

J. Emberlin · M. Detandt · R. Gehrig · S. Jaeger
N. Nolard · A. Rantio-Lehtimäki

Responses in the start of *Betula* (birch) pollen seasons to recent changes in spring temperatures across Europe

Received: 18 February 2002 / Revised: 19 March 2002 / Accepted: 5 June 2002 / Published online: 26 July 2002
© ISB 2002

Abstract A shift in the timing of birch pollen seasons is important because it is well known to be a significant aeroallergen, especially in NW Europe where it is a notable cause of hay fever and pollen-related asthma. The research reported in this paper aims to investigate temporal patterns in the start dates of *Betula* (birch) pollen seasons at selected sites across Europe. In particular it investigates relationships between the changes in start dates and changes in spring temperatures over approximately the last 20 years. Daily birch pollen counts were used from Kevo, Turku, London, Brussels, Zurich and Vienna, for the core period from 1982 to 1999 and, in some cases, from 1970 to 2000. The sites represent a range of biogeographical situations from just within the Arctic Circle through to North West Maritime and Continental Europe. Pollen samples were taken with Hirst-type volumetric spore traps. Weather data were obtained from the sites nearest to the pollen traps. The timing of birch pollen seasons is known to depend mostly on a non-linear balance between the winter chilling required to break dormancy, and spring temperatures. Pollen start dates and monthly mean temperatures for January through to May were compiled to 5-year running means to examine trends. The start dates for the next 10 years were calculated from regression equations for each site, on the

speculative basis that the current trends would continue. The analyses show regional contrasts. Kevo shows a marked trend towards cooler springs and later starts. If this continues the mean start date will become about 6 days later over the next 10 years. Turku exhibits cyclic patterns in start dates. A current trend towards earlier starts is expected to continue until 2007, followed by another fluctuation. London, Brussels, Zurich and Vienna show very similar patterns in the trends towards earlier start dates. If the trend continues the mean start dates at these sites will advance by about 6 days over the next 10 years. Following this work, amendments will be needed to pollen calendars and local predictive models. It will also be important to assess the implications of earlier seasons for allergy sufferers.

Keywords Birch pollen · Climate change · Allergy · Aerobiology

Introduction

The research reported in this paper aims to investigate temporal patterns in start dates of *Betula* (birch) pollen seasons at selected sites across Europe. In particular it investigates relationships between the changes in start dates and changes in spring temperatures over approximately the last 20 years. The results of the analysis are used in an attempt to predict trends in start dates over the next decade. This work has important implications for the use of phenology as an indicator of climatic changes and also for allergology. A shift in the timing of the pollen season for the birch is important because it is well known as a significant aeroallergen, especially in NW Europe where it appears among the top-ranked aero-allergenic pollen types. Estimates suggest that between 20% and 25% of hay fever sufferers are allergic to birch pollen (Hörak and Jaeger 1979) and it can make the symptoms of asthma worse.

Spieksma et al. (1995) investigated atmospheric birch pollen seasons in Europe and identified some trends in

J. Emberlin (✉)
National Pollen Research Unit, University College,
Worcester WR2 6AJ, UK
e-mail: j.emberlin@worc.ac.uk
Tel.: +44-1905-855200, Fax: +44-1905-855234

M. Detandt · N. Nolard
Ist Sci Sante Publique Louis Pasteur, Mycologie,
Juliette Wystmanstraat 14, 1050 Brussels, Belgium

R. Gehrig
MeteoSwiss, Kraehbuehlstrasse 58, 8044 Zürich, Switzerland

S. Jaeger
Department of Otorhinolaryngology, University Hospital,
Währinger Gürtel 18–20, 1090 Wien, Austria

A. Rantio-Lehtimäki
Aerobiology Unit, 20014 University of Turku, Finland

the fluctuations of annual quantities and the starting dates of seasons. The research indicated that the season was tending to start earlier but the work did not relate the observed trends to weather factors. In the 1970s and early 1980s the birch pollen season in the UK typically lasted from mid April to mid May. However, research (Emberlin et al. 1997) on the trend to earlier birch pollen seasons found that records of the start of the birch pollen season, monitored at three sites in the UK for periods of up to 42 years, indicate a recent tendency for the seasons to begin earlier. This trend shows a close relationship to an increase in cumulative temperatures (over 5.5 °C) in the months of January, February and March of about 25–30 °C in total for the 3 months, recorded near each of the sites in the study. Analyses have indicated that birch pollen seasons in the areas examined have advanced by about 5 days per decade compared with the previous 10 years. This illustrates the scale of effect that temperature changes due to global warming may have on the timing of pollen seasons, with implications for several aspects including plant distributions and the timing of the treatment required for allergy sufferers.

This current work extends the investigation of relationships between trends in the start of birch pollen seasons and spring temperatures to other NW European countries where birch pollen is a major aeroallergen, namely Belgium, Austria, Switzerland and Finland.

In order to make comparative analyses it is useful to consider the distribution of the birch in Europe. The genus *Betula* (birch) includes some 120 existing species and grows only in the northern hemisphere. Birch trees grow wild throughout the whole of Europe and are very frequent in northern and central regions. They often grow in extreme habitats such as tree lines or at high altitude or latitudes, but also thrive well in lowlands. *Betula pendula* (= *B. verrucosa*; Silver birch), one of the most common species, grows wild throughout the whole of Europe, east to Siberia and closely related species extend through North America. They form part of many natural plant communities and are also planted extensively as ornamental trees. Birch flowering results in the release of large numbers of pollen grains into the air. Erdtman (1954) estimated the pollen output of one inflorescence of *Betula pubescens* as 6,000,000 grains. Not surprisingly, birch pollen is the most abundant tree pollen type in the UK and much of NW Europe. Extremely high counts can be experienced in Scandinavia, where the amounts of birch pollen can increase from low to thousands per cubic metre of air over a few days at the start of the season. Many trees, including the birch, flower just before budburst, otherwise the presence of leaves would interfere with the dispersal of pollen.

In temperate regions there is likely to be a selective pressure towards early foliation in the spring because this confers a competitive advantage. The peak of solar radiation levels occurs in midsummer before seasonal temperatures reach their maximum. For instance in England, the risk of frost damage is about the same for May/June as it is for September/October but about

12–15 MJ m⁻² intercepted radiation is lost for each day's delay in canopy development whereas only 2–5 MJ m⁻² is gained for each extra day before leaves are lost in the early autumn. In response to this, many species have evolved mechanisms to optimise the earliness of budburst in relation to the risk of frost. The strategy usually involves a requirement for winter chilling to break dormancy followed by warmth as thermal time (temperature summation above a base temperature, often taken as 5 °C), as in the case of the birch.

