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EFFECTS OF CLIMATE CHANGE ON SPRING ARRIVAL TIMES OF BIRDS IN THOREAU'S CONCORD FROM 1851 TO 2007

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Abstract. The effects of climate change have been detected in numerous biological systems. Study of phenology, including the timing of bird migrations, has proven to be an effective tool for understanding the degree to which plants and animals are affected by climate change. In this study, we analyzed records of birds' arrival at Concord, Massachusetts, over 157 years, compiling the longest known record of bird-arrival dates in North America. Using records of bird arrivals by American philosopher and naturalist Henry David Thoreau for 1851–1854 and the well-known ornithologists William Brewster for 1886 and 1900–1919 and Ludlow Griscom for 1930–1931 and 1933–1954, we examined whether birds are shifting their arrival times in response to a warming climate. Concord resident Rosita Corey provided a set of recent observations for the years 1956–1973 and 1988–2007. When we considered all 22 species of migratory songbirds we analyzed together, we found no average change in arrival date over time, though when we analyzed each species separately, we found that three species are arriving significantly earlier and four species are arriving later. The arrival dates of eight species are significantly correlated with temperature, seven of these species arriving earlier during warmer years. At Concord in general, birds' arrival times are apparently less responsive to temperature than are plants' flowering times, a disparity that has the potential to lead to ecological mismatches in this ecosystem. This study demonstrates the challenges of using nontraditional natural-history data in climate-change research.

Key words: *Brewster, climate change, Griscom, Massachusetts, migration, Thoreau.*

Efectos del Cambio Climático en las Fechas de Llegada de Aves en el Concord de Thoreau de 1851 a 2007

Resumen. Los efectos del cambio climático han sido detectados en numerosos sistemas biológicos. El estudio de la fenología, incluyendo las fechas de las migraciones de aves, ha probado ser una herramienta útil para entender el grado en el que plantas y animales son afectados por el cambio climático. En este estudio, analizamos registros de fechas de arribo de aves a Concord, Massachussets, durante 157 años, compilando el registro de fechas de arribo de aves más grande de América del Norte. Usando los registros de fechas de arribo del filósofo y naturalista estadounidense Henry David Thoreau de 1851 a 1854 y los de los conocidos ornitólogos William Brewster de 1886 y 1900 a 1919 y Ludlow Giscom de 1930 a 1931 y 1933 a 1954, examinamos si las aves están cambiando sus fechas de arribo en respuesta a un clima más cálido. La residente de Concord, Rosita Corey, nos proveyó de una serie de observaciones recientes para los años 1956 a 1973 y 1988 a 2007. Cuando consideramos en conjunto las 22 especies de aves canoras migratorias, no encontramos un cambio promedio en la fecha de arribo con el paso del tiempo, aunque cuando analizamos cada especie por separado, encontramos que tres especies están arribando significativamente antes y cuatro especies están arribando después. Las fechas de arribo de ocho especies están significativamente correlacionadas con la temperatura, siete de las cuales están arribando antes en los años más cálidos. En Concord en general, las fechas de arribo de las aves son aparentemente menos sensibles a la temperatura que las fechas de floración de las plantas, una disparidad que tiene el potencial de llevar a desacoples ecológicos en este ecosistema. Este estudio demuestra los desafíos de usar datos no tradicionales de historia natural en la investigación del cambio climático.

INTRODUCTION

The study of phenology, the timing of natural events, has taken on new significance in recent decades, as researchers have been able to use phenological observations to address issues of climate change (e.g., Parmesan 2007). Signs of climate change are becoming increasingly apparent in ecosystems around the world. However, the degree to which individual organisms are affected is highly variable. The timing of bird migrations is considered to be one of the most sensitive indicators of climate change (Root et al. 2003, Parmesan 2007), and data on bird migration are particularly abundant. Several studies in North America and Europe have shown that some species of migratory birds are arriving earlier at points along

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migration routes or at the breeding grounds (e.g., Butler 2003, Ledneva et al. 2004, Jonzén 2006, Sparks et al. 2007, Charmantier et al. 2008). Yet other species and at other locations arrival dates are later or unchanged (e.g., Hüppop and Winkel 2006, Askeyev et al. 2007, Weidinger and Král 2007, Miller-Rushing et al. 2008b, c). Further significance of the spring phenology of migratory birds lies in the potential for ecological mismatches with other species and their consequent effect on bird populations. As plants and insects adjust the timing of their flowering and emergence, the availability of these food sources to migratory birds is altered. Although some birds have been able to adapt to the changing phenology of plants and insects (e.g., Charmantier et al. 2008) it is likely that once the synchrony of the phenology of plants, insects, and birds is broken, at least some bird populations will suffer because of a lack of reliable sources of food for adults and growing nestlings (Both et al. 2006). Understanding the timing of birds' spring migrations in relation to climate change is critical to conservation efforts, as species that are unable to adjust their phenology are the ones that tend to decline in abundance over time (Møller et al. 2008, Willis et al. 2008).

