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SPRING PHENOLOGICAL TRENDS IN SLOVENIA

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ABSTRACT

The long-term phytophenological and meteorological data set for the 1955-2000 period was analysed to assess the impact of increased winter and spring temperatures on the plant development in Slovenia. The 46-year series of the leaf unfolding and flowering were studied for 11 plants (herbaceous plants, shrubs and trees) at eight selected observation points. The mean linear trends in phenophases appearance were negative, ranging from -1.4 days per decade for leaf unfolding, -2.2 days per decade for late-spring flowering, and -3.1 days per decade for early-spring flowering. This resulted in earlier leaf unfolding of 6 days and earlier flowering of 10-14 days for the discussed period. A 10-day shift to earlier spring in Slovenia corresponded well with changes in early-spring temperatures from February to April.

Key words: phenology, growing season, trends, air temperature changes, Slovenia

TENDENZE FENOLOGICHE PRIMAVERILI IN SLOVENIA

SINTESI

L'articolo riporta l'analisi di una serie pluriennale di dati fitofenologici e meteorologici per il periodo 1955-2000, effettuata allo scopo di valutare l'impatto dell'innalzamento delle temperature invernali e primaverili sullo sviluppo delle piante in Slovenia. La serie studiata comprende dati inerenti la schiusa delle gemme e la fioritura per 11 piante (erbacee, arbusti ed alberi) in otto postazioni d'osservazione per un periodo di 46 anni. Le tendenze lineari medie delle fenofasi sono risultate negative, variando tra -1.4 giorni per decennio per la schiusa delle gemme, -2.2 giorni per decennio per la fioritura tardo-primaverile, e -3.1 giorni per decennio per la fioritura all'inizio della primavera. Considerando l'intero periodo di osservazione, le autrici concludono che la schiusa delle gemme si è verificata nell'ultimo decennio con un anticipo medio di 6 giorni, mentre hanno calcolato un anticipo di 10-14 giorni per la fioritura rispetto alla prima decade di osservazione. Le variazioni osservate in Slovenia, ossia un anticipo di 10 giorni nella comparsa della primavera, corrispondono alle variazioni della temperatura dell'aria all'inizio del periodo primaverile, da febbraio ad aprile.

Parole chiave: fenologia, stagione di crescita, tendenze, variazioni della temperatura dell'aria, Slovenia

INTRODUCTION

Phytophenology deals with the recurring growth and development phenomena of plants in their annual rhythm (Lieth, 1974). The occurrence times of characteristic vegetation stages (phenophases) are in close relation to the climate of the observation site and current weather. Inter-annual changes in spring plant phenology may be the most sensitive and observable indicators of the plant response to climate change (Beaubien & Freeland, 2000). There are significant differences between the way different plants species respond to climate change. Even small differences in phenology between species can lead to rather large changes in growth when they grow in mixed stands, and consequently also to a significant change of selection pressure (Kramer *et al.*, 2000).

Earlier spring development is occurring in different parts of Europe. The earliest flowering species in the growing season show more variability in bloom time over the years than later-flowering species (Fitter *et al.*, 1995). Ahas (1999) reported that springtime has advanced 8 days on average over the last 80-year period; the last 40-year period has warmed even faster. Phenological data of the International Phenological gardens for the period 1969-1998 showed that the average beginning of growing season across Europe advanced by 8 days (Chmielewski & Rötzer, 2002). The investigation showed (Chmielewski & Rötzer, 2001) that a warming in the early spring (February-April) by 1 °C causes an advance in the beginning of growing season of 7 days. Study by Defila & Clot (2001) showed a clear trend towards earlier appearance dates in spring in Switzerland. For Hungary, Walkovszky (1998) investigated the changes in phenology of the locust tree: a rise in temperature by 1 °C led to a week earlier flowering. Trends in timing of phenological events have been described for England by Fitter *et al.* (1995) and Sparks *et al.* (2000). Earlier spring plant development has been reported also for North America (Beaubien & Freeland, 2000): a movement forwards by 8 days in the timing of spring development was noticed in the Edmonton area (Alberta/Canada) over the last six decades. The observed trends in the onset of spring corresponded well with changes in air temperatures and circulation (North Atlantic Oscillation) in Europe (Chmielewski & Rötzer, 2001; Črepinšek *et al.*, 2002) respectively with Southern Oscillation over western Canada (Beaubien & Freeland, 2000).

