



INTERPRETING VARIATION IN BIRD MIGRATION TIMES AS OBSERVED BY VOLUNTEERS

ABRAHAM J. MILLER-RUSHING,^{1,3} RICHARD B. PRIMACK,¹ AND ROBERT STYMEIST²

¹Department of Biology, Boston University, 5 Cummington Street, Boston, Massachusetts 02215, USA; and ²Nuttall Ornithological Club,
Department of Ornithology, Harvard University, 26 Oxford Street, Cambridge, Massachusetts 02138, USA

ABSTRACT.—As a result of changes in climate over the past 100 years, many birds are arriving at points along their migration routes earlier in the spring now than they did in the past. Increasingly, researchers are relying on a variety of data sources, such as naturalist journals and bird-club records, to document migration times. However, it is not clear whether researchers can successfully use different sources of data to compare changes in migration times. We examined 25 years of changes in migration times for 30 species of birds at Mt. Auburn Cemetery in Cambridge, Massachusetts, as documented by bird-club members and published in a regional bird journal. We found that, overall, birds arrived earlier in warmer springs in eastern Massachusetts. We compared our findings with those of previous studies in Massachusetts, which included data from a standardized bird-banding station and observations from a naturalist's journal and bird-club records. On a species-by-species basis, changes in migration times were not correlated among the studies. We believe that local changes in population sizes and sampling effort at some of the sites may have contributed to the lack of correlation. For the purpose of comparing changes in migration times across species and locations, standardized bird-banding data are preferable to data collected by volunteer naturalists. However, naturalist data sources are useful and reflect the widely observed trend toward earlier migrations in warm springs. Received 5 January 2007, accepted 3 November 2007.

Key words: bird migration, climate change, Massachusetts, Mt. Auburn Cemetery, phenology.

Interpretación de la Variación en los Tiempos de Migración de las Aves a partir de las Observaciones de Voluntarios

RESUMEN.—Como resultado de los cambios climáticos durante los últimos 100 años, muchas aves están llegando a puntos en sus rutas migratorias durante la primavera más temprano de lo que llegaban en el pasado. Cada vez con mayor frecuencia, los investigadores están utilizando una variedad de fuentes de información, como diarios de naturalistas y registros de clubes de observadores de aves, para documentar los tiempos de migración. Sin embargo, no está claro si los investigadores pueden usar exitosamente diferentes fuentes de datos para comparar cambios en los tiempos de migración. Examinamos 25 años de cambios en los tiempos de migración para 30 especies de aves en el Cementerio Mt. Auburn en Cambridge, Massachusetts, según fue documentado por los miembros de los clubes de observadores y publicado en una revista regional de aves. Encontramos que, en general, las aves llegaron más temprano en las primaveras más cálidas en el este de Massachusetts. Comparamos nuestros hallazgos con los de estudios previos en Massachusetts, los cuales incluyeron datos de una estación estandarizada de anillado de aves y observaciones de un diario de un naturalista y registros de un club de observadores. Considerando especie por especie, los cambios en los tiempos de migración no estuvieron correlacionados entre los estudios. Creemos que los cambios locales en los tamaños poblacionales y el esfuerzo de muestreo en alguno de los sitios pueden haber contribuido a la falta de correlación. Para las comparaciones de cambios en los tiempos de migración entre especies y localidades, los datos estandarizados de anillado de aves son mejores que los datos colectados por voluntarios naturalistas. Sin embargo, las fuentes de datos de los naturalistas son útiles y muestran la tendencia ampliamente observada hacia migraciones más tempranas en las primaveras cálidas.

CHANGES IN THE timing of spring migrations of birds are one of the most well-documented biological responses to recent climate change (Root et al. 2003). Many migratory birds are arriving earlier at locations along their migration routes now than they did in the past, largely because of changes in climate such as warming temperatures and shifts in climate indices such as the North Atlantic Oscillation (e.g., Cotton 2003, Hüppop and Hüppop 2003,

Marra et al. 2005, Mills 2005; reviews in Lehtikoinen et al. 2004, Sparks et al. 2005). However, not all species migrate earlier in warmer springs. For example, banding observations of peak migration dates in eastern Massachusetts show that several species, such as Eastern Wood-Pewee (*Contopus virens*) and Mourning Warbler (*Oporornis philadelphia*), migrate about the same time each year regardless of temperature (Miller-Rushing et al. 2008).

³Present addresses: Rocky Mountain Biological Laboratory, P.O. Box 519, Crested Butte, Colorado 81224, USA, and Department of Biology, University of Maryland, College Park, Maryland 20742, USA. E-mail: abe@rmbi.org

This variation in migratory changes may cause interactions among species to change (e.g., Both et al. 2006).

To investigate the variation in species' migratory responses to climate change, researchers must compare arrival, peak, and departure dates for as many species and locations as possible. Bird-banding stations, which usually contain the most standardized data and controlled sampling methods, are relatively rare compared with naturalist observations. To supplement banding data, researchers have examined records from bird-club publications (Butler 2003) and private journals (Sparks and Carey 1995, Bradley et al. 1999, Ledneva et al. 2004). These records greatly increase the number of species and locations for which data are available. However, naturalist observations rarely control for sampling methods or effort. A bird-club record may reflect the effort of 10 observers in one year and 20 observers the next year; or an observer may spend 5 h per week making observations in one year and 15 h per week in another year. In addition, naturalist observations often contain data on only the first bird observed in a particular year. These first observations may be significantly affected by changes in population size (or migration cohort size), sampling effort, and unusual weather (Sparks et al. 2001, Tryjanowski and Sparks 2001, Tryjanowski et al. 2005). Individual birds that migrate unusually

early, independent of when the populations migrate as a whole, also could affect first observations made by naturalists.

Because an increasing number of studies use naturalist observations to describe trends toward earlier migration times in warmer springs (e.g., Sparks and Carey 1995, Bradley et al. 1999, Butler 2003, Ledneva et al. 2004), it is important to understand how observations collected by naturalists compare to banding-station data. For example, if a series of studies suggests that migration times of Black-and-white Warblers (scientific names for this and other species in our study are given in Table 1) are changing at different rates across North America, it is important to understand what might cause these different rates—for example, the different migratory behaviors of the migration cohorts (departure time, migration speed, migration route) or differences in the methods of data collection. Unfortunately, few researchers have compared methods for observing migration patterns (Lehikoinen et al. 2004). Here, we address three questions concerning naturalist observations of changes in bird migration times. (1) Do data gathered by naturalists indicate that birds are arriving earlier in warmer springs than in cooler springs? (2) Are trends in bird migration times shown by naturalists' data consistent with those obtained from bird-banding stations? (3) If differences exist between

TABLE 1. Relationship between peak arrival dates at Mt. Auburn Cemetery and mean March–April temperatures, the Southern Oscillation Index (SOI), and the North Atlantic Oscillation Index (NAOI), as determined by linear regression. Slopes are given as days °C⁻¹ (temperature) or days index unit⁻¹ (SOI and NAOI). Statistically significant *P* values (*P* < 0.05) are given in bold.

