# Chapter 2
# Temporal Rhythmicity of Plant Phenology

**Abstract** Plant phenological observations show that plant growth and reproduction obey a certain temporal rhythmicity, which is a macroscopic and integrative reflection of local and regional natural landscape dynamics. The most obvious temporal rhythmicities of plant phenology are displayed as sequential and correlative rhythm, circannual rhythm, multi-year rhythm, circadian rhythm, and overlap rhythm. Temporal rhythmicity of plant phenology is mainly attributed to climatic rhythmicity, photoperiod, and response properties of phenological phenomena to weather and climate.

**Keywords** Sequential and correlative rhythm · Circannual rhythm · Multi-year rhythm · Circadian rhythm · Overlap rhythm

## 2.1 Sequential and Correlative Rhythm

Plant phenology sequential and correlative rhythm is defined as follows:

> The occurrence dates of various plant phenological phenomena obey a certain time sequence within a year, and synchronously advance or postpone among years.

The time sequence depends highly on geographical locations and specific plant communities. External causes of the sequential and correlative rhythm of plant phenology are seasonal insolation induced weather and climatic seasonal rhythms, including temperature, precipitation, photoperiod, humidity, wind, etc. These meteorological factors evolve along the time sequence within a year and fluctuate among years, which form the environmental background of sequential and correlative rhythm of plant phenology. With regard to plant phenological adaptation and response to climate change, if a species is to thrive and extend its range in a certain region, it must be able to coordinate its life cycle with the progression of periodic phenomena in its environment (Larcher 1975). Because a plant phenological phenomenon occurrence reflects the accumulation of environmental conditions (especially weather and climatic conditions) over a past time period, continuous accumulation of climatic variables along the time sequence will subsequently



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trigger occurrence of various phenological phenomena. Sequential and correlative rhythm can be statistically expressed by correlation coefficient as follows:

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}}$$

where $x_i$ and $y_i$ denote the occurrence dates of two arbitrary phenophases in year $i$; $\bar{x}$ and $\bar{y}$ denote the multi-year mean occurrence dates of the two phenophases; $n$ is the number of years. If $x_i$ and $y_i$ have significant positive correlation, sequential and correlative rhythm exists between them. The larger the correlation coefficient is, the stronger the sequential and correlative rhythm is. Contrarily, if they have non-significant positive correlation, only sequential rhythm but not correlative rhythm exists between them. Table 2.1 and Fig. 2.1 show an example of sequential and correlative rhythm of plant phenology in the Beijing Botanical Garden. Other examples of sequential and correlative rhythm of plant phenology have also been reported in Germany (Pfau 1964; Menzel 2003). Generally speaking, as the time interval between two phenological occurrence dates expands, sequential and correlative rhythm may become weaker due to the decrease of continuity of weather processes influencing the two phenological occurrence dates (Fig. 2.2).

## 2.2 Circannual Rhythm

Plant phenology circannual rhythm can be expressed as:

> The occurrence dates of various plant phenological phenomena have a recurrence interval of approximate one year.

**Table 2.1** Correlation coefficients between first flowering dates in the Beijing Botanical Garden (1979–2013)

| Species | *Pd* | *Fs* | *Md* | *Cs* | *So* | *Rx* | *Pp* |
|---|---|---|---|---|---|---|---|
| *Jn* | 0.826* | 0.803* | 0.780* | 0.636* | 0.661* | 0.703* | 0.546* |
| *Pd* | | 0.766* | 0.805* | 0.572* | 0.697* | 0.669* | 0.494* |
| *Fs* | | | 0.823* | 0.589* | 0.736* | 0.720* | 0.551* |
| *Md* | | | | 0.658* | 0.819* | 0.770* | 0.653* |
| *Cs* | | | | | 0.641* | 0.715* | 0.731* |
| *So* | | | | | | 0.613* | 0.644* |
| *Rx* | | | | | | | 0.739* |

*Data source* Personal field observations conducted by Xiaoqiu Chen and Guodong Yang
*$P < 0.01$
*Jn*: *Jasminum nudiflorum*; *Pd*: *Prunus davidiana*; *Fs*: *Forsythia suspensa*; *Md*: *Magnolia denudata*; *Cs*: *Chaenomeles speciosa*; *So*: *Syringa oblata*; *Rx*: *Rosa xanthina*; *Pp*: *Philadelphus pekinensis*