Besides being influenced by temperature and the length of day, phenological dates are mainly induced by weather during the actual vegetation period, the past vegetation period and the dormancy period (Defila & Clot, 2001). Man-induced changes are thought to be among the causes of global warming, and higher temperatures in late winter and early spring induce growing season to become earlier (Bergant *et al.*, 2002). This study analyses long-term phenological time series to assess the impact of air temperature changes on selected plants in Slovenia.

MATERIAL AND METHODS

For the long-term phenological analyses only the best quality phenological data, that over at least 30 years, were selected. The study is based on eleven common plants at eight different observation points (Tab. 1). These phenological data-series were extracted from the historical phenological data set of the Environmental Agency of Slovenia. Spring phenophases (leaf unfolding, flowering) were selected for study as the effect of climate change is more pronounced in early spring in Slovenia and owing to the availability of quality data set. First, logical and critical control of the data was performed including plotting of all phenological data. No data were added or corrected because filling in the gaps could change the trends of complete records. For this study, the phenological dates of eleven species were combined in an annual leaf unfolding index, early-spring flowering index and late-spring flowering index to determine the changes at the beginning of the growing season in Slovenia for the 1955-2000 period (Tab. 1). Combining species phenophases to derive an index value has the advantage of summarizing plant responses to weather conditions over extended period or region (Castonguay & Dube, 1985; Beaubien & Freeland, 2000; Chmielewski & Rötzer, 2001). Such phenological information, combined from several stations, obtain a common but more reliable data (Schaber, 2002). For the study of phenological and mean monthly air temperature time series, the linear trend analysis was used. For statistical analysis, the STATGRAPHICS Plus 4.0 and EXCEL 2002 standard modules were applied. Correlations were calculated between phenological data and mean monthly air temperatures for 46 years (1955-2000).

Tab. 1: Phenological data: phenophases, indicator plants, phenological indexes and locations.
Tab. 1: Fenološki podatki: fenofaze, indikatorske rastline, fenološki indeksi, lokacije.

PHENOPHASES
- First leaf unfolding date
- Flowering date

INDICATOR PLANTS

- beech	*Fagus sylvatica* L.
- black locust	*Robinia pseudacacia* L.
- common elder	*Sambucus nigra* L.
- common lilac	*Syringa vulgaris* L.
- common silver birch	*Betula pendula* Roth.
- dandelion	*Taraxacum officinale* Weber/Wiggers
- goat willow	*Salix caprea* L.
- hazel	*Corylus avellana* L.
- horse-chestnut	*Aesculus hippocastanum* L.
- large-leaved lime	*Tilia platyphyllos* Scop.
- snowdrop	*Galanthus nivalis* L.

PHENOLOGICAL INDEXES
Phenological data set was used to calculate four phenological indexes:
Leaf unfolding index - LI
Leaf unfolding index is determined as the annual mean of the leaf unfolding dates for beech, common silver birch, large-leaved lime and horse-chestnut.
Early-spring flowering index - F_1I
Early-pring-flowering index is determined as the annual mean of the flowering dates for common silver birch, dandelion, goat willow, hazel and snowdrop.
Late-spring flowering index - F_2I
Late-spring flowering index is determined as the annual mean of the flowering dates for black locust, common elder, common lilac and large-leaved lime.
Growing season index - GSI
Growing season index is the mean value of the three phenological indexes (LI, F_1I, F_2I) for eleven species at eight locations: **GSI = (LI + F_1I + F_2I)/3**