Common name	Scientific name	Temperature			SOI			NAOI		
		Slope	SE	<i>P</i>	Slope	SE	<i>P</i>	Slope	SE	<i>P</i>
Ruby-throated Hummingbird	<i>Archilochus colubris</i>	-1.927	1.759	0.289	0.765	0.788	0.346	0.080	0.781	0.920
Least Flycatcher	<i>Empidonax minimus</i>	3.664	1.990	0.090	-1.39	1.18	0.261	0.081	1.184	0.946
Red-eyed Vireo	<i>Vireo olivaceus</i>	-3.844	1.623	0.034	-0.330	0.715	0.652	0.255	0.644	0.699
Golden-crowned Kinglet	<i>Regulus satrapa</i>	-3.942	2.158	0.086	-1.458	1.077	0.195	0.578	1.146	0.621
Ruby-crowned Kinglet	<i>Regulus calendula</i>	-1.968	1.401	0.173	0.000	0.676	0.999	-1.041	0.673	0.136
Veery	<i>Catharus fuscescens</i>	-1.828	1.613	0.278	-0.796	0.712	0.283	0.422	0.739	0.577
Swainson's Thrush	<i>C. ustulatus</i>	0.022	1.353	0.987	0.365	0.630	0.568	0.372	0.586	0.532
Hermit Thrush	<i>C. guttatus</i>	0.146	1.797	0.936	-0.335	0.781	0.674	-0.503	0.844	0.558
Nashville Warbler	<i>Vermivora ruficapilla</i>	-2.258	0.984	0.033	0.263	0.500	0.604	0.515	0.512	0.326
Northern Parula	<i>Parula americana</i>	-1.202	1.043	0.261	-0.209	0.491	0.674	0.503	0.483	0.309
Yellow Warbler	<i>Dendroica petechia</i>	1.021	3.029	0.742	-1.023	1.909	0.603	0.796	1.067	0.471
Chestnut-sided Warbler	<i>D. pensylvanica</i>	-0.957	1.590	0.556	-0.810	0.657	0.237	0.851	0.589	0.169
Magnolia Warbler	<i>D. magnolia</i>	0.846	1.609	0.605	0.065	0.743	0.930	-0.289	0.742	0.701
Black-throated Blue Warbler	<i>D. caerulescens</i>	-3.667	1.062	0.003	-1.860	0.575	0.004	0.469	0.535	0.392
Yellow-rumped Warbler	<i>D. coronata</i>	-0.647	1.220	0.601	0.187	0.563	0.743	-0.021	0.586	0.971
Black-throated Green Warbler	<i>D. virens</i>	-2.354	1.251	0.074	-0.613	0.596	0.315	1.213	0.576	0.047
Blackburnian Warbler	<i>D. fusca</i>	0.515	1.262	0.689	0.747	0.527	0.175	0.589	0.528	0.280
Palm Warbler	<i>D. palmarum</i>	-4.449	1.165	0.001	-0.244	0.679	0.723	-0.191	0.683	0.782
Blackpoll Warbler	<i>D. striata</i>	1.579	1.087	0.164	-0.061	0.515	0.908	-0.129	0.504	0.801
Black-and-white Warbler	<i>Mniotilta varia</i>	-0.035	1.333	0.980	0.233	0.622	0.712	-0.193	0.632	0.764
American Redstart	<i>Setophaga ruticilla</i>	-0.951	1.671	0.577	0.528	0.741	0.486	1.22	0.699	0.098
Ovenbird	<i>Seiurus aurocapilla</i>	-1.162	1.592	0.476	0.518	0.674	0.453	0.745	0.665	0.278
Northern Waterthrush	<i>S. noveboracensis</i>	-1.447	1.923	0.471	1.026	0.792	0.227	-0.619	0.788	0.453
Common Yellowthroat	<i>Geothlypis trichas</i>	-1.288	2.384	0.600	1.219	1.020	0.257	-0.836	0.960	0.402
Wilson's Warbler	<i>Wilsonia pusilla</i>	0.573	2.076	0.787	-1.648	0.756	0.047	0.703	1.001	0.494
Canada Warbler	<i>W. canadensis</i>	-3.296	1.703	0.068	-1.029	0.861	0.247	0.780	0.775	0.327
Lincoln's Sparrow	<i>Melospiza lincolnii</i>	-0.071	2.155	0.974	-0.502	0.636	0.445	0.591	0.808	0.479
White-throated Sparrow	<i>Zonotrichia albicollis</i>	3.072	3.080	0.330	-0.570	1.403	0.688	0.691	1.301	0.601
White-crowned Sparrow	<i>Z. leucophrys</i>	-3.173	1.952	0.124	-0.769	1.169	0.520	1.139	0.731	0.139
Rose-breasted Grosbeak	<i>Pheucticus ludovicianus</i>	0.509	1.194	0.676	0.463	0.569	0.428	0.377	0.502	0.465

trends in naturalists' data and banding data, what factors might contribute to the differences?

METHODS

Mt. Auburn Cemetery.—We analyzed the dates that migratory birds were detected by volunteers at the Mt. Auburn Cemetery in Cambridge, Massachusetts, a well-known site for observing migrating birds (Hill and Hagan 1991). The cemetery consists of 71 ha of well-maintained grounds with widely spaced trees and shrubs, much like a botanical garden. Many of the trees and shrubs are native to New England, but species from other northern temperate areas are also present. The cemetery is surrounded primarily by the urban landscape of metropolitan Boston.

Volunteers observed migratory birds present at the cemetery for ~3 h each morning, except for very rainy mornings, during each spring migration since 1980. They then submitted their observations to the regional journal *Bird Observer*, where they were published. The volunteers who submitted their observations were all skilled birders and were able to identify all birds by sight and most by song. Although it was impossible to quantify sampling effort, volunteers state that more people made observations in April and May, when attempting to see the first bird of each species to arrive, than at the end of the migration in June. Some volunteers continued to visit the cemetery and make observations throughout the summer, ensuring that they observed the entire spring migration.

