Climate change and extension of the *Ginkgo biloba* L. growing season in Japan

KAZUHO MATSUMOTO*, TAKESHI OHTA*, MICHIYA IRASAWA †, TSUTOMU NAKAMURA ‡

**Graduate School of Bioagricultural Sciences, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan; † Faculty of Agriculture, Iwate University, Ueda 3-18-8, Morioka 020-8550, Japan; ‡ Kotorizawa 2-23-13, Morioka 020-0104, Japan*

Key words: phenology, growing season, air temperature, spatial distribution, climate change, Japan

Correspondence: Kazuho Matsumoto, Graduate School of Bioagricultural Sciences, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan

Fax: +81 52 789 5038; E-mail: i021033m@mbox.nagoya-u.ac.jp

Abstract

To understand the effects of climate change on the growing season of plants in Japan, we conducted trend analysis of phenological phases and examined the relationship between phenology and air temperatures. We used phenological data for *Ginkgo biloba* L., collected from 1953 to 2000. We defined the beginning and the end of the growing season (BGS and EGS) as the dates of budding and leaf fall, respectively. Changes in the air temperature in the 45 days before the date of BGS affected annual variation in BGS. Annual variation in air temperature over the 85 days before EGS affected the date of EGS. The average annual air temperature in Japan has increased by 1.3℃ over the last four decades (1961-2000), and this increase has caused changes in ginkgo phenology. In the last five decades (1953-2000), BGS has occurred approximately 4 days earlier than previously, and EGS has occurred about 8 days later. Consequently, since 1953 the length of the growing season (LGS) has been extended by 12 days. Since around 1970, LGS and air temperatures have shown increasing trends. Although many researchers have stated that phenological events are not affected by the air temperature in the fall, we found high correlations not only between budding dates and air temperatures in spring but also between leaf-fall dates and air temperatures in autumn. If the mean annual air temperature increases by 1℃, LGS could be extended by 10 days. We also examined the spatial distribution of the rate of LGS extension, but we did not find an obvious relationship between LGS extension and latitude.

Key words: phenology, growing season, air temperature, spatial distribution, climate change, Japan

Introduction

Changes in the phenology of deciduous trees, e.g., the unfurling of leaves, flowering, leaf color changes, and leaf fall, depend on many environmental factors. Among these factors, air temperature is the most related to plant phenology in the temperate zone (e.g., Sparks & Carey, 1995; Abu-Asab *et al.*, 2001; Cayan *et al.*, 2001; Peñuelas *et al.*, 2002). Thus, it is thought that plant phenology may be an important indicator of global warming.

Many recent studies have shown an advance of spring phenological events (e.g., Ahas, 1999; Ahas *et al.*, 2002; Beaubien & Freeland, 2000; Schwartz & Reiter, 2000), and a number of other studies have reported a general delay in autumn phenology (e.g., Menzel & Fabian, 1999; Chemielewski & Rötzer, 2001; Defila & Clot, 2001). However, changes were less pronounced in autumn events as compared to spring events (Sparks & Menzel, 2002; Walther *et al.*, 2002). In recent years, an increasing number of studies have described an extended growing season, which has resulted from earlier spring events and later autumn events. For example, Menzel (2000) indicated that the average growing season for sixteen plant species in the International Phenological Garden (IPG) in Europe lengthened by 10.8 days between 1959 and 1996. In addition to investigations using direct observational data, indirect studies using CO_2 data (Keeling *et al.*, 1996) or normalized difference vegetation index (NDVI) data (Myneni *et al.*, 1997; Tucker *et al.*, 2001; Zhou *et al.*, 2001) have also indicated an extension of the growing season.

Many studies have examined the effects of air temperature on these conspicuous changes in phenology (e.g., Walkovszky, 1998; Sparks *et al.*, 2000; Cayan *et al.*, 2001; Chemielewski & Rötzer, 2001; Peñuelas *et al.*, 2002); they have generally shown that warming leads to earlier spring events and later autumn events. However, autumn events were less influenced by air temperature than were spring events, (e.g., Chemielewski & Rötzer, 2001; Menzel, 2002; Sparks & Menzel 2002). Generally, most of the above studies conducted regression analyses of monthly mean air temperatures and event dates to determine the relationship between phenological events and air temperature. However, the periods that affect phenological events may not necessarily correspond to the monthly data used by many of the studies. Until now, period lengths have not been clarified.

Determining period length could lead to a better understanding of the relationship between phenology and climate.

Most phenological studies have examined conditions in Western countries, and thus data for Asia are lacking. While Japanese phenologists have generally used phenological data to predict the flowering date of plants such as the cherry (e.g., Aono & Omoto, 1990), few studies have connected phenology to climate change in an Asian setting.

This paper (1) estimates the length of air temperature periods that affect variation in the phenological events of Japanese ginkgo trees; (2) examines long-term variation in BGS, EGS, and LGS; and (3) shows the effects of air temperature on phenological variation by using the results of (1). Furthermore, we investigate the spatial distribution of LGS extension rates.

Materials and methods

Phenological and temperature data

This study used a dataset of the annual budding and leaf-fall dates of *Ginkgo biloba* L. in Japan between 1953 and 2000. Phenological observation guidelines (Japan Meteorological Agency, 1985) define the budding date as the date when approximately 20% of all buds are open and the leaf-fall date as the date when about 80% of all leaves have fallen. We defined BGS as the budding date and EGS as the leaf-fall date. LGS was defined as the period between BGS and EGS. Figure 1 shows the locations of the 82 meteorological stations that observed the phenology of ginkgo trees. In Fig. 1, open-circle stations had only some of the necessary data points (6 ~ 25 years of data) and were suitable only for calculating average values. For the main analysis, we used data from the 67 stations indicated by the solid circles, where phenological events were observed for more than 25 years. Since some stations did not have the required 25 years of data (specifically, BGS data at stations 7, 9, and 54, and EGS data at stations 10, 26, and 41), the data from those stations were used only for calculating average values. Thus, 64 stations provided data for BGS and EGS analysis, while 61 provided data for LGS analysis.

For air temperature data, we used the daily mean air temperature data from 1961 - 2000 collected by the 67 meteorological stations indicated by solid circles in Fig. 1. Although the phenological data used in this study go back to 1953, air temperature data were not available for 1953-1960.

Examination of average phenological phases

To examine the spatial distribution of BGS, EGS, and LGS among all of the meteorological stations surveyed, we calculated average values for each of the 82 stations and used the averages to create a rough distribution map, with isobars representing each phenological phase.

