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INFLUENCE OF CLIMATE CHANGE ON AVIAN MIGRANTS' FIRST ARRIVAL DATES

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Abstract. Long-term studies over a variety of regions, species, and time periods can help link trends in climate to changes in bird phenology and provide better understanding of potential effects of climate change. We analyzed first spring arrival dates of 93 species of migrants from the Buffalo Ornithological Society's database covering the period from 1967 to 2008. Migrants appeared a mean 0.10 days earlier each year. Short-range migrants, traveling from a winter range within North America, have advanced their average arrival more, 0.15 days per year, than have long-range migrants from Central America, South America, or the West Indies, whose advance averaged 0.06 days per year. We regressed arrival dates against the temperature of short-range migrants' winter range, as represented by Houston, Texas, and the North American Oscillation Index as indicators of climate change. The Houston temperature correlates well with earlier arrival dates, especially for short-range migrants. We compared our results with similar studies across North America and found general agreement with the trends we observed. These results are consistent with the hypothesis that climate change has a strong influence on the phenology of bird migration.

Key words: *avian migration, climate change, first arrival date, migration, phenology.*

Influencia del Cambio Climático sobre la Fecha de los Primeros Arribos de las Aves Migratorias

Resumen. Los estudios de largo plazo en una variedad de regiones, especies y períodos de tiempo pueden ayudar a vincular las tendencias en el clima con los cambios en la fenología de las aves y brindar un mejor entendimiento de los efectos potenciales del cambio climático. Analizamos las fechas de los primeros arribos de primavera de 93 especies de migrantes usando la base de datos de la Buffalo Ornithological Society, que cubre un período desde 1967 hasta 2008. Los migrantes aparecieron una media de 0.10 días más temprano cada año. Los migrantes de corto alcance, que viajaban desde un rango invernal adentro de América del Norte, han adelantado aún más su promedio de arribo, 0.14 días por año, que lo que lo han hecho los migrantes de largo alcance desde América Central y del Sur, cuyos adelantos promedian 0.06 días por año. Realizamos una regresión entre las fechas de arribo y la temperatura del rango invernal de los migrantes de corto alcance, representados por Houston, Texas y el Índice de Oscilación de América del Norte como indicadores de cambio climático. Esta temperatura se correlacionó bien con las fechas de arribo más tempranas, especialmente para los migrantes de corto alcance. Comparamos nuestros resultados con estudios similares a través de América del Norte y encontramos una coincidencia general con las tendencias que observamos. Estos resultados son consistentes con la hipótesis de que el cambio climático tiene una fuerte influencia sobre la fenología de migración de las aves.

INTRODUCTION

Climate change is generally recognized as having the potential to affect the phenology of avian life cycles, particularly migration timing (Cotton 2003, Jones and Cresswell 2010, Puildo and Berthold 2010). Photoperiod is thought to be the primary mechanism cueing migration (Gwinner 1996) but cannot by itself account for changes in migration phenology. Interaction between photoperiod and climate-related factors such as temperature and food availability most likely determines overall migration timing (Bauer et al. 2008). Long-term changes in temperature may upset the normal synchronization of migration cues. When arrival on breeding grounds is disconnected from the proper conditions breeding success may be reduced, ultimately affecting species' survival (Bauer et al 2008, Jones and Creswell 2010, Visser and Both 2005). However, the extent of change in both climate and migration phenology over time differs by species and area and is not fully understood. Studies by different methods at different locations and in different time frames continue to find differing degrees of evidence for climate-based phenological change (Wilson et al. 2000, Marra et al. 2005, Mills 2005, Ledneva et al. 2004, MacMynowski and Root 2007). Differences in migration-change rates based on time frame and geography are worth

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interpreting as part of the effect of climate change, whereas differences due to study method may be confounding factors.

An emerging approach to the study of long-term and large-scale trends involves the use of citizen science, including data from bird-club data bases, breeding-bird atlases, and Christmas bird counts (Greenwood 2007). There are numerous examples of analyses based on large citizen-science databases, including successful analysis of data on first arrival dates (Butler 2003, Lehikoinen et al. 2004, Murphy-Klassen et al. 2005, Miller-Rushing et al. 2008, Swanson and Palmer 2009, Lehikoinen and Sparks 2010). Here we present an analysis of the database of first arrival dates accumulated by the Buffalo Ornithological Society over 42 years. Advantages of the data set include long duration and coverage of a large and diverse terrain including eight counties in western New York State and the area of the Niagara Escarpment in southeastern Ontario, Canada. Of even more importance is the diversity of the 93 species in the data set, including shore birds, waterfowl, raptors, wading, and marsh birds in addition to a variety of passerines. The data set can be used to address three important questions that could help decipher the effect of climate change on North American birds. First, is there evidence of long-term climate change affecting the phenology of bird migration at the regional level? Second, do these patterns hold true over a variety of species, and if so, which birds appear most susceptible to change? Finally, how do the temporal and species-based patterns observed compare to patterns observed in studies differing only in either geographical region or study method?