We extracted first, peak, and last arrival dates of 30 species of migratory birds observed at the cemetery between 1980 and 2004. We considered the day on which the largest number of individuals of a particular species was observed in a given year to be the peak arrival date (corresponding to the mode of the arrival distribution). For each species, volunteers reported observations in at least 11 of the 25 years. Of the 30 species, none breeds at Mt. Auburn Cemetery. Although some of the species—for example, Golden-crowned Kinglet and White-throated Sparrow—winter in the area, which may bias the date of first observation, the peak arrival date should reflect birds migrating from outside the area.

Changes over time in temperature and migration times.—We obtained temperature data from the Blue Hill Meteorological Observatory in East Milton, Massachusetts, ~14 km southeast of Cambridge. Blue Hill is the longest-running weather station in the Cambridge area. Spring temperatures at Blue Hill are highly correlated with temperatures at weather stations south along the eastern coast of the United States to Wilmington, North Carolina ($P < 0.05$ for all correlations).

We obtained the winter North Atlantic Oscillation Index (NAOI) and the winter Southern Oscillation Index (SOI) from the National Center for Atmospheric Research (see Acknowledgments). These indices integrate many climate variables over large regional areas, including the migration routes of these bird species. Although neither index was correlated with March–April temperatures in Cambridge during our study period ($P > 0.88$ for both correlations), they are correlated with several relevant weather patterns. Positive NAOI values are correlated with anomalous southerly winds in the eastern United States (Hurrell 1995), and negative values are correlated with increased precipitation in the eastern United States (Mauget 2006). Positive SOI values are correlated with relatively warm temperatures during winter and spring in the southeastern

United States and with relatively cool temperatures in Central America, the southern Caribbean, and much of South America (Trenberth and Caron 2000). Positive SOI values are also correlated with relatively dry years in the southeastern United States and with relatively wet years in Central America, the southern Caribbean, and northern South America (Trenberth and Caron 2000). Several studies have suggested that climate indices can explain ecological phenomena better than local climate variables such as temperature (Stenseth et al. 2003, Hallett et al. 2004).

Before analysis, we converted arrival dates to days after the vernal equinox. This transformation avoided biases in Julian or calendar dates caused by changes in the timing of the vernal equinox (Sagarin 2001). We then used linear regression to estimate changes in first, peak, and last arrival dates over time for each species. Because spring temperature did not change over time during the period of observation at Mt. Auburn Cemetery, we did not expect migration times there to change over time.

Role of temperature and climate indices.—We used linear regression to determine the relationship between peak arrival dates and the SOI, NAOI, and mean March–April temperatures in the Cambridge area. In cases where species arrival dates were significantly related to multiple climate variables, we used multiple regression to determine the responses to each variable. We considered only peak arrival dates because they should be less susceptible than first and last arrivals to changes in population sizes or sampling effort, or to unusual meteorological events. We used March–April temperatures because these are the months immediately preceding and during spring migrations. We have previously found that temperatures in these months explain a significant portion of the variation in migration times (Ledneva et al. 2004). We also know that March and April temperatures are strongly correlated with the spring phenology of plants in eastern Massachusetts (Miller-Rushing et al. 2006, Miller-Rushing and Primack 2008), which, in turn, probably correlate with insect phenology (Root et al. 2003). Studies have also linked SOI and NAOI to bird migration times in several locations (Forchhammer et al. 2002, MacMynowski and Root 2007).

We did not use any study-wide corrections for statistical results, such as Bonferroni corrections, because they can be overly conservative (i.e., increase rates of type II error; Nakagawa 2004). The effects of climate on bird migration times are generally only weakly detectable, as measured by P values, if they are detectable at all (Lehikoinen et al. 2004). However, meta-analysis shows that there is, in fact, a general effect of climate on migration times (Root et al. 2003). Thus, corrections such as the Bonferroni could mask a relationship between migration times and climate variables. Here, we present our statistical results without correction and usually indicate the number of statistically significant results expected by chance alone (5% of the tests).

Role of migration cohort size.—We tested whether changes in migration cohort size (i.e., the number of birds migrating through an area in a given year) affected changes in first arrival dates as determined by the *Bird Observer* records. We use the term “migration cohort” to distinguish our subjects of observation from populations because the group of birds migrating through our observation area probably includes birds from many distinct breeding populations. For this test, we assumed that peak arrival dates were not affected by changes in migration cohort sizes. We expected that if a species' peak arrival dates were not changing and

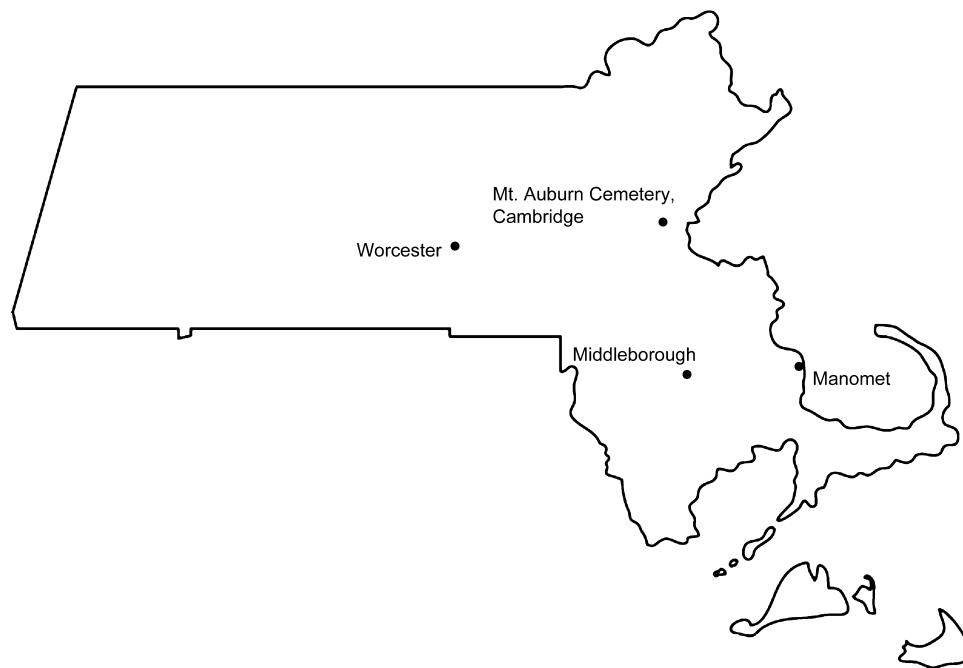


FIG. 1. Map of Massachusetts with locations of studies of changes in migration times.

its cohort size were declining over several years, first arrival dates would become later over time and last arrival dates would become earlier, simply as a function of the changes in migration cohort size. That is, as migration cohort sizes decline, the detection time-frame between the first and last arrivals will shrink. A similar effect has been demonstrated in previous studies (Tryjanowski and Sparks 2001, Tryjanowski et al. 2005, Miller-Rushing et al. 2008).