Previous North American studies have begun to piece together birds' changing phenology from records that are generally 25 to 90 years in length (e.g., Butler 2003, Ledneva et al. 2004, Marra et al. 2005, Mills 2005, Miller-Rushing et al. 2008b, c). These investigations lead to useful conclusions and intriguing new hypotheses, but longer time series could provide additional insight, particularly if they were to include data from prior to the onset of recent anthropogenic climate change. Research that makes use of phenological datasets of this length—those that date back to the start of the 20th century or earlier—is very limited because of the paucity of data. In spite of the limited availability of data that go back to the 1850s, the greater length of the time series might reveal patterns undetectable in datasets that span a shorter period.

The research we present here makes use of one of the longest records of bird migration data in the United States, a dataset spanning 157 years of first arrival dates of migratory songbirds common at Concord, Massachusetts. It begins with the observations of Henry David Thoreau in 1851 and continues with the journals of several distinguished Concord ornithologists and naturalists. Thoreau is well known to Americans as a philosopher, the author of the widely read book *Walden*, and as an early advocate of nature conservation. The habitats he frequented and the birds he saw are recognizable to many Americans. Linking the observations of Thoreau with the topic of climate change makes this issue more accessible to the general public. Thoreau was aware of the ecological importance of phenology as described in his journal on 23 April 1852: *Vegetation starts when the earth's axis is sufficiently inclined; i.e. it follows the sun. Insects and the smaller animals (as well as many larger) follow vegetation . . . The greater or less abundance of food determines migrations. If the buds are deceived and suffer from frost, then are the birds.*

From this information on arrival time, several important questions addressing migratory birds' responses to climate change can be answered: Are birds arriving at Concord earlier (or later) than they did in the past? Are arrival times changing in response to climate change? If so, are certain groups of species more or less responsive to climate change than are others? We also need to consider how different methods of observing birds' arrivals may affect apparent patterns of arrival times.

Previous research on times at which plants flower in Concord has shown that since the 1850s spring-flowering plants are flowering, on average, 7 days earlier than Thoreau observed (Miller-Rushing and Primack 2008). Miller-Rushing and Primack (2008) also found that the dates of species flowering earlier tended to be less variable but more associated with temperature than those of species flowering later. In this paper we also address whether birds' arrival dates in Concord are changing in the same way as plants' flowering dates, an important consideration because these migratory birds tend to feed on insects, which likely emerge synchronously or nearly synchronously with particular life-history stages of plants (Both et al. 2006). Although insects' emergence dates are not known for this area, comparing the arrival times of birds to the flowering times of plants is a valuable step toward understanding the effect of climate change on interactions of species in this ecosystem.

METHODS

Concord, located 30 km northwest of Boston, Massachusetts, covers 64 km^2, with 40% of this area protected as parks and other conservation areas (Miller-Rushing and Primack 2008). Concord's landscape has changed dramatically over the past 150 years. In 1850, around the time when Thoreau was recording his observations, Concord was only 10% forest and around 50% grasslands, pastures, and farmlands (Walton 1984, Primack et al. 2009). At present, around half of Concord is forested and only around 4% of the land area is grasslands, pastures, and farms. In addition, the temperature of Concord has increased since 1852, with most of this increase caused by the urban heat-island effect of metropolitan Boston (Miller-Rushing and Primack 2008). Although much of the current warming can be attributed to the growth of Boston, patterns of change found here can also serve as predictions of future conditions in rural regions where global climate change will likely be a strong factor in temperature increases and subsequent effects on the ecosystem.

The dataset we used is a compilation of the records of first arrival dates of migratory birds at Concord as recorded by several observers. The records of Henry David Thoreau (1817–1862) for the years 1851–1854 are housed in the special collections of the Ernst Mayr Library, Museum of Comparative Zoology (MCZ), Harvard University, Cambridge, Massachusetts. William Brewster (1851–1919), renowned ornithologist, founder of the American Ornithologists' Union and the

Nuttall Ornithological Club, and curator of birds at the MCZ from 1885 to 1919, donated his journals and birding records from the years 1886 and 1900–1919 to MCZ's library. Ludlow Griscom (1890–1959), also curator of birds at the MCZ, a president of the American Ornithologists' Union and the Nuttall Ornithological Club, and author of *The Birds of Concord* (1949) and *Birds of Massachusetts* (Griscom and Snyder 1955), recorded first arrivals in 1930, 1931, and from 1933 to 1954; these records are at the Peabody Essex Museum in Salem, Massachusetts. Rosita Corey, a retired school teacher and contemporary birdwatcher from Concord, made observations of first arrival dates for two distinct periods, 1956–1973 and 1988–2007; in our analysis we treat these intervals separately as "Corey early" and "Corey late."

We believe the methods of observation of these four individuals provide comparable information on birds' arrival times. Each walked in the Concord area multiple times each week, visited a variety of habitats, and recorded their observations of arriving birds. What remains unknown are the number of hours each day that each observed birds, the area covered each day, and relative skill of each observer at recognizing species by sight and sound.

In this study we address only passerines that do not overwinter in Massachusetts. Although interesting in their own right, species that migrated during Thoreau's time and now winter in Concord could not be included in the analysis. Such wintering species include the Field Sparrow (*Spizella pusilla*), Fox Sparrow (*Passerella iliaca*), Swamp Sparrow (*Melospiza georgiana*), and Purple Finch (*Carpodacus purpureus*). We analyzed 22 species, each with a minimum of 22 years of observations over the 157-year span of the study. Both Thoreau and Corey recorded each of the 22 species, with the exception of the Common Yellowthroat (*Geothlypis trichas*), for which Corey late did not have records. All four observers recorded 15 species in common.