The potential to change the timing of bud burst in response to climatic warming depends partly on the shape of the thermal-time/chilling-requirement curve for the species, and partly on where they exist on the curve at present. Evidence suggests that the thermal time to budburst decreases with increased duration of previous chilling, down to some minimal thermal time when the buds have received the full chilling needed. Several authors (for example Cannell and Smith 1986; Murray et al. 1989) have suggested that the potential effects of climatic warming depend on the current fulfilment of chilling requirements. If current winters are sufficiently cold to far exceed the chilling requirements, then climatic warming and a decrease in winter chilling will not alter the thermal time needed to reach budburst and it will occur earlier in a warmed climate. If the vernalisation does not occur because of climatic warming, then a larger thermal time will be required to reactivate growth. The dates of phenological events such as the release of pollen and subsequent budburst could be the same after climatic warming. In between these two extremes are those species which have evolved under current climates with a strong selective pressure for optimal dates of early budburst. In a warmer climate bud burst would occur slightly earlier but would require a greater thermal time in order for the risk of frost damage to be the same. Examination of relationships between changing start dates for pollen seasons (which immediately precede budburst), and changing spring temperatures provides an indication of the current status of the species' thermal-time/chilling curve and the likely response to future changes in spring temperatures.

Annual combined land surface and sea surface temperature anomalies for the period 1860–1999 relative to the mean for 1961–1990 show a distinct trend towards warming since 1980 in the Northern Hemisphere. Only 2 years had anomalies below the mean. These were both in the 1980s and were less than 0.1 °C below. In contrast all years in the 1990s had temperatures above the long-term mean with 1998 being 0.7 °C above the mean (Mann 2001). The influence of this trend differs at the regional level within Europe with some areas at high latitudes experiencing little or no warming, whereas areas of mid latitude in Europe and Mediterranean areas have experienced trends towards increased warmth. The repercussions of the changes in climate on the phenology of birch trees will not be uniform across Europe, partly because of these differences in impact and partly because the current relationships with chilling and thermal times differ in various biogeographical regions.

Table 1 Descriptive statistics for the pollen data. Start dates are shown as days from 1 January

Site	Years for which data are available	Statistics using data for 1982–1999		
		Mean start date	Range	SD
Kevo	1980–2000	139	99–171	19.2
Turku	1982–2000	120	92–135	9.4
Brussels	1982–2000	95	74–117	11.6
London	1970–1984, 1987–2000	94	80–111	8.6
Zurich	1976–2000	97	77–111	10.4
Vienna	1980–2000	92	60–106	10.8

Table 2 Product–moment correlations between start dates (1%) and mean monthly temperatures: both variables as 5-year running means. *NS* not significant

Site	Jan	Feb	March	April	May
Kevo	NS	NS	–0.58*	–0.55*	–0.60*
Turku	NS	NS	–0.87**	–0.76**	
Brussels	–0.80**	–0.73**	–0.98**	NS	
London	NS	NS	–0.45*	–0.76**	
Zurich		–0.95**	–0.93**		
Vienna	–0.56**	–0.44*	NS	–0.44*	

* Significant at 0.05 level

** Significant at 0.01 level

Table 3 Multiple regressions of start dates of the birch pollen season against mean monthly temperatures. Variables as 5-year running means

Site	Independent variables	R^2
Kevo	March, April, May	0.62
Turku	March, April	0.78
Brussels	January, February, March	0.99
London	March, April	0.58
Zurich	February, March	0.98
Vienna	January, February, April	0.71

Materials and methods

Pollen and weather data

Records of daily average birch pollen counts were used from six European sites, namely Kevo, Turku, London, Brussels, Zurich and Vienna (Table 1) for the period 1982–1999. In some cases longer records were available and were used in addition to the core years. The sites were chosen to represent a range of biogeographical situations ranging from just within the Arctic Circle through to north west maritime and continental Europe. Pollen sampling has been undertaken at all the sites with volumetric spore traps of the Hirst design (Hirst 1952) on exposed roof tops. The technique of volumetric trapping used has been standard across the six sites during the period of study and is the common method used throughout most of Europe (British Aerobiology Federation 1995).

Typically the birch pollen season starts with a short period of low counts before the main season commences. This may bias any statistical analysis and is usually excluded by defining the start date by set criteria (e.g. Mullenders 1974; Nilsson and Persson 1981). Approaches include defining the start date as the day when the counts pass a certain threshold either as a daily or cumulated count, or defining it as the day when a certain percentage (often 1% or 2.5%) of the total catch for the season has been recorded.

This latter method has been used in this study with the 1% threshold. It has some disadvantages as it can be applied only when the season has finished but it has the advantage of facilitating comparisons between years. Birch pollen seasons can differ a great deal in the severity or quantity of pollen produced. In many data sets there are indications of runs of alternate high and low years but these are not always regular (Spieksma et al. 1995). The cumulated percentage method of defining the start dates avoids the influence of annual differences in pollen production.

Weather data were obtained from the nearest meteorological sites to the pollen traps. In all cases daily average temperatures and rainfall were obtained.

Analysis

The general features of the data were analysed for the years 1982–1999 as no information was missing for this period with the exception of 1985 and 1986 for London birch pollen counts. This was done to compare the features of the sites over the same period. Descriptive statistics for the start dates were calculated as the day on which the cumulated counts reached 1% of the total catch for the season. The mean start dates (given as days from 1 January) show a general relationship to geographical location, with the earliest mean start being at the most southerly site, Vienna (day 92) and the latest at the most northerly site, Kevo (day 139), but there is considerable overlap in the ranges (Table 1). Kevo shows the most variability and London the least. In the more detailed analysis against temperatures, longer data sets were used if available in order to show trends over more extensive periods and to build stronger predictive models.

The data for daily temperatures for January through to May at each of the sites over the 18 years were compiled to monthly means. These were then smoothed to 5-year running means of monthly temperatures to examine trends. Five-year running means were also calculated for the 1% start dates for the birch pollen season. As a first step, simple product-moment correlation coefficients were calculated between the start dates and the mean monthly temperatures for each year (Table 2). The results were significant for at least 2 months at each site, and for 3 months at Kevo, Brussels and Vienna. In all cases the relationships were negative. For each site the significant temperature variables were entered into a multiple regression analysis of the start dates with both pollen start dates and temperature variables as 5-year running means in order to examine trends (Table 3). R^2 values differed from 0.99 for Brussels to 0.58 for London, showing the high degree of explanation achieved. The predicted start dates for the next 10 years were calculated from the regression equations for each site, on the basis that the current trends would continue. The 5-year running means for these were plotted together with the 5-year running means of actual start dates. Trend lines were fitted as fifth-order polynomials.