Thus, we tested whether first arrivals occurred later over time in relation to peak arrival dates for species with declining migration-cohort sizes. We also investigated whether last arrivals occurred earlier over time in relation to peak arrival dates for species with declining cohort sizes. We used a paired *t*-test to make these comparisons. For these tests, we considered only species with migration cohort sizes that declined significantly ($P < 0.05$) in eastern Massachusetts from 1980 to 2003, given that no species' population sizes increased significantly over the same period (Lloyd-Evans and Atwood 2004). We used changes in species' capture rates at the Manomet Center for Conservation Sciences (Lloyd-Evans and Atwood 2004), a bird-banding station 68 km southeast from Mt. Auburn Cemetery, to extrapolate changes in migration cohort sizes at the cemetery. These estimates of changes in migration cohort sizes were significantly correlated with regional changes in population sizes documented by the North American Breeding Bird Survey (Lloyd-Evans and Atwood 2004).

Comparison with banding results.—We compared first, peak (i.e., mode), and last arrival dates from *Bird Observer* data with first, peak, and last arrival dates observed at Manomet Center for Conservation Sciences, a bird-banding station that has been active since 1966 (Lloyd-Evans and Atwood 2004, Miller-Rushing et al. 2008). Specifically, we used yearly observations to calculate the correlation between arrivals from *Bird Observer* records and those from Manomet capture data for each species. This comparison

allowed us to test whether *Bird Observer* data deviated significantly from controlled observations at a nearby location. Manomet staff have used the same number of mist nets and the same sampling effort since 1970. The staff operated 50 mist nets daily on a 16-ha property of scrub and forest beginning in 1970, and we used their data from the period 1970–2002.

Both Mt. Auburn Cemetery and Manomet Center for Conservation Sciences are near the Atlantic Coast. Mt. Auburn Cemetery is located in Cambridge, Massachusetts ($42^{\circ}22'30''\text{N}$, $71^{\circ}06'20''\text{W}$), ~7.5 km from Boston Harbor, which opens to the Atlantic Ocean. Manomet Center for Conservation Sciences is located in Manomet, Massachusetts ($41^{\circ}55'07''\text{N}$, $70^{\circ}33'58''\text{W}$), 68 km southeast of Cambridge, on the coastline of the Atlantic Ocean (Fig. 1). Despite the proximity of both locations to the coast, the urban landscape that surrounds Mt. Auburn Cemetery causes the vegetation there to leaf out earlier each year than the vegetation at Manomet (Zhang et al. 2004).

As a point for comparison, we also tested how results from Manomet correlated with observations from two other bird-banding stations, Powdermill Nature Reserve in Rector, Pennsylvania (746 km west-southwest of Manomet), and Long Point Bird Observatory near Port Rowan, Ontario (786 km west of Manomet). Specifically, we compared (using correlation) the slopes of the regression of mean arrival date with spring temperature at each location. We obtained changes in median arrival dates in response to changes in spring temperatures at Powdermill and Long Point from Marra et al. (2005).

Comparison of results within Massachusetts.—We also compared rates of change in migration times from Mt. Auburn and Manomet with results from two previously published studies from Massachusetts (Butler 2003, Ledneva et al. 2004). Butler (2003) used bird-club records to determine rates of change in first arrival dates for species in Worcester, Massachusetts ($42^{\circ}15'45''\text{N}$,

71°48'08"W), 58 km west of Mt. Auburn and 110 km northwest of Manomet (Fig. 1). These club records consisted of daily observations made by an unknown number of volunteers in Worcester County from 1932 to 1993. Ledneva et al. (2004) used journal observations of a keen naturalist to calculate changes in first arrival dates of species in Middleborough, Massachusetts (41°53'35"N, 70°54'40"W), 56 km south of Mt. Auburn and 30 km west of Manomet (Fig. 1). Each day during the spring migration from 1970 to 2002, the naturalist recorded when she saw certain species of birds on her farm. By comparing the findings from these four collections of observations, we tested whether different methods of observation in nearby locations yielded similar rates of change in migration times.

RESULTS

Change in temperature over time.—Over the 25 years of observations at Mt. Auburn Cemetery (1980–2004), mean (\pm SE) March–April temperatures at Blue Hill Observatory did not change significantly (slope = $0.20 \pm 0.27^\circ\text{C decade}^{-1}$, $R^2 = 0.023$, $P = 0.46$; Fig. 2). Nor did temperatures at Blue Hill Observatory warm significantly over the periods of observation at Manomet or Middleborough (1970–2002; slope = $0.16 \pm 0.22^\circ\text{C decade}^{-1}$, $R^2 = 0.018$, $P = 0.45$). However, temperatures warmed 1.3°C during the time covered by the Worcester study (1932–1993), as determined by linear regression (slope = $0.21 \pm 0.09^\circ\text{C decade}^{-1}$, $R^2 = 0.081$, $P = 0.025$).

Role of temperature and climate indices.—Mean March–April temperatures explained a significant amount of the variation in peak arrival dates for four species—Red-eyed Vireo, Nashville Warbler, Black-throated Blue Warbler, and Palm Warbler—as determined by regression analysis (Table 1). These four species arrived earlier in warm springs than in cool springs. Black-throated Blue Warbler's peak arrival dates were significantly associated with both mean March–April temperatures and the SOI, as determined by multiple regression (temperature coefficient = -2.70 ± 1.04 days $^\circ\text{C}^{-1}$; SOI coefficient = -1.30 ± 0.55 days index unit $^{-1}$; $R^2 = 0.531$,

$P = 0.001$). One species, the Black-throated Green Warbler, showed a significant relationship between peak arrival dates and NAOI, arriving earlier in years with a negative index value ($P = 0.047$; Table 1). By chance, we would have expected one or two species (5%) to show a significant relationship with each of the climate variables.

