Potential Effects on the Phenological Observation of Plants by Global Warming in Japan

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Abstract

Strong correlations were found between blooming dates and meteorological factors. Based on these correlations, predictive maps of blooming dates in the Japanese Islands were proposed for each case of 1, 2 and 3°C of warming. The correlation was tested for the blooming dates of Prunus yedoensis, Prunus mume, Camellia japonica, Taraxacum, Rhododendron kaempferi, Wisteria floribunda, Lespedeza bicolor, Hydrangea macrophylla, Lagerstroemia indica, Miscanthus sinensis, etc., using the data of monthly mean temperatures, warming indices and cold indices from 102 meteorological stations in Japan between 1953-1990. Simple and multiple regression analyses were used for the correlation.

Among meteorological factors, the strongest correlation was shown for monthly mean temperatures. Notably, the strongest was obtained for the case of Prunus yedoensis. The cold index and mean temperature of the previous December also showed the best correlation for species such as Prunus mume and Camellia japonica. Strong correlations between the leaf color-changing dates of Ginkgo biloba and Acer palmatum and the monthly mean temperature were found in one month of autumn. In these species, there was a delay of 2-7 days with a 1°C increase in mean temperature.

The 30-year 1 km² temperature-climate mesh-file developed by the Japan Meteorological Agency was used for the phenological estimation and predictive maps of blooming dates. Each observatory station was classified according to its annual mean temperature. Blooming for each mesh was estimated through monthly mean temperatures and regression equations of corresponding stations. Then, distribution maps of predictive blooming dates distinguished by 5-day divisions were made.

Key words: phenology, global warming, mean temperature, Prunus yedoensis, Prunus mume, Taraxacum

1. Introduction

Natural processes, which are good indicators of seasonal change, have been themselves changing due to the effects of global warming. According to a recent report by the Japan Meteorological Agency (JMA), a significant shift was found in phenological phenomena between the thirty-year averaged period of 1956-1985 and that of the thirty-year averaged period of the Manual of Phenological Observation 1961-1990. The secular change of blooming and sprouting dates in Japan has a close relation to meteorological indices such as monthly mean temperature, precipitation, solar radiation, monthly maximum temperature, monthly minimum temperature, and humidity, especially with monthly mean temperature (JMA, 1988).

The blooming date is controlled by the progression of temperature change before the blooming date and the temperature just before the blooming date (Shigehara, 1991). The blooming date of P. yedoensis shifts by 4 days with a 1°C change of temperature in March (Ohshima, 1987). Inversely, an attempt was made to estimate the blooming dates of plants by using the method of simple and multiple regression analysis, degree-day and degree-hour, the number of days transformed to standard temperature, latitude, distance from shoreline, cold index, and warmth index (Oimoto and Aono, 1990; Aono and Omoto, 1990a; Aono and Omoto, 1990b). Since 1987 JMA has been reporting forecasts of blooming dates of P. yedoensis by means of simple and multiple regression equations, formula of bud-weight, long-term prediction, analogue of year, variables of mean temperature, lowest temperature, and precipitation etc.

We estimated blooming or leaf-color change dates affected by global warming using simple temperature data. This would be a good strategy for the study of indicators of shifting of seasons and environmental change, estimation of phenological phenomena in places where meteorological data are absent, investigation of the climate of historical ages, application for agricultural aspects such as budding, blooming, harvesting, and utility in recreation and sightseeing.

2. Materials and method

Observation of phenological phenomena has been carried since 1953 based on the “Manual of Phenological Observation” which suggests using the observatory method and its provisions (JMA, 1988). Using these phenological data, the relation between the blooming dates of each plant (P. yedoensis, P. mume, Taraxacum, Wisteria floribunda, etc.) and the monthly means of meteorological factors (monthly mean temperature, precipitation, solar radiation, monthly highest temperature, monthly lowest temperature, humidity, etc.) were investigated. We tried to estimate the shift of phenological phenomena under the warming effect using monthly mean temperature, because the monthly mean temperature shows the highest correlation with the blooming dates of each plant.