Of the 157 years, arrival dates were recorded in 82. We included specific years in the analysis only when there were records for at least three of the 22 species (Thoreau, 61 observation points over 4 years; Brewster, 215 observation points over 34 years; Griscom, 351 observation points over 25 years; Corey early, 236 observation points over 18 years; Corey late, 192 observation points over 20 years). Only records from Concord were used in our analysis.

STATISTICAL ANALYSES

We assessed the relationship between the arrival date of each species and temperature by regression analysis. Temperature data for Concord are limited and do not span the entire period of our study, so we used mean monthly temperatures from the Blue Hill Meteorological Observatory in East Milton, Massachusetts, 33 km southeast of Concord; temperatures there are highly correlated with those at Concord (Miller-Rushing and Primack 2008). To represent conditions each species experiences on its migration, we used the mean temperature for the 2 months prior to each species' mean arrival date, as temperatures at various locations along the east coast of the United States are highly correlated (Miller-Rushing et al. 2008b). If, for instance, a species usually arrives in May, then we used the mean temperature for March and April. These temperatures may also influence the development of spring leaf-out, the emergence of insects, and, in turn, the behavior of a bird, thereby affecting its arrival date.

In some years, fewer than half of the 22 bird species were observed. To allow comparisons among years when not all species were observed, it was necessary to transform the data to put all species on the same time scale (Miller-Rushing and Primack 2008). We calculated a correction factor for each species from the difference between the mean first arrival date of all species and the mean first arrival date of that species. This correction factor for the species was then applied to the date of its arrival in each of the other years. For example, the average arrival date of the Chipping Sparrow (*Spizella passerina*) is 20 April, while the average arrival date for all species over all years is 3 May. We added this 13-day difference to the arrival date every year in which the Chipping Sparrow was observed. For instance, in 1942 Griscom observed the first Chipping Sparrow on 17 April. We transformed this date to 30 April for this year and applied a similar transformation for other years, then used these corrected dates in the analysis that followed. This correction factor had the effect of bringing the values for each species closer to the mean value for all species, in effect adding days to early-arriving species and subtracting days from late-arriving species. This technique eliminated much of the inherent variation within the dataset among species, and it eliminated the problem of observations of different species in different years.

To examine how temperature has changed over time, we apportioned the data into two groups. Regression over the entire 157 years was possible for temperature only. Because the arrival data are somewhat sporadic, regressions of arrival data across the full 157 years were not possible, and instead we analyzed the data by grouping the years into two intervals. The first group was composed of mean temperatures in March and April, the months just prior to when the majority of birds arrive, during the years when Thoreau, Brewster, Griscom, and Corey early were making their observations. The second group included temperature data during the time of observations by Corey late. We chose this separation because temperatures have been considerably warmer recently than in the past (IPCC 2007; Fig. 1). Also, a break in the arrival data provides a logical point at which to divide the data for comparison of the earlier and more recent time periods of 1851–1973 and 1988–2007. We averaged mean March and April temperatures over each period and tested for a difference with a t-test.

Similarly, we examined changes in arrival dates over time, averaging each species' arrival dates for both periods and testing for differences between the periods with a t-test. To determine whether a species' response to temperature has