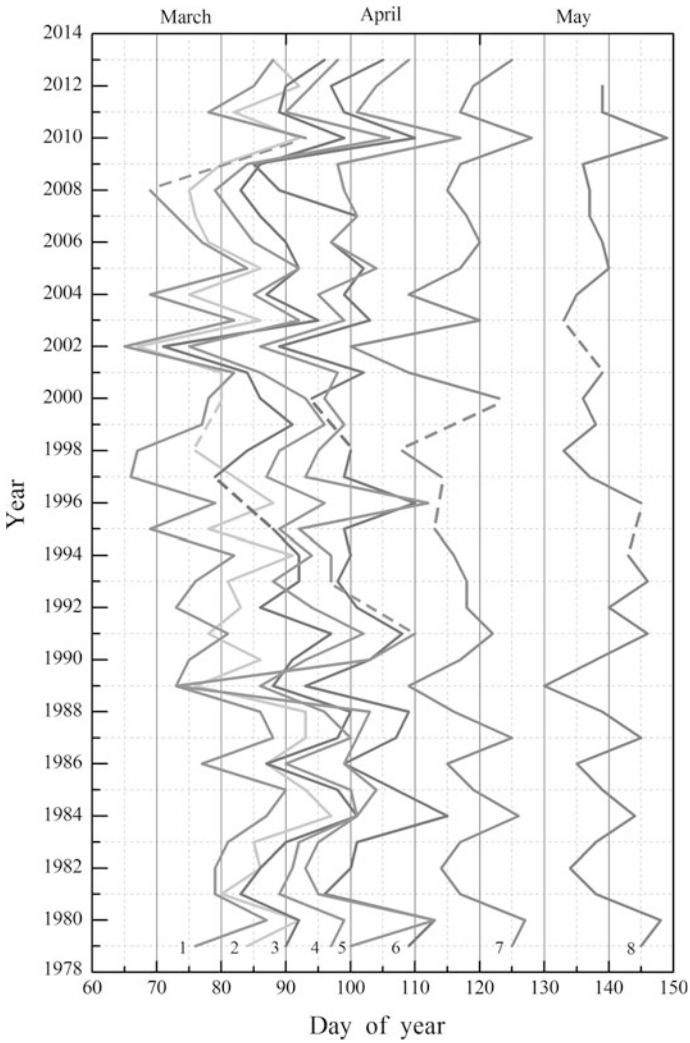
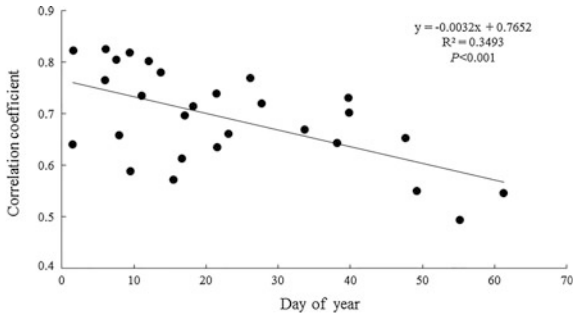



**Fig. 2.1** Plots of sequential and correlative rhythm of the first flowering dates in the Beijing Botanical Garden (1979–2013). *1 Jasminum nudiflorum*; *2 Prunus davidiana*; *3 Forsythia suspensa*; *4 Magnolia denudata*; *5 Chaenomeles speciosa*; *6 Syringa oblata*; *7 Rosa xanthina*; *8 Philadelphus pekinensis* (*Data source* Personal field observations conducted by Xiaoqiu Chen and Guodong Yang)

Since the recurrence interval is usually less dependent on geographical locations and specific plant species, circannual rhythm is the essential characteristic of plant phenological phenomena. External causes of plant phenology's circannual rhythm are the Earth's revolution-induced weather and climatic annual cycles, including temperature, precipitation, photoperiod, humidity, wind, etc. Circannual rhythm of plant phenology can be measured by multi-year mean value ($\bar{x}$), standard deviation

**Fig. 2.2** Relationship between correlation coefficient and corresponding average time interval among first flowering dates




(*SD*), and range (*R*; difference between maximum value and minimum value) of the recurrence interval. Table 2.2 shows circannual rhythm of individual plant phenophases in the Beijing Botanical Garden. On average, the recurrence intervals of all plant phenophases are about 365 days, and the standard deviation (SD) of the recurrence intervals display a decreasing tendency from midspring to early summer. Namely, circannual rhythm of plant phenology is stronger for later phenophases than earlier phenophases in the first half-year.

Further statistical analysis indicated that the first date for the daily mean air temperature to steadily pass 0, 5, and 10 °C characterizes also circannual rhythm (Table 2.3). It is worth noting that the mean recurrence intervals are also about 365 days, but the SD and R values of the recurrence intervals are much larger than those of spring plant phenology. This shows that circannual rhythm of spring plant phenology can reflect annual cycle of threshold daily mean air temperatures to a large extent, and spring plant phenology is a more stable indicator in displaying circannual rhythm of natural landscape dynamics than air temperature.