Fig. 1 Kevo. Running 5-year means of monthly temperatures 1980–1999 for March April and May

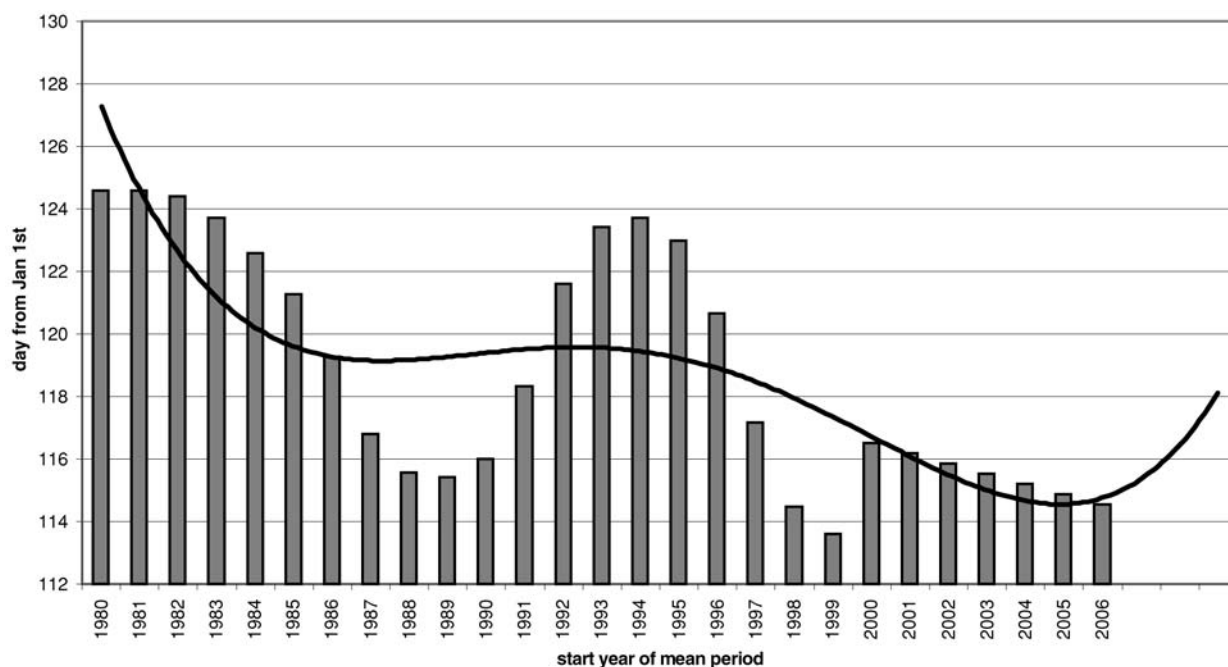
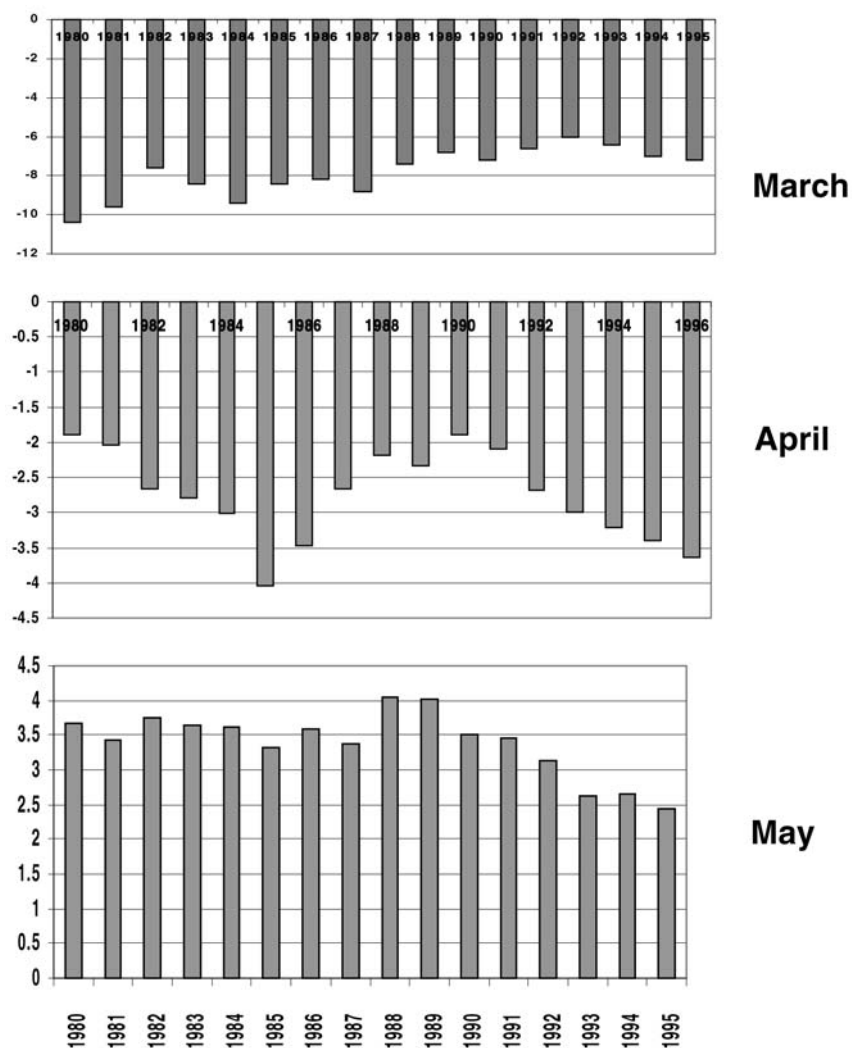


Fig. 2 Kevo. *Betula* pollen season start dates (1%). Five-year running means 1980–2000 and predictions from regression. Trend line as fifth-order polynomial

Fig. 3 Turku. Running 5-year means of monthly temperatures 1980–1999 for March and April. Trend lines are fifth-order polynomials