METHODS

The Buffalo Ornithological Society administers a database of reports from experienced birders. Unusual records, in particular, observations of species outside of their normal occurrence dates, require verification by the society's statistics committee prior to inclusion in the database. For the period 1967–2008, we selected 93 species of migrants from this database, giving no special consideration to variables explicitly analyzed in our study (Appendix 1).

We performed linear regressions for each species, comparing first arrival dates against year to determine any overall change in arrival dates. Days of the year were numbered consecutively starting with January 1. The resulting regression slopes are the change in arrival day (in units of days per year). For brevity we refer to the change in arrival by year as the year slope, with a negative slope indicating an earlier arrival date.

To explore the specific association between climate change and earlier first arrival dates, we regressed these dates against representative temperatures at a source of migrants and the North American Oscillation Index (NAOI). We used the temperature in Houston, Texas, over the 30 days prior to a species' average arrival date as an indicator of climate change (as supported by Lehikoinen et al. 2004, Gordo 2007, and Lehikoinen and Sparks 2010). We selected Houston as geographically representative of potential sources of migrants and becuase of the availability of temperature data throughout the study period. Although Houston is obviously not the source of all migrants addressed in this study, for brevity we refer to the representative Houston temperature as the source temperature. The temperature at Houston, as a function of year, is approximately linear with a positive slope. We detrended the temperature data and repeated the regression analysis to determine if the birds were arriving earlier in warm springs independent of any general trend of climate warming and to assess the relative effect of the warming trend itself. Following MacMynowski and Root (2007), we also regressed first arrival dates against the average of the NAOI for the month prior to each species' arrival date (National Oceanic and Atmospheric Administration 2010a,b).

We partitioned the 93 species as 37 short-range migrants, those with substantial populations wintering in North America, and 56 long-range migrants, those with principal wintering grounds in Central America, South America, or the West Indies (Appendix 1). We compared arrival date with year and both climate indices for each category. Last, we compared the overall patterns seen in our analysis with those of several related studies.

RESULTS

REGRESSION OF ARRIVAL DATE AGAINST YEAR

Of the 93 species, 71 had negative year slopes, indicating a change to earlier arrival; 22 had positive slopes, indicating a change to later arrival (Appendix 1). Provided that the species are independent, the binomial-distribution probability that no more than 22 slopes would be positive is 2×10^{-7}, indicating a significant trend to earlier first observation dates.

Fifty-two species had slopes that were definitively negative, and only seven species had slopes that were definitively positive (Fig. 1). Here we define a definitively negative slope as a negative slope whose value at the upper error bar (one standard error) is still negative. Similarly, a definitely positive slope is a positive slope whose value at the lower error bar is still positive. A zero-overlapping slope is one for which the values at the upper error bar and lower error bar have different signs. Of the 93 regressions, 32 had $P < 0.05$. The average of the slopes for all 93 migrants was -0.10 ± 0.02 days per year, indicating an average advance in arrival date of 4.2 days over the 42-year period of the database. Throughout the text, the number following the ± sign is the standard error. Figure 2 shows data from three example species: a definitively negative slope, a zero-overlapping slope, and a definitively positive slope.

The average date of first arrival of the 37 short-range migrants was day 104 (14 April); the average arrival date for the

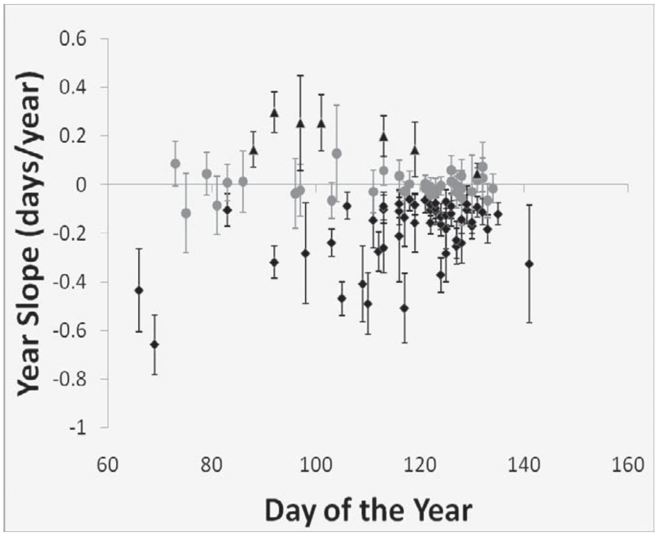

FIGURE 1. Plot of the year slope (days year^{-1}) obtained from the regression of average arrival day vs. year. Slopes are coded to show definitively negative (52 points, diamonds), definitively positive (7 points, triangles), and zero-overlapping (34 points, gray circles) species.

