

Urbanization on the Advancement of Avian Migration

Word Count: 4358



American Robin as photographed by Chris Wood, Macaulay Library

Abstract

Over the last century, urbanization has been occurring at an alarming rate, significantly impacting the ecosystems which preceded the cities. To cope with these changes, adaptive city birds have learned to live alongside humans within urban environments. In order to analyze the impact of residing in this unique urban habitat on avian species, this study explores whether differences exist and their trends over time between the onset of spring migration of populations of the American Robin (*Turdus migratorius*), a short distance migratory songbird of North America, that winter in rural areas when compared to those who winter in urban areas. While human altered environments have been proven to influence other aspects of birds such as with the frequency of their songs and even the physical shape of their wings, little research has been done on the impact on migration, one of the most crucial aspects of a bird's life. A causal comparative and trend analysis was carried out using the citizen science eBird dataset from which the mean departure date (MDD) and last departure date (LDD) of rural and urban departing Robins in the Southwest U.S. were extracted for each migratory season from 2000-2018. While we found no significant differences in the overall time frame in which spring departure occurs, we were able to determine a significant difference in timing within the migration season. Surprisingly, we found no trend in migration timing for both populations of birds.

1. Literature

From hunting animals to creating landfills, human activities have made notable impacts on our natural world, altering the ecology of the environment. While in some cases, the damage caused by human alterations can be “undone” to an extent such as by remedying deforestation through reforestation efforts to return environments to their original states (Ryngaert, 2017), this is difficult, near impossible, in the case of the process of urbanization, “one of the most extreme forms of environmental alteration” (Batary, 2017). Over the course of the last century, urbanization, has been occurring at an alarming rate (Batary, 2017), significantly impacting the ecosystems which preceded the cities. Svirejeva-Hopkins of the Potsdam Institute for Climate Impact Research explains that urban cities create a completely new human ecosystem which undergo fundamentally different carbon cycles that “destroy the... processes of production and decomposition of living matter that is typical for natural ecosystems” (2008). With such drastic changes to their habitat, many species of animals are dislocated and significantly crippled by the processes of urbanization and are forced to alter their behaviors to adapt (Abilhoa, 2017). One notable adaptation is the emergence of city birds who have “adapted to living alongside humans” (Fuller, 2009). The study of these city birds is of particular interest due to the unique interactions between aviary species and their environments in the form of migration. Avian migration is an impressive feat of evolution, with migratory birds who brave the “rigors of the annual migratory journey” between their wintering and breeding grounds, benefitting by being “able to inhabit two different areas during seasons when each region provides favorable conditions” (Lincoln, 1983). On the flip side, the viability of many birds hinges on migratory success. For instance, the mis-synchronization or delay of migration timing can cause a population to arrive later than the peak of its insect food source and harm the population as a whole (Tryjanowski, 2013). With migration timing being affected by environmental factors, research into the differences in the migration patterns of city birds wintering in altered urban environments compared to their rural counterparts will shed light on the unintended ecological impacts of urbanization. This leads to the question: to what extent do there exist differences in the onset of spring migration of populations of the American Robin (*Turdus migratorius*), a short distance migratory songbird of North America, that winter in urban areas when compared to populations that winter in rural areas?

Avian migration is complicated and its factors under much scholarly academic debate. Over the past century there have been numerous models proposed for avian migration. Most early researchers such as the founder of aviphenology Carl Linnaeus concluded that migration was controlled by “[environmental] factors, such as air temperature and food availability” (Sokolov, 2016). This model was eventually scraped after various experimental studies with captive birds subjected to constant environmental conditions still showing migratory behavior (Bairlein, 2015). Franz Bairlein, Director of the Institute of Avian Research in Wilhelmshaven, Germany, supports a different model in his study measuring the migratory tendency of caged Northern Wheatears (2015). In birds, the onset of migration is marked by a pre-breeding moult, gonadal development, buildup of fat, and migratory restlessness (Sokolov, 2016). Bairlein found that his Northern Wheatears maintain

rhythms of migratory behavior, notably with migratory restlessness which is recorded by a motion-sensitive cage, in captivity even when they were not exposed to changes in environmental factors and pushes a model based on endogenous control or an internal circannual clock and photoperiod control, the length of day (2015). This experiment supports the early studies done by Rowan (1926), which found that artificially increased day length advances migration, and Gwinner (1971), who conducted a similar study on Garden Warblers. Recently with more research into the genetic and endocrine control of spring migration, this understanding has begun to shift yet again (Sokolov, 2016). For this paper, we will be building off of Tsvey Sokolov of the Zoological Institute of the Russian Academy of Sciences who synthesizes nearly 120 studies to create a relatively comprehensive model for the mechanisms controlling migration timing (2016). In comparing previous studies with his own research on the endocrine pathways controlling migratory behavior, he concludes that the innate migration template of birds is formed by the aforementioned endogenous and photoperiodic controls and variations in this template brought on by environmental factors such as air temperature, weather, food availability, and more.

