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Phenological sensitivity of the Yoshino cherry (*Prunus* × *yedoensis*) to rising average spring temperatures in Kyoto, Japan

Eesha Thali

I. Introduction:

The cherry blossom in Japan is a globally captivating event that occurs every year in the spring season. Amongst all the cherry trees in Japan, the Yoshino cherry (*Prunus × yedoensis*) is one of the most popular and elegant hybrid cherry trees, thought to have emerged naturally through cross pollination.[1]

Initially, it was their diversity and pure charm that caught my attention to explore cherry blossom trees. But as I researched more on these trees, I observed that there was a link between its full bloom timing and temperature. Therefore, to understand exactly how and why the plant's internal responses were related to temperature, I researched deeper using more biological data collected on Yoshino cherry (Prunus × yedoensis), along with the spring temperatures in the location it was closely recorded in (Kyoto, Japan).[2]

Apart from this, the Yoshino cherry trees also serve as an example of how species around the world are responding to increases in temperatures, and hence they may be useful in predicting future ecological changes that can take place.

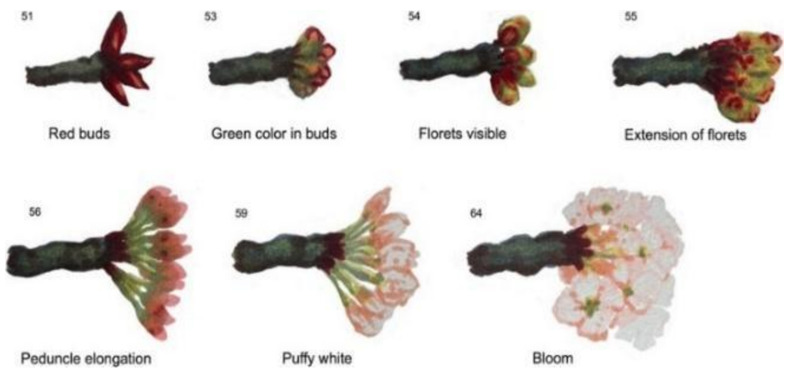
This research in turn seeks to find how much increasing spring temperatures have contributed to changes in the date of flowering of the Yoshino cherry in Kyoto for the years 1920-2024, with an ultimate goal of better understanding how species' phenological sensitivity is impacted by temperature increases.

II. Background Information:

2.1: The Yoshino Cherry in Kyoto

In Japan, the Sakura forecast (annual cherry blossom forecast) predicts when the cherry blossoms are likely to bloom in different regions of Japan, and relies heavily on the Yoshino cherry (Somei-Yoshino). This is because its bloom timing responds consistently to temperature, making their prediction easier to forecast when combined with historical bloom dates and current weather conditions. This forecast also helps to predict the various stages of the blossoms like Kaika- first bloom, Mankai- full bloom, Sakurafubuki- falling of cherry blossom petals. [3]Out of these, the focus of this essay is on the Mankai stage (full bloom) as it represents the peak flowering used in scientific analysis.

Figure 1: Bud development stages of Yoshino cherry (*Prunus × yedoensis*) from red buds to full bloom (stages 51–64) [4]



[1] Cho, M-S., & Kim, S-C. (2019, December 19). Multiple lines of evidence for independent origin of wild and cultivated flowering cherry (Prunus yedoensis*). Frontiers in Plant Science, vol. 10.* https://doi.org/10.3389/fpls.2019.01555

[2] Spooner, F. (2025, April 10). *Japan's cherry trees have been blossoming earlier due to warmer spring temperatures.* Our World in Data. https://ourworldindata.org/data-insights/japans-cherry-trees-have-been-blossoming-earlier-due-to-warmer-spring-temperatures

[3] Hatsukoi. (2025, February 20). Japan's sakura forecast: Spring is on its way. *Hatsukoi.* https://hatsukoi.co.uk/blog/133-japans-sakura-forecast.html

[4] Figure 1. Maust, A., Bradshaw, M.J., Braun, M., Kim, S-H., Tobin, P.C. (2025, June 16). *Citizen science data reveals winter warming delays cherry bloom in the Pacific Northwest, USA.* New phytologist foundation. https://doi.org/10.1002/ppp3.70037

Amongst all the regions, Kyoto is especially useful to study as full bloom dates there have been recorded for decades from articles, newspapers and official observations. From the time frame selected for this research (1920-2024), only 2 years (1921 and 1945) lack records, making it one of the most complete phenological datasets in the world. This makes the Yoshino cherry in Kyoto ideal to study how rising temperatures change full bloom date.[5]

2.2: Phenology and Phenological Sensitivity

Phenology is the study of the cyclical seasonal events that occur in nature. Being specific to plants, it is the recurring events in the plant's life cycle such as flowering and leafing, and how these are influenced by environmental changes. These changes can be in temperature, precipitation, photoperiod (day length), etc.[6]

Phenological sensitivity furthermore refers to the extent to which the timing of one of these events shifts in response to a change in an environmental factor.[7]

In this essay, the focus will be on temperature in Kyoto, Japan, and how it affects the full bloom of the Yoshino cherry *(Prunus × yedoensis),* providing a measure of the species' sensitivity to temperature.

