. We found that the curves for Ontario and Alberta were nearly identical (Figure 13). In contrast, the curves for boreal NWT indicate that a greater proportion of the total species pool could be observed, with less effort.

We assessed whether this might be a function of total species richness in the different regions. Specifically, we evaluated if alpha or gamma richness per station differed between the regions. We found that average species richness per 3-minute point count was not significantly different between the three regions ($x^2 = 0.14$, $P < 0.001$: Figure 14). In contrast, total species richness pooled across the 12 visits to each station was significantly lower in the NWT than in Alberta or Ontario ($x^2 = 107.4$, $P < 0.001$: Figure 14). This suggests that the absolute values of gamma richness at a station influence how species accumulate with increasing effort.

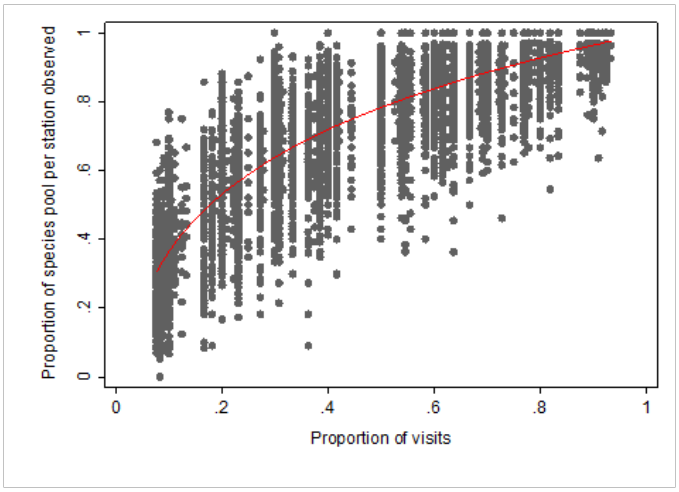


Figure 13. Scatterplot of proportion of visits versus proportion of passerine species pool observed. Red line indicates line of best fit and dots indicate random samples from each station.

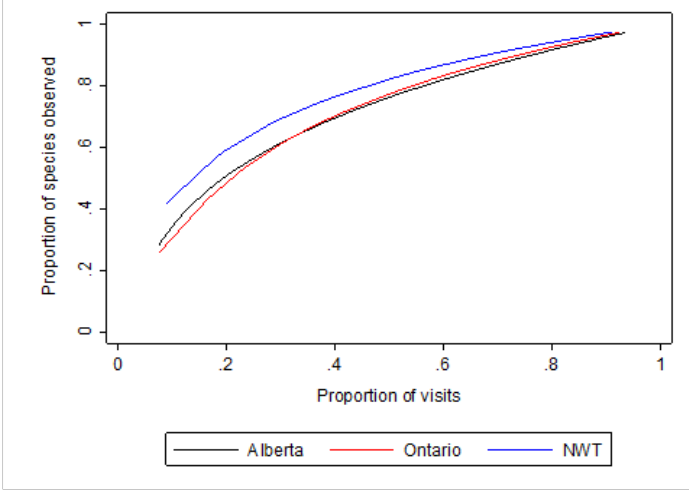
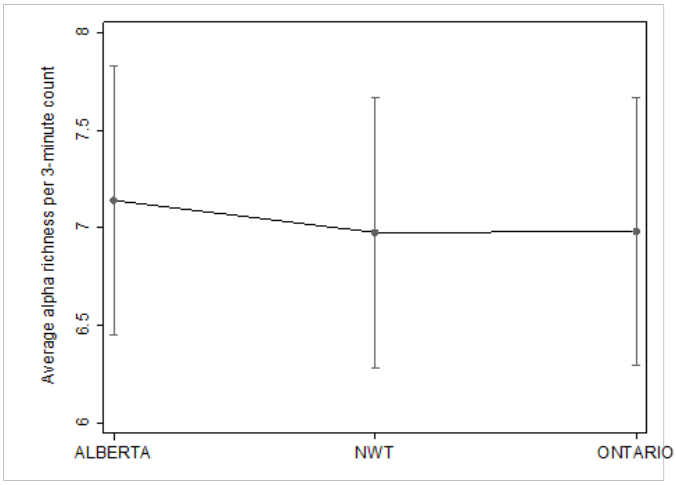


Figure 14. Line plots showing line of best fit for Alberta, Ontario, and NWT in terms of how the proportion of passerine species pool observed as a function of the proportion of visits used to determine which species were detected.



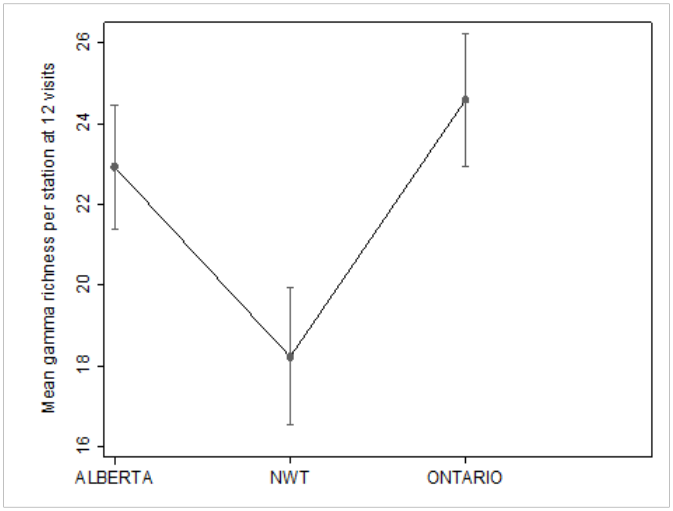


Figure 15. Mean species richness per station at: (TOP) the 3-minute survey duration level in Alberta, NWT, and Ontario; (BOTTOM) per station over twelve 3-minute survey visits to each station. Error bars are 95% confidence intervals.

(Archer, 2014)

Q10: How much effort is needed to ensure the entire species pool is detected at a station? If you have a limited listening budget, what is the optimal listening schedule?

We conducted 10-minute point counts at a single wetland station in NE Alberta for 9 days, every hour on the hour. A total of 217 10-minute point counts were available for that station. We randomly sampled 1,2,3 … 217 10-minute point counts 1000 times. From each sample, we computed the proportion of the cumulative species detected across that number of point counts. We then selected the solution from each run, that resulted in the maximum proportion of the species detected, and examined the times of day that were sampled to get the best solution. We also computed the average proportion of the cumulative species detected per the proportion of all 217 point counts examined.

A total of 67 species were detected over the entire 9 days. Figure 19 shows the proportion of the cumulative species detected using the optimal solution for an increasing proportion of the point counts examined. On average, using 25% of the recordings from this station resulted in 52.8% of the cumulative species were detected. Based on the optimal solution, 71.6% of the cumulative species were detected. While more data is required, the optimal solution changes in terms of which hours of the day should be processed depending on the proportion of available point counts sampled. In other words, as a larger proportion of the total number of point counts are used there is evidence that a more uniform sample achieves greater representation of the cumulative species detected. While if you sample only a few point counts from the total number of available recordings there is strong evidence that avoiding afternoon sampling is warranted (Figure 20).

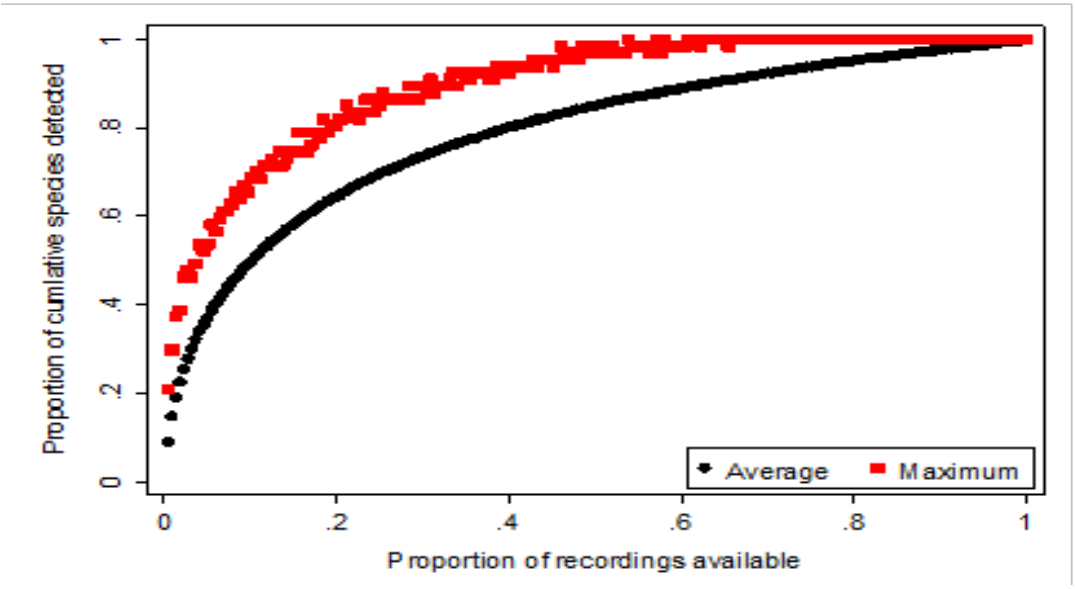


Figure 16. Proportion of cumulative number of species detected at a single station where 217 different 10-minute point counts were available based on the proportion of available recordings sampled. The maximum is an optimized scenario based on randomly drawing 1000 different combinations of 2, 3, 4 etc… point counts and selecting the scenario that maximized the proportion of the total species pool detected with that number of point counts. The average comes from a random sample.

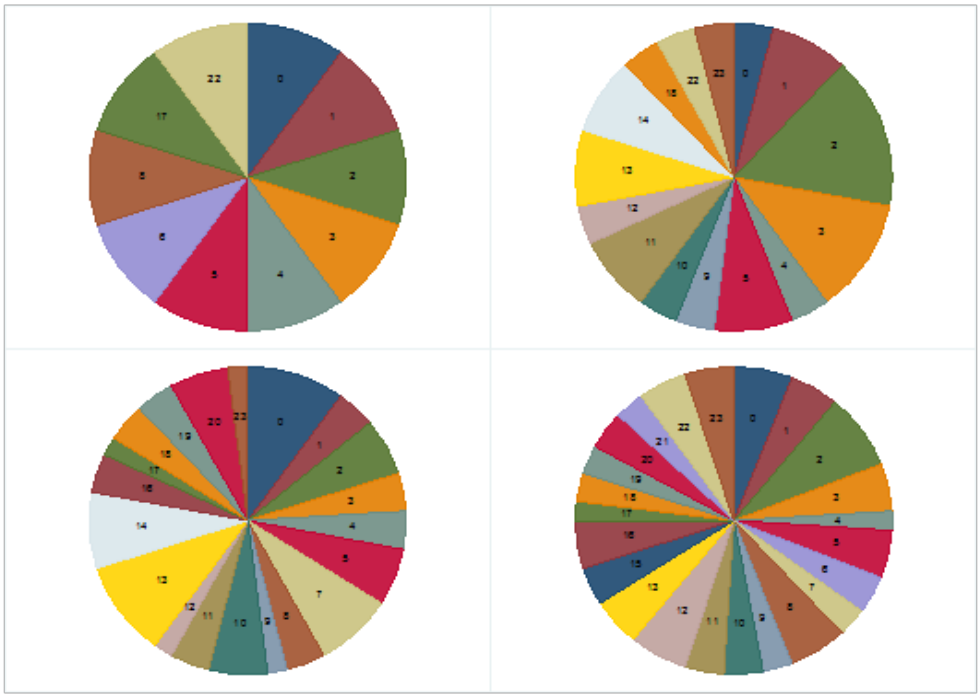


Figure 17. Proportion of point counts done at certain hours of the day that maximized the proportion of cumulative species detected using 10 (top left), 25 (top right), 50 (bottom left), or 100 (bottom right) point counts at a single wetland station. At 10, 25, 50, and 100 point counts, the selected optimization of sampling effort by hour detected 52.2%, 71.6%, 83.5%, and 95.5% of the 67 species cumulatively detected in 217 visits to this station. Numbers in the slices of the pie chart indicate the hour of the day. The size of the slice indicates the proportion of point counts done at that hour of the day that was optimal for this station during the time of year where recording took place.

Q 11: What attributes of a species ecology might influence how we sample?

Accurately monitoring the status and trend of rare species is a fundamental challenge in biodiversity conservation. Effective monitoring of rare species requires a firm understanding of why a species is rare in the first place. When a species is common within a habitat (i.e. locally abundant) but uses a habitat that is rare, the optimal monitoring layout is quite different than if a population has few individuals widely spread across different habitats. Similarly, knowing if a species is rare but easily detected versus hard to detect even when present (hereafter elusive) can have significant implications for how we monitor species. Detectability is the probability of observing a species given that is present at a location. A growing body of evidence demonstrates that detectability is less than 100% for almost all species. Imperfect detectability can have significant implications for understanding status and trend.

While the idea that rare species have lower detectability may seem intuitive, there have been few explicit tests of how rarity influences detectability. Our objectives were to: 1) Evaluate the hypothesis that rare species have lower detectability, and 2) Determine if innate differences among species in terms of how they produce sound cues influence relationships between rarity and detectability. Specifically, we test if calling rate, sound frequency, body size, and timing of calling influence the relationship between detection rate and rarity. Calling rate (number of sounds made per unit time) should increase detection rate as the number of cues available to a receiver to detect the species will also be higher. Calls and songs of different species create sound waves with very different frequencies or pitch (i.e. 2000 vs 6000 hertz). Low pitch sound waves can be detected by a receiver at further distances than high pitch sounds, potentially increasing the detection rate of species with lower pitch. Sound pitch is correlated with the body weight of species, with smaller animals generally generating higher pitched sounds. Body weight is also correlated with home range or territory size. When animals have larger home ranges, detection probability may drop because the chance a receiver of a sound cue the generator of that sound overlap in space and time and is less likely than for more stationary species. The time period when an animal calls (night versus day) may influence detectability because the distance at which sounds can be heard is typically larger during the night than the day, because of calmer and cooler conditions at night that influence sound wave propagation.

Data for this analysis were collected across the province of Alberta in a variety of habitat types including agricultural fields, native prairie, black spruce dominated forest, aspen dominated forest, and a variety of wetland types. A total of 1793 stations were used in generating detection rates for the various species. At each station an automated recording unit (hereafter ARU) was placed for a period of at least 3 days. Recordings took place on the hour for 3 minutes for the entire period of time the ARU was in place.

Human observers listened to 3 recordings from each station. Each recording from the same station was separated by at least one day. Detection rate for each species between the separate recording times at each station (hereafter visit) were used to compute detection rate. The three visits to the same station took place at the same time on subsequent days. Approximately ½ of the

recordings processed were at midnight and ½ between 5 and 6 AM. To compute detection rate, we calculated the proportion of visits where a species was detected for each station. We then calculated the average detection rate based on only those stations where the species was detected at least once. Thus, the number of stations used to compute detection rate varied among species.

Calling rate was estimated by splitting each 3-minute recording into three 1-minute intervals. In each 1-minute interval, human observers kept track of whether or not each species was detected. The proportion of 1-minute segments for each 3-minute recording was computed. We then calculated the average calling rate based on only those recordings where the species was detected. Thus, the number of recordings used to compute calling rate also varied among species.

Regional abundance per species was computed by taking the natural log of the total number of stations where each species was detected. Only those species detected at least 10 times were included. Local abundance was the mean count of each species when the species was detected. Values closers to 1 indicate that when a species is found at a station there is typically only a single individual detected.

Sound pitch was computed by looking at sonograms for each species in the dataset and determining the minimum and maximum sound frequency in kilohertz of the calls. Approximately 5-10 calls for each species were computed this way and the average value used in analysis. Natural log body mass was taken from the literature. Time period was a categorical variable coded as 0 for species that typically call during the day versus 1, which described species typically calling at night.

Detection rate was regressed against the predictor variables using ordinary least squares regression (hereafter OLS). A global OLS model with all predictor variables (calling rate, local abundance, log regional abundance, log body weight, minimum pitch, maximum pitch, and time period) was reduced in complexity by removing non-significant variables ($P > 0.1$). A similar approach was used to evaluate how local abundance, log regional abundance, log body mass, minimum sound frequency, maximum sound frequency, and time period influenced calling rate. When there was evidence of non-linear functional relationships between detection rate or calling rate and the predictor variables, we evaluated if we could improve model fit using breakpoint regression.

We had sufficient data to estimate detection rate for 118 species (4 species of mammals, 4 species of amphibians, and 110 species from 12 orders of birds). The mean detection rate was 0.473 ± 0.100 (SD) across species (Figure 15) with a range from 0.33 – 0.72. The average calling rate was 0.693 ± 0.114 (SD) across species (Figure 15) with a range from 0.46 – 0.87.

Overall, we could explain 69% of the variance in detection rate with a model containing four predictor variables (Figure 16). The predictor variable with the greatest effect on detection rate was calling rate ($\beta_{std} = 0.417$, $t = 6.73$, $P < 0.001$), with species that call more often being more likely to be detected. Calling rate alone explained 49% of the variation in detection rate. Local abundance was the next strongest predictor variable ($\beta_{std} = 0.364$, $t = 4.79$, $P < 0.001$) followed by log regional abundance ($\beta_{std} = 0.200$, $t = 2.80$, $P = 0.006$) and time period ($\beta_{std} = -0.100$, $t = -1.91$, $P = 0.06$). Minimum and maximum pitch and log body weight were significant predictor variables prior to other predictor variables being entered into the model but were never

significant if calling rate was included.