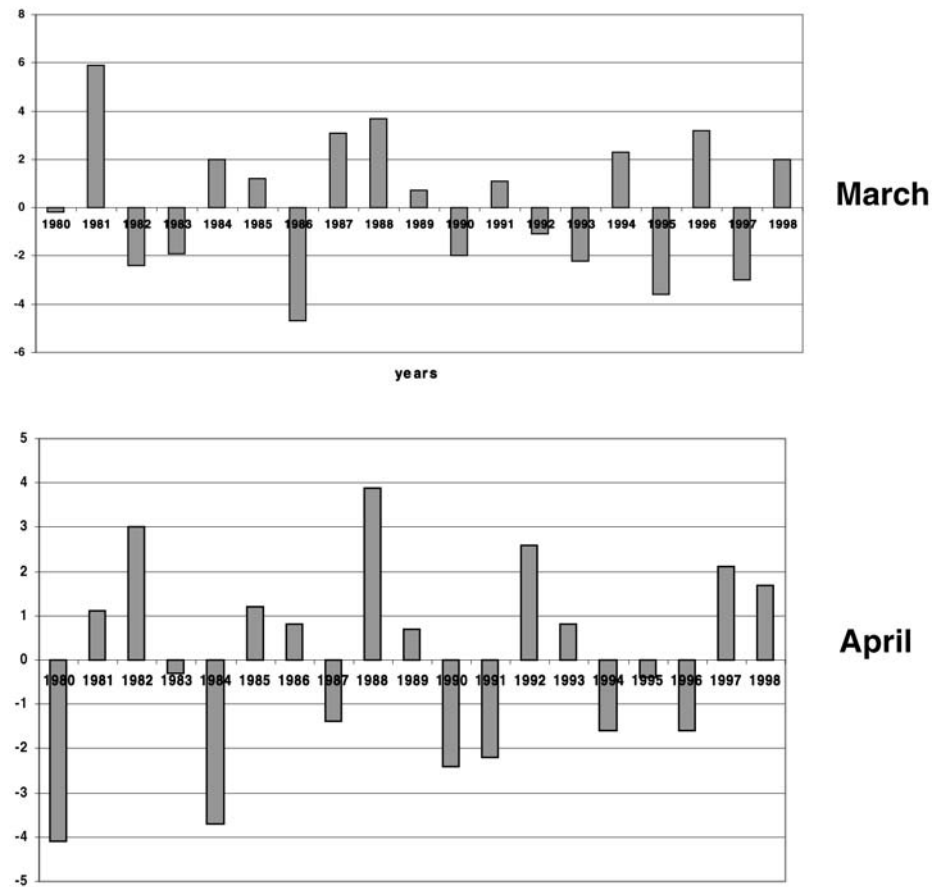
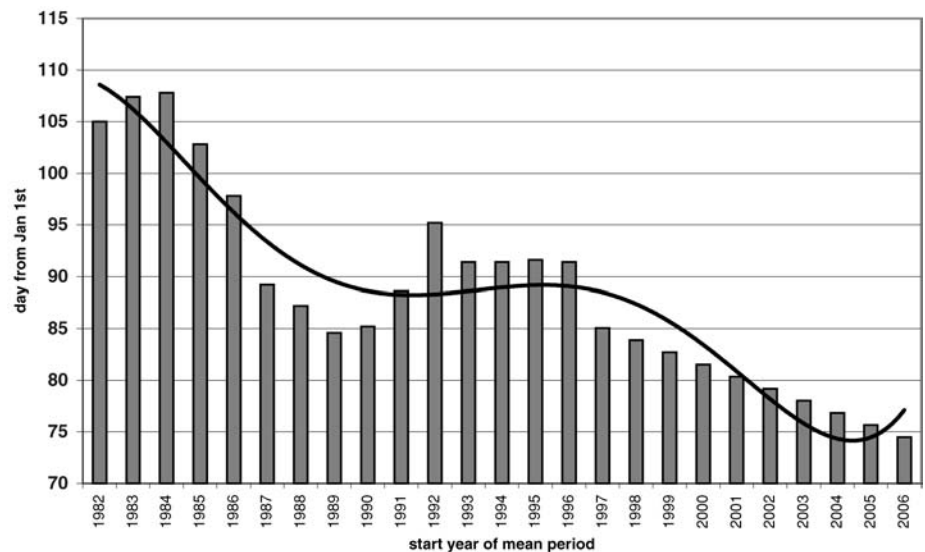


Fig. 4 Turku. *Betula* pollen season start dates (1%). Five-year running means 1980–2000 and predictions from regression. Trend line as fifth-order polynomial



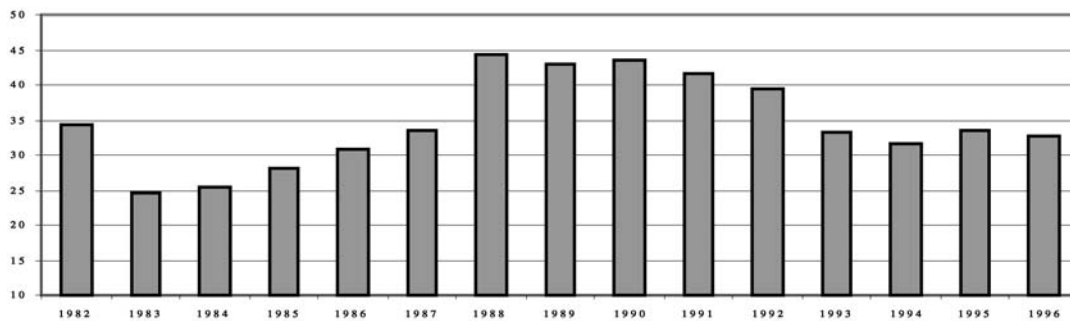
Results

Kevo, Finland: 69°28'N 27°25'E. Data 1980–2000

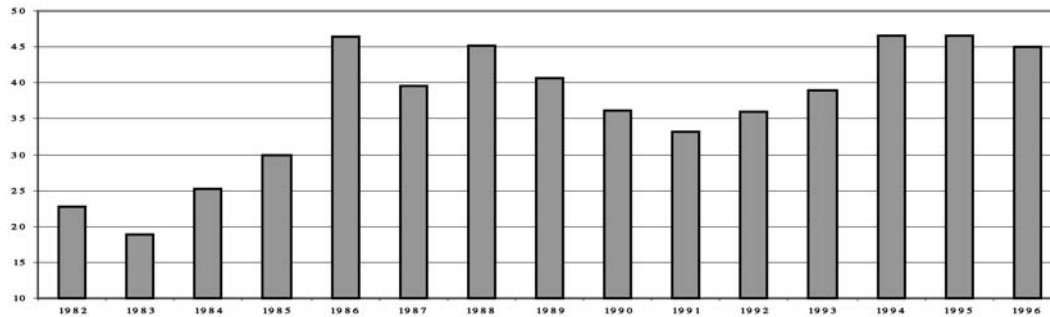
Mean monthly temperatures for March and April were all below freezing (Fig. 1) but March temperatures indicated a trend towards warming with the eight most recent sets of 5-year means having temperatures above –8,

compared with only one of the previous set of eight. April temperatures showed fluctuations with a recent trend towards cooling of about 1.5 °C over the last six sets of 5-year running means. May temperatures were above freezing with a trend towards warming since 1989 of about 1 °C.