Human activities can have major impacts on environmental factors and thereby alter avian migration. This phenomenon has been studied in great depth with the case of global climate change and the increase in air temperature. Jason Courter, in the *Wilson Journal of Ornithology*, conducted a study analyzing the change in arrival dates of the Rufous Hummingbird (*Selasphorus rufus*) to breeding sites in Oregon, Washington and British Columbia (2017). He compared historical arrival dates from 1855-1969 retrieved from the North American Bird Phenology Program and arrival dates from 2006-2015 retrieved from eBird (Courter, 2017). Courter found that “hummingbirds arrived... 7-17 days earlier” in the more recent range of years, suggesting a “climate-related advancement of Rufous Hummingbird [migration]” caused by human activity (2017). These findings were expanded upon by Zaifman (2017) who concluded in his study that “changing temperatures and migration timing suggest that global climate change may have consequential effects on all bird migration patterns throughout the United States.”

Similar to human altered climates, human altered urban environments have been shown to have significant impacts on birds. Dowling (2011) explains that the noise pollution in cities have altered the frequency of bird songs which enable birds to successfully “transmit their signals to intended receivers” such as mates. An experimental study conducted by Ducatez (2016) has an observer record the activity of birds as they walked towards the bird at a constant speed. He found that urban birds were more likely to show “risk-taking behaviors” than rural birds (Ducatez, 2016). Apart from altering behavior, urbanized environments have also been shown to have such a drastic effect on bird species as to even impact bird physiology. Saccavino (2018) found in his study on Blackbirds (*Turdus Merula*), that urbanization drastically affects wing morphology of urban birds and “[may] coincide with reduced migratory behavior”.

While there has been lots of research done about other human activity on bird migration, such as with human triggered climate change (Courter, 2017), and research about urbanization on bird physiology and behavior, there has been limited research conducted about urbanization on avian migration. The only study that directly addresses this topic is by Tryjanowski (2012), the director of the Poznań University of Life Sciences. Tryjanowski found that due to urban area’s high exchange of

energy, they are often referred to as “heat islands”, whose high temperature can advance bird migration (2012). In his study conducted on migratory bird species in Poland, most bird species had “significantly earlier arrival times in rural areas”, but there existed a “trend towards earlier first arrival dates... in urban areas” (Tyranowski, 2012). Tyranowski’s study is heavily limited in its scope as it only analyzed migration of birds to rural and urban areas. My study seeks to explore the impact of human altered environments on migration of birds already living in urbanized areas, which should have a more significant impact than birds arriving to urbanized areas due to the relatively closer proximity to altered environmental conditions. In addition, my study explores a drastically different geographic area, North America compared to Poland, which presents a completely different set of climate factors and species and can help explore to extent of the validity of his findings.

This study explores the impact of urbanization on migration on an individual species level with the American Robin (*Turdus migratorius*), rather than for birds as a whole. Jones (2012) explains the importance of the Robin:

Few species of birds in the United States are as recognizable or iconic as the American Robin. The *en masse* arrival and familiar song of this species in spring evoke excitement for the impending return of many more songbirds, and for biologists signifies the annual onset of a critical seasonal transition. For both amateur bird enthusiasts and professional researchers, the American Robin is the classic harbinger of spring.

The Robin is a very adaptive bird, thriving in diverse rural environments like woodlands and farmlands along with urban concrete jungles across the entirety of the United States (Vanderhoff, 2016). In fact, it is one of the few birds who have seemingly benefited, rather than suffered, at the hands of rampant urbanization (Vanderhoff, 2016). Boasting a bright orange underbody and dark heads, the American Robin is one of the most iconic and recognizable birds leading to there being a abundance of records for this species available. In terms of its annual cycle, the Robin winters in the Southern United States but year round populations can be found throughout the most of the rest of the country. Northern regions near North Dakota, Minnesota, and the majority of Canada are the typical spring breeding grounds for this bird. Due to their ability to thrive in cities, it is common for Robins to even remain year-round in their southern wintering grounds foregoing their annual migration in a process known as overwintering (Vanderhoff, 2016).

In the context of the literature, we hypothesize that there exists a significant difference in migratory timing for the American Robin due to the existing evidence of how greatly urban environments can alter avian physiology and behavior. In terms of long-term trends, we believe that populations of urban Robins will trend towards earlier departure dates in comparison to their rural counterparts as a result of the existing trend towards earlier arrival dates in cities.

2. Methods

Type of Method

While the initial goal of the research was to determine if a casual relationship existed between the wintering homes of American Robins and the advancement of spring migration, such a question would not be feasible for this study to answer as reaching a causal conclusion would require conducting an experimental study. The independent variables, the wintering homes of American Robins, would not be realistic for a researcher to manipulate, and if it were, it would pose numerous environmental and ethical concerns. However, adjusting the question to determining whether a difference exists and the magnitude and trend of such difference made this a perfect candidate for a causal-comparative and trend design. Jason D. Schenker at the Kent State University explains that a causal-comparative design use “pre-existing or derived groups to explore differences between or among those groups on outcome on dependent variables” (2004). In this case, the pre-existing groups are of the American Robins in either wintering homes.

Causal-comparative analysis often exhibit lower internal validity compared to experimental studies as “independent variables are not manipulated” (Schenker, 2004). For instance, the population of urban residing birds are not random but self selecting, bringing in other confounding variables into play which can threaten the validity of the conclusions. However, this flaw in validity is overshadowed by an critical advantage of causal-comparative design: its strong claim to external validity as a result of being able to work with a exorbitantly large sample size, which is taken advantage of in this study to the fullest and is often impractical in experimental designs (Schenker, 2004).

