RES 500C - Vancouver Avian Research Centre (VARC)

Examining trends in bird populations over 10 years of data from a local banding station in the BC Lower Mainland

Authored by: Amy Liu, Carla Di Filippo, Erin Ryan

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ABSTRACT

Bird monitoring programs provide the foundational data for programs that study and conserve birds. More than ever, with the uncertainty of climate change and increasing human impacts, research and monitoring to quantify species abundance are essential for our understanding of changing avian communities to guide successful conservation and management actions. This project examined 11 years (2009 - 2019) of bird banding data from a community banding station in Coquitlam, BC, Canada. The research approached three main questions: 1) Has the avian community changed over these years? 2) How have capture frequencies of individual species changed over time? 3) Can ecological factors explain the changes observed in the community and species of interest? Here, we have highlighted patterns in local abundance over time in the avian community, demonstrated case examples of decline and recovery in local species, and presented possible ecological factors that could be influencing these patterns. While migration seemed to have no correlation, avian diet showed that nectarivores were generally increasing, and significant patterns for breeding and wintering habitats are driven by small sample sizes of species with interesting trends. For the ecological categories of diet, wintering habitat, and breeding habitat, insectivores and woodland users comprise the majority of species captured at Colony Farm. These results could be due to human-influenced changes, such as changes in vegetation in the local area (affecting Brown-Headed Cowbirds) and the addition of bird feeders in the community (affecting nectarivores). Our analysis supports the importance of long-term monitoring, as ongoing avian mark-recapture data provides valuable insight into how local biodiversity and ecosystem health change over time. With an understanding of how local avian communities are changing, avian monitoring centers can adjust their goals to focus on these trends and species of concern or interest, in addition to public education, outreach, and community conservation engagement.

1. RESEARCH REPORT

Introduction

Over the past 50 years, wide-spread bird population declines are being reported across North America as a result of human impacts - not just in rare or endangered species, but also in species previously considered common and widespread [1–3]. These declines represent a net loss of nearly 3 billion breeding individuals across a wide range of both habitats and species, which has serious implications for wildlife conservation and ecosystem integrity - loss of bird abundance results in decreased pollination, seed dispersal, and disruptions to trophic systems [1]. This staggering decline in bird populations was only realized due to the long-term reliable records collected by individuals and dedicated institutions.

Monitoring bird populations is a useful tool to indicate ecosystem health and integrity [4–7]. Birds have a direct and simple cause-and-effect relationship with environmental change - they are sensitive to environmental perturbation, and play many different functional roles within ecosystems including pollinators, seed dispersers, predators, and prey [6,7]. Now more than ever,

research and monitoring to quantify species abundance and assess how it changes over time are essential for our understanding of changing avian communities to guide successful conservation and management actions. For example, community monitoring efforts were responsible for detecting severe population declines in the western subspecies of Purple Martins. This data led to their legal protection status, and resulted in considerable community recovery efforts [8]. The subspecies has since rebounded from 5 breeding pairs (1985) to more than 300 (2004) entirely as a result of these efforts [8].

Indeed, long-term programs to monitor avian abundance provide foundational data for programs that study and conserve birds [9–11]. These programs are most successful with thoughtful design and coordination [9]. Bird monitoring programs can broaden their impacts by coordinating efforts at appropriate scales (e.g., for species at risk, working at the scale of their range), integrating datasets between programs (e.g., World Bird Research portal), appropriately managing data for long-term storage, encouraging citizen science data collection, and even the development of continent-wide bird monitoring plans [9].

This project examined long-term banding and monitoring data from the Vancouver Avian Research Centre (VARC), a charitable organization dedicated to wild bird research, conservation and education. VARC conducts bird monitoring and banding, research, education, volunteer opportunities, and visitor programs at its main Colony Farm field station, in the city of Coquitlam, British Columbia (BC). VARC's primary objective is to provide data and research support that will allow for the safeguarding of bird habitats. This safeguarding will ensure long-term survival of avian species by providing science-based strategies for bird and ecosystem conservation.

VARC conducts extensive public outreach and education to raise awareness of environmental issues that relate to birds. In 2019, VARC provided volunteer opportunities and educational programs to more than 600 people, promoting conservation by giving people hands-on experience and demonstrations with birds and bird monitoring. Such outreach programs are effective for enhancing children's knowledge of local biodiversity, and likely to result in continuing conservation engagement [12].

In this project we examined a banding dataset spanning 10 years (2010-2019) to investigate the general patterns observed in species capture rates through time for the birds captured at VARC. We identified trends in this data using statistical models to outline local and regional bird behaviour patterns that may be due to natural (e.g., yearly fluctuations of prey or migration conditions) or anthropogenic factors (e.g., local habitat alterations, global climate change). We asked three broad questions about the avian community and individual bird species using this data:

1. Has the local avian community changed over the years of 2010-2019 at VARC?
2. How have capture frequencies of individual species changed over time?

3. Can ecological factors explain the changes observed in the community and species of interest?

Here, we present general community patterns of avian species, as well as case studies of certain species that can be highlighted for local conservation interests and outreach. One component of VARC's mandate is education - offering outreach opportunities to hundreds of people every year. To help communicate the value of the work that VARC does, and translate this research project to non-scientists, we have also included a few science communication elements in our results.

With an understanding of how local avian communities are changing, avian monitoring centers like VARC can adjust their goals to focus on community and species trends and aid species of concern or interest, in addition to public education, outreach, and community conservation engagement.

Methods

Study area and data collection

VARC operates a network of mist nets during spring migration, summer breeding, and fall migration seasons (Figure 1). On any given banding day, as many as 40 mist nets are in operation, depending on weather conditions and the availability of qualified volunteers. Banding operations begin at sunrise (or just before), and last 5 hours. During banding sessions, each captured bird is safely extracted from the mist net and processed. Captured birds were identified to species, sexed, aged, and fitted with a uniquely numbered Canadian Wildlife Service band, and, when possible, subjected to additional measurements and data collection (e.g., wing length, fat score, weight). Data collection also occurred on any captured birds that had been previously captured to facilitate long-term assessment of known individual birds. As part of the banding operation, during each banding session daily activity was recorded, including net hours, weather, personnel and bird observations of non-banded birds.

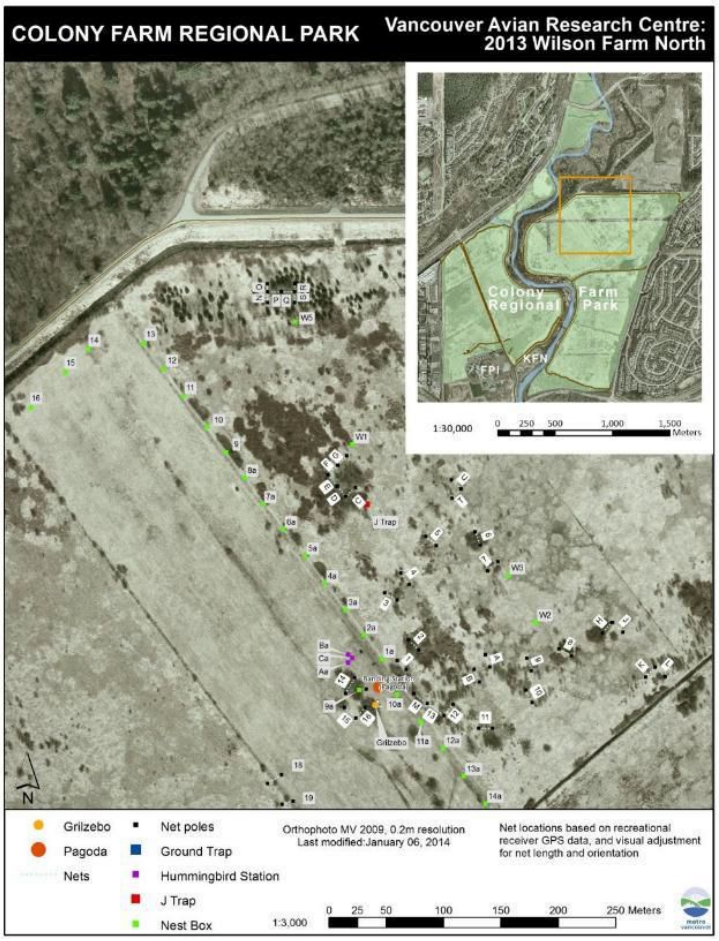

Figure 1*. Aerial view of Vancouver Avian Research Center (VARC) banding station at Colony Farm Regional Park.*

Dataset management

We standardized the number of captures by capture effort (i.e., net hours) in a given year (according to annual net hours in Table 1 of VARC's annual report [13]) to birds captured per 100 net hours. Although the dataset is recorded for captures in 2009, there were no net hours recorded in 2009 and thus this year was excluded from our analyses. Nets 14-17 were located near bird feeders to help attract birds into the nets; however, because of the increased bird activity associated with baiting nets, and nets 14-17 being taken down after 2014 and never used subsequently, birds captured in those nets were excluded from our analysis. The removal of these nets from the dataset altered the annual number of net hours for these years. To correct for this, we calculated the percent difference between new and original net hours for 2013 and 2014, and multiplied the percent difference by the original net hours to receive the corrected hours of 46.710 and 70.505 for 2013 and 2014, respectively. Information from the Cornell Lab of

Ornithology website was added to the original dataset to provide additional information on ecological categories (including diet, migration patterns, breeding habitat, and overwintering habitat) and the guilds within these categories that could help explain capture trends over time [14]. We kept the number of categories within each ecological category low to increase statistical power in our analyses. For example, in the breeding habitat and overwintering habitat guilds, we merged marsh and riparian habitats into marsh/riparian, and scrub and grassland habitats into scrub/grassland. Deciduous and coniferous were categorized where species indicated strong preference in those habitats, based mainly on BC data where possible, and woodland habitats were listed for generalists [14].

