PLANT CONSERVATION

A NATURAL HISTORY APPROACH

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CHAPTER 8

GLOBAL CLIMATE CHANGE: THE SPRING TEMPERATE FLORA

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A CONSENSUS OF scientists and environmentalists has been reached over the past few years that the earth's atmosphere is warming, and that humans are the main contributors to this trend. This conclusion was reached by the United Nations' Intergovernmental Panel on Climate Change (IPCC). The IPCC report (Watson et al. 2001), the most definitive on the subject, declared that the 1990s had the warmest years on record, and most of the increase is attributed to human activities—the burning of fossil fuels and the release of carbon dioxide and greenhouse gases. The report also predicts that global average surface temperature will increase by 1.4 to 5.8°C during this century.

Spring advances in first-flowering in plants from the Washington, DC, area provide evidence for global warming. The trend of average first-flowering times per year for 100 species with 20 years' or more data shows a significant advance of 3.2 days over a 32-year period. When 10 species that exhibit later first-flowering times are excluded from the data set, the remaining 90 species show a significant advance of 5.1 days. Trends for 80 species flowering significantly earlier range from −2.8 to −44.2 days, while those for 7 significantly later-flowering species range from +2.2 to +9.7 days. Advances of first-flowering in these 90 species are directly correlated with local increase in minimum temperature (T_{MIN}). These results are consistent with other studies showing that changes in air temperature have advanced the average annual growing season by 6 days in Europe and that warmer temperatures and higher carbon dioxide levels have promoted summer plant growth, thereby advancing the season by 7 days in northern latitudes.

CLIMATE CHANGE

The effects of global warming in the 20th century, mostly caused by human activity, have been marked by a rise in the average surface temperature (about 0.6°C), a 40% thinner Arctic ice cover, and increased levels of carbon dioxide in the atmosphere (Houghton et al. 1995). The northern high latitudes have warmed by about 0.8°C just since the early 1970s (Hansen et al. 1999). These changes appear to have had a profound effect on the first-flowering times of plants in the Washington, DC, area.

Climate change is an important environmental issue affecting not only entire ecosystems but also the dominant plants of a given region (Melillo 1999). Other studies of the natural vegetation indicate that nocturnal global warming may be an important factor in plant growth (Alward et al. 1999; Chapin et al. 1995). A study of short-grass steppe vegetation over a ten-year period shows that net primary production of a C_4 grass (*Bouteloua gracilis*) was lower with increasing T_{MIN}, whereas native and exotic C_3 forbs increased in production and abundance (Alward et al. 1999). Long-term ecological research in the Alaskan Arctic indicates that climate change, when simulated by increasing the mean daily air temperature above the vegetation by 3.5°C, can alter plant species composition (Chapin et al. 1995). Changes in the periodicity in plants as related to climatic events (phenology) have been found in Europe, where leaf unfolding in spring has advanced 6 days, whereas leaf coloring has been delayed 4.8 days, thus lengthening the average annual growing season by 10.8 days (Menzel and Fabian 1999).

Flowering in angiosperms is an important phenological cycle. Plants in temperate areas, such as the mid-Atlantic region of the North America, are adapted to an annual seasonal cycle with a winter dormancy period that is sensitive to temperature and light. Flowering time is directly related to temperature. To investigate potential changes in the timing of first-flowering, Abu-Asab et al. (2001) examined first-flowering records of 100 plant species, representing 44 families of angiosperms, for 31 years of the 32-year period 1970–2001 (1984 not recorded) in the Washington, DC, area. Because this investigation suggested that global climate change has an effect on plant flowering in the capital of the United States, more details are provided in this chapter.

MEASURING FIRST-FLOWERING

From a database of first-flowering records for over 600 species, the 100 species with the greatest number (20 or more) of recorded years were selected (Abu-Asab et al. 2001). First-flowering here refers to the stage at which a mono- or diclinous-flower begins anthesis or is receptive to pollen. Washington and vicinity (35-mile radius from center of DC; latitude 38°24′ to 39°23′ N, longitude 76°24′ to 77°42′ W) is a large area, and thus many different observers (>125) were involved in the recording. In actual practice the date of first-flowering is the first observed date and not necessarily the absolute earliest (Shetler and Wiser 1987). Using average first-flowering time per year, linear trends and their significance according to the F-test were calculated, along with confidence intervals, for the 100 species, the 90 species that exhibit only an earlier flowering, and 10 species that exhibit only later flowering (fig. 8.1A–C). Trends for the majority of the species (80%) are statistically significant (table 8.1).