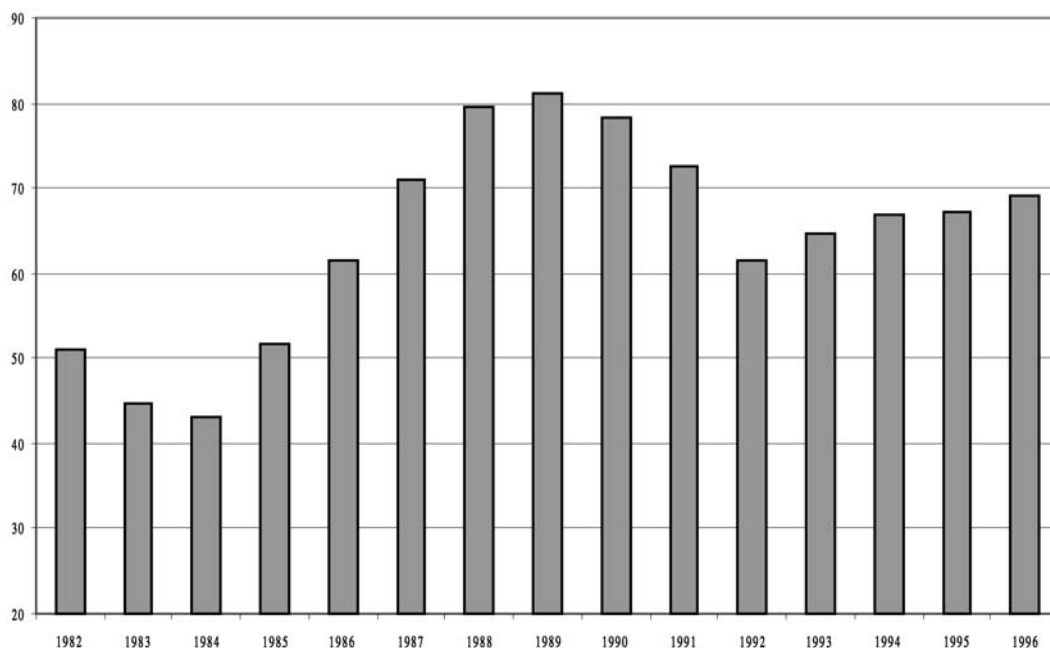
The analysis of the start dates of birch pollen seasons at Kevo shows a distinct trend towards becoming later



January



February



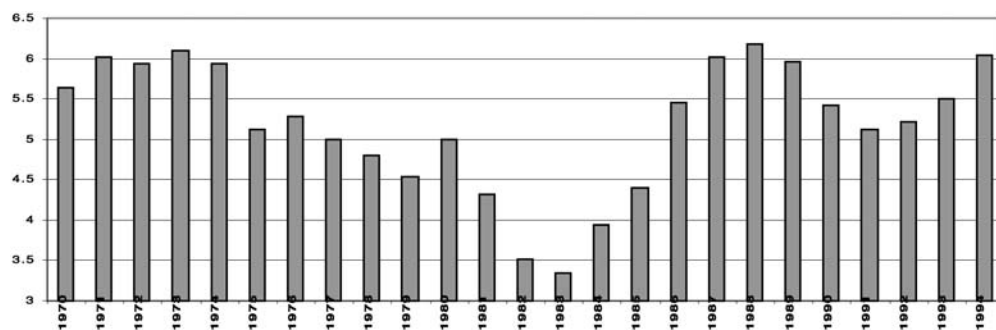
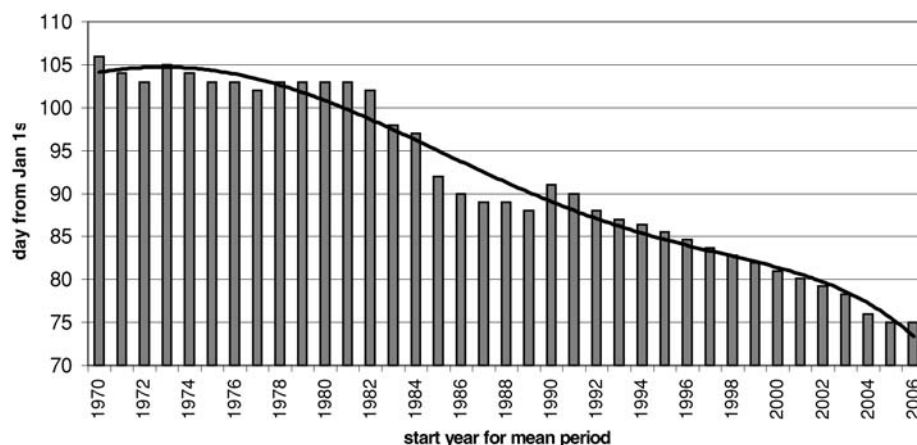
March

Fig. 5 Brussels. Running 5-year means of sums of monthly temperatures 1982–1999 for January to April

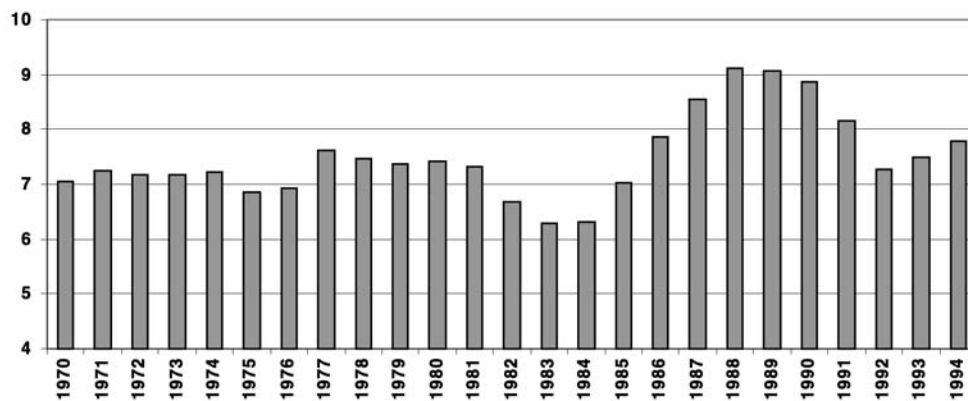
(Fig. 2). From 1980 to 2000 the 5-year running mean for the start dates increased from day 122 to day 152. The predicted trend for the next 10 years was for this pattern of later starting to continue to become later by another 9 days. This reflects the recent trend towards cooling in April and May and concurs with other evidence from the

region for the trend towards later springs (Rantio-Lehtimäki, personal communication). Between 1962 and 2000 the average start date of the period without snow cover in the spring was 20 May and the average snow depth was 81 cm. In the last 5 years (1996–2000) snow lie was later than average in 4 years and deeper in all years. In the previous 5 years snow lie was later than average in 2 years and deeper in 3 years.

