

SPRING ARRIVAL DATES OF MIGRATORY BREEDING BIRDS IN MAINE: SENSITIVITY TO CLIMATE CHANGE

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ABSTRACT.—I analyzed the relationship between spring temperature and arrival date for 105 species using over 32,000 arrival records of migratory breeding birds in Maine collected by a volunteer network between 1994 and 2005. I used quantile regression analysis, testing three different quantiles (0.1, 0.25, 0.5). Only 69 of 315 regressions yielded a significant negative relationship. Five species showed significant regressions for all three quantiles and 15 showed significant regressions for two quantiles. Quantile regressions of arrival date with a hemispheric measure of climate variability, the North Atlantic Oscillation index, produced only 63 statistically significant regressions for the three quantiles. Seven species and 12 species had significant regressions with three and two quantiles, respectively. Overall, 60 species had at least one significant relationship with a climatic variable. These results indicate the arrival dates of most migratory breeding birds in Maine show a modest relationship with the significant temperature variability seen over the 12-year study period. The data suggest the response of migratory birds in Maine to global warming impacts will be a gradual process. *Received 10 April 2006. Accepted 31 January 2007.*

The monotonic rise of atmospheric carbon dioxide over the past 150 years is certain evidence of global warming (Root et al. 2005, Smith et al. 2005). Melting of the polar ice caps and increased mean annual temperatures across the globe are but two manifestations of recent climate change attributed to the unprecedented rate of increase of greenhouse gases. Climate has a fundamental effect on the distribution and abundance of virtually all species. The northern extension of species such as American Robin (*Turdus migratorius*) in northern Alaska (Sallabanks and James 1999) or lepidopterans in Great Britain (Hill et al. 1999) has been linked to environmental warming. Species can adapt evolutionarily to global climate change, but the pace at which climate change appears to be occurring greatly concerns conservation biologists and resource managers.

Ecologists are concerned with the effects of global climate change on the population dynamics of species, but the effort and time required to assess those effects present daunting challenges (Crick 2004). To date, most of the impacts of global warming on organisms have been based on easier-to-measure phenological effects such as first flowering date or arrival dates for migratory animals (Sparks et al. 2001, Sparks and Menzel 2002).

Modeling is another approach to assess the

impacts of global climate change. Modeling effects of climate change on vascular plants is reasonably straightforward because local temperature and precipitation serve as the main parameters in the models (e.g., Iversen et al. 1999). For example, models of the distribution of tree species in northeastern North America, assuming that carbon dioxide levels will continue to rise at current rates, indicate dramatic changes in distribution over the next 100 years (Iversen et al. 1999). Balsam fir (*Abies balsamea*), a dominant tree in northern New England is predicted to be extirpated by 2100. Changes in distribution and abundance of trees will have strong cascading effects on the animals that depend on particular tree species (e.g., Matthews et al. 2004).

Modeling the impact of global climate change for species that are migratory is much more complex (Cotton 2003, Sæther et al. 2004). Changes in temperature in wintering areas may impel earlier departures to northern breeding sites (Anthes 2004, Saino et al. 2004, Gordo et al. 2005). Temperature along the migratory route may influence timing of the continuation of migration. Finally, temperatures in breeding areas may affect the optimal time for nesting and reproductive success. Although migratory birds will be strongly affected by temperatures in their breeding areas, birds cannot predict the particular climate from afar (Lehikoinen et al. 2004). The appropriate temperature data to test as determinants of phenological events are not clear.

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Recent research has suggested that broad-scale climatic approaches to understanding the phenology of migration can be more informative than research based on local climate. A number of studies in western Europe and eastern North America have demonstrated that intensity of the North Atlantic Oscillation (NAO) strongly influences avian phenological events in Europe and North America (Huppopp and Huppopp 2003, Hubálek 2004, Vähätalo et al. 2004, Marra et al. 2005). The NAO is measured as the difference in pressure between the subtropical high centered over Portugal and the subarctic low centered over Iceland. Strong differences in pressure produce wet and warm winters in Europe and cold, dry winters in Canada and the northeastern United States. Reduced differences in pressure lead to colder winters in northern Europe and warmer, snowier winters in northeastern North America.

Birds are often touted as sensitive sentinels of environmental change. The detection of effects of global warming by measuring the demography of woody plants will be straightforward but may require decades to see definitive evidence. As mobile organisms with high metabolic demands, birds should be capable of responding more quickly to the direct effects of global warming on their own physiology and to the indirect effects of resource alteration (seed abundance, insect herbivore abundance). In this paper, I ask if migratory breeding birds in Maine respond in spring arrival dates to yearly differences in temperature using data from 1994 through 2005. I also examine the power of the NAO in affecting the arrival date of migratory breeding birds. My goal was not to seek evidence of earlier arrival dates over this brief 12-year period but rather to ask how sensitive arrival date is to temperature that varied significantly among the 12 years of the study.

METHODS

Data on arrival dates of migratory breeding birds in Maine come from a citizen-science project I organized in spring 1994 to improve our understanding of spring bird migration in Maine. This on-going project has now yielded data on arrival dates for the past 12 springs. The framework for data collection is the map of Maine biophysical regions developed by

McMahon (1990) who divided the state into 15 biophysical regions based on climatic and vegetation data (Fig. 1). The south coastal region (Region 12) has the mildest climate with a frost-free period of 160 days compared to the most severe climate in the Boundary Plateau (Region 1) with a frost-free period of only 80 days (McMahon 1990).

