## Phenological changes reflect climate change in Wisconsin

(climate warming/phenology/flowering/bird migration/photoperiod)

NINA L. BRADLEY\*, A. CARL LEOPOLD<sup>†‡</sup>, JOHN ROSS<sup>§</sup>, AND WELLINGTON HUFFAKER\*

\*The Aldo Leopold Foundation, E12919, Baraboo, WI 53919; <sup>†</sup>The Boyce Thompson Institute, Ithaca, NY 14853; and <sup>§</sup>Department of Agricultural Journalism, University of Wisconsin, Madison, WI 53706

Communicated by Estella B. Leopold, University of Washington, Seattle, WA, June 17, 1999 (received for review February 1, 1999

ABSTRACT A phenological study of springtime events was made over a 61-year period at one site in southern Wisconsin. The records over this long period show that several phenological events have been increasing in earliness; we discuss evidence indicating that these changes reflect climate change. The mean of regressions for the 55 phenophases studied was -0.12 day per year, an overall increase in phenological earliness at this site during the period. Some phenophases have not increased in earliness, as would be expected for phenophases that are regulated by photoperiod or by a physiological signal other than local temperature.

Phenology is the study of the cycling of biological events throughout the year—a reading of the "pulse of life." The cycling of phenological events such as flowering, fruiting, bird migration, or animal reproduction is frequently used to define annual seasonal sequences. Phenological studies have also proved useful in predicting the production stages of certain crops (1) and in measuring the response of plant systems to changes in temperature (2).

Climatic warming would be expected to have an impact on some phenological sequences (3, 4). If phenological records are continued over a sufficient length of time, they may reflect climate change, as has been suggested by Beaubien and Johnson (5). With widespread evidence that climate warming has occurred over the past 40 years (6–8), long-term phenological records may reflect such climate warming. We report here such a record of phenological events at a site in southern Wisconsin. This record offers an unusual opportunity to observe long-term changes by various phenophases (seasonal biological events).

## **METHODS**

Phenological data have been collected at a farm in Fairfield Township, Sauk County, in southern Wisconsin during two intervals of time. From 1936 to 1947, Aldo Leopold (9) maintained records of spring events. After a lapse of 29 years, similar records were kept by Nina Leopold Bradley at the same farm for a subsequent 22 years, from 1976 to 1998, spanning a total of 61 years. The record includes 74 phenophases, focusing especially on arrival dates for migratory birds and dates of first bloom of spring flowers. We estimate the accuracy during the first 11-year period to be  $\pm 4$  days and during the later 22-year interval to be  $\pm 2$  days.

In this work, we refer to climate warming as a rise in analogous temperatures over the 61-year period, not as seasonal warming within a single year.

To limit our analysis to phenophases that can be identified with the spring season, we report only those events that occur before the end of June (Julian calendar day 181). We used only

PNAS is available online at www.pnas.org.

phenophases for which there were at least six yearly records in each of the two recording periods. We analyzed 55 phenophases within these parameters for long-term changes in the dates of springtime events. Regression analysis (10) performed on the yearly records for each phenophase yielded an approximation of the slope of the data for the six-decade period. For each phenophase we report the average date of occurrence across the entire data collection period, the number of yearly observations recorded for that phenophase, and the slope of the linear regression plot for those observations (Table 1). In addition, for each phenophase we report the *t* value (Student's *t* distribution), an estimate of the deviation from the population mean, and the *p* value, a measure of the statistical probability of fit to the regression line.

An effective component of this study would be a record of actual temperatures indicating the increase over the past decades. However, the scatter of daily, weekly, and monthly temperatures encompasses a vast range, and a significant drift in local temperatures over the decades is difficult to define. The data on planetary warming indicate a very small total increase, less than 1°C over 50 years (6-8, 11). For a natural integrator of seasonal temperature changes, we have selected the date of ice-melt in Lake Mendota, located in the adjoining county. A regression analysis of the melt dates for the succession of years is presented in Fig. 1A; it indicates an overall increase in earliness over the 61-year period, with a slope of -0.124 days per year, and with a 97% probability of significance (P = 0.031). For evidence that the regression of Lake Mendota ice-melt is driven by temperature, we plotted the melt dates against the average March temperature (Fig. 1B); we find a regression of -2.72 days in earliness per °C.

## RESULTS

The long-term phenological record at one site presents an opportunity to examine changes in the dates of occurrence of various phenophases over a period of climate change. In Table 1 we present springtime phenophases in the order of their occurrence. For example, the average date of the first song of cardinals occurred on day 46 of the Julian calendar; there were 29 year-records of the date of that event. These records yielded a regression with a slope of -0.365 day in earliness per year. The *t* test yielded -2.75; and the *p* value was 99% (P = 0.01).

Seventeen phenophases [indicated by section marks (§) in Table 1] show significant advances in springtime occurrence. The data also indicate that 20 phenophases [indicated by paragraph marks (¶) in Table 1] do not appear to be increasing in earliness. These are phenophases with *t* values between +1 and -1, thus with minimal divergence from the average date of occurrence. The remaining 18 phenophases show intermediate regressions, and are statistically not assignable to either the responder or the nonresponder class.

Examples of responders and nonresponders are illustrated in Fig. 2; individual plots of four phenophases with increasing

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked "*advertisement*" in accordance with 18 U.S.C. §1734 solely to indicate this fact.

<sup>&</sup>lt;sup>‡</sup>To whom reprint requests should be addressed. E-mail: ACL9@ cornell.edu.

Table 1.	Regression	analyses of	the	changes	in	phenophases	over	a 6	1-year	period.
						r · · r			J	r · · · ·