Estimation of the period during which air temperature affects phenological events

The length of the period during which air temperature affects phenological events was estimated statistically by linear regression analysis (Shinohara, 1951). In this method, the length of the period during which a particular temperature might influence a phenological event is defined as

$$LP = EP - BP \qquad (1)$$

where *LP* is the period length (number of days), *EP* is the end date of the period (day of year, DOY), and *BP* is the beginning date of the period (DOY). The *EP* is defined as the date of the phenological event. Average budding or leaf-fall dates between 1953 and 2000 were used to represent *EP*. Using this equation, we decreased the value of the *BP* from the date of the *EP* one by one, and calculated the correlation coefficient between the date of the phenological event (budding or leaf fall) and the average air temperature during the period *EP-BP*. It was assumed that the period showing the highest correlation was the period during which air temperature affected phenological events most markedly. Figure 2 shows examples of this analysis (using Station 25 as a case study). In this figure, 0 on the x-axis indicates the *EP*; the number of days on the x-axis indicates the length of *BP-EP*, i.e., the value of *LP*. The y-axis represents the correlation coefficient between the average air temperature of *BP-EP* and the DOY of phenological events. The correlation shows an extreme value for some x-values. When the correlation coefficient indicates an extreme value, the value of the x-axis is regarded as an exact value of *LP*. Using this method, we estimated the *LP* for each of the 67 meteorological stations. The *LP* differed among stations; however, because the use of various values for *LP* would have complicated further analysis, we used an average value as each station's *LP* for the phenology-temperature relation analysis. The values of *BP* were calculated by substituting the *EP* values of each station and the common *LP* value from Eq. (1).

Analyzing long-term trends and relationships between air temperature and phenology

We conducted linear regression analysis to investigate how air temperature and the phenology of ginkgo trees have changed. To examine the effect of climate change on phenological events, we investigated the correlation between phenology (BGS, EGS, and LGS) and air temperature. To analyze BGS and EGS, we used the average temperature of period *BP-EP* obtained from the above analyses. For LGS, we analyzed the relationship between LGS and annual air temperature, since LGS covers a long term and this parameter does not itself constitute an event.

Results

Outline of average air temperatures (1961 - 2000) and average phenological phases (1953-2000) in Japan

The average air temperature in Japan (1961-2000) was 14.2℃. The average air temperature at the different stations ranged from approximately 10 - 20℃. The average air temperature at the coldest station (Station 1) was 8.4℃, while that at the warmest station (Station 82) was 21.4℃.

Figure 3 shows the distribution of BGS (a), EGS (b), and LGS (c) isobars. The average BGS across Japan was DOY 104 (April 14); BGS occurred later at higher latitudes than at lower latitudes (Fig. 3a). BGS was earliest at Station 81 (DOY 90, March 31) and latest at Station 4 (DOY 142, May 22). The average EGS was earlier in northern regions than in southern regions (Fig. 3b). Average EGS across Japan was DOY 330 (November 26) and ranged from DOY 304 (October 31) at Station 3 to DOY 351 (December 17) at Station 82.

The average LGS (= EGS – BGS) was longer in the south than in the north, as seen in Fig. 3c, reflecting the results of BGS and EGS. The difference in LGS between north and south was about 100 days; the average LGS across Japan was 226 days.

Period during which air temperature affects phenological events

Figure 4 shows the values of the *LP* of BGS (a) and EGS (b) at the 67 meteorological stations. Generally, the *LP* of BGS was < 50 days, while the *LP* of EGS was > 50 days. We found uneven values in the *LP* of EGS, as compared to those of BGS. The average *LP* of BGS was 45 days, while that of EGS was 85 days. These averages were used as the values of *LP* at all stations in subsequent analyses, as mentioned in the "Materials and Methods" section above. Hereafter, we define the average air temperature of the period *BP-EP* of BGS and EGS as the "spring air temperature" and "autumn air temperature," respectively.

Long-term trends in air temperatures

Figures 5a and 5b show long-term variation in spring and autumn air temperatures, respectively, throughout Japan. All stations showed positive trends in spring air temperatures, i.e., spring air temperatures increased at all stations; slopes among stations ranged from 0.11℃-0.65℃·decade^{-1}. Across Japan, spring air temperatures increased at a rate of 0.31℃ per decade (Fig. 5a). Autumn air temperatures showed significant increases at all stations, ranging from 0.18-0.65 ℃ ·decade^{-1}. In comparison to spring air temperature changes, autumn air temperature changes appeared significant and had large positive slopes at many stations. Across the whole of Japan, the slope was 0.35℃ ·decade^{-1} (Fig. 5b). All stations had positive slopes of annual air temperature, with significance levels of < 1 or 5%. Mean annual air temperature increased at a rate of 0.21 - 0.74℃ per decade. Across the whole of Japan, this rate was 0.28℃·decade^{-1} (Fig. 5c).

That is, the annual mean air temperature in Japan increased by approximately 1.3℃ over the 48 years studied.

Long-term phenological trends

Figure 5 also shows the slopes of long-term trends in BGS (a), EGS (b), and LGS (c) between 1953 and 2000 across Japan. In this figure, negative trends are indicative of an advance of phenological events, and positive trends indicate delayed events. The slopes of BGS at each station range from -4.1 to +4.5 days·decade^{-1}. While 42 stations showed a negative trend, 20 stations showed positive trends. However, few of the positive stations had significant trend lines. Since 1953, BGS across all of Japan shifted to 4.2 days earlier at a rate of -0.9 days·decade^{-1} ($p < 0.01$; Fig. 5a). EGS at 52 stations revealed positive trends. Only 12 stations showed negative trends, and of these 10 were not significant. The slopes of EGS at each station ranged from –2.1 to +7.2 days·decade^{-1}. For Japan as a whole, the slope of EGS was 1.6 days·decade^{-1} ($p < 0.01$; Fig. 5b), i.e., EGS was pushed back by 7.7 days between 1953 and 2000. Temporal trends in LGS, reflecting BGS and EGS data, are shown in Fig. 5c. LGS expanded at a rate of 2.5 days·decade^{-1} ($p < 0.01$) across Japan and increased by 12 days since 1953. The highest value appeared at Station 22 (9.1 days·decade^{-1}), whereas the most negative slope was observed at Station 77 (-2.5 days·decade^{-1}). LGS tended to be positive (i.e., increasing) at most stations; only four stations showed negative trends, though they were not significant. Since approximately 1970, in conjunction with air temperature changes, BGS has come earlier, EGS has arrived later, and LGS has been extended. Since 1985 in particular, LGS appears to have increased remarkably.

Spatial distribution of temporal LGS trends

Figure 6 shows the relationship between the temporal rate of change in LGS (days·year^{-1})

and the latitude of each meteorological station. We found a large difference in the rate of LGS change among the stations but found no significant relationship between the rate of LGS change and latitude. We also tested for a relationship between the rate of LGS change and average air temperatures (1961-2000) among stations but found no clear relationship.