Volunteer observers are sent a standardized data sheet and asked to report the first date of each migratory species they observe in their biophysical region. Some active birders regularly report arrival dates of a given species from several biophysical regions. The data sheet lists 119 species, all of which nest in at least one biophysical region in the state. Over 200 birders have contributed data to the project and the data base currently has over 32,000 arrival records. I report data on 105 species in this paper; data on the remaining 14 species were too sparse for meaningful statistical analysis.

The arrival dates of each record were converted to Julian day. For example, 31 March is the 100th day of the year (101st during leap years). Data for biophysical region of the observation, year, and Julian date were entered into a Stata data set for analysis.

Wilson et al. (1997) found that arrival dates of the vast majority of Maine migratory breeding birds for 1994–1997 did not vary across biophysical regions. The few differences that emerged were between the six northernmost zones and some southern zones. I excluded data from the six most northern zones (zones 1–6). Therefore, the data used for this paper were for only biophysical regions 7–15. Observations reflect the distribution of the human population in the state. The relatively populous regions 10, 12, and 13 accounted for 69.6% of the observations.

Both local temperature and hemispheric temperature data were used in the analysis. Data from the National Climatic Data Center (NCDC) were used as measures of local springtime temperatures. Rather than use daily or weekly temperature records, I chose to use monthly data as reasonable measurements of deviations from the average temperature (Table 1). I chose 11 stations across the study area that had complete data for the 12-year period. These stations were Farmington and Dover-Foxcroft in Region 7, Augusta, Lew-

Biophysical Regions

1. Boundary Plateau
2. Saint John Uplands
3. Aroostook Hills
4. Aroostook Lowlands
5. Western Mountains
6. Central Mountains
7. Western Foothills
8. Eastern Lowlands
9. Southwest Interior
10. Central Interior
11. Eastern Interior
12. South Coastal Region
13. Midcoast Region
14. Penobscot Bay Region
15. East Coastal Region

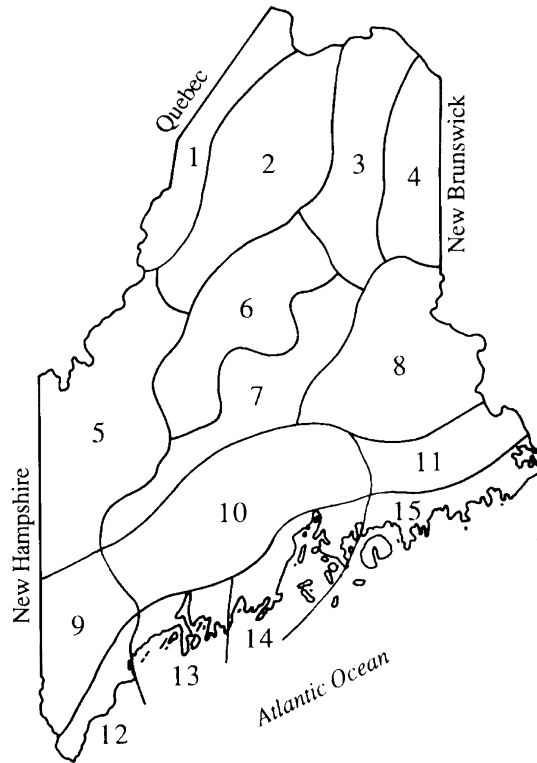


FIG. 1. Biophysical regions of Maine based on climatic and vegetative data (after McMahon 1990).

TABLE 1. Deviations from annual monthly temperature in °C of selected southern and central Maine weather stations as well as the North Atlantic Oscillation index, measured as the difference between the Icelandic subarctic low and the southwestern Europe subtropical high from December through March, 1994–2005.

Year	Mar	Apr	May	NAO Index
1994	-1.1	0.1	-0.7	3.03
1995	0.7	-1.3	-0.5	3.96
1996	-1.3	-0.1	-1.0	-3.78
1997	-1.8	-1.1	-1.9	-0.20
1998	1.4	1.2	2.5	0.72
1999	1.7	1.2	1.8	1.70
2000	2.7	0.1	-0.7	2.80
2001	-1.4	-0.3	1.4	-1.89
2002	0.3	0.5	-1.1	0.76
2003	-1.3	-1.3	-1.0	0.20
2004	0.8	0.3	0.3	-0.07
2005	-1.7	1.0	-2.6	0.12

iston, Madison, Orono, and Waterville in Region 10, Sanford in Region 12, Portland in Region 13, Belfast in Region 14, and Eastport in Region 15. Deviations from the monthly mean for each station were averaged for each year. Deviation data for combined March and April as well as April and May were prepared by averaging the means for each month.

I examined the relationship between Maine spring temperatures and temperatures in other states in the northeast and mid-Atlantic region by obtaining NCDC data on monthly deviation from the mean temperature for New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Delaware, and Maryland. The NCDC partitions most states into several divisions, each of which was considered separately. I used Pearson product-moment correlations to assess the relationship between the Maine temperature over the 12-year period

with each division of the 10 other states for March, April, and May. I used the North Atlantic Oscillation winter index (Dec through Mar) as a measure of hemispheric weather. Values were obtained at: <http://www.cgd.ucar.edu/cas/jhurrell/nao.stat.winter.html>.