We combined several bird subspecies and hybrid codes to reduce ambiguities that arise with subspecies and hybrid identification. Specifically, subspecies of Yellow-Rumped Warbler (Myrtle = MYWA, Audubon's = AUWA, and category unknown = UYRW) were merged into the species code for Yellow-Rumped Warbler (YRWA), and Dark-Eyed Junco (Oregon = ORJU and slate-colored = SCJU) were merged into the species code for Dark-Eyed Junco (DEJU). We excluded recordings of any hybrid birds (i.e., hybrid hummingbirds - HYHU) and incorrect data recording (e.g., the species code FLIN that is assumed to be a typo for Northern Flicker - NOFL). Dataset management was conducted using Microsoft Excel, Google Sheets, and R (R Core Team 2017).

Statistical Analysis

To explore our main questions about bird species capture rates through time, we performed linear and polynomial regressions to view trends of standardized bird capture rates by years 2010 to 2019. We first plotted a regression for total bird capture rates per year to understand the general capture numbers at VARC each year. One-way analysis of variance (ANOVA) was used to compare the fit between linear and polynomial relationships after confirming the variables fit ANOVA assumptions.

An ordination plot was used to visualize variation of standardized avian community capture rates across years. A non-metric dimensional scaling (NMDS) plot was generated using the R package ‘vegan’ and a matrix of species standardized capture rates through the years 2010-2019 [15]. Many species showed few captures per 100 net hours across the total years and masked possible trends observed in species with higher captures. Thus, a qualitative sensitivity analysis was performed to remove those outlier species that appeared to have a disproportionate effect on the ordination. After removing outlier species to view the variation in the NMDS ordination plot, a total of 45 species out of the original 101 species remained in our analysis. A majority of the removed species had less than a total of 30 captures throughout the ten years, with a handful of species being captured only once or twice. A linear regression was used to test relationships between change in capture rates through time of each species (captures ~ year * species), and the coordination along the axis of the NMDS plot that appeared to identify declining or increasing

species captures through time. It is important to note the slopes for each species generated from the linear regressions are rough estimates of increasing and decreasing captures through time, as not all the capture rate trends in each bird species follow a linear model. To show an example of qualitatively assessing how ecological categories may be contributing to community variation, we overlaid an ecological guild over the NMDS plot. Finally, we picked out species of interest from the graph to discuss their trends. Specifically, we identified species that seemed to have the highest increase or decrease of capture rates over time, as well as any species that seemed to subjectively stand out in the ordination.

To visualize differences among individual trends of top ten species captured through 2010 to 2019, we plotted the number of birds captured for each species over time to view their trends in the number of captures. We tested changes in captures over time by fitting linear and polynomial regression models to each species.

We conducted univariate analyses for four avian ecological categories (migration, diet, breeding habitat, and overwintering habitat) to test whether the guilds within these categories help explain any trends in the observed capture rates through time. We pooled captures per year for each species assigned to a guild within an ecological category. Each data point would be the total of all species that fall into a given guild in a given year (n = 10). These univariate analyses were used to address: 1) Which guild has the species members that show a detectable pattern in the number of captures through time?; and 2) Which guild has the species members with the cumulative highest capture frequencies over the entire period (2010-2019)? For the first question, we used regression models to address how species within these guilds may be changing through time, the data was log transformed to fit regression and ANOVA assumptions of equal variance in residuals, and obtain a more normal distribution. Regression models were selected based on Akaike Selection Criterion (AIC), and ANOVA summary statistics. We used regression models and type II ANOVA to test for interaction effects between the guilds and year on capture rates (Linear: Captures ~ Year * Guild; Quadratic: Captures ~ Year + Year^2 * Guild). Furthermore, we plotted regression coefficients after removing intercepts and their 95% confidence intervals to test if trends of any guilds within each ecological category were significantly different from another. If a guild within the category had a linear regression while other categories had a polynomial regression, the linear regression was considered different than the other models. To address the second question, we looked at the number of captures for all years for a given guild. A type I ANOVA was conducted for each ecological category and a post-hoc Tukey-Kramer test was conducted if the results of the ANOVA were significant to assess whether the number of captures for each guild within a category were significantly different from one another. This section of our analysis allows us to address temporal and within category trends that may be of great interest in deciding what groups to prioritize for future conservation efforts.

All Statistical analyses were performed using R (R Core Team 2017).

Results

Changes in local avian community through time

After removing baited nets and editing for species codes as described in the methods, there are a total of 101 species represented over 39,208 individuals captured from 2010 to 2019 at VARC. Avian capture rates at VARC from 2010 to 2019 did not show a statistically significant linear pattern (Figure 2). Rather, the overall pattern is defined by a quadratic regression ($p = 0.001$) showing a decrease in capture rates until 2015, followed by a recent recovery.

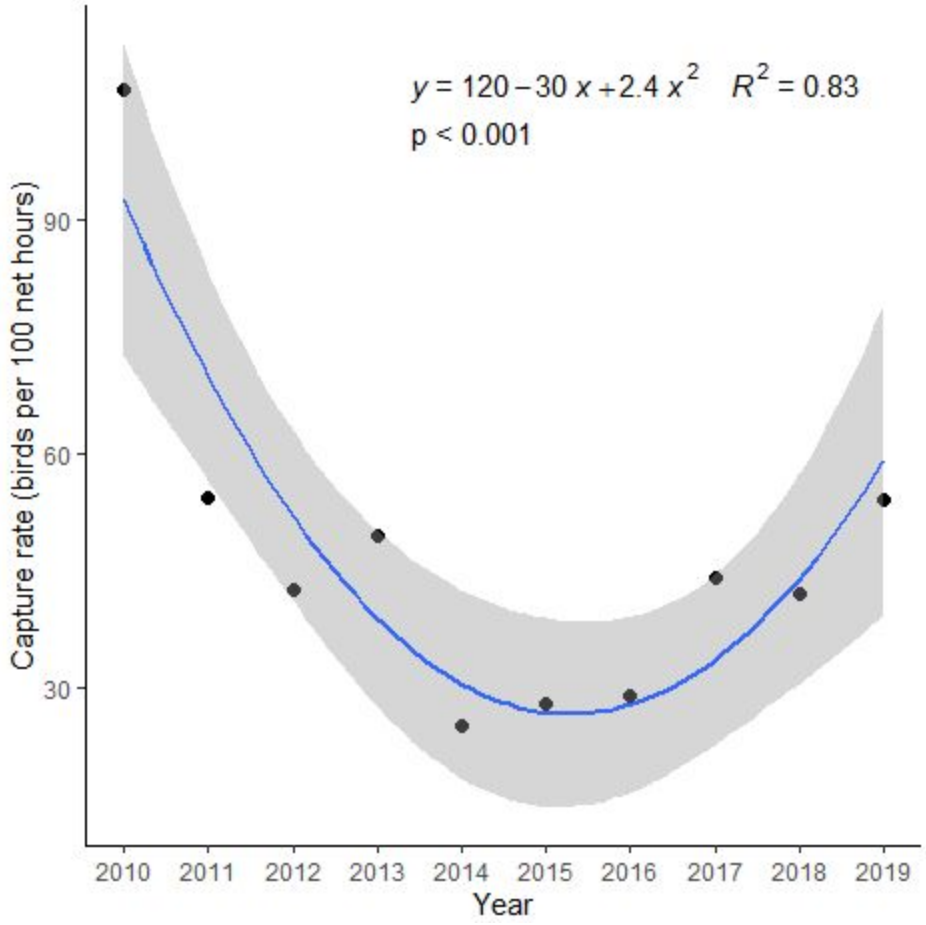

Figure 2. *Relationship between capture rate of birds per 100 net hours caught at Vancouver Avian Research Center at Colony Farm Regional Park (2010-2019). Gray shading shows 95% confidence interval.*

The avian community, in the form of frequently caught species at VARC, varied in capture rates through the years 2010 to 2019 (Figure 3). There are two main features of the plot evident in the NMDS plot. First, the majority of bird species are clustered in the middle, where they follow a trend similar to the capture rates by year polynomial model in Figure 2. Second, there is a significant linear correlation ($F(1, 42) = 18.53$, $p < 0.001$) between the NMDS1 axis and change in capture rates through time (Figure 4). The pattern shows bird species that have general increased capture rates through time (positive slopes) on the negative NMDS1 axis, and general decreased capture rates through time (negative slopes) on the positive NMDS1 axis while most species that have similar patterns of distributions fall in the center. The adjusted R^2 value (our model explaining only 31% of the variation) of the linear regression is not high, however that is likely skewed by the variation plotted along the NMDS2 axis, where the species are grouped by different patterns of capture frequency data. The ordination analysis has a stress value of 0.159, nonmetric fit R^2 of 0.975, and linear fit R^2 of 0.919; values suggesting our two-dimensional plot does well in presenting the variation in our variables for capture rates by year.