The results indicate that when the local abundance of a species is higher, there is higher detectability. Species that were regionally more common also had higher detectability. There was no evidence that interactions between any of the predictor variables influenced detection rate. Contrary to expectations, detection rate for species that call at night was lower than for species that call during the day.

The original OLS model predicting calling rate explained 53% of the variation in the data. However, residual analysis indicated one species had a strong influence on the model. After dropping cows, which had the highest log body weight, the model was able to explain 58% of the variation in calling rate. The predictor variable with the greatest effect on calling rate was log body weight (β_{std} = -0.547, t = -8.83, P < 0.001) followed by local abundance (β_{std} = 0.470, t = 7.62, P < 0.001), and time period (β_{std} = 0.199, t = 3.22, P = 0.002). Minimum and maximum pitch were significant predictor variables alone, but were not significant once log body weight was included. Log regional abundance was significant until local abundance was included. The results indicate that larger species have lower calling rates (Figure 17).

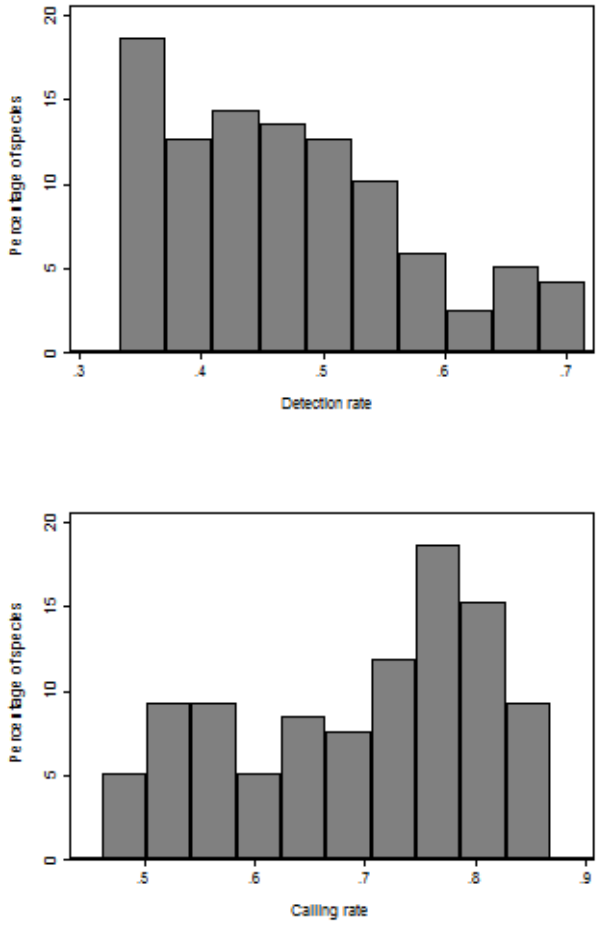


Figure 18. Histogram(s) showing distribution of detection rate across species based on three-minute points counts done on three unique days at the same station (TOP) and calling rate across species based on three unique 1-minute sampling intervals within the same three-minute point count (BOTTOM).

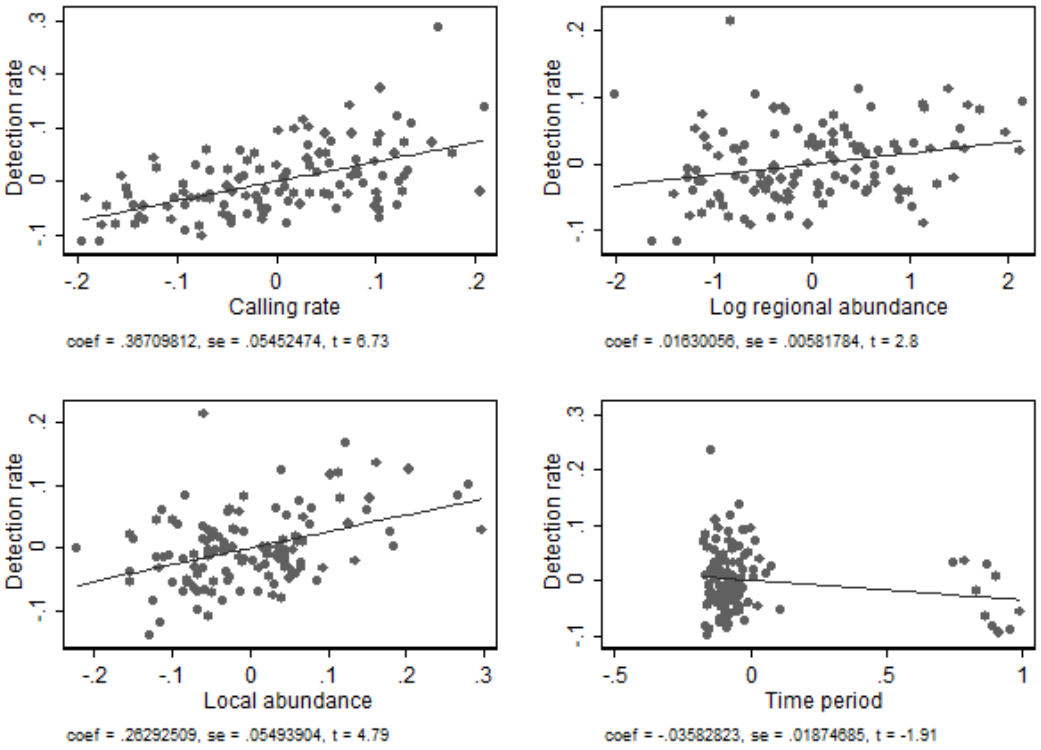


Figure 19. Partial regression plots showing the relationships between each predictor variable and detection rate after removing the effect of the other predictor variables. The intercept for this model with non-standardized coefficients was -0.1682.

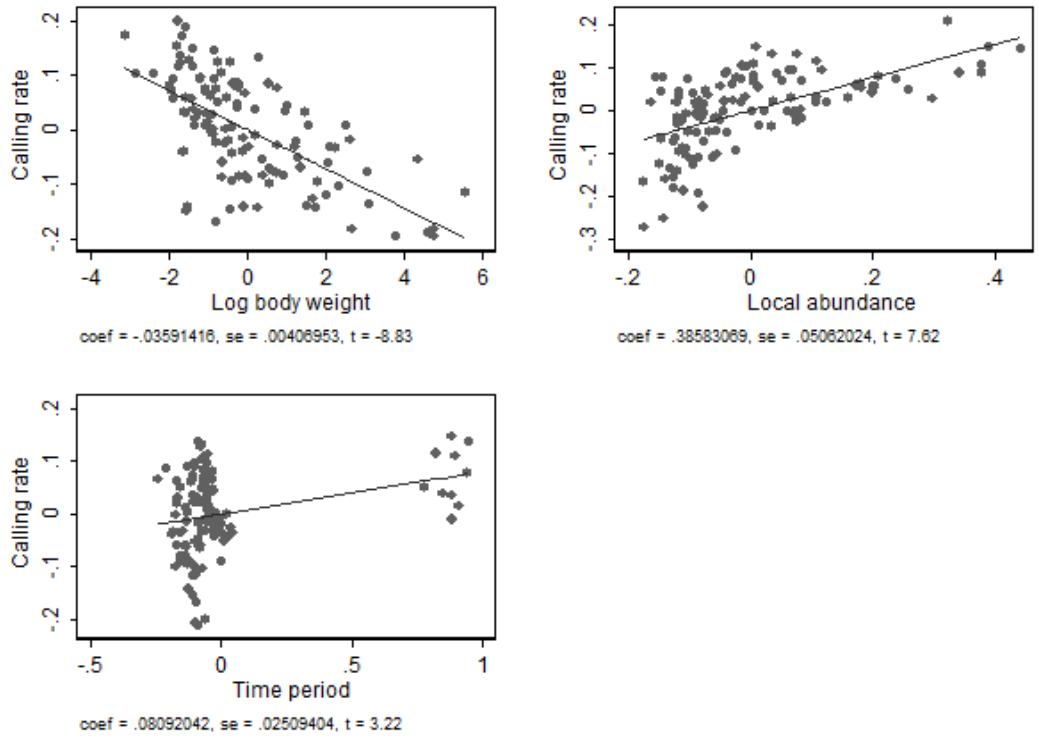


Figure 20. Partial regression plots showing the relationships between each predictor variable and calling rate after removing the effect of the other predictor variables. The intercept for this model with non-standardized coefficients was 0.3823.

Q12: Can we count birds by measuring calling rate?

In Figure 17, there is evidence of a positive relationship between local abundance of a species (number of unique individuals of a species recorded by human listener) and calling rate. Additional analyses indicated this relationship was not linearly related to local abundance and a breakpoint regression model improved the r^2 of the model to 0.60 and indicated that after a local abundance of 1.19 was reached there was no longer an increase in calling rate with higher local abundance. This suggests that calling rate could be used as a surrogate for counting number of individuals if we changed the way we estimate calling rate. There are several reasons why this might be a good idea: 1) we could use cheaper recording equipment that only records; 2) counts of calls may be more consistent among observers than trying to estimate abundance; and 3) automated recognition via computers can more easily recognize unique calls over unique individuals. Past work by ABMI has indicated considerable observer variability in counts of birds on the same recordings.

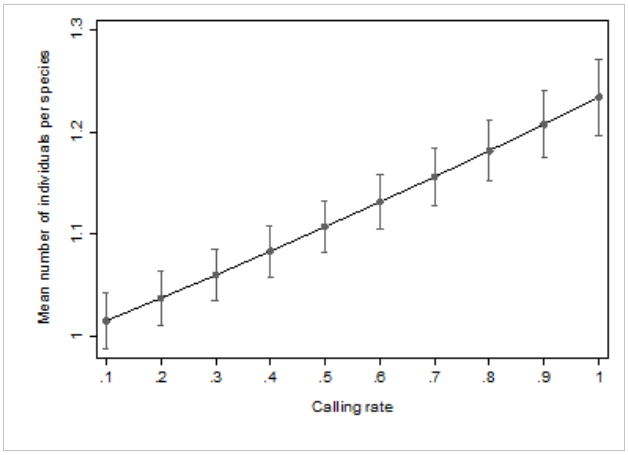


Figure 21. Results from mixed effects Poisson regression predicting the number of individuals per species as a function of calling rate. Error bars are 95% confidence intervals.

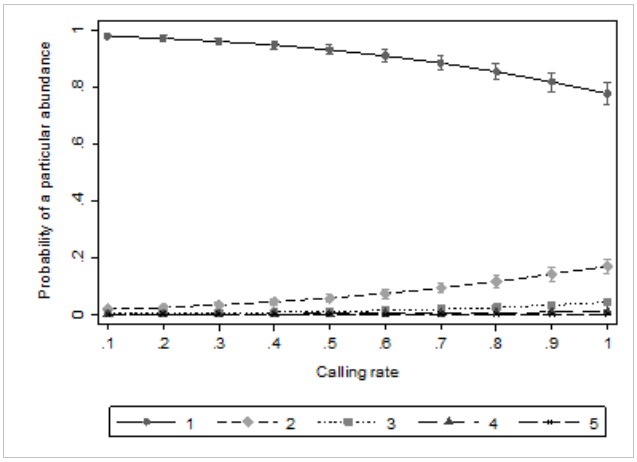


Figure 22. Results from mixed effects ordered multinomial regression predicting the probability of getting a count of 1,2,3,4, or 5 individuals per species as a function of calling rate. Error bars are 95% confidence intervals.

We used the entire Bioacoustic Unit dataset of 10-minute recordings to determine if estimated abundance from human listeners was correlated with calling rate within that point count. Here we used all species. Calling rate was estimated as the proportion of 1-minute sub-intervals from the entire 10-minute period where a species was observed calling or singing.

We modelled this data four ways: 1) using a mixed effects Poisson regression with calling rate as the predictor variable and the mean number of individuals per species as the response (Figure 18) ; 2) using a mixed ordered multinomial regression where we computed the probability of observing a particular abundance as the response variable based on calling rate as the predictor variable (Figure 19) ; 3) using a mixed linear regression where calling rate was the response variable (logit-transformed) and the number of individuals was treated as a categorical predictor (Figure 20); and 4) using a mixed logistic regression where the response was whether or not the count of birds was 1 or > 1 and calling rate was the predictor variable (Figure 21). Species was treated as a

random effect in all models. All models indicated that there was a pattern between calling rate and observer estimates of local abundance.

We then evaluated using the mixed logistic regression approach, how well the model fit for each individual species in terms of pseudo-r^2 and area under the curve (ROC score). A total of 82 species had sufficient data to test if calling rate predicted the abundance of a species. Overall, 42 species showed a significant relationship ($P < 0.05$) between calling rate and local abundance. The average ROC score was 0.75 and pseudo-r^2 was 0.16.

Figures 22-24 demonstrate how effective this might be for White-throated Sparrows. Figure 22 shows the probability of getting a count of 1 versus more than one as a function of calling rate. With a calling rate of 1 there is a 75% chance this represented more than one individual. Figure 23 shows a sensitivity vs. specificity plot, indicating the best cut-off for when to decide whether there is one versus more than one White-throated Sparrow based on calling rate.

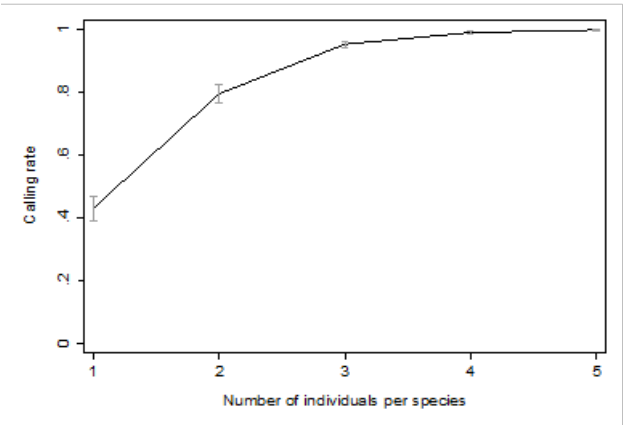


Figure 23. Results from mixed effects regression with a logit transformation predicting calling rate as function of number of individuals per species as a categorical predictor variable. Error bars are 95% confidence intervals.

Figure 23 suggests the cut-off for treating a count as >1 individual occurs at a probability of 0.33 for White-throated Sparrow, which is consistent with Figure 24 showing a similar pattern based on the area under the curve. In other words, at a calling rate of approximately 0.6 there it would be reasonable to conclude that more than one individual is calling in a recording. More work is needed to refine these estimates and assess consistency among habitats and regions, but suggest an area of research that might improve consistency in abundance estimation.

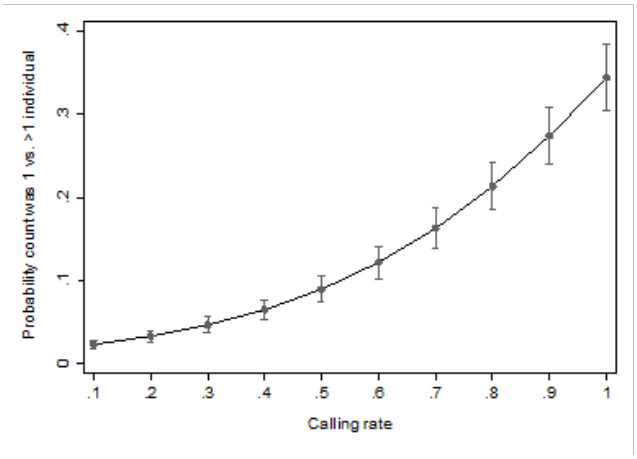


Figure 24. Results from mixed effects logistic regression predicting whether or not a count was a 1 versus >1 individual for each species as a function of calling rate. Error bars are 95% confidence intervals.

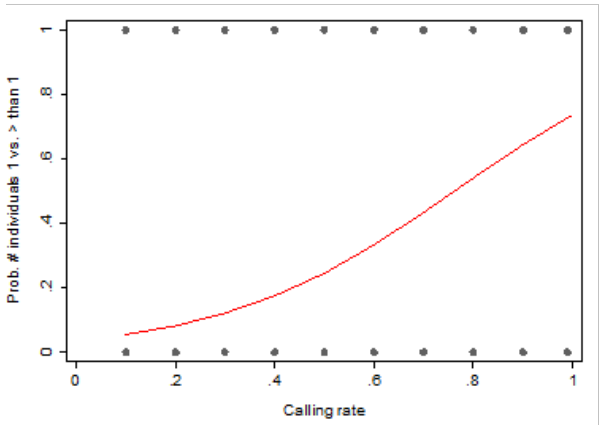


Figure 25. Probability that the number of White-throated Sparrows in a recording is 1 versus more than one as a function of calling rate.