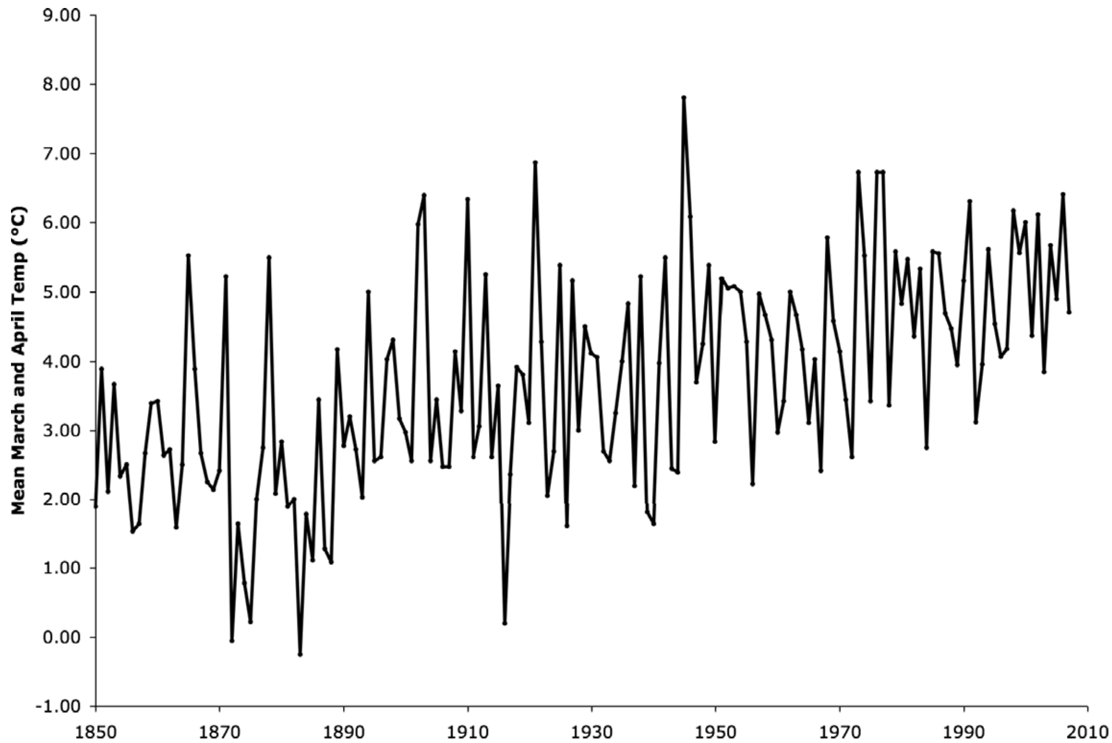

FIGURE 1. Mean March and April temperatures from 1850 to 2007 at Blue Hill Meteorological Observatory, Massachusetts.

changed, we used ANCOVA to test for differences between the two periods in the relationship between arrival date and temperature, with temperature as a covariate.

In an attempt to explain differences among species in the regression of arrival times and temperature, we categorized species by their winter range in two ways. First, following Miller-Rushing and Primack (2008b), we assigned each species to one of three areas representing short-, mid-, and long-distance migrants: North America, Central America and the Caribbean, and South America. Second, following Butler (2003), we categorized winter ranges by just two areas, United States and south of the United States.

Another factor we considered was the variation of species' arrival dates over the entire 157 years, using a Spearman rank correlation to determine if this variation was different for species with earlier or later mean arrival dates.

We did not apply corrections for multiple regressions, such as Bonferroni. Such corrections can increase the rate of type II errors (Nakagawa 2004), thereby obscuring relationships between arrival dates, years, and temperature. Instead, we considered results significant at $P < 0.05$.

RESULTS

During the periods of observations by Thoreau, Griscom, and Corey late birds arrived, on average, on 3 May. They arrived slightly earlier, on 2 May, during the period of Brewster's observations. During Corey's early observation period the average arrival date was 4 May. From one year to the next, the mean arrival date of all species varied somewhat, as seen in the ranges of observations (Fig. 2), with no clear directional trend over the entire 157 years. Of the 21 species we analyzed during the most recent period, seven arrived at a date significantly earlier or later than during the earlier period (Table 1). Three of these species are arriving earlier; four are arriving later. The range of variation in each species was wide (see Appendix 1).

The mean temperature in March and April increased from 3.0 °C in the time of Thoreau to 5.0 °C for the time of the later observations of Corey. Values for the years of Brewster (3.5 °C), Griscom (4.1 °C), and early Corey (4.3 °C) were intermediate. There is a significant relationship between the annual arrival of all species averaged together and the mean temperature of March and April ($P < 0.001$; $R^2 = 0.150$; $F = 14.154$; Fig. 3), with earlier arrival in warm years. On average, birds arrive at Concord 0.77 days earlier with each 1 °C increase in temperature. Of the 22 species, arrival of eight was significantly correlated with the mean temperature in the Concord area during 2 months prior to the species' arrival (Table 1). In only one of these eight species was the relationship of arrival time with temperature negative: the Wood Thrush (*Hylocichla mustelina*) arrived later in warmer years, 1.3 days later for each 1 °C increase in temperature. The seven others arrived earlier in warmer years, with a range of 0.8 to 3.3 days earlier for each 1 °C increase in temperature.