2.3: Biological Basis of Flowering and the Role of Temperature

Flowering is one of the most vital phases in the life cycle of the Yoshino cherry, as in any other angiosperm[8], marking the transition from vegetative growth to reproduction. This development is regulated by environmental cues (temperature, photoperiod, etc.), genetic cues, as well as by plant hormones, such as abscisic acid (ABA) that ensures the initiation of bud dormancy during the cold winter season, whereas gibberellins and florigen induce growth and differentiation of floral tissues once temperatures stabilize.[9] In Yoshino cherries, the buds go into winter dormancy before flowering occurs, a survival mechanism which protects them against adverse conditions. For this to be overcome, they require a minimum number of chilling hours (cold temperature periods), a phenomenon known as vernalization[10]. It guarantees that plants flower at appropriate times to maximise successful reproduction opportunities.

In these processes, temperature has a dual role. Extended low temperatures are required for breaking dormancy, but after this need of chilling hours is fulfilled, increased spring temperatures speed up bud growth and initiate flowering as a result of enhanced metabolic processes. Therefore, small temperature fluctuations annually may directly change the date of peak blossom, and that is why cherry blossom predictions in Japan might have close connections to temperature trends.[11, 12]

2.4: Importance of Flowering Time

The full bloom time is important for Yoshino cherry trees because it influences reproduction, which needs to occur when conditions for survival and pollination are favourable. If the blooming occurs too early, flowers risk damage by frost and decreased pollination if bees are still dormant, while delayed blooming could lose ideal conditions that existed. This full bloom time also affects other species. For example, several bees rely on these flowers for nectar and pollen, while birds eat the cherries once they have been pollinated. Hence, variations in blooming time have the ability to impact a number of interactions of the Yoshino cherry within its natural environment, hence the influence of temperature on its phenological sensitivity is significant to study.[13]

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5 Yamaguchi, D. (2018, April 30). Kyoto historical cherry blossom flowering dates. *The North American Post.* https://napost.com/2018/kyoto-historical-cherry-blossom-flowering-dates/

6 USA National Phenology Network. (2019, February 25). Phenology report guide (Education Series 2017-001). *USA National Phenology Network*. https://mnpn.usanpn.org/files/education/USA-NPN_Phenology_Report_Guide-2019Feb25.pdf

7 Zettlemoyer, M. A., Wilson, J. E., & DeMarche, M. L. (2022, December). Estimating phenological sensitivity in contemporary vs. historical data sets: Effects of climate resolution and spatial scale. *American Journal of Botany, vol. 109(12), 1981-1990.* https://doi.org/10.1002/ajb2.16087

8 Berry, P.E., Stevenson, D.W., Dilcher, D.L., Cronquist, A., Zimmermann, M.H., Stevens, P. (2025, September 26). Angiosperm. *Encyclopedia Britannica*. https://www.britannica.com/plant/angiosperm

9 Jagadish, S. V. K., Bahuguna, R. N., Djanaguiraman, M., Gamuyao, R., Prasad, P. V. V., & Craufurd, P. Q. (2016, June 27). Implications of high temperature and elevated CO_2 on flowering time in plants. *Frontiers in Plant Science, vol. 7.* https://doi.org/10.3389/fpls.2016.00913

10 Britannica Editors (2025, September 30). Vernalization. *Encyclopedia Britannica*. https://www.britannica.com/topic/vernalization

11 Giovannini, A. (2025, January 2). The effects of climate change on the flowering of Yoshino cherry trees in Japan. *Cherry Times.* https://cherrytimes.it/en/news/The-effects-of-climate-change-on-the-flowering-of-Yoshino-cherry-trees-in-Japan

12 Luedeling, E., Kunz, A. & Blanke, M.M. (2013, September). Identification of chilling and heat requirements of cherry trees—a statistical approach. *International journal of biometeorology, Vol. 57, 679–689.* https://doi.org/10.1007/s00484-012-0594-y

13 Freimuth, J., Bossdorf, O., Scheepens, J. F., & Willems, F. M. (2022, March 30). Climate warming changes synchrony of plants and pollinators. *The royal society publishing, vol. 289(1971).* https://doi.org/10.1098/rspb.2021.2142

III. Hypothesis:

3.1: Null Hypothesis (H_0): The average spring temperature changes have no relationship with the flowering time of Yoshino cherry trees (*Prunus × yedoensis)* in Kyoto, Japan.

3.2: Alternative Hypothesis (H_1): Increases in average spring temperature significantly influence the flowering time of Yoshino cherry trees (*Prunus × yedoensis)* in Kyoto, Japan, causing earlier or delayed blooming depending on temperature changes.

3.3: Scientific Hypothesis:
If Kyoto's Spring average temperatures continue to increase, then the date of Yoshino cherry (*Prunus × yedoensis*) full bloom (mankai) in Kyoto will continue to happen earlier in successive years. This is because increasing average spring temperature is likely to cause heat accumulation that speeds up metabolic processes and reduces the duration of bud development. There would also be a faster transition from the hormones that help maintain dormancy, such as abscisic acid (ABA), towards growth hormones such as gibberellins and florigen, which would collectively cut time to reach full bloom.
Though the main focus is on average spring temperatures, the winter temperatures also play a role in influencing the degree to which rising average spring temperatures will impact peak bloom of Yoshino cherry trees. If winter temperatures continue to become warmer, their effect in influencing peak bloom is likely to outweigh the effect of increasing average spring temperatures. This is because if these trees do not receive adequate chilling hours, it might lead to irregularities and delays in peak bloom time. However, in the 104-year time frame selected for this study, it is most probable that rising average spring temperatures have been the dominant factor influencing the date of full bloom of the Yoshino cherry (*Prunus × yedoensis*) in Kyoto, Japan.[14, 15]