Effects of air temperature on phenology

Table 1 shows the regression coefficients of BGS and spring air temperatures, EGS and autumn air temperatures, and LGS and mean annual air temperatures at each station. These relationships are shown for the whole of Japan in Fig. 7. All phenological phases across Japan correlated well to each air temperature parameter. The slope of the significant linear regression line between BGS and spring air temperature was -2.9 days·$℃^{-1}$ ($p < 0.01$; Fig. 7a). As indicated in Table 1, the slope of the regression equation showed a negative trend at all stations, i.e., higher spring air temperatures induced an earlier BGS. Station 5 had the largest gradient of -4.95 days·℃$^{-1}$, while Station 27 had the smallest gradient, though not significantly so (-1.14 days·℃$^{-1}$). Correlations between BGS and spring air temperatures were close at many stations (maximum $|r| = 0.85$ at Station 1). Low correlations at some stations (minimum $|r| = 0.17$ at Station 82) were probably influenced more by environmental factors than air temperatures. For all of Japan, the correlation coefficient was -0.88.

We observed a strong correlation ($r = 0.87$) between EGS and autumn air temperatures throughout Japan (Fig. 7b); rising air temperatures caused EGS to occur later. An increase in autumn air temperature of 1℃ induced a 4.4-day delay in EGS. The correlation coefficients at each station ranged from 0.17 at Station 64 to 0.71 at Station 63. All stations showed positive regression slopes (Table 1), most of which were significant. The value of the most positive slope was 13.6 days·℃$^{-1}$ (Station 31), while the least positive, though not significant, slope was 1.18 days·℃$^{-1}$ (Station 5).

Reflecting features of both BGS and EGS, the fluctuation of LGS also depended on fluctuation in air temperatures (Fig. 7c). The correlation coefficients ranged from 0.15 at Station 82 to 0.81 at Station 19; for all of Japan, the correlation coefficient was 0.87. The gradients of the regression lines were very steep, indicating that increased air temperatures caused a considerable extension of the growing season. In all of Japan, LGS was extended by 9.6 days for every 1℃ increase in air temperature. At Station 31, which showed the highest extension rate among the 61 survey stations, an increase in annual mean air temperature of 1℃ extended LGS by 21.7 days. The lowest extension rate was observed at Station 46 (1.9 days·$℃^{-1}$).

Discussion

In this study, the estimated lengths of the periods during which air temperatures affected variation in budding and leaf-fall dates were 45 days and 85 days, respectively. It is interesting that the values differed for the phenological events. The length of this period varied among stations more than we expected (Fig. 4). We used only average values so as to take full advantage of the usefulness of air temperature as a plain indicator. For more detailed studies, in which regional differences with respect to the effects of air temperature on phenological phase variation are required, differences in *LP* among regions should be considered.

Almost all phenological studies have reported an advance in spring phenology, a delay in autumn phenology, and therefore lengthening of the growing season. Since our study yielded similar results, it is possible that the length of the growing season is increasing in all mid- and high-latitude regions. Temporal trends in BGS obtained from multiple studies generally range from about -0.1 to -0.4 days·year^{-1}, while temporal trends in EGS range from about +0.05 to +0.15 days·year^{-1} (e.g., Menzel & Fabian, 1999; Roetzer *et al.*, 2000; Chemielewski & Rötzer, 2001; Defila & Clot, 2001; Menzel *et al.*, 2001; Peñuelas *et al.*, 2002). Thus, it seems that the changes in the autumn phase are smaller than those in the spring phase. However, in our study, changes in EGS (+0.16 days·year^{-1}) were greater than those in BGS (-0.09 days·year^{-1}). LGS changes for ginkgo trees in Japan (+0.25 days·year^{-1}) were somewhat smaller than results from Europe (+ 0.36 days·year^{-1}: Menzel & Fabian, 1999) due to the small changes in BGS. According to the Intergovernmental Panel on Climate Change (IPCC, 2001), global air temperatures have changed most noticeably since the mid-1970s. Therefore, we can assume that global climate change has extended LGS since the 1970s (Fig. 5c).

Although we also examined the relationship between temporal trends in LGS and spatial parameters (latitude and normal temperature) at each station, we found no significant relationships. A similar study in Germany (Menzel *et al.*, 2001) also found no regional differences. Because very little is known about the factors that cause spatial differences in phenological trends, more detailed studies in this area are required.

According to other studies (e.g., Fitter *et al.*, 1995; Kai *et al.*, 1996; Sparks *et al.*, 2000; Chemielewski & Rötzer, 2001; Peñuelas *et al.*, 2002), an increase in air temperature of 1℃ generally induces an earlier spring (by 3-10 days) and a delayed autumn (by 3-4 days), thereby extending the growing season. In our results, the advance in BGS per 1℃ was 2.9 days. The smaller change in BGS per 1℃ may be one reason for the small temporal trends in BGS. In contrast, changes in EGS for ginkgo trees (4.4 days·℃$^{-1}$) were relatively large, as compared to other reported results (although only a few studies have investigated EGS).

Chemielewski and Rötzer (2001) suggested that leaf fall is induced by various environmental factors, and therefore cannot be explained by temperature alone. However, we found that ginkgo leaf fall was closely correlated only with air temperature and budding date (e.g., Fig. 7b). Thus, temperature may affect EGS for some plants. Studies that for convenience suppose *LP* to be one month may underestimate the effects of temperature.

Conclusions

Using a long-term phenological dataset for ginkgo trees in Japan, we examined the effects of changes in air temperature on ginkgo tree phenology, and how recent increases in air temperatures have changed LGS. Our study revealed a number of new findings.

1. Variation in BGS is closely related to air temperatures in the 45-day period before the budding date. Variation in EGS is affected most by the air temperatures in the 85 days before the leaf-fall date.
2. LGS of ginkgo trees in Japan has increased by twelve days over the last fifty years, as a result of BGS being four days earlier and EGS being eight days later.
3. No significant relationships were found between the temporal rate of change in LGS and spatial parameters (latitude and normal temperature).
4. An increase in the average air temperature of 1℃ in spring may advance BGS by about 3 days. If the average autumn air temperature increases by 1℃, EGS may be

delayed by about 4 days. Furthermore, LGS may be extended by about 10 days when the mean annual air temperature increases by 1℃.

5. Inter-annual variation in ginkgo tree leaf fall is substantial and depends on variation in air temperatures as well as on budding dates.

This research suggests that global warming may cause a substantial extension of Japan’s growing season. An extended growing season could lead to an increase in photosynthesis and transpiration. To date, however, the physiological and/or ecological effects on plants of an extended growing season have not been well documented. To evaluate the effects of global warming more specifically, more detailed studies are required.