LOCATIONS

- Celje	46°15'N, 15°15'E, 242 m a.s.l.
- Ilirska Bistrica	45°34'N, 14°15'E, 414 m a.s.l.
- Lesce	46°22'N, 14°11'E, 515 m a.s.l.
- Ljubljana	46°04'N, 14°31'E, 299 m a.s.l.
- Maribor	46°32'N, 15°39'E, 275 m a.s.l.
- Murska Sobota	46°39'N, 15°12'E, 190 m a.s.l.
- Novo mesto	45°48'N, 15°11'E, 220 m a.s.l.
- Rateče	46°30'N, 13°43'E, 864 m a.s.l.

RESULTS

Growing season index and its variability

The beginning of growing season is an important feature in agriculture and forestry. Its variability is mainly driven by environmental factors, particularly by temperature. As a long-term average (1955-2000), the beginning of growing season (defined as growing season index - GSI) in Slovenia starts on 24 April. Standard deviation of growing season index is 6.7 days and variation interval 30 days. Between 1988 and 2000, 11 out of

13 years showed an earlier onset of spring comparing long-term average (Fig. 1). Five earliest springs were noticed in 1994, 1990, 1989, 2000 and 1998. The beginning of growing season was extremely early in 1994 (10 April), and extremely late in 1956 (8 May).

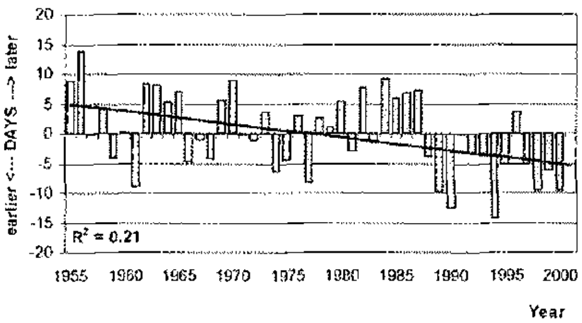

Fig. 1: Long-term trend in growing season index. The Julian days are shown as deviations from the mean growing season index for all data.
Sl. 1: Dolgoletni trend indeksa rastne sezone. Julijanski dnevi so prikazani kot odkloni od povprečnega indeksa rastne sezone za vse podatke.

Trends

The trends of all phenological phases (each phenological phase is average for eight locations) are given in Table 2. All but one of the trends of the spring records were significantly negative (38% at the 0.01 level, 31% at the 0.05 level, 23% at the 0.10 level; 8% were not significant). Negative trends indicate an earlier onset of leaf unfolding and flowering during the past decades. The mean linear trends (days/decade) ranged from -1.4 for leaf unfolding, -2.2 for late-spring flowering, and -3.1 for early-spring flowering. This means a movement forward by 6 days in the timing of leafing and of 10-14 days in the timing of flowering. The growing season index showed a significant negative trend of –2.2 days per decade, corresponding to 10 days earlier beginning of growing season over the last five decades.

There are differences among the spring trends of different phenophases observed, the higher trends being found for early-spring flowering of *Coryllus*, *Salix* and *Galanthus*, indicating that changes of events occurring in the early spring are more distinct and related to considerable change in late-winter and early-spring temperatures (Fig. 3). Changes are more distinct for phenophases of flowering, indicating that these phenophases are more sensitive to air temperatures.

Tab. 2: Long-term trends of spring phenological phases in Slovenia for the 1955-2000 period. Significant trends are marked as follows: *** p<0.01, ** p<0.05, * p<0.10.
Tab. 2: Dolgoletni trendi pomladanskih fenofaz v Sloveniji za obdobje 1955-2000. Značilni trendi so označeni: *** p<0.01, ** p<0.05, * p<0.10.