IV. Variables:

4.1: Independent Variable: Average Spring temperature in Kyoto, Japan (1920–2024)
Units: °C
Rationale: The independent variable, average spring temperature is selected since temperature is one of the climatic factors whose alteration affects phenological events such as flowering. This variable naturally changes over the period selected, and this study therefore seeks to analyse the impact this had on the date of peak bloom of the Yoshino cherry *(Prunus × yedoensis)* present in Kyoto, Japan.

4.2: Dependent Variable: Date of full bloom of the Yoshino cherry *(Prunus × yedoensis)* in Kyoto, Japan (1920–2024)
Units: DOY (day of year)
Rationale: The full bloom date is a direct indicator of the phenological sensitivity of the Yoshino cherry *(Prunus × yedoensis)* to temperature changes. Due to this, making the bloom date the dependent variable enables us to quantify how alterations in average spring temperatures influence the peak bloom of this species.

4.3: Control Variables:

Table 1: Control variables, explanation and method of control

Control Variable	**Explanation**	**Method of control**
Species chosen	Different cherry tree species have different phenological responses to temperature.	The research focussed only on the Yoshino Cherry (*Prunus × yedoensis*).
Location	The temperature and climatic conditions vary based on the place and altitude.	Within Japan only records from Kyoto were utilized.
Years selected	Blooming dates may vary each year due to different climatic conditions, especially with changing temperature.	Only Kyoto Yoshino cherry peak bloom data was selected for the years 1920-2024.
Definition of spring	Different months taken/ considered as spring change the average temperature values.	Since March-April are the peak months that affect Yoshino cherry blossom, their temperature was defined as average spring temperature. (calculated later in this study)

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[14] Bouqueuniaux, C. (2025, May 8). Sakura season in Japan: science, culture and ecology. *Gentian.* https://gentian.io/blog/sakura-season-in-japan-science-culture-and-ecology

[15] Hsu, H-W., Yun, K., Kim, S-H. (2023, August 15). Variable warming effects on flowering phenology of cherry trees across a latitudinal gradient in Japan. *Agricultural and forest meteorology: ScienceDirect, vol. 339.* https://doi.org/10.1016/j.agrformet.2023.109571

Developmental Stage	First bloom and full bloom [16]data mixing can affect the date of bloom significantly, often overestimating the effect of temperature on the selected species.	Only the full bloom (Mankai) data was selected as it best represents the effect temperature has on Yoshino cherry bloom.
Photoperiod[17]	Photoperiod is the length of daylight and is another factor that affects flowering.	Since the location (Kyoto), months (march-april) and latitude is fixed, the length of daylight remains constant for the same date each year, varying very slightly.
Precipitation	Rainfall can be both beneficial and harmful. Light rains may aid blooming to occur faster if coupled with warmer temperatures, while heavy rains could damage soil and the buds, leading to rotting of their roots and knocking off of petals.[18]	Heavy rainfall is not typical in the springs of Kyoto, Japan, however, it may occur. To minimize the effect this has on blooming, a wide dataset of 104 years was used, since precipitation cannot be manipulated.[19]
Winter chilling	Insufficient chilling hours can alter responses to the rising spring temperature.	Any natural variations in winter temperatures that may affect chilling hours were minimized by the broad dataset used (1920-2024), thus preventing it from influencing the central focus of rising spring temperatures.

V. Methodology:

5.1: Safety, Ethical and Environmental Considerations:

- Since the research was based on existing phenological and temperature data, there was no handling of living organisms and no direct risks from laboratory or field experiments.
- The data required was obtained from official, reliable, openly accessible sources and no pirated or unsafe sites were used.
- The research conducted in the original studies also posed no significant safety concerns for the researcher or the environment.
- The cultural significance of cherry blossoms in Japan was respected, and through the use of secondary data, no disturbances were caused to the environment.

5.2: Selection Criteria:

Table 2: Selection of factors and reasoning

Factor in consideration	Chosen	Reason
Species	Yoshino cherry (*Prunus × yedoensis)*	It is widely studied, dominant, and a culturally significant species.
Location	Kyoto, Japan	Extensive data on both temperature and peak bloom date of Yoshino cherry is available for Kyoto, Japan.
Years	1920 to 2024	Long enough and reliable to identify and analyse trends of phenological sensitivity of Yoshino cherry to temperature.
Bloom stage	Full bloom (Mankai)	It proves to be more accurate to measure phenological response instead of first bloom data.
Definition of spring	March-April	It aligns with the peak bloom season of Yoshino cherry.
Type of data	Secondary, published data	Is reliable, accessible, and efficient, especially since primary data collection is unfeasible.

