Using Photographs to Show the Effects of Climate Change on Flowering Times

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There are many indications that global warming is affecting natural processes around the world. Glaciers are melting and many species are shifting their ranges poleward and up mountain slopes while others are becoming extinct. Changes in the timing of phenological events like the flowering of plants and the arrival of migratory birds are among the most sensitive indicators of global warming's effect on biological systems. In England, plants now flower up to a month earlier than they did fifty years ago. Across Europe, leaves emerge an average of six days earlier than they did thirty years ago. In Massachusetts, we have observed earlier flowering, earlier bird migrations, and earlier frog reproduction in recent warmer years.

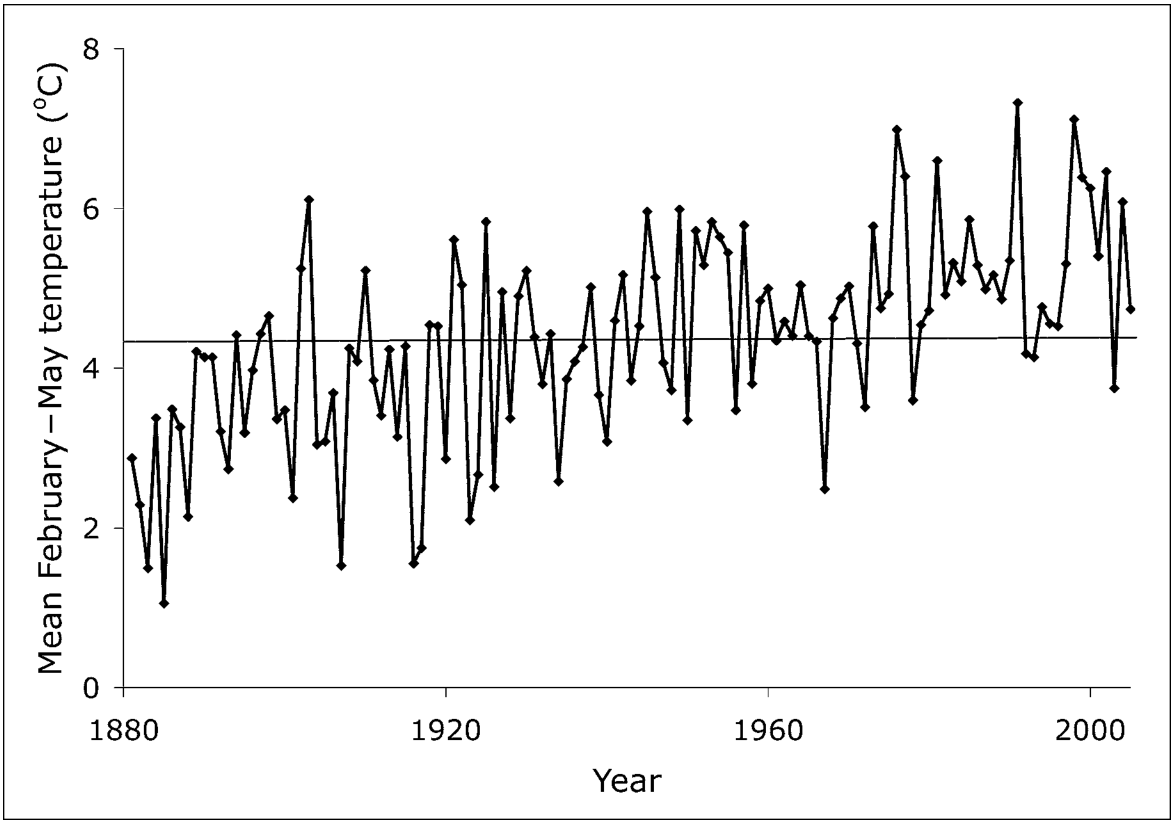
Clearly, current changes in plant phenology will have widespread impacts on critical ecosystem processes such as carbon dioxide storage in plants, interactions between land and atmosphere, and relationships among species. In the Netherlands, for example, dramatic declines in some populations of pied flycatchers *(Ficedula hypoleuca)* have been attributed to changes in the time-sensitive relationships between oak tree leaf-out, caterpillar emergence, and bird breeding times: earlier leaf-out, linked to warmer temperatures, causes the caterpillars to finish their lifecycle earlier, thereby depriving later-arriving birds of the caterpillars required to feed their nestlings.