(arg)         (arg)         Phenoplase (species)         observations         Sippe <sup>+</sup> $t$ $P$ 46         15 Feb         Cardinal first song (Cardinals)         29         -0.36         -2.75         0.017           47         Har         Geese arrival (themic condensity)         27         -4.46         -2.75         0.017           47         Har         Receivinged blackbird arrival (theplain phenelecus)         30         -0.128         -2.21         0.018           47         Har         Robin arrival (Tenho mignotrico)         25         -0.121         -1.50         0.15           580         21 Mar         Narro karatorical (Samella magua)         25         -0.124         -1.50         0.15           580         21 Mar         For sparrow arrival (Carlo arleand)         18         0.000         0.000           88         29 Mar         Photes arrival (Carlo arleand)         13         -0.124         -1.43         0.17           101         14 pr         Fraction fits bloom (Account patos)         13         -0.124         -1.43         0.17           11         14 pr         Hegation station         13         -0.144         -1.33         0.045           110         15	Julian day	Date		No. of	Regression			
46       15 Feb       Cardinal first song (Cardinals condensis)       29 $-0.636$ $-2.75$ 0.005         73       14 Mar       Bucbrid arrival (Bandu condensis)       27 $-0.476$ $-5.25$ 0.004         74       15 Mar       Robin arrival (Carda migratoria)       28 $-0.166$ $-2.21$ 0.044         74       15 Mar       Robin arrival (Carda migratoria)       25 $-0.121$ $-1.50$ 0.15         80       21 Mar       Waser Metadoruk arrival (Annuella migratoria)       28 $-0.234$ 0.000       0.000         80       21 Mar       For sparrow arrival (Gray and gray)       23 $-0.144$ $-1.43$ 0.17         80       21 Mar       For sparrow arrival (Gray and gray)       23 $-0.144$ $-1.43$ 0.17         91       1 Apr       Gravita trival (Andenkas and Cardy and gray)       13 $-0.170$ $-0.134$ $-0.14$ $0.017$ 101       11 Apr       Gravita trival (Andenkas and gray)       14 $-0.134$ $-1.43$ $0.17$ 103       11 Apr       Cowita trival (Andenkas and gray)       19 $-0.134$ $-1.43$ $0.017$ 104	(avg)	(avg)	Phenophase (species)	observations	Slope*	$t^{\dagger}$	$P^{\ddagger}$	
66         9 Mar         Geosa arrival ( <i>Binata canadessi</i> )         27 $-0.476$ $-5.42$ 0.004           73         14 Mar         Bluehol arrival ( <i>Challa sinfa</i> )         18         0.024         0.25         0.079           74         15 Mar         Robin arrival ( <i>Challa sinfa</i> )         25 $-0.150$ $-2.21$ 0.014           79         20 Mar         Mcadewlark arrival ( <i>Scipmen inigratoria</i> )         25 $-0.121$ $-1.50$ 0.15           80         21 Mar         Woodcock first poett ( <i>Scopna inigratoria</i> )         18         0.010         0.000           80         21 Mar         Prozene arrival ( <i>Charle singratoria</i> )         28 $-0.239$ $-0.99$ 0.019           81         Apr         Gracia first bloom ( <i>Loreatica as attribia</i> )         31 $-0.144$ $-1.43$ $0.17$ 101         11 Apr         Hepatic first bloom ( <i>Loreatica as attribia</i> )         32 $-0.144$ $-0.33$ $0.044$ 103         1.4 Apr         Coshrid arrival ( <i>Charle as attrib</i> )         24 $-0.035$ $-0.44$ $0.037$ 104         0.4 Apr         Passite first bloom ( <i>Attreatica as attrib</i> )         22 $-0.13$	46	15 Feb	Cardinal first song (Cardinalis cardinalis)	29	-0.365	-2.75	$0.01^{\$}$	
73       14 Mar       Bluchird arrival ( <i>Saluta sulus</i> )       18       0.026       0.278         74       15 Mar       Robin arrival ( <i>Chothas migratorius</i> )       25       -0.159       -2.71       0.044         79       20 Mar       Meadowlark arrival ( <i>Saluta sphonicuss</i> )       25       -0.159       -2.71       0.045         80       21 Mar       Meadowlark arrival ( <i>Saluta sphonicuss</i> )       25       -0.151       -2.71       0.045         80       21 Mar       Meadowlark arrival ( <i>Saluta sphonicus</i> )       28       -0.029      159       0.09         91       1 Apr       Floodbe arrival ( <i>Galuta sculubo</i> )       31       -0.178       -1.87       0.09         95       5 Apr       Kinglisher arrival ( <i>Cloyle alsym</i> )       23       -0.144       -1.43       0.17         101       11 Apr       Cowlin arrival ( <i>Mealan sculubo</i> )       31       -0.170       0.111         118       18 Apr       Passyne first bloom ( <i>Hennutar anglecal</i> )       28       -0.142       -1.36       0.09         110       20 Apr       Duchmar's britches first bloom ( <i>Mealancine</i> )       28       -0.013       -0.17       0.10         110       20 Apr       Duchmar's britches first bloom ( <i>Mealancine</i> )       22	68	9 Mar	Geese arrival (Branta canadensis)	27	-0.476	-5.42	0.00§	
74       15 Mar       Redwinged blackbird arrival ( <i>Augelatia phoeniceus</i> )       30 $-0.166$ $-2.21$ 0.048         79       20 Mar       Meadowlark arrival ( <i>Starella miguo</i> )       25 $-0.121$ $-1.50$ $0.15$ 80       21 Mar       Woodcock first peeri ( <i>Scolpan minor</i> )       27 $-0.136$ $-2.21$ 0.018         80       21 Mar       Woodcock first peeri ( <i>Scolpan minor</i> )       28 $-0.29$ $-3.99$ 0.09         91       1 Apr       Greats Ubue heen arrival ( <i>Areasella illaca</i> )       13 $-0.185$ $-1.87$ 0.09         95       5 Apr       Kingfisher arrival ( <i>Areasella illaca</i> )       31 $-0.170$ $-1.23$ 0.044         101       1 Apr       Greate first bloom ( <i>Hepatica acuiliba</i> )       31 $-0.170$ $-2.13$ 0.014         105       15 Apr       Pauge Ilower first bloom ( <i>Hepatica acuiliba</i> )       24 $-0.036$ $-0.43$ $0.05$ 110       20 Apr       Dorkmark britches first bloom ( <i>Dicorar acuilibari</i> )       28 $-0.142$ $-1.36$ $0.019$ 120       20 Apr       Howin th asher arrival ( <i>Togladyn acuilibari</i> )       22 $-0.160$ $-1.27$ $0.221$ </td <td>73</td> <td>14 Mar</td> <td>Bluebird arrival (Sialia sialis)</td> <td>18</td> <td>0.024</td> <td>0.26</td> <td>0.79<sup>¶</sup></td>	73	14 Mar	Bluebird arrival (Sialia sialis)	18	0.024	0.26	0.79 <sup>¶</sup>	
74       15 Mar       Robin arrival (Tardus migratorius)       25 $-0.159$ $-2.71$ 0.011         79       20 Mar       Meadowlark arrival (Staurella magna)       25 $-0.150$ $-2.71$ 0.015         80       21 Mar       Woolcock first pearly       18       0.000       0.000         88       29 Mar       Photes arrival (Archae handlas)       13 $-0.156$ $-2.39$ 0.09         91       1 Apr       Great blue heron arrival (Archae handlas)       13 $-0.144$ $-1.43$ 0.01         101       11 Apr       Great blue heron arrival (Archae handlas)       13 $-0.144$ $-0.135$ $-1.57$ 0.004         103       11 Apr       Great first bloom (Hepatica cauliaba)       24 $-0.036$ $-0.44$ $0.077$ 110       20 Apr       Touchmar's britekes first bloom (Cheentae cauliaria)       28 $-0.132$ $-1.70$ $-0.646$ 112       22 Apr       Brown traiska arrival (Trajokojks acdon)       24 $-0.233$ $-3.33$ $0.005$ 112       23 Apr       Belbort first bloom (Hubadris archae a	74	15 Mar	Redwinged blackbird arrival (Agelaius phoeniceus)	30	-0.166	-2.21	0.04	
79       20 Mar       Madowlark arrival (Starnella magua)       25 $-0.121$ $-1.50$ 0.15         80       21 Mar       Fox sparrow arrival (Scapatta minor)       27 $-0.156$ $-2.041$ 0.089         80       21 Mar       Fox sparrow arrival (Kasuella likea)       18       0.000       0.000         81       23 Mar       Phoche arrival (Scapatta likea)       28 $-0.299$ $-3.99$ 0.09         95       S Apr       Kingfisher arrival (Actala hendulay)       13 $-0.170$ $-2.13$ 0.044         101       11 Apr       Greate farts Hoom ( <i>Hepatica acuilloba</i> )       21 $-0.036$ $-0.44$ 0.679         105       15 Apr       Pasque flower first bloom ( <i>Ateennaria neglecta</i> )       24 $-0.036$ $-0.44$ 0.679         110       20 Apr       Dytchmairs britches first bloom ( <i>Dicentra cuullaria</i> )       28 $-0.122$ $-1.56$ 0.19         110       20 Apr       Dytchmairs britches first bloom ( <i>Ateennaria neglecta</i> )       24 $-0.233$ $-3.33$ 0.049         110       20 Apr       Tothe arrival ( <i>Toglobirs acuellanus</i> )       22 $-0.161$ $-1.27$ $0.222$ 110       <	74	15 Mar	Robin arrival (Turdus migratorius)	25	-0.159	-2.71	0.01§	
80         21 Mar         Woodcock first pearl ( <i>Scolgar, minor</i> )         27        0.55        2.04         0.005           80         21 Mar         Proseparrow arrival ( <i>Suprain phoch</i> )         28        0.29         -3.99         0.09           91         1 Apr         Great blue heron arrival ( <i>Ardea herodia</i> )         13        0.143         -1.17           101         11 Apr         Great blue heron arrival ( <i>Ardea herodia</i> )         31        0.144         -1.43         0.17           101         11 Apr         Great blue heron arrival ( <i>Caryle alcyni</i> )         23        0.144         -1.43         0.17           103         11 Apr         Covid arrival ( <i>Morothras arep</i> )         19         -0.148         -1.70         0.11           108         18 Apr         Pussytoss first bloom ( <i>Alcarunar angecta</i> )         28         -0.023         -0.44         0.043           110         20 Apr         Owne haraker arrival ( <i>Torgadytes acadea</i> )         22         0.100         08         0.35           112         22 Apr         Brown hrasher arrival ( <i>Torgadytes acadea</i> )         22         -0.233         -0.76         0.45           116         26 Apr         Mores marigold first bloom ( <i>Caluna palastris</i> )         22         -0.133	79	20 Mar	Meadowlark arrival (Sturnella magna)	25	-0.121	-1.50	0.15	
50         21 Mar         For sparrow arrival ( <i>Pasarelle illaca</i> )         18         0.000         0.000         0.001           88         29 Mar         Phoche arrival ( <i>Caryle allyon</i> )         23 $-0.185$ $-1.87$ 0.09           91         1 Apr         Great blue heron arrival ( <i>Ardea herodias</i> )         13 $-0.185$ $-1.87$ 0.09           95         5 Apr         Kngtisher arrival ( <i>Caryle allyon</i> )         23 $-0.144$ $-1.43$ $0.17$ 101         11 Apr         Hoptian first bloom ( <i>Hoptica acutiliob</i> )         31 $-0.170$ $-2.13$ $0.041$ 103         11 Apr         Cowbird arrival ( <i>Monothus are</i> )         19 $-0.188$ $-1.70$ $0.011$ 108         18 Apr         Pusytoss first bloom ( <i>Alenome paten</i> )         24 $-0.036$ $-0.44$ $0.67^{11}$ 110         20 Apr         Duche arrival ( <i>Toologins acutilini</i> )         28 $-0.012$ $-0.133$ $-0.176$ $0.46^{11}$ 112         22 Apr         Brown thrasher arrival ( <i>Toologins acutilini</i> )         22 $-0.133$ $-1.70$ $0.02$ 112         2 Apr         Bellowort firb blo	80	21 Mar	Woodcock first peent (Scolopax minor)	27	-0.156	-2.04	$0.05^{\$}$	
88         29 Mar         Phoche arrival ( <i>Sayomin phoche)</i> 28         -0.299         -3.99         0.09           91         1 Apr         Great blue heron arrival ( <i>Ardea heroday</i> )         13         -0.185         -0.185         0.09           95         5 Apr         Kingfäsher arrival ( <i>Cople alcyon</i> )         23         -0.144         -1.43         0.17           101         11 Apr         Cowind arrival ( <i>Monothrus etar)</i> 14         -0.213         0.044           103         11 Apr         Cowind arrival ( <i>Monothrus etar)</i> 14         -0.213         0.045           106         15 Apr         Pasque flower first bloom ( <i>Ichennore patens</i> )         24         -0.036         -0.44         0.675           110         20 Apr         Dutchman's britches first bloom ( <i>Dicentra cucullaria</i> )         28         -0.037         -0.76         0.465           112         22 Apr         Brown firsthe arrival ( <i>Toxofouches aelan</i> )         24         -0.233         -1.71         0.10           119         29 Apr         Bellwort first bloom ( <i>Ubudaria grandiffon</i> )         19         -0.116         -1.27         0.22           120         30 Apr         Amelanchier first bloom ( <i>Vindaria grandiffon</i> )         2         -0.024         -0.044	80	21 Mar	Fox sparrow arrival ( <i>Passarella iliaca</i> )	18	0.000	0.00	0.00	