16 National Park Service. (2025, March 31). B*loom watch- cherry blossom festival.* National Park Service. https://www.nps.gov/subjects/cherryblossom/bloom-watch.htm

17 Major, D. J., & Kiniry, J. R. (n.d.) Predicting daylength effects on phenological processes. *U.S. Department of Agriculture.* https://www.ars.usda.gov/ARSUserFiles/30980500/Major%20Chapter%204.pdf

18 Sano, T. (n.d.) Cherry blossom and climate change. *WWF Japan.* https://www.wwf.or.jp/activities/files/20140325Shirakami_Sakura_ENG.pdf

19 Japan meteorological agency. (2025) *Monthly total of precipitation (milli meters).* Japan meteorological agency. https://www.data.jma.go.jp/stats/etrn/view/monthly_s3_en.php?block_no=47759&view=13

5.3: Data Sources and Justification:

Table 3: Data sources, Content and Justification

Source	What it provides	Justification
Our World in Data (OWID)[20, 21]	Provides an extensive dataset on the peak bloom dates of Cherry blossom in Kyoto, Japan. Although earlier records focussed on *Prunus jamasakura*, records after the mid-19th century focus on Yoshino cherry *(Prunus × yedoensis)*.	It curates peer-reviewed, official, and accurate datasets, ensuring reliability. It is used widely by researchers to assess the relation of climate change with phenology, adding credibility to its use.
Japan Meteorological Agency (JMA)[22]	Provides the monthly mean air temperature for Kyoto, Japan.	It is an official, national meteorological authority in Japan that is standardized and consistent with its data collection methodologies. It has a long-term climate record that is recognized worldwide for its reliability.

Both these main sources used for this research are globally recognized, peer-reviewed or official, and therefore a reliable source to use for this investigation.

5.4: Uncertainty:

- Earlier phenological records (prior to the mid-19th century) relied on *Prunus jamasakura*, as the Somei Yoshino (*Prunus × yedoensis*) came into existence and dominance only after the mid-19th century. This is important to address because a change in species representation may alter the phenological comparisons made.[23]
- Even within *Prunus × yedoensis*, small amounts of uncertainty can arise from different observation techniques (e.g. defining "full bloom" or small variations between monitoring locations).
- Historical records relied on human observations (e.g. dates of viewing cherry blossoms), which vary in their criteria for "full bloom", lack uniformity of measurements, and are subject to interpretive bias, particularly with 20th century data.

5.5: Procedure:

1. Extraction of monthly mean air temperature data from the Japan Meteorological Agency (JMA), KYOTO WMO Station ID:47759, for the months March and April (representing main spring months) for years 1920-2024.
2. Extraction of DOY (day of year) with peak bloom and 20-year average data from Our World in Data (OWID)
3. Preparation of raw data table with Year, Mean air temperature for March and April and DOY (day of year) with peak bloom of yoshino cherry.
4. Processing the data and presenting Year, average spring temperatures, SD in Average Spring Temperatures (21 years moving window), Bloom DOY, SD in Bloom DOY (21 years moving window), and 20-Year Average of Bloom DOY.
5. Presenting formulas used along with sample calculations.
6. Preparing graphs- scatter plot and time series stacked panels, to portray the relationship between rising spring temperature and date of bloom of Yoshino cherry through the years.
7. Supporting the graphs with relevant statistical tools [24](like linear regression) to quantify the strength of the relationship and compare slopes to interpret phenological sensitivity of Yoshino cherry (*Prunus × yedoensis*) to rises in average spring temperature.

[20] Our world in data (1920-2024). *Day of the year with peak cherry tree blossom in Kyoto, Japan.* Our world in data. https://ourworldindata.org/grapher/date-of-the-peak-cherry-tree-blossom-in-kyoto

[21] Aono, Y. (2021, 2025). *Day of the year with peak cherry tree blossom in Kyoto, Japan.* Our world in data. https://ourworldindata.org/grapher/date-of-the-peak-cherry-tree-blossom-in-kyoto

[22] Japan meteorological agency. (2025) *Monthly mean air temperature (degree Celsius).* Japan meteorological agency. https://www.data.jma.go.jp/stats/etrn/view/monthly_s3_en.php?block_no=47759&view=1

[23] Aono, Y., & Kazui, K. (2008). Phenological data series of cherry tree flowering in Kyoto, Japan, and its application to reconstruction of springtime temperatures since the 9th century. *International journal of climatology, vol.* 28. https://svalgaard.leif.org/EOS/Aono-Cherry-Blossom.pdf

[24] Haese, M., Humphries, M., Sangwin, C., & Vo, N. (2019). *Mathematics: Applications and Interpretation HL*. Haese Mathematics. (pp. 141-148)

VI. Data Collection and Processing:

6.1: Raw Data Table

Table 4: Raw historical data for Kyoto, Japan (1920-2024)