Data Acquisition and Preparation

The data for the movement of the American Robin was retrieved from the December 2018 release of the eBird dataset (EBD), an open-access dataset provided by the eBird citizen-science project run by the Cornell Institute of Ornithology. While traditional ornithological research is conducted via observations by the researcher or a bird-watching group, the EBD takes advantage of the “enormous popularity of watching birds to create a global network of volunteers who submit bird observations via the Internet to a central data repository (Sullivan, 2013). While the data is of much more variable quality as contributors aren't always professionals, the sheer volume of observations, reaching in the hundred millions, along with the eBird project’s efforts in cleaning and reviewing of collected data has proven the dataset to be a extremely useful tool for academic research (Sullivan, 2013). In fact, numerous studies cited in this paper, such as Courter (2017), La Sorte (2017), and many more have utilized the EBD in tracking aviary migration, showing that it is suitable for research. In this study, like with Courter’s (2016), only vetted and complete checklists were included to minimize error.

There are a few caveats when using eBird data that are still important to note. First, the quality and thoroughness of a checklist varies by observer activity and the “duration and spatial coverage” of the survey (Hurlbert, 2012). In this study it is assumed that the variation in survey

quality “is independent of date, year, geographic location... and that this variation is primarily a source of noise” (Hurlbert, 2012). Additionally, there is by nature a larger sampling effort in urban areas which results in inaccuracies in relative species abundance between different areas. For this study, this observer effect may lead to “geographic variations in effect size”, but should not lead “to any bias in the estimates themselves” (Hurlbert, 2012). Additionally, the EBD is often inaccurate or incomplete in earlier years due to the limited number of contributors in the earlier stages of the project but their addition of historical observations from other projects to compensate for this (Zaifman, 2017).

Various data science Python libraries, notably Pandas and Georasters, were used to prepare and filter the EBD in preparation for analysis. Unnecessary columns in the EBD were stripped and the dataset was filtered to just American Robin observations in the United States between 2000 and 2018 that are located south of the 33.5 latitude line (depicted in Figure 1), the Robin’s wintering grounds as referenced in the literature (Vanderhoff, 2016). This was further limited to only observations within the spring migration season of the Robin for each year, January 1st and May 1st (Vanderhoff, 2016).

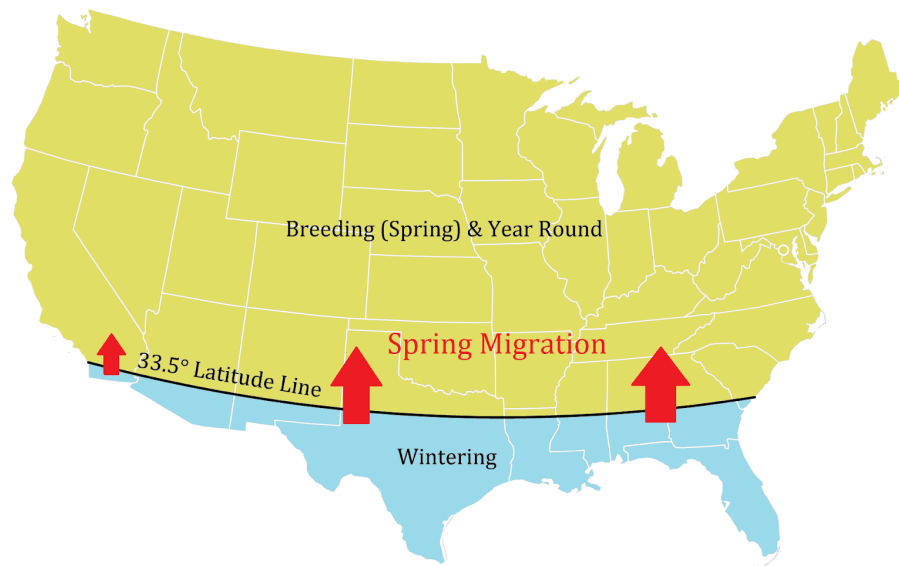


Figure 1. Distribution of the American Robin across the United States over its annual cycle with the direction of spring migration marked.

Adopting the method from La Sorte (2017), we used the EarthEnv land-cover georaster to classify Robins into two populations, urban and rural. Birds found in regions having >0% urban land-cover according to the land cover georaster were classified as urban while all others were classified as rural (La Sorte, 2017).

Analysis

Through the filtered dataset, we were able to extract the Median Departure Date (MDD) and Last Departure Date (LDD) of the Robin by combining the methods used in Jones (2012) and Wilson

(2018). We calculated the MDD of a given year by pinpointing the median observation date of the American Robin across its migration season. At the MDD, the proportion of Robin sightings which occurred before this date is equivalent to 0.5 (Figure 2). We calculated the LDD of a given year by only using the upper 60% quantile of the distribution and calculating the median of that as done in Wilson (2018). At the LDD, the proportion of Robin sightings which occurred before this date is equivalent to 0.8 (Figure 2). The exact thresholds, 0.5 for MDD and 0.8 for LDD were derived from Jones (2018). MDD and LDD were calculated for rural and urban Robin populations for all spring migration seasons between 2000 and 2018.

