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Response of tree phenology to climate change across Europe

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Abstract

To investigate the impact of recent climatic changes on the plant development in Europe, this study uses phenological data of the International Phenological Gardens for the period 1969–1998. For this study, the leafing dates of four tree species (*Betula pubescens*, *Prunus avium*, *Sorbus aucuparia* and *Ribes alpinum*) were combined in an annual leaf unfolding index to define the beginning of growing season. The end of growing season was defined using the average leaf fall of *B. pubescens*, *P. avium*, *Salix smithiana* and *R. alpinum*. A nearly Europe-wide warming in the early spring (February–April) over the last 30 years (1969–1998) led to an earlier beginning of growing season by 8 days. The observed trends in the onset of spring corresponded well with changes in air temperature and circulation (North Atlantic Oscillation Index (NAO-index)) across Europe. In late winter and early spring, the positive phase of NAO increased clearly, leading to prevailing westerly winds and thus to higher temperatures in the period February–April. Since the end of the 1980s the changes in circulation, air temperature and the beginning of spring time were striking. The investigation showed that a warming in the early spring (February–April) by 1°C causes an advance in the beginning of growing season of 7 days. The observed extension of growing season was mainly the result of an earlier onset of spring. An increase of mean annual air temperature by 1°C led to an extension of 5 days.

Keywords: Phenology; Growing season; Climate change; NAO; Temperature

1. Introduction

Phenological observations are some of the most sensitive data in identifying how plant species respond to regional climate conditions and to climatic changes. Therefore, phenology has emerged recently as an important focus for ecological research (Schwartz, 1999). In mid-latitudes the seasonal timing of spring events such as budding, leafing or flowering of plants depends highly on air temperature. With increasing temperatures plant development in spring starts earlier within a year.

A lot of recent phenological studies were reported on earlier spring events in recent decades. Depending on the species and the investigated period, the results vary to a certain extent.

Beaubien and Freeland (2000) reported on a long-term trend (1900–1997) in timing of first bloom of *Populus tremuloides* (aspen poplar) of −2.7 days/decade at Edmonton/Alberta (Canada). Mainly since 1973 the negative deviations from the long-term mean prevail. The spring flowering index — mean of the first flowering dates of *P. tremuloides*, *Amelanchier alnifolia* (saskatoon) and *Prunus virginiana* (chokecherry) — had also advanced by 1.3 days/decade in the

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1936–1996 period in the Edmonton area. Menzel (2000) investigated the trends of individual species of the International Phenological Gardens (IPGs) in Europe for the period 1959–1996. She found an average trend of −2.1 days/decade for all springtime phases (leaf unfolding, May-shoot and flowering of different species) and a mean trend of +1.6 days/decade for the autumn phases (leaf colouring and leaf fall). The data point to an extension of growing season by 3.6 days within 10 years.

Timings of spring and summer species have been mostly related to air temperatures. Fitter et al. (1995) found a relationship between first flowering date in England and air temperature of −4 days/°C. Likewise for the British Isles, Sparks et al. (2000) detected a response of flowering times of different spring and midseason species to warming of 2–10 days/°C. For Hungary, Walkovszky (1998) reported that a rise of temperature by 1°C causes an advanced flowering of *Robinia pseudoacacia* (locust tree) by 7 days. Generally, higher temperatures in the late winter and early spring promote earlier flowering and leafing of plants.

This study attempts to explain the trends observed in the phenological data of the IPGs in Europe, with the aim of showing whether the detected regional or Europe-wide trends in the beginning of growing season correspond with climatic trends on the same spatial scale.

2. Materials and methods

2.1. Phenological data

The IPGs are a phenological network in Europe which was founded by F. Schnelle and E. Volkert in 1957 (http://www.agrar.hu-berlin.de/pflanzenbau/agrarmet/ipg.html). At present the network is co-ordinated by the Humboldt-University of Berlin, Institute of Crop Sciences (Chmielewski, 1996). The idea of this network was to obtain comparable phenological data across Europe (among others beginning of leaf unfolding, flowering, autumn colouring, leaf fall) from plants which are not influenced by different genetic conditions. For this reason, vegetative