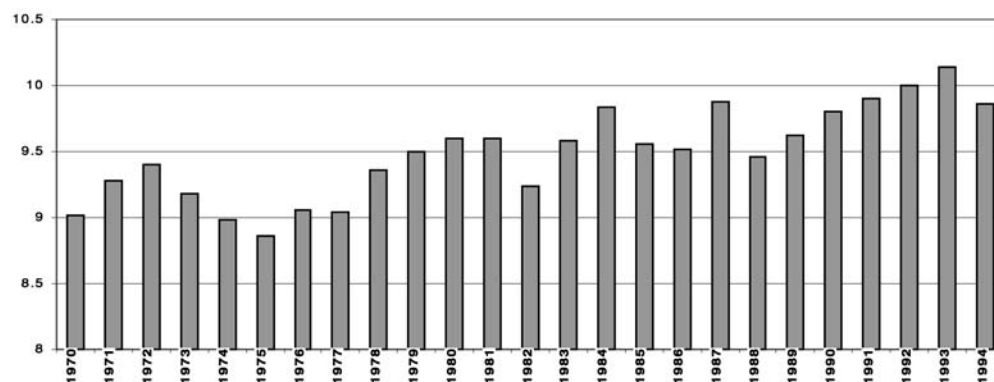
Fig. 6 Brussels. *Betula* pollen season start dates (1%). Five-year running means 1982–1999 and predictions from regression. Trend line as fifth-order polynomial



February



March



April

Fig. 7 London. Running 5-year means of monthly temperatures 1970–1998 for February, March and April

Fig. 8 London. *Betula* pollen season start dates (1%). Five-year running means 1970–1998 and predictions from regression. Trend line as fifth-order polynomial

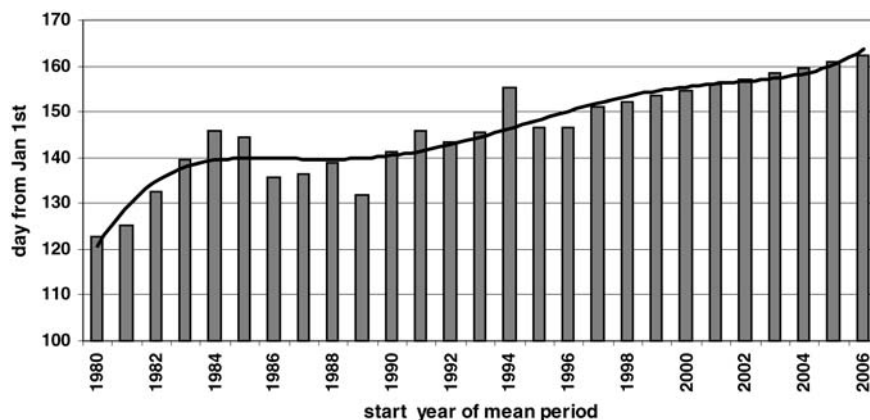
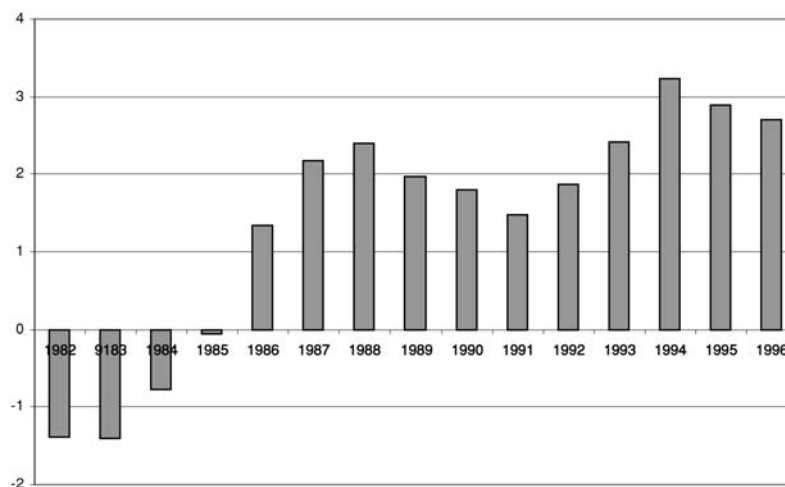
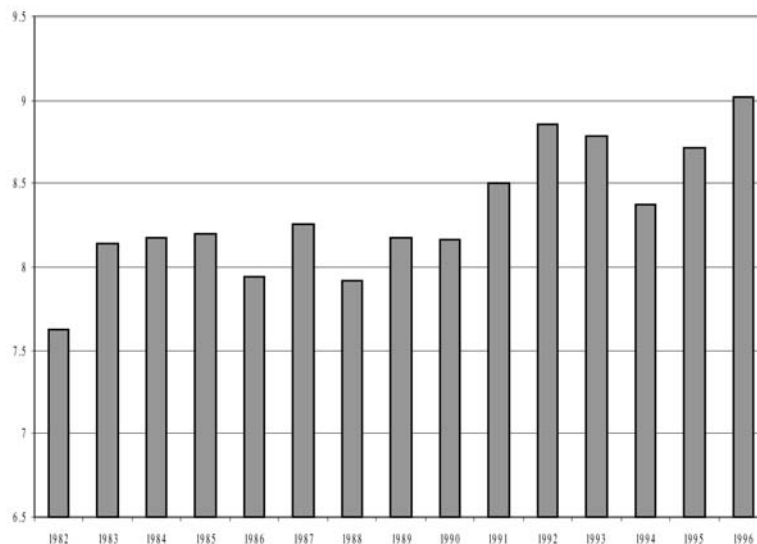


Fig. 9 Zurich. Running five-year means of monthly temperatures 1982–2000 for February and March



February



March

Turku, Finland: 60°28'N 22°12'E. Data 1980–1999

Both March and April mean monthly temperatures show no evidence of consistent trends but have fluctuated considerably since 1980 (Fig. 3) with some months having means below freezing and some above. The average date

for the start of the birch pollen season is the beginning of May so April temperatures are likely to exert a great influence. The last two figures for the 5-year means in April (from 1997) are above freezing whereas the previous three figures are below.