56 long-range migrants, day 123 (3 May), was substantially later. This difference was statistically significant (t_{55} = 5.0, $P < 0.0001$) and served to emphasize the distinction between the two classes of migrants. The average change, as indicated by the year slope for the short-range migrants, was –0.15 ± 0.03 days per year, while the long-range migrants averaged a change of only –0.06 ± 0.02 days per year (t_{62} = 2.2, P = 0.01).

REGRESSION OF ARRIVAL DATE AGAINST MIGRATION-SOURCE TEMPERATURE AND NAOI

We compared the linear regression of the 93 migrants' arrival days with the average temperature in Houston for the 30 days preceding their average arrival dates (Appendix 1). We define this change in arrival day with temperature as the temperature slope. The average temperature slope was –0.74 ± 0.11 days per °C with 76 negative and 17 positive values. This negative slope indicates that migrants arrive earlier with increasing temperature. In comparison to the year regressions, there were fewer definitively negative (46), more zero-overlapping values (43), and fewer definitively positive values (4). We detrended the temperature data, repeated the regression analysis, and found that birds do arrive earlier in warm springs with a mean temperature slope of –0.52 ± 0.11. That is, this trend is independent of temporal changes in temperature.

We also regressed arrival day against the NAOI for the month prior to the average migration date and obtained 18 definitively negative slopes, 14 definitively positive slopes, and 61 zero-overlapping slopes. Only seven of the 93 species' regressions showed a statistically significant slope; five negative and two positive.

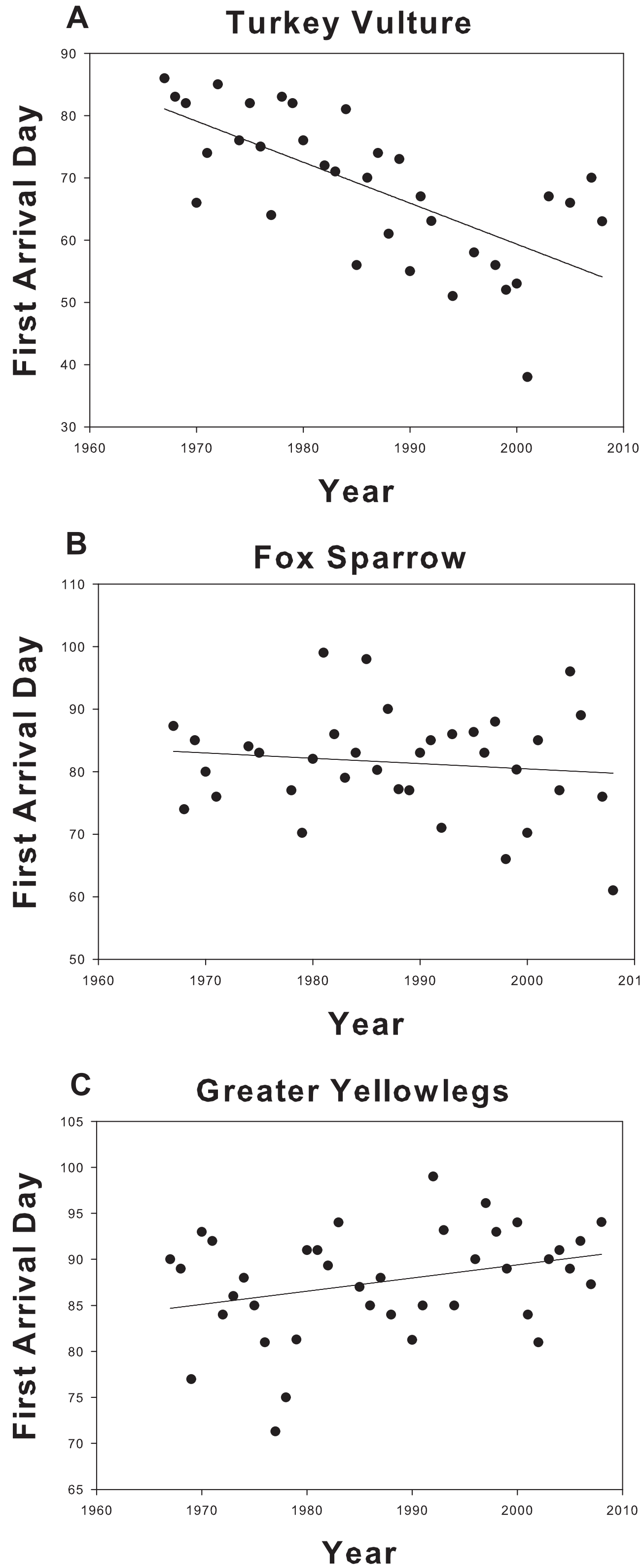

FIGURE 2. Linear regressions of first arrival day vs. year. A, Turkey Vulture; slope –0.658 days year^{-1}, SE = 0.124, $P < 0.0001$. B, Fox Sparrow; slope –0.085 days year^{-1}, SE = 0.120, P =0.48. C, Greater Yellowlegs; slope +0.151 days year^{-1}, SE = 0.071, P = 0.05.