1         Apr         Great blue heron arrival (Arda herodias)         13         -0.185         -1.87         0.09           95         5 Apr         Kingfisher arrival (Ceryle alcyon)         23         -0.144         -1.43         0.17           101         11 Apr         Feptiain first bloom (Hepuica acculiolay)         31         -0.170         -2.13         0.044           103         11 Apr         Cowhird arrival (Monothrus acril)         14         0.231         2.12         0.036           105         15 Apr         Pasupe Clower first bloom (Anenome paton)         24         -0.036         -0.44         0.671           110         20 Apr         Towhe carrival (Pito cythorphhalmants)         22         0.100         0.89         0.385           112         22 Apr         Brown thrasher arrival (Tozlostyna accon)         24         -0.233         -0.76         0.46           116         26 Apr         Hones were arrival (Tozlostyna accon)         22         -0.133         -1.71         0.10           119         29 Apr         Bellwort first bloom (Cultur gradiforn)         19         -0.16         -1.27         0.22           120         30 Apr         Ameaheric first bloom (Clutur gradiforn)         22         -0.013	88	29 Mar	Phoebe arrival (Savornis phoebe)	28	-0.299	-3.99	0.09	
955 AprKingfisher arrival (Ceryle alcyon)23 $-0.144$ $-1.43$ $0.17$ 10111 AprPequica first bloom (Hequica acuiloba)31 $-0.170$ $-2.13$ $0.044$ 10311 AprCowhi arrival (Monothus atery)14 $0.231$ $0.213$ $0.044$ 10515 AprPasque flower first bloom (Anemana neglecta)24 $-0.036$ $-0.44$ $0.671$ 10818 AprPusytos first bloom (Anemana neglecta)28 $-0.142$ $-1.56$ $0.191$ 11020 AprDutchmark britches first bloom (Clocentra cucullaria)28 $-0.037$ $-0.67$ $0.467$ 1122.2 AprBrown thrasher arrival (Toxosomu rufum)28 $-0.037$ $-0.76$ $0.467$ 1162.6 AprMasth marigod first bloom (Cloudris grandiflom)24 $-0.233$ $-1.71$ $0.10$ 11929 AprBellwort first bloom (Cloudris grandiflom)19 $-0.116$ $-1.27$ $0.22$ 12030 AprAmelanchier first bloom (Cloudris lawricata)22 $-0.013$ $-0.044$ $0.008$ 1222 MayForest phlox first bloom (Chour largedua)10 $-0.0144$ $-0.34$ $0.041$ 1232 MayRose-broasted grobock arrival (Cargo gradula)10 $-0.0140$ $-0.34$ $0.741$ 1244 MayWood anemone first bloom (Linka pedua)10 $-0.040$ $-0.34$ $0.741$ 1255 MayNinther morio arrival (Cargo gradula)30 $-0.077$ $-1.52$ $0.024$ <t< td=""><td>91</td><td>1 Apr</td><td>Great blue heron arrival (<i>Ardea herodias</i>)</td><td>13</td><td>-0.185</td><td>-1.87</td><td>0.09</td></t<>	91	1 Apr	Great blue heron arrival ( <i>Ardea herodias</i> )	13	-0.185	-1.87	0.09	
101       11 Apr       Hepatica first bloom ( <i>Hepatica acuiloba</i> )       31 $-0.170$ $-2.13$ $0.048$ 103       11 Apr       Cowbid arrival ( <i>Monothrus aurery</i> )       14 $0.231$ $2.12$ $0.048$ 105       15 Apr       Pasue flower first bloom ( <i>Aneaman patens</i> )       19 $-0.188$ $-1.70$ $0.111$ 108       18 Apr       Pusytoes first bloom ( <i>Aneaman patens</i> )       24 $-0.036$ $-0.44$ $-1.36$ $0.191$ 110       20 Apr       Duchmarks britches first bloom ( <i>Dicentra cucullaria</i> )       28 $-0.142$ $-1.36$ $0.019$ 112       22 Apr       Brown thrasher arrival ( <i>Togologates acullan</i> )       24 $-0.233$ $-3.33$ $0.006$ 116       26 Apr       Marsh marigold first bloom ( <i>Calida palustrix</i> )       22 $-0.133$ $-1.71$ $0.10$ 122       2 May       Forest photo first bloom ( <i>Viada varicati</i> )       22 $-0.224$ $-3.44$ $0.018$ 123       3 May       Birdstoot violet first bloom ( <i>Viada varicati</i> )       22 $-0.244$ $-3.44$ $0.016$ 124       4 May       Mood aneanone first bloom ( <i>Viadia varicati</i> ) $10$ $-0$	95	5 Apr	Kingfisher arrival (Ceryle alcyon)	23	-0.144	-1.43	0.17	
103       11 Apr       Constrat arrival (Manothnes auer)       14       0.231       2.12       0.038         105       15 Apr       Passynchow Erist bloom (Antennaria neglecta)       24       -0.036       -0.44       0.671         110       20 Apr       Dutchmaris britches first bloom (Dicentra cucullaria)       28       -0.037       -1.36       0.11         110       20 Apr       Dutchmaris britches first bloom (Dicentra cucullaria)       28       -0.037       -0.76       0.446         112       22 Apr       Brown thrasher arrival (Toxostomum rufum)       23       -0.037       -0.76       0.464         116       26 Apr       Marsh marigold first bloom (Unlaria grandfforn)       24       -0.233       -3.33       0.069         112       29 Apr       Bellwort first bloom (Unlaria grandfforn)       19       -0.116       -1.27       0.22         120       30 Apr       Amelhanchier first bloom (Unlaria draristal)       26       -0.071       -0.09       0.337         122       2 May       Forest phos first bloom (Unlar draristal)       26       -1.128       -4.04       0.006         123       3 May       Birdstoot violet first bloom (Antenancia bluovicianus)       26       -0.242       -3.04       0.015	101	11 Apr	Hepatica first bloom ( <i>Hepatica acutiloba</i> )	31	-0.170	-2.13	0.04§	
105         15         Apr         Pasque flower first bloom (Ancenane patens)         19 $-0.188$ $-1.70$ 0.11           108         18         Apr         Pussytoes first bloom (Antennaria neglecta)         24 $-0.036$ $-0.44$ $0.57$ 110         20         Apr         Towhea arrival (Paplic orphrophthalamus)         22 $0.100$ $0.89$ $0.38$ 112         22         Apr         Brown thrasher arrival (Congloytes acedon)         24 $-0.233$ $-1.71$ $0.10$ 116         26         Apr         House were arrival (Congloytes acedon)         24 $-0.233$ $-1.71$ $0.10$ 117         Do on (Urularia grandifforn)         19 $-0.116$ $-1.27$ $0.22$ 120         30         Apr         Amclanchier first bloom (Vida divaricat)         22 $-0.242$ $-3.04$ $0.018$ 122         2 May         Forset pluko first bloom (Vida divaricat)         22 $-0.242$ $-3.04$ $0.018$ 123         3 May         Birdstoot violet first bloom (Vida pedata)         10 $-0.040$ $-3.32$ $0.024$ <	103	11 Apr	Cowbird arrival (Monothrus ater)	14	0.231	2.12	$0.05^{\$}$	
108         18 Apr         Pussytoes first bloom (Antennaria neglecto)         24 $-0.36$ $-0.44$ $0.67^{11}$ 110         20 Apr         Dutchman's britches first bloom (Dicentra cucullaria)         28 $-0.142$ $-1.36$ $0.19$ 110         20 Apr         Towhe arrival (Proglodytes action)         28 $-0.037$ $-0.76$ $0.44^{01}$ 116         26 Apr         House were arrival (Proglodytes action)         24 $-0.233$ $-0.133$ $-1.71$ $0.10$ 119         29 Apr         Bellwort first bloom (Cultularia grandfflorn)         19 $-0.116$ $-1.27$ $0.22$ 120         30 Apr         Amelanchicir first bloom (Plota divaricata)         25 $-0.071$ $-0.99$ $0.33^{11}$ 122         2 May         Forest phlox first bloom (Plota dedata)         15 $0.062$ $0.66$ $0.52^{11}$ 123         3 May         Birdsfoot violet first bloom (Plota pedata)         30 $-0.074$ $-1.67$ $0.11^{11}$ 124         4 May         Wood anemone first bloom (Antenne quinquefolia)         10 $-0.040$ $-0.34$ $0.20^{11}$	105	15 Apr	Pasque flower first bloom (Anemone patens)	19	-0.188	-1.70	0.11	
$        \begin{array}{ccccccccccccccccccccccccccccc$	108	18 Apr	Pussytoes first bloom (Antennaria neglecta)	24	-0.036	-0.44	0.67¶	
110       20 Apr       Towhec arrival ( <i>Pipilio erythraphthalamus</i> )       22       0.100       0.89       0.387         112       22 Apr       Brown thrasher arrival ( <i>Troglodytes aedon</i> )       24 $-0.293$ $-3.33$ 0.008         116       26 Apr       House wren arrival ( <i>Troglodytes aedon</i> )       24 $-0.293$ $-3.33$ 0.008         119       29 Apr       Bellwort first bloom ( <i>Cultua grandifira</i> )       19       0.116 $-1.27$ 0.22         120       30 Apr       Amelanchier first bloom ( <i>Viniar grandifira</i> )       22 $-0.212$ $-3.04$ 0.018         122       May       Rose-breasted grosbeak arrival ( <i>Pheticicus ludovicianus</i> )       26 $-0.128$ $-4.04$ 0.008         123       May       Birdstori violet first bloom ( <i>Viola gedata</i> )       10 $-0.040$ $-0.34$ $0.74^{H}$ 125       S May       Northern oriole arrival ( <i>Cerninulgus vociferus</i> )       17 $-0.107$ $-1.67$ $0.111$ 125       S May       Whip-poor-will arrival ( <i>Cerninulgus vociferus</i> )       16 $0.244$ 2.08 $0.06$ 127       7 May       Wood thrush arrival ( <i>Hylocical musclifarma</i> )       20 $-0.110$ $-1.28$	110	20 Apr	Dutchman's britches first bloom (Dicentra cucullaria)	28	-0.142	-1.36	0.19	
112       22 Apr       Brown thrasher arrival (Toxosionum rafiam)       28 $-0.037$ $-0.76$ 0.46 <sup>†</sup> 116       26 Apr       House wren arrival (Toxosionum rafiam)       24 $-0.233$ $-3.33$ 0.008         116       26 Apr       Marsh marigold first bloom (Cultha palustris)       22 $-0.133$ $-1.71$ 0.10         119       29 Apr       Bellwort first bloom (Inita farandfffan)       19 $-0.116$ $-1.27$ $0.22$ 120       30 Apr       Amelanchier first bloom (Inita divaricua)       22 $-0.071$ $-0.99$ $0.331$ 122       May       Rose-breasted grosbeak arrival (Pheacticus ludovicianus)       26 $-0.128$ $-4.04$ 0.008         123       May       Birdsfoot violet first bloom (Invia paradfform)       15       0.062 $0.655^{11}$ 124       4 May       Wood anemone first bloom (Anemone quinquefolia)       10 $-0.040$ $-0.34$ $0.74^{41}$ 125       5 May       Northern oriole arrival (Iderens galbula)       30 $-0.074$ $-1.67$ $0.11$ 125       5 May       Wolp-poor-will arrival (Iderens galbula)       20 $-0.100$ $-1.28$ $0.022$	110	20 Apr	Towhee arrival (Pipilio erythrophthalamus)	22	0.100	0.89	0.38¶	
11626 Apr (26 AprHouse wren arrival (Troglodyte: actor)24 $-0.293$ $-3.33$ $0.008$ 11626 AprMarsh marigold first bloom ( <i>Cultura jargnatiffora</i> )19 $-0.116$ $-1.27$ $0.22$ 2030 AprAmelanchier first bloom ( <i>Liularia grandiffora</i> )19 $-0.116$ $-1.27$ $0.22$ 21030 AprAmelanchier first bloom ( <i>Viola grandiffora</i> )22 $-0.071$ $-0.99$ $0.33^{11}$ 1222 MayForest phlox first bloom ( <i>Viola peduta</i> )15 $0.002$ $-0.66$ $0.52^{11}$ 1233 MayBirdsfoot violet first bloom ( <i>Viola peduta</i> )10 $-0.040$ $-0.34$ $0.74^{11}$ 1255 MayNorthern oriole arrival ( <i>Carsus galbula</i> )30 $-0.074$ $-1.32$ $0.028$ 1266 MayLarge trillium first bloom ( <i>Lithospermum canescens</i> )16 $0.244$ $2.08$ $0.066$ 1277 MayWood thrush arrival ( <i>Hylocicla mustelina</i> )20 $-0.110$ $-1.28$ $0.22$ 13212 MayColombic first bloom ( <i>Lithospermum canescens</i> )16 $0.244$ $0.36^{11}$ 13313 MayWild geranium first bloom ( <i>Carsuim maculatum</i> )24 $-0.064$ $-0.63$ $0.51^{11}$ 13313 MayWild geranium first bloom ( <i>Carsuim maculatum</i> )24 $-0.064$ $-0.63$ $0.51^{11}$ 13414 MayBlue-eyed grass first bloom ( <i>Oadcarbos metais</i> )23 $-0.081$ $0.94$ $0.36^{11}$ 13414 MayBlue-eyed grass first bloom ( <i>C</i>	112	22 Apr	Brown thrasher arrival (Toxostomum rufum)	28	-0.037	-0.76	$0.46^{\P}$	
11626 AprMarsh marigold first bloom (Caltha palustris)22 $-0.133$ $-1.71$ $0.10$ 11929 AprBellwort first bloom (Uvularia grandflora)19 $-0.116$ $-1.27$ $0.22$ 12030 AprAnnelanchier first bloom (Amelanchier lavis)25 $-0.071$ $-0.99$ $0.33^{T}$ 1222 MayForest phlox first bloom (Phlox divaricata)22 $-0.242$ $-3.04$ $0.018$ 1233 MayBirdsfoot viole first bloom (Viola pedata)15 $0.062$ $0.66$ $0.52^{T}$ 1244 MayWood anemone first bloom (Anemone quinquefolia)10 $-0.040$ $-0.34$ $0.74^{T}$ 1255 MayNorthern oriole arrival (Cerus galbula)30 $-0.074$ $-1.67$ $0.111$ 1255 MayNorthern oriole arrival (Cierus galbula)30 $-0.074$ $-1.67$ $0.111$ 1266 MayLarge trillium first bloom (Lithospernum canescens)16 $0.244$ $2.08$ $0.06$ 1277 MayWood thrush arrival (Chiccla musclina)20 $-0.110$ $-1.28$ $0.22$ 13212 MayColumbine first bloom (Aguilegia canadensis)25 $-0.013$ $-2.83$ $0.018$ 13313 MayWild geranium first bloom (Aguilegia canadensis)25 $-0.010$ $-1.28$ $0.22$ 13212 MayColumbine first bloom (Lagung percensi)23 $-0.081$ $-1.45$ $0.111$ 13313 MayWild geranium first bloom (Calus violaca)11 $0.030$ $0.24$	116	26 Apr	House wren arrival (Troglodytes aedon)	24	-0.293	-3.33	$0.00^{\$}$	