Ecological categories were overlaid on the NMDS to visualize any apparent patterns. While migration, overwintering habitat and breeding habitat did not seem to exhibit any patterns related to where species fell in the ordination space, the diet category suggested that nectarivores were generally increasing, whereas seed eaters were decreasing. The most abundant diet category, insectivores, mostly show similar trends clustered around the middle of NMDS1 axis but spread out along NMDS2 axis. We identified several species of interest from the NMDS to discuss. Anna's Hummingbird (ANHU), Rufous Hummingbird (RUHU), Golden-Crowned Kinglet (GCKI), and Ruby-Crowned Kinglet (RUKI) have the most positive changes. Red-Winged Blackbird (RWBL), and Brown-Headed Cowbird have the most negative changes. One notable outlier is Pine Siskin (PISI), in which a spike in frequency was observed in 2013.

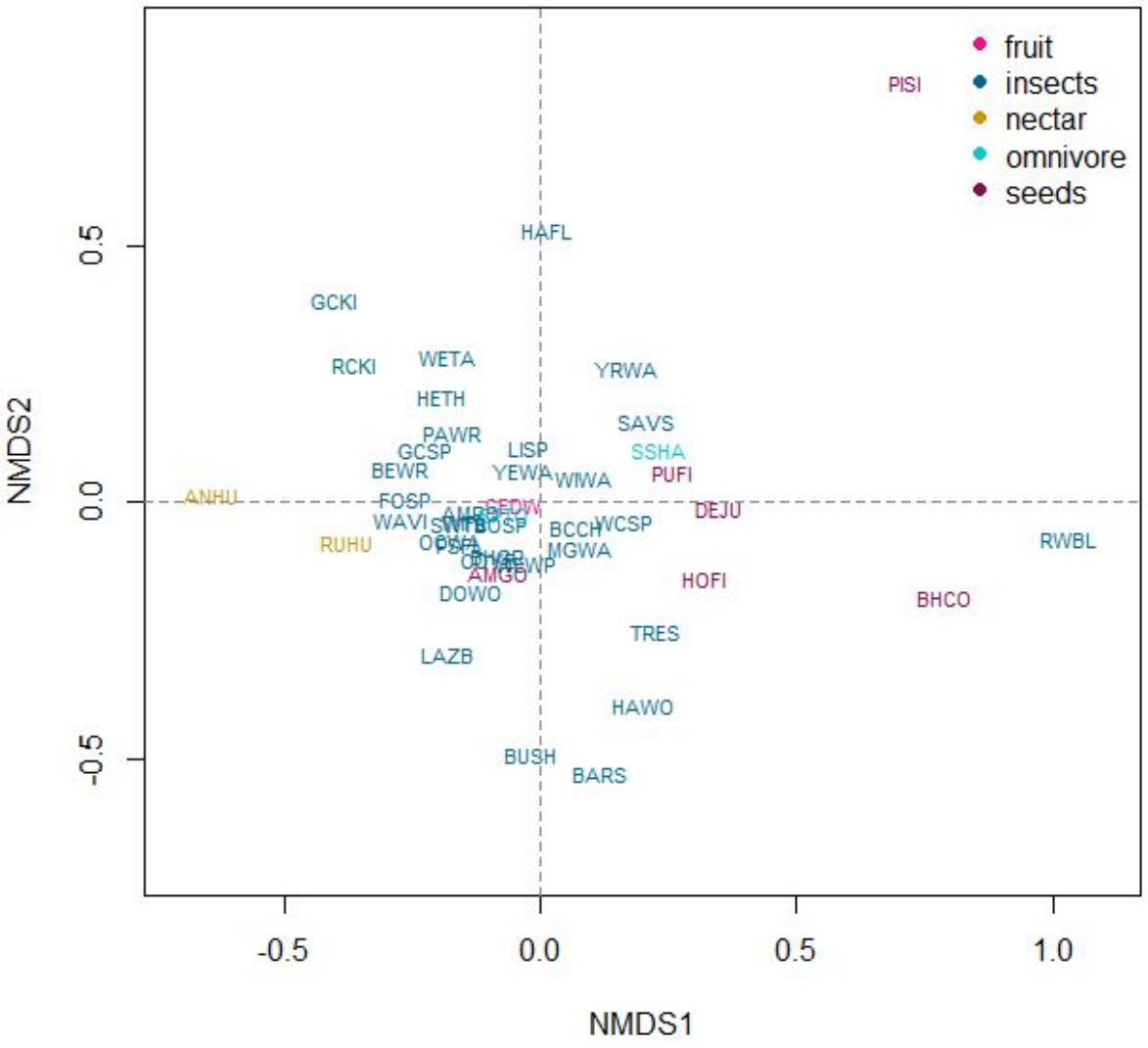

Figure 3. *Non-metric multidimensional scaling (NMDS) plot of bird species captured (standardized per 100 net hours) through time (2010 to 2019) by VARC banding station. Colours identify species by diet to provide an example of a qualitative evaluation of ecological guilds using the NMDS plot.*

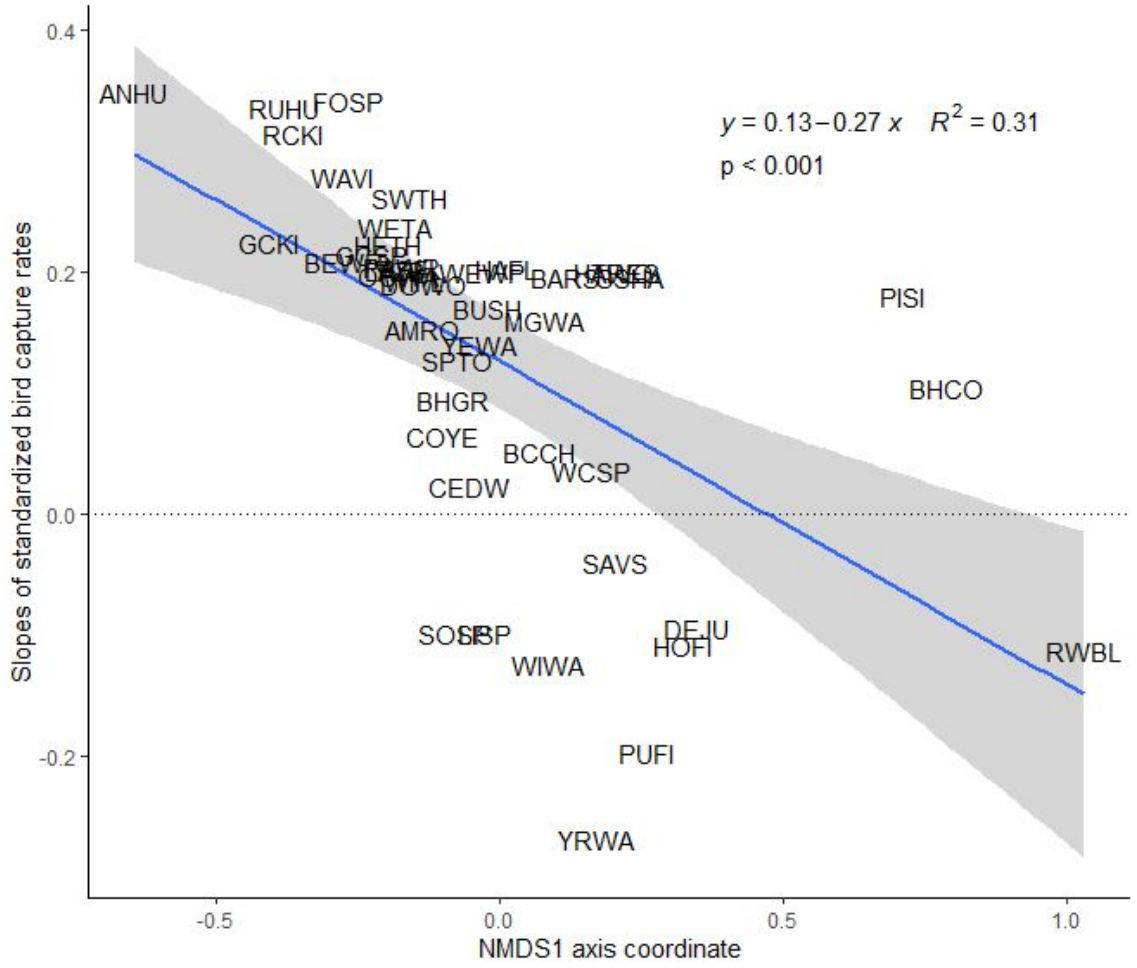

Figure 4. Relationship between slopes of linear standardized capture rates over years (2010-2019) and non-metric dimensional scaling axis 1 coordinates in Figure 3. Gray line shows a 95% confidence interval for the regression. Horizontal dash line shows a calculated slope of zero (unchanging capture rate through time) for a species, thus species below the line are generally declining, and species above the line are generally increasing.