DISCUSSION

Although there is a trend toward earlier first arrival dates, determining the cause is not simple (Parmesan and Yohe 2003). The hypothesis that climate change is responsible for earlier arrival dates is supported by our temperature analysis; however, other causes must be considered. One possibility is change in observer effort. Although actual observer hours throughout spring migration are not available, the number of birders who participated in the Buffalo Ornithological Society's counts in April and May is a good indicator of the number of active birders in the region who could contribute to the database of first arrival dates. Over the 42 years of the study, there was a small, statistically insignificant positive trend in number of observers (for April an increase of 2 observers out of an average of 252, for May an increase of 18 observers out of an average of 253). To further verify the uniformity of observer effort over the course of the study, we also checked the number of duplicate sightings for a given species' first arrival date and the number of observers reporting sightings of the species. All metrics tested indicate a relatively uniform effort.

Another possible confounding factor could be systematic trends in the bird populations themselves since large increases or decreases could affect species' observability. DeLeon (2009) examined Buffalo Ornithological Society data from the May count over this period for population trends in the set of 93 species. For a few species with the largest population changes it is possible that changes in first arrival date could be related to this factor, but for the majority of the species there seems to be no strong relation between changes in population and in first arrival date.

COMPARISON WITH OTHER NORTH AMERICAN STUDIES

A number of recent studies over a variety of locations in North America have also used first arrival dates, allowing for direct comparison and an overview of migration advance in eastern North America as it relates to climate change. Comparison of multiple regional studies is the most promising method for determining overall effects of climate change (Parmesan and Yohe 2003). We compared our migration-advance results with four previous studies at five North American locations over long time spans, 33 to 63 years, 1932–2008. There was wide variation in the migration advance (year slope) of the species covered in each study, so we compared only the species the studies have in common to ascertain if trends were consistent over a wide geographical region. For the species in common between our study and each of the other studies, we compared the average advance and the correlation coefficients of the year slopes (Table 1).

Studies of first arrival dates. The study of Murphy-Klassen et al. (2005) is based on data from Delta Marsh, Manitoba, Canada (1700 km from Buffalo, heading 306°). In spite of Delta Marsh being the farthest geographically from our study site, among the species in common, its trends in first arrival dates are remarkable similar to ours. The study by Butler (2003) is based on data from Massachusetts (570 km from Buffalo, heading 93°) and shares the most species with our analysis. Butler's data show the largest migration advance of all of the studies with a mean value slightly larger than that of our data (Table 1). The results of the study by Miller-Rushing et al. (2008), also for Massachusetts (690 km from Buffalo heading 96°), differ from both ours and those of Butler (2003). However, as they discussed, Miller-Rushing et al. (2008) placed more confidence in their analysis of peak arrival dates, which agree better not only with our results ($\mu_{MR} = -0.06 \pm 0.02$, $\mu_P = -0.07 \pm 0.02$, correlation coefficient 0.43), but also with those of the other studies we compared (Table 1). Swanson and Palmer (2009) did a study in Minnesota (1100 km from Buffalo, heading 294°) and another in South Dakota (1700 km from Buffalo, heading 283°).

TABLE 1. Comparison of studies of change in first arrival dates of migrants in eastern North America. Sp = number of species in common, *R* = correlation coefficient, μ = mean ± standard error. The boxes above the diagonal show species in common and correlation coefficients, the boxes below the diagonal mean ± SE for each study.

	This study (P)	Butler (2003) (B)	Murphy-Klassen et al. (2005) (K)	Swanson and Palmer (2009): Minnesota (M)	Swanson and Palmer (2009): South Dakota (D)	Miller-Rushing et al. (2008) (R)
P	—	Sp = 75 $R = 0.12$	Sp = 25 $R = 0.46$	Sp = 23 $R = 0.52$	Sp = 23 $R = 0.50$	Sp = 15 $R = -0.29$
B	$\mu_P = -0.09 \pm 0.02$ $\mu_B = -0.16 \pm 0.02$	—	Sp = 26 $R = 0.14$	Sp = 25 $R = 0.29$	Sp = 25 $R = 0.34$	Sp = 16 $R = -0.36$
K	$\mu_P = -0.06 \pm 0.03$ $\mu_K = -0.03 \pm 0.02$	$\mu_B = -0.35 \pm 0.08$ $\mu_K = -0.05 \pm 0.01$	—	Sp = 29 $R = 0.39$	Sp = 29 $R = 0.41$	Sp = 7 $R = 0.18$
M	$\mu_P = -0.09 \pm 0.03$ $\mu_M = -0.08 \pm 0.04$	$\mu_B = -0.27 \pm 0.08$ $\mu_M = -0.09 \pm 0.04$	$\mu_K = -0.07 \pm 0.01$ $\mu_M = -0.15 \pm 0.05$	—	Sp = 43 $R = 0.55$	Sp = 6 $R = -0.77$
D	$\mu_P = -0.09 \pm 0.03$ $\mu_D = -0.22 \pm 0.05$	$\mu_B = -0.27 \pm 0.08$ $\mu_D = -0.23 \pm 0.05$	$\mu_K = -0.07 \pm 0.01$ $\mu_D = -0.27 \pm 0.04$	$\mu_M = -0.26 \pm 0.04$ $\mu_D = -0.13 \pm 0.04$	—	Sp = 6 $R = -0.73$
R	$\mu_P = -0.07 \pm 0.02$ $\mu_R = 0.13 \pm 0.02$	$\mu_B = -0.08 \pm 0.06$ $\mu_R = 0.02 \pm 0.02$	$\mu_K = -0.04 \pm 0.03$ $\mu_R = 0.04 \pm 0.03$	$\mu_M = -0.02 \pm 0.07$ $\mu_R = 0.02 \pm 0.04$	$\mu_D = -0.26 \pm 0.11$ $\mu_R = 0.02 \pm 0.04$	—