To investigate potential correlation between flowering trends and environmental factors during the last 30 years, linear trends and confidence intervals for local climate data were calculated. The climate data include average minimum temperature (T_{MIN}), average precipitation (fig. 8.2), and precipitation per month. In

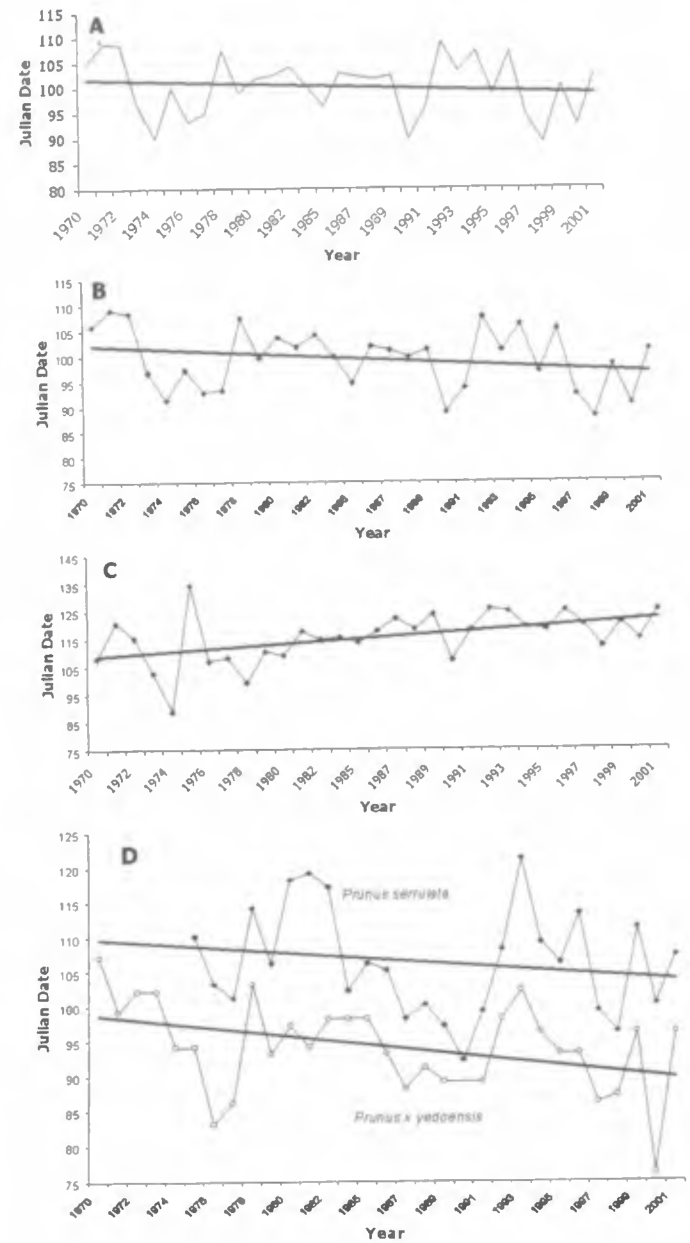

Figure 8.1 Average first-flowering times (Julian dates) for plants in the Washington, DC, area for 1970–2001. Bold line represents the trend, and regular line indicates the average. A, For all 100 plant species. B, For 80 plant species flowering significantly earlier. C, For 7 species flowering significantly later. D, Trends of the Japanese cherry trees *Prunus serrulata* (6.1 days' advance in flowering) and *Prunus* × *yedoensis* (9 days' advance in flowering).