Correlations between the blooming dates and monthly mean temperatures at each station (102 localities) were examined and simple and multiple regression equations were calculated as a function of
correlated monthly mean temperature. Shifts of blooming day due to temperature rise were obtained for each station from this formula. The values of the shift at each station were plotted on the Japanese map with the advantage of the 30-year 1 km temperature-climate mesh-file. First, each observatory station was classified by a 1°C temperature according to its annual mean temperature. Second, each km² mesh-file was integrated into km² scaled monthly and annual mean temperatures. By substituting these values for the equations of each station within the 5x5 grid, estimations of blooming dates were made. Distribution maps of the blooming dates were made by assuming that the mean values of the estimated blooming dates were the blooming dates of each grid.

3. Results
3.1 Estimation of the blooming date of Prunus yedoensis
Most effective over 2-3 month periods, correlation of blooming dates and monthly mean temperatures were examined for the 38 years from 1953 to 1990. There were strong correlations for the previous month of blooming day or the month including the blooming day. Regression equations were calculated at each station. The results show that the blooming dates before April 21 have high correlation with the monthly mean temperature of March (mean correlation coefficient of 0.773); the blooming dates after April 20 have high correlation with those of April (mean correlation coefficient of 0.775). According to multiple regression analysis for two months, the mean correlation coefficient is about 0.84 for March and April, 0.861 for April and May.

Overall, a 1°C rise of monthly mean temperature leads to 2.7-4.8 days of blooming with a mean of 3.24 days. There were local differences in blooming under the warming effect: In southern Kyushu, southern Shikoku, the Goto and Bonin islands, correlation coefficients became lower when the monthly mean temperatures were above 10°C. If the monthly mean temperature was higher than 12°C there was almost no correlation. The shift when the monthly mean temperature rose by 1°C was about 2.5 days for these regions. On the other hand, the shift was more than 4 days in Hokkaido. Distribution maps shifting the blooming dates of each station in the cases of 1°C, 2°C and 3°C rises in monthly mean temperature were made for the 10-days intervals of March 17-26, March 27-April 5, April 6-15 and April 16-25.

Figure 1(a) shows the 30-year (1951-1980) mean blooming dates and the shifted dates under a 1°C rise of monthly mean temperature. The gray areas, which spread between 31°34’N-36°33’S, indicate the regions where the blooming dates were from March 27 to April 5. The Kanto Plain, the Pacific side of Honshu, some parts of Shikoku and Kyushu are included within this area. Black areas are the places where the blooming dates were before March 26. Under the condition of a 1°C rise, the black areas shifted northward to include Kyushu, Shikoku, the Kii Peninsula, the coastal region of Tokai, and the southern Kanto Plain. The blooming front is thought to shift northward by 1 degree in latitude under the 1°C rise of mean temperature. An estimated shift of blooming date under a 3°C rise of mean temperature in March is shown in Figure 1(b). Gray areas are migration northward including Sendai (38°16’), Akawa, Niigata and Wajima. The pattern of distribution appears very similar to the pattern of April 6-15 for the 30-year mean.

The blooming front (Sakura Zensen) shifted about 3’ in latitude relative to that of the 30-year mean. At the end of the 21st century, it is thought that the global temperature will rise by 3°C. This simulation indicates that Sakura Zensen shifts northward from northern Kanto to the Tohoku and Hokuriku regions, and the blooming dates in the region south of northern Kanto shifted within the March 17-26 period.

3.2 Estimation of the blooming date of Prunus mume
The same analysis was carried out P. mume. P. mume was classified as a warming-fuddled type by JMA (1991). However, the results indicate that the correlation between the blooming dates of P. mume and the mean temperature of a two or three month interval is as high as that of P. yedoensis. The values of correlation coefficients were relatively higher at the stations in northern Japan (r=0.85 in north, while r=0.68 is the mean for Shikoku and Kyushu). The correlation decreases if the monthly mean temperatures are above 12°C or below 5°C. The blooming dates shifted by 4-13 days (about 6 days on average) with a 1°C mean temperature rise. Distribution maps of blooming dates of each station were made for 30-year means and for the cases of 1°C, 2°C and 3°C rises in monthly mean temperature in December, January, February, March, April and May, for the 30-day intervals of January 1 to February 4, February 5 to March 6, and after March 7 (Fig. 2). Various species are included in this case. Black colored areas indicate the distribution of the blooming dates from January 1 to February 4. The estimated distribution map in the case of a 2°C rise of monthly mean temperature is a good analogue of the map for blooming dates from March 27 to April 5 for the 30-year mean.