I performed quantile regression analysis (Koenker and Hallock 2001, Cade and Noon 2003) using Stata (Macintosh) to examine if arrival dates were earlier in warmer springs for each of the 105 species of birds. This technique has an advantage over least-squares regression because quantile regression can accommodate unequal variation in the distribution of data. If such variation exists, a single rate of change (measured by the slope) will be misleading because portions of the data may produce different slopes. It is possible, for instance, that the relationship between the earliest arrivals and temperature deviation may be different than the relationship between median arrivals and temperature deviation. *A priori*, I expected the earliest arrival dates or the median arrival dates might be more sensitive to temperature deviations or to the NAO index than later arrivals. Accordingly, I tested the 0.1, 0.25 and 0.5 (median) quantiles. I do not report the data for the 0.75 and 0.9 quantiles which were heavily biased toward later first arrivals. Each quantile regression analysis uses all of the data in the data set.

The temperature data used reflected time of arrival of a particular species (Table 2). For instance, March temperature departures were used for the Red-winged Blackbird (scientific names in Table 2) analysis because most arrival dates were in March. The March–April combined temperature data were used for species such as American Woodcock for which arrival records spanned the latter half of March and the first half of April.

I performed analogous quantile regression analyses for the North Atlantic Oscillation data, regressing the NAO index against the same three quantiles of arrival for each of the 105 species in this study. When performing a large number of regressions, rejecting the null hypothesis of no relationship for each individual regression analysis at the $P = 0.05$ level may result in an erroneously high number of significant relationships (Davis 1989, Töttrup et al. 2006). I used the Bonferroni sequential

procedure to produce a table-wide significance level of $P = 0.05$ to avoid this bias.

RESULTS

Temperatures for March, April, and May of each year of the study varied (Table 1). Examination of the deviation from the monthly mean for any given year indicates that some springs were consistently warmer (e.g., 1998) or cooler (e.g., 1997) for all 3 months. Some years had a mixed pattern with some months cooler than normal and others warmer than normal (e.g., 1995 and 2002). The magnitude of the departures from the mean indicate considerable variation among years (e.g., March 1997 vs. March 2000). The annual NAO Index for the 12 years of the study also varied among years (Table 1). Linear regressions of NAO against temperature deviation were not significant for any of the 3 months.

Correlation analysis of the Maine monthly temperature deviation data with corresponding data from other northeastern and mid-Atlantic States revealed a strong regional climatic signature. Deviations from the monthly mean for all New England states and New York were strongly correlated ($P < 0.01$) in every case for the March, April, and May data. About half of the correlations for Pennsylvania and New Jersey were statistically significant with even less concordance with temperature deviations for Delaware and Maryland. The data clearly indicate that New York and the six New England states have highly similar spring weather from year-to-year over the study period.

Temperatures and the total number of arrival dates reported by species varied (Table 2) across all years for Biophysical Regions 7–15. Median arrival dates over all years as well as the range of annual medians as a simple measure of variability among year also varied (Table 2).

The results of each of the quantile regressions, listing the value of the slope of the regression as a measure of the strength of the relationship, were not constant (Table 2). The most obvious result of the statistical analyses of the Maine temperature data was the absence of a significant regression between temperature and arrival date for most species and quantile combinations. Only 69 (21.9%) of the 315 regressions were statistically significant

TABLE 2. Species included in the analysis arranged in phylogenetic order. Number of arrival dates, grand mean of arrival date over the 12 years of the study, and the range of the 12 annual median dates for each species as an indication of variability are given. The temperature data used in the regression analysis are given. The slopes of the quantile regressions for temperature deviation and NAO index are provided. Statistically significant regressions are indicated by * ($0.01 < P \leq 0.05$) or ** ($P < 0.01$).