Year	Mean Air Temperature March/ °C	Mean Air Temperature April/ °C)	Bloom DOY/days
1920	7.2	12.2	104
1921	5.3	13.2	NA
1922	5.8	12.8	101
1923	8.1	12.2	97
1924	4.0	13.8	111
1925	5.3	10.7	108
1926	5.4	10.5	107
1927	6.1	12.4	107
1928	6.4	12.5	107
1929	5.9	12.1	103
1930	8.3	13.9	95
1931	6.8	11.6	105
1932	5.8	11.0	105
1933	5.2	12.7	106
1934	5.5	11.4	104
1935	6.8	12.2	102
1936	4.5	11.6	111
1937	7.3	12.5	100
1938	9.0	12.5	98
1939	6.8	12.7	104
1940	6.3	12.2	110
1941	7.7	11.8	100
1942	9.9	12.1	96
1943	6.1	10.9	101
1944	5.7	11.0	100
1945	6.6	12.9	NA
1946	6.1	13.3	97
1947	5.4	12.0	107
1948	6.4	13.5	102
1949	5.5	10.4	107
1950	6.8	13.8	99
1951	7.4	12.5	98
1952	6.8	13.3	105
1953	8.6	11.6	101
1954	7.6	14.5	98
1955	9.0	14.1	97
1956	8.3	12.8	99
1957	5.2	14.1	103
1958	7.5	13.9	99
1959	9.0	14.0	92
1960	8.9	12.3	95
1961	8.0	14.1	99
1962	7.3	13.1	102
1963	7.0	14.2	101
1964	6.6	17.2	99
1965	5.5	10.7	110
1966	8.5	13.5	97
1967	7.7	13.8	97

1968	8.0	14.3	99
1969	6.9	13.8	101
1970	5.0	13.1	107
1971	7.4	13.6	98
1972	8.8	14.4	99
1973	7.8	15.8	97
1974	7.0	14.4	99
1975	7.4	14.1	100
1976	7.9	13.5	99
1977	8.7	14.5	93
1978	7.6	13.4	104
1979	8.0	12.9	97
1980	7.3	12.7	102
1981	8.3	13.5	99
1982	8.6	13.4	93
1983	7.8	15.9	99
1984	5.1	13.1	109
1985	8.5	14.6	99
1986	7.6	14.1	102
1987	8.2	13.9	95
1988	7.3	13.5	106
1989	8.2	14.5	93
1990	9.3	13.8	88
1991	9.4	15.0	97
1992	9.7	14.4	94
1993	7.6	13.3	97
1994	7.1	15.6	99
1995	8.6	13.6	99
1996	7.7	11.7	103
1997	9.3	14.4	97
1998	9.7	17.3	91
1999	9.9	14.1	94
2000	7.5	13.5	100
2001	8.6	14.7	96
2002	10.3	15.8	91
2003	7.3	15.1	98
2004	9.1	15.4	92
2005	7.7	15.3	99
2006	7.5	12.6	98
2007	8.6	13.5	97
2008	9.6	14.4	95
2009	8.8	14.6	95
2010	8.5	12.6	95
2011	6.8	12.5	99
2012	8.3	14.2	101
2013	9.7	13.4	93
2014	9.0	14.4	94
2015	9.4	15.6	93
2016	9.9	16.1	95
2017	8.2	14.8	99
2018	10.9	16.4	89
2019	9.6	13.9	95
2020	10.6	12.9	92
2021	11.6	14.8	85

2022	10.5	16.5	91
2023	12.3	15.4	84
2024	8.7	17.6	95

6.2: Processed Data Table

Table 5: Processed data

Year	**Average Spring Temperature/°C**	**SD in Average Spring Temperatures (21 years moving window) /°C**	**Bloom DOY/days**	**SD in Bloom DOY (21 years moving window)/days**	**20-Year Average of Bloom DOY/days**
1920	9.70	0.831	104	4.459	103.5
1921	9.25		NA		NA
1922	9.30		101		103.4
1923	10.15		97		103.2
1924	8.90		111		103.8
1925	8.00		108		104.3
1926	7.95		107		104.3
1927	9.25		107		104.3
1928	9.45		107		104.5
1929	9.00		103		104.5
1930	11.10		95		104.1
1931	9.20		105		104.0
1932	8.40		105		104.0
1933	8.95		106		104.4
1934	8.45		104		104.3
1935	9.50		102		104.3
1936	8.05		111		104.8
1937	9.90		100		104.7
1938	10.75		98		104.0
1939	9.75		104		104.0
1940	9.25		110		104.3
1941	9.75	1.007	100	3.782	104.1
1942	11.00		96		103.8
1943	8.50		101		104.0
1944	8.35		100		103.5
1945	9.75		NA		NA
1946	9.70		97		103.0
1947	8.70		107		102.9
1948	9.95		102		102.7
1949	7.95		107		102.7
1950	10.30		99		102.5
1951	9.95		98		102.6
1952	10.05		105		102.6
1953	10.10		101		102.4
1954	11.05		98		102.0
1955	11.55		97		101.7
1956	10.55		99		101.5
1957	9.65		103		101.1
1958	10.70		99		101.0
1959	11.50		92		100.8
1960	10.60		95		100.3
1961	11.05		99		99.8
1962	10.20		102		99.8
1963	10.60		101		100.1
1964	11.90		99		100.0