Acknowledgments

We would like to thank Mr. Mitsuhide Tomomura of the Japan Weather Association for providing the air temperature dataset. We are also grateful to Professor Toshiki Aoi, Dr. Akira Hiyane, Dr. Takashi Kunisaki, Dr. Manabu Shirahata, and Professor Isao Sawaguchi of Iwate University, who supported this study and provided helpful advice. The Japan Meteorological Business Support Center produced the phenology of *Ginkgo biloba* L. dataset. The authors would also like to thank the editor and referees for their useful and constructive suggestions and comments.

References

Abu-Asab MS, Peterson PM, Shetler SG, Orli SS (2001) Earlier plant flowering in spring as a response to global warming in the Washington, DC, area. *Biodiversity and Conservation*, **10**, 597-612.

Ahas R (1999) Long-term phyto-, ornitho-, and ichthyophenological time-series analyses in Estonia. *International Journal of Biometeorology*, **42**, 119-123.

Ahas R, Aasa A, Menzel A, Fedotova VG, Scheifinger H (2002) Changes in European spring phenology. *International Journal of Climatology*, **22**, 1727-1738.

Aono Y, Omoto Y (1990) Estimation of blooming dates of *Prunus yedoensis* using DTS combined with chill-unit accumulations. *Journal of Agricultural Meteorology*, **45**, 243-249 (in Japanese with English summary).

Beaubien EG, Freeland HJ (2000) Spring phenology trends in Alberta, Canada: links to ocean temperature. *International Journal of Biometeorology*, **44**, 53-59.

Cayan DR, Kammerdiener SA, Dettinger MD, Caprio JM, Peterson DH (2001) Changes in the onset of spring in the western United States. *Bulletin of the American Meteorological Society*,

82, 399-415.

Chemielewski FM, Rötzer T (2001) Response of phenology to climate change across Europe. *Agricultural and Forest Meteorology*, **108**, 101-112.

Defila C, Clot B (2001) Phytophenological trends in Switzerland. *International Journal of Biometeorology*, **45**, 203-207.

Fitter AH, Fitter RSR, Harris ITB, Williamson MH (1995) Relationships between first flowering date and temperature in the flora of a locality in central England. *Functional Ecology*, **9**, 55-60.

IPCC (2001) Climate Change 2001: *The Scientific Basis. Third Assessment Report of Working Group I* (eds Houghton JT *et al*.), Cambridge University Press, Cambridge.

Japan Meteorological Agency (1985) *Guidelines for the Observation of Phenology* (3rd edition), Japan Meteorological Agency (in Japanese).

Kai K, Kainuma M, Murakoshi N (1996) Effects of global warming on the phenological observation in Japan. In: *Climate Change and Plants in East Asia* (eds Omasa K *et al.*), pp. 85-92. Springer.

Keeling CD, Chin FJS, Whorf TP (1996) Increased activity of northern vegetation inferred from atmospheric CO_2 measurements. *Nature*, **382**, 146-149.

Menzel A (2000) Trends in phenological phases in Europe between 1951 and 1996. *International Journal of Biometeorology*, **44**, 76-81.

Menzel A (2002) Phenology: its importance to the global change community. *Climatic Change*, **54**, 379-385.

Menzel A, Fabian P (1999) Growing season extended in Europe. *Nature*, **397**, 659.

Menzel A, Estrella N, Fabian P (2001) Spatial and temporal variability of the phenological seasons in Germany from 1951 to 1996. *Global Change Biology*, **7**, 657-666.

Myneni RB, Keeling CD, Tucker CJ, Asrar G, Nemani RR (1997) Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature*, **386**, 698-702.

Peñuelas J, Filella I, Comas P (2002) Changed plant and animal life cycles from 1952 to 2000 in the Mediterranean region. *Global Change Biology*, **8**, 531-544.

Roetzer T, Wittenzeller M, Haeckel H, Nekovar J (2000) Phenology in central Europe – differences and trends of spring phenophases in urban and rural areas. *International Journal* *of Biometeorology*, **44**, 60-66.

Schwartz MD, Reiter BE (2000) Changes in North American spring. *International Journal of Climatology*, **20**, 929-932.

Shinohara H (1951) On the period, the temperature of which mostly influences the flowering date of the cherry (*P. yedoensis*). *Journal of Agricultural Meteorology*, **7**, 19-20 (in Japanese).

Sparks TH, Carey PD (1995) The responses of species to climate over two centuries: an analysis of the Marsham phenological record, 1736-1947. *Journal of Ecology*, **83**, 321-329.

Sparks TH, Jeffree EP, Jefree CE (2000) An examination of relationships between flowering times and temperature at the national scale using long-term phenological records from the UK. *International Journal of Biometeorology*, **44**, 82-87.

Sparks TH, Menzel A (2002) Observed changes in seasons: an overview. *International Journal of Climatology*, **22**, 1715-1725.

Tucker CJ, Slayback DA, Pinzon JE, Los SO, Myneni RB, Taylor MG (2001) Higher northern latitude normalized difference vegetation index and growing season trends from 1982 to 1999. *International Journal of Biometeorology*, **45**, 184-190.

Walkovszky A (1998) Changes in phenology of the locust tree (*Robinia pseudoacacia* L.) in Hungary. *International Journal of Biometeorology*, **41**, 155-160.

Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, Fromentin JM, Hoegh-Guldberg O, Bairlein F (2002) Ecological responses to recent climate change. *Nature*, **416**, 389-395

Zhou L, Tucker CJ, Kaufmann RK, Slayback DA, Shabanov NV, Myneni RB (2001) Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. *Journal of Geophysical Research*, **106**, 20069-20083.

.

Table 1 Slope of the regression line (days· ℃$^{-1}$) and significance level (p) between BGS-spring air temperature, EGS-autumn air temperature, and LGS-annual mean air temperature.

