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Research Article

Shifts in Bird Migration Timing in North American Long-Distance and Short-Distance Migrants Are Associated with Climate Change

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Bird migration is a synchronized event that has evolved over thousands of years. Changing temperatures due to climate change threaten the intricacies of migration timing for birds; however, the extent of these changes has only recently begun to be addressed. Utilizing data from the citizen-science website eBird and historical temperature data, we analyzed bird migration timing in two states warming quickly (Alaska and Maine) and one warming gradually (South Carolina). Using linear regressions, we looked at relationships between different temperature indices and year with bird migration timing from 2010 to 2016. Bird migration through all three states, regardless of warming rate, showed similar rates of alterations. Additionally, in every state over half of the birds that had altered migration timing were long-distance migrants. Furthermore, we performed feature selection to determine important factors for changing migration timing of birds. Changes to summer resident and transient bird migration were most influenced by state. In winter resident migration, departure date and length of stay were most influenced by maximum temperature, while arrival date was most associated with minimum temperature. Relationships between changing temperatures and migration timing suggest that global climate change may have consequential effects on all bird migration patterns throughout the United States.

1. Introduction

Scientists agree that humans are causing recent global warming [1]. One of the anthropogenic drivers of mean global warming is the increasing concentration of Green House Gas (GHG) emissions, from molecules like CO_2, CH_4, N_2O, and O_3 (Rodhe Bera et al. (2009) [2]). Despite recent efforts to limit GHG emissions, they continue to rise. For example, global production of CO_2 has continued to grow by an average of 2.5% per year over the past decade [3]. As GHGs accumulate in the atmosphere, they continuously decrease the amount of solar radiation that is reflected back into the space and effectively warm the earth's climate like a greenhouse (Mohajan (2011)). Previous studies have determined that additional global warming of more than ~1°C will be detrimental due to the probable rising of sea levels and the extinction of species that cannot adjust to rising temperatures (Hansen et al. 2006). Several recent models used to predict global climate change indicate that temperatures will continue to rise (Hansen et al. (2006) [4], Iselin et al. (2017)). With no slowing to global warming in sight, all organisms will have to respond to this change. Generally, animal populations have three options to deal with increases in temperature: physiologically adjust to new thermal regimes, change distribution patterns, or, at worst, face local extinction [5].

From a conservation standpoint, it is essential to determine traits of animal species that make them physiologically susceptible or resilient to global warming [6]. The most relevant environment variable of interest is temperature, the abiotic master factor, as every other abiotic parameter is affected by temperature, and many species' distributions are dictated by their thermal tolerances [7].

Phenological changes are perhaps the most ubiquitous consequence of climate change [8]. Bird migration is a biological process that depends on phenology and has been shown to alter with current climate change [9, 10].

Changing bird migration is a classic topic in phenology and has become a widely studied phenomenon as climate change has progressed [11]. The shift in migratory strategy for different bird populations presents an ecological conundrum for bird species: if birds leave wintering grounds too early, they may arrive to breeding grounds before cold temperatures subside, and many species may be physiologically unprepared to deal with cold temperatures. Conversely, if they leave too late, birds miss prime reproductive and feeding opportunities [12]. On the other hand, flexibility around migration allows migrants to utilize resources as they appear, to reproduce and to avoid detrimental environmental conditions [13].

Migratory birds are often categorized into two groups: short- and long-distance migrants. Many studies have shown that short-distance migrants have advanced their arrival dates more than long-distance migrants have [14–16]. It is hypothesized that short-distance migrants may be better able to adapt to climate change than long-distance migrants. Short-distance migrants can respond to meteorological cues indicating weather conditions at their migration destination, whereas long-distance migrants must rely on photoperiod, genetic, and endocrine predisposition [14]. In consequence, species that have not shown phenological responses to increases in mean global temperatures, like some long-distance migrants, have recently shown population declines [17], though other long distant migrant species have also shown declines for reasons not associated with climate change, pointing to a potential speculation with respect to what is driving population declines. Most studies examining first arrival dates of migrants have focused on European birds [18, 19]. However, additional ornithological studies are revealing that more North American short-distance migrants are altering their migration patterns than long-distance migrants are and that they are altering their migration patterns to a greater degree than long-distance migrants [13, 20, 21].