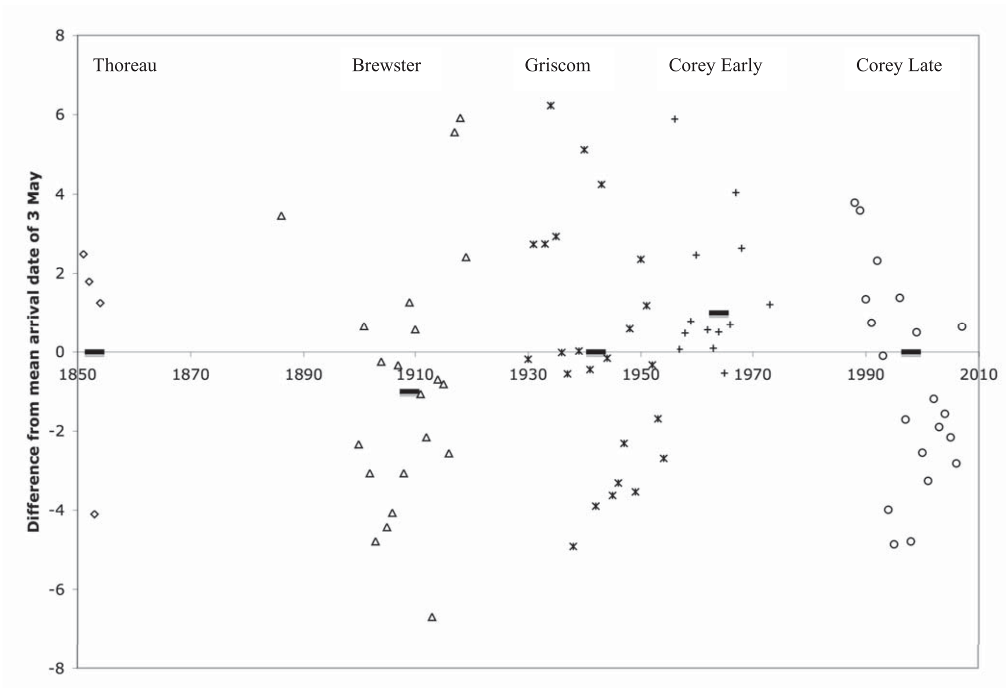

FIGURE 2. Corrected mean arrival date for all birds in each year as recorded by each observer. Mean arrival date for all species and all years for each observer is shown with a bold horizontal line.

TABLE 1. Comparison of mean arrival dates over two periods, Thoreau through Corey early (T-CE: 1851–1973) and Corey late (CL: 1988–2007), and simple linear-regression analysis of arrival date with temperature. An asterisk follows values that are statistically significant.

		Year					Temperature				
Species	English name	df	T-CE	CL	SE	P	Slope (days °C^{-1})	R^2	F	SE	P
Contopus virens	Eastern Wood-Pewee	42	22 May	23 May	2.607	0.804	−1.024	0.056	2.415	0.659	0.128
Sayornis phoebe	Eastern Phoebe	72	2 Apr	30 Mar	2.535	0.362	−1.892	0.070	5.343	0.819	0.024*
Tyrannus tyrannus	Eastern Kingbird	66	7 May	5 May	1.387	0.095	−0.466	0.022	1.484	0.382	0.228
Vireo gilvus	Warbling Vireo	46	13 May	4 May	1.806	<0.001*	−1.971	0.113	5.748	0.822	0.021*
Vireo olivaceus	Red-eyed Vireo	32	14 May	15 May	1.428	0.579	0.181	0.004	0.134	0.494	0.717
Riparia riparia	Bank Swallow	47	1 May	7 May	2.344	0.028*	0.465	0.005	0.212	1.009	0.647
Hirundo rustica	Barn Swallow	55	22 Apr	1 May	2.000	<0.001*	0.117	0.000	0.025	0.747	0.876
Hylocichla mustelina	Wood Thrush	36	7 May	12 May	2.314	0.026*	1.305	0.125	5.009	0.583	0.032*
Dumetella carolinensis	Gray Catbird	21	6 May	4 May	1.362	0.069	−0.392	0.027	0.549	0.530	0.468
Toxostoma rufum	Brown Thrasher	30	2 May	6 May	4.733	0.241	−0.707	0.017	0.496	1.004	0.487
Dendroica petechia	Yellow Warbler	76	6 May	2 May	0.808	<0.001*	−0.817	0.082	6.696	0.316	0.012*
Dendroica coronata	Yellow-rumped Warbler	27	24 Apr	18 Apr	1.840	0.23	−3.311	0.254	8.851	1.113	0.006*
Dendroica pinus	Pine Warbler	47	16 Apr	16 Apr	3.874	0.968	−1.534	0.059	2.909	0.900	0.095
Mniotilta varia	Black-and-white Warbler	64	1 May	3 May	1.213	0.127	−0.511	0.026	1.671	0.395	0.201
Seiurus aurocapilla	Ovenbird	55	6 May	14 May	2.544	0.001*	−0.242	0.009	0.475	0.352	0.494
Geothlypis trichas	Common Yellowthroat	34	10 May	n/a[a]	n/a	n/a	−1.013	0.057	1.989	0.718	0.168
Spizella passerina	Chipping Sparrow	49	21 Apr	18 Apr	2.393	0.147	−2.131	0.159	9.062	0.708	0.004*
Piranga olivacea	Scarlet Tanager	45	12 May	13 May	2.912	0.759	−1.062	0.086	4.159	0.521	0.047*
Pheucticus ludovicianus	Rose-breasted Grosbeak	41	9 May	6 May	2.629	0.265	−1.736	0.188	9.277	0.570	0.004*
Passerina cyanea	Indigo Bunting	42	18 May	22 May	3.924	0.275	0.885	0.028	1.178	0.815	0.284
Dolichonyx oryzivorus	Bobolink	63	10 May	13 May	2.181	0.272	0.056	0.000	0.019	0.407	0.892
Icterus galbula	Baltimore Oriole	62	8 May	6 May	1.393	0.027*	−0.546	0.06	3.891	0.277	0.053

[a]Not applicable, species not recorded.