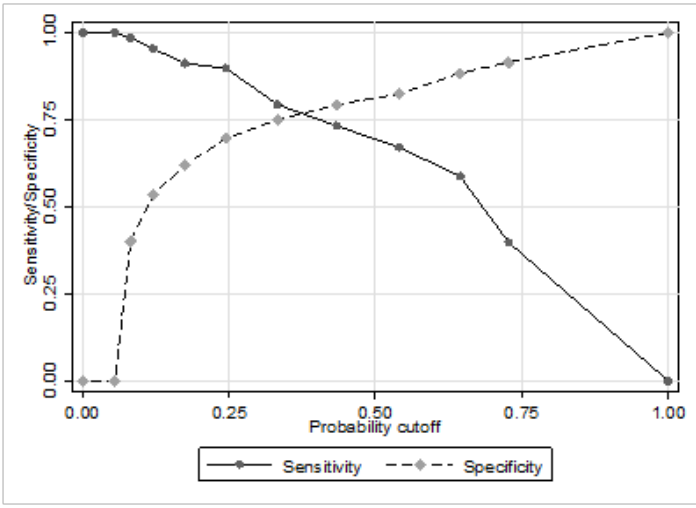


Figure 26. Sensitivity/ specificity curve showing probability cutoff for Figure 22 that balances the chance of making an error in defining the abundance of White-throated Sparrows as one or more than one. Where the lines crossed balances the chance of making an error in categorization.

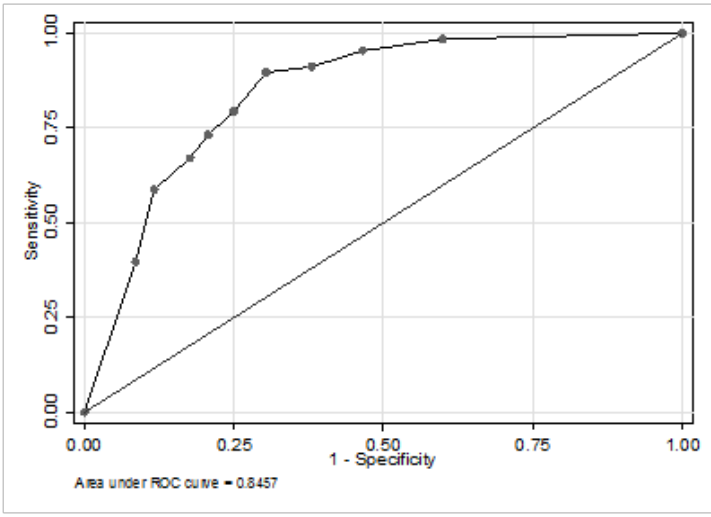


Figure 27. Area under a ROC curve for White-throated Sparrow model predicting whether there was 1 or more than one White-throated Sparrow on a recording as a function of calling rate.

Q13: What about animals outside of June?

The Bioacoustic Unit and ABMI does a combination of sampling in Alberta. ABMI core sites are placed out in February and March and record daily into July and are not moved. For the Bioacoustic Unit we place ARUs out in March/ April and don't move them until early June. The early season are intended for owls and amphibians which call more intermittently or have high variation in seasonality. In June, we have been following a 3-5 day recording schedule. Using these data we have been trying to develop a listening protocol that maximizes species detections within ABMI based on the following schedule (Table 5).

Table 5. Listening schedule used by ABMI for seasonal recordings.

	90-104	105-119	120-139	140-149	150-159	160-169	170-179	180-210
3 min at 2:00 am								
10 min at 30 min after sunrise	1x 1min		1x 1min	1x 3min		1x 3min		
3 min 2 hours after sunrise		1x 1min			1x 3min		1x 3min	1x 1min
3 min at noon								
3 min at 3:00 pm								
3 min 1 hour before sunset								
3 min 1 hour after sunset								
10 min at midnight	1 min			1x 1min		1x 1min		1x 1min

We used all the ARU data from ABMI 2015 (Northern Alberta). 124 sites and 3967 unique sampling events (sessions, 0--1 or 0--1--2--3 min duration recordings) have been transcribed (32 files per site). We used the first 1-minute part of the 3-minutes sessions, and all the 1-minute sessions to standardize for sampling effort. We tabulated counts (number of individuals detected in 1-minute interval) of 157 taxa by sampling events.

We used date and start time of each session to classify these into date and time categories. We differentiated the following time-of-day categories: Midnight, Morning. Time-of-year was categorized into weeks using the following ordinal days as breaks: 105, 120, 140, 150, 160, 170, 180 (Table 6).

Table 6. Number of point counts in each date and time of day.

	Midnight	Morning
(0,105]	77	328
(105,120]	102	333
(120,140]	155	403
(140,150]	150	371
(150,160]	157	362
(160,170]	164	344
(170,180]	172	352
(180,365]	214	283

Dates were further pooled into 3 main time-windows: Early (89--140), Mid (141--180), and Late (181--209), where the mid-season is defined by the range of existing May/June data from RiverForks and human observer based point counts (Table 7).

Table 7. Collapsed number of point counts into three seasons.

	Midnight	Morning
Early	334	1064
Mid	643	1429
Late	214	283

We used the opticut package to classify species according to their associations with dates and times using detections in a logistic regression. The method seeks to find the binary partition that maximizes model fit in terms of information criteria. First we split the data into two classes, Midnight and Morning. Species can be associated to either or both of these classes. We use the indicator value (I) to describe the contrast between the 2 classes. Values close to 0 indicate weak differentiation between the Morning and Midnight samples.

We used bootstrapping to understand the uncertainty with respect to the indicator value (I) and the best supported model. This latter metric is the reliability (R), c-hat is the probability that the same model would be best supported if we were to replicate the surveys. High reliability indicates that the best model (called split in the tables, indicating positive association with that class) was very consistent across the 99 bootstrap samples.

There were 22 species that associated more often to Midnight sampling, although some of these had really low reliability (e.g. Wilson's Snipe and Western Kingbird) indicating no particular preference towards morning or midnight. The other species were the expected suspects (owls, bats, amphibians, waterfowl, rails).

The other 135 species associated with Morning. A lot of these species had high indicator value and reliability. A few species had low reliability (e.g. Greater White-fronted Goose, American Bittern, Common Loon) which, again, do not differentiate between time-of-day that well as other species. Table 8 (Appendix) shows the results for time of day.

Figure 27 is a visual with similar information (but without

bootstrap based reliability). The coloring refers to the indicator value. Higher indicators are represented by more contrast (line width and color contrast). Species with not enough model support (log likelihood ratio < 2 compared to the null model of no association) were dropped and are not shown.

With 3 classes for season, there are 6 different combinations for positive associations between season and taxa. Based on the same bootstrapping procedure as described above, we identified associations for the various taxa. There were 34 early species. One early-late species, the Black-capped Chickadee, which being a resident seems less likely to be observed in mid-season. There were 27 early-mid species, 51 mid species, and 39 mid-late species. There were only 5 late-season, species all of which had low indicator and reliability scores. We incorporated proportions when early/mid/late season was part of the best supported partition (P.Early, P.Mid, P.Late). Red-breasted Nuthatch seemed to be mostly a late-season species, all of the other of late-season species showed an early+late pattern indicating decreased vocal activity in mid season. Potentially this is because these species have young later in the season that possibly begin vocalizing (Table 9 - Appendix).

Figure 28 shows (Appendix) a heatmap that summarizes the similarity across species and sub-seasons. The graph uses the proportions (P.Early, P.Mid, P.Late). Late and mid season communities were more similar, and species formed and early and a mid+late group.

Finally, we fit a GAM model to the number of detections per minute (sum across all species and individuals). Based on this summary, there were five times more individuals detected during a 1-minute morning session than in a 1-minute midnight session. We used a spline for date for morning and midnight sessions separately. Detection rate increased steadily untill day 145 and began decreasing after day 170 for the morning sessions. Midnight detections shows an earlier peak around day 130 and stayed high till day 160, so nocturnal species seem to start activity earlier. Results for the number of taxa were very similar due to the high correlation (0.96).

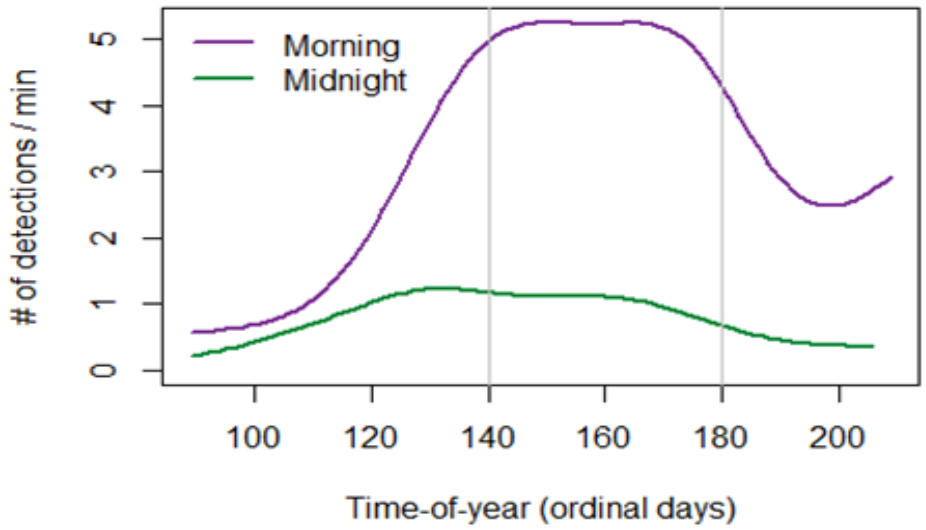


Figure 30. Line plot showing the number of detections per minute for morning versus midnight as a function of day of the year.

Q14: Do repeat visits really help us with individual species? Trend estimation

A fundamental goal of many monitoring agencies is to establish trends in species occurrence or abundance over time. Current trend assessment in Canada tends to use single-visit 3-minute duration unlimited-distance road-side surveys that are done by volunteers annually (Breeding Bird Survey - BBS). Limitations of this approach have been identified in the scientific literature. A primary concern is the issue of detection error. Detection error is when a species was present or uses a location in a given year but was not detected when the observer was present. ARUs are very good at reducing detection error because they allow a far greater duration of sampling to occur. The trade-off is that BBS, other types of human-based point counts, or moving ARUs regularly increases the number of locations that can be reached per unit time. Thus, understanding the relative merit of repeat surveys at the same location within a season versus visiting more locations a single time needs to be assessed relative to the goals of assessing population trends.

We used a long-term trend dataset from Calling Lake, AB conducted by human observers with 3-5 repeat surveys per year done at each station. Calling Lake, AB is a continuous 23-year time series in patches of varying size located in mature to old mixed-wood forest. Each year, visits to the same 186 stations occurred. Point counts were 100-metre radius point counts with a duration of 5 minutes.

A total of 122 species were detected in more than one year and were considered for analysis. We conducted two analyses of these data. First, we determined the proportion of stations where each species was observed each year. We modeled the proportion of stations occupied each year using a generalized linear model (hereafter GLM) with a binomial error family with robust standard errorss and included year as a continuous linear covariate. We separately estimated trends using 1, 2, 3, and 4 visits to each station. Trends were estimated 100 times for each species for each number of visits by selecting randomly drawn visit(s) to each station in each year. When we selected 2, 3, or 4 visits per station per year, we collapsed these data into whether or not the species was detected at any visit and then computed the proportion of stations where species was observed as our response variable.

Our second analysis used a generalized linear mixed model with a binomial error family and a random intercept with station identity (hereafter GLMM). In this analysis, we controlled for hour of day and day of the year as linear functions when assessing annual trend. In other words, the probability a species was observed at any visit was the response variable. The random intercept for station identity accounted for the repeat sampling at the same station within years. The selection of random visits to each station was done the same way as for analysis 1 except that we did not collapse the data into a proportion of stations occupied and simply used the data in its raw binary form for each visit to each station (observed vs. not observed).

For each analysis for each number of visits, we then computed the following summary statistics: 1) the percent of species where all 100 runs resulted in the model where annual trend was estimated with realistic standard errors; and 2) the median and average absolute trend estimate across all species for X visits. Summary statistics for trend were created by calculating the median and average

trend estimate for the Y runs that solved for each species and then collapsing this by taking the median or average for all the species pooled; 3) the average standard error (SE) of each trend was calculated the same way as for median and average absolute trend; 4) the average standard deviation (SD) in trend was the variability in trend for each species for X visits and the data were collapsed to calculate an average across all species; 5) the percent of species where at least one significant trend was observed in a random draw; and 6) the percent of species where 95% of the randomly drawn trends were statistical significant for that species.

Both analyses showed consistent benefits of repeatedly visiting the same station when estimating annual trend (Table 4 - Appendix). The percent of species where trend could be consistently estimated increased consistently with more visits. In general, GLM models were more likely to solve than the more complex GLMM. Perhaps more importantly, GLM models with 3 visits were equally likely to solve as 4 visit models while GLMM models consistently increased the number of species for which a realistic solution was possible. The average and median absolute trend decreased with more visits. This was generally caused by randomly drawn trends with extreme values becoming less likely with more visits. This can be seen by looking at differences between the average and median absolute trends with increasing number of visits. It is also supported by the fact that there are much higher SD in trends from 1 visit relative to using data from 2, 3, or 4 visits. The GLMM models tended to have less extreme trends than the GLM models but were also less likely to be statistically significant, particularly for rare species. In contrast, the results from the GLMM were more "consistent" as a greater number of species had >95% of their results statistically significant. Our results indicate that when estimating trends that having multiple visits to stations within the same year results in a greater number of robust but less extreme trend estimates when using an equivalent number of stations.

These results demonstrate a benefit of repeated sampling at the same station when assessing trend. However, the analysis done here assumes that the effort to get up to 4 visits to the same station does not come at a time or financial cost to the number of stations that are visited. We believe this assumption can be met in some circumstances (i.e. leave an ARU out for a day). However, whether or not the benefits of repeated sampling comes from multiple samples on the same day are as great from repeatedly sampling over the entire breeding period remain unknown. We are currently creating a data set to test this assumption. We are also working on a cost per point count analysis to determine how the repeated surveys from ARUs compare to repeated samples by field observers.

Q15: Do occupancy models correct for variation in sampling duration?

The primary idea behind occupancy modelling is that by correcting for detection error, a more robust estimate of the true proportion of locations where a species is observed. Presumably by correcting for detection error, methodological and sampling biases should be better accounted for. To test this idea, we generated occupancy estimates using program unmarked in R. This allowed us to correct for detection error for all species using all of the data from every station (average of 12 visits per station) versus using 4 visits per day on average, 4 visits in a week, and 4 visits over a month. The objective was to see if occupancy can correct for biases created by sampling for only a short period of time.

The answer to this question depended highly on what species were kept in the results. To analyse these results we used the occupancy estimate for each species from each sampling method as the response variable in mixed effects models. Using species as a random effect, we tested if the duration

of sampling was a significant predictor of occupancy on average. When all species were included there was a significant effect of sampling duration on average occupancy across species. However, pairwise comparisons with a Bonferroni correction demonstrated that week was significantly higher than the whole season and week was significantly higher than a day but no other pairwise comparisons were significant. However, in this approach the average occupancy estimate was quite high (range 0.42 to 0.52 across methods). This is because many species estimates are not robust and have errors in the estimation of standard errors. In other words, there simply is not enough data to accurately estimate occupancy rates given the low detection rates for many species. In these cases, the program typically estimated that these species had an occupancy rate of 1.

When we excluded all the species for which the estimation resulted in poorly estimated standard errors, the results changed (Figure 30). Occupancy estimates for all species were significant lower using a day of surveys than any other duration. Month and week were not significant different than each other but were significantly lower than season. A very similar pattern was observed with passerines only. The average occupancy rates dropped considerably with a range from 0.18 to 0.31 when the poorly estimated species were dropped.

The lower occupancy rates with a day of surveys is caused by two factors. First, many species are not likely present at a location during a day due to movement outside the sampling area but are more likely to move into the sampling area over a longer period of sampling. Second, those species that are present during a day are more likely to be detected that day presumably because they don't move out of the sampling area as much. This is reflected in the detection rates for both passerines and all species with reasonable standard errors as daily detection rate was significantly higher than all other sampling durations. Month was not significantly higher than season but all other pairwise comparisons were significantly different. These patterns were the same for passerines and all species. Occupancy estimates for each species are shown in Table 11 (Appendix).

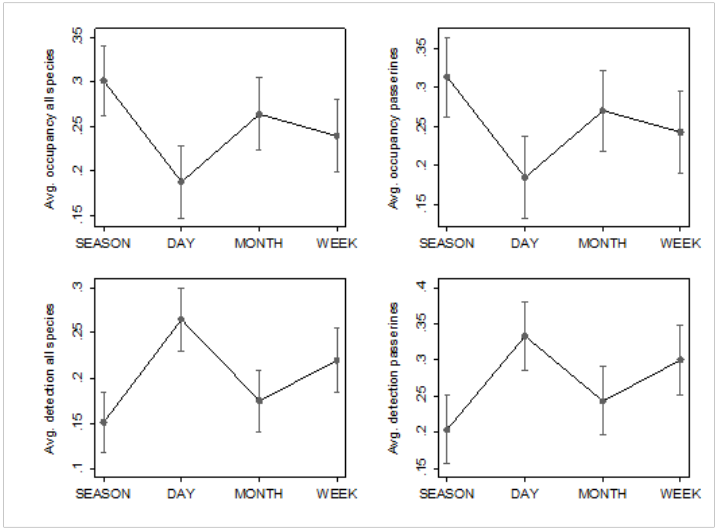


Figure 31. Average occupancy and detection rates for all species (with reasonable standard errors) and passerines across different sampling durations. Error bars are 95% confidence intervals.