Global warming has affected parts of the United States unevenly. Over the past 60 years, Alaska's average annual air temperature has increased by ~1.7°C and average winter temperature by ~3.4°C, with substantial year-to-year and regional variability (Stewart et al. (2013)). Similarly, average annual temperature across Maine warmed by ~1.7°C between 1895 and 2014 (Fernandez et al. (2015)). On the other hand, South Carolina's average temperature has been increasing more gradually; since the mid-1970s, the average surface temperature has increased by ~0.56°C (South Carolina Department of Natural Recourses 2013). When investigating bird migration timing and temperature alterations in the United States, it is imperative to compare states that have experienced faster increases in temperature, such as Alaska and Maine, to those with slower warming trends, such as South Carolina. This addresses the questions of whether differing rates of temperature change affect bird migration timing differently or whether birds are responding to climate change as a global phenomenon.

We used the citizen data website, eBird, to determine differences in bird migratory patterns correlated with historical temperature changes through 2010–2016 within three Maine counties: Aroostook, Cumberland, and Hancock; three South Carolina counties: Charleston, Georgetown, and Oconee; and two Alaska counties: Anchorage and Fairbanks. Additionally, we used feature selection to determine which variables were associated most with shifting migratory timing of North American birds.

2. Methods

2.1. Bird Data Acquisition and Preparation. Bird observations from 2010 to 2016 were extracted from the eBird database for each county (http://ebird.org/content/ebird/). Observation data from before 2010 did not have enough observations to analyze. We looked at bird migration through two drastically warming states, Maine and Alaska, and one state not drastically changing in temperature, South Carolina. In Maine, we looked at eBird data from three counties: Aroostook, Cumberland, and Hancock. In Alaska, we looked at eBird data from two counties, Anchorage and Fairbanks, and, in South Carolina, we looked at eBird data from three counties: Charleston, Georgetown, and Oconee. We selected these counties based on observation frequency on eBird to ensure we collected the most data possible within each state. Species of birds in Anchorage ($n = 229$), Aroostook ($n = 242$), Charleston ($n = 370$), Cumberland ($n = 338$), Fairbanks ($n = 167$), Georgetown ($n = 332$), Hancock ($n = 236$), and Oconee ($n = 211$) were manually categorized using eBird observation frequency tables into year-round residents, summer residents, winter residents, and transient migrants. Birds with unclear patterns were crosschecked with literature (Kaufman (2005), Peterson (2010)) and birds with indefinable migration patterns were simply removed from the analysis. Birds were, then, manually categorized into two groups, long- and short-distance migrants. Birds migrating more than ~2000 km were considered long-distance and those migrating less than ~2000 km were considered short-distance [22]. Migration distance was determined using All About Birds (https://www.allaboutbirds.org) and Audubon (http://www.audubon.org).

2.2. Temperature Data Acquisition and Preparation. Historical temperature data for each county was downloaded from the National Climatic Data Center's National Oceanic and Atmospheric Administration site (https://www.ncdc.noaa.gov). Each county temperature file had multiple weather stations, and some stations had incomplete data. To combat this incomplete data, the mean of the minimum and maximum and mean temperatures of all stations were calculated and used for analysis.

2.3. Bird Observation Data Cleaning. eBird data comes from a citizen-science source that presents many statistical challenges. These challenges include inconsistent observation efforts over time, the possible misidentification of birds, and poor sample sizes for some species [23]. However, eBird is constantly improving through a variety of means like using automated filters in combination with a growing network of regional editors [24]. Through the below described data cleaning, we selected for species with large volumes of data