The fundamental questions being asked by scientists are: How is the timing of phenological events changing? And how will continued climate change affect this timing in the future? Most studies documenting the impact of climate change on phenological events have relied on long-term written records. Although many such records have been found and analyzed in Europe, they are too rare in the United States and elsewhere to help answer these questions. To expand our information base to more species and more geographic locations, scientists must therefore seek out reliable data from other kinds of records.

In an earlier *Arnoldia* (vol. 63, no. 4), we described how herbarium specimens collected over many years could be used with a single baseline season of field observations to provide data about changes in plant flowering times. Since then, we have discovered that like herbarium specimens, dated photographs of plants in flower can also inform us about those changes. These photographs are far more common than herbarium specimens or written records: collections can be found in many museums, libraries, universities, and private holdings. Scientists in other fields have used photographic records to document changes in soil and vegetation and to calculate the rate of glacier retreat. Recently, Tim Sparks and colleagues used dated photographs to document changes in plant development in response to weather conditions in particular years.

The photos (facing page top and bottom) show leaf-out at the Lowell, Massachusetts, Cemetery. Leaves are conspicuously missing on Memorial Day in this 1868 photograph by an unknown photographer.

In the bottom photo, taken on Memorial Day, 2005, at least two of the large, bare trees seen in the 1868 photo are alive and fully leafed out. They appear directly above the two large plinths at the far left and far right. Mean February-through-May temperature in 1868 was 35 degrees F (1.9 degrees C), whereas in 2005 it was 40 degrees F (4.7 degrees C).



Mean temperatures in February, March, April, and May from 1881 to 2004 as recorded at Blue Hill Meteorological Observatory in Milton, Massachusetts. The horizontal line represents the long-term mean February–May temperature, 40 degrees Fahrenheit (4.4 degrees C).

To test the value of photographs in our own phenological research, we examined two collections of dated photographs of flowering plants and a single, very unusual photograph of trees taken at the Lowell, Massachusetts, Cemetery.

The Test: Methodology

Our first step was to obtain temperature data from Blue Hill Meteorological Observatory in Milton, Massachusetts. The Blue Hill Observatory, located approximately five miles (8 km) south of the Arnold Arboretum and twenty miles (33 km) southeast of Concord, Massachusetts, has one of the longest continuous records of weather observations in the United States. These records allowed us to correlate temperatures with plant flowering times. From 1881 to 2004, mean February–May temperatures at the site warmed 4.5 degrees F (2.5 degrees C)—an increase in metropolitan Boston that is nearly as great as those predicted for western Massachusetts and beyond over the next fifty to one hundred years. About three-quarters of the increase at Blue Hill has been attributed to the urban heat island effect, that is, the warming associated with more buildings, streets, parking lots, and other human modifications. Urban areas, being in the vanguard of climate change, can therefore provide useful information about the ecological changes that will occur elsewhere, though somewhat later, as a result of global warming.

Our photographic data came from two collections of photographs. The first consisted of 251 dated images of 48 species of cultivated woody plants in flower at the Arnold Arboretum between 1904 and 2004. They had been taken by staff photographers as well as by other staff members and amateur photographers. In general, the individual plants shown in the photographs were not recorded, but the species were either recorded or clearly identifiable.

We examined the photographs taken at the Arnold Arboretum first, assuming that on average the photographs represented the mean flowering time of a species in a particular year. (We had previously confirmed a similar assumption during our study of herbarium specimens.) For each photograph, we calculated how much earlier or later a plant had flowered in the year it was photographed than it did in the benchmark year of 2003, when we observed the flowering times on the grounds. We then used statistical techniques to estimate the rate at which flowering dates changed over time and to relate that change to mean temperatures from February through May. We validated the magnitude of these changes by comparing them to the ones revealed by our herbarium-based study.

The second collection contained 34 dated photographs of 17 species of wild plants in flower in Concord, Massachusetts. Most were images of wildflowers, with a few of trees and shrubs as well. These photographs, spanning the years from 1900 to 1921, were taken by the landscape photographer Herbert Wendell Gleason, who was focusing on plants and places mentioned in the journals of Henry David Thoreau.

To demonstrate the general usefulness of the approach, in 2005 we analyzed the collection of flowering wild plants in Concord. By comparing the dates of the photographs to the mean

H. W. GLEASON. COURTESY OF THE CONCORD FREE LIBRARY

A. J. MILLER-RUSHING

Wild specimens of pink lady's slipper (Cypripedium acaule) in Concord, Massachusetts, flowered six weeks later in 1917, on June 22, than in 2005, when they were in flower on May 17. Mean February–May temperature in 1917 was 35 degrees F (1.8 degrees C) and in 2005, 40 degrees F (4.7 degrees C).