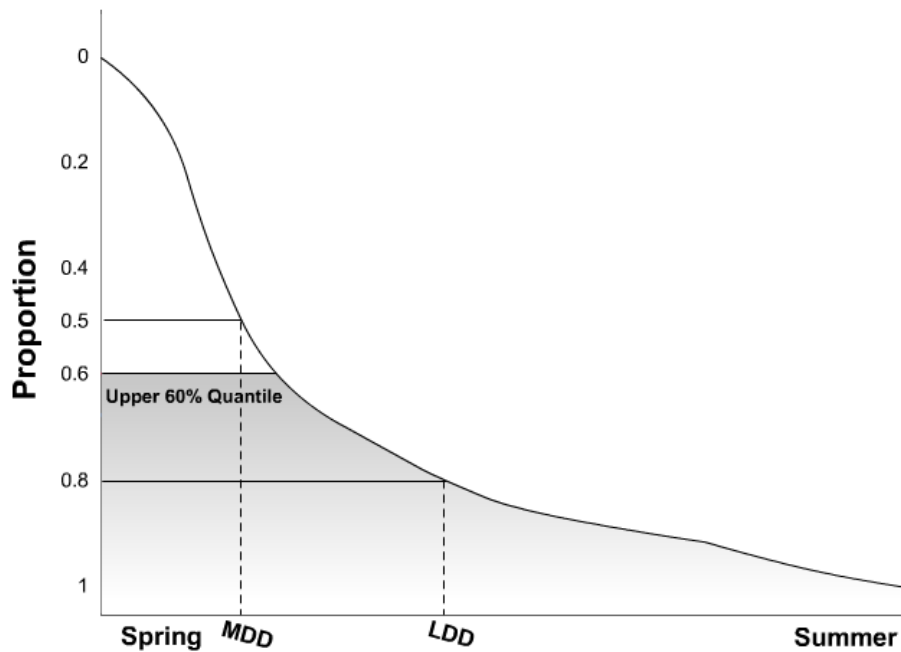
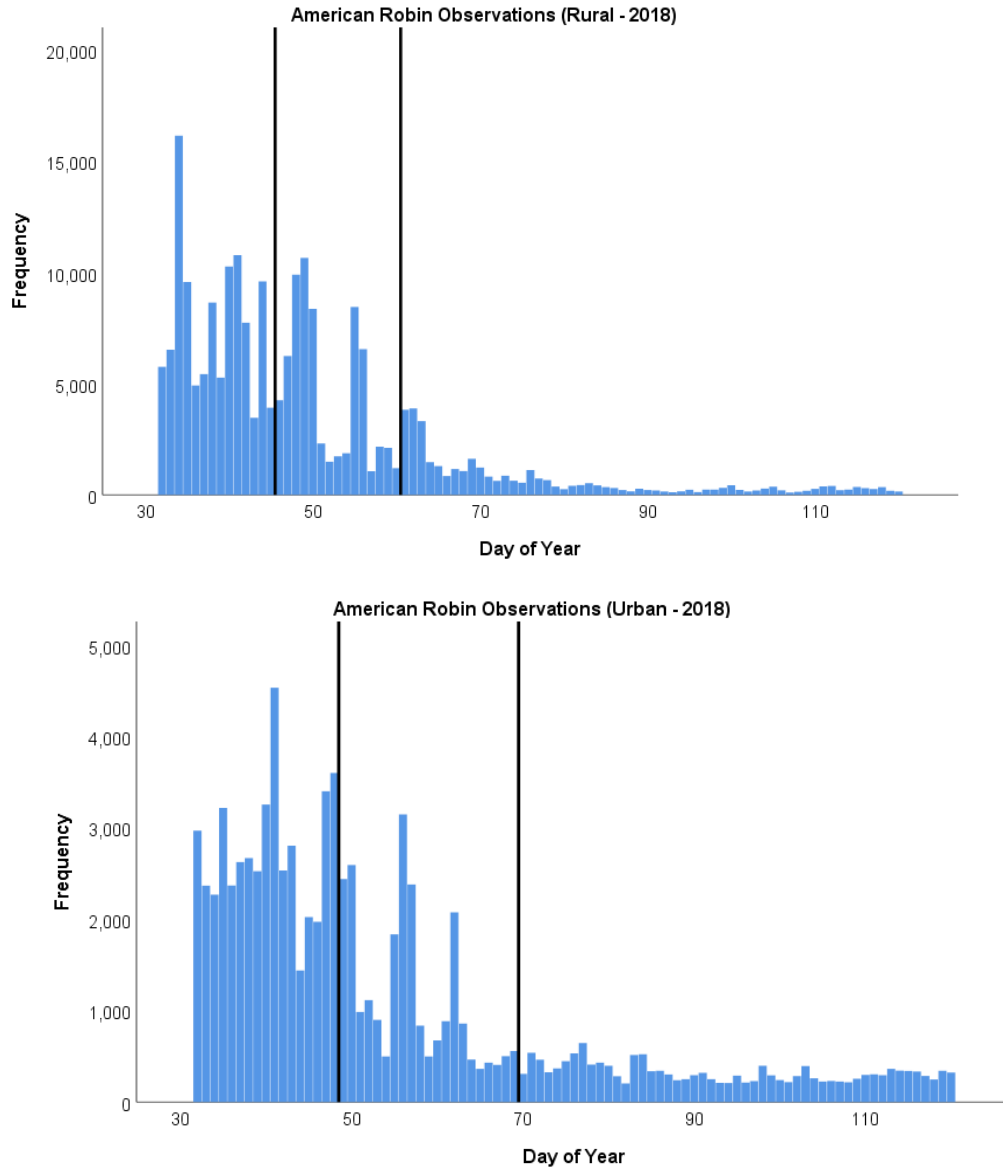