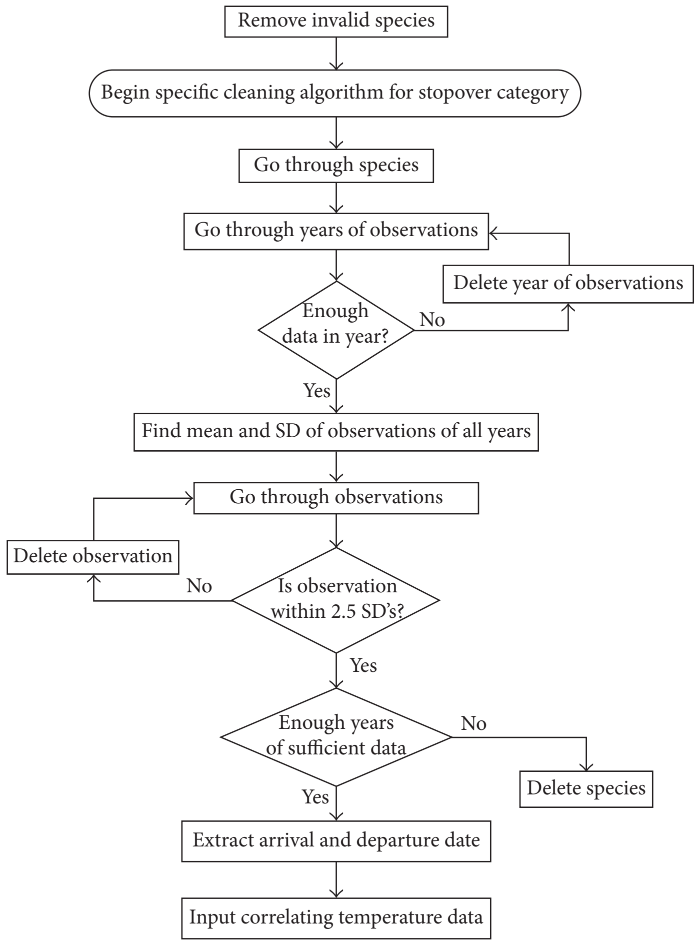

Figure 1: Flow chart of general data-cleaning algorithm.

so as to minimize the Eureka effect often associated with citizen science. We wanted to take a conservative approach and further clean the subsequent noise in the dataset. We developed a software package (available upon request) to clean the observation data and extract only the valid arrival and departure dates for each migration pattern category (Figure 1).

First, all invalid species like those with “hybrid” or a slash in their name were removed. Then, for each species, we determined whether there were enough data in each year. For winter resident species, a year of observations was deleted if there were no observations in the period of the migratory trajectory before the year change or after the year change. For summer resident migrants, a year of observations was deleted if there were less than 5 observations. A year was deleted from transient migrants if at least one of the stopovers did not have any observations.

In the next step, for each species, we found the mean and standard deviation of all years of observations combined. We, then, went through each year of observations and deleted outliers that were more than 2.5 standard deviations away from the mean stopover date. Subsequently, we deleted species that did not have enough years of valid data on which to perform analysis. Summer and winter resident birds were deleted if there was less than five years of data and transient birds were deleted if there was less than four years of data. Lastly, we extracted the arrival and departure dates for each stopover and attached the correlating temperature data: the mean, maximum, and minimum temperature on the day of arrival and departure and the mean, maximum, and minimum temperature experienced during the stopover (Figure 1). We correlated daily temperatures to the arrival and departure dates to determine the environmental conditions birds faced before and after the physiological challenge of migration. We used first observed arrival dates because it has been established that population-level advances in migration are ultimately dictated by individuals advancing or delaying migration [15, 25].

2.4. Linear Regression Analysis. In the data-cleaning step (Figure 1), many species that did not have enough data for reliable analysis were eliminated. Our dataset after cleaning included species in Anchorage ($n = 86$), Aroostook ($n = 103$), Charleston ($n = 114$), Cumberland ($n = 149$), Fairbanks ($n = 70$), Georgetown ($n = 94$), Hancock ($n = 115$), and Oconee ($n = 45$). Using this more conservative dataset, we analyzed the associations between mean, maximum, and minimum temperatures and year, spring and fall arrival date, spring and fall departure date, and numbers of days spent during stopover using linear regression. Linear relationships were considered significant if $P < 0.1$. Bonferroni correction was performed to compensate for multiple comparisons; 12 linear regressions are performed per stopover. After Bonferroni correction, the resulting P values were $P \leq 0.0083$ for winter or summer resident species and $P \leq 0.00417$ for transient species.

2.5. Feature Selection

2.5.1. Data Remodeling. To find the feature most associated with changes in bird migration patterns, we performed feature selection (described below) on summer resident, winter resident, transient spring, and transient fall birds. For each category, we combined the data from all counties. Each bird species was associated with its state, migration distance (long or short), and temperature. Temperature data included the slope (rate of change in time) of the mean, minimum, and maximum temperatures on the arrival date and departure date and during the stopover. The observed migration pattern included the trends of arrival date, departure date, and duration of stay versus the year. We defined slopes of the regression line greater than 0.3 as "positive" (later) and less than −0.3 as "negative" (earlier). Slope values between −0.3 and 0.3 were defined as stable (no change). The slopes for this analysis were obtained from the robust linear regression (rlm) model from MASS package in order to reduce the effect of outliers [26]. In cases where the regression line's fitness was worse than that of a horizontal line, the slope was assigned to 0.