E. H. WILSON, ARCHIVES OF THE ARNOLD ARBORETUM

ROBERT G. MAYER

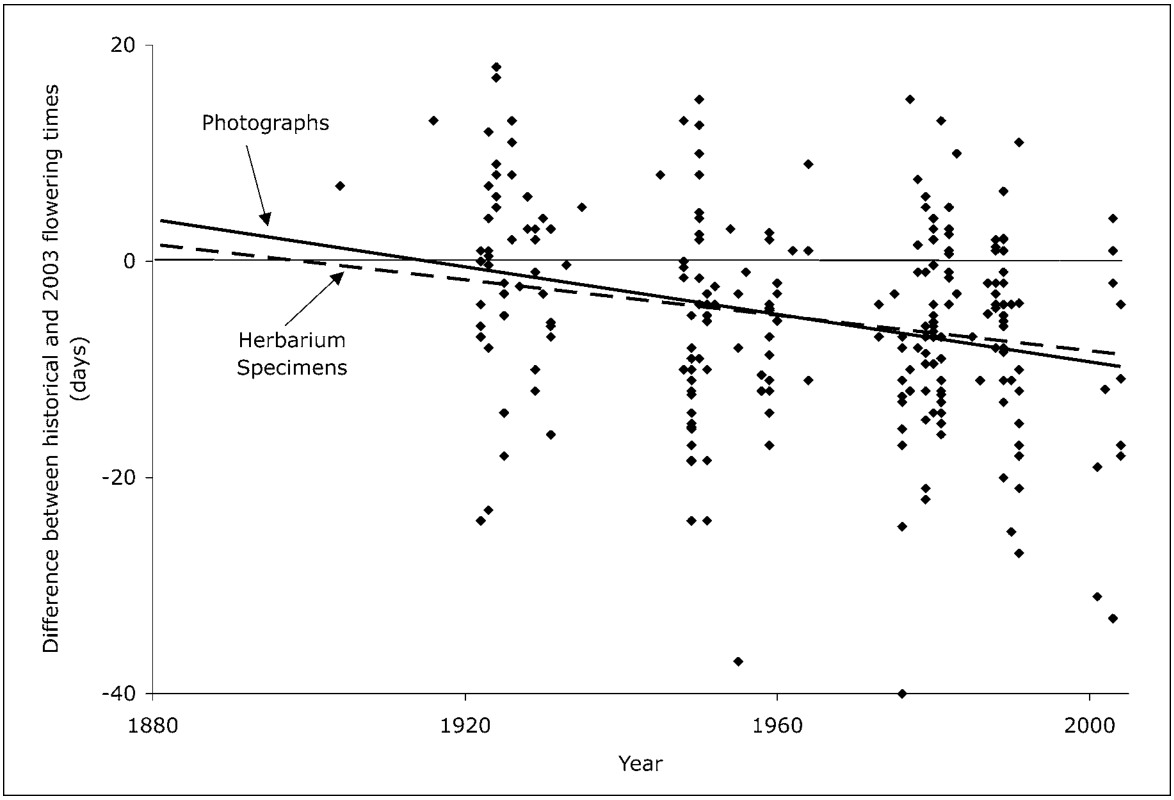
Another representative comparison of historical and recent photographs is this pair of native fringetrees (Chionanthus virginicus) *photographed at the Arnold Arboretum on June 20, 1926, and again in 2003, on May 7, when they flowered seven weeks earlier.*

plant flowering times of the same species that we found in our Concord field observations, we were able to calculate how much earlier or later a plant species had flowered in the year of the photograph than it did in the benchmark year of 2005. Again, we used statistical techniques to derive an average rate of change for all the photographed species in relation to mean temperatures from February through May. In this case, we validated our results by comparing them to trends shown by 13 of the same species in observations made by the botanist Alfred Hosmer in Concord each year from 1888 to 1902.