## 2.3 Multi-year Rhythm

Multi-year rhythm of plant phenology means that long time series of some plant phenological occurrence dates have a quasi-periodicity over one year. That is, notably early or late years in plant phenological occurrence dates appear at regular intervals. It should be noted that this kind of rhythm is not strictly periodic and depends highly on geographic location, time series length, and plant species. So far, the most famous example in plant phenology multi-year rhythm was reported by Margary (1926). He analyzed the annual mean flowering and leafing dates of seven plants from the Marsham phenological record (over 1736–1925 in Norfolk, England), and found the mean periods between early years or late years were 12.2 years for unsmoothed time series and 12.1 years for smoothed time series. Further analysis indicated that flowering and leafing dates and mean temperature during January to May showed an apparent correlation between earliness/lateness and warmness/coldness, and similar mean periods between 11.8 and 12.2 years. In addition, the flowering and leafing dates and sunspot numbers showed a moderate

**Table 2.2** Circannual rhythm of the first flowering dates from midspring to early summer in the Beijing Botanical Garden (1979–2013)

| Period | *Jn* | *Pd* | *Fs* | *Md* | *Cs* | *So* | *Rx* | *Pp* |
|---|---|---|---|---|---|---|---|---|
| 1979–1980 | 376 | 373 | 367 | 367 | 378 | 369 | 367 | 368 |
| 1980–1981 | 358 | 354 | 357 | 356 | 349 | 349 | 356 | 356 |
| 1981–1982 | 365 | 371 | 368 | 367 | 362 | 369 | 362 | 361 |
| 1982–1983 | 367 | 364 | 369 | 366 | 367 | 366 | 368 | 369 |
| 1983–1984 | 371 | 377 | 376 | 374 | 371 | – | 374 | 371 |
| 1984–1985 | 369 | 362 | 363 | 365 | 369 | – | 359 | 361 |
| 1985–1986 | 352 | 359 | 354 | 355 | 360 | 357 | 361 | 361 |
| 1986–1987 | 376 | 371 | 376 | 375 | 367 | 373 | 375 | 375 |
| 1987–1988 | 363 | 365 | 367 | 361 | 367 | 367 | 356 | 359 |
| 1988–1989 | 353 | 349 | 354 | 356 | – | 350 | 359 | – |
| 1989–1990 | 367 | 375 | 368 | 372 | – | 375 | 373 | – |
| 1990–1991 | 371 | 357 | 371 | 374 | 372 | 370 | 370 | 373 |
| 1991–1992 | 357 | 370 | 354 | 357 | – | 358 | 361 | 359 |
| 1992–1993 | 369 | 364 | 372 | 360 | – | 363 | 366 | 372 |
| 1993–1994 | 371 | 375 | 365 | 371 | 365 | 367 | 363 | 362 |
| 1994–1995 | 352 | 352 | 361 | 360 | 360 | 364 | 362 | – |
| 1995–1996 | 375 | 375 | – | 372 | 385 | 376 | – | – |
| 1996–1997 | 353 | 360 | – | 357 | 347 | 355 | – | 358 |
| 1997–1998 | 366 | 359 | 370 | 367 | 367 | 366 | 359 | 361 |
| 1998–1999 | 375 | – | 372 | 372 | 369 | – | – | 370 |
| 1999–2000 | 366 | – | 360 | 362 | 362 | – | – | 363 |
| 2000–2001 | 370 | 366 | 364 | 359 | 368 | 374 | 352 | 369 |
| 2001–2002 | 348 | – | – | – | 353 | 352 | – | – |
| 2002–2003 | 382 | – | – | – | 378 | 379 | – | – |
| 2003–2004 | 352 | 354 | 357 | 358 | 361 | 361 | 354 | 367 |
| 2004–2005 | 381 | 377 | 371 | 373 | 375 | 369 | 374 | 371 |
| 2005–2006 | 358 | 357 | 363 | 358 | 358 | 360 | 368 | 364 |
| 2006–2007 | 361 | 363 | 361 | 362 | 369 | 369 | 363 | 363 |
| 2007–2008 | 361 | 364 | 362 | 362 | 363 | 353 | 362 | 365 |
| 2008–2009 | – | 371 | 369 | 371 | 365 | – | 368 | 365 |
| 2009–2010 | – | 377 | 378 | – | – | – | 376 | – |
| 2010–2011 | – | 355 | 355 | – | – | 354 | 354 | – |
| 2011–2012 | 372 | 375 | 366 | 369 | 368 | 363 | 367 | 365 |
| 2012–2013 | 369 | 362 | 372 | 370 | 371 | 374 | 372 | – |
| $\bar{x}$ (days) | 365.4 | 365.1 | 365.4 | 364.9 | 365.9 | 364.4 | 364.3 | 365.1 |
| *SD* (days) | 9.0 | 8.3 | 6.8 | 6.4 | 8.2 | 8.3 | 6.8 | 5.1 |
| *R* (days) | 34 | 28 | 24 | 20 | 38 | 30 | 24 | 19 |