2.5.2. Feature Selection Analysis. Feature selection methods rank the features of given datasets based on their importance levels. To determine the most important features that are associated with changes in birds' migration timing we used Weka (Waikato Environment for Knowledge Analysis) software for feature selection analysis on the four combined datasets. Weka is a user-friendly machine learning software package with a graphical user interface [27]. Weka is widely utilized in biology, bioinformatics, and biochemistry [28]. For each dataset, we ranked five features (state, migration distance (long or short), and maximum, minimum, and mean temperature) according to their association level with changes in the migration pattern at arrival date, departure date, and duration of stay. We utilized three feature selection methods—Chi Squared, Information Gain, and Symmetrical Uncertainty—and chose the ranking that was observed in at least two of these methods. The final rankings were used to determine the association level of the five features with the changes in migration timing.

2.6. Coding. All data cleaning and linear regression analysis was performed using RStudio Version 1.0.136, an open-source statistical programming language.

3. Results

3.1. General Patterns. All states contained species that showed alterations in their migration timing correlated with temperature changes from 2010 to 2016. On a statewide level, about one-third (Table 1) of unique species analyzed showed some alteration in their migration timing. In every state, over half of the species that showed alterations in their migration timing were long-distance migrants (Figure 2). On a county level, about one-fifth (Table 2) of analyzed species showed some alteration in their migration timing that was associated with temperature changes from 2010 to 2016. For all counties except Anchorage, Alaska, at least half of the species that showed some alteration in their migration timing were long-distance migrants (Table 2).

In all states except Alaska, summer resident species stayed longer as temperature increased, while winter resident species left earlier and stayed for less time as temperature increased (Tables S1, S3, S5, S7, S9, S11, S13, and S15).

3.2. Alaska. We found that, of the total 97 species analyzed in Alaska using eBird sightings from 2010 to 2016, 31 species showed some alteration in their migration timing due to temperature changes or over the years of 2010–2016 (Table 1). 17 of the species were long-distance migrants and 14 of the species were short-distance migrants (Figure 2). In Anchorage County, there were consistent trends of advancing arrival dates, receding departures dates, and decreasing stopover duration for both short-distance migrants ($n = 8$) and long-distance migrants ($n = 10$) (Tables S1 and S2). As temperature

Table 1: Number of species analyzed, total number of species showing changes in migration timing, and proportion of species showing changes in migration timing by state.

State	Species analyzed	Total species showing changes in migration	Proportion of species showing change (%)
Alaska	97	31	32
Maine	197	75	38
South Carolina	149	49	33

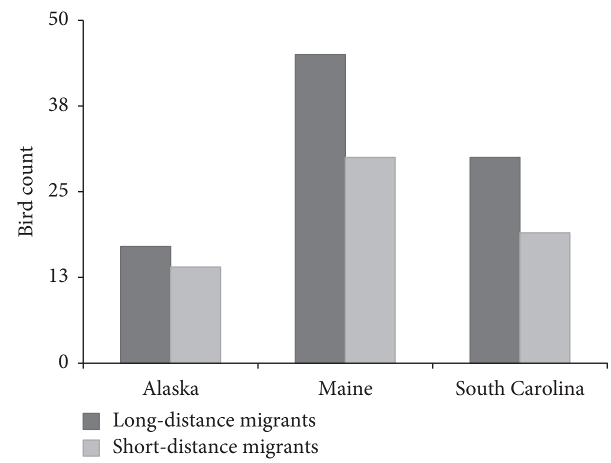

Figure 2: Number of long-distance and short-distance migrant species showing changes in migration patterns due to changing temperatures or over time during 2010–2016 in Alaska, Maine, and South Carolina.

TABLE 2: Number of species analyzed, total number of species showing changes in migration pattern, and rate of species showing changes in migration pattern by county.