Changes in capture rates of individual species through time

The most frequently captured species at Colony Farm was the Song Sparrow with 3,028 individuals caught between 2010 and 2019 (Figure 5). The next most common species was the Lincoln Sparrow, followed by the Common Yellowthroat, Purple Finch, Orange-Crowned Warbler, Swainson's Thrush, Willow Flycatcher, Yellow-Rumped Warbler, Fox Sparrow, and Cedar Waxwing. Most species showed a slight decrease in the number of captures between 2010 and 2014. After 2014, the top 10 species showed a gradual and ongoing increase in the number of birds captured.

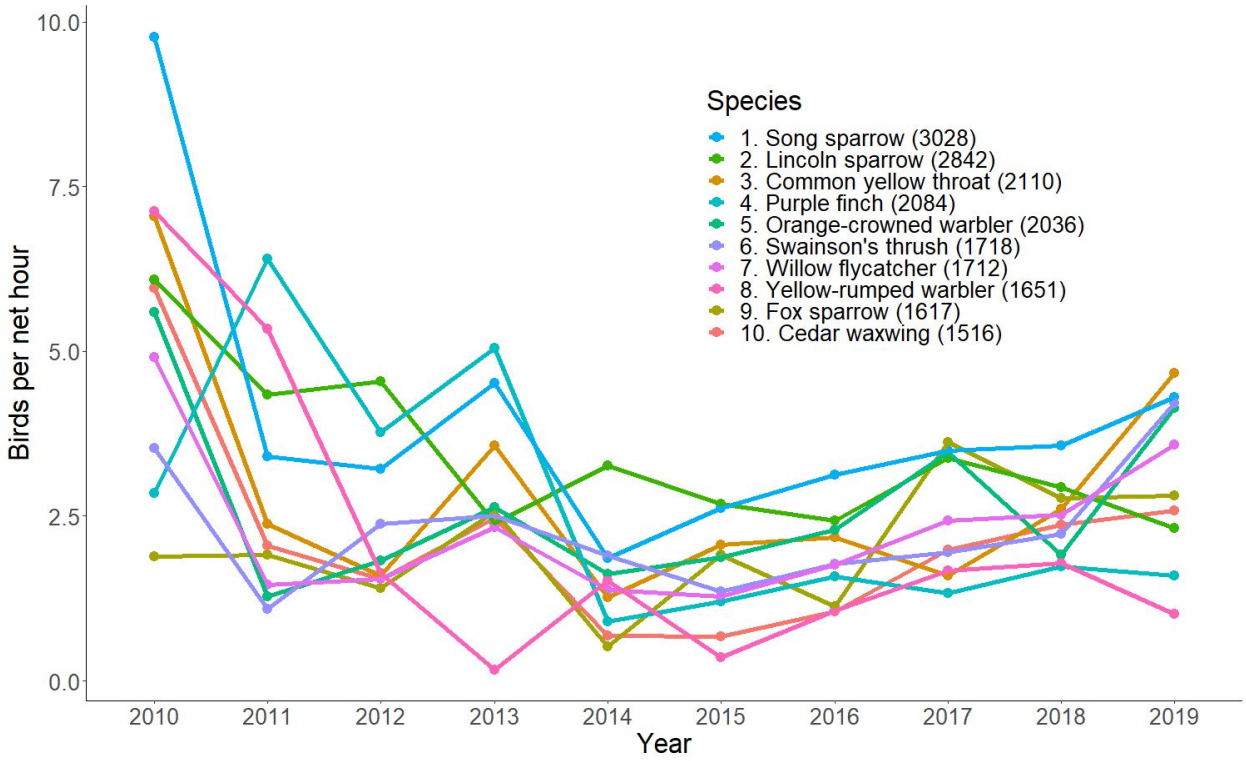

Figure 5. *The change in number of birds captured per 100 net hours for the top 10 species from 2010 to 2019 captured at Colony Farm. The figure legend shows the ranking of species, with the corresponding total number of individuals caught for a species over all years presented in brackets.*

The linear and polynomial regressions representing the univariate analyses for the top 10 species shows only the Lincoln Sparrow ($F_{(1, 8)} = 10.702$, $p = 0.011$), Purple Finch ($F_{(1,8)} = 5.979$, $p = 0.040$), and Yellow-Rumped Warbler ($F_{(1,8)} = 5.485$, $p = 0.047$) to have significant results for the change in captures from 2010 to 2019 ($p < 0.05$) (Figure 6; For regression values corresponding to all other species, please refer to Appendix 4a). These three species show a general decline between 2010 and 2014 followed by a plateau and little change in subsequent years. For all species, it is important to note that the number of captures in 2010 compared to all other years is generally higher, with most species showing the year 2010 to have the highest number of individuals caught compared to all other years (except for the Purple Finch, Swainson's Thrush, and Fox Sparrow).

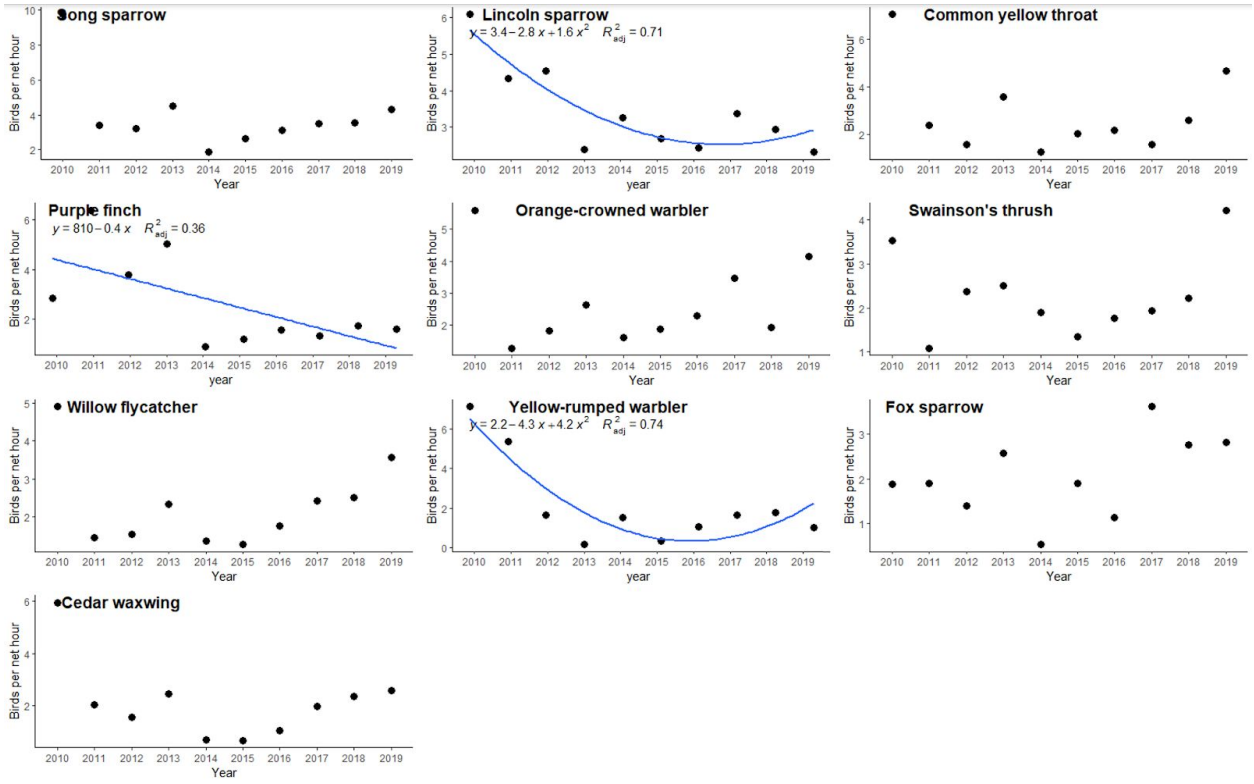

Figure 6. *Annual variation in capture rates for the top 10 species at Colony Farm (2010-2019). The three species of Lincoln Sparrow, Purple Finch, and Yellow-Rumped Warbler show predictable variation in the number of captures over years (with the line of best fit represented in blue alongside its corresponding equation and adjusted R^2 value).*

Patterns associated with ecological guilds and their categories.