Station No.	BGS	EGS	LGS	Station No.	BGS	EGS	LGS
1	-4.40***	+3.13***	+5.31**	42	-2.18***	+4.43***	+9.02***
5	-4.95***	+1.18^{ns}	+8.18***	43	-2.80***	+3.72***	+8.48***
6	-3.45***	+2.16**	+5.99***	44	-2.66***	+5.95***	+10.54***
7		+3.39***		45	-2.12***	+3.98***	+6.37***
8	-3.98***	+2.73**	+8.17***	46	-2.20***	+5.34***	+1.94*
9		+1.60^{ns}		47	-1.19*	+3.48**	+3.24^{ns}
10	-4.58***			48	-3.32***	+5.27***	+10.56***
11	-3.01***	+2.91**	+6.27**	49	-3.27***	+4.69***	+10.91***
12	-3.34***	+3.80***	+10.14***	50	-3.52***	+4.69***	+9.60***
13	-4.71***	+3.45***	+10.39***	52	-2.33***	+5.23***	+8.97***
14	-2.79***	+5.75***	+10.33***	54		+6.63***	
16	-3.49***	+4.41***	+9.52***	55	-2.95***	+3.91***	+7.64***
17	-3.30***	+3.59***	+5.99***	57	-2.61***	+3.63**	+8.67***
19	-3.51***	+6.19***	+14.79***	58	-2.82***	+6.68***	+14.23***
20	-4.28***	+3.74***	+9.08***	59	-2.31***	+5.81***	+11.38***
21	-3.45***	+4.79***	+9.84***	60	-3.22***	+5.57***	+10.11***
22	-3.11***	+6.44***	+14.85***	62	-2.26*	+4.47***	+10.95***
23	-4.03***	+3.94***	+11.22***	63	-2.12***	+4.55***	+7.88***
24	-2.19***	+3.33***	+8.07***	64	-3.33***	+0.84^{ns}	+4.11***
25	-2.25***	+4.39***	+8.85***	66	-1.30**	+4.34***	+6.37***
26	-2.36***			68	-2.09***	+1.95^{ns}	+3.65*
27	-1.14^{ns}	+2.48*	+5.59**	70	-2.41***	+6.10***	+11.31***
28	-2.90***	+5.28***	+10.19***	71	-1.25^{ns}	+4.30***	+7.86***
31	-2.69***	+13.63***	+21.66***	72	-2.82**	+3.05^{ns}	+7.05**
32	-2.76***	+3.48***	+9.48***	73	-1.62*	+2.63**	+3.16^{ns}
33	-2.32***	+3.15***	+9.41***	74	-2.28***	+4.17***	+7.44***
34	-3.45***	+2.83***	+9.10***	75	-3.34***	+5.14**	+9.10**
35	-2.64***	+2.53***	+9.67***	76	-2.58***	+5.65***	+9.79***
36	-2.93***	+2.62**	+7.91***	77	-2.41***	+3.56**	+3.39^{ns}
37	-3.17***	+3.05**	+5.04**	78	-2.75***	+3.40**	+10.25***
38	-1.38*	+2.17***	+2.23^{ns}	79	-2.36***	+5.35***	+10.10***
39	-2.37**	+3.64***	+9.47***	80	-2.88**	+3.10**	+7.36**
40	-1.92***	+2.95***	+6.83***	82	-1.30^{ns}	+6.23^{ns}	+6.53^{ns}
41	-2.48***						

ns: Not significant ($p \geqq 0.1$)

* Significant at $p < 0.1$

** Significant at $p < 0.05$

*** Significant at $p < 0.01$

Figure Legends

Fig. 1 Locations of meteorological stations at which ginkgo phenology was observed. Solid circles indicate stations with more than 25 years of observational data. Open circles indicate stations with less than 25 years of data.

Fig. 2 Examples of differences in the correlation coefficient between BGS (left) or EGS (right) and air temperature in various average periods (using Station 25 as a case study)

Fig. 3 Distribution of isobars of average BGS (a), EGS (b) and LGS (c) in Japan (1953-2000)

Fig. 4 Values of the *LP* of BGS (a) and EGS (b) at different meteorological stations

Fig. 5 (a) Long-term variation in spring air temperature (T_S) and BGS of ginkgo trees across Japan. (b) Long-term variation in autumn air temperature (T_A) and EGS. (c) Long-term variation in mean annual air temperature (T) and LGS.

Fig. 6 Relationship between temporal linear trends of LGS (1953-2000) and latitude at different meteorological stations

Fig. 7 (a) Correlation between spring air temperature (T_S) and BGS of ginkgo trees in Japan. (b) Correlation between autumn air temperature (T_A) and EGS. (c) Correlation between mean annual air temperature (T) and LGS.

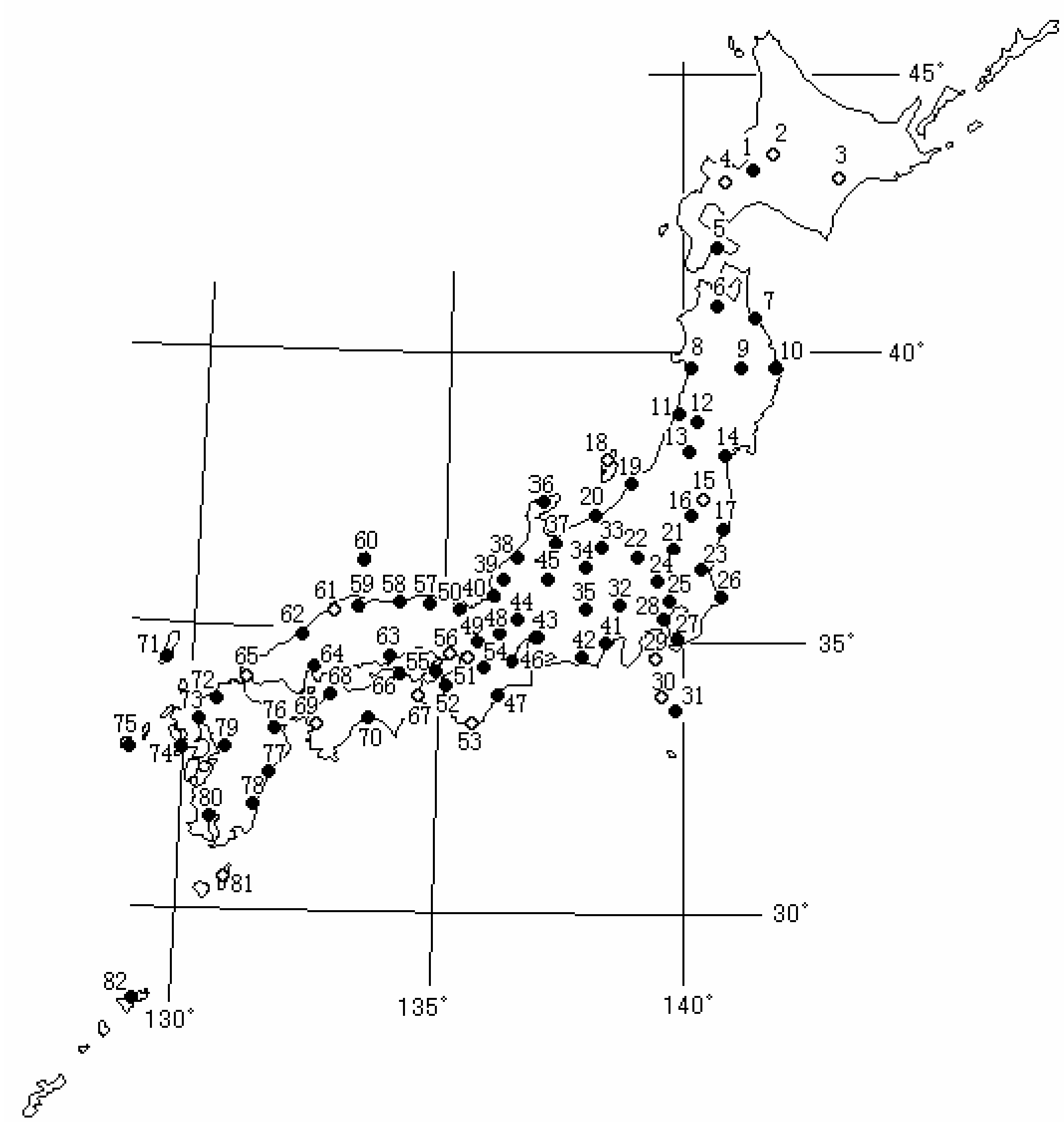

Fig. 1 Locations of meteorological stations at which ginkgo phenology was observed. Solid circles indicate stations with more than 25 years of observational data. Open circles indicate stations with less than 25 years of data.