(Kolaczan, 2014)

General Conclusions

1) More work is needed on the financial costs that breakdown deployment costs, purchasing of ARUs, storage, and processing are needed to define an optimal schedule. Regardless, as demonstrated by comparing all species to passerines alone, this cost-benefit structure will be very dependent on what species are of interest.

2) For migratory passerines, there is evidence that leaving an ARU out for several days results in higher occupancy rates and probability of observation than a single day with repeated samples. There is less of a benefit of leaving ARUs out for a month for passerines. However, all of the analyses done in this report indicate that an increasing number of species will be observed with more effort.

3) Whether this effort comes from increased time at the same location or moving different locations requires further work, but all of the results suggest considerable animal movement is occurring as it was rare in these analyses to reach a plateau in species number with increasing effort.

4) The lack of closure as well as lack of independence in repeated surveys done closer together causes several issues that need to be evaluated from a statistical perspective. First, the closure assumption for species at a single ARU is violated for many species. Thus, interpretation of occupancy must rely on the super-population concept. The idea of the super-population is that we are measuring the probability that the species will interact with a given space at least once during the period of observation. It is unclear however, whether we should conceptualize the super-population as existing over the entire period of sampling (i.e. the super-population exists between the data, the first ARU that was put out, and the last ARU that was retrieved). Alternatively, should occupancy estimates be envisioned as being relevant to the period of time that a single ARU was deployed (i.e. occupancy estimate is conceptualized as existing at a day, week, or month scale depending on sampling design). More work is need to see if correcting for other covariates (i.e. observer, time of day) can correct daily sampling designs such that occupancy estimates derived from a single day of sampling at multiple locations on different days result in the same estimates as when the station is sampled for an entire month.

5) With closure likely violated at longer time intervals due to animal movement, it would seem that repeatedly sampling within a short time period when movement is minimal might improve estimates. However, the results from the serial autocorrelation analyses suggest that there is a lack of independence in singing rate estimates. What biases this creates in occupancy estimates and/or corrections based on singing rate need further exploration. In particular, looking at how serial autocorrelation influences these estimates when calculating density needs to be done.

6) The use of short-duration point counts done at different times of day and year improve our ability to detect more species. With ARUs, the travel time between points is minimized making it logical to spread point counts out more. However, whether only doing 1-minute point counts is the completely optimal strategy needs more investigation. These results indicate a series of 1-minute point counts at different times of the day and year will increase the number of species observed more rapidly making listening more cost-effective. However, only doing 1-minute point counts limits some of our analytical options.

7) The potential for measuring singing rate from recordings split into many time periods is one example of why 1-minute point counts alone may not be ideal. Singing rates can help in density estimation and as demonstrated might be able to be used to identify numbers of individuals more consistently. In addition, there are no "true 1-minute point counts in this data". What we mean is that listening to 1-minute may result in "hard to identify" species being missed that might have been heard in a 3 or 5 minute count. For example, in 1-minute it often happens that a species sings but is always masked by another species. The observer might hear this masked bird and know it is present but not be able to clearly identify it to species. By listening for long in that same general period of time it is possible that the masked bird will be able to move closer to the ARU or simply sing at a time when the other bird is not, making it possible to identify the species properly. Whether the masked bird should be identified as present in the previous time step based on the ID in the next time step is an unresolved question.

8) Our analyses of trend indicate that there is significant benefit to multiple visits at the same location each year. Admittedly, we did not do analyses that traded off the effort in going to more stations versus repeated sampling at the same location. Furthermore, we have not yet assessed how occupancy or n-mixture modelling performs in this regard. Future work is intended in this area.

9) Our overall recommendation based on the analyses in this report are:

a. How long you place an ARU and how much data you process depends on your objective. Thus, there is no one answer that optimizes results for all species or for all questions. Inclusion of amphibians, owls, nocturnal species etc. changes the best ways of laying out ARUs.

b. For passerines, there is strong evidence that shorter duration point counts (1-minute) will increase detection rates and allow for greater number of recordings from different days to be processed. This will result in more species found faster. Trade-offs with other methodological approaches will occur however. For example, 1 minute point counts have higher detection error per visit but cumulatively have higher detection overall if you put in equal effort (10 1-minute point counts vs. 1 10 minute point counts). More work is need in understanding the implications from using occupancy estimates from short versus longer periods of sampling time per individual point counts in terms of the stability of occupancy estimates.

c. We do not have a firm recommendation on whether the total time should be 3,5, or 10 minutes per recording processed at this time. However, we do strongly recommend that listening in 1-minute time blocks within any longer interval provides the greatest flexibility in methods from an ARU and highest return on listening investment. The ability to estimate parameters such as song rate increases the utility of such data and has the potential to help us better measure a greater array of state variables (i.e. singing rate, occurrence, density.

d. A single day of recording does not seem to be the best way to estimate occupancy or assess probability of occurrence. Leaving an ARU for several days seems to provide a reasonable balance in getting detections from species that hold territories close to an ARU while also increasing the probability of getting rarer species with larger home ranges that only periodically are near an ARU. Less is gained by leaving them out for a month if it comes at the cost of visiting more stations.

Acknowledgements

We thank the Oil Sands Monitoring Program and Environment and Climate Change Canada for support, data, and staff funding.

Appendix

Table 2. Proportion of stations where species were observed using different sampling designs (n = 137 stations): 1) SEASON – entire sampling period with average 11.4 ± 1.7 (SD) of recordings processed; 2) MONTH - one recording per week was processed per 4.36 ± 0.74 weeks per station (range 3 to 5); 3) WEEK - one recording per day was processed for a single week with 3.72 ± 0.48 recordings per WEEK (range 3 to 5) ; and 4) DAY where 3.73 ± 0.46 recordings were processed per day (range 3 to 5).

CODE	SPECIES	SEASON	MONTH	WEEK	DAY
alfl	Alder Flycatcher	0.664	0.591	0.541	0.453
ambi	American Bittern	0.146	0.044	0.068	0.044
amco	American Coot	0.139	0.08	0.075	0.066
amcr	American Crow	0.153	0.08	0.075	0.08
amgo	American Goldfinch	0.058	0.029	0.03	0.022
amre	American Redstart	0.146	0.073	0.053	0.058
amro	American Robin	0.839	0.547	0.602	0.635
amto	American toad	0.095	0.022	0.098	0
amwi	American Wigeon	0.044	0	0.015	0.015
atsp	American Tree Sparrow	0.051	0.051	0.038	0.036
attw	American Three-toed Woodpecker	0.007	0	0	0.007
auwa	Audubons's Warbler	0.35	0.307	0.173	0.212
bado	Barred Owl	0.007	0	0	0
Baea	Bald Eagle	0.015	0.007	0	0.015
Bans	Bank Swallow	0.015	0.015	0.008	0
baor	Baltimore Oriole	0.029	0.007	0.008	0.015
baww	Black-and-white Warbler	0.109	0.066	0.083	0.073
bbma	Black-billed Magpie	0.073	0.036	0.045	0.044
bbwa	Bay-breasted Warbler	0.044	0.015	0.023	0.007
bbwo	Black-backed Woodpecker	0.139	0.051	0.053	0.066
bcch	Black-capped Chickadee	0.124	0.058	0.053	0.058
bcfr	Boreal Chorus Frog	0.219	0.131	0.173	0.146
beav	American Beaver	0.007	0	0.008	0.007
Beki	Belted Kingfisher	0.015	0	0.015	0
bhco	Brown-headed Cowbird	0.036	0.029	0.008	0.015

bhvi	Blue-headed Vireo	0.219	0.102	0.09	0.073
blbw	Blackburnian Warbler	0.007	0	0.008	0
blja	Blue Jay	0.036	0.029	0.008	0.015
blpw	Blackpoll Warbler	0.175	0.161	0.143	0.139
blte	Black Tern	0.066	0.036	0.038	0.036
boch	Boreal Chickadee	0.109	0.058	0.03	0.029
bogu	Bonaparte's Gull	0.073	0.036	0.045	0.022
Boow	Boreal Owl	0.015	0	0	0
bowa	Bohemian Waxwing	0.036	0.007	0.015	0.007
brbl	Brewer's Blackbird	0.044	0.036	0.023	0.015
brcr	Brown Creeper	0.088	0.029	0.038	0.022
brth	Brown Thrasher	0.007	0	0	0.007
btnw	Black-throated Green Warbler	0.007	0.007	0	0
Bwha	Broad-winged Hawk	0.015	0	0.015	0
cang	Canada Goose	0.474	0.204	0.256	0.226
cawa	Canada Warbler	0.029	0.015	0.008	0.007
ccsp	Clay-colored Sparrow	0.168	0.153	0.158	0.124
cedw	Cedar Waxwing	0.102	0.058	0.03	0.007
Chik	Domestic Chicken	0.015	0.015	0.008	0.007
chsp	Chipping Sparrow	0.759	0.555	0.436	0.547
cmwa	Cape May Warbler	0.08	0.036	0.03	0.051
colo	Common Loon	0.38	0.19	0.211	0.19
Come	Common Merganser	0.015	0.007	0	0.015
coni	Common Nighthawk	0.328	0.219	0.18	0.219
conw	Connecticut Warbler	0.19	0.109	0.083	0.029
cora	Common Raven	0.394	0.226	0.18	0.197

core	Common Redpoll	0.029	0.007	0	0.015
cote	Common Tern	0.007	0	0	0.007
coww	Domestic Cow	0.08	0.066	0.083	0.073
coye	Common Yellowthroat	0.453	0.343	0.278	0.182
cswa	Chestnut-sided Warbler	0.007	0	0	0.007
deju	Dark-eyed Junco	0.766	0.635	0.617	0.62
dogg	Domestic Dog	0.029	0.029	0.023	0.007
dowo	Downy Woodpecker	0.036	0.007	0	0.036
eagr	Eared Grebe	0.007	0	0	0.007
eaki	Eastern Kingbird	0.036	0.036	0.008	0.007
eaph	Eastern Phoebe	0.007	0	0	0.007
Eust	European Starling	0.015	0.007	0.008	0
evgr	Evening Grosbeak	0.044	0.007	0.008	0.029
ewpw	Eastern Whip-poor-will	0.007	0.007	0	0
fosp	Fox Sparrow	0.445	0.328	0.293	0.197
Frgu	Franklin's Gull	0.029	0.022	0.015	0.015
Gadw	Gadwall	0.022	0.015	0	0.007
gcki	Golden-crowned Kinglet	0.058	0.015	0.038	0.015
gcth	Gray-cheeked Thrush	0.161	0.131	0.09	0.102
Ggow	Great Gray Owl	0.015	0.007	0.008	0
ghow	Great Horned Owl	0.007	0	0	0.007
graj	Gray Jay	0.591	0.299	0.293	0.204
grye	Greater Yellowlegs	0.248	0.109	0.098	0.088
gwfg	Greater White-fronted Goose	0.007	0	0.008	0.007
Gwte	Green-winged Teal	0.022	0.007	0.015	0.007
hawo	Hairy Woodpecker	0.08	0.044	0.015	0.022
herg	Herring Gull	0.036	0.015	0.008	0.022
heth	Hermit Thrush	0.854	0.752	0.744	0.715
hogr	Horned Grebe	0.007	0	0.008	0
hola	Horned Lark	0.007	0.007	0	0
howr	House Wren	0.073	0.051	0.038	0.044

kill	Killdeer	0.044	0.029	0.015	0.015
lcsp	Le Conte's Sparrow	0.212	0.146	0.143	0.139
lefl	Least Flycatcher	0.416	0.248	0.203	0.168
leye	Lesser Yellowlegs	0.307	0.146	0.211	0.219
lisp	Lincoln's Sparrow	0.788	0.664	0.594	0.518
Ltdu	Long-tailed Duck	0.015	0.007	0.015	0
Mago	Marbled Godwit	0.022	0.007	0.008	0.007
mall	Mallard	0.058	0.022	0.03	0.029
mawa	Magnolia Warbler	0.409	0.27	0.248	0.197
mawr	Marsh Wren	0.007	0	0.008	0
Merl	Merlin	0.015	0.007	0.008	0.015
modo	Mourning Dove	0.007	0	0.008	0
mowa	Mourning Warbler	0.066	0.022	0.045	0.015
nawa	Nashville Warbler	0.204	0.117	0.083	0.095
nesp	Nelson's Sparrow	0.051	0.022	0.038	0.044
nhow	Northern Hawk Owl	0.007	0.007	0.008	0
nofl	Northern Flicker	0.19	0.088	0.12	0.088
nogo	Northern Goshawk	0.007	0	0	0
nowa	Northern Waterthrush	0.489	0.299	0.391	0.255
Nsho	Northern Shoveler	0.029	0.007	0.023	0.015
ocwa	Orange-crowned Warbler	0.547	0.372	0.368	0.27
osfl	Olive-sided Flycatcher	0.453	0.401	0.316	0.204
ospr	Osprey	0.007	0.007	0	0
oven	Ovenbird	0.139	0.117	0.098	0.095
Palo	Pacific Loon	0.022	0.007	0.023	0
pawa	Palm Warbler	0.657	0.496	0.421	0.387
pbgr	Pied-billed Grebe	0.124	0.066	0.068	0.066
phvi	Philadelphia Vireo	0.124	0.051	0.053	0.051
pisi	Pine Siskin	0.109	0.058	0.03	0.051
Piwa	Pine Warbler	0.015	0.007	0.015	0
piwo	Pileated Woodpecker	0.109	0.029	0.053	0.029

pufi	Purple Finch	0.007	0	0.008	0
rbgr	Rose-breasted Grosbeak	0.146	0.088	0.075	0.08
Rbgu	Ring-billed Gull	0.022	0	0.015	0
rbme	Red-breasted Merganser	0.007	0.007	0	0
rbnu	Red-breasted Nuthatch	0.08	0.029	0.045	0.029
rcki	Ruby-crowned Kinglet	0.723	0.562	0.556	0.489
recr	Red Crossbill	0.051	0.022	0	0.022
resq	Red Squirrel	0.35	0.285	0.241	0.212
revi	Red-eyed Vireo	0.314	0.248	0.143	0.066
Rhwo	Red-headed Woodpecker	0.015	0.007	0.015	0
rngr	Red-necked Grebe	0.036	0.015	0.023	0.022
rthu	Ruby-throated Hummingbird	0.015	0.007	0	0.007
rtlo	Red-throated Loon	0.058	0.051	0.038	0.051
rubl	Rusty Blackbird	0.102	0.036	0.038	0.044
rugr	Ruffed Grouse	0.197	0.051	0.12	0.109
rwbl	Red-winged Blackbird	0.197	0.139	0.15	0.073
sacr	Sandhill Crane	0.365	0.226	0.226	0.234
savs	Savannah Sparrow	0.139	0.095	0.098	0.102
sbdo	Short-billed Dowitcher	0.036	0.022	0.03	0.015
seow	Short-eared Owl	0.007	0	0	0
sewr	Sedge Wren	0.015	0	0.008	0.007
sora	Sora	0.234	0.175	0.128	0.146
sosa	Solitary Sandpiper	0.066	0.036	0.038	0.007
sosp	Song Sparrow	0.109	0.088	0.105	0.102
spgr	Spruce Grouse	0.139	0.066	0.053	0.029
sppe	Spring peeper	0.102	0.029	0.105	0
sppi	Sprague's Pipit	0.015	0.007	0	0.007
spsa	Spotted Sandpiper	0.044	0.022	0.015	0.022
Stgr	Sharp-tailed Grouse	0.022	0.007	0.023	0.007
swsp	Swamp Sparrow	0.533	0.35	0.316	0.263
swth	Swainson's Thrush	0.796	0.628	0.617	0.438

tewa	Tennessee Warbler	0.577	0.46	0.331	0.314
tres	Tree Swallow	0.285	0.153	0.165	0.08
tusw	Tundra Swan	0.007	0.007	0	0
upsa	Upland Sandpiper	0.015	0.007	0.015	0.007
vesp	Vesper Sparrow	0.051	0.036	0.038	0.029
wavi	Warbling Vireo	0.051	0.036	0.03	0.022
wbbe	Woodborer Beetle	0.007	0	0.008	0
wcsp	White-crowned Sparrow	0.131	0.117	0.098	0.102
weme	Western Meadowlark	0.044	0.036	0.023	0.029
weta	Western Tanager	0.117	0.058	0.068	0.022
weto	Western Toad	0.036	0.022	0.03	0.007
wewp	Western Wood-Pewee	0.051	0.044	0.03	0.007
wifl	Willow Flycatcher	0.015	0	0	0.007
will	Willet	0.007	0	0	0.007
wisn	Wilson's Snipe	0.613	0.423	0.391	0.416
witu	Wild Turkey	0.007	0	0	0.007
wiwa	Wilson's Warbler	0.533	0.401	0.316	0.234
wiwr	Winter Wren	0.416	0.328	0.338	0.255
wofr	Wood Frog	0.036	0.007	0.015	0.015
wtsp	White-throated Sparrow	0.876	0.788	0.812	0.81
wwcr	White-winged Crossbill	0.234	0.102	0.068	0.08
ybfl	Yellow-bellied Flycatcher	0.453	0.314	0.271	0.219
ybsa	Yellow-bellied Sapsucker	0.182	0.095	0.06	0.073
yera	Yellow Rail	0.036	0.029	0.023	0.022
yewa	Yellow Warbler	0.139	0.095	0.083	0.066
Yhbl	Yellow-headed Blackbird	0.029	0.015	0.015	0.022
yrwa	Yellow-rumped Warbler	0.591	0.394	0.451	0.445
ytvi	Yellow-throated Vireo	0.007	0.007	0.008	0

Table 3. Detection rate and number of visits required to have 95% certainty the species is absent for each species using different sampling designs (n = 137 stations). Detection rate was the average proportion of visits at a station where the species was observed for those stations where the species was known to occur. In other words, only those stations where the species were observed at least once were used to compute detection rates. 1) SEASON – entire sampling period with average of 11.4 ± 1.7 (SD) of recordings processed; 2) MONTH - one recording per week was processed per 4.36 ± 0.74 weeks per station (range 3 to 5); 3) WEEK - one recording per day was processed for a single week with 3.72 ± 0.48 recordings per WEEK (range 3 to 5) ; and 4) DAY where 3.73 ± 0.46 recordings were processed per day (range 3 to 5). SEASONvisits-DAYvisits is the number of unique 3-minute point counts within that particular time interval required to have 95% certainty that the species was absent from a station during that time interval. In other words, for Hermit Thrush it would require four 3-minute point counts across the entire season (one per week) to ensure with 95% certainty that the species was absent. It would only require three 3-minute point counts within a given day (one per hour) to ensure with 95% certainty that the species was absent.