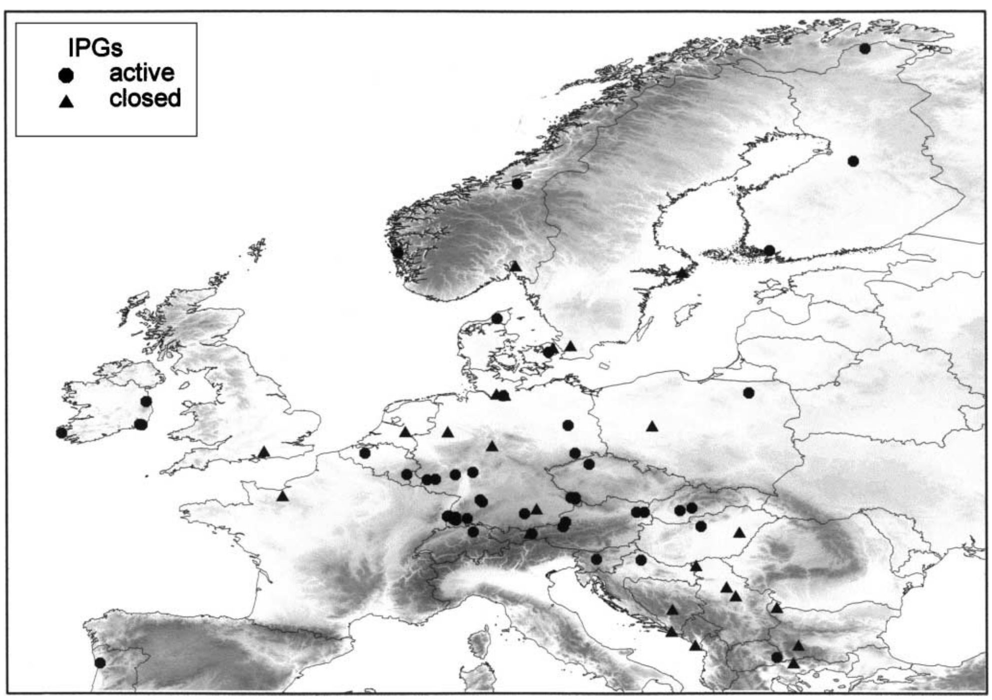

Fig. 1. Locations of the IPGs in Europe. Active and already closed stations with observations for more than 10 years are shown.

propagated species of trees and shrubs were planted at different sites in Europe. In 1959, the first IPG started its phenological observations. Today, about 50 IPGs across Europe record phenological data from 23 species (Fig. 1).

For this study, the leafing dates of four species (*Betula pubescens*, *Prunus avium*, *Sorbus aucuparia* and *Ribes alpinum*) were combined in an annual leaf unfolding index to define the beginning of growing season (BGS). For the end of the growing season (EGS) the average timing of leaf fall of *B. pubescens*, *P. avium*, *Salix smithiana* and *R. alpinum* were used. The difference between the end and the beginning of the growing season was defined as the length of growing season (LGS). For the selection of species used to calculate BGS and EGS, the quantity of observations between 1969 and 1998 was decisive. For the species above the largest amount of data for leafing and leaf fall was available.

The most important precondition of obtaining comparable observation values is the exact definition of the phenological phases which are observed. Beginning of leaf unfolding is registered when the first regular surfaces of leaves become visible in several places (about 3–4) on the observed plant. The first leaf of a plant has pushed out of the bud up to its leaf-stalk. The leaf fall is defined if more than half of the leaves of the observed plant have fallen.

Phenological data from single sites are often 'noisy' because the quality of data depends on the skills and precision of the observers (Schnelle, 1955; Sparks et al., 2000). Special microclimates can also lead to an advanced or delayed timing of spring. A good method to reduce the 'noise' in the data is to average the observations across several sites. For this reason, 12 natural regions (NRs) across Europe were defined (Fig. 2), considering the classification of Wagner (1971). The