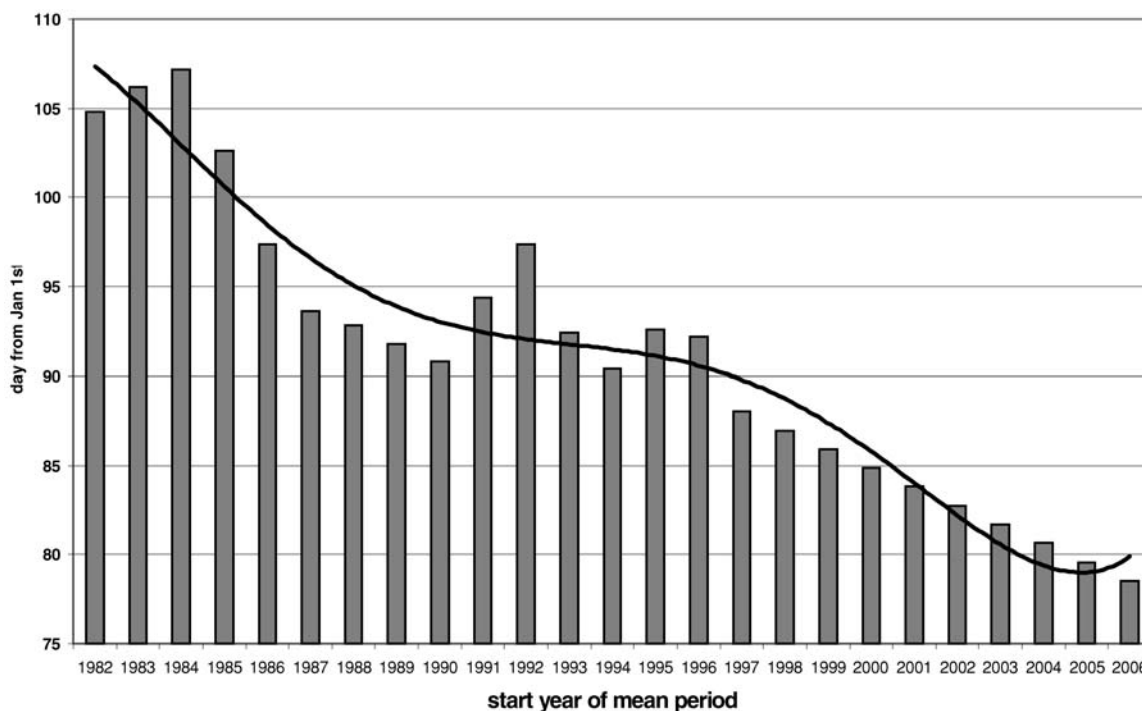


Fig. 10 Zurich. *Betula* pollen season start dates (1%). Five year running means 1982–2000 and predictions from regression. Trend line as fifth-order polynomial

This is reflected in the earlier start to the birch season in corresponding years (Fig. 4). The record of start dates over the period since 1980 shows fluctuations over about 10 days rather than a distinct trend. These fluctuations may continue rather than a sustained trend being established. However, the regression model predicts that if the move towards warmer spring, evident in the last few years, continues, it will lead to further earlier starts over the next 10 years but the difference will only be 1 or 2 days.

Brussels, Belgium: 50°51'N 4°21'E. Data 1982–2000

In Brussels the average date for the start of the birch pollen season falls in the first half of April. The patterns in temperature variation for January, February and March over the study period are similar, with all months showing a trend towards increasing warmth since 1982 (Fig. 5). Springs since 1986 have been notably warmer than those between 1982 and 1986. For illustration, the 5-year running means are shown as sums of the data for each month but in analysis they were treated separately.

In the analysis of the pollen data (Fig. 6) there is evidence of an overall trend towards earlier start dates since 1982, a shift of about 23 days. A period of fluctuation and a tendency for start dates to be about 5–10 days later occurs from 1991 to 1996. A similar period can be identified in the data for Turku at the same time. In both cases the fluctuation corresponds to a period of cooler

springs. For Brussels, if the trend continues for the next 10-years, regression calculations indicate that the start dates will continue to advance by about another 6 days. This rate is slower than that experienced in previous years and could reflect the fact that the relationship is reaching a different position on the thermal-time/chilling curve.

London, UK: 51°30'N 0°10'W. Data 1970–1984, 1987–2000

The average start date for the birch pollen season is in the first week of April, but the situation at this site is complicated as it represents a very large conurbation. The influence of the warm urban climate may affect trees in the city as much as if they grew several degrees of latitude to the south, whereas trees in the surrounding rural areas will have a different local climate. The temperature records for both February and March for the period 1970–1998 show considerable fluctuations, but both show a period of increasing temperatures from 1985 to 1991 (Fig. 7), followed by a fluctuation to decreasing temperatures through to 1996. This corresponds with similar fluctuations in the data for Turku and Brussels. In comparison, the 5-year mean running temperatures for April show a trend to increasing warmth since 1970, all temperatures since 1990 being over 9.5 °C whereas in the 1970s they were all below.

For this analysis the 2 missing years of pollen data (1985 and 1986) have been extrapolated by taking averages of the years on either side. The pollen data (the 5-year running means) show a clear trend towards earlier start dates from 1970 (Fig. 8). The change towards earlier

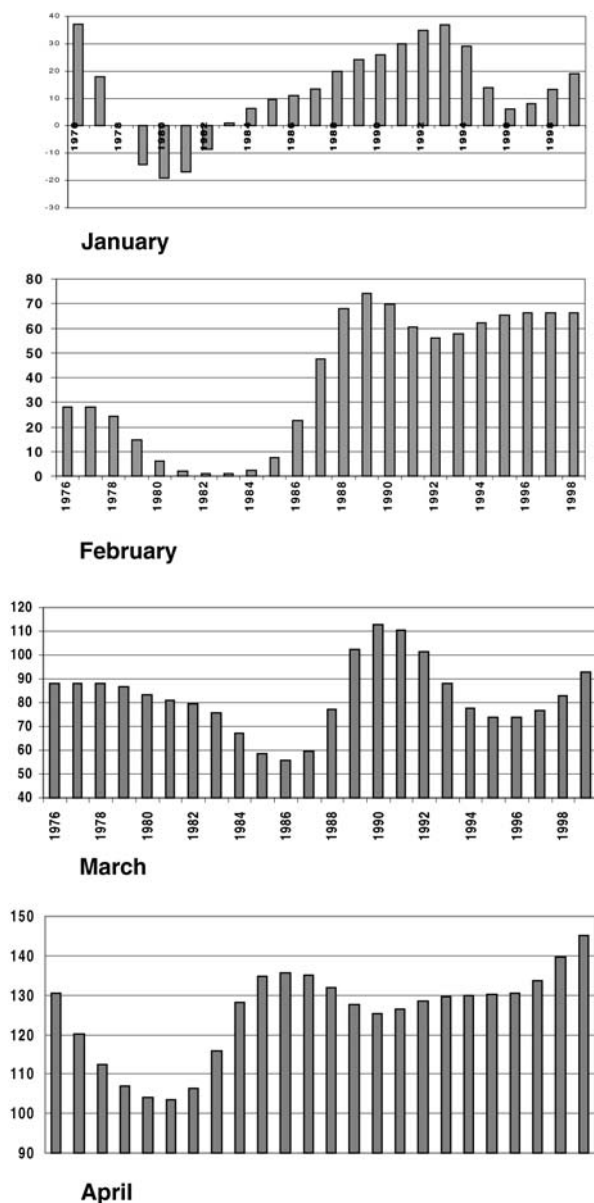


Fig. 11 Vienna. Running five-year means of monthly temperatures 1976–1999 for January, February, March and April

er starts is most noticeable from 1982. Before 1982, all starting dates are after day 100, but after 1982 they all occur before day 100. From 1982 to 2000 the change is about 16 days, equivalent to 8.4 days per decade. There is a slight fluctuation in 1990 and 1991 to later start dates but this represents a change only a few days. It corresponds to the fluctuation to later starts evident in the data for Turku and Brussels but is smaller and does not last so long.