11929 AprBellwort first bloom (Unularia grandiflora)19 $-0.116$ $-1.27$ $0.22$ 12030 AprAmelanchier first bloom (Unularia grandiflora)25 $-0.071$ $-0.99$ $0.35^{*}$ 1222 MayForest phlo Kirst bloom (Phloa divaricata)22 $-0.242$ $-3.044$ $0.018$ 1222 MayRose-breasted grosbeak arrival (Pheucticus Indovicianus)26 $-0.128$ $-4.04$ $0.068$ 1233 MayBirdsfoot violet first bloom (Viola pedata)10 $-0.040$ $-0.34$ $0.74^{*}$ 1244 MayWood anemone first bloom (Anemone quinquefolia)10 $-0.040$ $-0.34$ $0.74^{*}$ 1255 MayNorthern oriole arrival (Carrinulgus vociferus)17 $-0.197$ $-2.52$ $0.028$ 1266 MayLarge trillium first bloom (Cillium grandifforum)25 $-0.105$ $-1.32$ $0.20$ 1277 MayWood thrush arrival (Choricla musclina)20 $-0.110$ $-1.28$ $0.22$ 13212 MayColumbine first bloom (Carania maculatum)24 $-0.064$ $-0.63$ $0.51^{*}$ 13313 MayWild geranium first bloom (Carania maculatum)24 $-0.064$ $-0.63$ $0.51^{*}$ 13313 MayWild geranium first bloom (Carania maculatum)24 $-0.064$ $-0.63$ $0.51^{*}$ 13414 MayBlue-eyed grass first bloom (Carania maculatum)23 $-0.081$ $-1.45$ $0.16$ 13616 MayLupine first bloom (Carania maculatum)<	116	26 Apr	Marsh marigold first bloom (Caltha palustris)	22	-0.133	-1.71	0.10	
12030 Åpr Process phlox first bloom (Amelanchier laevis)25 $-0.071$ $-0.99$ $0.33^{\circ}$ 1222 May Rose-breasted grosbeak arrival (Phetecticus ludovicianus)26 $-0.128$ $-4.04$ $0.008$ 1233 MayBirdsfoot violet first bloom (Viola pedata)15 $0.062$ $0.66$ $0.52^{\circ}$ 1244 May Wood anemone first bloom (Anemone quinquefolia)10 $-0.040$ $-0.34$ $0.74^{\circ}$ 1255 May S MayNorthero roloe arrival (Cerurs galbala)30 $-0.074$ $-1.67$ $0.11$ 1255 May S MayWhip-poor-will arrival (Caprimulgus vociferus)17 $-0.197$ $-2.52$ $0.028$ 1266 May Large trillium first bloom (Itilhospranum canescens)16 $0.244$ $2.08$ $0.06$ 1277 May V Mood thrush arrival (Hylocicla mustelina)20 $-0.110$ $-1.28$ $0.22$ 13212 May Columbine first bloom (Prunus virginiana)25 $-0.213$ $-2.83$ $0.018$ 13313 May Wild geranium first bloom (Geranium naculatum)24 $-0.064$ $-0.63$ $0.51^{\circ}$ 13414 May Blue-eyed grass first bloom (Daclas violacea)11 $0.030$ $0.24$ $0.28^{\circ}$ 13516 May V violet wood-sorrel first bloom (Daclas violacea)11 $0.030$ $0.24$ $0.24^{\circ}$ 13616 May V uper down of Karbonen canadensis)23 $-0.081$ $-1.45$ $0.16$ 13616 May V uper down of Karbonen (Caralium naculatum)24 $-0.034$	119	29 Apr	Bellwort first bloom (Uvularia grandiflora)	19	-0.116	-1.27	0.22	
1222May Rose-breasted grosbeak arrival (Pheucicus ludovicianus)22 $-0.242$ $-3.044$ $0.018$ 1233MayBirdsfoot violet first bloom (Viola pediata)15 $0.062$ $0.660$ $0.52^{2}$ 1244MayWood anemone first bloom (International pediata)10 $-0.040$ $-0.34$ $0.74^{4}$ 1255MayNorthern oriole arrival (Icterus galbula)30 $-0.074$ $-1.67$ $0.11$ 1255MayWhip-poor-will arrival (Caprimulgus vocients)17 $-0.079$ $-1.22$ $0.028$ 1266MayLarge trillium first bloom (Trillium grandiflorum)25 $-0.105$ $-1.32$ $0.20$ 1277MayHoary puccoon first bloom (Linhospermum cancecens)16 $0.244$ $2.08$ $0.06$ 12312MayChoke cherry first bloom (Geranium maculaturn)24 $-0.064$ $-0.63$ $0.51^{41}$ 13313MayWild geranium first bloom (Geranium maculaturn)24 $-0.064$ $-0.63$ $0.51^{41}$ 13414MayBlue-eyed grass first bloom (Capalis vialacea)11 $0.030$ $0.24$ $0.24$ $0.28^{21}$ 13616MayViolet wood-sorrel first bloom (Lupinus perennis)23 $-0.081$ $0.36^{41}$ 13514MayShooting star first bloom (Lupinus perennis)23 $-0.163$ $-2.24$ $0.028^{51}$ 13616MayViolet wood-sorrel first bloom (Logalis vialacea)11	120	30 Apr	Amelanchier first bloom (Amelanchier laevis)	25	-0.071	-0.99	0.33¶	
1222 MayRose-breasted grosbeak arrival (Pheucticus ludovicianus)26 $-0.128$ $-4.04$ $0.008$ 1233 MayBirdstoot violet first bloom (Viola pedua)15 $0.062$ $0.66$ $0.52^{\text{ff}}$ 1244 MayWood anemone first bloom (Anemone quinquefolia)10 $-0.040$ $-0.34$ $0.74^{\text{ff}}$ 1255 MayWhip-poor-will arrival (Caprimulgus vocifents)17 $-0.197$ $-2.52$ $0.028$ 1266 MayLarge trillium first bloom (Lithospermum canescens)16 $0.244$ $2.08$ $0.066$ 1277 MayHoary puccoon first bloom (Lithospermum canescens)16 $0.244$ $2.08$ $0.066$ 1277 MayWood thrush arrival (Hylocicla mustelina)20 $-0.110$ $-1.28$ $0.221$ 13212 MayColumbine first bloom (Aquilegia canadensis)25 $-0.213$ $-2.83$ $0.018$ 13313 MayWild geranium first bloom (Geranium maculatum)24 $-0.064$ $-0.63$ $0.51^{\text{ff}}$ 13414 MayBlue-eyed grass first bloom (Nagiryinchium campestre)23 $-0.081$ $-1.45$ $0.16$ 13616 MayLupine first bloom (Lupinus prennis)23 $-0.135$ $-2.10$ $0.035$ 13530 MaySpiderwort first bloom (Dodecatheon media)22 $-0.163$ $-2.84$ $0.028$ 14929 MayCanadian anemone first bloom (Anemone canadensis)23 $-0.135$ $-2.10$ $0.055$ 15030 MaySpiderwort first bloom (Car	122	2 May	Forest phlox first bloom ( <i>Phlox divaricata</i> )	22	-0.242	-3.04	0.01§	
1233 MayBirdsfoot violet first bloom (Viola pedata)150.0620.660.52 $^{\text{H}}$ 1244 MayWood anemone first bloom (Viola pedata)10 $-0.040$ $-0.34$ 0.74 $^{\text{H}}$ 1255 MayNorthern oriole arrival ( <i>Icterus galbula</i> )30 $-0.074$ $-1.67$ 0.111255 MayWhip-poor-will arrival ( <i>Ceprinulgus vociferus</i> )17 $-0.197$ $-2.52$ 0.0281266 MayLarge trillium first bloom ( <i>Trillium grandifforum</i> )25 $-0.105$ $-1.32$ 0.201277 MayHoary puccoon first bloom ( <i>Crunis visginiana</i> )180.1361.700.1113212 MayColumbine first bloom ( <i>Prunus visginiana</i> )180.1361.700.1113212 MayColumbine first bloom ( <i>Aquilegia canadensis</i> )25 $-0.213$ $-2.83$ 0.01813313 MayWild geranium first bloom ( <i>Caralis vialacea</i> )21 $-0.081$ $-0.44$ 0.8413616 MayLupine first bloom ( <i>Calis vialacea</i> )110.0300.240.85 $^{\text{H}}$ 13717 MayShooting star first bloom ( <i>Chalis vialacea</i> )21 $-0.145$ $-1.72$ 0.1014929 MayCanadian anemone first bloom ( <i>Alais vialacea</i> )21 $-0.145$ $-1.72$ 0.1014929 MayCanadian anemone first bloom ( <i>Alenone canadensis</i> )23 $-0.031$ $-2.44$ 0.03815030 MaySpiderwort first bloom ( <i>Calescantia ohiensis</i> )26 $-0.110$ $-1.8$	122	2 May	Rose-breasted grosbeak arrival ( <i>Pheucticus ludovicianus</i> )	26	-0.128	-4.04	0.00\$	
1244 MayWood anemone first bloom (Anemone quinquefolia)10 $-0.040$ $-0.34$ $0.74^{4}$ 1255 MayNorthern oriole arrival ( <i>Letrus galbula</i> )30 $-0.074$ $-1.67$ $0.11$ 1255 MayWhip-poor-will arrival ( <i>Caprimulgus vociferus</i> )17 $-0.197$ $-2.52$ $0.02^{8}$ 1266 MayLarge trillium first bloom ( <i>Trillium grandiforum</i> )25 $-0.105$ $-1.32$ $0.20$ 1277 MayWood thrush arrival ( <i>Hylocicla mustelina</i> )20 $-0.110$ $-1.28$ $0.22$ 13212 MayColumbine first bloom ( <i>Pranus vigniana</i> )18 $0.136$ $1.70$ $0.11$ 13212 MayColumbine first bloom ( <i>Aquilegia canadensis</i> )25 $-0.213$ $-2.83$ $0.01^{8}$ 13313 MayWild geranium first bloom ( <i>Geranium maculatum</i> )24 $-0.064$ $-0.63$ $0.51^{4}$ 13414 MayBlue-eyed grass first bloom ( <i>Calis violacea</i> )11 $0.030$ $0.24$ $0.36^{8}$ 13616 MayUojet wood-sorrel first bloom ( <i>Chais violacea</i> )11 $0.030$ $0.24$ $0.32^{8}$ 13517 MayShooting star first bloom ( <i>Chais violacea</i> )21 $-0.145$ $-1.22$ $0.163$ 13616 MayViolet wood-sorrel first bloom ( <i>Chais violacea</i> )21 $-0.145$ $-1.22$ $0.163$ 13616 MayViolet wood-sorrel first bloom ( <i>Chais violacea</i> )21 $-0.145$ $-1.22$ $0.163$ 13717 MayShooting star first bloom ( <i>Chai</i>	122	3 May	Birdsfoot violet first bloom ( <i>Viola pedata</i> )	15	0.062	0.66	0.52 <sup>¶</sup>	
1255 MayNorthern oriole arrival ( <i>leterus galbula</i> )30 $-0.074$ $-1.67$ $0.111$ 1255 MayWhip-poor-will arrival ( <i>leterus galbula</i> )30 $-0.074$ $-1.67$ $0.111$ 1255 MayWhip-poor-will arrival ( <i>leterus galbula</i> )17 $-0.197$ $-2.52$ $0.028$ 1266 MayLarge trillium first bloom ( <i>Trillium grandiflorum</i> )25 $-0.105$ $-1.32$ $0.20$ 1277 MayWood thrush arrival ( <i>Hylocicla nustelina</i> )20 $-0.110$ $-1.28$ $0.22$ 13212 MayChoke cherry first bloom ( <i>Aquilegia canadensis</i> )25 $-0.213$ $-2.83$ $0.018$ 13313 MayWild geranium first bloom ( <i>Geraniun maculatum</i> )24 $-0.064$ $-0.63$ $0.51^{\circ\circ}$ 13414 MayBlue-eyed grass first bloom ( <i>Sisyinchium campestre</i> )23 $-0.081$ $0.94$ $0.36^{\circ\circ}$ 13616 MayLupine first bloom ( <i>Lupinus perennis</i> )23 $-0.081$ $-1.45$ $0.16$ 13616 MayLupine first bloom ( <i>Dadecatheon media</i> )22 $-0.163$ $-2.44$ $0.028^{\circ}$ 13717 MayShooting star first bloom ( <i>Hax philosa</i> )21 $-0.145$ $-1.72$ $0.10^{\circ\circ}$ 14323 MayPink prairie phlos first bloom ( <i>Hax philosa</i> )23 $-0.135$ $-2.10$ $0.058$ 15030 MaySpiderwort first bloom ( <i>Lagiscantia ohiensis</i> )23 $-0.135$ $-2.10$ $0.058$ 1532 JunSneder first bloom ( <i>Rasa carolina</i> )2	124	4 May	Wood anemone first bloom (Anemone auinquefolia)	10	-0.040	-0.34	0 74¶	
1255 MayWhip-porwill arrival (Caprinulgus vociferus)17 $-0.197$ $1.25$ $0.028$ 1266 MayLarge trillium first bloom ( <i>Culinospermum canescens</i> )16 $0.244$ $2.08$ $0.06$ 1277 MayWood thrush arrival ( <i>Hylocicla mustelina</i> )20 $-0.110$ $-1.28$ $0.22$ 13212 MayChoke cherry first bloom ( <i>Prunus virginiana</i> )18 $0.136$ $1.70$ $0.111$ 13212 MayChoke cherry first bloom ( <i>Geranium maculatum</i> )24 $-0.064$ $-0.63$ $0.511$ 13313 MayWild geranium first bloom ( <i>Siryinchium canestre</i> )23 $-0.081$ $0.44$ $0.361$ 13616 MayLupine first bloom ( <i>Lupinus peremis</i> )23 $-0.081$ $-1.45$ $0.16$ 13616 MayViolet wood-sorrel first bloom ( <i>Cualis violacea</i> )11 $0.030$ $0.24$ $0.821$ 13717 MayShooting star first bloom ( <i>Lupinus peremis</i> )23 $-0.163$ $-2.44$ $0.058$ 14323 MayPink prairie phlox first bloom ( <i>Anex peremis</i> )23 $-0.163$ $-2.44$ $0.058$ 15030 MaySpiderwort first bloom ( <i>Tradescantia ohiensis</i> )23 $-0.135$ $-2.10$ $0.058$ 15030 MaySpiderwort first bloom ( <i>Rades carolina</i> )23 $0.031$ $0.49$ $0.637$ 1532 JunRose first bloom ( <i>Rades carolina</i> )25 $-0.295$ $-3.96$ $0.008$ 1547 JunRade carolina)25 $-0.295$ $-3.96$	125	5 May	Northern oriole arrival (Icterus galbula)	30	-0.074	-1.67	0.11	
1205 MayWintp Dot wint at Na (cup mining is volgens)170.1572.120.0521277 MayHoary puccoon first bloom (Lithospermum canescens)160.2442.080.061277 MayHoary puccoon first bloom (Lithospermum canescens)160.2442.080.061277 MayWood thrush arrival ( <i>Hylocicla mustelina</i> )20 $-0.110$ $-1.28$ 0.2213212 MayColumbine first bloom ( <i>Panus virginiana</i> )180.1361.700.1113313 MayWild geranium first bloom ( <i>Geranium maculatum</i> )24 $-0.064$ $-0.63$ 0.51 <sup>#</sup> 13414 MayBlue-eyed grass first bloom ( <i>Siryinchium campestre</i> )23 $-0.081$ $-1.45$ 0.1613616 MayLupine first bloom ( <i>Dadecatheon media</i> )22 $-0.163$ $-2.44$ $0.02^{8}$ 13717 MayShooting star first bloom ( <i>Dadecatheon media</i> )21 $-0.145$ $-1.72$ $0.00^{8}$ 14323 MayPink prairie phlox first bloom ( <i>Anemone canadensis</i> )23 $-0.013$ $-2.44$ $0.02^{8}$ 15030 MaySpiderwort first bloom ( <i>Tradescantia ohiensis</i> )26 $-0.110$ $-1.80$ $0.08$ 1521 JunRose first bloom ( <i>Rosa carolina</i> )23 $-0.031$ $0.24$ $0.32^{8}$ 15030 MaySpiderwort first bloom ( <i>Rosa carolina</i> )23 $-0.132$ $-2.10$ $0.05^{8}$ 15030 MaySpiderwort first bloom ( <i>Rosa carolina</i> )25 $-0.205$	125	5 May	Whip poor will arrival (Caprimulaus vocifarus)	17	-0.107	-2.52	0.11	
1200 MayLage finitum first blom ( <i>Initian galadijostun</i> )2.5-0.105-1.520.201277 MayHoary puccoon first blom ( <i>Lihospernum canescens</i> )160.2442.080.061277 MayWood thrush arrival ( <i>Hylocicla mustelina</i> )20-0.110-1.280.2213212 MayChoke cherry first bloom ( <i>Prunus virginiana</i> )180.1361.700.1113212 MayColumbine first bloom ( <i>Aquilegia canadensis</i> )25-0.213-2.830.01813313 MayWild geranium first bloom ( <i>Geranium maculatum</i> )24-0.064-0.630.51 <sup>¶</sup> 13414 MayBlue-eyed grass first bloom ( <i>Cisryinchium campestre</i> )23-0.081-1.450.1613616 MayLupine first bloom ( <i>Dodecatheon media</i> )22-0.163-2.440.02813717 MayShooting star first bloom ( <i>Dodecatheon media</i> )21-0.145-1.720.1014929 MayCanadian anemone first bloom ( <i>Phlox philosa</i> )21-0.145-1.720.1014929 MaySpidetwort first bloom ( <i>Rescantia ohiensis</i> )23-0.0310.490.63 <sup>¶</sup> 15030 MaySpidetwort first bloom ( <i>Rescantia ohiensis</i> )23-0.010-1.800.081521 JunRose first bloom ( <i>Rescantia ohiensis</i> )23-0.0310.490.63 <sup>¶</sup> 1532 JunSpidetwort first bloom ( <i>Rescantia ohiensis</i> )130.0120.140.39 <sup>¶</sup> 1565	125	6 May	Large trillium first bloom (Trillium grandiflorum)	25	-0.105	_1.32	0.02*	