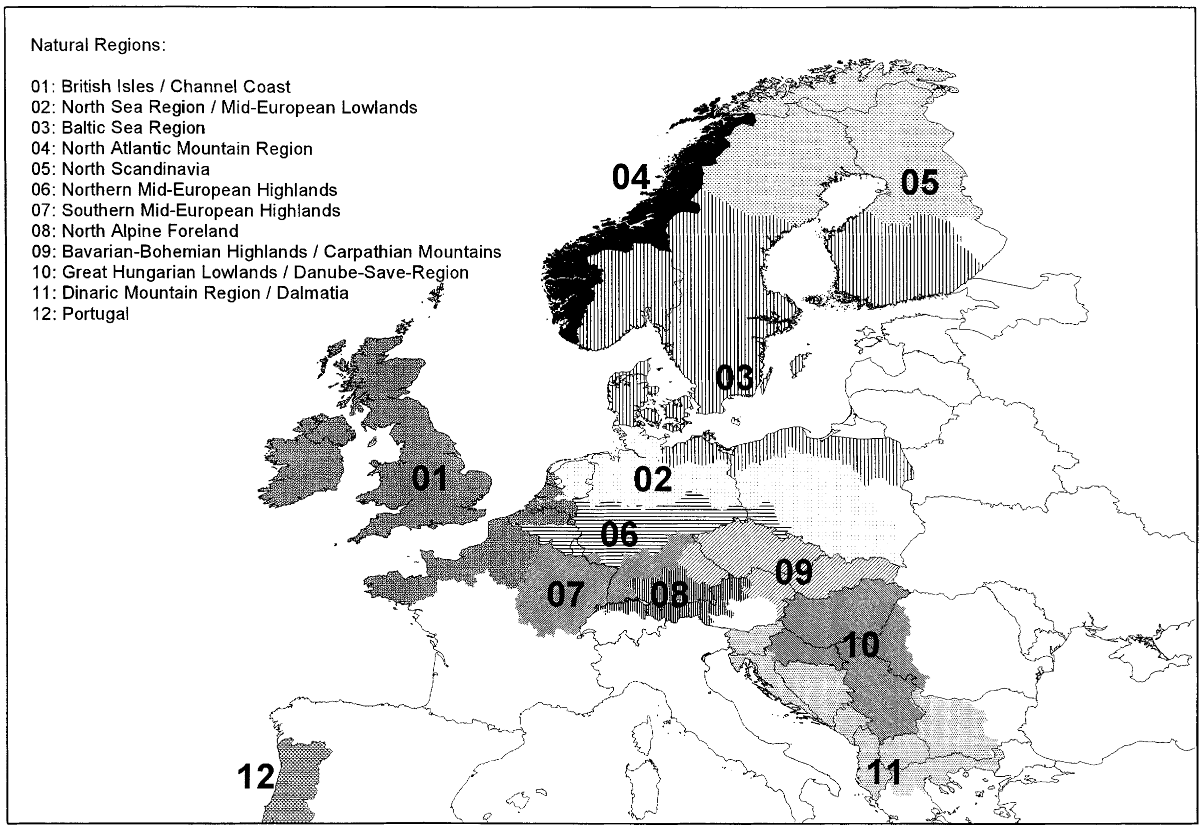

Fig. 2. Definition of NR in Europe (NR01–NR12).

Table 1
Classification of the IPGs to NRs (NR01–NR12), average of latitude, longitude and altitude of the NRs

No.	NR	Average latitude (°)	Average longitude (°)	Average altitude (m)	No. of IPGs[a]	No. of IPGs[b]
01	British Isles/Channel Coast	51.6	−3.8	50	7	4
02	North Sea/Central European Lowlands	52.9	10.1	45	5	3
03	Baltic Sea Region	57.2	15.2	53	8	7
04	North Atlantic Mountain Region	61.9	8.1	38	2	2
05	North Scandinavia	67.1	26.7	148	2	1
06	Northern Central European Highlands	50.4	8.7	307	6	6
07	Southern Central European Highlands	48.2	8.2	591	8	7
08	North Alpine Foreland	47.8	10.9	603	7	5
09	Bav.-Bohemian Highlands/Carpathian Mountains	48.6	15.5	611	8	8
10	Great Hungarian Lowlands/Danube-Save-Region	46.0	19.6	152	5	4
11	Dinaric Mountain Region/Dalmatia	42.9	20.3	601	8	4
12	Portugal	41.3	−8.5	30	1	0

[a] Total number of IPGs in each NR.
[b] Number of IPGs used for the calculation of length of growing season.

IPGs were associated to the regions (Table 1), so that up to eight phenological gardens belonged to an area. NR04, NR05 and NR12 are represented by only one or two stations. For Portugal where only one IPG is available the national boundary was used as NR.

2.2. Climatic data

In order to investigate trends in phenology in relation to climatic changes, gridded near surface temperatures (NCEP/NCAR reanalysis data, Kalnay et al., 1996) and the North Atlantic Oscillation Index (NAO-index) (NAO, Hurrel, 1995) for the period 1969–1998 were used. The horizontal resolution of NCEP data is about 210 km, a region extending from 70°N to 40°N and from 10°W to 25°E was selected. The used NAO-index is the difference of normalized sea level pressure between Ponta Delgada (Azores) and Stykkisholmur/Reykjavik (Iceland). A positive phase of the NAO reflects below-normal pressure in the northern North Atlantic (Iceland) and above-normal pressure over the central North Atlantic (Azores). This usually leads to strong westerly winds which are associated with warm and moist air masses across the North European continent in winter (December–March). In this case, in southern Europe and the Middle East often below-normal temperatures are observed (Hurrel, 1995). A negative phase reflects an opposite pattern in circulation and air temperature across Europe.

3. Results

3.1. Average growing season in Europe (1969–1998)

The length of growing season is an important measure in forestry, agriculture and horticulture. Its variability is mainly caused by temperature-induced variations in the timing of spring events (budding, leafing, and flowering). The autumn phases (leaf colouring and leaf fall) usually show smaller annual variations.

On an average the beginning of growing season in Europe starts on 23 April (Table 2). In south-west (NR12) and south-east Europe (NR10) as well as in the thermal favoured region NR01, growing season starts before 15 April. In Portugal, it already starts at the end of March (25 March). The latest onset of spring can be observed in the cold areas of Europe (NR04: 7 May; NR05: 23 May). On an average the green wave in Europe moves annually with 44 km/day from south to north, with 200 km/day from west to east and with 32 m/day with increasing altitude (Rötzer and Chmielewski, 2001).

The end of growing season generally shows a smaller variability across Europe. On an average leaf fall starts on 28 October. An early EGS can be observed in the high latitudes (NR05: 9 October; NR04: 26 October) and in the highlands (NR09: 23 October). In the maritime region (NR03) the EGS occurred relatively late (5 November).