The univariate analysis and type I ANOVA for each ecological category shows statistical significance between guilds for food type, wintering habitat and breeding habitat ($p < 0.001$) (Figure 7; for a complete list of test values, please refer to Appendix 4b). The ecological category of migration did not show significance; however, long-distance migrants show the highest capture frequency compared to resident and short-distance migrants. Diet type shows statistical significance for insects ($F_{(7,27)} = 37.97$, $p < 0.001$) compared to all other guilds, with species that feed on insects showing the highest number of captures. Species that primarily use woodland habitat during the winter season and for breeding show the highest frequency of captures compared to all other habitat types (Winter: $F_{(5,54)} = 34.15$, $p < 0.001$; Breeding: $F_{(5,54)} = 15.40$, $p < 0.001$). Also of interest are the breeding habitats of coniferous forests, scrub/grassland, and marsh/riparian, that show similar numbers and are the next most commonly used habitats for breeding.

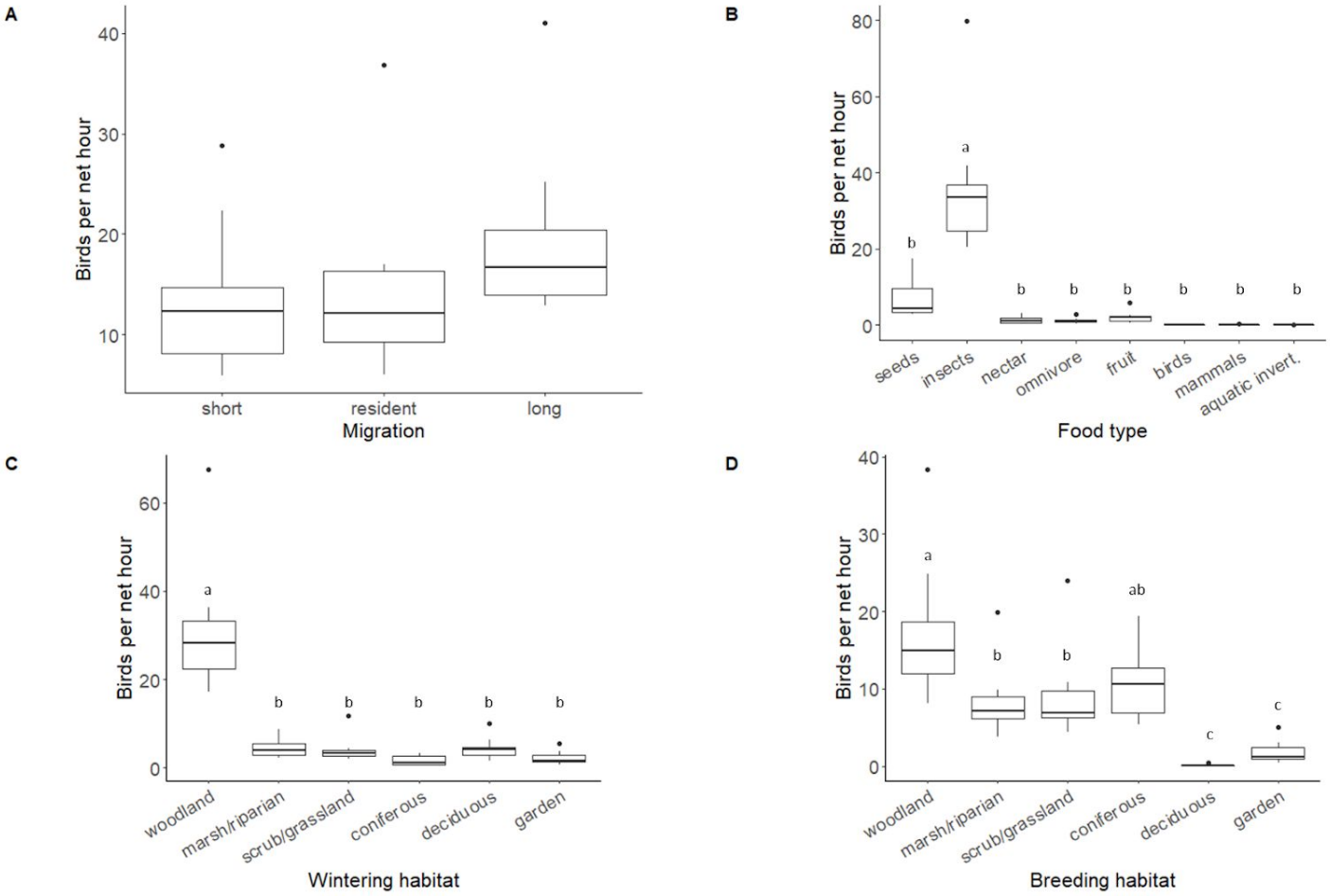

Figure 7. *Univariate analysis presenting the number of birds captured (standardized to per 100 net hours) for each guild within an ecological category from 2010 to 2019 captured at Colony Farm. Results from a Tukey-Kramer test are presented with letters. Shared letters show no significant difference between groups while different letters indicate significant difference. The ecological categories presented are: A) Migration behavior, B) Diet, C) Wintering habitat, and D) Breeding habitat.*

Three of the four ecological guilds, diet, breeding habitat, and wintering habitat were shown to have significant interaction effects with year to explain bird capture rates through time (Figure 8; Appendix 5). After removing the intercept term of the regression equations for each guild, most categories within the guilds had no significant differences in their trends comparatively. The exceptions are as follows: in the diet guild, nectar was significantly different ($p < 0.001$) and exhibited a positive linear trend; in the breeding habitat guild, deciduous habitats was significantly different ($p < 0.05$); in the wintering habitat guild, coniferous habitats had a negative linear trend.

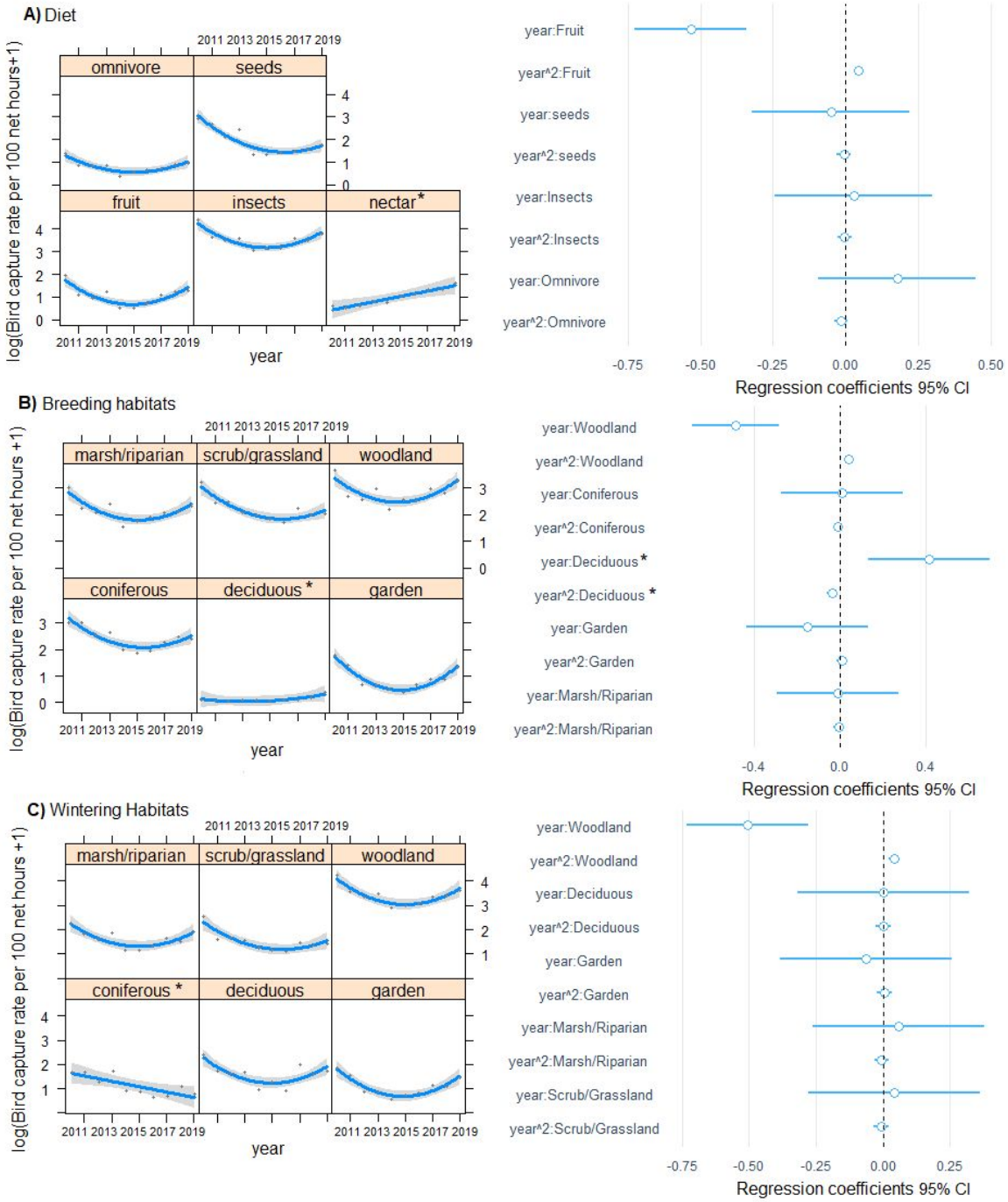

Figure 8. Quadratic *relationships between standardized frequency of birds caught per 100 hours in Colony Farm from 2010-2019 categorized in ecological guilds (A. Diet B. Breeding habitats and C. Wintering habitats) and their respective categories. Gray lines show 95% confidence intervals of the regression model. Coefficients for each regression (circles), with intercept removed from the model, and their 95% confidence intervals shown on the right (blue lines). Significantly different coefficients and their regression are marked with an asterisk. Significantly different linear models for Diet-Nectar, and Wintering habitat-Coniferous are omitted from the regression coefficient plots on the right.*