Figure 2. An example diagram of the onset of migration from a given area. The vertical axis refers to the proportion of observations which occurred prior to the given date. The MDD and LDD are at the 0.5 and 0.8 thresholds. The upper 60% quantile, shaded in gray, is used for calculating the LDD and the Mann–Whitney U tests.

Due to the normal distributions of Robins across the migratory season as seen in Figure 2, the non-parametric Mann–Whitney U test was used in place of a typical parametric ANOVA test in order to determine whether there showed a significant difference in shape between rural and urban populations for both the full distribution and the upper 60% quantile across all years. Afterwards, t-tests were used to determine the statistical difference between the departure dates. In order to determine the trends of departure dates across the years, linear regression models were calculated for MDD and LDD for both populations of birds.

3. Results

Migratory Timing Distributions



Figures 3 & 4. American Robin observations for rural and urban populations across its migratory season, February 1st to May 1st. The dates are written in day of year (DOY) notation with January 1st as DOY 1. The vertical lines represent the MDD and LDD respectively.

As expected, throughout the spring migration season the populations of American Robins declines over time as birds leave for their breeding grounds as seen by how the distributions are strongly skewed towards the right (Figures 3 & 4). In both rural and urban populations, the observations quickly drop from the winter populations and plateau around the LDD leaving a small,

relatively constant population (Figures 3 & 4). As mentioned in the literature review, this population is likely to be year-round Robins who overwinter and do not migrate at all (Vanderhoff, 2016). The greater proportion of overwintering birds in urban areas may point toward decreased level of migration in urban areas. In addition, it is obvious that there are considerably more observations in rural areas when compared to urban areas ($n_{\text{rural}} = 2,065,223$, $n_{\text{urban}} = 996,236$; total number of observations across all years). While only the distributions for 2018 are shown, all other years exhibit similar patterns.

Mann–Whitney U tests were conducted to determine whether there is a difference in the overall shape between the distributions of rural and urban migration. This test was conducted between rural and urban distributions for both the full migration season and just the upper 60% quantile across all migration seasons. For all 38 conducted tests (2 per year for 19 years), there was found to be a statistically significant difference in the overall shape of the distributions ($p < 0.05$ two-tailed). The fact that every single one of these tests returned a positive result strongly supports our hypothesis of a difference in migration patterns between these two populations.

Median and Last Departure Dates

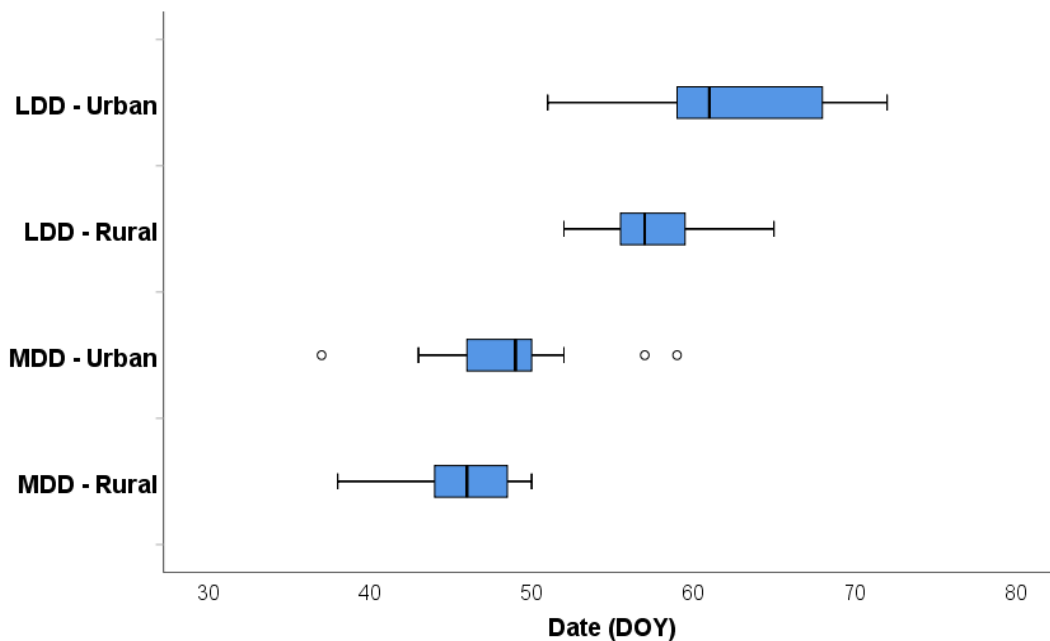


Figure 5. Boxplot of annual departure dates from Table 1. The outliers for “MDD - Urban” are 2001, 2000, and 2002 from left to right.