Species	n	Median arrival	Range of medians	Temp range	Temp departure			NAO index		
					0.1	0.25	0.5	0.1	0.25	0.5
Wood Duck (<i>Aix sponsa</i>)	253	4/7	17	Mar/Apr	-1.66	-0.23	-0.60	-0.16	-0.57	-0.59
Green-winged Teal (<i>Anas crecca</i>)	199	4/21	17	Apr	-2.19	0.02	-0.94	-1.27	-1.02	-1.79**
Blue-winged Teal (<i>A. discors</i>)	134	4/4	24	Mar/Apr	-0.87	0.19	-0.53	-0.24	-1.04	-0.21
Ring-necked Duck (<i>Aythya collaris</i>)	246	3/29	20	Mar/Apr	-2.01	-0.34	-1.14	-0.37*	-0.61	-0.95
Common Loon (inland only) (<i>Gavia immer</i>)	148	4/16	13	Apr	-0.76	-1.33*	-0.67	-1.05	-0.74	-0.34
Pied-billed Grebe (<i>Podilymbus podiceps</i>)	99	4/15	20	Apr	-1.09	-1.22	-1.76	-1.29	-0.97	-0.47
American Bittern (<i>Botaurus lentiginosus</i>)	165	4/30	17	Apr/May	1.17	1.88	1.40	-0.77	-1.50**	-1.57*
Great Blue Heron (<i>Ardea herodias</i>)	415	4/9	12	Mar/Apr	1.35*	0.52	-0.39	-0.72	-0.76**	-1.76**
Green Heron (<i>Butorides virescens</i>)	112	5/6	17	Apr/May	3.74	1.38	0.25	0.42	1.10	-0.11
Black-crowned Night-heron (<i>Nycticorax nycticorax</i>)	84	5/5	19	Apr/May	2.69	1.45	1.32	-0.40	1.27	1.93
Glossy Ibis (<i>Plegadis falcinellus</i>)	92	4/16	35	Apr	0.99	-0.09	0.50	-0.48	0.30	-0.22
Turkey Vulture (<i>Cathartes aura</i>)	424	4/8	35	Mar/Apr	-1.21	-1.12	-1.08	-1.10*	-0.52	-0.68
Osprey (<i>Pandion haliaetus</i>)	382	4/15	11	Apr	-0.49	-0.76	-0.50	-0.99**	-0.77*	-0.53
Northern Harrier (<i>Circus cyaneus</i>)	304	4/12	43	Apr	-0.27	0.98	-0.01	-0.98	-1.06*	-0.76
Broad-winged Hawk (<i>Buteo platyterus</i>)	312	4/26	7	Apr	-0.34	-0.48	0.38	-0.61	-0.27	0.28
American Kestrel (<i>Falco sparverius</i>)	398	4/3	18	Mar/Apr	-0.19	0.86	-0.31	-1.40**	-1.18**	-1.78**
Virginia Rail (<i>Rallus limicola</i>)	96	5/9	13	May	0.96	-0.17	-0.42	-2.33	-0.75	0.07
Sora (<i>Porzana carolina</i>)	93	5/12	14	May	0.18	0.28	-0.00	-0.11	0.29	1.06
Killdeer (<i>Charadrius vociferus</i>)	405	3/28	14	Mar/Apr	-2.03*	-1.48**	-0.43	-0.52	-1.48**	-0.43
Willet (<i>Catoptrophorus semipalmatus</i>)	82	5/8	13	May	-2.29	0.31	-0.74	0.15	-0.17	0.11
Upland Sandpiper (<i>Bartramia longicauda</i>)	74	5/12	21	May	0.43	0.18	0.22	0.34	0.37	-1.06*
Spotted Sandpiper (<i>Actitis macularia</i>)	190	5/14	11	May	-0.50	-0.13	-0.11	-0.36	-0.22	-0.11
Wilson's Snipe (<i>Gallinago delicata</i>)	191	5/19	13	Apr	-0.91	-1.22*	-0.73	-0.25	-0.61	-1.20**
American Woodcock (<i>Scolopax minor</i>)	312	3/29	16	Mar/Apr	-3.08**	-1.34**	-0.89**	0.20	-0.53	-0.82**

TABLE 2. Continued.

Species	n	Median arrival	Range of medians	Temp range	Temp departure			NAO index		
					0.1	0.25	0.5	0.1	0.25	0.5
Black-billed Cuckoo (<i>Coccyzus erythrophthalmus</i>)	82	5/27	13	May	-3.31	-0.42	-0.79*	1.02	0.15	0.01
Common Nighthawk (<i>Chordeiles minor</i>)	131	5/26	16	May	-0.20	-0.26	-0.63	-0.59	0.14	-0.27
Whip-poor-will (<i>Caprimulgus vociferus</i>)	66	5/19	14	May	0.09	-0.22	-0.46	-0.73	0.14	-0.10
Chimney Swift (<i>Chaetura pelagica</i>)	251	5/11	9	May	-0.07	-0.16	-0.11	-0.26	-0.14	-0.45*
Ruby-throated Hummingbird (<i>Archilochus colubris</i>)	438	5/10	8	May	0.02	-0.26	-0.36**	0.83**	0.16	0.37
Belted Kingfisher (<i>Ceryle alcyon</i>)	367	4/19	13	Apr	1.74	0.59	-0.52	-2.47**	-2.21**	-1.01**
Yellow-bellied Sapsucker (<i>Sphyrapicus varius</i>)	236	4/19	10	Apr	-1.27	-2.05**	-1.14**	-0.47	-0.45	-0.24
Northern Flicker (<i>Colaptes auratus</i>)	464	4/14	15	Apr	0.38	-0.59	-1.41**	-0.36	-1.60**	-1.31**
Olive-sided Flycatcher (<i>Contopus cooperi</i>)	101	5/25	9	May	-2.48	-1.03**	-0.42	-0.11	-0.21	-0.09
Eastern Wood-pewee (<i>C. virens</i>)	233	5/24	6	May	-0.45	-0.53	-0.67**	-0.26	0.19	0.16
Yellow-bellied Flycatcher (<i>Empidonax flaviventris</i>)	90	5/23	11	May	-2.36	-0.59*	-0.33	1.95	-0.12	0.00
Alder Flycatcher (<i>E. alnorum</i>)	157	5/25	11	May	0.71	0.36*	-0.20	-0.73	-0.34	-0.01
Willow Flycatcher (<i>E. traillii</i>)	79	5/26	6	May	0.23	0.00	-0.30	0.11	0.00	0.42
Least Flycatcher (<i>E. minimus</i>)	242	5/13	13	May	-0.91**	-0.65**	-0.47	0.54	0.04	0.16
Eastern Phoebe (<i>Sayornis phoebe</i>)	467	4/7	21	Mar/Apr	-0.07	-0.28	-0.26	-0.68**	-1.06**	-1.71**
Great Crested Flycatcher (<i>Myiarchus crinitus</i>)	301	4/30	8	Apr/May	-0.32	-0.78**	-0.83	0.36	0.07	0.13
Eastern Kingbird (<i>Tyrannus tyrannus</i>)	377	5/14	10	May	-0.19	-0.38	-0.20	-0.15	-0.13	-0.12
Blue-headed Vireo (<i>Vireo solitarius</i>)	331	5/2	14	Apr/May	-0.62	-0.65	-0.66**	-0.26	-0.05	-0.03
Warbling Vireo (<i>V. gilvus</i>)	183	5/14	13	May	-1.13**	-0.51**	-0.74*	-0.21	-0.42*	-0.29
Red-eyed Vireo (<i>V. olivaceus</i>)	302	5/16	8	May	-0.62	-0.95**	-0.47*	-0.45	-0.16	0.05
Tree Swallow (<i>Tachycineta bicolor</i>)	497	4/13	13	Apr	-0.52	-0.30	-0.27	-0.74**	-0.98**	-1.20**
Northern Rough-winged Swallow (<i>Stelgidopteryx serripennis</i>)	148	5/5	16	Apr/May	1.38	-0.13	-0.32	0.23	0.46	0.57
Bank Swallow (<i>Riparia riparia</i>)	136	5/17	9	May	1.75	-0.38	0.05	0.44	-0.30	-0.56
Cliff Swallow (<i>Petrochelidon pyrrhonota</i>)	157	5/14	13	May	0.08	0.35	0.12	-0.58	-1.11	-0.16
Barn Swallow (<i>Hirundo rustica</i>)	364	5/5	8	Apr/May	-0.65	-0.64	0.11	-0.98*	-0.24	0.21
House Wren (<i>Troglodytes aedon</i>)	156	5/9	12	May	-0.13	-0.69*	-1.23**	0.29	0.29	-0.03