Discussion

The long-term monitoring conducted at bird banding stations like VARC provides crucial data to assess the health and trends of our ecosystems. To address the local patterns of bird capture rates through a decade of bird banding at Colony Farm, we tackled the dataset and presented our results and discuss our findings in three sections: 1) Changes in local avian community through time, 2) Changes in capture rates in specific individual species through time, and 3) Ecological categories that could explain these patterns in capture rates. We use case studies of species of interest to explain intriguing trends highlighted in our results.

Changes in local avian community through time

We found the capture rate of birds varied each year, and that the local avian community has changed in different ways from 2010 to 2019. The general trend we observed in the number of birds captured each year showed the highest captures in 2010, and dips in 2014-2016 followed by an increase in the subsequent years. It is possible that 2010 was a productive year for bird captures whether regionally or locally, as numerous factors such as food productivity, weather, and migratory conditions being more ideal. A study conducted by Holmes and Sherry (2001) showed natural fluctuations in bird populations in a successive forest over 30 years, and highlighted variation due to habitat change and local events [16]. Given how Colony Farm has changed over the past ten years and located in a rapidly changing Lower Mainland, many patterns in our dataset could be due to local natural and urban conditions. Comparisons with other west coast bird monitoring datasets for capture rates over years can give us better indication whether the pattern was local to Colony Farm, or more consistent across the region. However it is uncommon to find abundance by year data in BC's public bird banding station's annual reports.

Changes in individual species through time

In this section, we discuss the trends of top 10 bird species, as well as several bird species of interest identified from Figure 3 and the results section. As outlined in the previous section, we showed that the local avian community is changing, and different species have shown different trends. Capture numbers through time are compared to other regional datasets, as well as patterns in BC [17].

Among the top 10 species, many species showed similar patterns in their capture rates over time. With the number of captures being an indicator for population size, our findings show that most species may have fluctuating populations with no true predictable pattern. Three species that are of interest to highlight are the Lincoln Sparrow, Purple Finch, and Yellow-Rumped Warbler. These three species showed statistically significant changes in their abundance over time, which would indicate a predictable trend in population fluctuations; however, it is important to note that these

results may be largely influenced by earlier years. The year 2010, and often 2011 as well, show the highest number of captures for most of the top 10 species (Figure 6). If we excluded the data from the years of 2010 and 2011 we may not detect a noticeable capture trend in the Lincoln Sparrow, Purple Finch, and Yellow-rumped Warbler. It is a bit unclear as to what caused the increased number of captures in these earlier years for the majority of the top 10 species, but it is important to keep this in mind when assessing temporal effects on capture, and inferred, population trends.

The high number of captures in the earlier years would lead us to believe that for the three species of interest, there is a notable decrease in population size between 2010-2014, and slow increase in population size for the Purple Finch and Yellow-rumped warbler in subsequent years. However, it is most likely that these three species show similar population fluctuations as other species within the top 10, and would show no noticeable trend. For example, the trend observed for the Lincoln Sparrow captures could be in part, due to its migratory nature. The Lincoln Sparrow is a short-distance migrant, and shows similar survival to that of other resident sparrows and other migratory sparrows found in BC (regardless of migratory distance) [18]. This means that Lincoln Sparrow captures should be similar to that of other sparrow species at the park, and would suggest as such if excluding the outlier year of 2010. Therefore, Lincoln Sparrow populations should not be declining as indicated by our results.

For the Purple Finch, the literature suggests that this species showed a global population decline between the years of 1989-1998 and was large enough to be listed as “vulnerable” or “endangered” by the IUCN [19]. Due to its current status showing “low concern” [20], Purple Finch populations have inclined and may be more stable at this time. A species that may have contributed to the decline in Purple Finch populations is the common House Sparrow and House Finch. Negative relationships in population density were found between House Sparrows, House Finches and Purple Finches during summer months due to range overlaps and competition for resources [21]. This would suggest that range overlaps for these species can cause a disadvantage for Purple Finch reproduction and survival, ultimately impacting population densities if the House Sparrow and House Finch populations increased.

For the Yellow-rumped Warbler, it may show relatively stable populations, with its high abundance in Alaska and generally robust nature (residing in a variety of habitats and showing a generalist diet) allowing for increased resilience to stochastic events [22,23]. The initial decrease in captures at Colony Farm between 2010-2011 does not accurately represent temporal population trends for this species, and may be explained by a local event that has caused us to detect a predictable trend in captures over time.

The increasing trend observed for nectarivores abundance could be in part due to the number of captures for the Anna’s Hummingbird and Rufous Hummingbird. The increasing trend in

nectarivores associated with the Anna's Hummingbird captured at Colony Farms appears to be consistent with the literature of an increasing population in British Columbia. This increase in abundance over time could be due to a historical range expansion, as well as human-driven resource alteration leading to their success in urban garden environments [17]. Anna's Hummingbirds have expanded from their native populations in California up the Pacific Northwest to the northern range of British Columbia and coastal Alaska since the mid-1900s due to planting of introduced ornamental garden species [24]. There is a positive relationship between the presence of hummingbird feeders in urban areas and the increase of hummingbird populations documented in the past decade [25]. Finally, while climate change was not stated as the main driver of this range expansion, there is a strong correlation between where populations have the fastest growth rates at ranges where minimum breeding temperatures are located [24]. An indication of population growth and further range expansion of Anna's Hummingbird could be related to elevated seasonal temperatures in those areas.

In contrast to Anna's Hummingbird, Rufous Hummingbirds are a species of concern both locally in British Columbia and all of North America. Another difference is the extensive migration Rufous Hummingbirds take from the Pacific northwest in spring breeding season, down to Mexico during the fall-winter season. The increase in this hummingbird's capture rates at Colony Farm could be due to similar reasons listed above for Anna's Hummingbirds. Both hummingbirds showed an increase in captures from 2014 to 2015, when hummingbird feeders were being put out more consistently at VARC. It is recommended to keep an eye on this species' abundance as it has recently been changed from least concern to near threatened by IUCN [26].

Despite having generally increasing captures, Golden-Crowned Kinglets and Ruby-Crowned Kinglets both have oscillating captures that vary each year. The more abundant Ruby-Crowned Kinglet shows similar frequency trends with data from Mackenzie Nature Observatory in BC, and the North American Bird Breeding Survey (BBS) [27]. Specifically, there has been an overall increase since 1970 in Canada. Our data is also consistent with the Mackenzie Nature Observatory's data in which the species' abundance fluctuates each year, explained by the fluctuation in spruce budworms yearly [17]. The Golden-Crowned Kinglet has lower overall abundances and their numbers do not fluctuate yearly like the Ruby-Crowned Kinglet [17]. There was a spike in captures in 2018, where the numbers usually ranging from 6-10 suddenly increased to 30. The conservation status for Golden-Crowned Kinglets is of low concern in Canada overall.

Red-Winged Blackbirds and Brown-Headed Cowbirds showed the steepest declines in capture frequencies at VARC. There were no reported captures of either species in 2019, with a steep drop from 2013 to only 3 captures in 2014 each. Red-Winged Blackbirds are common and ranked as 'least concern' in BC, therefore the recently lowered capture rates could possibly be an indication of local habitat alteration. The Colony Farm Enhancement Project changed the

hydrology and increased riparian planting in the regional park to improve wildlife habitats around 2012 [28]. Red-Winged Blackbirds nest and breed in wetlands and marshes, and there is a breeding marsh near the banding area. The trend of this species is a puzzle and it is not clear the exact effect of the enhancement project on local abundance, as the habitats should not be reduced in quality. This also could be a sign of regional decline, as wetlands in Canada are disappearing [29].