Table 2
Beginning (B), end (E) and length (L) of growing season in Europe (EU) and in different NRs (NR01–NR12), 1969–1998, s: standard deviation; DOY: day of the year

NR	B (DOY)	s (within NR) (days)	E (DOY)	s (within NR) (days)	L (days)	s (within NR) (days)
EU (NR01–NR11)	113 (23 April)	5.8	301 (28 October)	2.4	188	5.5
01	101	8.2	301	3.4	200	8.1
02	104	9.4	302	4.8	198	9.9
03	120	7.3	309	3.0	189	7.0
04	127	6.2	299	6.7	172	8.0
05	143	6.3	282	10.0	139	9.2
06	106	8.4	305	5.2	199	8.4
07	108	9.1	305	3.2	197	9.2
08	110	7.9	303	3.8	193	7.2
09	119	6.8	296	5.1	177	7.8
10	101	6.3	303	5.6	202	6.9
11	109	7.4	300	6.2	191	8.9
12	84	10.7	No data		No data	
s (NR01–NR11)	12.8		7.0		18.6	

The average length of growing season in Europe (EGS–BGS) lasts 188 days and depends highly on the mean annual air temperature (Fig. 3). The regression equation indicates that 1°C increase in mean air temperature is associated with an extension of growing season by about 5 days.

The shortest duration was observed in North Scandinavia (NR05) with only 139 days (4.5 months) and in NR04 with 172 days. NR05 has the most continental climate of all regions with positive monthly air temperatures only between May and September. NR04 is slightly thermal favoured because of the North Atlantic gulf stream. Compared with NR05, the LGS is 1 month longer. A long duration of growing season of about 6.5 months was calculated for the natural regions 01, 02, 06, 07. The longest period, with an average of 202 days, occurred in the 'Great Hungarian Lowlands/Danube-Save-Region' (NR10).

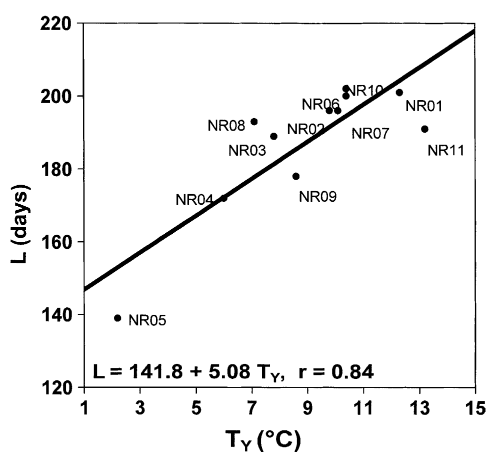

Fig. 3. Relationship between mean annual air temperature (T_Y) and length of growing season (L) in different NRs of Europe.

3.2. *Trends of growing season in Europe (1969–1998)*

In the last 30 years, the beginning of growing season in Europe has advanced altogether by 8 days, this corresponds to a significant trend ($p < 0.05$) of 2.7 days/decade (Fig. 4). Mainly, since the end of the 1980s, early dates prevail. Between 1989 and 1998, 8 out of 10 years had an advanced onset of spring. In 1989 and mainly in 1990, the BGS was extremely early. Compared to the long-term mean, in 1990 leafing in Europe started 14 days earlier (9 April). Because of the long and strong winter in 1995/1996, the BGS in 1996 was again relatively late. However, with 10 days above-normal (3 May) the latest date was observed in 1970, a year with strong negative temperature anomalies of up to −3.5°C between February and April in central and northern Europe.

Compared to the BGS, the end of growing season shows smaller annual variations (Fig. 4). The

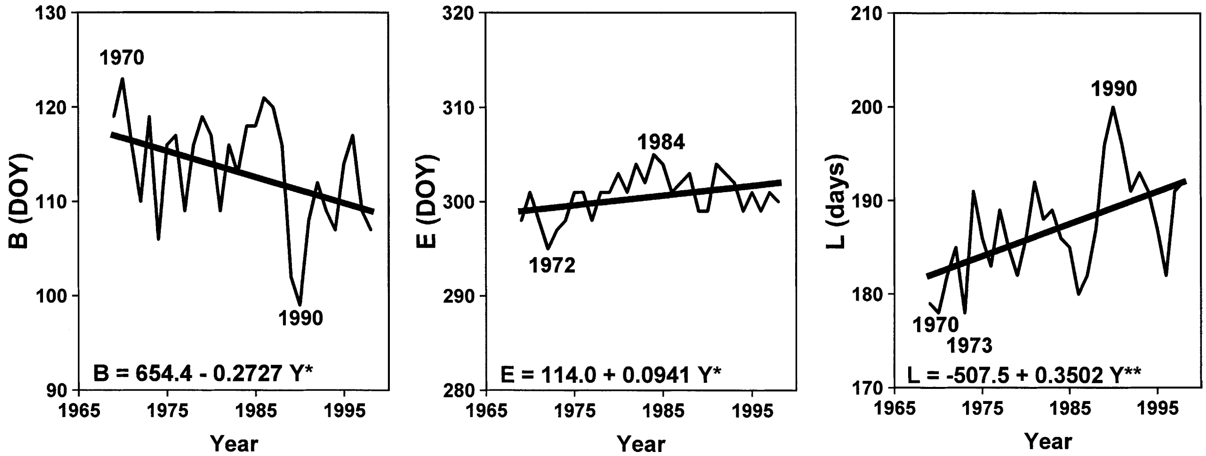

Fig. 4. Trends in the average beginning (B), end (E) and length (L) of growing season in Europe, 1969–1998, Y: year; DOY: day of the year; trend with $*p < 0.05$, $**p < 0.01$.