1277May Wood thrush arrival (Hylocical unstelina)20 $-0.110$ $-1.28$ $0.22$ 13212May Columbine first bloom ( <i>Prunus virginiana</i> )18 $0.136$ $1.70$ $0.11$ 13212May Columbine first bloom ( <i>Aquilegia canadensis</i> )25 $-0.213$ $-2.83$ $0.018$ 13313May Wild geranium first bloom ( <i>Ceranium maculatum</i> )24 $-0.064$ $-0.63$ $0.51^{m}$ 13414May Blue-eyed grass first bloom ( <i>Lupinus peremis</i> )23 $-0.081$ $0.94$ $0.36^{m}$ 13616May Violet wood-sorrel first bloom ( <i>Dodecatheon media</i> )22 $-0.163$ $-2.44$ $0.02^{g}$ 13717May Shooting star first bloom ( <i>Dodecatheon media</i> )21 $-0.145$ $-1.72$ $0.05^{g}$ 14323MayPink prairie phlox first bloom ( <i>Anemone canadensis</i> )23 $-0.135$ $-2.10$ $0.05^{g}$ 15030MaySpiderwort first bloom ( <i>Tradescatia ohiensis</i> )26 $-0.110$ $-1.80$ $0.08^{g}$ 1521JunRose first bloom ( <i>Resa carolina</i> )23 $0.031$ $0.49$ $0.39^{m}$ 1532JunSheder pentstemon first bloom ( <i>Pentstemon gracilis</i> )13 $0.012$ $0.14$ $0.39^{m}$ 1531JunRose first bloom ( <i>Achilae millefoliun</i> )15 $0.142$ $0.47$ $0.64^{m}$ 16312JunDairy fleabane first bloom ( <i>Cargeron striigosus</i> )12 $0.020$ $0.31$ $0$	120	7 May	Hoary puccoon first bloom ( <i>Lithospermum canescens</i> )	16	0.105	2.08	0.20	
12714 MayWood finitial arrival (rybotchi misselinit)200.1101.230.22113212 MayColumbine first bloom (Aquilegia canadensis)25 $-0.213$ $-2.83$ 0.01813313 MayWild geranium first bloom (Geranium maculatum)24 $-0.064$ $-0.63$ 0.51f13414 MayBlue-eyed grass first bloom (Sisryinchium campestre)23 $-0.081$ $0.94$ $0.36^{9}$ 13616 MayLupine first bloom (Lupinus perennis)23 $-0.081$ $-1.45$ $0.16$ 13616 MayViolet wood-sorrel first bloom (Oxalis violacea)11 $0.030$ $0.24$ $0.82^{9}$ 13717 MayShooting star first bloom (Dadecatheon media)22 $-0.163$ $-2.44$ $0.028$ 14323 MayPink prairie phlox first bloom (Anemone canadensis)23 $-0.135$ $-2.10$ $0.058$ 15030 MaySpiderwort first bloom (Tradescantia ohiensis)26 $-0.110$ $-1.80$ $0.08$ 1521 JunRose first bloom (Radia canelina)25 $-0.295$ $-3.96$ $0.08$ 1532 JunSlender pentstemon first bloom (Patheson gracilis)13 $0.012$ $0.14$ $0.39^{9}$ 1565 JunBaptisia first bloom (Carpanula network) for 0.16116 $0.037$ $0.47$ $0.64^{9}$ 16312 JunDaisy fleabane first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^{9}$ 16312 JunHarebell first bloom (Campanula rotundifolia) <td< td=""><td>127</td><td>7 May</td><td>Wood thrush arrival (Hylocicla mustaling)</td><td>20</td><td>-0.110</td><td>-1.28</td><td>0.22</td></td<>	127	7 May	Wood thrush arrival (Hylocicla mustaling)	20	-0.110	-1.28	0.22	
13212MayCelobe clierly first bloom ( <i>Aquilegia canadensis</i> )160.1301.700.01113212MayColumbine first bloom ( <i>Aquilegia canadensis</i> )25 $-0.213$ $-2.83$ 0.01813313MayWild geranium first bloom ( <i>Geranium maculatum</i> )24 $-0.064$ $-0.63$ 0.51¶13414MayBlue-eyed grass first bloom ( <i>Lupinus perennis</i> )23 $-0.081$ $0.94$ 0.36¶13616MayLupine first bloom ( <i>Lupinus perennis</i> )23 $-0.081$ $-1.45$ 0.1613616MayViolet wood-sorrel first bloom ( <i>Dadies violacea</i> )110.0300.240.82¶13717MayShooting star first bloom ( <i>Dadecatheon media</i> )22 $-0.163$ $-2.44$ 0.02\$14323MayPink prairie phlox first bloom ( <i>Anemone canadensis</i> )23 $-0.135$ $-2.10$ 0.05\$15030MaySpiderwort first bloom ( <i>Tradescantia ohiensis</i> )26 $-0.110$ $-1.80$ 0.081521JunRose first bloom ( <i>Rosa carolina</i> )23 $0.031$ 0.490.63¶1532JunSlender pentstemon first bloom ( <i>Perstemon graciis</i> )130.0120.140.39¶1565JunBaptisia first bloom ( <i>Achillea millefolium</i> )15 $0.142$ 0.470.16¶16312JunDaisy fleabane first bloom ( <i>Campanula rotundifolia</i> )190.0370.470.64¶167 <t< td=""><td>127</td><td>12 May</td><td>Choka charry first bloom (Prunus virginiang)</td><td>20</td><td>-0.110</td><td>-1.28</td><td>0.22</td></t<>	127	12 May	Choka charry first bloom (Prunus virginiang)	20	-0.110	-1.28	0.22	
13212 MayColumbine first bloom (Aquilegia candaents)25 $-0.213$ $-2.23$ $0.013$ 13313 MayWild geranium first bloom (Geranium maculatum)24 $-0.064$ $-0.63$ $0.51^{\dagger}$ 13414 MayBlue-eyed grass first bloom (Sisryinchium campeste)23 $-0.081$ $0.94$ $0.36^{\dagger}$ 13616 MayLupine first bloom (Lupinus perennis)23 $-0.081$ $-1.45$ $0.16$ 13616 MayViolet wood-sorrel first bloom (Dadecatheon media)22 $-0.163$ $-2.44$ $0.02^{\$}$ 13717 MayShooting star first bloom (Dadecatheon media)21 $-0.145$ $-1.72$ $0.10$ 14929 MayCanadian anemone first bloom (Anemone canadensis)23 $-0.135$ $-2.10$ $0.05^{\$}$ 15030 MaySpiderwort first bloom (Tradescantia ohiensis)26 $-0.110$ $-1.80$ $0.08$ 1521 JunRose first bloom (Rosa carolina)23 $0.031$ $0.49$ $0.63^{\$}$ 1532 JunSlender pentstemon first bloom (Pentstemon gracilis)13 $0.012$ $0.14$ $0.39^{\$}$ 1565 JunBaptisia first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^{\$}$ 16312 JunDaisy fleabane first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^{\$}$ 16312 JunHarebell first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^{\$}$ 16410 JunFlowering spurge first bloom (Campa	132	12 May	Colore cherry first bloom (Frunus Virginiuna)	10	0.150	1.70	0.11	
15315 MayWild geranium first bloom (Geranium maculatum)24 $-0.064$ $-0.63$ $0.51^{\circ}$ 13414 MayBlue-eyed grass first bloom (Sisryinchium campestre)23 $-0.081$ $0.94$ $0.36^{\circ}$ 13616 MayLupine first bloom (Lupinus perennis)23 $-0.081$ $-1.45$ $0.16$ 13616 MayViolet wood-sorrel first bloom (Odelas violacea)11 $0.030$ $0.24$ $0.82^{\circ}$ 13717 MayShooting star first bloom (Dedecatheon media)22 $-0.163$ $-2.44$ $0.02^{\circ}$ 14323 MayPink prairie phlox first bloom (Anemone canadensis)23 $-0.135$ $-2.10$ $0.05^{\circ}$ 15030 MaySpiderwort first bloom (Tradescantia ohiensis)26 $-0.110$ $-1.80$ $0.08^{\circ}$ 1521 JunRose first bloom (Rosa carolina)23 $0.031$ $0.49$ $0.63^{\circ}$ 1532 JunSlender pentstemon first bloom (Pentstemon gracilis)13 $0.012$ $0.14$ $0.39^{\circ}$ 1565 JunBaptisia first bloom (Baptisia leucantha)25 $-0.295$ $-3.96$ $0.008$ 1587 JunYarrow first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.47^{\circ}$ 16312 JunDaisy fleabane first bloom (Campanula rotundifolia)19 $0.037$ $0.47^{\circ}$ 16312 JunHarebell first bloom (Campanula rotundifolia)19 $0.037$ $0.47^{\circ}$ 16416 JunFlowering spurge first bloom (Acclepias tuberosa)25 <td>132</td> <td>12 May</td> <td>Columbine first bloom (Aquilegia canadensis)</td> <td>25</td> <td>-0.213</td> <td>-2.83</td> <td>0.018</td>	132	12 May	Columbine first bloom (Aquilegia canadensis)	25	-0.213	-2.83	0.018	
13414 MayBinde-eyed grass first bloom (Stryinchiam campeshe)25 $-0.061$ $0.94$ $0.50^{-1}$ 13616 MayLupine first bloom (Lupinus perennis)23 $-0.081$ $-1.45$ $0.16$ 13616 MayViolet wood-sorrel first bloom (Oxalis violacea)11 $0.030$ $0.24$ $0.82^{\$}$ 13717 MayShooting star first bloom (Dodecatheon media)22 $-0.163$ $-2.44$ $0.02^{\$}$ 14323 MayPink prairie phlox first bloom (Phlox philosa)21 $-0.145$ $-1.72$ $0.10$ 14929 MayCanadian anemone first bloom (Anemone canadensis)23 $-0.135$ $-2.10$ $0.05^{\$}$ 15030 MaySpiderwort first bloom (Tradescantia ohiensis)26 $-0.110$ $-1.80$ $0.08$ 1521 JunRose first bloom (Rosa carolina)23 $0.031$ $0.49$ $0.63^{\$}$ 1532 JunSlender pentstemon first bloom (Pentstemon gracilis)13 $0.012$ $0.14$ $0.39^{\$}$ 1565 JunBaptisia first bloom (Achilea millefolium)15 $0.142$ $0.47$ $0.16^{\$}$ 16312 JunDaisy fleabane first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^{\$}$ 16716 JunFlowering spurge first bloom (Campanula rotundifolia)10 $-0.046$ $-0.41$ $0.69^{\$}$ 17423 JunDogbane first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.008$ 17625 JunButterfly weed first bloom (Asclep	133	13 May	Wild geranium first bloom (Geranium maculatum)	24	-0.064	-0.63	0.51	
13616 MayLupine first bloom (Lupinus perenns)23 $-0.081$ $-1.45$ $0.16$ 13616 MayViolet wood-sorrel first bloom (Oxalis violacea)11 $0.030$ $0.24$ $0.82^{11}$ 13717 MayShooting star first bloom (Dodecatheon media)22 $-0.163$ $-2.44$ $0.02^{21}$ 14323 MayPink prairie phlox first bloom (Phlox philosa)21 $-0.145$ $-1.72$ $0.10$ 14929 MayCanadian anemone first bloom (Anemone canadensis)23 $-0.135$ $-2.10$ $0.05^{8}$ 15030 MaySpiderwort first bloom (Tradescantia ohiensis)26 $-0.110$ $-1.80$ $0.08$ 1521 JunRose first bloom (Rosa carolina)23 $0.031$ $0.49$ $0.63^{11}$ 1532 JunSlender pentstemon first bloom (Pentstemon gracilis)13 $0.012$ $0.14$ $0.39^{11}$ 1565 JunBaptisia first bloom (Baptisia leucantha)25 $-0.295$ $-3.96$ $0.00^{8}$ 16312 JunDaisy fleabane first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^{11}$ 16312 JunHarebell first bloom (Campanula rotundifolia)20 $0.087$ $0.75$ $0.47^{11}$ 164190.0370.47 $0.64^{11}$ $15$ $0.142$ $-0.132$ $-2.15$ $0.04^{8}$ 17423 JunDogbane first bloom (Campanula rotundifolia)20 $0.087$ $0.75$ $0.47^{11}$ 16519Butterfly weed first bloom (Apcynum	134	14 May	Blue-eyed grass first bloom ( <i>Sisryinchium cumpesire</i> )	23	-0.081	0.94	0.50*	
13616 MayViolet wood-sorrel first bloom (Oxalis violacea)110.0300.240.82 <sup>m</sup> 13717 MayShooting star first bloom (Oxalis violacea)22 $-0.163$ $-2.44$ 0.02 <sup>§</sup> 14323 MayPink prairie phlox first bloom (Phlox philosa)21 $-0.145$ $-1.72$ 0.1014929 MayCanadian anemone first bloom (Anemone canadensis)23 $-0.135$ $-2.10$ 0.05 <sup>§</sup> 15030 MaySpiderwort first bloom (Tradescantia ohiensis)26 $-0.110$ $-1.80$ 0.081521 JunRose first bloom (Rosa carolina)23 $0.031$ $0.49$ $0.63^m$ 1532 JunSlender pentstemon first bloom (Pentstemon gracilis)13 $0.012$ $0.14$ $0.39^m$ 1565 JunBaptisia first bloom (Baptisia leucantha)25 $-0.295$ $-3.96$ $0.008$ 1587 JunYarrow first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^m$ 16312 JunDaisy fleabane first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^m$ 16418 JunRudbeckia first bloom (Rudbeckia hirta)24 $-0.132$ $-2.15$ $0.04^s$ 17423 JunDogbane first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.06^s$ 17625 JunButterfly weed first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.06^s$ 17625 JunButterfly weed first bloom (Asclepias syriaca)17 $-0.206$ <td>136</td> <td>16 May</td> <td>Lupine first bloom (Lupinus perennis)</td> <td>23</td> <td>-0.081</td> <td>-1.45</td> <td>0.16</td>	136	16 May	Lupine first bloom (Lupinus perennis)	23	-0.081	-1.45	0.16	
13717 MayShooting star first bloom (Dodecatheon media)22 $-0.163$ $-2.44$ $0.02^8$ 14323 MayPink prairie phlox first bloom (Phlox philosa)21 $-0.145$ $-1.72$ $0.10$ 14929 MayCanadian anemone first bloom (Anemone canadensis)23 $-0.135$ $-2.10$ $0.05^8$ 15030 MaySpiderwort first bloom (Tradescantia ohiensis)26 $-0.110$ $-1.80$ $0.08$ 1521 JunRose first bloom (Rosa carolina)23 $0.031$ $0.49$ $0.63^{\$}$ 1532 JunSlender pentstemon first bloom (Pentstemon gracilis)13 $0.012$ $0.14$ $0.39^{\$}$ 1565 JunBaptisia first bloom (Achillea millefolium)25 $-0.295$ $-3.96$ $0.008$ 1587 JunYarrow first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^{\$}$ 16312 JunDaisy fleabane first bloom (Eugeron striigosus)12 $0.020$ $0.31$ $0.77^{\$}$ 16312 JunHarebell first bloom (Eughorbia corollata)20 $0.087$ $0.75$ $0.47^{\$}$ 16918 JunRudbeckia first bloom (Audbeckia hirta)24 $-0.132$ $-2.15$ $0.04^{\$}$ 17423 JunDogbane first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.008^{\$}$ 17625 JunButterfly weed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.23^{\$}$ 17625 JunSt. Johns wort first bloom (Asclepias syriaca)1	136	16 May	Violet wood-sorrel first bloom (Oxalis violacea)	11	0.030	0.24	0.821	
14323 MayPink prairie phlox first bloom ( <i>Phlox philosa</i> )21 $-0.145$ $-1.72$ $0.10$ 14929 MayCanadian anemone first bloom ( <i>Anemone canadensis</i> )23 $-0.135$ $-2.10$ $0.05$ 15030 MaySpiderwort first bloom ( <i>Tradescantia ohiensis</i> )26 $-0.110$ $-1.80$ $0.08$ 1521 JunRose first bloom ( <i>Rosa carolina</i> )23 $0.031$ $0.49$ $0.63$ 1532 JunSlender pentstemon first bloom ( <i>Pentstemon gracilis</i> )13 $0.012$ $0.14$ $0.39$ 1565 JunBaptisia first bloom ( <i>Achillea millefolium</i> )15 $0.142$ $0.47$ $0.16$ 16312 JunDaisy fleabane first bloom ( <i>Erigeron striigosus</i> )12 $0.020$ $0.31$ $0.77$ 16312 JunHarebell first bloom ( <i>Campanula rotundifolia</i> )19 $0.037$ $0.47$ $0.64$ 16716 JunFlowering spurge first bloom ( <i>Rudbeckia hirta</i> )24 $-0.132$ $-2.15$ $0.04$ 17423 JunDogbane first bloom ( <i>Rudbeckia hirta</i> )24 $-0.132$ $-2.15$ $0.04$ 17423 JunDogbane first bloom ( <i>Asclepias suberosa</i> )25 $-0.300$ $-4.43$ $0.08$ 17625 JunButterfly weed first bloom ( <i>Asclepias syriaca</i> )17 $-0.206$ $-2.49$ $0.02$ 17625 JunSt. Johns wort first bloom ( <i>Asclepias syriaca</i> )17 $-0.206$ $-2.49$ $0.02$ 17726 JunCommon milkweed first bloom ( <i>Linaria vulgaris</i> )12 </td <td>137</td> <td>17 May</td> <td>Shooting star first bloom (Dodecatheon media)</td> <td>22</td> <td>-0.163</td> <td>-2.44</td> <td>0.02§</td>	137	17 May	Shooting star first bloom (Dodecatheon media)	22	-0.163	-2.44	0.02§	