When we considered all species together in a single regression, birds arrived, on average, 1.1 ± 0.5 days earlier for each 1°C increase in mean March–April temperatures ($R^2 = 0.01$, $P = 0.023$). In addition, mean March–April temperatures were related to the range between first and last arrival dates. Although there was no statistically significant relationship between temperatures and range for any individual species, when we considered all species together in a single regression, we found a statistically significant relationship between mean March–April temperatures and the range between first and last arrival dates (slope = -1.40 days $^\circ\text{C}^{-1}$; $R^2 = 0.02$, $P = 0.002$). The range was smaller in warmer years.

Role of migration cohort size.—Migration cohort sizes declined significantly for 16 of the 30 species commonly observed at Mt. Auburn Cemetery, according to banding data at the Manomet Center for Conservation Sciences (Lloyd-Evans and Atwood 2004). None of the species experienced an increase in cohort size. For those 16 species with declining migration cohort sizes, first arrival dates occurred later over time in relation to peak arrival dates ($t = 3.25$, $P = 0.003$). In addition, last arrival dates occurred earlier over time relative to peak arrival dates ($t = 4.62$, $P < 0.001$). Averaging the changes in migration times for these migration cohorts, first birds arrived approximately the same day during the study period (average slope = -0.03 ± 0.39 days decade $^{-1}$); peak arrival dates occurred 1.40 ± 0.55 days earlier each decade; and last birds arrived 4.00 ± 0.66 days earlier each decade. Critically, though, nearly all species follow this pattern, regardless of whether their population sizes are changing. Of the 30 species we examined at Mt. Auburn Cemetery, 25 had first arrival dates that occurred later over time in relation to peak arrival dates, and 28 had last arrival dates that occurred earlier over time in relation to peak arrival dates.

Comparison with banding results.—For most species, arrival dates at Mt. Auburn were not correlated with arrival dates at Manomet Center for Conservation Sciences (Table 2). First arrival dates at the two sites were significantly correlated for just 2 of 17 species, Yellow Warbler and Ovenbird. Peak arrival dates were significantly correlated for just two species, Least Flycatcher and Magnolia Warbler. Last arrival dates were correlated for only one species, Swainson's Thrush. In addition, for most species, first, peak, and last arrival dates occurred significantly earlier at Mt. Auburn than at Manomet (Table 2).

We also compared how the variation in mean arrival dates related to spring temperature at three widely separated banding stations—Manomet Center for Conservation Sciences in Massachusetts, Powdermill Nature Reserve in Pennsylvania, and Long Point Bird Observatory in Ontario (Marra et al. 2005). The relationships between arrival date and temperature were different at each location. None of the station's results were correlated with one another ($P > 0.30$ for all correlations, with 16 species observed at all three stations). The differences among the stations did not appear to be systematic. That is, species' arrival dates were not more strongly related to temperature at one location than at another, as determined by paired t -tests ($P > 0.168$ for all comparisons among the three locations).

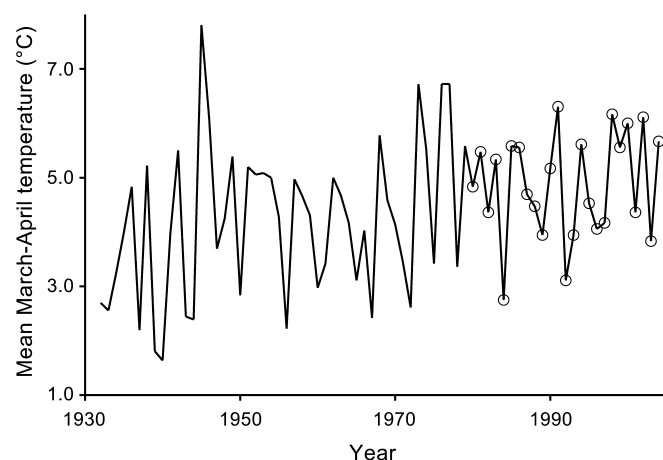


FIG. 2. Mean March–April temperatures as observed at Blue Hill Observatory in East Milton from 1932 to 2004, the period for which there are observations of bird migrations in eastern Massachusetts. The years 1980–2004 are highlighted with open circles. These are the years for which there are observations of bird migration times at Mt. Auburn Cemetery.

TABLE 2. Correlation (r) between arrival dates at Mt. Auburn Cemetery and at Manomet Center for Conservation Sciences in years in which observations were made at both locations (n = number of years included in correlation). Statistically significant ($P < 0.05$) results are given in bold. "Earlier observation" indicates the site where the arrival date tended to be observed first for each species, as determined by two-tailed paired t -tests (Mt. A = Mt. Auburn, Man = Manomet, and ND = no difference [if $P > 0.05$]).

Common name	First arrival				Peak arrival				Last arrival			
	r	P	Earlier observation	n	r	P	Earlier observation	n	r	P	Earlier observation	n
Least Flycatcher	0.308	0.214	ND	18	0.808	0.008	ND	9	0.285	0.268	Mt. A	17
Red-eyed Vireo	-0.103	0.693	Mt. A	17	0.374	0.208	Mt. A	13	0.162	0.535	Mt. A	17
Veery	-0.340	0.182	Mt. A	17	0.303	0.314	Mt. A	13	-0.055	0.839	Mt. A	16
Swainson's Thrush	0.375	0.085	Mt. A	22	-0.110	0.617	Mt. A	23	0.638	0.001	Mt. A	22
Hermit Thrush	0.159	0.503	Mt. A	20	0.034	0.889	ND	19	0.138	0.563	Mt. A	20
Northern Parula	0.190	0.397	Mt. A	22	-0.334	0.243	Mt. A	14	0.214	0.338	ND	22
Yellow Warbler	-0.565	0.044	Mt. A	13	-0.422	0.225	ND	10	-0.286	0.368	Mt. A	12
Magnolia Warbler	0.184	0.412	Mt. A	22	0.512	0.018	Mt. A	21	0.344	0.126	Mt. A	21
Yellow-rumped Warbler	-0.217	0.331	Mt. A	22	0.373	0.140	ND	17	0.214	0.338	Man	22
Blackpoll Warbler	0.009	0.968	Mt. A	21	-0.061	0.815	ND	17	0.083	0.722	Mt. A	21
Black-and-white Warbler	0.116	0.606	Mt. A	22	-0.231	0.341	Mt. A	19	0.289	0.192	Mt. A	22
American Redstart	-0.032	0.890	Mt. A	21	0.019	0.939	Mt. A	18	0.277	0.237	Mt. A	20
Ovenbird	0.624	0.004	Mt. A	19	0.238	0.326	Mt. A	19	0.418	0.085	Mt. A	18
Northern Waterthrush	-0.222	0.445	ND	14	0.147	0.667	Mt. A	11	-0.175	0.549	Mt. A	14
Common Yellowthroat	0.340	0.280	ND	12	0.497	0.084	Mt. A	13	0.423	0.171	Mt. A	12
Wilson's Warbler	-0.191	0.407	Mt. A	21	0.118	0.675	Mt. A	15	0.007	0.975	Mt. A	21
Canada Warbler	-0.004	0.986	Mt. A	20	-0.321	0.181	Mt. A	19	-0.085	0.723	Mt. A	20