Findings

Our study of the photographs from the Arnold Arboretum indicated that plants are flowering about eleven days earlier on average than they were a century ago. The rate of change was 3.9 days for each increase of one degree Centigrade (.5556 degree F) in mean February–May temperatures—in other words, plants were flowering earlier because the temperatures in the months before flowering were getting warmer over time. On average, mean February–May temperatures at Blue Hill Observatory warmed 2.1 degrees C (just over one degree F) from 1904 to 2004. In the particularly cold springs of 1916, 1923, 1924, and 1926 (mean February–May temperatures less than 37 degrees F [3 degrees C]), plants flowered nine days later than average. In the particularly warm springs of 1976, 1977, 1981, 1991, 2002, and 2004 (mean February–May temperatures greater than 43 degrees F [6.0 degrees C]), they flowered two days earlier. This rate closely matched the response to temperature change that we had found in our previous study, using herbarium specimens and the living plants at the Arnold Arboretum.

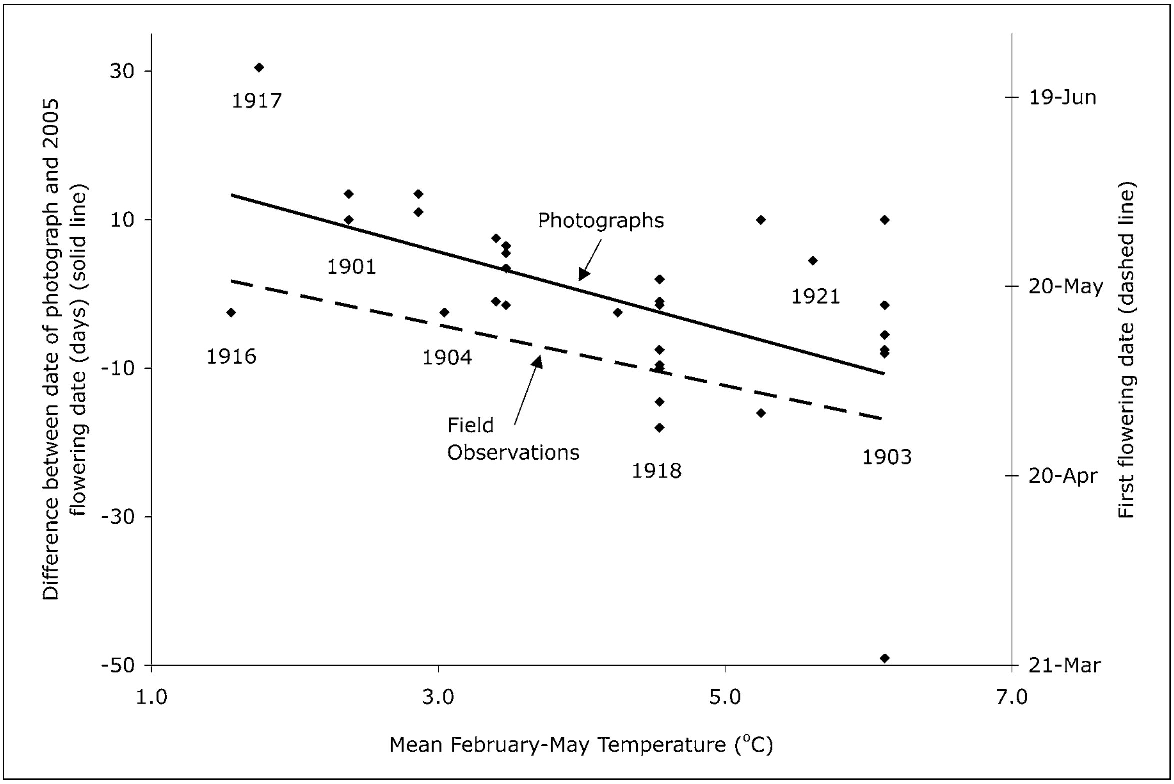
These findings were confirmed by the study of wild species in Concord. Flowering times as recorded in the Concord photographs were the same in 1921 as



Changes in flowering times of woody plants at the Arnold Arboretum of Harvard University in Boston for the period 1904–2004. Each point represents the difference between the date a historical photograph showed a specimen in flower and the date that the same species was in flower in 2003 (historical date–2003 date). Negative values indicate historical flowering times that were earlier than flowering times in 2003. The line represents the best fit to the data. For comparison, the dashed line represents the same relationship using herbarium specimens but without individual points being shown. It is readily apparent that both dated photographs and herbarium specimens indicate that plants are flowering earlier during this hundred-year period.

they had been in 1900; this was to be expected since temperatures at Blue Hill Observatory did not on average increase between those years. However, during these years the photographic record showed plants flowering 5.3 days earlier for each single degree Centigrade increase in spring temperatures. In warm years, such as 1903, plants flowered earlier than in cool years, such as 1916. In the particularly cold springs of 1901, 1916, 1917, and 1920 (mean February–May temperatures less than 37 degrees F [3.0 degrees C]), plants flowered eight days later than average. In the particularly warm spring of 1903 (mean February–May temperature more than 43 degrees F [6.0 degrees C]), they flowered eight days earlier.