1965	8.10		110		100.5
1966	11.00		97		100.5
1967	10.75		97		100.0
1968	11.15		99		99.8
1969	10.35	0.870	101	3.979	99.5
1970	9.05		107		100.0
1971	10.50		98		100.0
1972	11.60		99		99.7
1973	11.80		97		99.5
1974	10.70		99		99.5
1975	10.75		100		99.7
1976	10.70		99		99.7
1977	11.60		93		99.2
1978	10.50		104		99.4
1979	10.45		97		99.7
1980	10.00		102		100.0
1981	10.90		99		100.0
1982	11.00		93		99.5
1983	11.85		99		99.5
1984	9.10		109		100.0
1985	11.55		99		99.4
1986	10.85		102		99.7
1987	11.05		95		99.5
1988	10.40		106		99.9
1989	11.35		93		99.5
1990	11.55	1.011	88	4.996	98.5
1991	12.20		97		98.5
1992	12.05		94		98.3
1993	10.45		97		98.3
1994	11.35		99		98.3
1995	11.10		99		98.2
1996	9.70		103		98.4
1997	11.85		97		98.6
1998	13.5		91		98.0
1999	12.00		94		97.8
2000	10.50		100		97.7
2001	11.65		96		97.5
2002	13.05		91		97.5
2003	11.20		98		97.4
2004	12.25		92		96.5
2005	11.50		99		96.5
2006	10.05		98		96.3
2007	11.05		97		96.5
2008	12.00		95		95.9
2009	11.70		95		96.0
2010	10.55		95		96.3
2011	9.65	1.147	99	4.358	96.5
2012	11.25		101		96.8
2013	11.55		93		96.6
2014	11.70		94		96.3
2015	12.50		93		96.0
2016	13.00		95		95.7
2017	11.50		99		95.8
2018	13.65		89		95.7

2019	11.75		95		95.7
2020	11.75		92		95.3
2021	13.20		85		94.8
2022	13.50		91		94.8
2023	13.85		84		94.0
2024	13.15		95		94.2

6.3: Formulas and Sample Calculations:

1. Average spring temperature in °C:

$$\frac{Mean\ air\ Temperature\ in\ March + Mean\ air\ temperature\ in\ April}{2}$$

Example: For Year 2024-

$$\frac{8.7 + 17.6}{2} = 13.15°C$$

2. Standard deviation in Average Spring Temperatures and Bloom DOY, both with 21 years moving window:

The SD was calculated using Microsoft Excel which applies the sample standard deviation formula [STDEV.S]:

$$\sqrt{\frac{\Sigma_{i=1}^{\eta}(x_i - \underline{x})^2}{n - 1}}$$

Where x_i is each value in the selected window, $\underline{x}$ is the mean of the window, and n is the number of values (21 for the moving window).

Demonstration of manual calculation (5-year example):

Year	Average Spring Temp (°C)
1920	9.7
1921	9.25
1922	9.3
1923	10.15
1924	8.9

1. Calculating mean $\underline{x}$:
   = (9.7 + 9.25 + 9.3 + 10.15 + 8.9)/5 = 9.46°C

2. Subtracting mean from each value and then squaring the difference

Year	$x_i - \underline{x}$	$(x_i - \underline{x})^2$
1920	0.24	0.0576
1921	-0.21	0.0441
1922	-0.16	0.0256
1923	0.69	0.4761
1924	-0.56	0.3136

3. Sum of the squared differences and dividing by n-1:
   $\Sigma(x_i - \underline{x})^2$ = 0.0576 + 0.0441 + 0.0256 + 0.4761 + 0.3136 = 0.9169
   $n - 1 = 5 - 1 = 4$ 0.9169/4 =0.2292

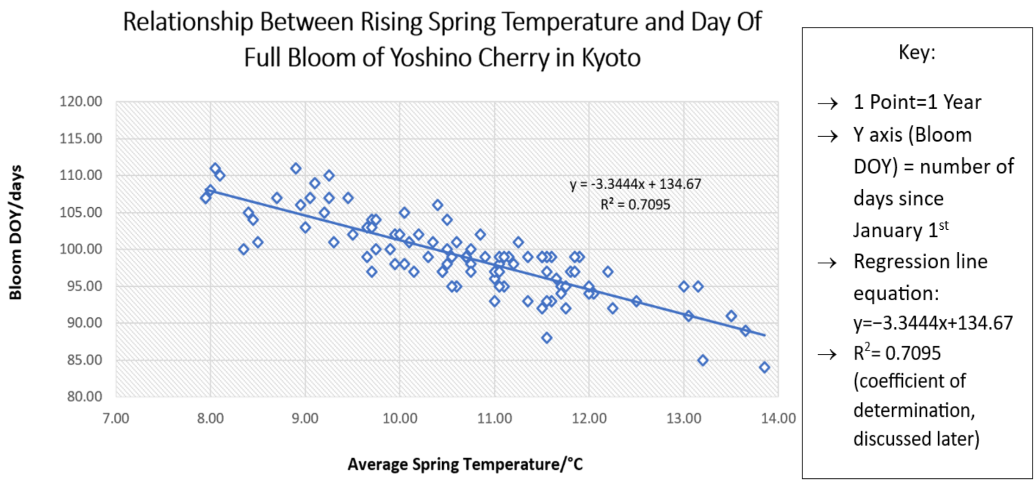
4. Square root to get SD:
   $\sqrt{0.2292}$ = 0.48°C

This SD demonstrates the variability of average spring temperatures from 1920–1924 (5-year window). For the full dataset (1920–2024), SDs were calculated using the same formula in Excel with a 21-year moving window. SDs for Bloom DOY were calculated similarly, using the day-of-year (DOY) values instead of temperature. The final SD value was assigned to the central year within the 21-year window to act as a representative point for the period.