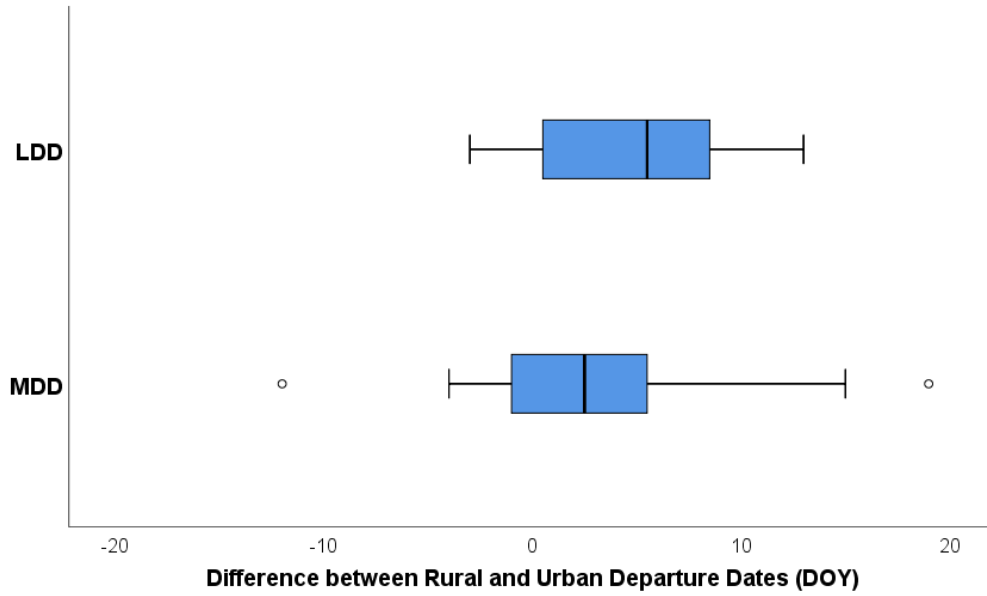


Figure 6. Boxplot of annual differences between rural and urban departure dates for MDD and LDD from Table 1. The outliers for MDD are 2001 and 2000 from left to right. Calculated by the formula, $DD_{urban} - DD_{rural}$, in order to return a mostly positive differences.

A few of the departure dates and differences, notably for the earliest years, were classified as outliers through comparison with the other results across the 19 years (Figure 5 & 6). For the subsequent tests, these outliers were often removed on the basis that the eBird Dataset is often inaccurate or incomplete in earlier years as explained by Zaifman (2017).

It was found that the American Robin departed for spring migration earlier in populations wintering in rural areas as opposed to urban areas for both the MDD (2/15 vs 2/17) and LDD (2/26 vs 3/3) (Figure 5). Only 2 of the years (2005 & 2008) reported MDD and LDD that were earlier for the urban population (Table 1). Ignoring outliers, the differences in migration dates, calculated by subtracting the urban departure dates with the rural departure dates, ranged from -4 to 15 days for MDD and -3 to 13 days for the LDD (Figure 6). The mean differences in MDD and LDD between the two populations is 1.71 days and 4.75 days respectively (Figure 6).

Paired-samples t-tests found there to be no significant difference between the MDD but a significant difference for the LDD of the rural and urban populations across all years ($t_{19} = -1.613$, $p = .124$ for MDD; $t_{19} = -4.527$, $p = .00026$ for LDD). However, performing the t-test for MDD again having removed the years which contain outliers (2000, 2001, & 2002) yielded a more statistically significant value ($t_{16} = -1.837$, $p = .086$). While this value approached significance by Trojanowski (2013) ($0.05 < p < 0.10$), we were still unable to reject the null hypothesis that there is no statically significant difference in the MDD between the populations.

Many studies have concluded that rural and urban birds differ from one another including Dowling (2011), Ducatez (2016), Saccavino (2018), among numerous others. As such, the literature supports the claim that differences do exist in migration dates between these populations. On one hand, we found that there exist strong differences in the shape and distributions of migration timing

via Mann–Whitney U. However, when looking at departure dates, despite significant differences existing in LDD, there was no statistically significant difference found in the MDD between rural and urban populations of American Robins. Our hypothesis, which was created on the basis of the prior literature, was contradicted by this finding.

Table 1. Summary of Median Departure Dates (MDD) calculated using the full distribution and the Last Departure Date (LDD) calculated using the upper 60% of the distribution for the American Robin in the Southern United States. The count, n, is the number of total observations recorded for the American Robin between February 1st and May 1st. The differences (Diff) are the number of days between the the respective urban departure date and the rural departure date. Totals are cumulative for n and averages for departure dates and differences. Mean departure dates and difference is calculated ignoring outliers for MDD. (*) Outliers.