					Visits			
SPECIES	SEASON	MONTH	WEEK	DAY	SEASON	MONTH	WEEK	DAY
Alder Flycatcher	0.48	0.54	0.62	0.65	5	4	3	3
American Bittern	0.16	0.26	0.3	0.56	17	10	8	4
American Coot	0.25	0.37	0.42	0.53	11	7	6	4
American Crow	0.26	0.42	0.43	0.48	10	5	5	5
American Goldfinch	0.17	0.25	0.3	0.44	16	10	8	5
American Redstart	0.17	0.31	0.35	0.43	16	8	7	5
American Robin	0.34	0.42	0.48	0.57	7	6	5	4
American Wigeon	0.09	0.33	0.26	0.29	34	7	10	9
American Tree Sparrow	0.5	0.5	0.82	0.6	4	4	2	3
Audubons's Warbler	0.25	0.33	0.28	0.41	10	7	9	6
Baltimore Oriole	0.19	0.32	0.75	0.33	14	8	2	7
Black-and-white Warbler	0.3	0.37	0.57	0.61	8	7	4	3
Black-billed Magpie	0.35	0.56	0.4	0.67	7	4	6	3
Bay-breasted Warbler	0.14	0.23	0.44	0.33	19	12	5	7
Black-backed Woodpecker	0.08	0.2	0.25	0.28	34	13	10	9
Black-capped Chickadee	0.18	0.26	0.46	0.42	15	10	5	6
Boreal Chorus Frog	0.35	0.33	0.5	0.75	7	7	4	2

Brown-headed Cowbird	0.09	0.17	0.33	0.29	33	16	7	9
Blue-headed Vireo	0.12	0.21	0.28	0.46	23	13	9	5
Blue Jay	0.18	0.18	0.33	0.5	15	15	7	4
Blackpoll Warbler	0.58	0.58	0.81	0.8	3	3	2	2
Black Tern	0.25	0.39	0.61	0.52	10	6	3	4
Boreal Chickadee	0.13	0.24	0.28	0.35	21	11	9	7
Bonaparte's Gull	0.25	0.44	0.5	0.58	10	5	4	3
Bohemian Waxwing	0.1	0.21	0.25	0.25	29	13	10	10
Brewer's Blackbird	0.13	0.23	0.33	0.25	21	12	7	10
Brown Creeper	0.1	0.2	0.27	0.44	27	14	10	5
Canada Goose	0.15	0.27	0.33	0.37	18	10	8	7
Canada Warbler	0.09	0.17	0.33	0.25	32	16	7	10
Clay-colored Sparrow	0.65	0.69	0.75	0.91	3	3	2	1
Cedar Waxwing	0.1	0.2	0.27	0.33	27	14	9	7
Chipping Sparrow	0.32	0.37	0.5	0.5	8	7	4	4
Cape May Warbler	0.22	0.3	0.6	0.62	12	8	3	3
Common Loon	0.18	0.26	0.36	0.43	15	10	7	5
Common Nighthawk	0.23	0.34	0.33	0.42	12	7	7	6
Connecticut Warbler	0.11	0.24	0.33	0.46	25	11	7	5
Common Raven	0.18	0.34	0.44	0.39	15	7	5	6
Common Redpoll	0.09	0.19	0.25	0.25	30	14	10	10
Domestic Cow	0.45	0.46	0.58	0.53	5	5	3	4
Common Yellowthroat	0.28	0.4	0.48	0.61	9	6	5	3
Dark-eyed Junco	0.42	0.47	0.53	0.55	5	5	4	4
Domestic Dog	0.19	0.27	0.33	0.33	14	9	7	7
Eastern Kingbird	0.1	0.2	0.5	0.25	29	13	4	10
Evening Grosbeak	0.1	0.17	0.25	0.4	28	16	10	6
Fox Sparrow	0.35	0.5	0.58	0.63	7	4	3	3
Franklin's Gull	0.19	0.23	0.45	0.5	14	11	5	4
Golden-crowned Kinglet	0.11	0.25	0.37	0.33	26	11	7	7

Gray-cheeked Thrush	0.36	0.47	0.6	0.48	7	5	3	5
Gray Jay	0.15	0.28	0.33	0.36	18	9	7	7
Greater Yellowlegs	0.11	0.2	0.28	0.3	26	13	9	8
Green-winged Teal	0.08	0.33	0.29	0.33	34	7	9	7
Hairy Woodpecker	0.09	0.19	0.29	0.28	31	14	9	9
Herring Gull	0.08	0.2	0.25	0.25	37	13	10	10
Hermit Thrush	0.54	0.61	0.59	0.61	4	3	3	3
House Wren	0.36	0.37	0.68	0.61	7	7	3	3
Killdeer	0.17	0.26	0.5	0.5	16	10	4	4
Le Conte's Sparrow	0.45	0.65	0.62	0.7	5	3	3	2
Least Flycatcher	0.16	0.28	0.34	0.35	17	9	7	7
Lesser Yellowlegs	0.23	0.32	0.37	0.42	12	8	6	5
Lincoln's Sparrow	0.39	0.47	0.55	0.63	6	5	4	3
Marbled Godwit	0.12	0.2	0.33	0.33	24	13	7	7
Mallard	0.14	0.22	0.3	0.31	20	12	8	8
Magnolia Warbler	0.22	0.3	0.41	0.51	12	8	6	4
Mourning Warbler	0.17	0.33	0.41	0.33	16	8	6	7
Nashville Warbler	0.14	0.22	0.32	0.4	20	12	8	6
Nelson's Sparrow	0.37	0.51	0.75	0.46	6	4	2	5
Northern Flicker	0.15	0.22	0.31	0.34	18	12	8	7
Northern Waterthrush	0.28	0.36	0.45	0.57	9	7	5	4
Northern Shoveler	0.09	0.25	0.29	0.33	32	10	9	7
Orange-crowned Warbler	0.23	0.32	0.36	0.43	12	8	7	5
Olive-sided Flycatcher	0.29	0.35	0.51	0.44	9	7	4	5
Ovenbird	0.46	0.55	0.74	0.72	5	4	2	2
Palm Warbler	0.33	0.41	0.5	0.53	8	6	4	4
Pied-billed Grebe	0.16	0.33	0.33	0.44	17	7	7	5
Philadelphia Vireo	0.09	0.19	0.26	0.31	30	15	10	8
Pine Siskin	0.12	0.21	0.28	0.43	23	13	9	5
Pileated Woodpecker	0.1	0.2	0.28	0.27	30	14	9	9

Rose-breasted Grosbeak	0.19	0.27	0.42	0.52	14	10	6	4
Red-breasted Nuthatch	0.13	0.25	0.27	0.5	22	11	10	4
Ruby-crowned Kinglet	0.41	0.46	0.6	0.61	6	5	3	3
Red Crossbill	0.08	0.2	0.25	0.25	34	13	10	10
Red Squirrel	0.34	0.46	0.49	0.59	7	5	4	3
Red-eyed Vireo	0.24	0.37	0.5	0.61	11	7	4	3
Red-necked Grebe	0.3	0.39	0.67	0.53	8	6	3	4
Red-throated Loon	0.33	0.45	0.6	0.29	8	5	3	9
Rusty Blackbird	0.12	0.22	0.32	0.24	24	12	8	11
Ruffed Grouse	0.19	0.25	0.36	0.56	14	10	7	4
Red-winged Blackbird	0.31	0.54	0.46	0.79	8	4	5	2
Sandhill Crane	0.21	0.28	0.37	0.48	13	9	7	5
Savannah Sparrow	0.43	0.63	0.6	0.6	5	3	3	3
Short-billed Dowitcher	0.13	0.21	0.31	0.38	21	13	8	6
Sora	0.32	0.39	0.54	0.52	8	6	4	4
Solitary Sandpiper	0.12	0.26	0.24	0.25	24	10	11	10
Song Sparrow	0.61	0.77	0.77	0.73	3	2	2	2
Spruce Grouse	0.09	0.23	0.25	0.27	32	12	10	9
Spotted Sandpiper	0.1	0.19	0.25	0.28	30	14	10	9
Swamp Sparrow	0.26	0.37	0.43	0.46	10	6	5	5
Swainson's Thrush	0.39	0.48	0.52	0.58	6	5	4	3
Tennessee Warbler	0.42	0.55	0.7	0.76	5	4	3	2
Tree Swallow	0.13	0.24	0.31	0.3	21	11	8	8
Vesper Sparrow	0.4	0.47	0.63	0.58	6	5	3	3
Warbling Vireo	0.19	0.22	0.33	0.56	14	12	7	4
White-crowned Sparrow	0.55	0.65	0.71	0.7	4	3	2	3
Western Meadowlark	0.51	0.6	0.89	0.67	4	3	1	3
Western Tanager	0.18	0.24	0.41	0.5	15	11	6	4
Western Toad	0.09	0.23	0.33	0.25	32	12	7	10
Western Wood-Pewee	0.28	0.44	0.58	0.67	9	5	3	3

Wilson's Snipe	0.34	0.46	0.5	0.55	7	5	4	4
Wilson's Warbler	0.23	0.34	0.35	0.37	11	7	7	6
Winter Wren	0.31	0.37	0.42	0.44	8	6	6	5
Wood Frog	0.09	0.2	0.29	0.29	34	13	9	9
White-throated Sparrow	0.76	0.82	0.86	0.84	2	2	2	2
White-winged Crossbill	0.11	0.25	0.26	0.28	26	11	10	9
Yellow-bellied Flycatcher	0.23	0.33	0.43	0.39	11	8	5	6
Yellow-bellied Sapsucker	0.13	0.27	0.4	0.3	21	9	6	8
Yellow Rail	0.39	0.56	0.63	0.42	6	4	3	6
Yellow Warbler	0.32	0.34	0.59	0.74	8	7	3	2
Yellow-headed Blackbird	0.53	0.67	1	0.78	4	3	NA	2
Yellow-rumped Warbler	0.38	0.52	0.54	0.56	6	4	4	4

Table 4. Results for each species predicting whether the count of a species was one versus more than one per 10-minute recording as a function of calling rate.

Species	#obs	r^2	lroc	CallingRate	Lower95CR	Upper95CR	Constant
Alder Flycatcher	232	0.39	0.9	6.139	4.14	8.137	-5.74
American Coot	180	0.27	0.9	5.273	2.14	8.406	-5.789
American Crow	100	0.09	0.71	3.374	0.347	6.4	-3.803
American Redstart	36	0.29	0.87	5.464	0.211	10.717	-5.628
American Robin	247	0.3	0.87	6.787	3.923	9.652	-7.107
American Wigeon	98	0.01	0.59	0.893	-2.887	4.673	-3.152
Barred Owl	100	0.04	0.66	1.921	-0.073	3.915	-2.489
Black-capped Chickadee	131	0.21	0.81	5.068	1.838	8.297	-4.947
Boreal Chorus Frog	1133	0	0.61	-0.444	-1.214	0.326	-2.472
Blue-headed Vireo	13	0.2	0.77	5.057	-2.283	12.397	-4.749
Bonaparte's Gull	50	0.11	0.78	3.034	-0.582	6.649	-4.083
Boreal Owl	335	0.14	0.77	4.513	1.984	7.041	-6.135
Brown Creeper	34	0.15	0.82	3.847	-1.599	9.292	-5.01
Blue-winged Teal	59	0.06	0.68	-4.297	-17.794	9.201	-2.874
Canada Goose	291	0.08	0.76	2.784	1.063	4.505	-4.002
Clay-colored Sparrow	223	0.12	0.77	3.058	1.355	4.761	-4.252
Chipping Sparrow	397	0.29	0.87	5.116	3.71	6.521	-5.243
Common Loon	328	0.15	0.76	5.94	4.181	7.698	-2.894
Common Nighthawk	166	0.3	0.87	5.38	2.876	7.885	-5.834
Connecticut Warbler	52	0.11	0.71	3.159	0.252	6.067	-3.549
Common Raven	166	0.25	0.89	5.063	2.425	7.7	-5.026
Common Yellowthroat	169	0.45	0.91	9.608	5.849	13.367	-8.617
Coyote	75	0.02	0.64	2.009	-1.927	5.944	-2.931
Dark-eyed Junco	165	0.29	0.86	5.348	3.274	7.423	-5.077
Forster's Tern	134	0.05	0.72	2.518	-0.324	5.359	-3.97
Franklin's Gull	39	0.3	0.93	6.63	-3.905	17.164	-7.477
Great Horned Owl	206	0.07	0.72	2.288	0.589	3.986	-3.749

Gray Jay	130	0.29	0.83	6.205	2.193	10.216	-6.007
Greater Yellowlegs	159	0	0.45	-0.063	-2.932	2.805	-2.916
Greater White-fronted Goose	17	0	0.56	0.018	-7.707	7.744	-2.782
Green-winged Teal	96	0.14	0.78	3.711	0.759	6.664	-4.138
Hairy Woodpecker	10	0.03	0.66	1.663	-4.519	7.845	-1.964
Hermit Thrush	276	0.14	0.75	4.071	2.236	5.905	-4.891
Killdeer	44	0.42	0.93	11.284	-2.284	24.853	-9.868
Le Conte's Sparrow	505	0.19	0.78	4.335	3.211	5.459	-4.525
Least Flycatcher	106	0.05	0.68	1.889	-0.358	4.136	-3.499
Lesser Yellowlegs	49	0.02	0.6	1.565	-1.365	4.496	-2.102
Lincoln's Sparrow	316	0.21	0.83	4.051	2.648	5.453	-4.627
Mallard	158	0.11	0.8	3.649	1.09	6.208	-4.13
Magnolia Warbler	36	0.2	0.77	4.132	-0.227	8.49	-4.629
Marsh Wren	85	0.45	0.92	10.743	-1.051	22.536	-11.009
Mourning Warbler	36	0	0.51	0.12	-3.179	3.419	-2.141
Northern Flicker	43	0.33	0.91	6.393	-0.761	13.548	-6.682
Northern Waterthrush	60	0.21	0.82	3.909	1.294	6.524	-3.966
Orange-crowned Warbler	39	0.46	0.93	9.781	-1.565	21.128	-9.706
Olive-sided Flycatcher	18	0.15	0.76	3.245	-1.543	8.033	-3.714
Ovenbird	160	0.13	0.75	2.741	1.57	3.912	-2.546
Palm Warbler	44	0.07	0.7	2.539	-1.376	6.453	-3.761
Pied-billed Grebe	49	0.19	0.81	5.198	-0.529	10.925	-4.896
Philadelphia Vireo	13	0.2	0.79	7.032	-7.977	22.04	-8.043
Rose-breasted Grosbeak	43	0.1	0.74	3.147	-0.773	7.066	-4.19
Ring-billed Gull	38	0	0.38	-0.699	-9.701	8.303	-3.388
Ruby-crowned Kinglet	98	0.18	0.82	4.16	1.167	7.152	-5.073
Red Squirrel	105	0.48	0.99	10.468	0.067	20.869	-9.706
Red-eyed Vireo	165	0.13	0.76	3.773	1.765	5.78	-4.394
Red-necked Grebe	229	0.09	0.71	2.232	1.364	3.099	-1.365