TABLE 2. Continued.

Species	n	Median arrival	Range of medians	Temp range	Temp departure			NAO index		
					0.1	0.25	0.5	0.1	0.25	0.5
Winter Wren (<i>T. troglodytes</i>)	191	4/19	21	Apr	-1.78	-1.48	-1.79**	0.07	-1.10*	-0.89*
Marsh Wren (<i>Cistothorus palustris</i>)	80	5/17	7	May	0.91	-0.42	-0.91	0.52	1.71**	0.88
Ruby-crowned Kinglet (<i>Regulus catenulata</i>)	302	4/21	25	Apr	-1.52**	-1.02**	-1.28**	-0.80**	-1.01**	-1.28**
Blue-gray Gnatcatcher (<i>Polioptila caerulea</i>)	92	5/8	16	Apr/May	2.63	1.67	0.96	-0.82	-0.93	-0.26
Eastern Bluebird (<i>Sialia sialis</i>)	308	4/7	15	Mar/Apr	-1.65	-0.81	-1.51	-0.23	-0.57	-1.70
Veery (<i>Catharus fuscescens</i>)	304	5/16	7	May	-0.30	-0.25	-0.16	-0.09	-0.01	0.14
Swainson's Thrush (<i>C. ustulatus</i>)	156	5/18	9	May	-1.81	-1.00**	-0.51	0.30	-0.09	0.07
Hermit Thrush (<i>C. guttatus</i>)	374	4/22	13	Apr	-1.70**	-0.56**	0.04	-0.99**	-0.83**	0.04
Wood Thrush (<i>Hylocichla mustelina</i>)	293	5/12	8	May	-0.12	-0.11	-0.28	-0.25	-0.29	-0.29
American Robin (<i>Turdus migratorius</i>)	413	3/21	7	Mar	0.00	-0.90	-0.69**	0.00	0.25	-0.43
Gray Catbird (<i>Dumetella carolinensis</i>)	420	5/11	12	May	-0.16	-0.21	-0.25	-0.01	0.07	-0.18
Brown Thrasher (<i>Toxostoma rufum</i>)	209	5/8	12	May	-0.03	-0.19	-0.21	-0.44	-0.66	0.07
Tennessee Warbler (<i>Vermivora peregrina</i>)	118	5/20	17	May	-0.76	0.05	-0.47*	-0.36	-0.29	-0.11
Nashville Warbler (<i>V. ruficapilla</i>)	298	5/10	8	May	0.33**	-0.30	-0.33*	-0.22	0.03	-0.41**
Northern Parula (<i>Parula americana</i>)	380	5/9	9	May	-0.32**	-0.47**	-0.73**	-0.01	0.26	0.20
Yellow Warbler (<i>Dendroica petechia</i>)	404	5/12	8	May	-0.28	0.29	0.23	0.26	-0.29	-0.54
Chestnut-sided Warbler (<i>D. pensylvanica</i>)	358	5/12	11	May	-0.91**	-0.28*	-0.16	-0.57*	-0.47**	0.00
Magnolia Warbler (<i>D. magnolia</i>)	304	5/15	7	May	-0.55**	-0.39**	0.00	-0.73**	-0.56**	0.00
Cape May Warbler (<i>D. tigrina</i>)	100	5/15	11	May	-0.91**	-0.28*	-0.16	-0.56*	-0.47**	0.00
Black-throated Blue Warbler (<i>D. caerulescens</i>)	270	5/13	8	May	-0.38*	0.84	0.00	0.05	-0.57	0.00
Yellow-rumped Warbler (<i>D. coronata</i>)	439	4/28	12	May	0.18	0.42	-0.36	-0.42	0.03	0.20
Black-throated Green Warbler (<i>D. virens</i>)	406	5/8	16	May	-0.36**	-0.60**	-0.45	-0.12	0.10	0.00

TABLE 2. Continued.