In comparison to our results, the South Dakota study shows a larger average migration advance but a similar number of negative slopes, while the Minnesota study shows a very similar average migration advance but fewer negative slopes (Table 1). Four other studies of first arrival dates share fewer than 10 species with our analysis (Bradley et al. 1999, Ledneva et al. 2004, Mills 2005, Strode et al. 2003), and although they are not included in Table 1, they all indicate a net advance in migration date for species in common with our study. Taken together, these studies demonstrate a fairly consistent advance in spring migration across a wide geographic area and provide strong support for climate change as the underlying cause for this phenological shift.

Banding studies with similar geographical location. Van Buskirk et al. (2009) discussed data from 46 years of mist netting at Powdermill Avian Research Center (located 300 km from Buffalo, heading 186°) covering 58 spring migrants whose passage was analyzed by quantiles. We compared our data on first arrival dates against their first 10% quantile. Of the 34 species in common, 27 species at Powdermill and 31 species at Buffalo show an advance in migration. The two studies' average migration advance does not differ significantly (t_{66} = 0.94, P = 0.35), being 0.072 ± 0.019 days year^{-1} at Powdermill and 0.096 ± 0.018 days year^{-1} in Buffalo. The correlation coefficient between the data sets is only 0.28, but the studies agree in other respects. Of the species in common, 26 have negative and two have positive year slopes in both studies, and the slopes of only six species have different signs. At Powdermill, passage time for the first 10% of migrants of a given species tended to advance faster over the period of the study than did the peak migration date. If this trend is even more exaggerated when extrapolated to first arrival dates, it could explain the slightly larger mean value of migration advance we observed.

REGRESSION BASED ON YEAR AND MIGRATION-SOURCE TEMPERATURE

The time frame and magnitude of change in migrants' arrival at Buffalo are consistent with a climate-change hypothesis (Walther et al. 2002, Lehikoinen et al. 2004, Lehikoinen and Sparks 2010). The similarity of the breakdown of year and temperature slopes into definitively positive, zero-overlapping, and definitively negative slopes is also consistent with climate change. However, the correlation coefficient of the two arrays of slopes is only 0.32. Therefore, we cannot conclude that source temperature alone accounts for the advance in arrival day. This is not surprising because many species in the analysis are long-range migrants from the neotropics and influenced by a geographically diverse set of temperatures and other far-ranging conditions. The detrended data, with a mean temperature slope of –0.52 ± 0.11, clearly indicate that birds migrate earlier in warm springs even independent of global-warming effects. Comparison of this detrended mean with the trended mean (–0.74 ± 0.11) gives a measure of the effect of long-term global warming. The better correlation coefficient between year slope and trended temperature slope (0.32) versus that of the detrended temperature slope (–0.03) also suggests that global warming is responsible for advances in migration date. This analysis is a correlation between temperature at a surrogate migration source and arrival time at Buffalo. Therefore, it is not actually examining whether birds leave earlier in warm years, just if they arrive earlier. A relationship between temperature in source areas and arrival time might arise because in warm years migrants depart earlier, speed up their journey, or both.

COMPARISON OF LONG- AND SHORT-DISTANCE MIGRANTS

It has been previously noted that short-distance migrants show greater ability to advance their migration timing to adapt to climate change (Both and Visser 2001, Butler 2003, Jones and Cresswell 2010, Lehikoinen and Sparks 2010). We found that short-distance migrants, traveling from North American wintering grounds, advanced their average arrival more, 0.15 ± 0.03 days per year, than did long-distance migrants from Central and South America, which averaged 0.06 ± 0.02 days per year. Our analysis showing greater migration advance for short-distance migrants lends support to the hypothesis that long-distance migrants with complex multi-stage routes are not as able to adjust migration timing to account for climate change as effectively as short-distance migrants.