Ruffed Grouse	234	0	0.4	-0.11	-9.708	9.487	-5.418
Red-winged Blackbird	277	0.17	0.79	4.056	2.508	5.604	-4.469
Sandhill Crane	40	0.11	0.74	5.287	-0.627	11.202	-3.321
Savannah Sparrow	114	0	0.51	-0.097	-2.45	2.256	-2.4
Sedge Wren	35	0.03	0.65	1.808	-5.145	8.761	-4.644
Sora	267	0.35	0.9	4.777	3.346	6.209	-4.614
Song Sparrow	133	0.16	0.77	3.453	1.592	5.313	-3.909
Sprague's Pipit	41	0.11	0.77	3.738	-1.829	9.305	-5.085
Swamp Sparrow	169	0.32	0.88	5.486	3.431	7.542	-5.224
Swainson's Thrush	266	0.18	0.77	3.963	2.656	5.271	-3.977
Tennessee Warbler	336	0.13	0.75	3.03	2.17	3.89	-2.645
Tree Swallow	123	0.02	0.55	-1.749	-9.351	5.853	-4.152
Vesper Sparrow	32	0.39	0.9	8.178	2.068	14.287	-6.65
Warbling Vireo	18	0	0.56	0.578	-7.494	8.649	-3.112
White-crowned Sparrow	12	0	0.55	0.56	-4.478	5.598	-1.875
Western Toad	225	0.12	0.79	3.507	0.92	6.094	-5.358
Western Wood-Pewee	16	0.49	0.92	20.52	-9.619	50.66	-19.466
Wilson's Snipe	614	0.21	0.83	4.687	3.333	6.041	-5.559
Winter Wren	76	0.05	0.7	1.933	-0.759	4.626	-3.521
Wood Frog	902	0.05	0.66	2.243	1.1	3.387	-4.511
White-throated Sparrow	615	0.29	0.85	4.3	3.619	4.982	-3.275
Yellow-bellied Sapsucker	89	0.24	0.88	4.541	1.682	7.401	-4.564
Yellow Warbler	48	0.02	0.53	1.11	-0.975	3.195	-0.96
Yellow-rumped Warbler	224	0.09	0.77	2.723	1.216	4.23	-3.476

Table 8. Indicator values for each species for time of day based on midnight versus morning.

	split	R	I	Lower	Upper
BarredOwl	Midnight	1.00	1.00	1.00	1.00
CanadianToad	Midnight	1.00	1.00	1.00	1.00
BorealOwl	Midnight	1.00	0.98	0.95	1.00
CommonNighthawk	Midnight	1.00	0.98	0.95	1.00
WoodFrog	Midnight	1.00	0.87	0.80	0.91
BorealChorusFrog	Midnight	1.00	0.85	0.80	0.89
NorthernSawwhetOwl	Midnight	1.00	0.83	0.51	1.00
GreatHornedOwl	Midnight	1.00	0.81	0.54	1.00
Coyote	Midnight	1.00	0.53	0.17	0.83
Sora	Midnight	1.00	0.49	0.29	0.65
LeContesSparrow	Midnight	1.00	0.21	0.05	0.37
HoaryBat	Midnight	0.96	0.93	0.00	1.00
GreatGrayOwl	Midnight	0.96	0.55	0.07	0.97
CaliforniaGull	Midnight	0.94	0.95	0.00	1.00
YellowRail	Midnight	0.93	0.95	0.00	1.00
GreenwingedTeal	Midnight	0.90	0.35	0.01	0.70
VirginiaRail	Midnight	0.88	0.69	0.07	1.00
AmericanCoot	Midnight	0.88	0.19	0.02	0.41
LongearedOwl	Midnight	0.79	0.56	0.06	1.00
RedneckedGrebe	Midnight	0.79	0.20	0.00	0.52
WilsonsSnipe	Midnight	0.64	0.06	0.00	0.15
WesternKingbird	Midnight	0.56	0.39	0.00	1.00
VesperSparrow	Morning	1.00	1.00	1.00	1.00
HouseWren	Morning	1.00	1.00	1.00	1.00
SwampSparrow	Morning	1.00	1.00	1.00	1.00
AmericanRobin	Morning	1.00	1.00	1.00	1.00
WesternMeadowlark	Morning	1.00	1.00	1.00	1.00
PineSiskin	Morning	1.00	1.00	1.00	1.00

WinterWren	Morning	1.00	1.00	1.00	1.00
BorealChickadee	Morning	1.00	1.00	1.00	1.00
PhiladelphiaVireo	Morning	1.00	1.00	1.00	1.00
CapeMayWarbler	Morning	1.00	1.00	1.00	1.00
YellowWarbler	Morning	1.00	1.00	1.00	1.00
WarblingVireo	Morning	1.00	1.00	1.00	1.00
FoxSparrow	Morning	1.00	1.00	1.00	1.00
BaybreastedWarbler	Morning	1.00	1.00	1.00	1.00
SandhillCrane	Morning	1.00	1.00	1.00	1.00
MagnoliaWarbler	Morning	1.00	1.00	1.00	1.00
BrownheadedCowbird	Morning	1.00	1.00	1.00	1.00
BlackcappedChickadee	Morning	1.00	1.00	1.00	1.00
NorthernFlicker	Morning	1.00	1.00	1.00	1.00
SpraguesPipit	Morning	1.00	1.00	1.00	1.00
OlivesidedFlycatcher	Morning	1.00	1.00	1.00	1.00
AmericanRedstart	Morning	1.00	1.00	1.00	1.00
AmericanGoldfinch	Morning	1.00	1.00	1.00	1.00
NorthernWaterthrush	Morning	1.00	1.00	1.00	1.00
YellowbelliedSapsucker	Morning	1.00	1.00	1.00	1.00
CedarWaxwing	Morning	1.00	1.00	1.00	1.00
GoldencrownedKinglet	Morning	1.00	1.00	1.00	1.00
SharptailedGrouse	Morning	1.00	1.00	1.00	1.00
Mallard	Morning	1.00	1.00	1.00	1.00
OrangecrownedWarbler	Morning	1.00	1.00	1.00	1.00
WilsonsWarbler	Morning	1.00	1.00	1.00	1.00
BlackbilledMagpie	Morning	1.00	1.00	1.00	1.00
BlackAndWhiteWarbler	Morning	1.00	1.00	1.00	1.00
ChestnutcollaredLongspur	Morning	1.00	1.00	1.00	1.00
CanadaWarbler	Morning	1.00	1.00	1.00	1.00
TreeSwallow	Morning	1.00	1.00	1.00	1.00
Willet	Morning	1.00	1.00	1.00	1.00

EuropeanStarling	Morning	1.00	1.00	1.00	1.00
BonapartesGull	Morning	1.00	1.00	1.00	1.00
BaltimoreOriole	Morning	1.00	1.00	1.00	1.00
HairyWoodpecker	Morning	1.00	1.00	1.00	1.00
BairdsSparrow	Morning	1.00	1.00	1.00	1.00
GrayCatbird	Morning	1.00	1.00	1.00	1.00
RedbreastedNuthatch	Morning	1.00	1.00	1.00	1.00
BlueheadedVireo	Morning	1.00	1.00	1.00	1.00
YellowheadedBlackbird	Morning	1.00	1.00	1.00	1.00
RedneckedPhalarope	Morning	1.00	1.00	1.00	1.00
WesternWoodPewee	Morning	1.00	1.00	1.00	1.00
PurpleFinch	Morning	1.00	1.00	1.00	1.00
Veery	Morning	1.00	1.00	1.00	1.00
BlackbackedWoodpecker	Morning	1.00	1.00	1.00	1.00
BlackTern	Morning	1.00	1.00	1.00	1.00
TennesseeWarbler	Morning	1.00	0.99	0.98	1.00
YellowrumpedWarbler	Morning	1.00	0.99	0.97	1.00
AmericanTreeSparrow	Morning	1.00	0.99	1.00	1.00
NorthernShoveler	Morning	1.00	0.99	1.00	1.00
RubycrownedKinglet	Morning	1.00	0.98	0.96	1.00
Ovenbird	Morning	1.00	0.98	0.96	1.00
RedeyedVireo	Morning	1.00	0.98	0.95	1.00
RedwingedBlackbird	Morning	1.00	0.98	0.94	1.00
UplandSandpiper	Morning	1.00	0.98	1.00	1.00
SavannahSparrow	Morning	1.00	0.97	0.91	1.00
ChippingSparrow	Morning	1.00	0.97	0.94	1.00
SongSparrow	Morning	1.00	0.97	0.92	1.00
RosebreastedGrosbeak	Morning	1.00	0.96	0.87	1.00
GrayJay	Morning	1.00	0.95	0.88	1.00
WhitethroatedSparrow	Morning	1.00	0.95	0.91	0.97
DarkeyedJunco	Morning	1.00	0.95	0.88	1.00

PalmWarbler	Morning	1.00	0.94	0.85	1.00
LincolnsSparrow	Morning	1.00	0.92	0.85	0.98
WhitewingedCrossbill	Morning	1.00	0.90	0.78	1.00
CommonRaven	Morning	1.00	0.90	0.81	0.97
LesserYellowlegs	Morning	1.00	0.90	0.71	1.00
WesternTanager	Morning	1.00	0.90	0.65	1.00
MourningWarbler	Morning	1.00	0.88	0.56	1.00
AmericanCrow	Morning	1.00	0.88	0.79	0.96
GreaterYellowlegs	Morning	1.00	0.88	0.58	1.00
MourningDove	Morning	1.00	0.86	0.66	1.00
AlderFlycatcher	Morning	1.00	0.82	0.69	0.91
LeastFlycatcher	Morning	1.00	0.81	0.67	0.92
HermitThrush	Morning	1.00	0.81	0.73	0.90
YellowbelliedFlycatcher	Morning	1.00	0.81	0.52	1.00
ClaycoloredSparrow	Morning	1.00	0.74	0.63	0.82
BrownCreeper	Morning	1.00	0.73	0.15	1.00
BlueJay	Morning	1.00	0.72	0.35	1.00
SwainsonsThrush	Morning	1.00	0.71	0.62	0.82
RingbilledGull	Morning	1.00	0.71	0.21	1.00
CanadaGoose	Morning	1.00	0.67	0.57	0.78
SolitarySandpiper	Morning	1.00	0.42	0.06	0.81
DomesticCow	Morning	1.00	0.37	0.21	0.53
EasternKingbird	Morning	0.99	1.00	1.00	1.00
DownyWoodpecker	Morning	0.99	1.00	1.00	1.00
HornedLark	Morning	0.99	0.99	1.00	1.00
RustyBlackbird	Morning	0.99	0.98	1.00	1.00
EaredGrebe	Morning	0.99	0.97	0.45	1.00
GrasshopperSparrow	Morning	0.99	0.97	0.45	1.00
RedCrossbill	Morning	0.99	0.96	0.00	1.00
CommonRedpoll	Morning	0.99	0.95	0.00	1.00
Killdeer	Morning	0.99	0.69	0.14	1.00
AmericanWigeon	Morning	0.99	0.46	0.12	1.00

CommonTern	Morning	0.98	0.98	1.00	1.00
RockPigeon	Morning	0.98	0.98	1.00	1.00
BlackpollWarbler	Morning	0.98	0.97	0.42	1.00
BarnSwallow	Morning	0.98	0.93	0.00	1.00
ForstersTern	Morning	0.97	0.99	1.00	1.00
BrewersBlackbird	Morning	0.97	0.97	0.40	1.00
EasternPhoebe	Morning	0.96	0.98	1.00	1.00
PurpleMartin	Morning	0.96	0.94	0.00	1.00
ShortbilledDowitcher	Morning	0.96	0.91	0.00	1.00
SpottedTowhee	Morning	0.96	0.89	0.00	1.00
Gadwall	Morning	0.96	0.65	0.05	1.00
CommonGrackle	Morning	0.95	0.94	0.00	1.00
PacificWren	Morning	0.95	0.92	0.00	1.00
AmericanKestrel	Morning	0.95	0.84	0.00	1.00
MarbledGodwit	Morning	0.94	0.96	0.00	1.00
WhitebreastedNuthatch	Morning	0.94	0.91	0.00	1.00
BankSwallow	Morning	0.94	0.91	0.00	1.00
SpottedSandpiper	Morning	0.93	0.45	0.02	1.00
BohemianWaxwing	Morning	0.90	0.67	0.00	1.00
Merlin	Morning	0.85	0.76	0.00	1.00
BlackthroatedGreenWarbler	Morning	0.85	0.75	0.00	1.00
WesternGrebe	Morning	0.84	0.77	0.00	1.00
Bufflehead	Morning	0.84	0.76	0.00	1.00
TundraSwan	Morning	0.83	0.78	0.00	1.00
NashvilleWarbler	Morning	0.83	0.77	0.00	1.00
Beaver	Morning	0.82	0.77	0.00	1.00
BrownThrasher	Morning	0.81	0.80	0.00	1.00
MarshWren	Morning	0.81	0.25	0.01	0.56
AmericanThreetoedWoodpecker	Morning	0.80	0.82	0.00	1.00
RednapedSapsucker	Morning	0.80	0.76	0.00	1.00
NorthernGoshawk	Morning	0.79	0.77	0.00	1.00

BluewingedTeal	Morning	0.75	0.63	0.03	1.00
GreaterWhitefrontedGoose	Morning	0.64	0.43	0.04	1.00
AmericanBittern	Morning	0.56	0.31	0.02	1.00
CommonLoon	Morning	0.55	0.20	0.02	0.60

Table 9. Indicator values showing seasonality scores for each species.

	split	R	I	Lower	Upper	P.Early	P.Mid	P.Late
WoodFrog	Early	1.00	0.80	0.71	0.89	1.00	0.00	0.00
CanadaGoose	Early	1.00	0.64	0.56	0.71	1.00	0.00	0.00
CommonRedpoll	Early	0.98	0.99	1.00	1.00	0.98	0.01	0.01
AmericanTree Sparrow	Early	0.94	1.00	1.00	1.00	0.94	0.05	0.01
Mallard	Early	0.91	0.72	0.51	0.94	1.00	0.03	0.06
WesternGrebe	Early	0.86	0.79	0.00	1.00	0.86	0.13	0.01
Northern Goshawk	Early	0.84	0.86	0.00	1.00	0.84	0.14	0.02
Rednecked Phalarope	Early	0.82	0.81	0.49	1.00	0.96	0.18	0.00
Blackthroated GreenWarbler	Early	0.81	0.79	0.00	1.00	0.81	0.17	0.02
Rednaped Sapsucker	Early	0.80	0.76	0.00	1.00	0.80	0.16	0.04
GreaterWhite frontedGoose	Early	0.78	0.77	0.51	1.00	1.00	0.22	0.00
TundraSwan	Early	0.77	0.87	0.00	1.00	0.77	0.21	0.02
SandhillCrane	Early	0.77	0.43	0.29	0.58	1.00	0.23	0.00
NorthernFlicker	Early	0.76	0.46	0.28	0.64	1.00	0.23	0.01
Bufflehead	Early	0.73	0.84	0.00	1.00	0.73	0.25	0.02
BorealOwl	Early	0.72	0.47	0.30	0.67	1.00	0.28	0.00
UplandSandpiper	Early	0.71	0.85	0.57	1.00	0.93	0.29	0.00
Downy Woodpecker	Early	0.71	0.82	0.56	1.00	0.97	0.29	0.00
NorthernSawwhet Owl	Early	0.71	0.69	0.50	1.00	1.00	0.29	0.00
BrownCreeper	Early	0.64	0.66	0.51	0.90	1.00	0.36	0.00
BrewersBlackbird	Early	0.62	0.86	0.51	1.00	0.95	0.37	0.01
AmericanCoot	Early	0.61	0.30	0.09	0.48	1.00	0.32	0.07
AmericanWigeon	Early	0.60	0.63	0.49	0.84	1.00	0.40	0.00
VirginiaRail	Early	0.59	0.83	0.51	1.00	0.91	0.40	0.01

Yellowbellied Sapsucker	Early	0.58	0.56	0.49	0.68	1.00	0.42	0.00
Sharptailed Grouse	Early	0.54	0.68	0.51	0.92	1.00	0.46	0.00
GreatHornedOwl	Early	0.54	0.47	0.24	0.74	0.96	0.29	0.18
GreatGrayOwl	Early	0.52	0.83	0.55	1.00	0.99	0.01	0.47
LongearedOwl	Early	0.42	0.75	0.01	1.00	0.78	0.58	0.00
AmericanKestrel	Early	0.42	0.75	0.00	1.00	0.66	0.57	0.01
PacificWren	Early	0.37	0.85	0.00	1.00	0.68	0.63	0.00
Shortbilled Dowitcher	Early	0.37	0.78	0.00	1.00	0.67	0.60	0.03
CaliforniaGull	Early	0.37	0.76	0.00	1.00	0.67	0.61	0.02
CommonGrackle	Early	0.36	0.84	0.00	1.00	0.66	0.64	0.00
Blackcapped Chickadee	Early Late	0.90	0.46	0.27	0.61	1.00	0.00	0.90
BorealChorusFrog	Early Mid	1.00	0.85	0.69	1.00	1.00	1.00	0.00
Rubycrowned Kinglet	Early Mid	1.00	0.75	0.61	0.87	1.00	1.00	0.00
RingbilledGull	Early Mid	0.88	1.00	1.00	1.00	0.96	0.92	0.00
HairyWoodpecker	Early Mid	0.85	1.00	1.00	1.00	0.91	0.94	0.00
AmericanCrow	Early Mid	0.80	0.28	0.07	0.45	0.94	0.86	0.02
CommonRaven	Early Mid	0.79	0.37	0.13	0.59	0.99	0.80	0.01
GreenwingedTeal	Early Mid	0.77	1.00	1.00	1.00	0.91	0.86	0.00
Western Meadowlark	Early Mid	0.73	0.40	0.13	0.70	0.83	0.90	0.00
MourningDove	Early Mid	0.71	0.57	0.22	1.00	0.78	0.93	0.02
BlackbilledMagpie	Early Mid	0.66	0.47	0.14	0.85	0.79	0.84	0.05
AmericanBittern	Early Mid	0.63	1.00	1.00	1.00	0.64	0.99	0.00
PurpleFinch	Early Mid	0.60	1.00	1.00	1.00	0.92	0.68	0.00
AmericanRobin	Early Mid	0.60	0.31	0.15	0.50	0.60	1.00	0.00
Gadwall	Early Mid	0.59	1.00	1.00	1.00	0.69	0.90	0.00
RedneckedGrebe	Early Mid	0.56	0.56	0.14	1.00	0.75	0.79	0.09