difference between the extreme years was only 10 days whereas for BGS it was 24 days. The trend to a later end of about 1 day/decade is also relatively small.

Mainly influenced by the BGS, the length of growing season had advanced for the period 1969–1998 by 10.5 days, corresponding to a significant trend of 3.5 days/decade ($p < 0.01$). Because of the very early onset in 1990, this year had the longest growing season (200 days).

Most of the European regions showed significant negative trends in BGS, which range between 3 and 6 days/decade (Table 3). The strongest trends were observed in central Europe: in the NRs 'British Isles/Channel Coast', 'North Sea and Central European Lowlands', 'Baltic Sea Region', 'Northern and Southern Central European Highlands' as well as in the 'North Alpine Foreland'. Also for the IPG in Portugal (NR12) a trend of −4.7 days/decade was

Table 3
Long-term trends of the beginning (B), the end (E) and the length (L) of growing season in Europe (EU) and in different NRs (NR01–NR12) for the period 1969–1998 (significant trends are printed in italics)

No.	NR	B (days/decade)	E (days/decade)	L (days/decade)
	EU (NR01–NR11)	*−2.7***	*+0.9**	*+3.5****
01	British Isles/Channel Coast	*−5.7****	−0.4	*+5.3****
02	North Sea/Central European Lowlands	*−5.0****	+0.4	*+5.9****
03	Baltic Sea Region	*−4.3****	−0.1	*+4.5****
04	North Atlantic Mountain Region	−0.9	+0.2	+0.6
05	North Scandinavia	−1.9	+2.4	*+4.3***
06	Northern Central European Highlands	*−4.5****	+0.5	*+4.9****
07	Southern Central European Highlands	*−5.0****	*+1.5***	*+6.3****
08	North Alpine Foreland	*−3.1**	+0.5	*+3.5***
09	Bav.-Bohemian Highlands/Carpathian Mountains	−0.8	+0.9	+1.6
10	Great Hungarian Lowlands/Danube-Save-Region	−0.1	+1.0	+1.1
11	Dinaric Mountain Region/Dalmatia	+2.4	*+3.4****	+0.9
12	Portugal	*−4.7***	No data	No data

* Significant at $p < 0.1$.
** Significant at $p < 0.05$.
*** Significant at $p < 0.01$.

Table 4
Correlation between monthly air temperature from January (T_1) to May (T_5) and the beginning of growing season (B) in Europe (EU) and in different NRs (NR01–NR12) for the period 1969–1998 (significant coefficients ($p < 0.05$) are printed in italics)

NR	B (average date)	T_1	T_2	T_3	T_4	T_5	T_{24}[a]
EU	23 April	*−0.54*	*−0.65*	*−0.72*	*−0.43*	−0.19	*−0.83*
01	11 April	−0.24	*−0.51*	*−0.77*	*−0.45*	*−0.40*	*−0.75*
02	14 April	−0.26	*−0.63*	*−0.55*	−0.32	−0.12	*−0.75*
03	30 April	*−0.60*	*−0.62*	*−0.59*	*−0.70*	−0.18	*−0.75*
04	7 May	*−0.56*	*−0.47*	*−0.54*	*−0.44*	−0.23	*−0.66*
05	23 May	−0.15	−0.35	−0.01	*−0.53*	−0.33	*−0.60*[b]
06	16 April	−0.20	*−0.50*	*−0.69*	−0.21	−0.13	*−0.77*
07	18 April	−0.09	*−0.52*	*−0.68*	−0.14	−0.30	*−0.81*
08	20 April	−0.10	*−0.43*	*−0.60*	−0.25	−0.16	*−0.71*
09	29 April	−0.34	*−0.49*	*−0.51*	−0.21	0.03	*−0.66*
10	11 April	0.03	−0.29	*−0.75*	−0.31	0.15	*−0.70*
11	19 April	0.06	*−0.36*	*−0.68*	−0.12	0.15	*−0.64*
12	25 March	0.24	*−0.41*	−0.35	−0.21	−0.09	*−0.45*[c]

[a] T_{24}: average air temperature from February to April.
[b] T_{45}: April–May.
[c] T_{23}: February–March.

calculated. Weak trends were found in northern Scandinavia and in south-east Europe. The latter region even had a positive trend (NR11: Dinaric Mountain Region/Dalmatia) which, however, was not significant.