Phenological phase	Change (days per decade)	Regression	R^2
Flowering of black locust	-2.6	-0.27	0.21***
Flowering of common elder	-2.6	-0.25	0.21***
Flowering of common lilac	-2.2	-0.21	0.16***
Flowering of common silver birch	-1.3	-0.14	0.06*
Flowering of dandelion	-1.7	-0.18	0.07*
Flowering of goat willow	-4.6	-0.45	0.24***
Flowering of hazel	-4.3	-0.44	0.13**
Flowering of large-leaved lime	-1.3	-0.14	0.08*
Flowering of snowdrop	-3.7	-0.37	0.17***
Leaf unfolding of beech	-1.1	-0.11	0.10**
Leaf unfolding of common silver birch	-2.0	-0.19	0.13**
Leaf unfolding of horse-chestnut	-1.7	-0.18	0.14**
Leaf unfolding of large-leaved lime	-0.6	-0.07	0.03

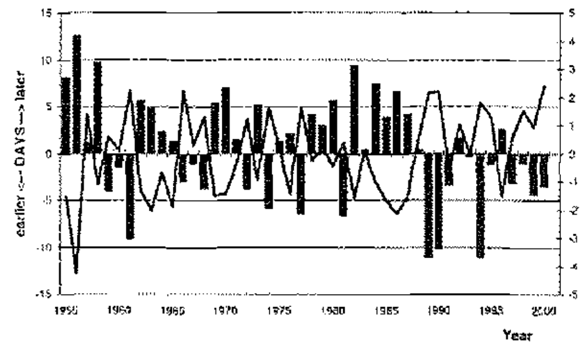

Fig. 2: Leaf unfolding index and air temperatures with deviations from the long-term means (1955-2000). Vertical bars represent the annual leaf unfolding indexes (the mean of first leaf unfolding dates for: *Fagus sylvatica, Betula pendula, Aesculus hippocastanum* ***and*** *Tilia platyphyllos)* ***expressed as deviations in days from the mean value. The line represents the annual deviations of temperature (°C) from the spring mean temperature (February-April).***

Sl. 2: Indeks olistanja in temperature zraka z odkloni od dolgoletnega povprečja (1955-2000). Navpični stolpci ponazarjajo letne indekse olistanja (povprečje datumov olistanja za *Fagus sylvatica, Betula pendula, Aesculus hippocastanum* ***in*** *Tilia platyphyllos),* ***izražene kot odklon (število dni) od povprečja. Krivulja ponazarja letni odklon temperature zraka (°C) od povprečja temperature pomladnih mesecev (februar-april).***

Relations to air temperatures

The annual timing of spring phenophases is largely a response to temperature and reflects thermal conditions of the current year and location. From February to April, significant negative correlation coefficients between GSI and temperature were found, meaning that higher temperatures in early spring promote earlier flowering and leaf unfolding (Fig. 4). Annual monthly temperatures for eight locations for February, March and April were averaged for each year. These temperatures and GSI correlated at high significant correlation coefficient (R = -0.90). A comparison with the simpler relationship with the one-month temperatures confirmed that relationships were tighter when the temperatures of many months were dealt with together. The later beginning of growing season was associated well with lower than average temperatures (Figs. 1 &. 2). According to the regression equation, a warming of 1 °C promotes beginning of growing season by 4.1 days in Slovenia (Fig. 4).

A trend analysis of air temperature was carried out in order to investigate the cause of spring phenological trends. Mean temperatures for the months of February, March and April were averaged for each year for eight selected locations. We found positive trend in air temperature (+ 1.6 °C) for months from February to April in the last 46 years, which explicated the observed trend at the beginning of growing season (Fig. 5).