The temperature slope was more negative for the short-distance migrants we studied (–0.91 ± 0.15) than for the long distance migrants (–0.63 ± 0.07) (one tailed t-test: t_{53} = 1.4, P = 0.14). Comparing year slopes and temperature slopes for the short-distance migrants alone, we found an increased correlation coefficient of 0.42, indicating the temperature trend driving advance in first arrival dates by year has a greater effect on short-distance migrants. In contrast, for long-distance migrants this correlation coefficient was very small, 0.04. Comparing the trended and detrended data also shows the effect of global warming on the short-distance migrants. The smaller mean temperature slope of the detrended data for short-distance migrants is –0. 55 ± 0.15 and has a small coefficient (0.13) of correlation with the year slope for short-distance migrants.

REGRESSION AGAINST NAOI

Some studies have found the NAOI useful in describing migration (Hüppop and Hüppop 2010, MacMynowski and Root 2007). Our analysis of NAOI, however, showed no significant difference in the average slope between long- and short-distance migrants. The lack of differentiation we found in NAOI is in agreement with the study of Marra et al. (2005) at Powdermill but differs from that of MacMynowski and Root (2007), who found NAOI correlated with earlier arrival dates for long-distance migrants. We also found an insignificant difference in correlation coefficients between year slope and NAOI slope for both short-distance migrants (0.28) and long-distance migrants (0.24).

CONCLUSIONS

From 1967 to 2008, migrants observed in western New York and the area of the Niagara Escarpment in Ontario advanced their spring arrival dates an average of 0.10 ± 0.02 days per year. For short-distance migrants this advancement, 0.15 ± 0.03 days per year, was significantly greater than for long-distance migrants, 0.06 ± 0.02 days per year. These trends fit qualitatively with a pattern of advancing migration dates observed in a number of long-term studies of first arrival dates across eastern North America. Results are also in quantitative agreement with those from a nearby banding station. The temperature in migrants' winter range partially accounts for observed advances in migration date, especially for short-distance migrants. The trend of earlier arrival dates over a long time scale and a diverse range of species supports the conclusions of many continuing studies of bird phenology and emphasizes the importance of continued investigation of the effect of long-term climate change on migratory birds. Understanding the link between migration timing and climate change is the first step in determining how disruptions of this system could affect populations and which groups of birds are at highest risk.

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APPENDIX 1. First arrival day, linear regression slope of arrival day vs. year, and linear regression slope of arrival day vs. local temperature for 93 species of migrants at Buffalo, New York.

				Year slope			Temperature slope		
Common name	Scientific name	Distance of migration[a]	Arrival day	Slope (days year^{-1})	SE	*P*	Slope (days °C^{-1})	SE	*P*
Snow Goose	*Chen caerulescens*	short	66	–0.435	0.170	0.021	–3.071	1.886	0.122
Blue-winged Teal	*Anas discors*	short	79	0.044	0.089	0.622	–0.873	0.702	0.222
Northern Shoveler	*Anas clypeata*	short	75	–0.117	0.163	0.478	–1.234	0.926	0.194
American Bittern	*Botaurus lentiginosus*	short	104	0.128	0.199	0.525	–0.397	1.944	0.839
Great Egret	*Ardea alba*	short	98	–0.283	0.207	0.190	–2.690	1.912	0.179
Green Heron	*Butorides virescens*	short	111	–0.029	0.088	0.744	–0.417	0.850	0.628
Turkey Vulture	*Cathartes aura*	short	69	–0.658	0.124	0.0001	–3.222	0.876	0.001
Osprey	*Pandion haliaetus*	short	92	–0.319	0.067	0.0001	–0.044	0.695	0.950
Broad-winged Hawk	*Buteo platypterus*	long	106	–0.088	0.055	0.121	–0.337	0.722	0.644
Virginia Rail	*Rallus limicola*	short	110	–0.490	0.127	0.0006	–0.337	0.722	0.644
Sora	*Porzana carolina*	short	117	–0.135	0.121	0.276	0.325	1.217	0.792
Common Moorhen	*Gallinula chloropus*	short	111	–0.146	0.117	0.221	–3.865	1.325	0.007
Black-bellied Plover	*Pluvialis squatorola*	short	130	–0.030	0.149	0.843	0.014	1.413	0.992
Semipalmated Plover	*Charadrius semipalmatus*	short	130	–0.170	0.052	0.003	0.363	0.618	0.562
Spotted Sandpiper	*Actitis macularius*	short	113	0.057	0.059	0.345	–0.910	0.659	0.177
Solitary Sandpiper	*Tringa solitaria*	long	116	0.036	0.065	0.585	–0.218	0.654	0.740
Greater Yellowlegs	*Tringa melanoleuca*	short	88	0.151	0.072	0.054	0.700	0.605	0.255
Lesser Yellowlegs	*Tringa flavipes*	short	96	–0.036	0.144	0.832	1.179	1.118	0.302
Semipalmated Sandpiper	*Calidris pusilla*	long	132	0.072	0.101	0.481	–0.050	1.065	0.963
Least Sandpiper	*Calidris minutilla*	short	125	–0.182	0.083	0.034	0.099	0.887	0.912
Pectoral Sandpiper	*Calidris melanotos*	long	97	0.253	0.195	0.205	–1.761	1.593	0.278
Dunlin	*Calidris alpina*	short	116	–0.211	0.188	0.276	–3.960	2.066	0.070
Short-billed Dowitcher	*Limnodromus griseus*	short	141	–0.326	0.241	0.185	1.307	2.831	0.648
American Woodcock	*Scolopax minor*	short	73	0.086	0.092	0.355	–1.208	0.687	0.087
Caspian Tern	*Hydroprogne caspia*	short	105	–0.468	0.070	0.0001	–2.696	1.199	0.032
Black Tern	*Chlidonias niger*	long	123	–0.035	0.058	0.557	–0.403	0.603	0.508
Common Tern	*Sterna hirundo*	long	103	–0.066	0.074	0.384	–1.087	0.787	0.183
Black-billed Cuckoo	*Coccyzus erythropthalmus*	long	132	0.027	0.081	0.742	–2.066	0.851	0.021
Chimney Swift	*Chaetura pelagica*	long	113	–0.088	0.057	0.130	–0.386	0.624	0.541
Ruby-throated Hummingbird	*Archilochus colubris*	long	126	–0.119	0.053	0.031	–1.377	0.498	0.009
Eastern Wood-Pewee	*Contopus virens*	long	131	0.045	0.041	0.282	0.190	0.402	0.639
Willow Flycatcher	*Empidonax traillii*	long	135	–0.121	0.044	0.010	–0.842	0.433	0.062
Least Flycatcher	*Empidonax minimus*	long	122	–0.014	0.042	0.751	–0.948	0.385	0.018
Eastern Phoebe	*Sayornis phoebe*	short	83	0.008	0.074	0.920	–1.056	0.671	0.124
Great Crested Flycatcher	*Myiarchus crinitus*	long	122	–0.156	0.048	0.003	–0.853	0.546	0.127
Eastern Kingbird	*Tyrannus tyrannus*	long	121	–0.063	0.052	0.231	–0.518	0.519	0.325