LesserYellowlegs	Early Mid	0.55	0.57	0.16	1.00	0.64	0.90	0.07
EaredGrebe	Early Mid	0.54	1.00	1.00	1.00	0.66	0.88	0.00
Willet	Early Mid	0.53	1.00	1.00	1.00	0.55	0.98	0.00
NorthernShoveler	Early Mid	0.48	1.00	1.00	1.00	0.80	0.68	0.00
RustyBlackbird	Early Mid	0.45	1.00	1.00	1.00	0.85	0.60	0.00
WesternKingbird	Early Mid	0.43	1.00	1.00	1.00	0.63	0.80	0.00
EasternPhoebe	Early Mid	0.42	1.00	1.00	1.00	0.65	0.77	0.00
EuropeanStarling	Early Mid	0.41	0.81	0.25	1.00	0.65	0.70	0.21
PurpleMartin	Early Mid	0.38	1.00	1.00	1.00	0.70	0.67	0.01
Goldencrowned Kinglet	Early Mid	0.37	0.92	0.19	1.00	0.66	0.63	0.31
Coyote	Early Mid	0.26	0.69	0.22	1.00	0.46	0.72	0.43
Chestnutcollared Longspur	Early Mid	0.25	0.71	0.14	1.00	0.41	0.61	0.50
Redbreasted Nuthatch	Late	0.75	0.56	0.28	0.80	0.09	0.16	0.95
BorealChickadee	Late	0.55	0.40	0.17	0.62	0.40	0.05	0.95
BlueJay	Late	0.53	0.42	0.20	0.65	0.35	0.17	0.89
Whitebreasted Nuthatch	Late	0.41	0.94	0.86	1.00	0.50	0.09	0.67
HornedLark	Late	0.25	0.62	0.36	0.89	0.59	0.30	0.63
RockPigeon	Mid	1.00	0.98	1.00	1.00	0.00	1.00	0.00
CommonTern	Mid	1.00	0.96	0.00	1.00	0.00	1.00	0.00
BlueheadedVireo	Mid	1.00	0.89	0.68	1.00	0.00	1.00	0.00
TennesseeWarbler	Mid	1.00	0.87	0.82	0.90	0.00	1.00	0.00
ChippingSparrow	Mid	1.00	0.65	0.58	0.73	0.00	1.00	0.00
Yellowrumped Warbler	Mid	0.99	0.33	0.25	0.40	0.00	1.00	0.01
Rosebreasted Grosbeak	Mid	0.97	0.72	0.58	0.84	0.00	1.00	0.03
YellowRail	Mid	0.96	0.98	1.00	1.00	0.04	0.96	0.00
HoaryBat	Mid	0.96	0.92	0.00	1.00	0.03	0.96	0.01
WesternTanager	Mid	0.95	0.70	0.51	0.88	0.00	1.00	0.05
SpottedTowhee	Mid	0.94	1.00	1.00	1.00	0.05	0.94	0.01
BankSwallow	Mid	0.94	0.89	0.00	1.00	0.06	0.94	0.00

Marbled Godwit	Mid	0.92	0.91	0.00	1.00	0.04	0.92	0.04
DomesticCow	Mid	0.92	0.29	0.16	0.43	0.02	1.00	0.06
Beaver	Mid	0.89	0.76	0.00	1.00	0.09	0.89	0.02
Yellowheaded Blackbird	Mid	0.88	0.78	0.56	1.00	0.12	1.00	0.00
Merlin	Mid	0.85	0.78	0.00	1.00	0.13	0.85	0.02
YellowWarbler	Mid	0.85	0.61	0.52	0.70	0.00	1.00	0.15
Brownheaded Cowbird	Mid	0.85	0.55	0.31	0.78	0.01	1.00	0.14
WinterWren	Mid	0.85	0.34	0.17	0.52	0.10	1.00	0.05
BohemianWaxwing	Mid	0.84	0.81	0.00	1.00	0.15	0.84	0.01
AmericanThreetoed Woodpecker	Mid	0.83	0.76	0.00	1.00	0.13	0.83	0.04
BrownThrasher	Mid	0.83	0.73	0.00	1.00	0.12	0.83	0.05
SavannahSparrow	Mid	0.83	0.28	0.13	0.44	0.15	1.00	0.02
BaltimoreOriole	Mid	0.81	0.84	0.55	1.00	0.19	0.98	0.00
CanadaWarbler	Mid	0.81	0.72	0.48	0.92	0.01	1.00	0.18
VesperSparrow	Mid	0.81	0.26	0.14	0.42	0.14	1.00	0.05
SwampSparrow	Mid	0.80	0.40	0.25	0.59	0.00	1.00	0.20
Northern Waterthrush	Mid	0.79	0.64	0.46	0.82	0.00	1.00	0.21
NashvilleWarbler	Mid	0.78	0.82	0.00	1.00	0.18	0.78	0.04
RedwingedBlackbird	Mid	0.78	0.26	0.16	0.39	0.22	1.00	0.00
DarkeyedJunco	Mid	0.77	0.29	0.18	0.41	0.00	1.00	0.23
Sora	Mid	0.74	0.52	0.31	0.72	0.00	1.00	0.26
WilsonsSnipe	Mid	0.73	0.41	0.34	0.49	0.00	1.00	0.27
BlackTern	Mid	0.70	0.85	0.55	1.00	0.30	0.97	0.00
SongSparrow	Mid	0.70	0.21	0.06	0.33	0.13	0.99	0.17
BlackAndWhite Warbler	Mid	0.68	0.52	0.31	0.70	0.32	1.00	0.00
Orangecrowned Warbler	Mid	0.65	0.47	0.24	0.65	0.02	0.99	0.33
MagnoliaWarbler	Mid	0.64	0.87	0.79	0.94	0.00	1.00	0.36

CedarWaxwing	Mid	0.62	0.52	0.32	0.77	0.00	1.00	0.38
AlderFlycatcher	Mid	0.59	0.87	0.82	0.93	0.00	1.00	0.41
MarshWren	Mid	0.58	0.46	0.22	0.73	0.13	0.98	0.30
Ovenbird	Mid	0.57	0.73	0.64	0.78	0.00	1.00	0.43
FoxSparrow	Mid	0.56	0.64	0.51	0.80	0.44	1.00	0.00
GreaterYellowlegs	Mid	0.55	0.48	0.22	0.71	0.44	1.00	0.01
ForstersTern	Mid	0.54	0.85	0.55	1.00	0.46	0.91	0.00
Blackbacked Woodpecker	Mid	0.52	0.88	0.54	1.00	0.48	0.88	0.00
BarredOwl	Mid	0.51	0.73	0.54	1.00	0.49	1.00	0.00
Killdeer	Mid	0.50	0.70	0.52	1.00	0.50	1.00	0.00
RedCrossbill	Mid	0.42	0.86	0.00	1.00	0.57	0.80	0.01
BarnSwallow	Mid	0.40	0.72	0.00	1.00	0.04	0.65	0.56
RedeyedVireo	Mid Late	1.00	0.98	0.95	1.00	0.00	1.00	1.00
Common Nighthawk	Mid Late	1.00	0.97	0.90	1.00	0.00	1.00	1.00
PineSiskin	Mid Late	1.00	0.90	0.78	1.00	0.00	1.00	1.00
Whitewinged Crossbill	Mid Late	1.00	0.88	0.74	1.00	0.00	1.00	1.00
HermitThrush	Mid Late	1.00	0.59	0.51	0.68	0.00	1.00	1.00
Mourning Warbler	Mid Late	0.99	1.00	1.00	1.00	0.00	1.00	0.99
SwainsonsThrush	Mid Late	0.99	0.87	0.78	0.93	0.00	1.00	0.99
Yellowbellied Flycatcher	Mid Late	0.96	1.00	1.00	1.00	0.00	1.00	0.96
Whitethroated Sparrow	Mid Late	0.96	0.58	0.50	0.65	0.00	1.00	0.96
BairdsSparrow	Mid Late	0.94	1.00	1.00	1.00	0.00	0.96	0.98
AmericanRedstart	Mid Late	0.93	0.95	0.85	1.00	0.00	1.00	0.93
AmericanGoldfinch	Mid Late	0.93	0.86	0.57	1.00	0.00	0.96	0.97
SpraguesPipit	Mid Late	0.92	0.77	0.42	1.00	0.00	0.95	0.97
GrayCatbird	Mid Late	0.88	1.00	1.00	1.00	0.00	1.00	0.88
LeContesSparrow	Mid Late	0.87	0.55	0.43	0.69	0.00	1.00	0.87
Olivesided Flycatcher	Mid Late	0.86	0.89	0.67	1.00	0.00	1.00	0.86

LincolnsSparrow	Mid Late	0.83	0.42	0.32	0.53	0.00	1.00	0.83
HouseWren	Mid Late	0.82	0.83	0.69	0.97	0.00	1.00	0.82
PhiladelphiaVireo	Mid Late	0.81	0.92	0.79	1.00	0.00	1.00	0.81
PalmWarbler	Mid Late	0.79	0.46	0.34	0.62	0.00	1.00	0.79
CommonLoon	Mid Late	0.77	0.51	0.23	0.86	0.01	0.86	0.91
BaybreastedWarbler	Mid Late	0.76	1.00	1.00	1.00	0.00	1.00	0.76
GrayJay	Mid Late	0.73	0.48	0.32	0.64	0.00	1.00	0.73
WesternWoodPewee	Mid Late	0.65	0.84	0.49	1.00	0.00	1.00	0.65
BlackpollWarbler	Mid Late	0.63	1.00	1.00	1.00	0.02	0.91	0.70
CapeMayWarbler	Mid Late	0.62	0.90	0.72	1.00	0.00	1.00	0.62
SolitarySandpiper	Mid Late	0.59	0.65	0.27	1.00	0.01	1.00	0.59
Veery	Mid Late	0.58	1.00	1.00	1.00	0.00	0.97	0.61
EasternKingbird	Mid Late	0.56	1.00	1.00	1.00	0.00	0.96	0.60
WilsonsWarbler	Mid Late	0.55	1.00	1.00	1.00	0.00	1.00	0.55
SpottedSandpiper	Mid Late	0.55	0.65	0.20	1.00	0.10	0.83	0.70
LeastFlycatcher	Mid Late	0.52	0.78	0.64	0.93	0.00	1.00	0.52
CanadianToad	Mid Late	0.50	0.72	0.46	1.00	0.05	0.98	0.52
ClaycoloredSparrow	Mid Late	0.50	0.61	0.51	0.71	0.00	1.00	0.50
WarblingVireo	Mid Late	0.50	0.40	0.14	0.71	0.04	0.92	0.58
GrasshopperSparrow	Mid Late	0.47	1.00	1.00	1.00	0.03	0.76	0.68
BonapartesGull	Mid Late	0.39	0.54	0.26	1.00	0.20	0.69	0.68
BluewingedTeal	Mid Late	0.36	0.76	0.15	1.00	0.26	0.62	0.67
TreeSwallow	Mid Late	0.33	0.57	0.16	1.00	0.26	0.66	0.60

Table 10. Assessment of how annual trend at Calling Lake changes as a function of analytical approach and number of visits used to assess trend.

Model	GLM - Proportion Stations Observed				GLMM - Observed vs. Not Observed			
Covariates	Year				Year+Day+Hour			
Visits	1	2	3	4	1	2	3	4
% Species where Trend Could Always Be Estimated[1]	60%	77%	90%	92%	25%	35%	48%	57%
Average Absolute Trend [2]	0.280	0.195	0.166	0.115	0.133	0.113	0.103	0.105
Median Absolute Trend[2]	0.212	0.121	0.080	0.073	0.114	0.110	0.099	0.104
Average SE of Trend[2]	0.046	0.044	0.043	0.041	0.123	0.087	0.065	0.061
Average Variation (SD) in Trends[2]	0.827	0.650	0.539	0.311	0.170	0.153	0.136	0.134
% Species With ≥ 1 Significant Trend[3]	86.9%	76.2%	70.5%	63.1%	82.8%	80.3%	67.2%	66.4%
% Species With >95% of Trends[2] Significant[3]	15.6%	21.3%	31.1%	34.4%	21.3%	30.3%	40.2%	48.4%

1 - The percentage of 122 species for which 100% of the random samples that were drawn for that species and for that number of visits resulted in a trend that could be statistically evaluated.

2 – Only includes combinations of species & visits where the model was able to solve computationally. Those species where the observed trends were identical between number of visits were treated as not solved.

3 – Significance was defined as $P \leq 0.05$.

Table 11. Occupancy rates for different sampling duration for each species. Those highlighted in red were not used in the analyses in Figure 30 as they had poor standard errors.

SPECIES	SEASON	DAY	MONTH	WEEK
Alder Flycatcher	0.65	0.47	0.60	0.61
American Bittern	0.18	0.05	0.14	1.00
American Coot	0.14	0.07	0.12	0.05
American Crow	0.17	0.10	0.12	0.19
American Goldfinch	0.08	1.00	0.12	0.03
American Redstart	0.22	0.08	0.11	1.00
American Robin	0.80	0.68	0.71	0.69
American toad	0.28		1.00	0.95
American Wigeon	0.20	0.96	0.98	0.99
American Tree Sparrow	0.05	0.04	0.05	0.03
American Three-toed Woodpecker		0.93		
Audubons's Warbler	0.34	0.29	0.38	1.00
Barred Owl			0.97	
Bald Eagle	1.00	0.97	1.00	
Bank Swallow	0.98			
Baltimore Oriole		0.92	1.00	0.02
Black-and-white Warbler	0.11	0.08	0.09	0.11
Black-billed Magpie	0.08	0.04	0.07	0.10
Bay-breasted Warbler	0.06	1.00	0.03	0.01
Black-backed Woodpecker	1.00	0.30		0.98
Black-capped Chickadee	0.15	0.09	0.07	0.89
Boreal Chorus Frog	0.23	0.15	0.23	0.20
American Beaver	0.01	0.01		0.01
Belted Kingfisher	1.00			
Brown-headed Cowbird	0.18	0.96	0.99	0.55
Blue-headed Vireo	0.38	0.09	0.33	0.21
Blackburnian Warbler	0.51			0.01

Blue Jay	0.04	0.02	0.04	
Blackpoll Warbler	0.16	0.14	0.13	0.13
Black Tern	0.07		0.04	0.04
Boreal Chickadee	0.20	0.05	0.06	0.97
Bonaparte's Gull	0.08	0.02	0.04	0.04
Boreal Owl	1.00		0.97	
Bohemian Waxwing	1.00	0.93	0.99	0.55
Brewer's Blackbird	0.07	0.97	0.95	0.02
Brown Creeper	0.18			0.20
Brown Thrasher	0.61	1.00		
Black-throated Green Warbler			0.97	
Broad-winged Hawk	1.00			
Canada Goose	0.62	0.41	0.36	0.37
Canadian Toad	0.61		1.00	
Canada Warbler		0.93	0.97	0.95
Clay-colored Sparrow	0.18	0.12	0.17	0.15
Cedar Waxwing	0.25	1.00	0.19	1.00
Domestic Chicken	0.02	0.01	1.00	0.95
Chipping Sparrow	0.79	0.62	0.81	0.53
Cape May Warbler	0.08	0.05	0.03	0.95
Common Loon	0.44	0.24	0.44	0.63
Common Merganser	1.00	0.97		
Common Nighthawk	0.32	0.29	0.31	0.21
Connecticut Warbler	0.40		0.21	0.12
Common Raven	0.51	0.31	0.33	0.25
Common Redpoll	1.00	0.97	0.98	
Common Tern	0.61	0.93		
Domestic Cow	0.09	0.08	0.09	0.06
Common Yellowthroat	0.46	0.19	0.42	0.31
Chestnut-sided Warbler		0.93		
Dark-eyed Junco	0.76	0.68	0.72	0.65

Domestic Dog	0.05	1.00	0.03	0.01
Downy Woodpecker	0.99	0.99	0.97	
Eared Grebe		1.00		
Eastern Kingbird		0.93	0.97	0.02
Eastern Phoebe		1.00	1.00	
European Starling	0.02		1.00	0.01
Evening Grosbeak	0.24	0.05	0.98	0.55
Eastern Whip-poor-will			1.00	
Fox Sparrow	0.41	0.20	0.36	0.30
Franklin's Gull	0.04	0.02	0.97	0.99
Gadwall	1.00	1.00		0.55
Golden-crowned Kinglet	0.12	0.92		0.99
Gray-cheeked Thrush	0.15	0.12	0.14	0.09
Great Gray Owl	1.00		1.00	0.55
Great Horned Owl	0.61	0.93		
Gray Jay	0.76	0.36	0.62	0.39
Greater Yellowlegs	0.55	0.27	1.00	1.00
Greater White-fronted Goose		1.00		
Green-winged Teal		1.00	0.92	0.55
Hairy Woodpecker	0.66	0.97	1.00	0.95
Herring Gull	1.00	0.97	1.00	
Hermit Thrush	0.84	0.75	0.81	0.78
Horned Grebe	0.61			0.55
Horned Lark	0.56		1.00	
House Sparrow	0.01			
House Wren	0.08	0.05	0.09	0.04
Killdeer	0.07	0.02	0.05	0.99
Le Conte's Sparrow	0.20	0.14	0.18	0.11
Least Flycatcher	0.52	0.30	0.50	0.23
Lesser Yellowlegs	0.33	0.28	0.30	1.00
Lincoln's Sparrow	0.78	0.54	0.68	0.51