The regional trends of the end of growing season tend to a latter timing, but in most areas no significant trend was found.

The significant trends in the length of growing season range between 4 days/decade (NR08) and 6 days/decade (NR02, NR07). Altogether seven out of 11 NRs showed an extended growing season in Europe.

3.3. Relations to air temperature

The annual timing of leaf unfolding is to a great extent a temperature response. Thus the beginning of growing season (in our case an average leaf unfolding index of four species) should reflect the thermal regime in Europe.

Table 4 shows that the BGS is mainly influenced by the air temperature in March. Also in February and partially in April significant correlation coefficients between temperature and BGS were found. In these 3 months all coefficients are negative, meaning that higher temperatures in the late winter and early spring promote earlier leaf unfolding. As it can be seen, in the last column of Table 4 all correlation coefficients between the average air temperature from February to April (T_{24}) and BGS are significant ($p < 0.05$). This means that the temperature in this period is decisive for the annual timing of spring in Europe. For the more extreme climatic regions (NR05, NR12) different periods, which correspond more closely to the onset of spring in this area, were used to calculate the mean temperature.

The correlation coefficient between the BGS in Europe (EU) and air temperature (T_{24}) is −0.83 ($p < 0.05$). The relationship between average temperature variations from February to April and BGS in Europe was strong (Fig. 5). The extreme years in phenology (late: 1970; early: 1989, 1990) correspond well with the deviations in air temperature. Both time-series show a significant trend. According to the regression equation, a warming in Europe of 1°C leads to an advanced beginning of growing season by 6.7 days.

In order to investigate the causes of regional trends in the BGS in a more detailed way, a trend analysis of air temperature for all NRs was done. The grid points of air temperature were associated to the NRs to calculate the trends (Table 5).

In most European regions, we found positive trends in air temperature for the last 30 years, which explain well the observed phenological trends in spring (e.g. in NR01, NR02, NR03, NR06, NR07, NR12). The highest positive trend in temperature was found

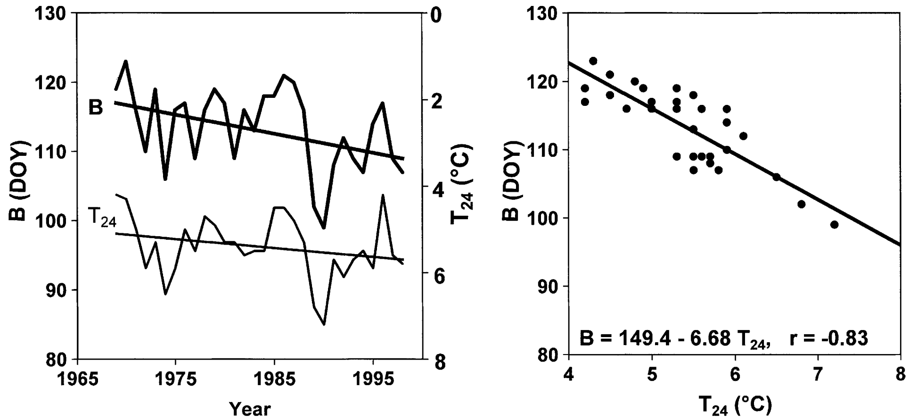

Fig. 5. Trends in air temperature (thin line) from February to April (T_{24}) and in the beginning of growing season (B) in Europe (bold line), 1969–1998 (left). Correlation between T_{24} and B, 1969–1998 (right), DOY: day of the year.

Table 5

Long-term trends of the beginning of growing season (B) and of mean air temperature from February to April (NR05: April–May; NR12: February–March) in Europe and in different NRs (NR01–NR12) for the period 1969–1998 (significant trends are printed in italics)

No.	NR	Trend in B (days/decade)	Trend in air temperature (°C/decade)
	EU (NR01–NR11)	*−2.7***	*+0.23*+
01	British Isles/Channel Coast	*−5.7****	*+0.34***
02	North Sea/Central European Lowlands	*−5.0****	*+0.51**
03	Baltic Sea Region	*−4.3****	*+0.47*+
04	North Atlantic Mountain Region	−0.9	+0.21
05	North Scandinavia	−1.9	−0.01
06	Northern Central European Highlands	*−4.5****	*+0.38*+
07	Southern Central European Highlands	*−5.0****	*+0.25*+
08	North Alpine Foreland	*−3.1**	+0.04
09	Bav.-Bohemian Highlands/Carpathian Mountains	−0.8	+0.02
10	Great Hungarian Lowlands/Danube-Save-Region	−0.1	−0.13
11	Dinaric Mountain Region/Dalmatia	+2.4	*−0.40*+
12	Portugal	*−4.7***	*+0.59****

+ Significant at $p < 0.2$.
* Significant at $p < 0.1$.
** Significant at $p < 0.05$.
*** Significant at $p < 0.01$.

in NR12. As a result, BGS in NR12 advanced by 4.7 days/decade. Negative trends in air temperature were only found in south-east Europe (NR10, NR11). The decreasing mean temperatures from February to April in NR11 corresponded well to the delayed beginning of growing season. Strong positive trends in air temperature were observed for central Europe, where the most striking changes in the BGS occurred.