*Data source* Personal field observations conducted by Xiaoqiu Chen and Guodong Yang

*Jn*: *Jasminum nudiflorum*; *Pd*: *Prunus davidiana*; *Fs*: *Forsythia suspensa*; *Md*: *Magnolia denudata*; *Cs*: *Chaenomeles speciosa*; *So*: *Syringa oblata*; *Rx*: *Rosa xanthina*; *Pp*: *Philadelphus pekinensis*

**Table 2.3** Mean recurrence interval and its variation of the first date for the daily mean air temperature to steadily pass 0, 5, and 10 °C in Beijing (1979–2013)

| Statistical indicator | First date ≥ 0 °C | First date ≥ 5 °C | First date ≥ 10 °C |
|---|---|---|---|
| $\bar{x}$ (days) | 365.7 | 365.2 | 365.1 |
| *SD* (days) | 14.1 | 13.5 | 8.8 |
| *R* (days) | 57 | 49 | 37 |

connection between earliness and maximum in nine times of fifteen and between lateness and minimum at the same degree. The period of sunspot numbers was 11.2 years. Nowadays, spectrum analysis and wavelet analysis are usually used for identifying phenological periodicity. A singular spectrum analysis has been implemented to delineate periodicity of flowering dates of four eucalypt species from 1940 to 1971 in Australia and a 4-year cycle was detected in *Eucalyptus tricarpa* (Hudson and Keatley 2010). Using first flowering time series of the eight plant species in the Beijing Botanical Garden from 1979 to 2013 (Fig. 2.1), a wavelet analysis was carried out for identifying the multi-year rhythm. Results showed that a 12-year major cycle exists in these phenological time series (Fig. 2.3), which is coincident with the major cycle in average air temperature during March to May in Beijing. Thus, multi-year rhythm of spring plant phenology can reflect periodic variation of air temperature to a certain extent.

## 2.4 Circadian Rhythm

Plant phenology circadian rhythm can be described as follows:

> The occurrence time of some plant phenological phenomena show a recurrence interval within 24 h at a specific site, which reflects the effect of photoperiod on plant phenological phenomena.

Studies showed that some leguminous plants and their seedlings open their leaves during the day and close them at night (Piltz and Bever 1970). Carolus Linnaeus (1707–1778) found that flowers of some plants opened and closed periodically at different hours of the day and that these times varied from species to species. Thus, he proposed a flower clock to show the time. Namely, cultivating these plants in a round flower bed according to time sequence of flowering within a day, they constituted a kind of flower clock (Riedman 1982; Foster and Kreitzman 2004). The flower clock was a garden plan hypothesized by Carolus Linnaeus, which would take advantage of several plants that open or close their flowers at particular times of the day to accurately indicate the time. Nevertheless, although many plants exhibit a strong circadian rhythm, few have been observed to open their flowers at a precise solar time. Therefore, the accuracy of such a clock is diminished because flowering time is also affected by weather and seasonal factors. In addition, the flowering times recorded by Linnaeus would also be subject to differences in daylight due to latitude (Gardiner 1987).