14929 MayCanadian anemone first bloom (Anemone canadensis)23 $-0.135$ $-2.10$ $0.05$ 15030 MaySpiderwort first bloom (Tradescantia ohiensis)26 $-0.110$ $-1.80$ $0.08$ 1521 JunRose first bloom (Rosa carolina)23 $0.031$ $0.49$ $0.63$ 1532 JunSlender pentstemon first bloom (Pentstemon gracilis)13 $0.012$ $0.14$ $0.39$ 1565 JunBaptisia first bloom (Baptisia leucantha)25 $-0.295$ $-3.96$ $0.00$ 1587 JunYarrow first bloom (Achillea millefolium)15 $0.142$ $0.47$ $0.16$ 16312 JunDaisy fleabane first bloom (Erigeron striigosus)12 $0.020$ $0.31$ $0.77$ 16312 JunHarebell first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64$ 16716 JunFlowering spurge first bloom (Euphorbia corollata)20 $0.087$ $0.75$ $0.47$ 16918 JunRudbeckia first bloom (Audbeckia hirta)24 $-0.132$ $-2.15$ $0.04$ 17423 JunDogbane first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.00$ 17625 JunButterfly weed first bloom (Hypericum perforatum)16 $-0.012$ $-0.15$ $0.89$ 17726 JunCommon milkweed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02$ 18029 JunButter-and-eggs first bloom (Asclepias syriaca)15 $-0.213$ $-3$	143	23 May	Pink prairie phlox first bloom ( <i>Phlox philosa</i> )	21	-0.145	-1.72	0.10	
15030 MaySpiderwort first bloom ( <i>Tradescantia ohiensis</i> )26 $-0.110$ $-1.80$ 0.081521 JunRose first bloom ( <i>Rosa carolina</i> )23 $0.031$ $0.49$ $0.63^{\texttt{H}}$ 1532 JunSlender pentstemon first bloom ( <i>Pentstemon gracilis</i> )13 $0.012$ $0.14$ $0.39^{\texttt{H}}$ 1565 JunBaptisia first bloom ( <i>Baptisia leucantha</i> )25 $-0.295$ $-3.96$ $0.00^{\$}$ 1587 JunYarrow first bloom ( <i>Achillea millefolium</i> )15 $0.142$ $0.47$ $0.16^{\texttt{H}}$ 16312 JunDaisy fleabane first bloom ( <i>Erigeron striigosus</i> )12 $0.020$ $0.31$ $0.77^{\texttt{H}}$ 16312 JunHarebell first bloom ( <i>Campanula rotundifolia</i> )19 $0.037$ $0.47$ $0.64^{\texttt{H}}$ 16716 JunFlowering spurge first bloom ( <i>Rudbeckia hirta</i> )24 $-0.132$ $-2.15$ $0.04^{\$}$ 17423 JunDogbane first bloom ( <i>Acclepias tuberosa</i> )25 $-0.300$ $-4.43$ $0.00^{\$}$ 17625 JunButterfly weed first bloom ( <i>Asclepias tuberosa</i> )25 $-0.300$ $-4.43$ $0.00^{\$}$ 17726 JunCommon milkweed first bloom ( <i>Asclepias syriaca</i> )17 $-0.206$ $-2.49$ $0.02^{\$}$ 18029 JunButter-and-eggs first bloom ( <i>Linaria vulgaris</i> )12 $0.041$ $0.23$ $0.23^{\texttt{H}}$ 18130 JunMarsh milkweed first bloom ( <i>Asclepias incarnata</i> )15 $-0.213$ $-3.69$ $0.00^{\$}$	149	29 May	Canadian anemone first bloom (Anemone canadensis)	23	-0.135	-2.10	0.05§	
1521 JunRose first bloom (Rosa carolina)23 $0.031$ $0.49$ $0.63^{\$}$ 1532 JunSlender pentstemon first bloom (Pentstemon gracilis)13 $0.012$ $0.14$ $0.39^{\$}$ 1565 JunBaptisia first bloom (Baptisia leucantha)25 $-0.295$ $-3.96$ $0.00^{\$}$ 1587 JunYarrow first bloom (Achillea millefolium)15 $0.142$ $0.47$ $0.16^{\$}$ 16312 JunDaisy fleabane first bloom (Erigeron striigosus)12 $0.020$ $0.31$ $0.77^{\$}$ 16312 JunHarebell first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^{\$}$ 16716 JunFlowering spurge first bloom (Euphorbia corollata)20 $0.087$ $0.75$ $0.47^{\$}$ 16918 JunRudbeckia first bloom (Rudbeckia hirta)24 $-0.132$ $-2.15$ $0.04^{\$}$ 17423 JunDogbane first bloom (Acclepias tuberosa)25 $-0.300$ $-4.43$ $0.00^{\$}$ 17625 JunButterfly weed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02^{\$}$ 17726 JunCommon milkweed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02^{\$}$ 18029 JunButter-and-eggs first bloom (Linaria vulgaris)12 $0.041$ $0.23$ $0.23^{\$}$ 18130 JunMarsh milkweed first bloom (Asclepias incarnata)15 $-0.213$ $-3.69$ $0.00^{\$}$	150	30 May	Spiderwort first bloom (Tradescantia ohiensis)	26	-0.110	-1.80	0.08	
1532 JunSlender pentstemon first bloom (Pentstemon gracilis)13 $0.012$ $0.14$ $0.39^{\P}$ 1565 JunBaptisia first bloom (Baptisia leucantha)25 $-0.295$ $-3.96$ $0.00^{\$}$ 1587 JunYarrow first bloom (Achillea millefolium)15 $0.142$ $0.47$ $0.16^{\P}$ 16312 JunDaisy fleabane first bloom (Erigeron striigosus)12 $0.020$ $0.31$ $0.77^{\P}$ 16312 JunHarebell first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^{\P}$ 16716 JunFlowering spurge first bloom (Euphorbia corollata)20 $0.087$ $0.75$ $0.47^{\P}$ 16918 JunRudbeckia first bloom (Rudbeckia hirta)24 $-0.132$ $-2.15$ $0.04^{\$}$ 17423 JunDogbane first bloom (Acclepias tuberosa)25 $-0.300$ $-4.43$ $0.00^{\$}$ 17625 JunButterfly weed first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.00^{\$}$ 17726 JunCommon milkweed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.28^{\$}$ 18029 JunButter-and-eggs first bloom (Linaria vulgaris)12 $0.041$ $0.23$ $0.23^{\P}$ 18130 JunMarsh milkweed first bloom (Asclepias incarnata)15 $-0.213$ $-3.69$ $0.00^{\$}$	152	1 Jun	Rose first bloom (Rosa carolina)	23	0.031	0.49	0.63¶	
1565 JunBaptisia first bloom ( <i>Baptisia leucantha</i> )25 $-0.295$ $-3.96$ $0.00\$$ 1587 JunYarrow first bloom ( <i>Achillea millefolium</i> )15 $0.142$ $0.47$ $0.16$ ¶16312 JunDaisy fleabane first bloom ( <i>Erigeron striigosus</i> )12 $0.020$ $0.31$ $0.77$ ¶16312 JunHarebell first bloom ( <i>Campanula rotundifolia</i> )19 $0.037$ $0.47$ $0.64$ ¶16716 JunFlowering spurge first bloom ( <i>Euphorbia corollata</i> )20 $0.087$ $0.75$ $0.47$ ¶16918 JunRudbeckia first bloom ( <i>Rudbeckia hirta</i> )24 $-0.132$ $-2.15$ $0.04\$$ 17423 JunDogbane first bloom ( <i>Acclepias tuberosa</i> )25 $-0.300$ $-4.43$ $0.00\$$ 17625 JunButterfly weed first bloom ( <i>Asclepias syriaca</i> )17 $-0.206$ $-2.49$ $0.02\$$ 17726 JunCommon milkweed first bloom ( <i>Asclepias syriaca</i> )17 $-0.206$ $-2.49$ $0.02\$$ 18029 JunButter-and-eggs first bloom ( <i>Asclepias incarnata</i> )15 $-0.213$ $-3.69$ $0.00\$$	153	2 Jun	Slender pentstemon first bloom (Pentstemon gracilis)	13	0.012	0.14	0.39¶	
1587 JunYarrow first bloom (Achillea millefolium)15 $0.142$ $0.47$ $0.16^{\$}$ 16312 JunDaisy fleabane first bloom (Erigeron striigosus)12 $0.020$ $0.31$ $0.77^{\$}$ 16312 JunHarebell first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64^{\$}$ 16716 JunFlowering spurge first bloom (Euphorbia corollata)20 $0.087$ $0.75$ $0.47^{\$}$ 16918 JunRudbeckia first bloom (Rudbeckia hirta)24 $-0.132$ $-2.15$ $0.04^{\$}$ 17423 JunDogbane first bloom (Acclepias tuberosa)25 $-0.300$ $-4.43$ $0.00^{\$}$ 17625 JunButterfly weed first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.00^{\$}$ 17625 JunSt. Johns wort first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02^{\$}$ 17726 JunCommon milkweed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02^{\$}$ 18029 JunButter-and-eggs first bloom (Asclepias incarnata)15 $-0.213$ $-3.69$ $0.00^{\$}$	156	5 Jun	Baptisia first bloom (Baptisia leucantha)	25	-0.295	-3.96	0.00§	
16312 JunDaisy fleabane first bloom ( <i>Erigeron striigosus</i> )12 $0.020$ $0.31$ $0.77$ 16312 JunHarebell first bloom ( <i>Campanula rotundifolia</i> )19 $0.037$ $0.47$ $0.64$ 16716 JunFlowering spurge first bloom ( <i>Euphorbia corollata</i> )20 $0.087$ $0.75$ $0.47$ 16918 JunRudbeckia first bloom ( <i>Rudbeckia hirta</i> )24 $-0.132$ $-2.15$ $0.04^{\$}$ 17423 JunDogbane first bloom ( <i>Apocynum androsaemifolium</i> )10 $-0.046$ $-0.41$ $0.69^{\$}$ 17625 JunButterfly weed first bloom ( <i>Asclepias tuberosa</i> )25 $-0.300$ $-4.43$ $0.00^{\$}$ 17625 JunSt. Johns wort first bloom ( <i>Asclepias syriaca</i> )17 $-0.206$ $-2.49$ $0.02^{\$}$ 17726 JunCommon milkweed first bloom ( <i>Asclepias syriaca</i> )17 $-0.206$ $-2.49$ $0.02^{\$}$ 18029 JunButter-and-eggs first bloom ( <i>Asclepias incarnata</i> )15 $-0.213$ $-3.69$ $0.00^{\$}$	158	7 Jun	Yarrow first bloom (Achillea millefolium)	15	0.142	0.47	0.16 <sup>¶</sup>	
16312 JunHarebell first bloom (Campanula rotundifolia)19 $0.037$ $0.47$ $0.64$ ¶16716 JunFlowering spurge first bloom (Euphorbia corollata)20 $0.087$ $0.75$ $0.47$ ¶16918 JunRudbeckia first bloom (Rudbeckia hirta)24 $-0.132$ $-2.15$ $0.04$ §17423 JunDogbane first bloom (Apocynum androsaemifolium)10 $-0.046$ $-0.41$ $0.69$ ¶17625 JunButterfly weed first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.00$ §17625 JunSt. Johns wort first bloom (Hypericum perforatum)16 $-0.012$ $-0.15$ $0.89$ ¶17726 JunCommon milkweed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02$ §18029 JunButter-and-eggs first bloom (Linaria vulgaris)12 $0.041$ $0.23$ $0.23$ ¶18130 JunMarsh milkweed first bloom (Asclepias incarnata)15 $-0.213$ $-3.69$ $0.00$ §	163	12 Jun	Daisy fleabane first bloom (Erigeron striigosus)	12	0.020	0.31	0.77 <sup>¶</sup>	
16716 JunFlowering spurge first bloom ( <i>Euphorbia corollata</i> )20 $0.087$ $0.75$ $0.47^{\$}$ 16918 JunRudbeckia first bloom ( <i>Rudbeckia hirta</i> )24 $-0.132$ $-2.15$ $0.04^{\$}$ 17423 JunDogbane first bloom ( <i>Apocynum androsaemifolium</i> )10 $-0.046$ $-0.41$ $0.69^{\$}$ 17625 JunButterfly weed first bloom ( <i>Asclepias tuberosa</i> )25 $-0.300$ $-4.43$ $0.00^{\$}$ 17625 JunSt. Johns wort first bloom ( <i>Hypericum perforatum</i> )16 $-0.012$ $-0.15$ $0.89^{\$}$ 17726 JunCommon milkweed first bloom ( <i>Asclepias syriaca</i> )17 $-0.206$ $-2.49$ $0.02^{\$}$ 18029 JunButter-and-eggs first bloom ( <i>Linaria vulgaris</i> )12 $0.041$ $0.23$ $0.23^{\$}$ 18130 JunMarsh milkweed first bloom ( <i>Asclepias incarnata</i> )15 $-0.213$ $-3.69$ $0.00^{\$}$	163	12 Jun	Harebell first bloom (Campanula rotundifolia)	19	0.037	0.47	0.64¶	
16918 JunRudbeckia first bloom (Rudbeckia hirta)24 $-0.132$ $-2.15$ $0.04\$$ 17423 JunDogbane first bloom (Apocynum androsaemifolium)10 $-0.046$ $-0.41$ $0.69$ ¶17625 JunButterfly weed first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.00\$$ 17625 JunSt. Johns wort first bloom (Hypericum perforatum)16 $-0.012$ $-0.15$ $0.89$ ¶17726 JunCommon milkweed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02\$$ 18029 JunButter-and-eggs first bloom (Linaria vulgaris)12 $0.041$ $0.23$ $0.23$ ¶18130 JunMarsh milkweed first bloom (Asclepias incarnata)15 $-0.213$ $-3.69$ $0.00\$$	167	16 Jun	Flowering spurge first bloom (Euphorbia corollata)	20	0.087	0.75	0.47¶	
17423 JunDogbane first bloom (Apocynum androsaemifolium)10 $-0.046$ $-0.41$ $0.69^{\$}$ 17625 JunButterfly weed first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.00^{\$}$ 17625 JunSt. Johns wort first bloom (Hypericum perforatum)16 $-0.012$ $-0.15$ $0.89^{\$}$ 17726 JunCommon milkweed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02^{\$}$ 18029 JunButter-and-eggs first bloom (Linaria vulgaris)12 $0.041$ $0.23$ $0.23^{\$}$ 18130 JunMarsh milkweed first bloom (Asclepias incarnata)15 $-0.213$ $-3.69$ $0.00^{\$}$	169	18 Jun	Rudbeckia first bloom ( <i>Rudbeckia hirta</i> )	24	-0.132	-2.15	0.04§	
17625 JunButterfly weed first bloom (Asclepias tuberosa)25 $-0.300$ $-4.43$ $0.00$ 17625 JunSt. Johns wort first bloom (Hypericum perforatum)16 $-0.012$ $-0.15$ $0.89$ 17726 JunCommon milkweed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02$ 18029 JunButter-and-eggs first bloom (Linaria vulgaris)12 $0.041$ $0.23$ $0.23$ 18130 JunMarsh milkweed first bloom (Asclepias incarnata)15 $-0.213$ $-3.69$ $0.00$	174	23 Jun	Dogbane first bloom (Apocynum androsaemifolium)	10	-0.046	-0.41	0.69¶	
17625 JunSt. Johns wort first bloom (Hypericum perforatum)16 $-0.012$ $-0.15$ $0.89^{\$}$ 17726 JunCommon milkweed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02^{\$}$ 18029 JunButter-and-eggs first bloom (Linaria vulgaris)12 $0.041$ $0.23$ $0.23^{\$}$ 18130 JunMarsh milkweed first bloom (Asclepias incarnata)15 $-0.213$ $-3.69$ $0.00^{\$}$	176	25 Jun	Butterfly weed first bloom (Asclepias tuberosa)	25	-0.300	-4.43	0.00§	
17726 JunCommon milkweed first bloom (Asclepias syriaca)17 $-0.206$ $-2.49$ $0.02^{\$}$ 18029 JunButter-and-eggs first bloom (Linaria vulgaris)12 $0.041$ $0.23$ $0.23^{\$}$ 18130 JunMarsh milkweed first bloom (Asclepias incarnata)15 $-0.213$ $-3.69$ $0.00^{\$}$	176	25 Jun	St. Johns wort first bloom (Hypericum perforatum)	16	-0.012	-0.15	0.89 <sup>¶</sup>	
18029 JunButter-and-eggs first bloom ( <i>Linaria vulgaris</i> )12 $0.041$ $0.23$ $0.23^{\parallel}$ 18130 JunMarsh milkweed first bloom ( <i>Asclepias incarnata</i> )15 $-0.213$ $-3.69$ $0.00^{\$}$	177	26 Jun	Common milkweed first bloom (Asclepias syriaca)	17	-0.206	-2.49	0.02§	
181 30 Jun Marsh milkweed first bloom (Asclepias incarnata) 15 $-0.213$ $-3.69$ $0.00$ §	180	29 Jun	Butter-and-eggs first bloom (Linaria vulgaris)	12	0.041	0.23	0.23¶	
	181	30 Jun	Marsh milkweed first bloom (Asclepias incarnata)	15	-0.213	-3.69	0.00§	