Spring Departure Dates for the American Robin

Year	n	<u>Full Dataset (MDD)</u>			<u>Upper 60% (LDD)</u>		
		Rural	Urban	Diff	Rural	Urban	Diff
2000	25566	2/7	2/26*	19*	2/25	3/6	10
2001	12456	2/18	2/6*	-12*	2/25	3/10	13
2002	3923	2/13	2/28*	15	3/6	3/13	7
2003	34791	2/19	2/16	-3	3/2	3/2	0
2004	42466	2/15	2/18	3	2/22	3/1	8
2005	59331	2/16	2/12	-4	3/2	3/1	-1
2006	38233	2/13	2/18	5	2/27	3/3	4
2007	100035	2/15	2/14	-1	2/21	2/28	7
2008	86772	2/18	2/15	-3	2/22	2/20	-2
2009	93365	2/14	2/20	6	2/26	3/1	3
2010	262986	2/13	2/14	1	2/24	3/4	8
2011	301014	2/13	2/21	8	2/23	2/26	3
2012	312594	2/19	2/18	-1	2/26	2/27	1
2013	150197	2/17	2/18	1	3/2	3/9	7
2014	233308	2/15	2/15	0	2/28	3/9	9
2015	312890	2/18	2/21	3	2/28	2/28	0
2016	197626	2/16	2/18	2	2/27	3/8	10
2017	492974	2/12	2/18	6	2/26	2/23	-3
2018	300932	2/14	2/17	3	3/1	3/10	9
Totals	3061459	2/15	2/17	1.71	2/26	3/3	4.75

Trends in Departure Dates

Table 2. Summary of best fit linear regression models of both MDD and LDD against year for both rural and urban populations. The unit for slope is number of days per year shift in departure date.

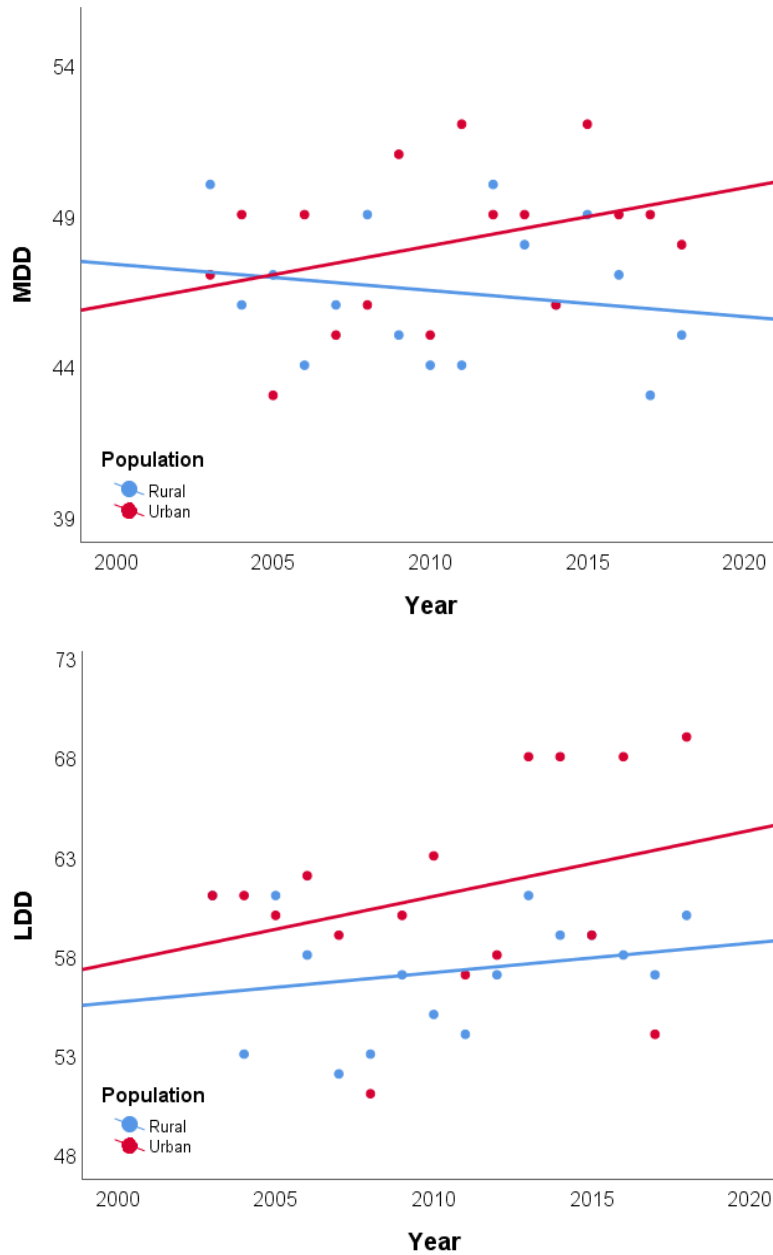
Threshold	Population	n	r	r ²	Slope	SE	p-value
MDD	Rural	19	0.144	0.021	0.075	0.126	0.556
MDD	Urban	19	0.006	0.000	-0.005	0.207	0.980
LDD	Rural	19	0.048	0.002	0.028	0.143	0.847
LDD	Urban	19	0.122	0.015	-0.123	0.232	0.618

Table 3. Summary of best fit linear regression models of both MDD and LDD against year for both rural and urban populations with outlier years removed. The unit for slope is number of days per year shift in departure date.