Species	n	Median arrival	Range of medians	Temp range	Temp departure						NAO index		
					0.1	0.25	0.5	0.1	0.25	0.5	0.1	0.25	0.5
Blackburnian Warbler (<i>D. fusca</i>)	253	5/16	6	May	-0.46	-0.30	-0.39*	0.05	0.28	0.17			
Pine Warbler (<i>D. pinus</i>)	263	4/20	9	Apr	-1.85**	-1.52**	-0.19	-0.96**	-0.84**	-0.50			
Prairie Warbler (<i>D. discolor</i>)	93	5/12	17	May	-0.65	-0.15	-0.95	0.03	-0.44	-0.95			
Palm Warbler (<i>D. palmarum</i>)	264	4/22	11	Apr	-0.74	-0.39	0.02	-1.03**	-0.72**	-0.27			
Bay-breasted Warbler (<i>D. castanea</i>)	129	5/19	10	May	-0.25	0.00	-0.54	0.13	0.00	-0.32			
Blackpoll Warbler (<i>D. striata</i>)	176	5/20	7	May	-0.14	-0.13	-0.43	0.07	-0.06	-0.29			
Black-and-white Warbler (<i>Mniotilta varia</i>)	420	5/6	10	Apr/May	-0.12	-0.19	-0.19	-0.40	-0.28*	-0.42			
American Redstart (<i>Setophaga ruticilla</i>)	353	5/15	6	May	-0.60**	-0.28*	0.00	-0.72**	-0.29	0.00			
Ovenbird (<i>Seiurus aurocapillus</i>)	396	5/9	7	May	-0.50**	-0.07*	-0.50	0.04	0.22	0.15			
Northern Waterthrush (<i>S. noveboracensis</i>)	219	5/9	12	May	0.09	-0.45	-0.79**	-0.44	-0.12	-0.43			
Mourning Warbler (<i>Oporornis phidalophia</i>)	68	5/7	9	May	-0.44	0.24	0.44	1.03	0.44	0.56			
Common Yellowthroat (<i>Geothlypis trichas</i>)	402	5/26	8	May	-0.05	-0.06	0.14	-0.29	-0.27	0.31			
Wilson's Warbler (<i>Wilsonia pusilla</i>)	188	5/13	8	May	-0.39	-0.38**	-0.43	-0.14	0.04	0.00			
Canada Warbler (<i>W. canadensis</i>)	215	5/16	5	May	0.00	0.00	0.00	0.00	0.00	0.00			
Scarlet Tanager (<i>Piranga olivacea</i>)	265	5/20	7	May	-0.15	-0.12	-0.60	-0.22	0.29	-0.60**			
Eastern Towhee (<i>Pipilo erythrophthalmus</i>)	208	5/19	19	Apr/May	-0.42	-0.74	-0.99*	0.12	0.48	1.20			
Chipping Sparrow (<i>Spizella passerina</i>)	457	5/4	13	Apr	-0.25	-0.42	-0.61	0.62	-0.36	0.32			
Field Sparrow (<i>S. pusilla</i>)	121	4/25	14	Apr/May	-0.21	-0.31	1.14	0.12	0.08	0.36			
Vesper Sparrow (<i>Poocetes gramineus</i>)	95	5/4	16	Apr/May	0.13	-0.23	0.55	-0.42	-1.10	-1.40			
Savannah Sparrow (<i>Passerculus sandwichensis</i>)	290	3/28	10	Apr	1.52	0.17	0.36	-0.83	-0.75**	0.36			
Fox Sparrow (<i>Passerella iliaca</i>)	217	5/1	20	Mar/Apr	-3.02**	-1.29**	-0.43	0.42	-0.61**	0.12			
Song Sparrow (<i>Melospiza melodia</i>)	388	4/24	21	Mar/Apr	-0.95	-0.65	-0.09	-0.68	-0.89*	-1.02**			
Lincoln's Sparrow (<i>M. lincolni</i>)	116	5/14	16	May	-4.28	-3.82**	-0.88	2.43	1.59	0.44			
Swamp Sparrow (<i>M. georgiana</i>)	224	4/29	11	Apr/May	-0.11	-0.05	0.69	-0.29	-0.88**	-1.11**			
White-throated Sparrow (<i>Zonotrichia albicollis</i>)	441	4/20	11	Apr	0.24	-0.88	0.06	0.02	-0.29	-0.24*			
Rose-breasted Grosbeak (<i>Pheucticus ludovicianus</i>)	410	5/17	13	May	0.17	0.00	-0.15	0.30	0.00	-0.22			

TABLE 2. Continued.

Species	n	Median arrival	Range of medians	Temp range	Temp departure			NAO index		
					0.1	0.25	0.5	0.1	0.25	0.5
Indigo Bunting (<i>Passerina cyanea</i>)	207	5/12	16	May	0.84	0.22	0.58*	0.70	0.81	0.45
Bobolink (<i>Dolichonyx oryzivorus</i>)	349	5/15	7	May	-0.44	-0.36**	-0.43*	-0.15	-0.22	-0.21
Red-winged Blackbird (<i>Agelaius phoeniceus</i>)	507	3/23	19	Mar	-1.70	-2.38	-1.97	1.44**	0.83**	0.72**
Eastern Meadowlark (<i>Sturnella magna</i>)	251	4/19	35	Apr	0.17	0.28	-0.55	-1.92**	-1.10*	-1.20
Rusty Blackbird (<i>Euphagus carolinus</i>)	113	4/10	38	Apr	0.63	-1.70	-1.26	-0.66	0.37	0.06
Common Grackle (<i>Quiscalus quiscula</i>)	508	3/21	16	Mar	-1.57**	-1.53**	-0.99**	0.63	-0.25	0.07
Baltimore Oriole (<i>Icterus galbula</i>)	413	5/12	10	May	0.67**	-0.48**	-0.25	0.07	-0.11	0.13

with the expected negative slope between temperature deviation from the mean and arrival date. Four additional significant regressions had a positive slope. These likely arose by chance and are not considered further. The 0.25 quantile yielded the most significant relationships (30 of 105) while the 0.1 quantile produced 18 significant relationships, and the median quantile yielded 21 significant relationships.