Long-tailed Duck	0.96			0.05
Marbled Godwit	1.00	1.00	0.97	
Mallard	0.10	0.97	1.00	0.97
Magnolia Warbler	0.45	0.23	0.39	0.82
Marsh Wren	0.96			
Merlin	0.01	0.92	0.02	0.01
Mourning Dove	0.96			1.00
Mourning Warbler	0.07	0.92	0.02	0.98
Northern Cardinal	1.00	0.99	0.99	0.55
Nashville Warbler	0.27	0.13	0.19	0.15
Nelson's Sparrow	0.05	0.05	0.04	0.02
Northern Flicker	0.28	0.18	0.46	1.00
Northern Goshawk			1.00	
Northern Waterthrush	0.48	0.27	0.32	0.51
Northern Shoveler		0.92	0.98	
Orange-crowned Warbler	0.58	0.35	0.57	0.86
Olive-sided Flycatcher	0.44	0.26	0.46	0.36
Osprey	0.74			
Ovenbird	0.16	0.10	0.14	0.12
Pacific Loon				0.70
Palm Warbler	0.67	0.43	0.58	0.53
Pied-billed Grebe	0.18	0.08	0.16	0.10
Philadelphia Vireo	0.37	0.99	0.24	0.30
Pine Siskin	0.32	0.07	0.25	0.98
Pine Warbler	1.00		1.00	0.55
Pileated Woodpecker	0.45	0.98		0.99
Purple Finch				0.95
Rose-breasted Grosbeak	0.19	0.09	0.21	0.13
Ring-billed Gull	0.04		0.03	0.99
Red-breasted Merganser			1.00	
Red-breasted Nuthatch	0.13	1.00	0.11	0.06

Ruby-crowned Kinglet	0.73	0.51	0.62	0.70
Red Crossbill	1.00	0.97	1.00	
Red Squirrel	0.38	0.23	0.32	0.38
Red-eyed Vireo	0.35	0.07	0.29	0.19
Red-headed Woodpecker	1.00		1.00	
Red-necked Grebe	0.06	0.02	0.03	0.04
Ruby-throated Hummingbird	1.00	0.93	1.00	
Red-throated Loon	0.05	0.19	0.08	0.04
Rusty Blackbird	0.19	0.99	0.10	0.95
Ruffed Grouse	0.24	0.12	0.24	0.06
Red-winged Blackbird	0.21	0.07	0.14	0.13
Sandhill Crane	0.41	0.27	0.40	0.53
Savannah Sparrow	0.15	0.11	0.11	0.06
Short-billed Dowitcher	0.06	0.02	1.00	0.95
Short-eared Owl	0.61			
Sedge Wren		1.00	0.95	
Sora	0.23	0.16	0.18	0.17
Solitary Sandpiper	0.12	0.93	0.99	0.15
Song Sparrow	0.12	0.10	0.10	0.10
Spruce Grouse	0.73	0.98	1.00	0.95
Spring peeper	0.32		1.00	0.98
Sprague's Pipit		1.00	1.00	
Spotted Sandpiper	0.20	0.97	0.98	0.55
Sharp-tailed Grouse	0.03	0.01	0.97	0.95
Swamp Sparrow	0.53	0.32	0.36	0.32
Swainson's Thrush	0.79	0.47	0.76	0.70
Tennessee Warbler	0.58	0.32	0.52	0.28
Tree Swallow	0.42	0.23	0.47	0.38
Tundra Swan	0.61		1.00	
Upland Sandpiper	0.02	1.00	0.98	0.55
Vesper Sparrow	0.06		0.06	0.13
Warbling Vireo	0.05	0.02	0.05	0.95

Woodborer Beetle	1.00		0.95	
White-crowned Sparrow	0.13	0.10	0.11	0.09
Western Meadowlark	0.05	0.03	0.05	
Western Tanager	0.14	0.02	0.12	0.12
Western Toad	0.99	0.93	1.00	1.00
Western Wood-Pewee	0.05	0.01	0.03	0.03
Willow Flycatcher	1.00	0.93	1.00	
Willet		1.00		
Wilson's Snipe	0.62	0.45	0.51	0.40
Wild Turkey		0.93	1.00	
Wilson's Warbler	0.52	0.37	0.45	0.48
Winter Wren	0.42	0.32	0.42	0.43
Wood Frog	0.99	0.96	0.97	0.55
White-throated Sparrow	0.87	0.81	0.78	0.79
White-winged Crossbill	0.54	0.41	0.69	0.95
Yellow-bellied Flycatcher	0.47	0.32	0.41	0.39
Yellow-bellied Sapsucker	0.29	0.30	0.23	1.00
Yellow Rail	0.03		0.04	0.01
Yellow Warbler	0.17	0.07	0.17	0.09
Yellow-headed Blackbird	0.03	0.02	0.03	0.01
Yellow-rumped Warbler	0.62	0.48	0.44	0.44
Yellow-throated Vireo			1.00	

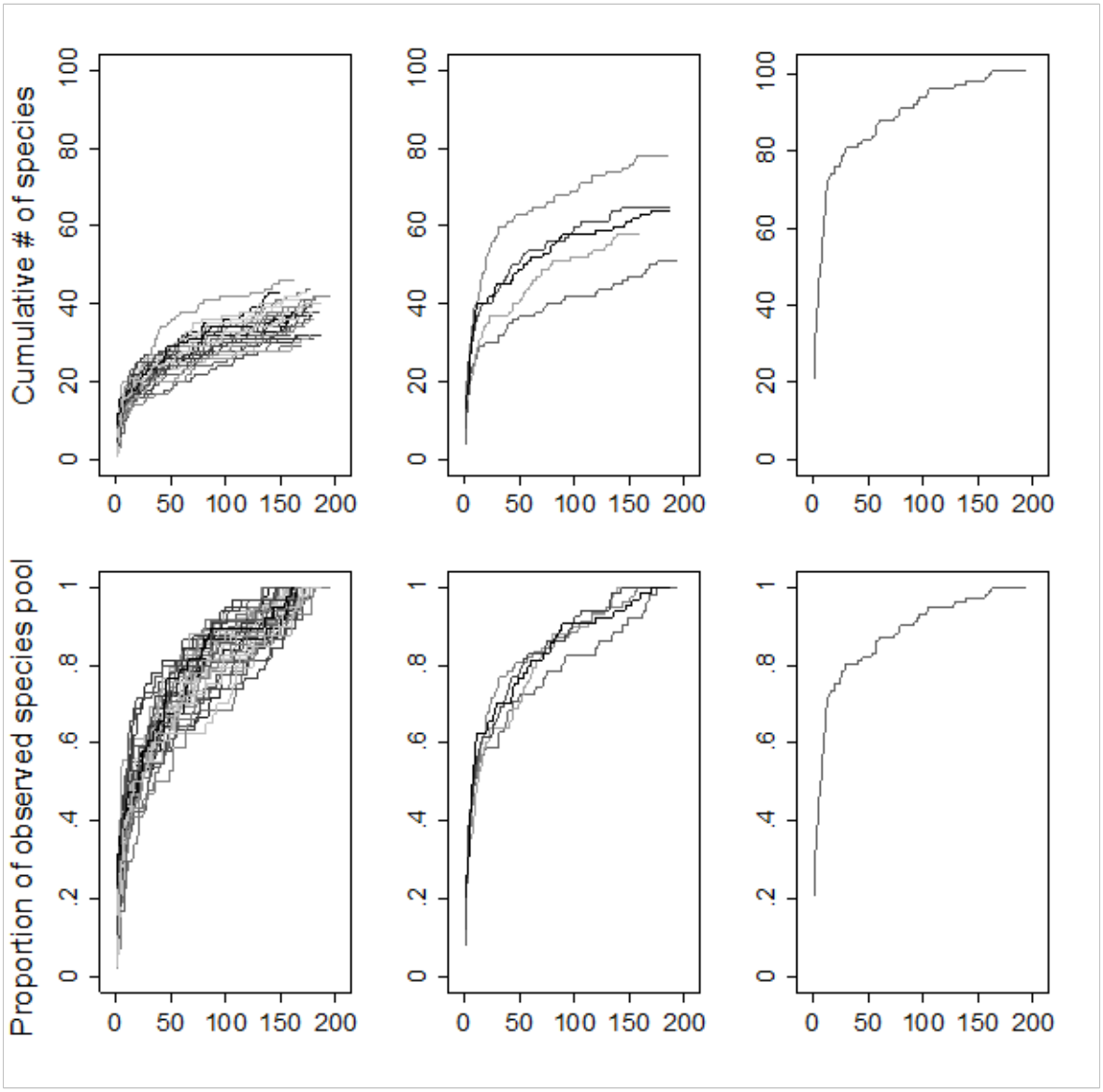


Figure 12. (TOP) Cumulative number of new species observed with addition visits to each station (LEFT), each site (MIDDLE), and the entire region for southern Ontario wetlands. (BOTTOM) Proportion of all species observed with additional visits to each station (LEFT), each site, (MIDDLE), and the entire region (RIGHT). The X-axis for all panels is the number of recordings processed (each recording was a 1 minute period separated from other recordings by at least an hour). A site ranged from having 3 to 9 stations. The region had 36 stations. Each line represents the season long accumulation of species or proportion for each station, site or the whole region.

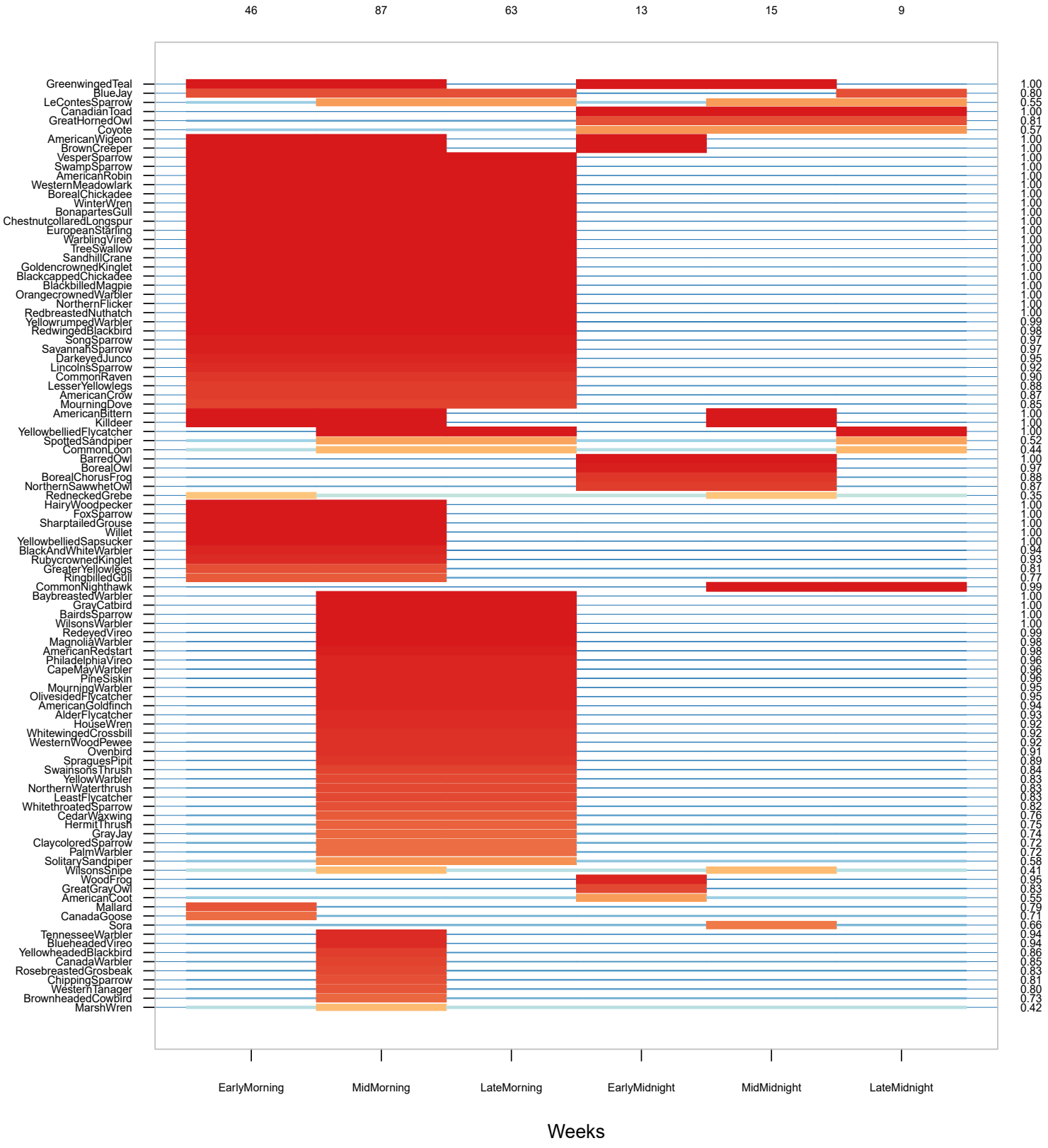


Figure 28. Heat map showing which species are more likely to be found at different times of day at different times of the year.

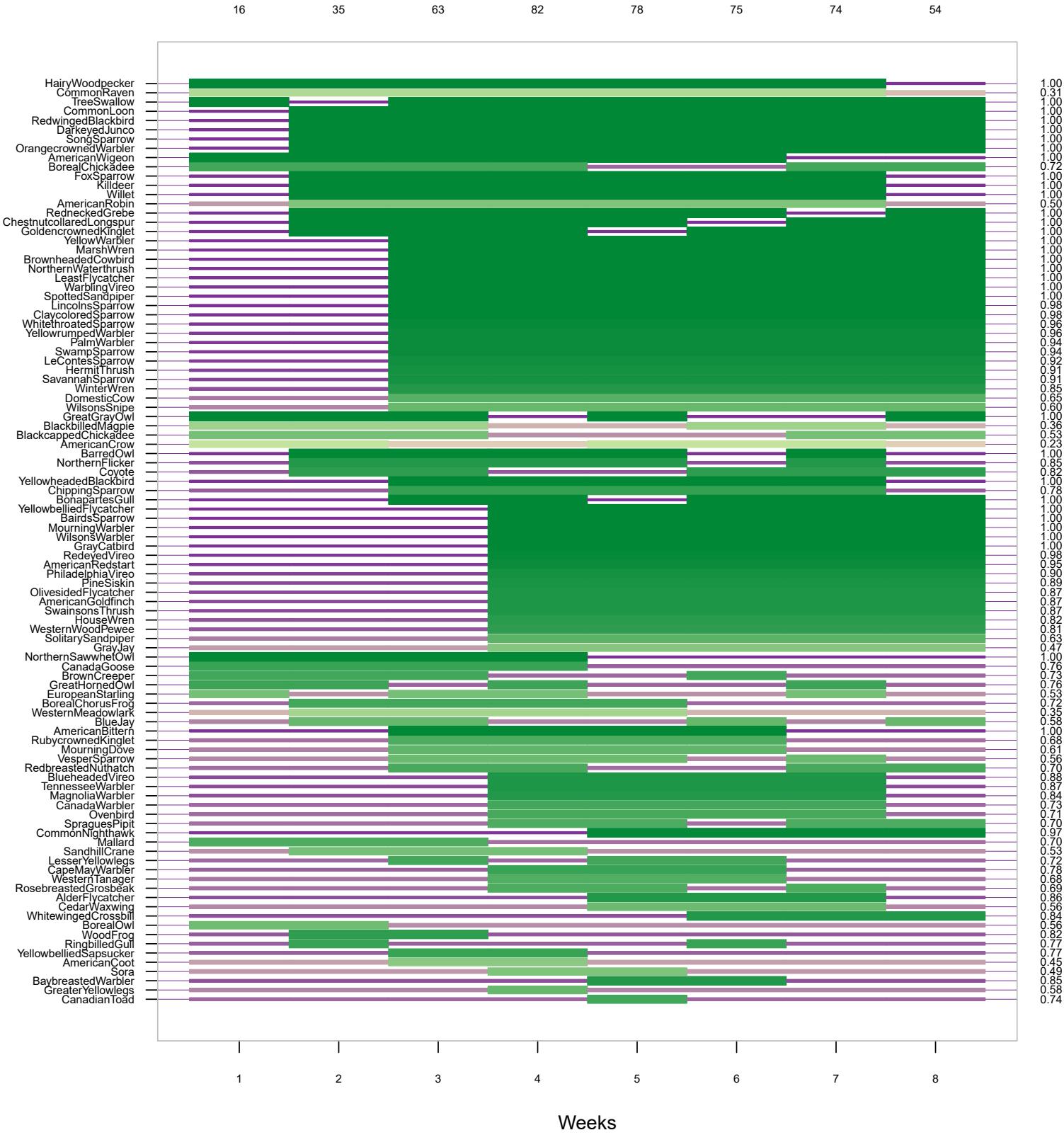


Figure 29. Heat map showing which species are more likely to be found in the early, mid, and late season.