State	County	Species Analyzed	Total species showing changes in migration	% long distance
Alaska	Anchorage	86	23	48
	Fairbanks	70	10	50
Maine	Aroostook	103	27	60
	Cumberland	149	34	59
	Hancock	115	34	59
South Carolina	Charleston	114	29	66
	Georgetown	94	20	50
	Oconee	45	7	58

TABLE 3: Most influential feature impacting changing arrival dates, departure dates, and number of days for summer resident (SR), winter resident (WR), and transient (T) spring and fall migrations.

	Most important feature			
	SR	WR	T spring	T fall
AD	State	Min temperature	State	State
DD	Mean temperature	Max temperature	State	State
ND	State	Max temperature	Max temperature	Max temperature

increased, birds spent less time in *Anchorage* County, arriving later and departing earlier. In Fairbanks, 50% of the species showing alterations in their migration timing from 2010 to 2016 or alterations associated with temperature changes had similar trends. For example, the bufflehead *(Bucephala albeola)* was the species most affected between 2010 and 2016 (Table 3). It arrived later ($P = 0.0009$) and departed earlier ($P = 0.0043$) over time. The bufflehead also decreased the length of its stopover over time ($P = 0.0008$). In total, ~26% of species analyzed in Alaska exhibited a later arrival date, earlier departure date, or shorter stopover as temperature increased over time (Tables S1, S2, S3, and S4). Conversely, only ~8% of species analyzed exhibited an earlier arrival date, later departure date, or longer stopover as temperature increased (Tables S1, S2, S3, and S4).

3.3. Maine. We found that, of the total 197 species analyzed in Maine using eBird sightings from 2010 to 2016, 75 species showed some alteration in their migration timing due to temperature changes (Table 1). Forty-five of the species analyzed were long-distance migrants, and 30 were short-distance migrants (Figure 2). Seventy-nine of 90 (Tables S5, S6, S7, S8, S9, and S10) relationships between number of days in Maine and any temperature index (mean, maximum, and minimum) yielded a positive slope, indicating that as temperature increased species stayed in Maine longer. Of all the birds in Maine, ~31% stayed in Maine longer as temperatures increased (Tables S5, S6, S7, S8, S9, and S10) and over half of these birds were long-distance migrants. Of considerable importance is one species listed as near-threatened, the semipalmated sandpiper *(Calidris pusilla)*, a long-distance transient migrant. As the minimum temperature that the semipalmated sandpiper experienced increased, it remained in Hancock County longer during its spring stopover ($P = 0.0034$). This relationship suggests that the semipalmated sandpiper may be responding to global warming.

3.4. South Carolina. We found that, of the total 149 species analyzed in South Carolina using eBird sightings from 2010 to 2016, 49 species showed some alteration in their migration timing due to temperature changes (Table 1). Thirty of the species that showed some alteration in their migration pattern were long-distance migrants, and 19 were short-distance migrants (Figure 2). Of the 82 winter resident migrants analyzed, ~18% had changes in their migration timing that indicated a later arrival date, an earlier departure date, or less time spent during stopover in South Carolina as temperature increased over the 7-year period (Tables S11, S12, S13, S14, S15, and S16). While only ~2% of the winter resident migrants indicated an earlier arrival date and a later departure date (Tables S11, S12, S13, S14, S15, and S16). Of the species indicating a shorter and shifting wintering stopover, 8 were short-distance migrants and 7 were long-distance migrants. This indicates that both short- and long-distance migrants are spending less time at their wintering sites.

3.5. Feature Selection. We found that for summer resident migrants the most important feature for arrival date and number of days stayed was the state in which the stopover occurred (Table 3). However, the departure date was most influenced by mean temperature (Table 3).

The departure date and number of days stayed for winter resident migration was most influenced by maximum temperature (Table 3). However, the minimum temperature was the most important feature for the departure date of winter resident migration (Table 3).

Both stopovers for transient species had similar important features. Arrival date for both stopovers was most influenced by state and the number of days stayed was most influenced by maximum temperature experienced during the stopover (Table 3). The spring stopover departure date was most influenced by state while the fall stopover departure date was most influenced by maximum temperature (Table 3).

A more detailed description of the feature selection results can be found in Table S17 for one-stopover summer migrants, Table S18 for winter resident migrants, and Tables S19 and S20 for transient migrants.