3.3 Estimation of the blooming date of Taraxacum
Estimation of blooming dates for Taraxacum was carried out. Taraxacum is classified as a warming-adaptation type by JMA (1991). The correlation between blooming dates of Taraxacum and monthly mean temperatures for the two or three month interval is not as high as those of P. yedoensis and P. mume. However, a similar trend of correlation coefficients with P. mume was found; a highest value (r=0.67) was observed in northern Japan and the value decreased in southern Japan. The correlation decreases if the monthly mean temperature is above 10°C or below 5°C. The blooming dates shift 3-8 days
(about 5 days average) earlier with a 1°C mean temperature rise. Distribution maps of blooming dates for each station were made for a 30-year mean and for the cases of 1°C, 2°C and 3°C rises in monthly mean temperature in December, January, February, March, April and May, for the 30-day intervals from January 1 to February 4, February 5 to March 6, and March 7 to April 5.

**Prunus yedoensis**

![Fig. 1 Estimation of blooming dates of *Prunus yedoensis*. a: 30-year (1951-1980) mean of blooming dates, b: shifted blooming dates under 3°C rise of mean temperature.](image)

**Prunus mume**

![Fig. 2 Estimation of blooming dates of *Prunus mume*. a: 30-year (1951-1980) mean of blooming dates, b: shifted blooming dates under 3°C rise of mean temperature.](image)
In the distribution map for the 3-year mean, the blooming dates were within March except for the mountainous region in southern Kanto. In the estimated distribution map, a 3°C rise shows the blooming dates at the stations south of Tohoku shifting to February.

3.4 Blooming, budding, and leaf-color changes of other plants

The relation of mean temperature to the blooming date of *Camellia japonica* L., *Rhododendron kaempferi*, *Wisteria floribunda*, *Lespedeza bicolor*, *Hydrangea macrophylla*, *Lagerstroemia indica* and *Miscanthus sinensis*, budding date of *Ginkgo biloba* L., and the dates of leaf-color change and leaf-falling of *Ginkgo biloba* L. and *Acer palmatum* were examined. The results indicate that a high correlation was observed during the relatively low-temperature months of March to April, and also that the cold indices have high correlation with *P. mume*, *Camellia japonica* L. and *Taraxacum*. The blooming dates of these three plants are earlier than that of *P. yedoensis*. Figure 3 shows the shift in days due to a 1°C rise of monthly mean temperature for each kind of plant. The magnitude of the shifts are 7.5 days for *C. japonica* L., 6.1 days for *P. mume* in the case of a 1°C rise in monthly mean temperature in January; 4.7 days for *Taraxacum* under a 1°C rise in monthly mean temperature in March. These magnitudes of shift are larger than that of *P. yedoensis*. For the plants with blooming dates after March, 2.6 days in shift were found for *Rhododendron kaempferi* and *Wisteria floribunda* under a 1°C rise in monthly mean temperature of April. The accuracy of estimation is the same with both plants (Aono and Omoto, 1992). Monthly mean temperatures for three months were effective on blooming dates of plants from late April; these include *Hydrangea macrophylla*, *Lagerstroemia indica*, *Lespedeza bicolor* and *Miscanthus sinensis*. On *Lagerstroemia indica*, the highest correlated month is June; a 1°C rise of temperature makes the blooming days 6.4 days earlier. On *Ginkgo biloba* L. and *Acer palmatum*, high correlation was found in September to November, and the leaf-color change dates and the leaf-falling dates shift about 4 days later under a 1°C temperature rise. These dates also have a high correlation with warmth indices.

![Fig. 3 Shifts in phenological dates for each kind of plant.](image)

References