We verified these findings by comparing them to the evidence in a set of unpublished observations of flowering times in Concord made by Alfred Hosmer from 1888 to 1902. Hosmer apparently carried out these observations as a continuation of similar observations begun by Thoreau in the 1850s. His observations indicated that the same species flowered 4.8 days earlier for each degree Centigrade warming. The results from the two sets of photographs and from Hosmer's observations are statistically indistinguishable. The results also reflect the disparity in dates: Hosmer recorded first flowering dates, whereas Gleason photographed plants on their peak flowering dates. Hosmer's observations are therefore



Changes in flowering times in response to changes in mean spring (February–May) temperatures for wild plants in Concord, Massachusetts, for the period 1900–1921. Each point represents the difference between the date a historical photograph showed a specimen in flower and the date that same species was in flower in 2005 (historical date–2005 date). Negative values indicate historical flowering times that were earlier than flowering times in 2005. Solid line represents the best fit to the data.

The dashed line represents independent data from field observations of first flowering dates collected by A. W. Hosmer between 1888 and 1902 but without the individual data points. The slopes of the lines are indistinguishable, indicating that they both show the same relationship between climate and flowering times; plants flower earlier in warm years than in cold years. The line using photographs is higher in the graphs because photographs are usually taken when plants are in full flower, which occurs several days after plants are in first flower, which is what Hosmer was recording.

dated several days earlier than Gleason's photographs.

We also noted an example of how photographs can be used to document changes in the timing of leaf-out as well as flowering. The striking photograph at the top of page 2 was taken in the Lowell Cemetery in Lowell, Massachusetts, on Memorial Day, 30 May 1868. In the photo, the trees have not yet leafed out, despite the late date, and people are wearing heavy clothing. The photograph below it, taken on the same date in 2005 at the same location, shows the trees fully leafed out. At least two of the large, leafless trees in the 1868 photo are still alive and had fully leafed out in 2005. An exceptionally cold spring probably caused the delayed leaf-out in 1868; the mean temperature from February to May of that year was 4 degrees F (2.2 degrees C) lower than the average over the past 150 years and nearly 5 degrees F (2.7 degrees C) colder than February to May 2005.

The Advantages and Problems of Using Photographs

Our study showed that photographs provide reliable estimates of the date of peak flowering and can be used to calculate rates of change in flowering times that are comparable to the rates determined from independently collected data sets, including direct field observations. Moreover, these results hold true for both wild and cultivated plants.

Because photographs are far more abundant than are scientists' field observations, they can dramatically increase the amount of reliable data available for studying the times not only of flowering but also of leaf-out, bird migration, the emergence in spring of hibernating animals, and other seasonal events. And even though the photographs may have been taken over several days or even several weeks, the flowering dates they reveal can be accurately correlated with temperatures as long as enough photographs are used and if analysis of the photographs is combined with studies in the field.

As noted, the analysis of a photograph collection may need to take account of the tendency of some people to photograph plants as soon as they start to flower while others photograph them when more flowers are open. These limitations did not substantially affect the results of our study, as demonstrated by the validation from independently collected data.

Researchers should also be aware of a problem inherent in using photographs of multiple species to calculate a single rate of change. In our study, we assumed for the sake of simplicity that the flowering times of all the plants we observed changed at similar rates in response to warming, even though we knew this is not the case. These differences added variation to our results, making them less reliable than if we had examined changes in the flowering times of individual species. Nevertheless, the indications are that on average, plants are flowering earlier now than in the past because of warmer temperatures.

Even though these alternative sources of information—herbarium specimens and photographs—can be used to show phenological responses to climate change, botanical gardens remain a particularly valuable source of long-term data. We hope that regular observations of key events such as leaf bud burst, flowering, fruiting, and leaf senescence will be recorded. At the same time, however, analysis of additional photograph collections could dramatically increase our understanding of how climate change affects a wide range of species at many previously unexamined localities. If you know of any such collections, please get in touch with us.

For Further Reading on Climate Change

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