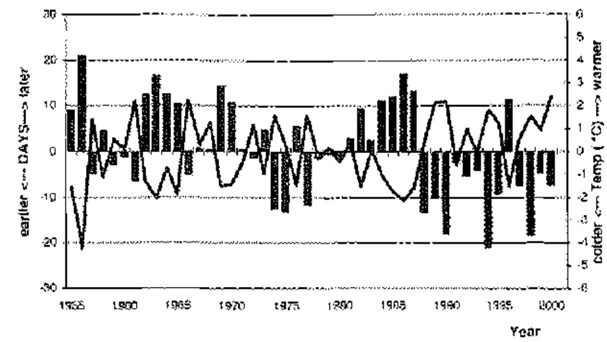

Fig. 3: Early-spring flowering index and air temperatures with deviations from the long-term means (1955-2000). Vertical bars represent the annual early-spring indexes (the mean of flowering dates for: *Betula pendula, Taraxacum officinale, Salix caprea, Corylus avellana* ***and*** *Galanthus nivalis)* ***expressed as deviations in days from the mean value. The line represents the annual deviations of temperature (°C) from the spring mean temperature (February-April).***

Sl. 3: Indeks cvetenja v zgodnji pomladi in temperature zraka z odkloni od dolgoletnega povprečja (1955-2000). Navpični stolpci ponazarjajo letne indekse cvetenja (povprečje datumov cvetenja za: *Betula pendula, Taraxacum officinale, Salix caprea, Corylus avellana* ***in*** *Galanthus nivalis),* ***izražene kot odklon (število dni) od povprečja. Krivulja ponazarja letni odklon temperature zraka (°C) od povprečja temperature pomladnih mesecev (februar-april).***

DISCUSSION

Our investigation has shown that there has been a trend to earlier leaf unfolding and flowering over the last 46 years in Slovenia. The obtained results concerning the regional trend in the beginning of growing season in Slovenia agreed with those for Europe-wide trends of Chmielewski & Rötzer (2002) and Menzel (2000). Spring phenological trends correspond well with changes in air temperature of early spring (February-April). The results of our analysis confirm the findings of others authors concerning the influence of air temperature on the timing of spring events (Chmielewski & Rötzer, 2001). The result that an increase in mean spring temperature of 1 °C is associated with an advanced beginning of growing season by 4 days coincide with the findings of Fitter *et al.* (1995) and Sparks *et al.* (2000).

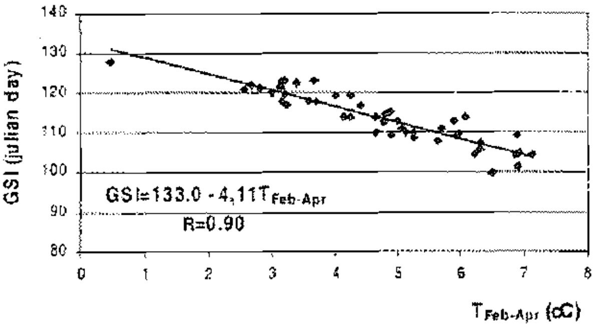

Fig. 4: Relationship between mean spring temperature $T_{Feb\text{-}Apr}$ (February to April) and growing season index (GSI). A warming of 1 °C in $T_{Feb\text{-}Apr}$ means approximately 4 days earlier beginning of growing season in Slovenia.
Sl. 4: Povezava med temperaturo pomladnih mesecev $T_{Feb\text{-}Apr}$ (februar-april) in indeksom rastne sezone (GSI). Otoplitev za 1 °C glede na $T_{Feb\text{-}Apr}$ pomeni približno 4 dni zgodnejši začetek rastne sezone v Sloveniji.

There is no doubt that the global warming led to an earlier beginning of growing season. What are implications of this trend to earlier development for plant species? Plants have different sensitivities to climatic oscillations; this could lead to changes in the population dynamics. Differences in phenological response may affect competition between plant species (Kramer *et al.*, 2000) and promote those with better adaptive response. Changes in species distribution and abundance are the expected results of climate change, which may have positive or negative effects. New crop varieties can become more productive for certain regions and on the other hand new pests, diseases or weediness risk can turn up. We would expect that flowering will remain in approximate synchrony with the pollinating species, but implications of trends in phenological responses need to be examined for all levels of system plant-environment system (Beaubien, 1996). An increasing frequency of warmer winters and springs may result in intensified damage because of late spring frosts in agronomy or forestry resulted in the year's seed production lost or decreasing forest community composition following early promoted growth.