Species	Advance in flowering (days)	Standard deviation	Number of years on record
Acer negundo	11.67	7.59	29
Acer rubrum	19.20	14.23	31
Achillea millefolium	11.62	8.77	23
*Alliaria petiolata**	11.77	7.56	28
Alnus serrulata	5.45	15.41	26
Amelanchier canadensis	6.28	6.74	22
Anemone quinquefolia	19.17	9.39	24
Anemonella thalictroides	9.18	9.02	26
*Anthoxanthum odoratum**	17.84	7.71	23
Aquilegia canadensis	17.57	9.94	27
Arisaema triphyllum	10.70	6.39	27
Aronia arbutifolia	20.91	10.05	24
Asarum canadense	5.16	8.21	30
Asimina triloba	17.64	8.80	27
*Barbarea vulgaris**	2.83	7.05	26
*Cardamine hirsuta**	41.17	25.60	30
Cercis canadensis	9.48	9.81	28
*Chelidonium majus**	17.32	7.64	22
Chionanthus virginicus	8.63	6.03	27
Chrysogonum virginianum	28.21	19.32	25
*Cichorium intybus**	11.40	6.30	23
Claytonia virginica	7.54	13.07	29
Cornus florida	8.75	8.48	29
Corydalis flavula	8.99	8.28	26
Dicentra cucullaria	2.86	7.00	29
Dirca palustris	13.81	8.83	22
*Duchesnea indica**	44.21	31.33	28
Erigenia bulbosa	9.17	15.27	23
*Erodium cicutarium**	8.94	7.65	31
Fragaria virginiana	22.91	18.79	26
Geranium maculatum	14.71	8.54	29
*Glechoma hederacea**	6.56	10.84	29
Hepatica americana	15.88	23.62	30
Ilex opaca	7.37	6.52	26
Kalmia latifolia	8.18	6.68	26
*Lamium purpureum**	36.53	19.69	30
Lindera benzoin	8.28	8.57	30
Liquidambar styraciflua	12.27	7.24	21
Liriodendron tulipifera	12.15	7.93	31
Maianthemum canadense	5.07	6.43	22
Mertensia virginica	16.01	11.02	29
Nyssa sylvatica	36.38	11.07	24
Panax trifolius	17.19	10.17	25
Phlox subulata	7.47	14.20	27
*Plantago lanceolata**	15.51	7.91	24
*Poa annua**	21.13	20.16	25
Podophyllum peltatum	11.03	7.34	30
Polygonatum biflorum	9.65	7.63	22
Potentilla canadensis	9.85	7.00	26
Prunus serrulata+	6.08	7.72	26
Prunus × yedoensis+	9.02	6.63	30
Ranunculus abortivus	3.18	7.83	29
*Ranunculus bulbosus**	20.82	20.95	25
Rhododendron periclymenoides	15.99	8.76	28
Robinia pseudoacacia	5.19	6.44	28
*Rumex acetosella**	7.58	9.81	23
*Rumex crispus**	17.56	9.69	22
Salvia lyrata	17.51	8.44	24
Sanguinaria canadensis	12.47	7.91	27
Sassafras albidum	8.69	8.30	29
Senecio aureus	14.23	13.22	29
Smilacina racemosa	4.10	4.99	28
Staphylea trifolia	7.02	6.92	25
*Stellaria media**	10.24	26.50	29
*Taraxacum officinale**	23.81	28.88	26
Toxicodendron radicans	5.83	6.44	23
*Trifolium pratense**	7.62	6.16	25
*Tussilago farfara**	5.37	14.80	28
Ulmus americana	3.65	10.12	30
Uvularia perfoliata	11.43	8.81	22
Vaccinium corymbosum	24.53	13.93	22
Vaccinium stamineum	15.40	10.97	27
*Veronica hederaefolia**	6.09	13.97	25
Viburnum acerifolium	15.20	6.31	22
Viburnum prunifolium	10.17	7.87	28
Viola bicolor	8.69	9.06	26
Viola pubescens	4.41	9.80	23
Viola sororia	10.71	7.84	31
Viola striata	14.09	10.38	24
Zizia aurea	21.55	18.30	22

Note: Species marked with an asterisk are naturalized, those marked with + are cultivated, and all others are native. Nomenclature largely follows Kartesz 1994.