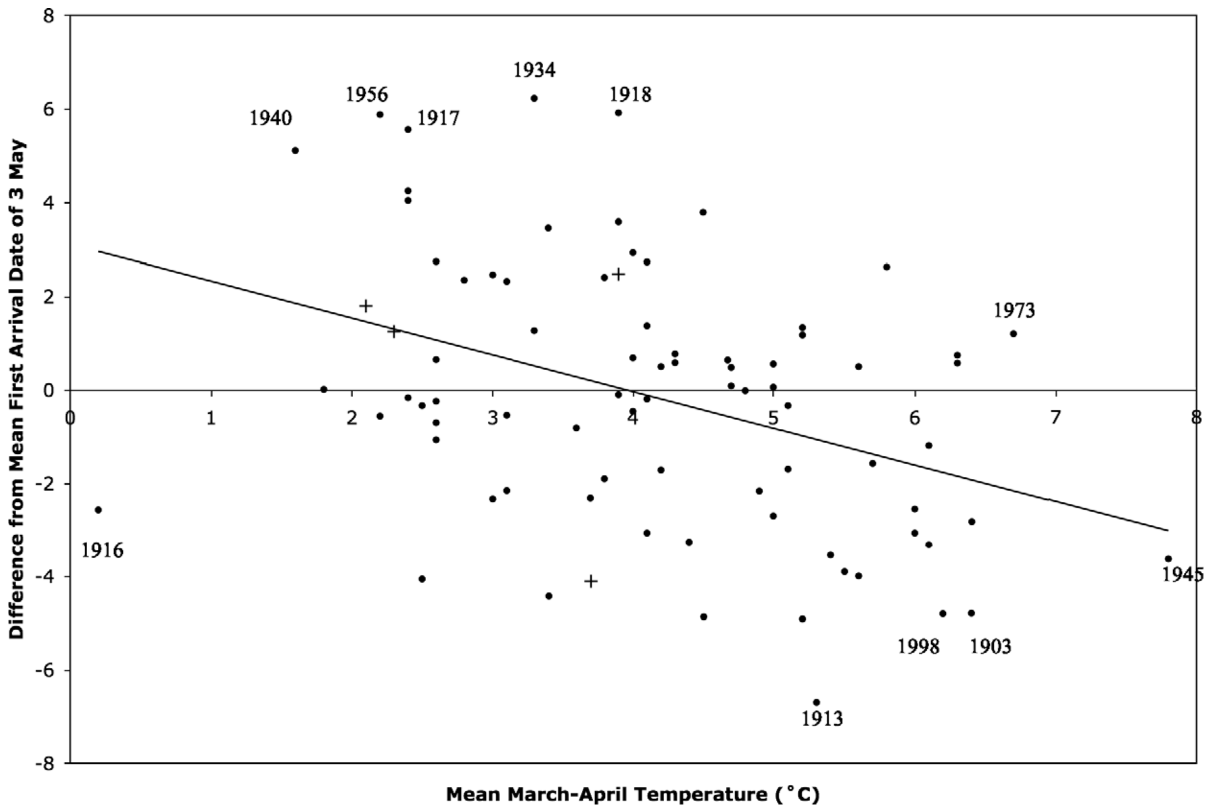

FIGURE 3. Mean arrival dates of all observed species in each year as a factor of mean March–April temperature in that year. Each point represents a single year. Values displayed as a "+" are those during Thoreau's years, 1851–1854, and are shown to highlight the oldest set of observations relative to the more recent.

We also examined the relationship of arrival date and temperature separately for the two periods to determine if species were changing in their responsiveness to temperature. Of the 21 species, 20 showed no difference between the two time periods in the slope of their relationship of temperature to arrival date. The Bank Swallow (*Riparia riparia*) was the only species whose response to temperature changed significantly between the two time periods (ANCOVA: $F = 4.24$, $P = 0.045$), with slightly earlier arrival with increased temperature during the earlier period and distinctly later arrival with increased temperature recently.

We found no significant differences by category of winter range in response to temperature ($P = 0.286$ between short- and mid-distance migrants, $P = 0.177$ between short- and long-distance migrants, and $P = 0.304$ between long- and mid-distance migrants). But the categorization by two areas did yield a significant difference ($P = 0.042$), short-distance migrants responding to temperature change more than did long-distance migrants. A comparison of the mean arrival date of all short-distance migrants combined to that of all long-distance migrants combined revealed that the mean arrival date of short-distance migrants is significantly earlier than that of long-distance migrants, 24 April as compared to 9 May ($P = 0.015$).

Results of the Spearman rank correlation provide evidence that the species arriving earlier, in particular the Eastern Phoebe (*Sayornis phoebe*) and Pine Warbler (*Dendroica pinus*), are more variable in their arrival dates than are the later arriving species, such as the Red-eyed Vireo (*Vireo olivaceus*) and Eastern Wood-Pewee (*Contopus virens*) (Spearman's $\rho = -0.425$, 20 d.f., $P = 0.049$, Fig. 4). Although this trend is most apparent in the earliest species, the relationship is evident across the range of species.