(Continued)

APPENDIX 1. Continued.

				Year slope			Temperature slope		
Common name	Scientific name	Distance of migration[a]	Arrival day	Slope (days year^{-1})	SE	*P*	Slope (days °C^{-1})	SE	*P*
White-eyed Vireo	*Vireo griseus*	short	125	–0.283	0.116	0.026	–0.410	1.436	0.779
Yellow-throated Vireo	*Vireo flavifrons*	long	127	–0.030	0.065	0.643	–0.378	0.609	0.538
Blue-headed Vireo	*Vireo solitarius*	short	112	–0.275	0.082	0.002	–0.378	0.609	0.538
Warbling Vireo	*Vireo gilvus*	long	122	–0.103	0.050	0.045	–1.489	0.452	0.002
Philadelphia Vireo	*Vireo philadelphicus*	long	132	–0.113	0.054	0.044	–0.549	0.605	0.371
Red-eyed Vireo	*Verio olivaceus*	long	128	–0.143	0.058	0.018	–0.510	0.610	0.408
Purple Martin	*Progne subis*	long	101	0.253	0.116	0.038	0.050	1.606	0.976
Tree Swallow	*Tachycineta bicolor*	short	83	–0.104	0.067	0.127	–0.128	0.629	0.840
No. Rough-winged Swallow	*Stelgidopteryx serripennis*	long	103	–0.239	0.055	0.0002	–1.947	0.676	0.008
Bank Swallow	*Riparia riparia*	long	113	0.199	0.085	0.026	0.923	1.108	0.411
Cliff Swallow	*Petrochelidon pyrrhonota*	long	119	0.143	0.112	0.212	–0.246	1.188	0.837
House Wren	*Troglodytes aedon*	short	113	–0.102	0.058	0.088	–0.733	0.695	0.299
Marsh Wren	*Cistothorus palustris*	short	124	–0.371	0.071	0.0001	–0.687	0.931	0.465
Ruby-crowned Kinglet	*Regulus calendula*	short	97	–0.024	0.106	0.825	–1.370	0.710	0.067
Blue-gray Gnatcatcher	*Polioptila caerulea*	short	113	–0.260	0.103	0.017	–2.699	0.960	0.009
Veery	*Catharus fuscescens*	long	124	–0.006	0.038	0.885	–0.826	0.354	0.025
Gray-cheeked Thrush	*Catharus minimus*	long	133	–0.066	0.070	0.348	0.183	0.682	0.791
Swainson's Thrush	*Catharus ustulatus*	long	127	–0.003	0.061	0.956	–0.594	0.586	0.318
Wood Thrush	*Hylocichla mustelina*	long	121	–0.015	0.054	0.786	–0.344	0.504	0.499
American Pipit	*Anthus rubescens*	short	86	0.013	0.125	0.921	1.092	1.105	0.330
Blue-winged Warbler	*Vermivora cyanoptera*	long	124	–0.132	0.053	0.018	–0.878	0.534	0.109
Golden-winged Warbler	*Vermivora chrysoptera*	long	129	–0.080	0.073	0.284	–0.762	0.691	0.278
Tennessee Warbler	*Oreothlypis peregrina*	long	128	–0.017	0.051	0.739	–0.810	0.474	0.096
Orange-crowned Warbler	*Oreothlypis celata*	short	128	–0.240	0.084	0.008	–0.407	0.893	0.652
Nashville Warbler	*Oreothlypis ruficapilla*	long	119	–0.083	0.043	0.061	–1.071	0.434	0.018
Northern Parula	*Parula americana*	long	127	–0.254	0.075	0.002	0.613	0.864	0.483
Yellow Warbler	*Dendroica petechia*	long	117	–0.029	0.038	0.456	–0.992	0.358	0.009
Chestnut-sided Warbler	*Dendroica pennsylvanica*	long	125	–0.126	0.047	0.011	–0.611	0.491	0.220
Magnolia Warbler	*Dendroica magnolia*	long	126	–0.088	0.051	0.095	–0.992	0.489	0.050
Cape May Warbler	*Dendroica tigrina*	long	126	0.011	0.053	0.831	–0.183	0.506	0.719
Black-throated Blue Warbler	*Dendroica caerulescens*	long	124	–0.163	0.050	0.002	–0.163	0.561	0.773
Black-throated Green Warbler	*Dendroica virens*	long	116	–0.078	0.058	0.184	–1.711	0.519	0.002
Blackburnian Warbler	*Dendroica fusca*	long	123	–0.097	0.056	0.091	–1.514	0.527	0.007
Pine Warbler	*Dendroica pinus*	short	109	–0.409	0.157	0.017	–3.184	1.773	0.088
Prairie Warbler	*Dendroica discolor*	long	128	–0.056	0.112	0.619	–0.608	0.982	0.540
Palm Warbler	*Dendroica palmarum*	short	116	–0.109	0.057	0.066	–0.886	0.606	0.154
Bay-breasted Warbler	*Dendroica castanea*	long	130	–0.154	0.045	0.002	–0.307	0.508	0.550
Blackpoll Warbler	*Dendroica striata*	long	133	–0.183	0.059	0.004	0.703	0.632	0.274
Cerulean Warbler	*Dendroica cerulea*	long	128	0.0347	0.068	0.614	–0.288	0.682	0.675
Black-and-white Warbler	*Mniotilta varia*	long	118	0.0016	0.052	0.976	–1.049	0.514	0.048
American Redstart	*Setophaga ruticilla*	long	125	–0.069	0.049	0.166	–0.555	0.493	0.267
Ovenbird	*Seiurus aurocapilla*	long	122	–0.043	0.049	0.382	–0.832	0.459	0.078