Comparison of results within Massachusetts.—We compared changes in first arrival dates at Mt. Auburn Cemetery (1980–2004), Manomet Center for Conservation Sciences (1970–2002; Miller-Rushing et al. 2008), Middleborough (1970–2002; Ledneva et al. 2004), and Worcester County (1932–1993; Butler 2003), all located in Massachusetts (Fig. 1). Results of the studies revealed different rates of change in migration times for the same species (Tables 3 and 4). In fact, of 17 species observed at both Manomet and Mt. Auburn, only seven had first arrival dates that changed in the same direction at both sites, no different than would be expected by chance. Of the 17 species observed at both Manomet and Worcester County, only seven had first arrival dates that changed in the same direction. Finally, of the four species observed at both Manomet and Middleborough, only two had first arrival dates that changed in the same direction. Thus, no significant relationship

existed between what was observed at any two sites for the same species. It is important to note that the periods of observation differ between the study sites, though there was significant overlap.

DISCUSSION

Do data gathered by naturalists indicate that birds are arriving earlier in warmer springs than in cooler springs? In our case, volunteers' observations of bird arrival dates published in *Bird Observer* show that species arrive earlier at Mt. Auburn Cemetery in warmer springs (Table 1). This finding supports the conclusions of many other studies that suggest that many birds are migrating earlier because of warming temperatures (e.g., Butler 2003, Ledneva et al. 2004, Sparks et al. 2005; review in Lehtikoinen et al. 2004).

TABLE 3. Descriptions of sampling methods and comparisons among investigations of bird migration times. For each pair of locations, we tested the correlation in change in arrival date over time (slope of the regression of arrival date with years) for 17 species, except Middleborough, where correlations included only four species. See Table 4 for regression results from each location. Change in temperature was calculated by linear regression using mean March–April temperatures at Blue Hill Observatory. "FAD" indicates observations of first arrival dates, and "PAD" indicates observations of peak arrival dates.

Location	Period	Change in temperature (°C decade ⁻¹ ± SE)	Sampling area (ha)	Number of observers	Observer effort (h day ⁻¹)	Correlation of changes in migration times over time (r , with P in parentheses)			
						Mt. Auburn (FAD)	Mt. Auburn (PAD)	Middleborough (FAD)	Worcester (FAD)
Manomet ^a	1970–2002	0.16 ± 0.22	0.16*	45–50*	12	0.141 ± 0.59	-0.223 ± 0.39	0.169 ± 0.83	-0.342 ± 0.18
Mt. Auburn	1980–2004	0.20 ± 0.27	71	>3	3			0.133 ± 0.87)	-0.211 ± 0.41
Middleborough	1970–2002	0.16 ± 0.22	40	1	3				0.708 ± 0.29
Worcester	1932–1993	0.21 ± 0.09	39,2000	Unknown	Unknown				

^aObservations at Manomet were made using 45–50 standardized mist nets, instead of observers making observations by sight or song, as was the case at all other locations.

TABLE 4. Changes in arrival dates over time as measured by regression at different sites in Massachusetts. Results include those from a bird-banding station at Manomet (Miller-Rushing et al. 2008), a bird journal at Mt. Auburn (present study), a naturalist's journal at Middleborough (Ledneva et al. 2004), and bird-club records at Worcester County (Butler 2003). Regression results (slopes) are provided as days year⁻¹. Negative slopes indicate trends toward earlier arrival over time. Statistically significant ($P < 0.05$) results are given in bold.

Species	First arrival				Mean-peak arrival	
	Manomet	Mt. Auburn	Middleborough	Worcester	Manomet	Mt. Auburn
Least Flycatcher	-0.132	0.060		0.004	-0.130	-0.073
Red-eyed Vireo	-0.063	0.267		0.070	-0.070	0.241
Veery	0.010	-0.037		-0.048	-0.018	-0.389
Swainson's Thrush	-0.026	0.168		-0.093	-0.028	-0.227
Hermit Thrush	0.065	0.217	-0.435	0.015	-0.044	0.151
Northern Parula	-0.017	0.045		0.088	-0.184	-0.110
Yellow Warbler	0.019	-0.063	-0.520	-0.149	0.015	-0.207
Magnolia Warbler	0.085	0.376		-0.090	-0.107	0.155
Yellow-rumped Warbler	0.152	0.248		-0.877	-0.063	0.143
Blackpoll Warbler	0.201	0.267		0.020	-0.005	0.132
Black-and-white Warbler	0.088	0.175	0.076	0.058	-0.081	0.262
American Redstart	0.087	-0.244		-0.024	-0.071	-0.203
Ovenbird	-0.043	-0.152	-0.148	-0.037	-0.014	-0.175
Northern Waterthrush	-0.057	0.482		-0.161	-0.075	0.232
Common Yellowthroat	0.063	-0.014		-0.052	-0.085	-0.477
Wilson's Warbler	0.030	-0.070		-0.041	-0.097	-0.123
Canada Warbler	-0.056	-0.033		-0.012	0.078	-0.237

Intriguingly, three of the four species with peak arrival dates significantly related to March–April temperatures (Table 1) are medium- to long-distance migrants. Red-eyed Vireo winters in South America, and Nashville Warbler and Black-throated Blue Warbler both winter in Central America and the Caribbean. Previous studies have shown that the onset of migration for long-distance migrants is set by endogenous circannual rhythms (Hagan et al. 1991, Gwinner 1996). Thus, our finding suggests that these long-distance migratory birds may adjust the rate of their migrations *en route* according to temperature or a correlate of temperature such as food availability (Marra et al. 2005).