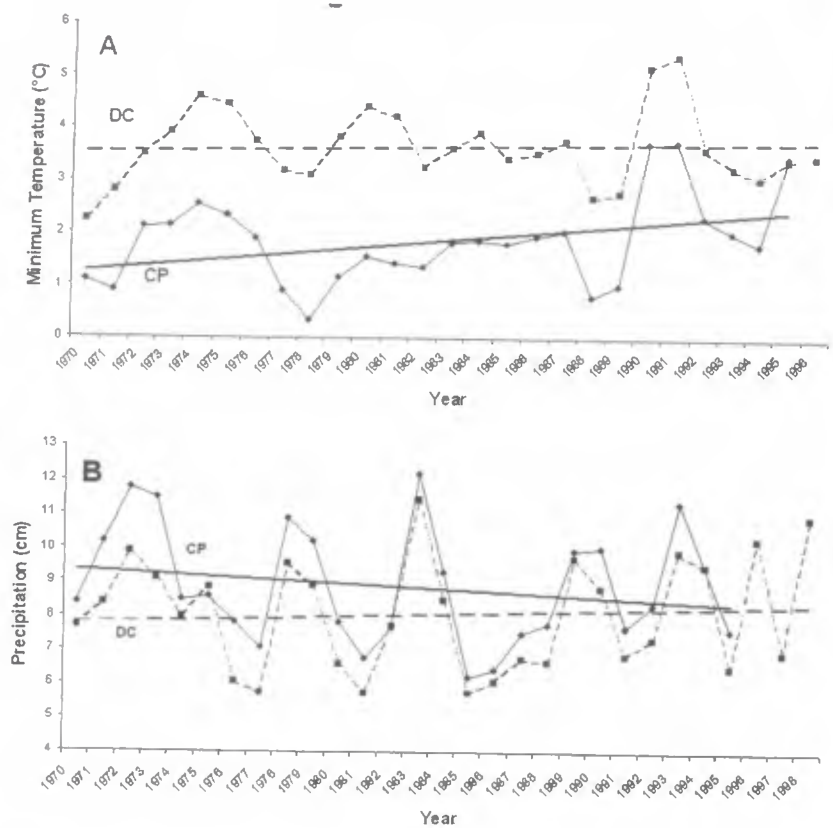

Figure 8.2 Climate data and their trends for Washington, DC (DC), and College Park, Maryland (CP), for 1970–1997. Solid lines with circles represent CP averages, and dashed lines with squares indicate DC averages. A, Average minimum temperature (T_{MIN}) for six months (December–May). B, Average precipitation for the same period. Data from National Oceanic and Atmospheric Administration, Climate Diagnostics Center.

addition, Pearson correlation coefficients were calculated to test for relationships between T_{MIN} and average precipitation versus first-flowering times.

EARLY FLOWERING

The linear trend of average first-flowering time for all 100 species shows a significant advance of 3.2 days for the 32-year period (fig. 8.1A). However, the elimination from the data set of the 10 species that exhibit the later flowering trend results in a significant advance of 5.1 days for the 32-year period (fig. 8.1B). Eighty of the 90 species exhibit a significant advance (table 8.1), and together show an average decrease of −5.8 days for the 32-year period. Ten of these 90 species have insignificant trends (an asterisk indicates naturalized species): **Capsella bursa-pastoris, Dentaria*

*laciniata, Epigaea repens, Euonymus americanus, Galium aparine, *Paulownia tomentosa, Phlox divaricata, Prunus serotina, Saxifraga virginiensis,* and *Sedum ternatum.* Significant trends for the 80 earlier flowering species range from −2.8 to −44.2 days. Of these 80 species, *Duchesnea indica* (false strawberry) shows the greatest advance in flowering time, with a trend of −44.2 days, whereas *Barbarea vulgaris* (yellow rocket) shows the smallest advance with a trend of −2.8 days. Both are naturalized species.

The following ten species exhibit later first-flowering times (an asterisk indicates naturalized species): *Acer saccharinum, *Ajuga reptans, Houstonia caerulea, *Lamium amplexicaule, *Lonicera japonica, *Melilotus officinalis, Osmorhiza claytonii, *Solanum dulcamara, Stellaria pubera,* and *Trillium sessile.* Seven of the ten species show significant delays in first-flowering; of these, *Lonicera japonica* (Japanese honeysuckle) has a trend of +9.7 days, and *Osmorhiza claytonii* (sweet cicely) has a trend of +2.2 days.

From 1970 to 1999, the average T_{MIN} for December to May, covering the recorded season of first-flowering, shows an increase of +1.2°C at College Park, Maryland (CP), and +0.2°C at Washington, DC (fig. 8.2A). The monthly average precipitation for the six-month period at DC has increased +0.6 cm, while it has decreased −1.1 cm at CP (fig. 8.2B). After surveying the precipitation by month, it appears that both stations show a decrease in precipitation during December (−0.7 cm for DC; −1.6 cm for CP), February (−0.2 cm for DC; −1.9 cm for CP), April (−0.6 cm for DC; −1.3 cm for CP), and May (−1.1 cm for DC; −0.8 cm for CP); whereas an increase in precipitation is seen in January (+1.7 cm for DC; +0.2 cm for CP) and March (+1.8 cm for DC and CP). Average flowering time (in Julian date) per year of the 100 species shows a significant negative correlation with T_{MIN} over the studied period for both CP and DC. No significant correlation was found between first-flowering and precipitation trends.

