The Special Role of Historical Plant Records in Monitoring the Impact of Climate Change

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The best available scientific evidence suggests that the world’s climate will change significantly over the present century because of increases in the greenhouse gases that result from burning fossil fuels and destroying tropical forests. Worldwide temperatures have already risen by sixth-tenths of one degree centigrade over the last four decades, according to the Intergovernmental Panel on Climate Change of the World Meteorological Organization and the United Nations Environmental Program. Estimates of the increase to be expected over the next hundred years range from three to ten degrees Fahrenheit. This change is comparable to the one that occurred after the last ice age.

The warmer temperatures will have a radical effect on many plant species. Some will no longer be able to grow at their present locations and will either migrate or go extinct. Others will be able to maintain their present ranges but will change their behavior—leafing out earlier, flowering and fruiting earlier, and holding their leaves later in autumn. Indeed, earlier flowering times will be one of the first indications that the climate is changing. This may at first strike some people as a pleasant change, but warmer summer temperatures, especially in dry years, are likely to reduce populations of many sensitive native plant species while favoring more heat-tolerant species. There are already signs that certain drought- and temperature-sensitive species could experience higher than normal mortality rates, as Peter Del Tredici described in a recent article in the New York Times. To put it another way, horticulturists’ long-standing concern about plants’ winter hardiness is being displaced by concerns about drought- and heat-tolerance. Taking a larger view, the expected increases in temperatures will have huge implications not just for horticulture but for agriculture, forestry, and wildlife conservation as well.

Behavior changes of this sort are the raw material of the science of phenology, the study of how biological phenomena are affected by climate and seasonality. Clearly, observations of phenological events in plants will play an important role in our efforts to evaluate the effects of rising temperatures. Climate change will affect the full range of organisms—plants, fungi, animals, and even microorganisms—but the sudden onset and cessation of flowering in plants make them particularly well suited to research on its effects. More important, we have extensive records of plant flowering times going back decades and even centuries, many of them gathered by government weather bureaus for agricultural purposes and others maintained by private individuals. By comparing current flowering times with historical records of this sort, a network of observers at European botanical gardens has found that European plants are now flowering six days earlier than they were in the 1960s and that the overall growing season has increased by one or two weeks.

The most comprehensive attempt to correlate weather and flowering times in North America was made by the Weather Regional Phenological Network (WRPN) between 1957 and 1994. The network spanned the United States, eventually including two thousand observers who monitored the behavior of three designated cultivars: the common lilac, Syringa vulgaris f. purpurei, and two honeysuckles, Lonicera tartarica cv. ‘Arnold Red’ and L. korolkowii var. zebelli. The observers were given specific instructions on how to record the dates of leafing out, of first flowering, of peak flowering, and of flower withering.
Average monthly temperatures with linear trendlines. The data was taken from online records of the United States National Weather Service. While the temperatures are variable from year to year, temperatures are getting warmer during this period.

The WPRN project was closed down in 1994 for lack of permanent institutional backing, but the massive data sets it generated are still being analyzed. Thus far, the major finding is that plants across the United States are now flowering about one week earlier than in the 1950s when the WPRN observations began. The data also showed a high degree of correlation among the various phenological events—in years with earlier first flowering, leafing out also occurred earlier—indicating that the events are developmentally linked. This finding can largely be explained by the responsiveness of the observed species to spring temperatures: they flower earlier when there are warm springs, and warm springs have become more common. Unfortunately, all the plants observed by the WPRN were exotic cultivars, which may respond to climatic variation differently from our native species. To understand the impact of climate change on native species, we need long-term observations of species living in their native habitats.

Not all recording of phenological events has been done by large organizations. In the United Kingdom, for example, there is a long tradition of families carrying out observations on their farms and estates. From 1736 to 1947 the Marsham family of Norfolk County observed and recorded the times of leafing out and flowering for a variety of plant species as well as of bird migrations. Their records show clearly that plants respond to annual fluctuations in climate; presumably they will continue to do so as the climate gradually warms.

In the United States, one of the most complete sets of observations was recorded by the famous naturalist Aldo Leopold from 1936 to 1947 and continued from 1976 to 1998 by his daughter, Nina Leopold Bradley, at their farm in southern Wisconsin. Of the fifty-five phenological events they followed, thirty-six were the

first flowering of plants. A significant trend toward earlier flowering was shown in ten of the thirty-six plant species, including forest phlox (Phlox divaricatus) and columbine (Aquilegia canadensis). An analysis of all their plant-related data showed that on average, the phenological events observed advanced by 0.12 days a year, the equivalent of about six days over a fifty-year period.

Historical records of this sort are of great value in tracking the effects of climate change. Another important resource is found in the herbaria of botanical gardens like the Arnold Arboretum, where extensive records of flowering times are preserved on the mounted sheets of flattened specimens. Many of the Arnold’s approximately 80,000 herbarium specimens were collected on the grounds from flowering individuals that are tagged and individually numbered. By comparing the current flowering time of a plant with its past flowering time (indicated by the collection date on its herbarium specimen), we can determine the impact of climate change on its behavior. And because of the “heat-island effect” common to large cities—which has helped to raise average temperatures in Boston by about five degrees Fahrenheit over the last 120 years while that of eastern North America overall has risen by only two degrees*—the behavior of plants growing on the Arboretum’s grounds may give an early warning of what will happen to plants growing in less urbanized locations in later decades.

In 2002 a group of Boston University students and I began to test this methodology at the Arnold Arboretum by making weekly observations of 67 plants for which the herbarium has flowering specimens. The sample size is not large, but the results were clear: plants did not flower any earlier in the warm year of 2002 than

Among thirty-six plants observed by the Leopolds, Aldo and his daughter Nina, over a sixty-one year period, Phlox divaricata (forest phlox) was one of ten that showed a significant trend toward earlier flowering. Plants are clearly flowering earlier in the 1976 to 1998 period in comparison with the 1936 to 1947 period; the overall change is about 10 days. Each dot represents the first flowering date observed in one year. From N. Leopold et al., “Phenological changes reflect climate change in Wisconsin,” Proceedings of the National Academy of Science (1999) 96: 9703.

* As shown by the National Weather Service. See also Roetzer et al. 2000, which points out that as cities become more urbanized, paved surfaces and buildings tend to absorb and retain heat from the sun, making the city warmer than the surrounding countryside.
they had in the similarly warm period of 1990 to 2001. However, they flowered an average of four days earlier than they had in the 1980s, and fifteen days earlier on average than they had in the years before 1980. For example, a flower was collected from a *Rosa pendulina* plant on June 19, 1916; the same plant was in peak flower on May 25 in 2003, 25 days earlier. A *Viburnum furcatum* plant flowered 23 days earlier in 2002 than it had in 1937; and a *V. scabrellum* plant flowered 24 days earlier than in 1973. During the growing season of 2003 we expanded the study to include a much larger sample of plants, especially older ones for which we have herbarium specimens for more than one year.

These comparisons from the Arnold Arboretum, together with others being made throughout the world, will quantify and highlight the impact of climate change on biological communities. But much more historical data on phenological events, whether collected by professionals or dedicated naturalists, is needed to expand our knowledge about plants' responses to warmer temperatures. Especially, we need to increase the number of localities for which there are good long-term records on phenomena such as flowering and leafing times, bird and fish migrations, insect appearance, and amphibian calling and movement. Any readers of this article who have recorded their observations over past decades are urged to get in touch with me. Perhaps by analyzing our data together we can make a valuable contribution to this important research.

References


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