Five species (Warbling Vireo, Ruby-crowned Kinglet, Northern Parula, Red-winged Blackbird, and Common Grackle) showed significant regressions for all three quantiles, demonstrating a strong response to spring temperatures. The regressions for two quantiles were significant for an additional 15 species. Eight of these species were parulids.

The results of the quantile regression analyses for the NAO index were similar to the temperature deviation regressions as only 63 of 315 regressions were statistically significant (Table 2). The 0.25 quantile had the greatest explanatory value, producing 25 significant regressions with negative slopes for the 105 species. The 0.1 and 0.5 quantile analyses yielded 18 and 20 significant relationships, respectively. The three significant regressions with positive slopes likely arose by chance.

Seven species (American Kestrel, American Woodcock, Belted Kingfisher, Eastern Phoebe, Tree Swallow, Ruby-crowned Kinglet, and Eastern Meadowlark) had significant relationships for all three quantiles. Twelve additional species had significant regressions for two of the three quantiles.

Only 45 of the 105 species failed to show a significant relationship for all six regressions. Thus, a minority of the species (42.9%) was unresponsive to some aspect of broad-scale temperature variability in their arrival.

DISCUSSION

Fundamental biotic changes are impelled by increasing global temperature. Abundant evidence of earlier leaf-out and flowering in vascular plants (e.g., Peñuelas et al. 2002) suggests phenological changes for pollinators, herbivores, and predators of herbivores. Responding to plant phenological changes, either by behavioral changes of individuals or pop-

ulation responses due to selection, should be relatively rapid for resident animals.

Finding the optimal schedule for departure from wintering areas, migration, and arrival in breeding areas is more complex for migratory species. Migratory birds may use higher than normal temperatures in wintering areas as a cue to begin migration. Some have argued that migrants may depart earlier than normal to avoid the physiological stress of high temperatures as summer approaches in areas used in winter. Alternatively, temperatures may be used as a predictor of earlier phenological events further north.

Migrant birds may migrate more rapidly if their appropriate food along their migratory pathway is phenologically advanced. This hypothesis seems reasonable but I know of no data on resource availability that can be used to test it with present knowledge. The strong correlation of spring temperatures from Maine south to Pennsylvania and New Jersey suggests there should be little difference in migration rate across that portion of the migratory route.

Ideally, migrant birds should respond to temperatures in breeding areas. Birds could then arrive sufficiently late to find adequate food for the metabolic demands of nesting and sufficiently early to compete for the best nesting sites. The difficulty is that birds have no way of predicting the climate from afar.

Quantifying changes in phenology provides one of the simplest means of assessing effects of global climate change on the biota of the earth. Phenologists can take advantage of stores of data on flowering dates, leaf-out dates, and nesting dates contributed by both professionals and amateur naturalists (Sparks and Menzel 2002). For example, Peñuelas et al. (2002) documented earlier leaf-out dates and later leaf-fall dates for vascular plants in the Mediterranean region from 1952 until 2000. On a broader scale, Parmesan and Yohe (2003) showed a global diagnostic fingerprint for 279 species.

For birds, global climate change has been invoked to explain earlier nesting in Tree Swallows (Dunn and Winkler 1999) throughout North America, and *Ficedula* flycatchers in Europe (Both et al. 2004) and India (Mitrus et al. 2005). However, the greatest amount of work on avian phenology with respect to glob-

al warming has been study of arrival dates of migratory birds. The data presented to date have shown strikingly different results. Wilson et al. (2000) documented no change in arrival date for migratory breeding birds in Maine between 1889–1911 and 1994–1997 while Peñuelas et al. (2002) showed that birds arrived at their Mediterranean site 15 days earlier in 2000 compared to 1952 (although lepidopterans appeared 11 days later).

At a local scale, Stervander et al. (2005) found a trend of earlier arrival (average of 0.9 day/decade) for 36 passerine migrants captured at Ottenby Bird Observatory in southeastern Sweden. They showed that arrival date was negatively correlated with the NAO index. Sokolov et al. (1998), at a banding station on the Courish Spit in the Baltic Sea, found a negative relationship between spring temperatures and late migrants (species arriving in May) but no relationships with earlier migrant species (those arriving in Apr). Mills (2005) analyzed data from Long Point Bird Observatory in Ontario, Canada over the period 1975 until 2000 and demonstrated that only 2 of 13 species analyzed had evidence of earlier arrivals through time. Töttrup et al. (2006) demonstrated birds were arriving 0.26 day/year earlier between 1976 and 1997 at a banding station on the Danish island of Christiansø.

Studies monitoring arrival dates by field observations also demonstrate changes in arrival date. Ledneva et al. (2004) found significant correlations of arrival dates at a farm in Massachusetts with spring temperatures. Bradley et al. (1999) reported that arrivals and first songs of several birds were earlier toward the end of a 61-year period at a single farm in Wisconsin. Tryjanowski et al. (2002) analyzed a data set spanning 1913 until 1996 at a farm in Poland and reported that 14 of 16 species of birds had a trend of earlier arrival dates over time. Each of these studies was based on a single, restricted site and any observed effects may have local rather than wide-scale explanations. One must extrapolate these results to the regional level with great caution.