Are trends in bird migration times shown by naturalists' data consistent with those found at bird-banding stations? Surprisingly, patterns of migration dates were very different between Mt. Auburn Cemetery (volunteer naturalists) and Manomet Center for Conservation Sciences (bird-banding station). Unlike first and last arrival dates, which we expected to differ because of methodological differences, we expected that changes in peak arrival dates would be similar at the two locations. However, peak arrival dates were not correlated at the two locations (Table 2). In addition, our comparison of four studies in Massachusetts showed great variation in rates of change in migration times among the locations.

If differences exist among trends in data collected by volunteer naturalists and bird banding stations, what factors might contribute to the differences? First, changes in migration cohort size could influence first arrival dates (Sparks et al. 2001, Tryjanowski and Sparks 2001, Tryjanowski et al. 2005, Miller-Rushing et al. 2008). By extension, changes in sampling effort could probably also influence first arrival dates. It is likely that cohort sizes and sampling effort changed differently at each site we examined. If sampling effort increased over time in location A but remained steady in location B, we would expect to see a faster trend toward earlier arrivals in location A than in location B simply as a result of

increasing sampling effort. Changes in sampling effort and population sizes could have masked similarities in migration patterns across sites by adding a high magnitude of variability to the observations shown in Tables 3 and 4.

When we looked for an effect of migration cohort size on migration times at Mt. Auburn Cemetery, we found that the duration between first and last arrivals was declining for most species, regardless of whether migration cohort sizes were declining. Thus, a factor other than declines in migration cohort size was probably responsible for the decline in duration. Overall, the duration between the first and last arrivals was shorter in warmer springs. It is possible that birds may have spent less time at Mt. Auburn Cemetery during warm springs—food may have been particularly abundant in those springs because of earlier leaf-out and insect emergence (Root et al. 2003, Parmesan 2007). A shorter stay would have made it more difficult for volunteers to observe the first and last birds.

A second set of factors that could account for differences among the Massachusetts migration studies are the counting methods and the sizes of the areas observed. The naturalists' observations included birds that were identified by song, whereas the bird-banding data included only birds that were captured in mist nets. The size of the area observed also varied significantly between studies. At Manomet, observations were made in mist nets that covered 1,560 m², or 0.156 ha. The observations in Middleborough (Ledneva et al. 2004) and Mt. Auburn (present study) covered areas of 40 and 71 ha, respectively. The observations at Worcester (Butler 2003) covered an entire county, a far larger sample area. The larger sampling areas and ability to observe birds by song made it relatively easy for the naturalists to observe unusually early-arriving individuals (i.e., outliers). In addition, urbanization may have funneled early migrants to the Mt. Auburn site, increasing the occurrence of unusually early birds there. At the bird-banding site in Manomet, however, it is probable that the first several migrants,

including those that arrived unusually early, were not counted because they did not fly into the nets (Pagen et al. 2002).

Third, the different periods of study may have contributed to the differences in rates of change in migration times (Table 3). Variation in spring temperatures in eastern Massachusetts has not been linear over time but, rather, has been quite variable (Fig. 2). Because temperatures changed differently over different periods, we would expect bird migration times to change differently over each period of study.

Finally, the differences may, in fact, reflect real differences in migratory patterns and site conditions among the locations. The different results among the three bird-banding stations suggest that different migratory cohorts within a species can respond very differently to variation in spring temperature. The banding stations were separated by hundreds of kilometers, though, whereas the volunteer observations in Massachusetts (Mt. Auburn Cemetery, Middleborough, and Worcester) were near the Manomet banding station. Even within eastern Massachusetts, however, there may have been separation among the migratory cohorts. For example, birds arrived significantly earlier at Mt. Auburn than at Manomet (Table 2). The earlier arrival at Mt. Auburn is correlated with the pattern of leaf-out on the trees and, thus, food availability; leaves emerge earlier at Mt. Auburn than they do at Manomet (Zhang et al. 2004). When the first birds arrive at Mt. Auburn, leaves are not yet out at Manomet. Thus, an early-arriving cohort may stop at Mt. Auburn, whereas a later-arriving cohort may stop at Manomet. It is possible that these cohorts behave differently from one another during migration in any given year, possibly because they are arriving from different wintering grounds (Studds and Marra 2007) or because they represent different breeding populations (Sparks et al. 2005).

Clearly, it is critical to consider the method of observation when comparing rates of change in migration times across geographic space. Several factors, including migration cohort size, sampling effort, sampling area, and the demography of the migration cohort can affect the observed migration patterns. In particular, to address questions regarding the relative rates of change in migration times, it is important to examine changes in peak as well as first arrival dates. Peak arrival dates are generally not influenced by migration cohort size or sampling effort, which could bias data on first arrivals (Sparks et al. 2001, Miller-Rushing et al. 2008). As we have seen here, however, peak arrival dates may vary between sites even if they are close to each other.

Importantly, each study we examined, no matter the method of observation, showed that many species of migratory birds are arriving earlier in warmer springs. Thus, although it is difficult to compare results collected with different methods, the studies show a broad pattern of earlier arrival consistent with observations from across much of North America and Europe (Lehikoinen et al. 2004). We believe that all the methods of observations of migration times examined here are important in documenting changes in migration times in a changing climate.

ACKNOWLEDGMENTS

We thank J. Jones, J. M. Reed, M. Rines, F. Wasserman, and two anonymous reviewers for providing valuable comments on this manuscript. The National Science Foundation, Nuttall Ornithological

Club, and Boston University provided funding for this work. The Southern Oscillation Index from the National Center for Atmospheric Research is available at www.cgd.ucar.edu/cas/catalog/limind/soi.html.