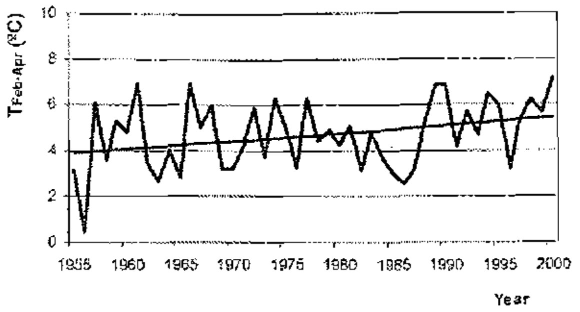

Fig. 5: Long-term trend in mean air temperature from February to April ($T_{Feb\text{-}Apr}$) in Slovenia for the 1955-2000 period.
Sl. 5: Dolgoletni trend povprečne temperature zraka od februarja do aprila ($T_{Feb\text{-}Apr}$) v Sloveniji za obdobje 1955-2000.

If the predicted winter and spring warming over the next decades is carried into effect, then we must expect a continued trend to earlier development, but a linear extrapolation of the statistical trends, found in our or in other investigations, is of course not adequate. The lower limit for a spring phenophases date is probably best determined by examining species phenology at the southern limit of their distribution (Sparks *et al.*, 2000). The early spring phenophases provides the best timing predictor for subsequent plant events and thus phenological data and trends over time could assist us in adapting to climate change and variability.

CONCLUSIONS

The most important results of this study can be summed up as follows:

1. Spring phenological data for the 1955-2000 period were combined in an annual leaf unfolding index, early spring flowering index and late spring flowering index to determine the changes at the beginning of growing season in Slovenia.
2. In the last five decades, the average beginning of growing season in Slovenia has advanced by 10 days, whereby the extreme early dates were observed in the last decade.
3. There were significant differences among the trends of different phenophases in spring: the mean linear trends ranged from -1.4 day per decade for leaf unfolding; -2.2 days per decade for late spring flowering, and -3.1 days per decade for early spring flowering.
4. The leaf unfolding was 6 days earlier and flowering 10-14 days earlier over the 46 years studied.

5. The observed trends at the beginning of growing season correspond well with the changes in air temperature in the early spring from February to April.

6. A warming in the early spring by 1 °C leads to an advanced spring by approximately 4 days in Slovenia.

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TRENDI POMLADANSKIH FENOFAZ V SLOVENIJI

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POVZETEK

Avtorici pričujočega prispevka sta na osnovi dolgoletnih fenoloških in meteoroloških podatkov za obdobje 1955-2000 analizirali vpliv naraščajočih temperatur zimskih in pomladnih mesecev na fenološki razvoj rastlin v Sloveniji. Na osmih izbranih lokacijah sta analizirali 46-letni niz podatkov za fenofazo olistanja pri bukvi, navadni brezi, navadni lipi in divjem kostanju ter za fenofazo cvetenja pri navadni brezi, regratu, ivi, leski, zvončku, robiniji, črnem bezgu, španskem bezgu in navadni lipi. Da bi ugotovili spremembe ob začetku rastne sezone, sta fenološke podatke združili v letnem indeksu olistanja, indeksu cvetenja v zgodnji pomladi in indeksu cvetenja v pozni pomladi. Trendi spomladanskih fenofaz različnih rastlin so se med sabo statistično značilno razlikovali. Srednji linearni trendi (dnevi na dekado) so se gibali med -1,4 za fenofazo olistanja, -2,2 za fenofazo cvetenja v pozni pomladi in -3,1 za fenofazo cvetenja v zgodnji pomladi. V preučevanem obdobju je olistanje nastopilo v zadnji dekadi v povprečju 6 dni zgodneje, cvetenje pa 10-14 dni zgodneje glede na začetno dekado. Ugotovljene spremembe (10-dnevni zgodnejši nastop pomladi) v povprečnem začetku rastne sezone v Sloveniji so se ujemale s spremembami temperature zraka zgodaj spomladi (med februarjem in aprilom). Raziskave so pokazale, da je otoplitev za 1 °C zgodaj spomladi pospešila začetek rastne sezone za 4 dni.