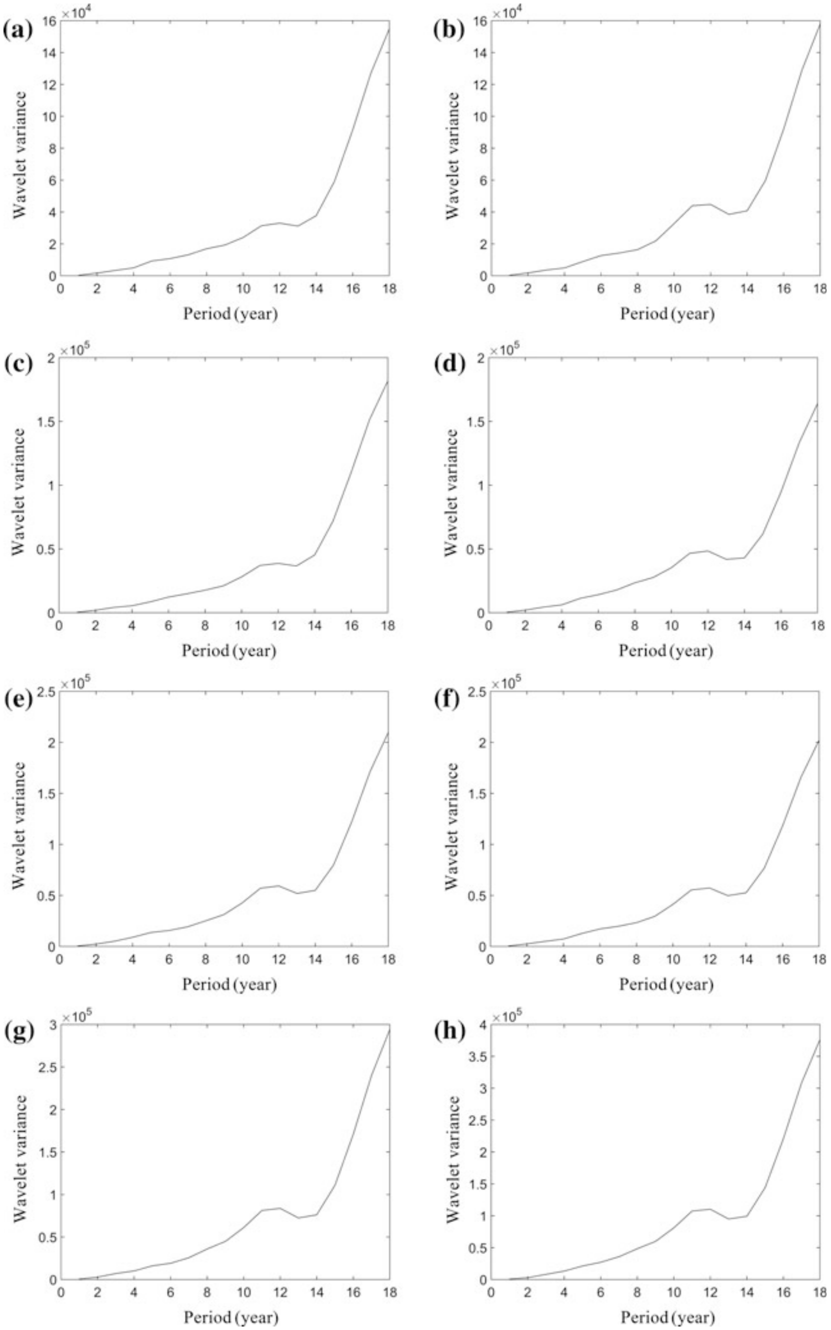



**Fig. 2.3** Wavelet variance diagram of the first flowering dates in the Beijing Botanical Garden. **a** *Jasminum nudiflorum*; **b** *Prunus davidiana*; **c** *Forsythia suspensa*; **d** *Magnolia denudata*; **e** *Chaenomeles speciosa*; **f** *Syringa oblata*; **g** *Rosa xanthina*; **h** *Philadelphus pekinensis*

## 2.5 Overlap Rhythm

Plant phenology overlap rhythm means that some plant phenological phenomena occur roughly at the same time each year. The biological cause of overlap rhythm is that occurrence of the overlapping phenological phenomena needs approximately the same amount of accumulation of environmental conditions. Plant phenology overlap rhythm can be measured by comparing average occurrence dates, standard deviations, and the earliest and latest occurrence dates of two or more phenophases. Obviously, the smaller the difference of these statistical indicators between two phenophases is, the more synchronous the plant phenology overlap rhythm. Based on overlap rhythm between two plant phenophases, the missing data in a phenological time series can be estimated using the observed data of another phenological time series (Schnelle 1955). From the perspective of the food chain, overlapping rhythms between plant and animal phenophases may reflect direct ecological relationships. For example, whenever pears blossom, adults of *Hoplocampa pyricola* lays eggs on the sepals of flowers in areas around Beijing. During the young fruit stage, larva of *H. pyricola* hatches and drills into young fruits, making them turn black and fall off (Yang and Chen 1995). Therefore, understanding overlapping rhythms of plant and insect phenology may also be beneficial for preventing and controlling pests.

Moreover, global climate warming and growing season shifts can alter the overlapping rhythms of producers, consumers, and decomposers, leading to asynchronies resulting in trophic mismatches, which may disrupt ecosystem interactions and food chains (Visser et al. 1998; Both and Visser 2001; Visser and Holleman 2001; Warren et al. 2001; Walther et al. 2002; Strode 2003).

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