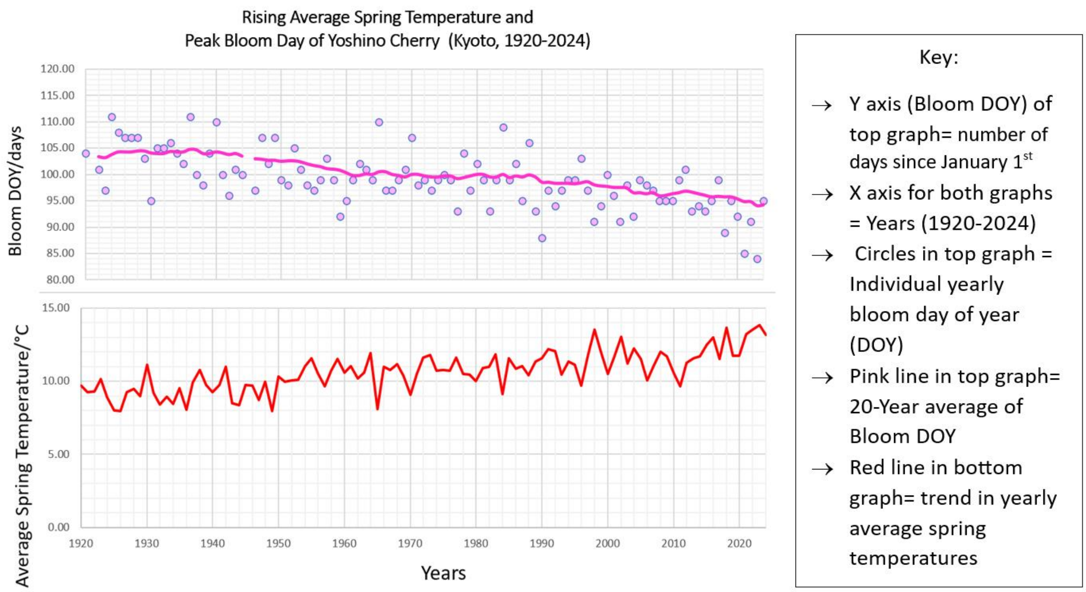
6.4: Data Presentation:

NOTE: Since the standard deviation was calculated within a 21-year moving window, error bars have not been added in the below graphs' data points. Instead, the variation is acknowledged and considered in the analysis section. In addition, data points on bloom DOY for 1921 and 1945 are missing in the graphs and table since they were not recorded.

GRAPH 1: Scatterplot graph showing the negative correlation between average spring temperature and full bloom day of year (DOY) of Yoshino cherry in Kyoto (1920-2024)



GRAPH 2: Time series displaying changes in bloom day (top) and average spring temperatures (bottom) in Kyoto over the same time period of 1920-2024.



6.5: Analysis:

This analysis examines the extent to which rising average spring temperatures have influenced the full bloom date (DOY) of the Yoshino cherry (*Prunus × yedoensis*) in Kyoto from 1920 to 2024. The relationship between these variables is quantitatively assessed to determine the species' phenological sensitivity to temperature change, thereby addressing the research question and testing the stated hypotheses.

The scatterplot seen in Graph 1 shows the correlation between average spring temperature and the full bloom date (DOY) of the Yoshino cherry, making it apparent how, as the average spring temperature increases, the bloom DOY decreases (the blossom occurs earlier in the year).

This correlation is quantified by the line of linear regression $Y = -3.3444x + 134.67$. The slope of −3.3444 days/°C is the key to understanding the phenological sensitivity of the Yoshino cherry to rise in average spring temperature. It indicates how for every 1°C rise in average spring temperature, the full-bloom date happens approximately 3.34 days earlier.

The strength and statistical significance of this is verified by the coefficient of determination r^2, which has a value of 0.7095. This means that about 71% of this variation in bloom date can be explained by the average spring temperature, showing how average spring temperature plays a large role in controlling bloom timing. The remaining 29% portrays how other factors (eg. Precipitation, photoperiod, winter chilling) must also be taken into consideration. Furthermore, the value of r (Pierson's product-moment correlation coefficient) that is $\sqrt{0.7095} \approx -0.842$ helps to confirm that a moderate to strong negative correlation exists between these two variables.

With reference to this statistical analysis, it certainly refutes the null hypothesis (H_0), which states there is no relationship between average spring temperature and the full bloom date (DOY) of the Yoshino cherry. On the other hand, the alternative hypothesis (H_1) that stated that an increase in average spring temperature would significantly influence flowering time is strongly supported. Moreover, the data agrees with the scientific hypothesis since rising spring temperatures have made the full bloom date occur increasingly earlier, in line with the mechanism of heat accumulation accelerating metabolic processes and bud development after winter dormancy requirements are fulfilled.

In the same manner, graph 2 serves to further confirm the trend seen in graph 1, wherein the top panel (Bloom DOY) and bottom panel (Spring Temperature) clearly indicate the negative correlation. The red trend line in the bottom panel indicates a well-established upward trend in average spring temperatures since the last century, and is consistent with global and regional warming patterns.

The top panel shows a corresponding long-term trend towards earlier bloom dates. The 20-year average (pink line) smoothens out annual variability and is seen to trend downward, from about 104 DOY (April 13) in 1920 to about 84 DOY (March 25) in 2023- a shift of about 20 days earlier.