Ključne besede: fenologija, rastna sezona, trendi, spremembe temperature zraka, Slovenija

REFERENCES

Ahas, R. (1999): Long-term phyto-, ornitho- and ichthyophenological research for the 21st century. Int. J. Biometeorol., 42(3), 119-123.

Beaubien, E.G. (1996): Relationships between plant phenology in continental western Canada and Pacific Ocean temperatures. In: Hočevar, A., Z. Črepinšek & L. Kajfež-Bogataj (eds.): Proceedings of the 14th International Congress of Biometeorology, Ljubljana, 1-8 Sept 1996. Mednarodno biometeorološko društvo in Slovensko meteorološko društvo, Ljubljana, p. 150-160.

Beaubien, E. G. & H. J. Freeland (2000): Spring phenology trends in Alberta, Canada: links to ocean temperature. Int. J. Biometeorol., 44(2), 53-59.

Bergant, K., L. Kajfež-Bogataj & Z. Črepinšek (2002): Statistical downscaling of GCM simulated average monthly air temperature to the beginning of flowering of dandelion *(Taraxacum officinale)* in Slovenia. Int. J. Biometeorol., 46(1), 22-32.

Castonguay, Y. & P. A. Dube (1985): Climatic analysis of a phenological zonation: A multivariate approach. Agric. Forest Meteorol., 35, 31-45.

Chmielewski, F. M. & T. Rötzer (2001): Response of tree phenology to climate change across Europe. Agric. Forest Meteorol., 108(2), 101-112.

Chmielewski, F. M. & T. Rötzer (2002): Annual and spatial variability of the beginning of growing season in Europe in relation to air temperature changes. Clim. Res., 19, 257-264.

Črepinšek, Z., L. Kajfež-Bogataj & K. Bergant (2002): Correlation between spring phenophases and North Atlantic oscillation index in Slovenia. Research reports. Biotechnical Faculty, University of Ljubljana, Ljubljana, 79(1), p. 89-98.

Defila, C. & B. Clot (2001): Phytophenological trends in Switzerland. Int. J. Biometeorol., 45(4), 203-207.

Fitter, A. H., R.S.R. Fitter, I.T.B. Harris & M. H. Williamson (1995): Relationships between first flowering date and temperature in the flora of a locality in central England. Funct. Ecol., 9, 55-60.

Kramer, K., I. Leinonen & L. Loustau D. (2000): The importance of phenology for the evaluation of impact of climate change on growth of boreal, temperate and Mediterranean forest ecosystems: an overview. Int. J. Biometeorol., 44(2), 67-75.

Lieth, H. (1974): Purposes of a Phenology Book. In: Lieth, H. (ed.): Phenology and Seasonality Modelling. Ecological Studies 8. Springer-Verlag, New York, 444 pp.

Menzel, A. (2000): Trends in phenological phases in Europe between 1951 and 1996. Int. J. Biometeorol., 44, 76-81.

Schaber, J. (2002): Phenology in Germany in the 20th century: Methods, Analyses and Models. PIK Report No. 78. Potsdam Institute for Climate Impact Research, Potsdam, 146, 39-91.

Sparks, T. H., E. P. Jeffree & C. E. Jeffree (2000): An examination of the relationship between flowering times and temperature at the national scale using long-term phenological records from the UK. Int. J. Biometeorol., 44(2), 82-87.

Walkovszky, A. (1998): Changes in phenology of the locust tree *(Robinia pseudoacacia* L.) in Hungary. Int. J. Biometeorol., 41(4), 155-160.