DISCUSSION

This study highlights how climate change may affect different components of the biota differently. Miller-Rushing and Primack (2008) found that plants in Concord are responding to temperature—the mean date of first flowering of plants is 3.1 days earlier per 1 °C of warming—so it is reasonable to hypothesize that the seasonal behavior of other organisms within the same habitat should change similarly. Our findings, however, show that this is not necessarily the case: clearly, the combined mean times of arrival at Concord of these species of migratory songbirds have not significantly changed over the past 157 years. This result is important because phenological responsiveness of species to climate change has been shown

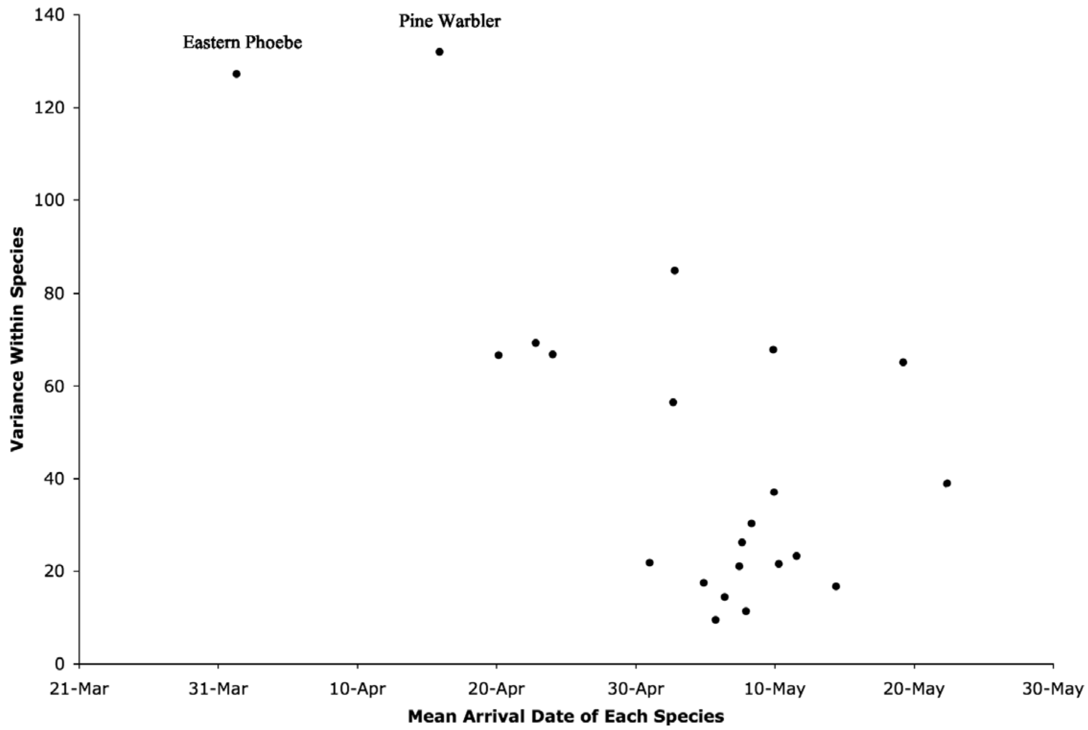

FIGURE 4. Variance in mean arrival date of 22 bird species in relation to when they arrive in the spring. Each dot represents the mean arrival date over all years of observation of a species in relation to the variation in that species' arrival dates. The Eastern Phoebe and Pine Warbler are shown as the species with the earliest arrival dates as well as the greatest variation in arrival dates.

to be a predictor of the tendency of both plants and birds to persist in a region (Møller et al. 2008, Willis et al. 2008).

All species we analyzed taken together, the average date of birds' arrival at Concord is associated with temperature and is advancing at 0.77 days earlier per 1 °C. Clearly, the phenology of spring-flowering plants is changing considerably more rapidly than are birds' arrival times, more than 2 days earlier per 1 °C than the birds. The implications of this asynchrony are difficult to isolate at this time. This finding may be representative of a continuing trend in which plant phenologies change rapidly while bird phenologies adjust more slowly. As temperatures continue to rise in coming decades, plants and birds will likely diverge in their springtime phenologies to a greater extent, with negative effects probable for some bird populations. The implications of this pattern are still poorly understood, but there is a potential for ecological mismatches. Critical to this research is field work on the times of emergence of insects at Concord, particularly in relation to temperature. Insects represent the missing link between plants and birds, and such research will help us to further understand the changing synchrony among these groups of organisms as the climate continues to warm. However, we consider this finding preliminary, not conclusive, because there are a number of factors that may make the results difficult to interpret.

One important potential source of bias in the data is that the later arrival times of species we noted may reflect declining population sizes more than an actual shift in migration dates. As a population declines, the peak arrival date may not change, but the earliest arrivals are observed later simply because fewer birds are migrating and the range of arrival dates tends to contract around the peak (or mean) arrival date (Tryjanowski and Sparks 2001, Miller-Rushing et al 2008b). Lloyd-Evans and Atwood (2004) as well as Sauer et al. (2008) have reported declines in most species included in our study. The degree of population decline has been difficult to quantify with these data, but it is also possible that the four species that are arriving later have experienced greater population loss than the three that are arriving earlier. Such declines in population size would decrease the probability of an observer's noting a species until closer to the peak date. For at least some species, an earlier first arrival time caused by a warming climate might be canceled out by a later first arrival time caused by a declining population, leading to no apparent change in first arrival date. Therefore, the three species that are arriving significantly earlier are likely responding strongly to climate change. Likewise, the six species whose arrival dates vary significantly with temperature but are not arriving significantly earlier may be shifting their arrival dates more than can be detected with these data. The most effective method to detect such changes is to use mean arrival dates rather than first arrival dates, if such data are available (Miller-Rushing et al. 2008b).