Although the onset of flowering is cued by photoperiodism, break of dormancy is triggered by temperature (Salisbury and Ross 1992). Because the annual photoperiodic cycle presumably has not changed during the last 32 years, we must assume that other factors, such as temperature and precipitation, are causing earlier spring flowering. The analysis presented here suggests that trends toward earlier flowering are the result of a warming trend in the study area. This warming trend, +1.2°C at CP, coincides with the global warming trend (Easterling et al. 1997). However, other causal factors not investigated by this study, such as carbon dioxide, cannot be eliminated as being important in regulating spring flowering. Likewise, why ten species exhibit later first-flowering times is difficult to explain. At this time, compelling evidence exists that the rise in the average minimum temperatures (T_{MIN}) is contributing to earlier flowering in at least 80 of the 100 species investigated. The results presented here are consistent with other studies showing that changes in air temperature have advanced the average annual growing season by six days in Europe and that warmer temperatures and higher carbon dioxide levels have promoted summer plant growth, thereby advancing the season by seven days in northern latitudes (Menzel and Fabian 1999).

Possible consequences of the warming and earlier-flowering trends should be investigated. Other studies (Shetler and Wiser 1987) have shown that the earliest noncultivated plants to flower in the Washington area are predominantly naturalized introductions, such as *Stellaria media* (common chickweed), *Taraxacum officinale* (dandelion), and *Lamium amplexicaule* (henbit). These species can exploit the slightest bit of warmth during the cold season and bloom quickly. The warming trend resulting in milder winters is likely to favor increasingly the naturalization of exotic species. The introduced element already appears to constitute about 40% of the local flora (Shetler and Orli 2000), and clearly these introductions have been rising steadily over the years.

Spring ephemerals require a tight synchrony with their pollinators, and the effects of earlier flowering on this relationship should be studied. Are the insects keeping pace? Likewise, the synchrony of the flowering cycles of the ephemerals with canopy closure needs examination. Of practical consequence is the earlier flowering of wind-pollinated trees and shrubs, which starts the season for allergy sufferers earlier. Finally, there is the Cherry Blossom Festival in Washington, DC, each spring. On average the two principal species, *Prunus serrulata* (Kwanzan cherry and other varieties) and *P. × yedoensis* (Yoshino cherry), bloom six and nine days earlier, respectively, than they did in 1970 (fig. 8.1D). This has major tourist implications since predicting peak-flowering from year to year can be problematic.

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LITERATURE CITED

Abu-Asab, M. S., Peterson, P. M., Shetler, S. G., and Orli, S. S. 2001. Earlier plant flowering in spring as a response to global warming in the Washington, DC, area. Biodiversity and Conservation 10:597–612.

Alward, R. D., Detling, J. K., and Milchunas, D. G. 1999. Grassland vegetation changes and nocturnal global warming. Science 283:229–231.

Chapin, F. S., Shaver, G., Giblin, A., Nadelhoffer, K., and Laundre, J. 1995. Responses of arctic tundra to experimental and observed changes in climate. Ecology 76:694–711.

Easterling, D. R., Horton, B., Jones, P. D., Peterson, T. C., Karl, T. R., Parker, D. E., Salinger, M. J., Razuvayev, V., Plummer, N., Jameson, P., and Folland, C. K. 1997. Maximum and minimum temperature trends for the globe. Science 277:364–367.

Hansen, J., Ruedy, R., Glascoe, J., and Sato, M. 1999. GISS analysis of surface temperature change. Journal of Geophysical Research 104:30997–31022.

Houghton, J. T., Meria Filho, L. G., Callender, B., and Harris, N., eds. 1995. The Science of Climate Change. Cambridge University Press, Cambridge.

Kartesz, J. T. 1994. A Synonymized Checklist of the United States, Canada, and Adjacent Greenland. 2nd edition. Timber Press, Portland, Oregon.

Melillo, J. M. 1999. Climate change: warm, warm on the range. Science 283:183–184.

Menzel, A., and Fabian, P. 1999. Growing season extended in Europe. Nature 397:659.

Salisbury, F. B., and Ross, C. W. 1992. Plant Physiology. 4th edition. Wadsworth Publishing, Belmont.

Shetler, S. G., and Orli, S. S. 2000. Annotated Checklist of the Vascular Plants of the Washington-Baltimore Area. Part 1, Ferns, Fern Allies, Gymnosperms, and Dicotyledons. Smithsonian Institution (National Museum of Natural History, Department of Botany), Washington, DC.

Shetler, S. G., and Wiser, S. K. 1987. First flowering dates for spring-blooming plants of the Washington, DC, area for the years 1970 to 1983. Proceedings of the Biological Society of Washington 100:993–1017.

Watson, R. T., and the Core Writing Team, eds. 2001. Climate Change 2001: Synthesis Report. Cambridge University Press, Cambridge.