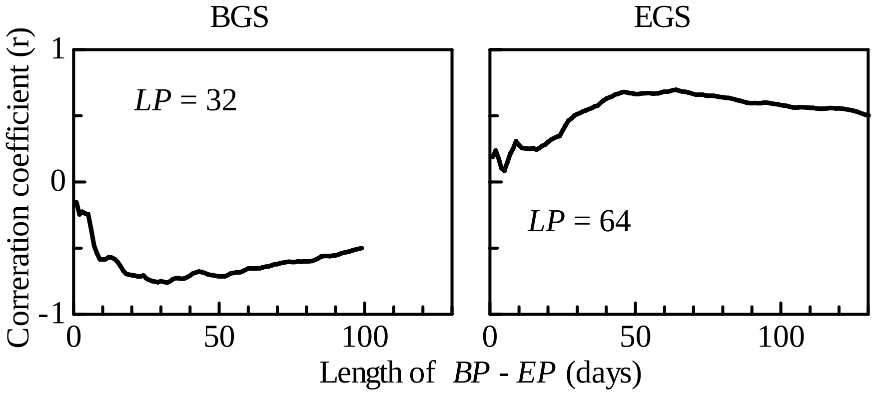

Fig. 2 Examples of differences in the correlation coefficient between BGS (left) or EGS (right) and air temperature in various average periods (using Station 25 as a case study).

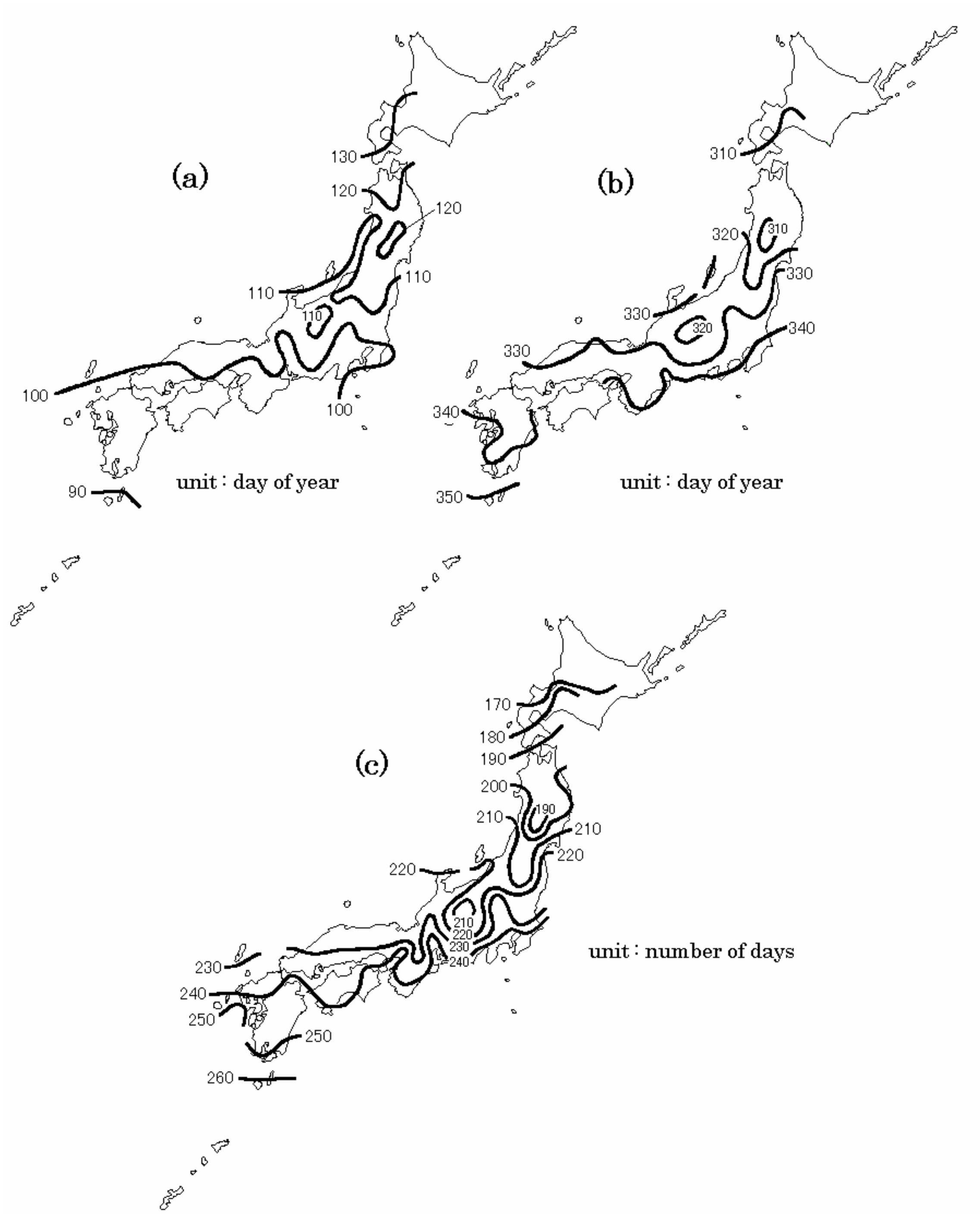

Fig. 3 Distribution of isobars of average BGS (a), EGS (b) and LGS (c) in Japan (1953-2000).