Brown-Headed Cowbirds are obligate brood parasites whose general populations have been declining in BC [17]. One potential source of decline for the Brown-Headed Cowbird at Colony Farm could be explained by the vegetation re-growth in and around the park. This cowbird species requires grassland or agricultural land interspersed with scattered trees, shrubs, or hedgerows [14]. Similar to the Red-Winged Blackbird, the increase in riparian planting and vegetation regrowth associated with the Colony Farm Enhancement Project resulted in a decrease in the available area of short-grass fields [28]. These short-grassy areas can now only be found alongside recreational paths within the park, thus leaving less suitable habitat to support higher populations of Brown-Headed Cowbirds.

The last species of interest was the Pine Siskin. The capture rates for Pine Siskins are annually less than 10 and spiked in 2011 and 2013 to 16 and 46 captures respectively. Pine Siskins have stark irruptive migratory patterns and perhaps not usually found at Colony Farm. Pine Siskins are abundant elsewhere in British Columbia. However, as a species of finch, they are in a general long-term decline across Canada [27]. Despite this, Pine Siskins may not be of immediate local concern to Colony Farm.

Trends associated with ecological guilds and their categories

With many species showing non-detectable trends in abundance over time and possibly stable abundances over time, the importance of assessing changes in abundance for ecological categories becomes evident when deciding future conservation focus for all species. The results from the ecological categories help to better understand commonalities between the species that reside at Colony Farm and how best to take care of populations in this local area and beyond. At Colony Farm, there are many long-distance and short-distance migrants that regularly visit the area, even more so than resident species. This is supported by current literature, with the highest migratory bird diversity found in the Northern Hemisphere and migratory birds constituting a large portion of local avifauna [30]. This suggests that efforts to ensure adequate habitat and stop-over sites for these migratory species are in place to ensure healthy populations, both locally and regionally, are maintained over time.

The woodland habitat was associated with the majority of species for both breeding and over-wintering habitat use. Because we designated the category of woodland habitat to represent generalist forest dwelling species, it is not too surprising that we see more captures of generalist than specialist species consistent with the findings of bird population studies in North

America [31–33]. The decrease in species captured correlating with coniferous over-wintering habitats is surprising as BC is covered by a majority of coniferous trees [34]. Looking at the dataset, it seems this trend is skewed negatively by Dark-Eyed Juncos and irruptive Pine Siskins, which seem to have decreasing trends according to Figure 3. While there has been a noticeable decline in Dark-Eyed Juncos since 2016, the species is considered to be very abundant and widespread in BC and North America. Species breeding in deciduous habitats showed a significant difference compared to the other trends in the breeding habitat guild. However, the deciduous category has only a sample size of 91 total captures over ten years, as well as twice as many captures in 2019. A more in-depth look into the trends of six species (all with low total capture numbers) and additional data would be needed to evaluate the importance of deciduous breeding habitats and rate of bird captures. It is important to note the slightly lower but still frequent use of coniferous forest, scrub/grassland, and marsh/riparian habitat for breeding activity. Woodland habitat, coniferous forest, and grasslands are all popular habitats (for both breeding and nonbreeding use) for migratory species in North America and are often of focus for conservation efforts [33,35].

An additional key ecological factor important to consider for migratory species is resource availability. It appears that over the decade at Colony Farm, the majority of species that visit this area tend to eat insects, with seeds being another popular second choice. Abundances of aerial insectivores and seed-eaters appear to be in decline in Canada compared to other diet categories [33,34]. This would mean that Colony Farm is an important location to study long-term trends of these dietary species, and construction or building around or within the area that could impact insect and seed resources should be taken into consideration. If large insect populations are found close to water sources (e.g., local ponds at Colony Farm), these water sources should be maintained and avoid harsh disturbance to promote healthy insect growth and abundance. For example, the migratory Tree Swallow is an aerial insectivore that relies on insect populations as a source of food and there have been notable declines in Tree Swallow populations associated with declining insect populations [36]. Therefore to maintain healthy Swallow populations, insect populations should be a part of a conservation management strategy for this species. .

Limitations and future research

Most of our analyses focused on the overall difference in capture rate per year, and not differences in patterns of capture rate fluctuations. As shown in our ecological guilds regression and coefficients, most of the captures for each category seemed to have similar numbers through time, with few significantly different categories due to their comparatively lower sample numbers with less species in the categories. The analyses of ecological guilds do not represent larger regional ecological trends that affect avian communities around BC, but outline the local patterns of species abundances to focus on. Capture numbers are also not a perfect indicator of bird populations or the avian communities at Colony Farm, as there are many biases with mist net

sampling such as missing certain groups of birds all together regardless of season [37]. Mist net sampling should be combined with visual and aural surveys to supplement the dataset and reduce bias.

The ongoing bird banding activities at VARC offer opportunities for further research with the dataset. Future research opportunities with the dataset may include:

1. Analysis focusing on the physiological categories of the dataset such as weight, sex, wing chord, fat scores and matching how they change by time or through species categories and conditions.
2. Comparison of abundance and species composition data with other local bird monitoring stations - e.g., Maplewood Mudflats, Reifel Bird Sanctuary, Stanley Park and Boundary Bay. These regional datasets can reflect a better understanding of whether trends observed at Colony Farm are due to local, regional, or global patterns.
3. A multivariate analysis of the ecological categories (diet, migration, overwintering habitat, breeding habitat) to determine which categories are significant and can identify key species corresponding to those factors, which may help identify species that may be vulnerable or recovering in the region.
4. An analysis of seasonality to look at spring trends (April and May) compared to fall trends (September and October). This would provide more data points per year to conduct more robust analyses for change in time, as well as analysing different trends among different migration strategies.

Conclusion

In a rapidly expanding region like the Lower Mainland area of BC, it is important to understand how changes are affecting local biodiversity. Through only ten years of bird banding data, we have highlighted variation in the avian community captured at VARC, demonstrated case examples of decline and recovery in local species, and presented possible ecological factors that could be influencing these patterns. Our analysis supports the importance of long-term monitoring, as more captures throughout time will give us a high quality understanding of our avian biodiversity and their direct ties to assessing local ecosystem health. We described how changes in the local environment due to natural and human efforts have driven the trends of certain species. The results of our data turn into stories through outreach to inform the public about conservation in their own communities.

2. SCIENCE COMMUNICATIONS

With the increasing popularity of social media, especially as a source of news, scientists must become increasingly fluent in sharing their work with the public. Good science communication builds support for scientific disciplines, makes science more inclusive, promotes trust and understanding, enables informed decision-making institutionally and individually, helps secure research funding, and can increase interdisciplinary collaboration and innovation.

Perhaps most importantly, good science communication helps teach and inspire youth who will become future scientists, conservationists, teachers, and other decision-makers. One component of VARC's mandate is education - offering outreach opportunities to hundreds of people every year. To help communicate the value of the work the VARC does, and translate this research project to non-scientists, we have also included a few science communication elements on our results.

Education presentation

Some of the results from this research project have been highlighted in an educational presentation sample as a separate attachment in Appendix 1.

Social media

Facebook

Facebook posts - Vancouver Bird Week:

Post #1

Our banding station has been operating since 2009. Each bird that visits our station is banded, and we also collect measurements like overall health (level of fat), age, sex and breeding characteristics. In just the past 3 years, that means more than 40,000 birds have been banded!

With so much data collected (and so little time to analyze it), VARC partnered with a team of UBC graduate students to analyze 11 years worth of data. Stay tuned during #VanBirdWeek to find out more about what we learned from this collaboration!

Post #2

After looking through 11 years of data, we found that hummingbird populations have been on the rise. Can you guess why that might be? Answer below!

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If you guessed it's because of increased hummingbird feeders, you nailed it!

Post #3

Did you know that Anna's Hummingbird is Vancouver's official city bird? These beautiful small birds are known for their big and feisty personality.

If you know where to look, it's easy to find them on a sunny day in parks and backyard, just listen for their distinctive song and check the tops of nearby trees. Their "song" is a series of buzzes that ends with a few chips and whistles. See if you can spot one during #VanBirdWeek!

Post #4

Anna's Hummingbirds used to be migratory, but now, many are choosing to stay year-round in Vancouver because they can get by on nectar hummingbird feeders. This has led to an increase in populations, but now it also means we have a responsibility to take care of them. Know how to safely make hummingbird nectar, and be sure to clean your feeders every few days to prevent lethal disease.

Post #5

As #VanBirdWeek comes to a close, we're starting to think about colder temperatures. If you're planning on putting out hummingbird feeders over the winter, make sure you can fully commit. They need fresh nectar in a clean feeder every few days to prevent disease, and make sure the feeder never freezes.

You may need to place the feeder near a light to keep it warm, or have a spare feeder to swap out if one gets too cold. If you're going to be travelling, have friends, family or a neighbour that can take care of your feeder while you're away.

Facebook is also an increasingly effective tool for soliciting donations. Make sure posts for donations, like the one below, are paired with eye-catching imagery that will resonate with your target audience. For example, donors may love to see photos of the same birds they are likely to see on walks or in their backyards, that are also particularly colourful (e.g., hummingbirds, goldfinch, barn swallows).