Leaf fall in autumn is a more complex process, which is also induced by lack of light and chilliness.

Table 6

Correlation coefficients (r) between NAO-index and mean air temperature in Europe for different months, 1969–1998 (correlation coefficients >0.36 are significant with $p < 0.05$)

Month	January	February	March	April	February–April
r	0.69	0.75	0.54	0.45	0.73

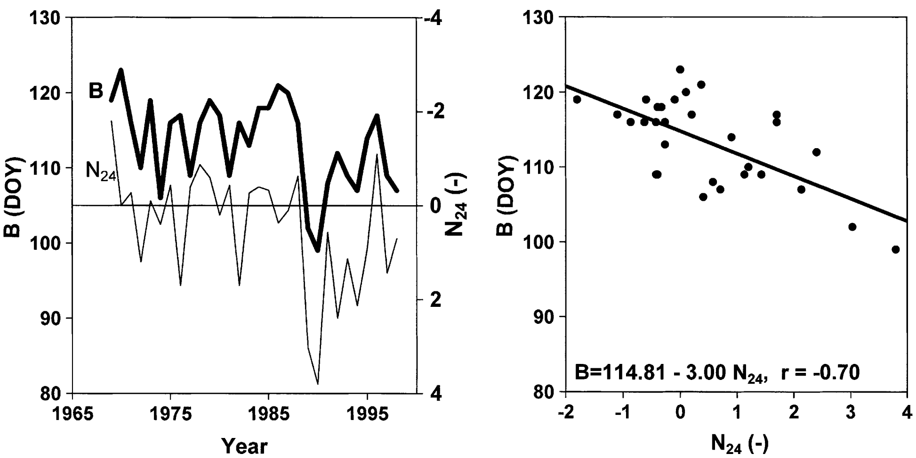

Fig. 6. Mean NAO-index (thin line) from February to April (N_{24}) and average beginning of growing season (B) in Europe (bold line), 1969–1998 (left). Correlation between N_{24} and B, 1969–1998 (right), DOY: day of the year.

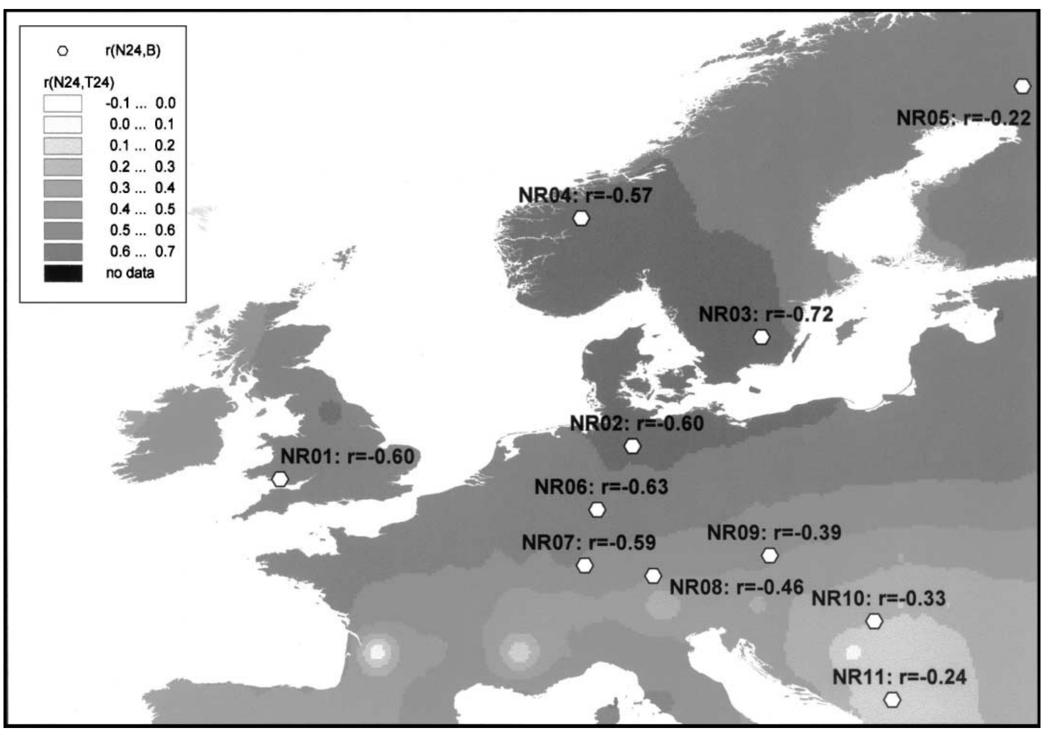

Fig. 7. Correlation between average NAO-index (N_{24}) and average air temperature (T_{24}) from February to April as well as correlation coefficients *r* between N_{24} and beginning of growing season (B) in different NRs (NR01–NR11).