4. Discussion

In order to use the most widely available data to track changing migration timing, we utilized the citizen-science database eBird to correlate migration patterns of birds through counties in Alaska, Maine, and South Carolina with temperature changes from 2010 to 2016. We found that, regardless of warming rate, an equal proportion of species altered their migration timing or experienced significant temperature changes upon arrival or departure or during their stay (Table 1). Additionally, we found that long-distance migrants are shifting their migration patterns just as much as if not more than short-distance migrants (Figure 2). Previous literature suggests that, in North America, short-distance migrants are altering their migration patterns significantly more than long-distance migrants [13, 20, 21]. Because long-distance migrants base the timing of migration predominantly on highly predictable cues, such as photoperiod [14], they must be adjusting their migration pattern during the migratory process.

Some colleagues may point out that 7 years' worth of data may not be sufficient to point out migration timing shifts; however, even seven years of data seems sufficient to investigate rising temperature's effect on bird migration. After a warm spring, female passerines often breed earlier than they do after a cold spring [29]. This simple change that occurs over one year is a result of phenotypic plasticity [29]. Thus, with variable temperatures, seven years of data is enough to observe phenotypic plasticity. Additionally, phenotypic plasticity is a better measure of a species' response to environmental change than heritability estimated in natural populations that are often moderate [30]. Phenotypic plasticity allows for faster tracking of responses to changes in the environment [31]. It is the first step towards adapting to changes in the environment.

Our analysis suggests that migration shifts may be at least a national phenomenon. There is no distinguishable difference between birds migrating through states warming quickly, Alaska and Maine, and those migrating through states warming slowly, South Carolina. In all states, about one-third of birds showed a change in migration patterns (Table 1). Because migration occurs over large areas, even for short-distance migrants, stopovers in regions not affected by global warming do not provide enough relief to hinder migration alteration. As a result, birds must either adjust their migration timing or face population declines [5].

Additionally, our results show that both long-distance and short-distance migrants are adjusting their migration pattern in accordance with changes in environmental temperature. The most accepted proposed mechanism for the observed alterations in migration is individual plasticity in timing of migration [32, 33]. This is often proposed because species migrating over short-distances have frequently shifted their migration to greater degree than longer distance migrants with a greater number of short-distance migrants showing these alterations [17, 34]. This may indicate that long-distance migrants are less capable of responding to changing conditions because the greater distance reduces their ability to respond to meteorological cues indicating destination temperature [21, 35]. Additionally, these species are more strongly controlled by endogenous cues [33] that are not affected by temperature.

However, our results indicate that long-distance migrants are now adjusting their migration patterns as well. In every state, over half of the species changing their migration patterns were long-distance migrants (Figure 2). Long-distance migrants base the timing of migration on highly predictable cues, such as photoperiod [14], but photoperiod is fixed; there is no variation between years. But long-distance migrants seem to be adjusting their migration somehow.

It seems that long-distance birds in North America may be, in part, adjusting their migration patterns during the migratory process. All bird species, regardless of migration distance, can be affected by temperature, at the whole-organism level [36]. Thus, shifting migratory patterns, potentially, in response to temperature should not be a trait that is selected for only in short-distance migrants in North America, as previous studies suggest [34, 37, 38]. While the initiation of migration may not vary greatly, as long-distance migrants get closer to their destination, their shifts in migration are more correlated to weather at the destination.

Food supply during the migratory process can also affect migration timing. Migrating birds have very unique nutrient requirements; they fuel long flights with the highest possible percentage of energy derived from fat oxidation [39]. Thus, it is imperative to migrating birds that there is an abundant and specific food supply at their stopover sites. For example, as temperatures increase, insects hatch earlier [40]. If the food supply at a stopover is no longer readily available, birds will stay for less time, adjusting to continue migrating and move to where there is an abundant food supply.

As long-distance migrants continue to adjust their migration patterns, population declines may decrease. For example, our results showed that the semipalmated sandpiper, a near-threatened long-distance migrant, was adjusting its migration pattern. As the minimum temperature that the semipalmated sandpiper experienced increased, it remained in Hancock County, Maine, longer ($P = 0.0034$). By shifting its migration pattern, the semipalmated sandpiper may be adjusting to find more advantageous conditions that may allow it to increase population numbers. However, not all species that are threatened have been able to shift their migration patterns like the semipalmated sandpiper; Bachman's sparrow *(Peucaea aestivalis)*, the buff-breasted sandpiper *(Tryngites subruficollis)*, the chimney swift *(Chaetura pelagica)*, the olive-sided flycatcher *(Contopus cooperi)*, the painted bunting *(Passerina ciris)*, the razorbill *(Alca torda)*, the sooty shearwater *(Ardenna grisea)*, and the wood thrush *(Hylocichla mustelina)*, all near-threatened species, did not alter their migration pattern in response to changes in temperature.