We also note that there is some evidence of differences in variability between short- and long-distance migrants, based on the high variability of two short-distance migrants. It is not surprising that short-distance migrants, such as the Pine Warbler or Yellow-rumped Warbler (*Dendroica coronata*), arrive earlier than long-distance migrants, such as the Bobolink (*Dolichonyx oryzivorus*) or Eastern Wood-Pewee. It is interesting, however, to note the increased variance in the arrival dates of the earlier-arriving species. Perhaps these short-distance migrants base their migration dates on erratic climate cues in the southern United States. In Florida, for example, a stormy spring with strong winds in an unfavorable direction may delay birds' efforts to begin flying north, while a succession of clear days with favorable winds could advance their arrival date. Such factors would explain the higher degree of year-to-year variance in such species. Long-distance migrants, on the other hand, may have their migrations timed to more consistent cues, such as photoperiod, making their arrival dates more predictable from year to year (Lehikoinen 2004). Yet long-distance migrants also have greater natural forces to contend with in their journey: more opportunity to encounter adverse weather or insufficient food en route, for example. Such factors complicate the analysis to an extent as yet undetermined, particularly in regard to data from the most recent half-century, during which much winter habitat for long-distance migrants has been altered, particularly in the tropics.

Differences among the methods of observers are inherent in studies such as this and are an additional source of variation requiring interpretation. Such differences could obscure patterns in birds' arrival dates (Miller-Rushing et al. 2008a). Furthermore, each observer could have been inconsistent over time. Despite these methodological considerations, all four of these individuals were or are experienced naturalists, made observations in the Concord area for many years, and visited many different habitats to find the first individual of a species each year. Although it is possible that differences among these observers, such as time devoted to making observations or specific location of observation, are sufficient to obscure changes over time, it appears that there is no one observer whose observations are drastically different from the others.

Thoreau's keen, multi-sensory observations and desire to record what he saw in the natural world serve as the cornerstone of this research. He inspired others to follow this path and with these historic observations and those of later observers we have been able to present research that is both timely and important in ways that Thoreau could not have imagined. The challenge in such research is to distinguish the effects of climate change from underlying problems related to sampling and methods, in particular, problems arising from different observers and changes in population size. However, even with many bird populations in decline, observers differing in their methods, and noise from annual variation in arrival time, these data provide evidence of climate change in this region. This research, in combination with the existing body of literature on the subject, shows that species are sensitive to changes in temperature and that future climate change will continue to affect biological systems in numerous ways. The exceptionally long dataset on which we based our study provides valuable insight into the times of migratory birds' arrival at Concord, Massachusetts.

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APPENDIX 1. Earliest, mean, and latest observed arrival date of 22 species at Concord, Massachusetts, from 1851 to 2007. Also included is whether the species is a short-distance (North America), mid-distance (Central America and the Caribbean), or long-distance (South America) migrant on the basis of categorization of its winter range by three groups, or a short-distance (United States) or long-distance (south of the United States) on the basis of two groups.

Species	English name	Earliest arrival	Mean arrival	Latest arrival	Migration distance (by three/two groups)
Contopus virens	Eastern Wood-Pewee	7 May	24 May	11 Jul	long/long
Sayornis phoebe	Eastern Phoebe	10 Mar	1 Apr	2 May	mid/short
Tyrannus tyrannus	Eastern Kingbird	26 Apr	8 May	22 May	long/long
Vireo gilvus	Warbling Vireo	27 Apr	10 May	10 Jun	mid/long
Vireo olivaceus	Red-eyed Vireo	5 May	14 May	21 May	long/long
Riparia riparia	Bank Swallow	16 Apr	3 May	21 May	long/long
Hirundo rustica	Barn Swallow	2 Apr	24 Apr	13 May	long/long
Hylocichla mustelina	Wood Thrush	26 Apr	8 May	19 May	mid/long
Dumetella carolinensis	Gray Catbird	13 Feb	3 May	13 May	mid/short
Toxostoma rufum	Brown Thrasher	19 Apr	3 May	29 May	short/short
Dendroica petechia	Yellow Warbler	24 Apr	5 May	17 May	long/long
Dendroica coronata	Yellow-rumped Warbler	5 Apr	23 Apr	8 May	short/short
Dendroica pinus	Pine Warbler	29 Mar	16 Apr	11 May	short/short
Mniotilta varia	Black-and-white Warbler	2 Apr	1 May	13 May	mid/short
Seiurus aurocapilla	Ovenbird	7 Apr	6 May	17 May	mid/short
Geothlypis trichas	Common Yellowthroat	2 May	10 May	27 May	mid/short
Spizella passerina	Chipping Sparrow	30 Mar	20 Apr	5 May	mid/short
Piranga olivacea	Scarlet Tanager	2 May	14 May	10 Jul	long/long
Pheucticus ludovicianus	Rose-breasted Grosbeak	29 Apr	8 May	25 May	mid/long
Passerina cyanea	Indigo Bunting	3 May	20 May	12 Jul	mid/long
Dolichonyx oryzivorus	Bobolink	29 Apr	10 May	21 May	long/long
Icterus galbula	Baltimore Oriole	28 Mar	7 May	17 May	mid/long