Threshold	Population	n	r	r ²	Slope	SE	p-value
MDD	Rural	16	0.184	0.034	-0.087	0.124	0.391
MDD	Urban	16	0.357	0.128	0.193	0.135	0.231
LDD	Rural	16	0.234	0.055	0.149	0.165	0.382
LDD	Urban	16	0.307	0.094	0.332	0.276	0.248

Urban populations of Robins were found to trend towards later MDD (slope = 0.193 day/yr, urban vs -0.087 day/yr, rural) and LDD (slope = 0.276 day/yr, urban vs 0.165 day/yr, rural) when compared to their rural counterparts (Table 3, Figure 7 & 8). However all of these trends were not statistically significant ($p > 0.05$) (Table 2). Removing data points for years containing outliers (2000, 2001, 2002) improved the statistical significance of the models a great deal, however it was not enough to support the claim that a statistically valid trend existed between departure dates and years (Table 3).

Jones (2012) found a significant trend in American Robins towards earlier first arrival dates for migration in Wisconsin from 1990-2010. Timing for departure dates and arrival dates are accepted to be strongly linked, with earlier arrival dates signaling earlier departure dates (Zaifman, 2017). While the literature and my hypothesis would support the claim of a strong trend towards earlier departure dates, three of the four regression models with departure dates against year showed a trend towards later departure dates based solely on the value of the slopes ignoring significance (Table 3). All four showed no trend when taking into account the p-values (Table 3), which also contradicted my initial hypothesis.



Figures 7 & 8. MDD and LDD against years with regression models (Table 3). The dates for MDD and LDD are in day of year notation.

4. Discussion

As previously mentioned, many studies have concluded that rural and urban birds differ from one another including Dowling (2011), Ducatez (2016), Saccavino (2018), among numerous others. The findings of this study offer some support on this view. While we found that there exist strong

differences in the shape of the distributions of migration timing via Mann–Whitney U, analysis of departure dates was not so conclusive. Despite significant differences existing in LDD, there was no statistically significant difference found in the MDD between rural and urban populations of American Robins. Going by Wilson (2018), which places greater weight on departure dates calculated using smaller upper quantiles of the dataset, i.e. LDD in this study rather than MDD, along with the significance in the differences of the MDD approaching significance, a case could be made that departure dates overall were found to be significantly different. Nevertheless, caution must be exercised when accepting this conclusion.

Nevertheless, we can conclude that rural and urban populations differ in *when they depart throughout the migration season* but not necessarily *when the season starts or ends*. The lack of a statistical difference in MDD demonstrates the lack of a drastic species wide shift in departure dates in one direction or another showing that the migration seasons remain relatively the same for both populations. However, the presence of a difference in LDD shows that the right extreme of the population of Robins, or those who migrate the latest, are migrating even later. This, along with the presence of a significant difference in the shape of the distributions in migration timing, point towards differences in the onset of migration *within* the migration season. Additionally, the greater proportion of overwintering Robins in urban areas may indicate that urbanization is suppressing migratory behavior in Robins, though research specifically on overwintering Robins must be conducted to draw any conclusions from this observation.

The differences in migration timing between rural and urban populations of the Robin warn us about the unintended consequences of urbanization on bird migration. As mentioned in the literature review, migration is a delicate and integral part of a bird's life cycle, with migratory success dictating the survival of avian populations (Tryjanowski, 2013). This study contributes to Tryjanowski (2013) which found differences in the migration patterns of rural and urban populations in Poland, by analyzing a different bird on a different continent, suggesting that this is a global trend that can disrupt populations of birds throughout the entire world.

As mentioned in the results section, the findings of this study differed from that of the general literature in terms of long term migration trends. While this disparity may indicate a reversal of trends over more recent years or a weaker link between arrival dates and departure dates for migration than is typically expected, the lack of statistical significance of the regression models call for further research in order to confirm such a conclusion. Additionally, differences in region, species, timeframe, analysis of departure dates rather than arrival dates, or other factors may account for these some of these contrasting results which differ from the general literature (Tryjanowski, 2013).

This study was by no means perfect. The use of the eBird dataset was revealed to be quite limiting. Checklists and observations have some element of sporadism and inaccuracy, leading to seemingly random spikes in frequencies that may not be representative of the actual populations (Figure 3 & 4). For instance, in Figure 3, the number of daily observations spikes to over 15,000 on DOY 34, then drops down to just around 5,000 after 2 days, only to double again around DOY 38. Even when considering the possibility of stop over birds coming from other areas impacting the distribution, changes this drastic are unlikely. More likely this is caused by human factors such as a

significant birding event increasing the number of observations recorded on a particular day, or bad weather preventing birders from birdwatching, reducing observations. Alternative approaches such as utilizing Project FeederWatch's observational database, having the research team birdwatch and record observations themselves, or directly tagging and tracking birds may allow for more accuracy in calculating migration dates at the cost of having a much smaller sample size than eBird allows. As mentioned previously, the eBird Dataset is often inaccurate or incomplete in earlier years making it unideal for tracking long term trends in migration patterns that stretch multiple decades (Zaifman, 2017). Pairing the eBird Dataset with historical bird checklists such as in Courter (2017), which used eBird to calculate migratory arrival dates in more recent years (2006-2015) and data provided by the the North American Bird Phenology Program to find historical arrival times in earlier years (1895-1969), offers a much stronger and more robust approach for tackling long term avian migratory trends. In calculating the trend in rural and urban areas, both our approach and the one suggested may be confounded by climate change which has been shown to alter migration timing in the long term (Courter, 2017).

Future research should be done to better understand the consequences of these migratory timing differences caused by urbanization now that they are shown to exist.

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