Marra et al. (2005) avoided the problem of lack of replication (Hurlbert 1984) by analyzing data from three banding stations in North America. They demonstrated that birds migrated earlier in warmer springs (about 1 day

for every 1° C increase in temperature). They were unable to show any relationships between arrival dates and the NAO index. Jonzén et al. (2006) used data from four banding sites in Scandinavia to show earlier recent arrival dates for a number of Scandinavian migratory breeding birds.

Analyses of arrival dates in a prescribed region may also avoid the problem of lack of replication (Sparks 1999). For example, Mason (1995) analyzed the arrival date records of the Leicestershire and Rutland Ornithological societies in Britain over a 50-year period and demonstrated earlier arrivals for 23 species in the latter part of the study period. Ptasnyk et al. (2003) demonstrated earlier arrivals for White Storks (*Ciconia ciconia*) from records collected across western Poland. Butler (2003) analyzed arrival date records from the Cayuga Lake region of New York and from central Massachusetts, and demonstrated that short-distance migrants arrived earlier in breeding areas in the later part of the 20th century compared to the first half. Long-distance migrants were influenced to a lesser extent by environmental warming.

The arrival date data from this study in Maine indicate modest temperature dependence (Table 2). For the median quantile, only 11 of 105 species had a significant relationship with temperature deviation. No weighting of the residual errors was used to produce the median quantile and, hence, this quantile is indicative of the entire population of first arrivals. Lower quantiles, biased toward early arrivals, resulted in a higher number of significant relationships (18 for the 0.1 quantile and 30 for the 0.25 quantile). Examination of the data indicates that only five species (American Woodcock, Warbling Vireo, Ruby-crowned Kinglet, Red-winged Blackbird, Common Grackle) had significant relationships for all three quantile regressions using temperature deviation as the predictor variable. The lack of concordance for the three quantiles for most species clearly indicates the heterogeneous variation across the statistical distribution.

Quantile regression analyses using the NAO index were similar with the 0.25 quantile producing 25 significant relationships. The median quantile analysis produced 20 significant relationships and the 0.1 quantile anal-

ysis only 18. Overall, only 20.0% of the regressions were significant. Seven species (American Kestrel, American Woodcock, Belted Kingfisher, Eastern Phoebe, Tree Swallow, Ruby-crowned Kinglet, and Eastern Meadowlark) had significant regressions for all three quantiles, demonstrating the heterogeneous nature of the arrival data for most species.

Only 45 of the 105 species analyzed failed to have a significant result in at least one of the six regressions. The pattern is that temperatures, measured either by spring departures from the mean or by the NAO index, are not strong determinants of arrival date for migratory breeding birds in Maine. The percentage of regressions showing a statistically significant effect of spring temperatures on arrival date (21.0%) is quite similar to the value of 29% reported by Lehikoinen et al. (2004) in a meta-analysis of the effect of spring temperature on the arrival of common European migratory breeding birds.

Why do the data from this study show a weaker dependence of arrival data on spring temperatures than most other studies? One possible explanation is the data are not sufficiently accurate to show differences. This explanation can be rejected by examining the low variance around arrival dates for particular species. There were significant differences (ANOVA) among years for most species, indicating the between-year variance was not overwhelming the within-year variance. Furthermore, the sample size for each year for many species was based on more than 30 records (Table 2). Finally, the same type of data has been used by other workers who were able to show patterns of change in arrival date related to climate (Bradley et al. 1999, Butler 2003, Ledneva et al. 2004, Mills 2005).

A second and more compelling explanation is the migratory schedule for migratory breeding birds in Maine may be driven by photoperiod or some other environmental cue that has less variability than the year-to-year variability in spring temperatures (Coppack and Both 2002, Both 2007). This explanation is in accord with the results of Strode (2003) who demonstrated that seven species of wood warblers (Parulidae) are not arriving earlier in their breeding areas in Minnesota despite clear evidence that spring is now arriving earlier.

Those wood warblers are uncoupled from their food resources. Similarly, Pied Flycatchers (*Ficedula hypoleuca*) in the Netherlands have declined over the past two decades because their arrival in breeding areas has not changed while local phenological events, including caterpillar emergence, have advanced due to climate warming (Both et al. 2006). I have no doubt that dramatic change in Maine breeding birds will occur as global warming proceeds. However, the available data suggest the response in terms of arrival date, nesting date, and other phenological events will be gradual. Cold springs are not necessarily correlated with later arrivals for migratory birds in Maine (Table 2). Similarly, warm springs are not necessarily accompanied by earlier arrivals of migratory breeding birds.

ACKNOWLEDGMENTS

I express my deep appreciation to more than 200 Maine birders who have contributed arrival data for this project over the past 12 years. Data entry was expertly done by students: Rita Campbell, Alec Helm, Karen Prisby, Ann Savage, Amanda Surette, and Rachel Zierzow. Financial support was provided by grants from the Division of Natural Sciences at Colby College and the Leslie Brainerd Arey Research Fund. I am grateful to Bets Brown, Brian Cade, Sam Droege, Esa Lehtikoinen, and Anders Töttrup for critical comments on earlier drafts of the manuscript.

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