\*The slopes of the regression plot are reported in days/year.
†t values are given as Student's t distribution.
‡P values are probability.
\$Values with a 95% probability of significance.
\$Values with no apparent change (t between +1 and -1).



FIG. 1. Regression analysis of the date of ice-melt from Lake Mendota over the years of phenological records. (A) The Julian calendar day of ice-melt is plotted against the year. The regression indicates a change in earliness of -0.124 day per year ( $R^2 = 0.046$ ). (B) the Julian calendar day of ice-melt is plotted against the average temperature for the month of march. The regression in this case indicates a change in earliness of -2.719 days per degree of March temperature ( $R^2 = 0.453$ ). Data on ice break-up are from State Climatology Office, 1999: Lake Mendota Ice Summary, 1853–1999, Electronic database appearing at http://www.uwex.edu/sco/icemend.html, Wisconsin Geological and Natural History Survey, Madison. Data for Madison temperatures are from National Climatic Data Center, Local Climatological Data for Madison, WI, at the Environmental Data and Information Service, National Oceanic and Atmospheric Administration, Asheville, NC.

earliness are compared with four phenophases without statistical increases in earliness. Each datum point in the graphs indicates the date for that event in a single year.

In Table 2, the numbers of phenophases are clustered for each of the five springtime months. The averages of the regression slopes are given for each month. The number and percentage of phenophases that show significant increases in earliness are recorded with the number and percentage of phenophases that qualify as nonresponders. Only one phenophase in February is represented. The regression averages for the eight phenophases in March yielded a value of -0.169day/year. The regression averages for all phenophases lessened in the subsequent months from March through June. As springtime advanced, the number (or percentage) of phenophases increasing in earliness diminished, whereas the number (or percentage) of phenophases not changing in earliness increased. The mean regression for all 55 phenophases was -0.12 day/year, comparable to the regression for the ice-melt data in Fig. 1A.