To begin to investigate why certain species were altering their migration timing and others were not, we performed feature selection analysis to examine which factors had the most influence on changes in migration timing. Summer resident migrants' timing changes were most influenced by state (Table 3). This can be attributed to the opposing trends observed between Alaska and Maine/South Carolina. In Maine and South Carolina, one-stopover summer species were staying longer as temperature increased, while the opposite occurred in Alaska. Alterations in bird migration timing in Europe have also been found to be location specific, with birds migrating through different latitudes adjusting their migration timing differently [34].

Winter resident migrants' arrival date was most associated with the minimum temperature (Table 3). Additionally, the departure date and the number of days that they stayed in their summer or wintering residence were most influenced by maximum temperature (Table 3). These results support the previous notion that birds may migrate to winter locations to avoid harsh (cold) temperatures in their breeding grounds [41–44]. As the maximum temperature during the winter increases, birds might then return back to their breeding grounds. Because temperature increases can indicate a temperature increase at breeding grounds, indicating a surge in food supply [45, 46]. Food supply at breeding grounds has been directly linked to migration and species richness [47]. Accordingly, we observed that maximum temperature had the most influence on departure date and number of days during winter or summer residence.

Our results suggest that alterations in migration timing in association with temperature changes are occurring in both long- and short-distance migrants all over the United States. Additionally, we showed that different features are impacting different migration patterns. As bird observation data become more robust and reliable, even more powerful results can be extracted from analyses like regression and feature selection that will reveal more of the ways in which climate change will affect birds across the globe.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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Supplementary Materials

Table S1. Migration pattern changes and significant environmental temperature changes experienced by species showing a summer or winter resident migration strategy through Anchorage County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S2. Migration pattern changes and significant environmental temperature changes experienced by species showing a transient migration strategy through Anchorage County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S3. Migration pattern changes and significant environmental temperature changes experienced by species showing a summer or winter resident migration strategy through Fairbanks County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S4. Migration pattern changes and significant environmental temperature changes experienced by species showing a transient migration strategy through Fairbanks County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S5. Migration pattern changes and significant environmental temperature changes experienced by species showing a summer or winter migration strategy through Aroostook County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S6. Migration pattern changes and significant environmental temperature changes experienced by species showing a transient migration strategy through Aroostook County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S7. Migration pattern changes and significant environmental temperature changes experienced by species showing a summer or winter resident migration strategy through Cumberland County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S8. Migration pattern changes and significant environmental temperature changes experienced by species showing a transient migration strategy through Cumberland County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S9. Migration pattern changes and significant environmental temperature changes experienced by species showing a summer or winter resident migration strategy through Hancock County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S10. Migration pattern changes and significant environmental temperature changes experienced by species showing a transient migration strategy through Hancock County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S11. Migration pattern changes and significant environmental temperature changes experienced by species showing a summer or winter resident migration strategy through Charleston County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S12. Migration pattern changes and significant environmental temperature changes experienced by species showing a transient migration strategy through Charleston County. Migration patterns were determined using data from the Cornell lab of ornithology and Zuckerberg et al. (2009). Table S13. Migration pattern changes and significant environmental temperature changes experienced by species showing a summer or winter resident migration strategy through Georgetown County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S14.

Migration pattern changes and significant environmental temperature changes experienced by species showing a transient migration strategy through Georgetown County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S15. Migration pattern changes and significant environmental temperature changes experienced by species showing a summer or winter resident migration strategy through Oconee County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S16. Migration pattern changes and significant environmental temperature changes experienced by species showing a transient migration strategy through Oconee County. Migration patterns were determined using data from the Cornell Lab of Ornithology and Zuckerberg et al. (2009). Table S17. Feature selection rankings for one-stopover summer migrants using three different feature selection methods. Table S18. Feature selection rankings for one-stopover winter migrants using three different feature selection methods. Table S19. Feature selection rankings for two-stopover spring migrants using three different feature selection methods. Table S20. Feature selection rankings for two-stopover fall migrants using three different feature selection methods. *(Supplementary Materials)*

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