Facebook post - donations:

Bird biodiversity is in trouble. Over just the past 50 years, wide-spread bird population declines are being reported - and not just in rare or endangered species. This staggering decline was only realized thanks to the long-term reliable records from institutions like VARC.

Now more than ever, the kind of research and monitoring conducted at VARC is essential to guide successful conservation and management actions. As a charitable organization, VARC relies on your generosity to save generations of birds to come. Will you help secure their uncertain future?

https://www.birdvancouver.com/donate/

Facebook post - evergreen content:

Have you ever been startled by a crow getting caw-fully close? Don't take it personally! It's nesting season for crows, which means anxious parents are starting to get protective of their young babies. Crow fledglings spend time on the ground hopping around while they develop their flight muscles. While they're this vulnerable, their parents want to make sure they stay safe.

During dive-bombing season, think about changing your route to avoid worried parents, or carry an umbrella with you. The babies will be up in the air in no time!

Instagram

During Bird Week 2020, we recommend VARC create daily Instagram videos to post to their story. These stories should feature interesting birds captured at the banding station, or birds spotted out in the "wild" (including backyards and urban spaces), with a focus on celebrating the wide diversity of birds in Vancouver.

Twitter

During Vancouver Bird Week, Twitter is the ideal place to share where bird events are happening, particularly what role VARC intends to take during the events. For example, if VARC is hosting a lecture or a workshop, make sure to share it on Twitter.

3. GENERAL COMMUNICATIONS

2019 Annual report sample

VARC produces a year-end report for Metro Vancouver. The reports include detailed methodology on how VARC conducts their banding operations, bird surveys, and species-specific studies. Similar to a scientific report, it also includes data analyses, results, and discussions for each of their study areas. These year-end reports contain rich data sources and discussions which are extremely valuable to the scientific community - this important data should continue to be collected and consolidated in an annual statistical report.

However, VARC identified a gap in being able to use this information to communicate the value of their work to potential funders, including private donors and granting agencies. The project team recommended creating a public-facing annual report to clearly communicate VARC's research, education, outreach, and other important activities and milestones. This report aimed to

present VARC with a current 2019 annual report sample, designed with professional and engaging imagery (featuring images taken by VARC staff).

The final presentation of the 2019 annual report is included as a separate attachment in Appendix 2. The final design files will be given to the project sponsor - including web-friendly and print-ready versions - and to use as a guideline developing future annual reports.

To support growing VARC's supporter and donor base, these annual reports could in future be rebranded as "generosity reports", and sent to previous donors either digitally or by physical mail. These generosity reports, combined with an ask to donate to keep the work going, are a very effective type of mailing that also increases donor retention.

Branded Powerpoint templates

To help VARC communicate a consistent brand and professional image to potential funders and the general public, our team created two Powerpoint templates (.potx) that can be used to develop new presentations. These templates are available in both standard and widescreen size, and include automatic, pre-formatted brand identity including logo, colour palette, font family, and image placeholders for a variety of slide layouts.

The final presentation of these templates are included as separate attachments in Appendix 3a and 3b.

Social media

Social media outlets are offering ever increasing functionality and have taken on new roles in society, including as sources of news and current events, and as key fundraising platforms. Facebook, Instagram, and Twitter continue to be the top 3 leaders in the world of social media (excluding YouTube). VARC is already serving a wide variety of audiences by having accounts on all of these platforms. However, they could be using these tools more effectively by gaining more insights into their current and target audiences for each platform.

Facebook

Facebook is the largest social media network with 2.44 billion monthly active users [38,39]. 84% of 25-30 year olds use Facebook, while 79% of 30-49 year olds use Facebook. Facebook usage among teenagers has dropped in recent years, with teenagers more likely to use Instagram and Snapchat [38,39].

Although seniors represent a relatively small portion of users on Facebook, it is their fastest growing age demographic, and the most popular social network for adults aged 65 and older [40].

Retired seniors with a secure source of retirement funds are likely to donate to causes they care about.

Most adults with Facebook check their account daily - they rely on Facebook as their source of news, local events, and engaging with friends and family members [38,39].

Facebook is the ideal place to use “evergreen content” - this is content that can be reused annually, or depending on how seasonal it is, more often. Note and document content that performs well when first posted, as this will indicate future success as evergreen content. For example, evergreen content might include what type of seeds attract which birds, when migration season is full-swing, what types of birds are hatching right now, crow dive-bombing season, providing spring cleaning tips each year to help protect bird nests, or how to maintain hummingbird feeders over winter. Because your audience cares about birds, they also likely have concerns about free-roaming outdoor cats. This is engaging evergreen content, but can be very polarizing. This topic must be handled carefully to ensure VARC hits the right tone with their audience.

Currently, VARC’s Facebook presence is as a public group, rather than a page. A group is ideal for engaging with volunteers and others in the ornithology community. However, a page is ideal for engaging with the general public - people who are bird lovers, but don’t necessarily consider themselves scientists. Users want to be able to like and follow pages that are interesting to them, and see news posted with a voice of authority (i.e., from “Vancouver Avian Research Centre”).

Recommendations for Facebook:

- Create a VARC Facebook page - add Jason and Derek as administrators
- Repost/share local news stories related to birds
- Share VARC education and outreach events via Facebook events
- Keep a list/document of evergreen content, including seasonal topics
- Use VARC group to engage with/recruit volunteers or others specifically the ornithology community

Instagram

Instagram has 1 billion monthly active users, and is the ideal platform for reaching teenagers and young adults [38,39]. 75% of 18-24 year olds use Instagram, this percentage decreases with increasing age demographic [38,39].

While Facebook users tend to check their accounts daily (74% of users), only 63% of Instagram users login at least daily. Instagram users are more selective about who they follow, and rely on Instagram for staying connected with friends, and photo/video content from causes they care about, travel destinations, and small, local businesses [38,39].

Instagram is the ideal platform for VARC to continue sharing bird photography, both local photography from the banding station, and travel photography.

Recommendations for Instagram:

- Use Instagram stories to feature live banding work done at VARC, or live videos of birds in the wild
- Share local and travel photos of birds, include popular hashtags
- Include ways to engage followers with images - “guess the species”, “did you know...?”, “It’s baby season for...”
- Cross-post popular Instagram content on Facebook page

Twitter

Twitter has a more modest 330 million active users [38,39]. Twitter’s largest age demographic is 18-24 year olds (44%), followed by 25-20 year olds (31%), and 30-49 year olds (26%). Although Twitter has a smaller user base, it is still the go-to social media tool for science communications.

Recommendations for Twitter:

- Use Twitter to promote VARC educational events and connections with other professional groups and events (e.g., International Ornithological Conference, Vancouver Bird Week)
- Post volunteer opportunities when volunteer recruitment needed
- Post seasonal science updates (e.g., “bird banding season has started!”, “Operations at VARC are in full-swing!”)

Target demographics

The general trends in target demographics described in the previous section are important to be aware of, but the most effective communications will come from diving deeper into the page insights for each platform.

For example, using Facebook’s Audience Insights tool: people in Canada (of all ages) that are also interested in “birds” and “birdwatching” are likely to be married, are educated (have graduated university), and likely employed in administrative services or government [41]. From this same source, we can also gather that our audience is likely to be women aged 25-34 (25%) and 35-44 (21%). They use Facebook to connect with local news and media, and are interested in travel and photography. These insights can help develop audience personas, a visual way to help content creators write for their target audience - because scientists and researchers often forget that others exactly like them are not the target audience.

Michelle Burton

- Age: 40
- Relationship: married
- Education: Bachelors
- Location: Vancouver
- Job: Administrative Services Manager

Michelle is a married working professional with two kids in middle school. She is in a dual-income household and secure housing situation. Michelle spends free time with her kids, and enjoys spending weekends outdoors hiking. Michelle loves animals - she has pets at home and a bird feeder in her backyard. She likes to travel at least once a year, and aims for local outdoor destinations or occasionally countries abroad with natural beauty for hiking and other activities.

An example of an audience persona based on VARC's target Facebook user

Social media insights offer important information about your target audience, but can also show how to better engage a target audience by tracking post reach, followers/likes, and engagement over time.

With login access to VARC's social media pages, they will be able to dive deeper into these insights from each platform, or by viewing using a social media tool like Sprout Social or Hootsuite. Note Instagram insights are available only for business accounts, and only visible when using the mobile app. Instagram accounts that have already been set up as personal accounts are able to be converted into business accounts.

Google also offers a suite of marketing tools that provide important insights for website traffic, and offers free training in how to use tools like Google Analytics and Google Ads [6]. Google Ad Grants is a program that offers $10,000 of in-kind advertising every month to charitable organizations, to help drive traffic to websites [42]. This traffic could be used to attract donations, volunteers, and help share VARC's education and outreach work.

LIST OF APPENDICES

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