It shows no strong relationship to air temperature like leafing in spring. For this reason, it is not possible to explain the beginning of leaf fall only by temperature. Here more detailed studies are necessary.

3.4. Relations to circulation

Winter and early spring temperatures in Europe are mainly influenced by the prevailing circulation. The NAO is a suitable and often used index to describe the circulation over Europe (Hurrel, 1995). Positive phases of NAO from January to April tended to be associated with above-normal temperatures in Europe in these months (Table 6). The highest correlation ($r = 0.75$) between NAO and air temperature exists in February. For the period February–April, average NAO-index and air temperature in Europe are well correlated ($r = 0.73$). This gives the possibility to investigate how the annual variability of NAO influences the timing of spring in Europe.

The very early beginning of growing season in 1989 and 1990 corresponds well with the high positive indices of NAO in both years (Fig. 6). Similar to the BGS the NAO showed strong positive values since 1989 as well. The relatively late spring in 1996 was also well reflected in the time-series of NAO. The correlation coefficient between NAO (February–April average) and the BGS in Europe was -0.70 for the period 1989–1998.

The highest regional correlation coefficients between NAO and BGS were calculated for central and northern Europe where the correlation between air temperature and NAO was high as well (Fig. 7). In these regions, the strongest negative trends of BGS were detected.

In south-east Europe (NR10, NR11) the relationship between NAO and air temperature was weak, so that in this region no tendency to an earlier beginning of growing season was found. Here, in last few years slightly decreasing temperatures were observed.

4. Discussion

The obtained results concerning the Europe-wide and regional trends in the beginning and end of growing season agreed with those of Menzel and Fabian (1999) as well as of Menzel (2000). In addition to these results, the climatic causes for the observed trends in the beginning of leafing could now be presented. The Europe-wide trend as well as the regional trends in the beginning of growing season correspond well with changes in circulation and in air temperature of the early spring. The analysed trends in temperature are in accordance with the results of Schönwiese and Rapp (1997) and Rapp (2000), who found increasing temperatures in central Europe and a tendency to declining temperatures in parts of south-east Europe as well. The strong positive trend in the Iberian peninsula is in accordance with IPCC (Watson et al., 1998).

The increased positive phase of NAO since 1989 led to milder temperatures in late winter and early spring because of prevailing westerly winds. This resulted in an advanced beginning of spring in Europe and thus in an extension of growing season by 3.5 days/decade.

The results of this paper confirm findings of other authors, concerning the influence of air temperature on the timing of spring events. In most recent studies, an advanced timing of spring events such as budding, leafing and flowering between 2 and 4 days per degree was found (e.g. Beaubien and Freeland, 2000; Kramer et al., 2000; Sparks et al., 1997, 2000). The result that an increase in mean annual air temperature of 1°C is associated with an extension of growing season by 5 days in Europe coincide exactly with the findings of White et al. (1999) for US stations.

There is no doubt that a global warming will lead to changes in the length of growing season within certain limits. This investigation showed that the extension of growing season was mainly influenced by an earlier beginning. The end of growing season showed a lower variability in all regions of Europe.

Generally, the impact of global warming on the extension of growing season will depend on what extent the timing of leaf unfolding and leaf fall will change in future. A linear extrapolation of the statistical trends, found in this or in other studies, is of course not possible. Forest growth models must be used for a better understanding of the responses of trees to climatic changes. Investigations by Kramer et al. (2000), Linkosalo (2000) and Chuine et al. (1999) showed that the phenological response of trees to an increase in temperature depends on the plant species. Both an extension as well as non-extension or a reduced length of growing season are possible (Kramer et al., 2000). In the latter case, the date of leaf fall advanced more than the date of leaf unfolding did.

5. Concluding remarks

This study presented a climatic approach to explain the observed changes in the timing of phenological events. It was possible to confirm that phenology is a good indicator of global warming.

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

1. In the last 30 years, the average beginning of growing season in Europe has advanced by 8 days, whereby the earliest dates were observed since the end of the 1980s.
2. In almost all NRs a trend of an earlier onset of spring was observed. Tendencies to a later beginning were only found in SE-Europe (NR10, NR11), where the average spring air temperature decreased over the 30-year period.
3. The strongest trends were noticed for central Europe (NRs: 01, 02, 03, 06, 07, 08), where the average spring air temperature increased over the 30-year period.
4. A warming in the early spring (February–April) of 1°C leads to an advanced beginning of growing season by approximately 7 days.
5. The end of growing season showed in nearly all NRs a tendency for a slight delay.
6. The length of growing season was mainly influenced by its beginning through which in seven out of 11 NRs a significant trend towards an extension of the growing season was observed.
7. The average growing season in Europe (period: 1969–1998) lasts 188 days (BGS: 23 April; EGS: 28 October). It extends by 5 days per 1°C increasing mean annual air temperature.
8. The observed Europe-wide and regional trends in the beginning of growing season correspond well with the changes in air temperature in early spring (February–April) and with the increased positive phases of NAO-index.

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