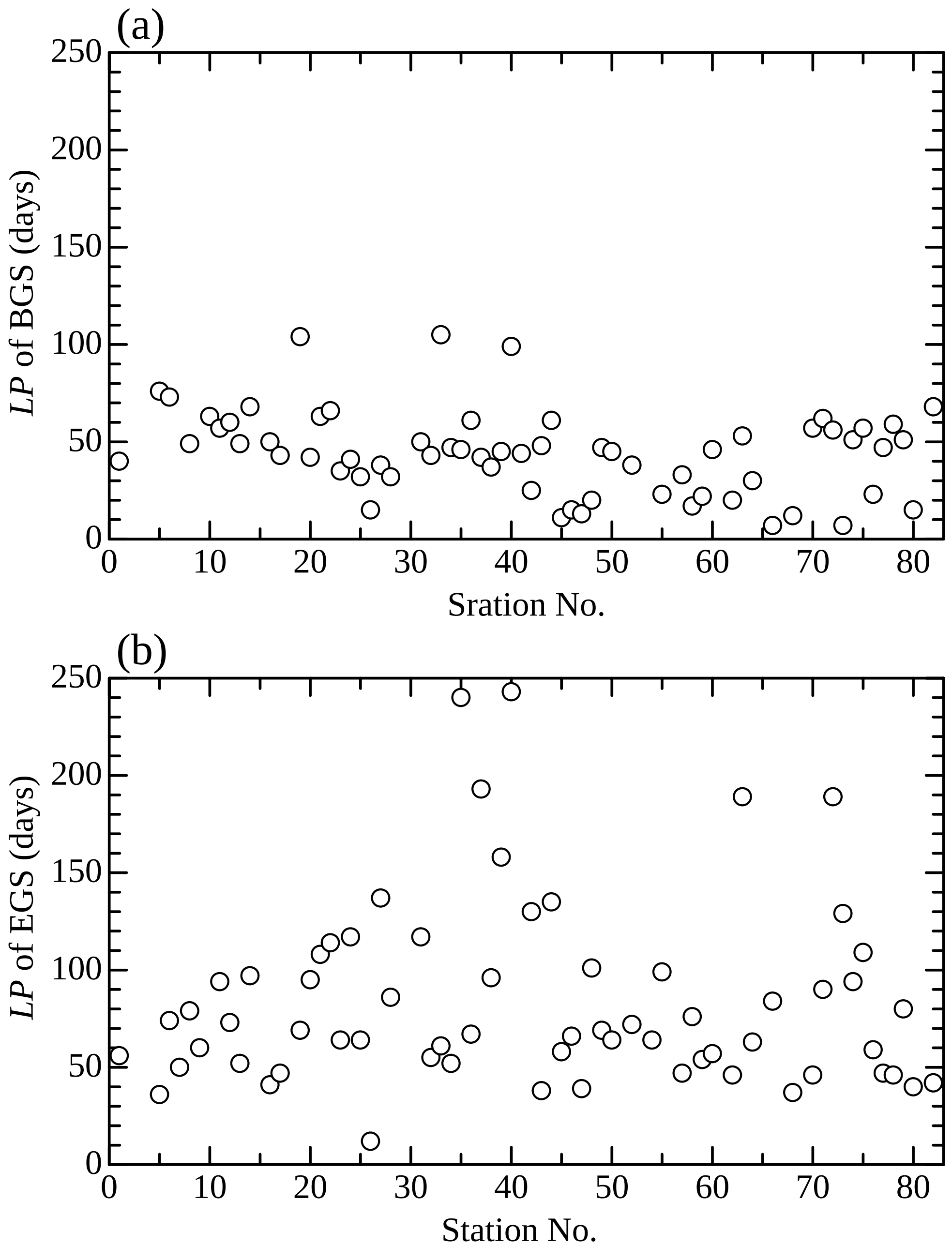

Fig. 4 Values of the *LP* of BGS (a) and EGS (b) at different meteorological stations.

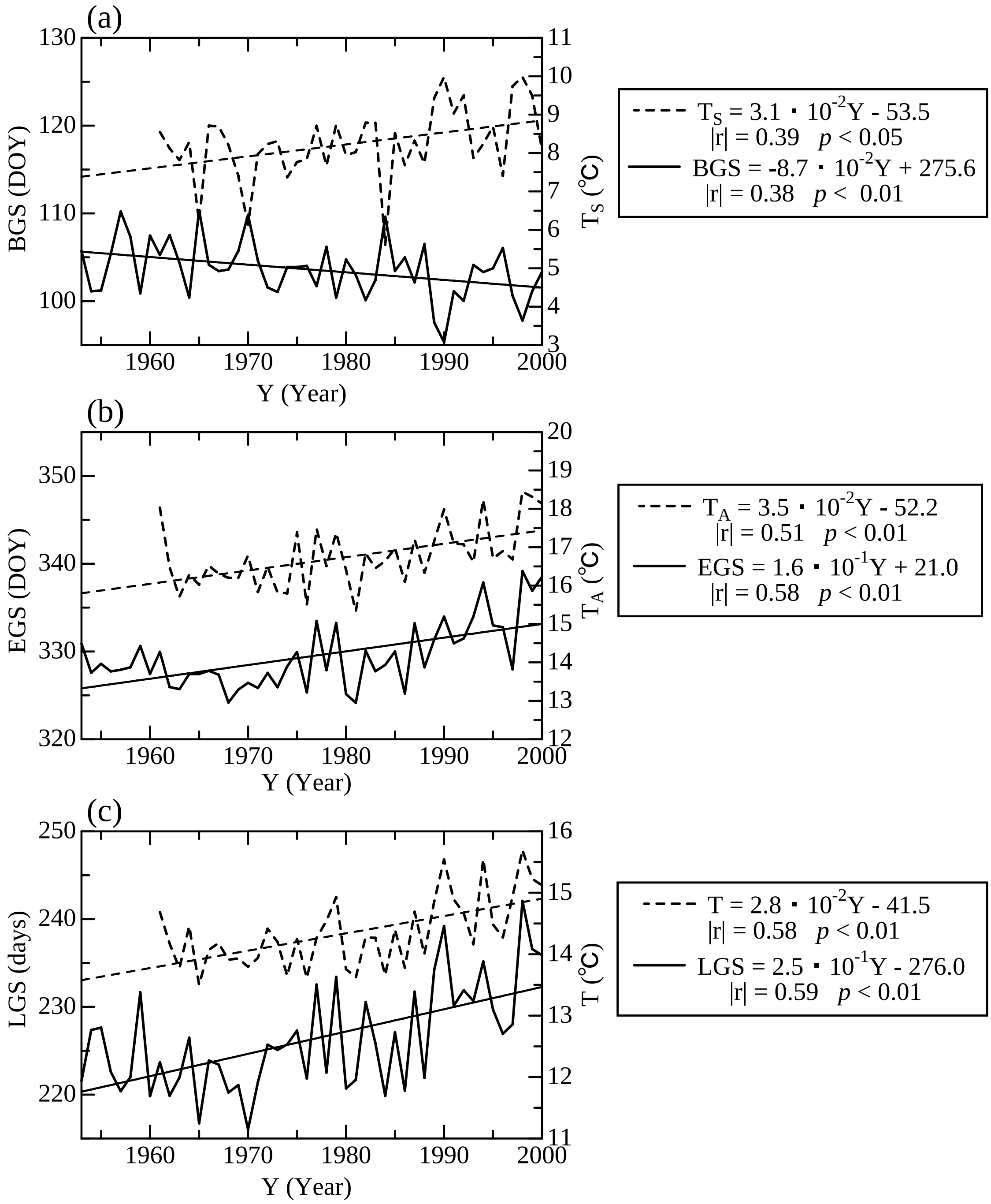

Fig. 5 (a) Long-term variation in spring air temperature (T_S) and BGS of ginkgo trees across Japan. (b) Long-term variation in autumn air temperature (T_A) and EGS. (c) Long-term variation in mean annual air temperature (T) and LGS.