## DISCUSSION

Of the 55 phenophases reported here for the 61-year period in southern Wisconsin, 19 showed statistically significant increases in earliness. Twenty phenophases were considered nonresponders, based on the range of t values. Thus, roughly one-third of the phenophases appeared to advance in earliness over the period, one-third appeared not to advance, and the remaining third were statistically intermediate.

Within the 61-year span of our observations, the surface temperatures of the planet have warmed (5, 6, 8, 12). Climate warming has frequently been reported to have resulted in increases in earliness of some phenophases (11, 13). Experimental applications of heat have also been shown to result in phenological advances in plants (2, 14–20). It seems reasonable to expect that climate warming can induce advances in some phenological events.



FIG. 2. On the left are regressions of four selected springtime phenophases that do show significant increases in earliness during the 61-year period of record: arrival dates of migrating eastern phoebe (*Sayornis phoebe*) and rose-breasted grosbeak (*Pheucticus ludovicianus*) and first-bloom date of forest phlox (*Phlox divaricata*) and baptisia (*Baptisia leucantha*). These are compared with four selected phenophases that do not show significant increases in earliness: arrival dates of fox sparrow (*Passarella iliaca*) and eastern towhee (*Pipilio erythrophthalamus*) and first-bloom dates of slender pentstemon (*Pentstemon gracilis*) and St. John's wort (*Hypericum perforatum*). The regression values are recorded in Table 1.

Our examples of phenophases showing increases in earliness may be responding to climate warming. Because the range of seasonal temperature changes is magnified at higher latitudes (11, 12) and may be almost imperceptible at tropical or even subtropical sites (21), phenological responses may be accentuated at more polar latitudes and minimal or even absent near the equator. Studies of phenological processes in Alaska and other near-polar sites have shown dramatic changes in various

Table 2. Comparison of 55 phenophases for springtime months in response to climate warming

	No. of	Avg regression slope.	Incre in ear	asing	Not increasing in earliness	
Month	phenophases	day/year	No.	%	No.	%
February	1	-0.365	1	100	_	
March	8	-0.169	4	50	2	25
April	13	-0.091	4	31	4	31
May	19	-0.074	6	31	5	27
June	14	-0.060	4	28	9	64
	Mean	= -0.12				

Those increasing in earliness had >95% probability of significance (P < 0.05). Those not increasing in earliness had *t* values between +1 and -1.

plant phenophases in response to increases in temperature (13, 22, 23). Satellites have recorded measurements of regional changes in photosynthesis showing increased earliness associated with climate warming in northern latitudes (17). In this study, maximal increases in earliness of photosynthetic activity were observed for latitudes between  $45^{\circ}$  and  $65^{\circ}$  N. Our site in Wisconsin at  $43.5^{\circ}$  N lies just below the range of the maximal photosynthesis response.

Several reports have shown that phenological responses to temperature in colder, northern climates can be simulated at sites along an altitudinal gradient (24, 25). Our preliminary evidence in Table 2 suggests that phenological advances may be more frequent in the colder months of early spring; phenological responses to warming may be more substantial in colder sites or seasons.

The fact that some phenophases respond to a drift toward climate change and other phenophases do not raises some questions about phenological adaptability and its possible relation to species survival during extended climate change. Is there a survival advantage for species having phenological adaptability to climate change? The checkerspot butterfly (*Euphrydryas editha*) is one documented species that has shifted its range as an adaptation to climate warming (26). Species lacking phenological adaptability, such as the amelanchier (*A. laevis*; see Table 1) may require a stronger signal or may be unable to adapt to climate warming. We speculate that species without phenological adaptability may experience greater stress or even extinction during extended climate change.

Among the species that do not show phenological adaptability are the many organisms in which seasonal developments are regulated by photoperiod or other genetic regulatory systems. Many seasonal biological events have been found to be controlled by photoperiod. These include dormancy, growth rates, and flowering in plants; diapause in insects; reproductive activity in vertebrates; and migration in birds (27). An abundance of literature describes phenological controls by photoperiod. We would expect that photoperiodic responders may fail to show changes in earliness in response to climate warming. For example, extensive literature describes photoperiodic regulation of bird reproduction and migration (28, 29). Our records include four bird migration phenophases that show no apparent change with climate warming: the arrival dates for bluebird (Sialia sialis), fox sparrow (Pasaella iliaca), towhee (Pipilio erythrophthalamus), and brown thrasher (Toxostomum rufum) (Table 1). These may be expected to be regulated by photoperiods.

A comparison of bird migration dates that are correlated with temperature and others that are not has been made by Temple and Cary (30). Their evidence indicates that shortdistance migrants may usually be correlated with temperatures, whereas long-distance migrants may not. The onset of flowering in plants serves as a contrast; the temperatureresponding and the nonresponding species grow in the same locality and have presumably developed different strategies of floral regulation.

From our data, we suggest that some organisms may be facile in changing their seasonal progressions in relation to climate changes, whereas others are less able to respond. Differences in phenological adaptability may be expected to bear on the ability of species to adapt to climate warming; species with poor phenological adaptability may face increasing stress during prolonged climate changes.

We thank John Cary and David Weinstein for assistance with the statistics.

- 1. Leith, H., ed. (1976) *Phenology and Seasonality Modeling* (Springer, New York), pp. 369, 401.
- 2. Suzuki, S. & Kudo, G. (1997) Global Change Biol. 3, 108-115.
- 3. Oettingen, A. J. (1879) *Phanologie der Dorpater Lignosum* (Heinrich Laakmann, Dorpot, Estonia).
- Waggoner, P. E. (1974) in *Phenology and Seasonality Modeling*, ed., Leith, M. (Springer, New York), pp. 401–405.
- 5. Beaubien, E. G. & Johnson, D. L. (1994) Int. J. Biometeorol. 38, 23–28.
- Jones, P. (1995) in *Analysis of Climate Variability*, eds., Stoich, H. V. & Navarra, A. (Springer, New York), pp. 53–75.
- 7. Monastersky, R. (1997) Sci. News 153, 38.
- 8. Kerr, R. A. (1998) Science 279, 315-316.
- 9. Leopold, A. & Jones, E. (1947) Ecol. Monogr. 17, 81-122.
- 10. Draper, N. R. & Smith, H. (1966) Applied Regression Analysis (Wiley, New York).
- Hansen, J., Johnson, D., Lacis, A., Lebedoff, S., Lee, P., Rind, D. & Russell, D. (1981) Science 213, 957–966.
- Smith, R. C., Ainley, D., Baker, K., Domack, E., Emslie, S., Fraser, B., Kennett, J., Leventer, A., Mosely-Thompson, E., Stammerjohn, S., *et al.* (1999) *BioScience* 49, 393–404.
- Callaghan, T. V., Carlsson, B. A. & Tyler, N. J. C. (1989) J. Ecol. 77, 823–827.
- 14. Podolsky, A. S. (1985) *New Phenology: Elements of Mathematical Forecasting in Ecology* (Wiley, New York).
- 15. Inouye, D. W. & McGuire, A. D. (1991) Am. J. Bot. 78, 997-1001.
- Farnsworth, E. J., Nunez-Farfan, J., Caeaga, S. A. & Bazzaz, F. A. (1995) J. Ecol. 83, 967–977.
- 17. Henry, G. H. R. & Molau, U. M. (1997) *Global Change Biol.* 3, 1–9.
- Wookey, P. A., Parsons, N. A. & Walker, J. M. (1993) Oikos 76, 490–502.
- Myneni, R. B., Keeling, C. D., Tucker, C. J., Asrar, G. & Nemai, R. R. (1997) *Nature (London)* 386, 698–702.
- 20. Price, M. V. & Waser, N. M. (1998) Ecology 79, 1261-1271.
- 21. Reich, P. B. (1995) Am. J. Bot. 73, 164-174.
- 22. Chapin, F. S., Shave, G. R., Gibbin, A. E., Nadelhoffer, K. J. & Laundre, J. A. (1995) *Ecology* **76**, 94–111.
- Saccheri, I., Koussaari, M., Kanakara, M., Vikman, P., Fortelius, W. & Hanskki, I. (1998) *Nature (London)* 392, 491–494.
- 24. Farquhar, G. D. (1997) Science 278, 1411.
- Street-Perrott, F. A., Huang, R. A., Perrott, R. A., Eglinton, G., Barker, P. & Ben Khelifa, L. (1997) *Science* 278, 1422–1426.
- Parmesan, R. (1996) *Nature (London)* 382, 765–766.
   Withrow, R. B., ed. (1959) *Photoperiodism and Related Phenom-*
- ena in Plants and Animals (AAAS, Washington, DC).
- Wolfson, A. (1959) in *Photoperiodism and Related Phenomena in Plants and Animals*, ed., Withrow, R. B. (AAAS, Washington, DC), pp. 679–716.
- 29. Berthold, P. (1996) *Control of Bird Migration* (Chapman & Hall, London).
- 30. Temple, S. A. & Cary, J. R. (1987) Passenger Pigeon 46, 70-75.