(Continued)

APPENDIX 1. Continued.

				Year slope			Temperature slope		
Common name	Scientific name	Distance of migration[a]	Arrival day	Slope (days year^{-1})	SE	*P*	Slope (days °C^{-1})	SE	*P*
Northern Waterthrush	*Parkesia noveboracensis*	long	118	–0.060	0.048	0.215	–0.030	0.484	0.951
Louisiana Waterthrush	*Parkesia motacilla*	long	117	–0.509	0.144	0.002	0.098	1.679	0.954
Mourning Warbler	*Oporornis philadelphia*	long	134	–0.016	0.059	0.787	–1.379	0.560	0.019
Common Yellowthroat	*Geothlypis trichas*	short	123	–0.076	0.064	0.241	–0.523	0.665	0.437
Hooded Warbler	*Wilsonia citrina*	long	127	–0.228	0.076	0.005	–0.452	0.815	0.583
Wilson's Warbler	*Wilsonia pusilla*	long	131	–0.092	0.043	0.039	–0.691	0.444	0.129
Canada Warbler	*Wilsonia canadensis*	long	131	0.019	0.051	0.713	–0.093	0.506	0.855
Savannah Sparrow	*Passerculus sandwichensis*	short	92	0.297	0.084	0.002	–0.255	0.907	0.781
Fox Sparrow	*Passerella iliaca*	short	81	–0.085	0.120	0.481	1.511	1.010	0.144
Lincoln's Sparrow	*Melospiza lincolnii*	short	123	–0.108	0.057	0.063	–1.050	0.547	0.062
Scarlet Tanager	*Piranga olivacea*	long	126	0.059	0.060	0.333	–0.933	0.564	0.106
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	long	122	–0.082	0.046	0.084	–0.389	0.478	0.421
Indigo Bunting	*Passerina cyanea*	long	129	–0.103	0.059	0.091	–0.171	0.606	0.779
Bobolink	*Dolichonyx oryzivorus*	long	121	0.0033	0.035	0.925	–0.409	0.349	0.249
Baltimore Oriole	*Icterus galbula*	long	119	–0.157	0.121	0.205	–2.578	1.070	0.021

[a]Short, within North America; long, to Central and/or South America or the West Indies.