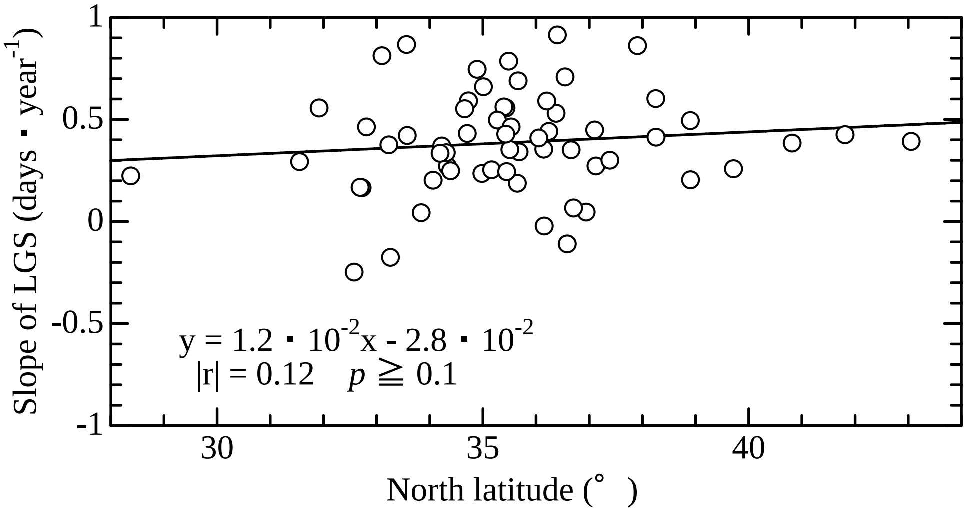

Fig. 6 Relationship between temporal linear trends of LGS (1953-2000) and latitude of different meteorological stations.

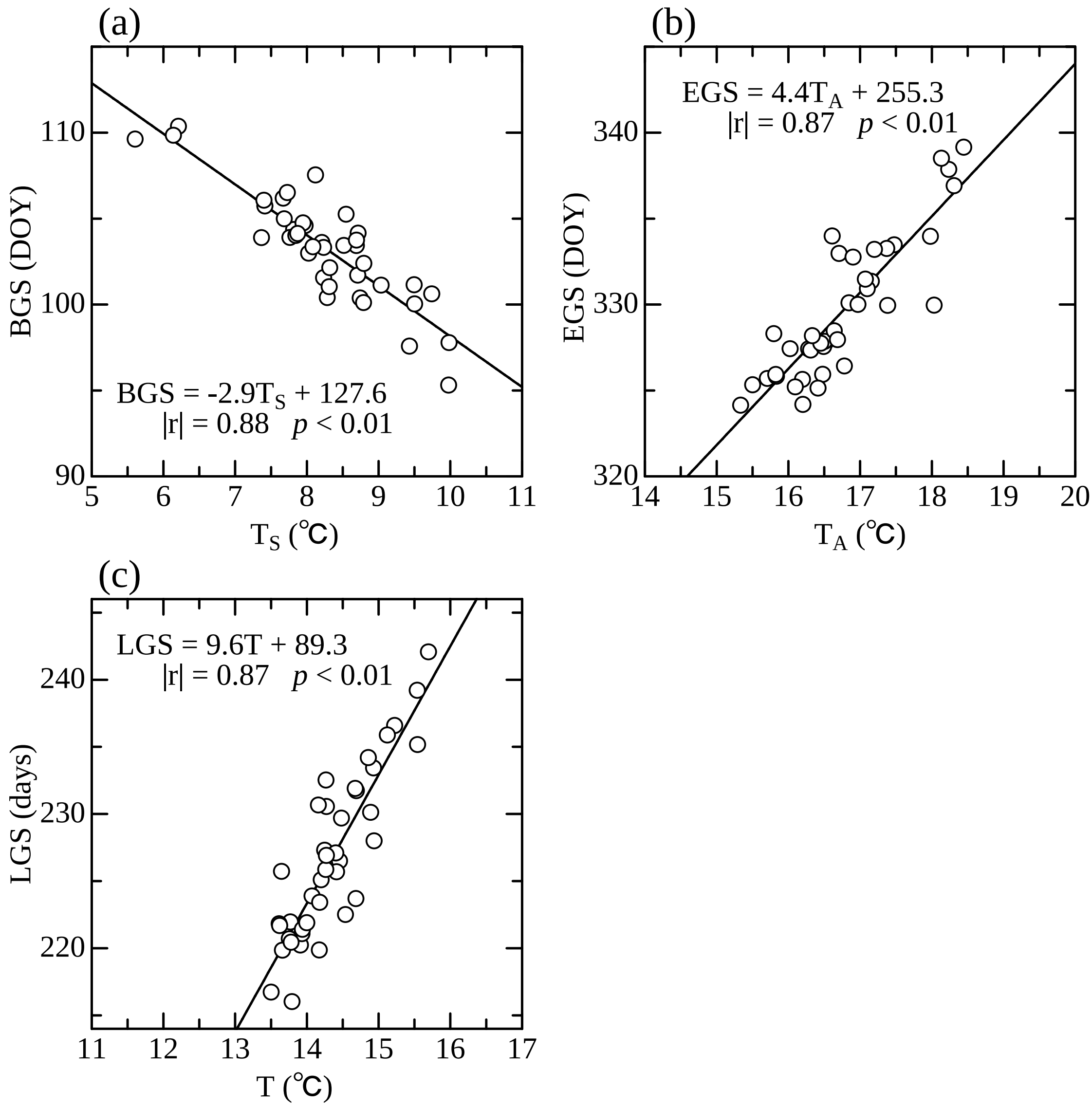

Fig. 7 (a) Correlation between spring air temperature (T_S) and BGS of ginkgo trees in Japan. (b) Correlation between autumn air temperature (T_A) and EGS. (c) Correlation between mean annual air temperature (T) and LGS.