LITERATURE CITED

- BOTH, C., S. BOUWHUIS, C. M. LESSELLS, AND M. E. VISSER. 2006. Climate change and population declines in a long-distance migratory bird. *Nature* 441:81–83.
- BRADLEY, N. L., A. C. LEOPOLD, J. ROSS, AND W. HUFFAKER. 1999. Phenological changes reflect climate change in Wisconsin. *Proceedings of the National Academy of Sciences USA* 96:9701–9704.
- BUTLER, C. J. 2003. The disproportionate effect of global warming on the arrival dates of short-distance migratory birds in North America. *Ibis* 145:484–495.
- COTTON, P. A. 2003. Avian migration phenology and global climate change. *Proceedings of the National Academy of Sciences USA* 100:12219–12222.
- FORCHHAMMER, M. C., E. POST, AND N. C. STENSETH. 2002. North Atlantic Oscillation timing of long- and short-distance migration. *Journal of Animal Ecology* 71:1002–1014.
- GWINNER, E. 1996. Circannual clocks in avian reproduction and migration. *Ibis* 138:47–63.
- HAGAN, J. M., T. L. LLOYD-EVANS, AND J. L. ATWOOD. 1991. The relationship between latitude and the timing of spring migration of North American landbirds. *Ornis Scandinavica* 22:129–136.
- HALLETT, T. B., T. COULSON, J. G. PILKINGTON, T. H. CLUTTON-BROCK, J. M. PEMBERTON, AND B. T. GRENFELL. 2004. Why large-scale climate indices seem to predict ecological processes better than local weather. *Nature* 430:71–75.
- HILL, N. P., AND J. M. HAGAN III. 1991. Population trends of some northeastern North American landbirds: A half-century of data. *Wilson Bulletin* 103:165–182.
- HÜPPOP, O., AND K. HÜPPOP. 2003. North Atlantic Oscillation and timing of spring migration in birds. *Proceedings of the Royal Society of London, Series B* 270:233–240.
- HURRELL, J. W. 1995. Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. *Science* 269:676–679.
- LEDNEVA, A., A. J. MILLER-RUSHING, R. B. PRIMACK, AND C. IMBRES. 2004. Climate change as reflected in a naturalist's diary, Middleborough, Massachusetts. *Wilson Bulletin* 116:224–231.
- LEHIKONEN, E., T. H. SPARKS, AND M. ZALAKEVICIUS. 2004. Arrival and departure dates. Pages 1–31 in *Birds and Climate Change* (A. P. Møller, W. Fiedler, and P. Berthold, Eds.). *Advances in Ecological Research*, vol. 35.
- LLOYD-EVANS, T. L., AND J. L. ATWOOD. 2004. 32 years of changes in passerine numbers during spring and fall migrations in coastal Massachusetts. *Wilson Bulletin* 116:1–16.
- MACMYNOWSKI, D. P., AND T. L. ROOT. 2007. Climate and the complexity of migratory phenology: Sexes, migratory distance, and arrival distributions. *International Journal of Biometeorology* 51:361–373.
- MARRA, P. P., C. M. FRANCIS, R. S. MULVIHILL, AND F. R. MOORE. 2005. The influence of climate on the timing and rate of spring bird migration. *Oecologia* 142:307–315.

- MAUGET, S. A. 2006. Intra- to multi-decadal terrestrial precipitation regimes at the end of the 20th century. *Climatic Change* 78:317–340.
- MILLER-RUSHING, A. J., T. L. LLOYD-EVANS, R. B. PRIMACK, AND P. SATZINGER. 2008. Bird migration times, climate change, and changing population sizes. *Global Change Biology*: doi:10.1111/j.1365-2486.2008.01619.x
- MILLER-RUSHING, A. J., AND R. B. PRIMACK. 2008. Global warming and flowering times in Thoreau's Concord: A community perspective. *Ecology* 89:332–341.
- MILLER-RUSHING, A. J., R. B. PRIMACK, D. PRIMACK, AND S. MUKUNDA. 2006. Photographs and herbarium specimens as tools to document phenological changes in response to global warming. *American Journal of Botany* 93:1667–1674.
- MILLS, A. M. 2005. Changes in the timing of spring and autumn migration in North American migrant passerines during a period of global warming. *Ibis* 147:259–269.
- NAKAGAWA, S. 2004. A farewell to Bonferroni: The problems of low statistical power and publication bias. *Behavioral Ecology* 15:1044–1045.
- PAGEN, R. W., F. R. THOMPSON III, AND D. E. BURHANS. 2002. A comparison of point-count and mist-net detections of songbirds by habitat and time-of-season. *Journal of Field Ornithology* 73:53–59.
- PARMESAN, C. 2007. Influences of species, latitudes and methodologies on estimates of phenological response to global warming. *Global Change Biology* 13:1860–1872.
- ROOT, T. L., J. T. PRICE, K. R. HALL, S. H. SCHNEIDER, C. ROSENZWEIG, AND J. A. POUNDS. 2003. Fingerprints of global warming on wild animals and plants. *Nature* 421:57–60.
- SAGARIN, R. 2001. False estimates of the advance of spring. *Nature* 414:600.
- SPARKS, T. H., F. BAIRLEIN, J. G. BOJARINOVA, O. HÜPPOP, E. A. LEHIKONEN, K. RAINIO, L. V. SOKOLOV, AND D. WALKER. 2005. Examining the total arrival distribution of migratory birds. *Global Change Biology* 11:22–30.
- SPARKS, T. H., AND P. D. CAREY. 1995. The responses of species to climate over two centuries: An analysis of the Marsham phenological record, 1736–1947. *Journal of Ecology* 83:321–329.
- SPARKS, T. H., D. R. ROBERTS, AND H. Q. P. CRICK. 2001. What is the value of first arrival dates of spring migrants in phenology? *Avian Ecology and Behaviour* 7:75–85.
- STENSETH, N. C., G. OTTERSEN, J. W. HURRELL, A. MYSTERUD, M. LIMA, K.-S. CHAN, N. G. YOCOZ, AND B. ÅDLANDSVIK. 2003. Studying climate effects on ecology through the use of climate indices: The North Atlantic Oscillation, El Niño Southern Oscillation and beyond. *Proceedings of the Royal Society of London, Series B* 270:2087–2096.
- STUDDS, C. E., AND P. P. MARRA. 2007. Linking fluctuations in rainfall to nonbreeding season performance in a long-distance migratory bird, *Setophaga ruticilla*. *Climate Research* 35:115–122.
- TRENBERTH, K. E., AND J. M. CARON. 2000. The Southern Oscillation revisited: Sea level pressures, surface temperatures, and precipitation. *Journal of Climate* 13:4358–4365.
- TRYJANOWSKI, P., S. KUŹNIAK, AND T. H. SPARKS. 2005. What affects the magnitude of change in first arrival dates of migrant birds? *Journal of Ornithology* 146:200–205.
- TRYJANOWSKI, P., AND T. H. SPARKS. 2001. Is the detection of the first arrival date of migrating birds influenced by population size? A case study of the Red-backed Shrike *Lanius collurio*. *International Journal of Biometeorology* 45:217–219.
- ZHANG, X., M. A. FRIEDL, C. B. SCHAAF, A. H. STRAHLER, AND A. SCHNEIDER. 2004. The footprint of urban climates on vegetation phenology. *Geophysical Research Letters* 31:L12209, doi:10.1029/2004GL020137.

Associate Editor: J. Jones