This early flowering date in the data corresponds to one of the highest average spring temperatures recorded (13.85°C in 2023), and highlights how Yoshino cherry in Kyoto is flowering now earlier than at any previous time in the historical record[25]. It also illustrates the added sensitivity of the Yoshino cherry to increased temperature and agrees with Allen et al., 2014[26], that if Kyoto's average spring temperature continues to escalate as predicted, the pattern of blooming earlier will accelerate, and by the year 2100, species such as Prunus × yedoensis would bloom on average 30 days earlier.

The values of standard deviation calculated by means of a 21-year moving window are also important to account for the variability in this evident trend. The SD for Average Spring Temperature between around 0.83°C and 1.15°C shows that, although the trend is general in the upward sense, there is significant inter-annual variation. Likewise, the SD for Bloom DOY varies from about 3.8 to 5.0 days, indicating that the biological response varies from year to year as well. Such variation can also be due to causes other than temperature. They are:

→ Insufficient winter chilling: Warmer winters reduce the rate of acquisition of needed chilling units, and this may postpone the date of bloom irrespective of increased spring temperatures[27].

→ Precipitation and extreme weather: Severe rainfalls, late frosts or dry springs may also change flowering dates or damage buds.

→ Urban island heat effect: Urban processes and structures (concrete and asphalt pavement, additional buildings, higher vehicle usage, etc.) trap and release heat, making urban areas much warmer than the surrounding rural landscapes, potentially speeding bloom times faster than would be produced by background climate change alone.[28, 29]

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→ Rising CO_2 emissions[30]: This is directly tied to climate changes and global warming, influencing blooming time, however its extent is not yet known.

In conclusion, the analysis provides quantitative evidence of how rising average spring temperature is the dominant factor driving the advancement of Prunus × yedoensis full bloom in Kyoto. Nevertheless, variability is probably also conditioned by other factors as stated, such as winter chilling, and rainfall, which can possibly interact with temperature and change bloom timing.

VII. Conclusion

This research aimed to determine the influence of rising spring temperatures on the full bloom date of Kyoto's Yoshino cherry between 1920-2024 and evaluate its phenological sensitivity. The analysis served to show how increased average spring temperature is one of the most important factors, causing the bloom date to shift about 3.3 days for each degree of warming.

This relationship, as indicated by a strong negative correlation ($r = -0.842$) and high coefficient of determination ($r^2 = 0.71$), resulted in rejection of the null hypothesis. The result was a net shift of over 20 days earlier in the timing of peak bloom over the century. The sensitivity calculated (-3.3 days/°C) gives a measure that is consistent with wider views of the high sensitivity of this species to climate change.

While some uncertainty remains due to past observational technique and year-to-year variation from processes such as winter chilling (as evidenced through the standard deviation of bloom dates), it does not reduce strength of the central trend. Thus, the Yoshino cherry tree in Kyoto can be regarded as a sensitive bio-indicator of increasing spring temperatures, with its phenological shift being clear biological evidence of its sensitivity.[31]

VIII. Evaluation

8.1: Strengths of the Research:

- Rich dataset: The century-long data on the cherry blossoms in Kyoto provided reliability and richness as the dataset is among the longest continuous phenological records in the world.
- Accurate and transparent temperature data: The temperature data from the Japan Meteorological Agency (JMA) were collected using standard and consistent methods. The data are publicly available and have clear documentation, which makes them trustworthy and easy to verify.
- Relevance to the study: The data was specific to Kyoto and covered the same period of study, making it directly relevant to the investigation. Linking long-term bloom records with temperature changes made the analysis scientifically meaningful and focused.

8.2: Limitations and Improvement

Table 6: Limitations and the Improvements

Limitation	Improvement
Uncertainties in data	Although the data was extensive, it relied solely on secondary data, which may contain uncertainties or inconsistencies in how flowering was recorded. Multiple sources should therefore be considered and compared to reduce the influence of uncertainty.
Regional focus	Since the study was limited to Kyoto, the findings may not fully represent broader trends in Japan or globally. Including multiple sites could enhance validity.
Climate complexity	Spring temperature was considered as the main factor, but other variables (precipitation, urban heat island effect, human intervention during cultivation, winter temperature) could also have influenced flowering. Therefore, research based on the influence of these factors should also be analysed.
Methodological improvement	Instead of relying solely on linear regression and averages, incorporating more advanced statistical models like multivariate regression could account for multiple influencing factors, especially winter chilling.
Non-linearity in bloom dates not emphasised	The non-linear responses of the Yoshino cherry are not fully examined and therefore, the actual biological relationship may not be fully represented. Analysis of short-term data should prevent this from occurring since it would aid in breaking down each year's input to the general trend.

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8.3: Further scope for investigation:

Provided the depth and potential of this topic, this study can be pursued in a number of different directions. For example, rather than restricting to Kyoto, other cherry blossom locations throughout Japan can also be compared in order to examine changes in flowering time. On an even larger scale, other locations outside of Japan, such as Washington D.C. (USA) or Seoul (South Korea) can also be used as useful locations for study. Because temperature increases are influencing species worldwide, it would also be of interest to investigate how it could be adding to the proportion of species becoming endangered (plants or animals) and the reason behind it. Moreover, the bloom data in Kyoto can be compared between urban and rural places to find out the influence of urban heat island effect. And lastly, predictive models from current climatic data can be used to predict future flowering time under different climate change scenarios. This would be of great significance as it would help in reflecting upon which factor is most influential in affecting changes of flowering time.

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