Surprisingly, April has the highest value for product-moment correlation in the individual monthly analysis. There are several possible reasons for this: good weather may influence the actual timing of pollen dispersal rather than when the pollen is ready on the plant, there is a

trend towards warmer springs apparent in the data for April, or of the urban climate may have some influence. If the present pattern continues, regression predicts that, over the next 10 years, the pollen season will start about 4 days earlier. This signals a slowing of the trend, in line with the thermal-warmth/chilling theory.

Zurich, Switzerland: 47°22'N 8°48'E. Data 1982–2000

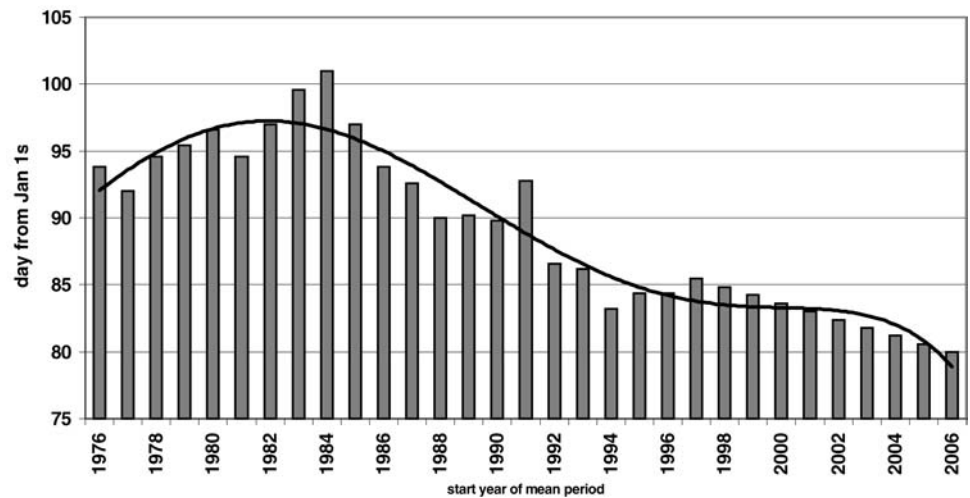
The mean date for the start of the birch pollen season is day 97 (the end of the first week of April). Five-year running means of temperatures for the 2 preceeding months, February and March (Fig. 9), show notable changes to warmer springs. This change in February temperatures is especially notable from 1986; all the running means before that are below freezing but after 1986 they are above freezing, and after 1993 all the means they are above 2 °C. A cooler period is evident in the running means from 1990 to 1992 (covering 1990–1996), corresponding to the cooler phases noticed in the data sets from the more northerly sites. In the running monthly means for March temperatures there has been a noticeable overall trend towards warmer weather since 1982, in the order of 2.5 °C.

In the birch pollen data there is a clear trend towards earlier start dates especially after 1986 (Fig. 10). Until then all running means show the pollen season starting after day 96. There is a fluctuation back to slightly later start dates in the period from 1991 to 1996, identified as having cooler springs (starts occurring between days 90 and 97), whereas after 1996 the season always starts before day 87. Overall, the means show a difference in start dates of 20 days over the period 1982–2000, giving an average advance of about 10 days per decade. Using a regression model to give predictions over the next 10 years on the basis of a continuing trend, start dates become earlier by about 7 days. This indicates a slowing down in the trend with the thermal-time/chilling curve becoming flatter, as noted in other regions.

Vienna, Austria: 48°13'N 16°22'E. Data 1976–1999

In Vienna the mean start day is day 92, (2 April). The temperature records show marked warming especially in February (Fig. 11). Since 1986 the running mean temperatures for February have been above 4 °C with some reaching above 7 °C, whereas before 1986 they were all below 3 °C. A slight fluctuation towards cooler weather from 1991 to 1996 occurred, as noted at other sites. March temperatures have a more complex pattern of changes, with a trend towards cooler conditions from 1976 to 1998, then a marked warming through to 1992. After this, the trend is for cooler conditions again until the last few years of the data set when the trend returns to an increase. This general pattern is similar to that in January. The temperature record for April shows fluctuations but the period since 1984 has seen a sequence of warm Aprils especially since 1998.

Fig. 12 Vienna. *Betula* pollen season start dates (1%). Five-year running means 1976–1999 and predictions from regression. Trend line as fifth-order polynomial



There is some indication of a slightly cooler period from 1990 to 1992 but this is not as marked as at other sites.

The running means of the start dates of the birch pollen season show a trend towards later starts from 1976 to 1985, corresponding to the cooler weather during January, February and April during this period (Fig. 12). After 1986 the trend is for earlier start dates, with the exception of 1991 which had a start date a few days later than that in the previous three running-mean periods. Overall the trend from 1984 to 1999 shows a difference of 17 days, an average of 11 days earlier per decade. The regression equation constructed from the three significant variables to predict trends over the next 10 years, assuming that the current trends continue, indicates that the start dates will advance by about 5 days. This indicates a slowing down in the rate of response as in the cases of the other sites.

Discussion

The analyses have revealed distinct patterns of changes in the start dates for birch pollen seasons in relation to spring temperatures. The approach taken has been deliberately broad (e.g. based on monthly means) rather than a detailed analysis of shorter runs of days, in order to identify the main trends. Monitoring airborne pollen gives a record of the times when pollen is in the air and not the time of actual flowering or when pollen matures on the plants. The start of the pollen season itself, as defined by airborne pollen, may be influenced by factors affecting pollen dispersal, such as rainfall or lack of wind, and may not coincide exactly with the maturation of the flowers. However, there is no indication from the weather records of a trend towards drier weather during the birch pollen seasons that would account for a change in the start dates or would introduce bias into the results. The methods used to collect the airborne pollen have been constant over the sampling periods and have been the same at all of the sites. An objection that the change

in the start dates could be due to the changing abundance of pollen could be raised against the “sum75” start date method, but the same patterns are evident if the start is defined by a certain percentage of the total catch being recorded which is independent of the actual amounts of pollen.

The scale of changes in the start dates of the birch pollen seasons, evident from the current analysis, is broadly comparable to changes in phenological responses of spring flowering trees from other sources. Several long-term phenological records exist for trees in Europe and North America. One of the longest of these is a systematic phenological record begun by the Marsham family in Norfolk UK in 1736. This data set has been analysed by several people, including Margary (1926), who suggested that a 1 °C mean rise in spring temperatures advanced many early spring events on trees by about only 5–7 days. Sparks and Carey (1995) subjected the Marsham data to an exhaustive statistical analysis and came to a similar conclusion. If the events occurred after a constant thermal time it can be shown they would be advanced by at least 10–15 days at most UK sites. Birch species often form the altitudinal or latitudinal tree line; they exist in harsh environments and have evolved high chilling requirements. If the high chill requirements for these species are not met, the compensatory increased thermal time needed will lead to little change in flowering time in a warmer climate.

Overall indications are that early species will be even earlier if the weather becomes warmer and that late spring species will not experience much change in phenology. For example, Cannell and Pitcairn (1993), analysing 12 years of data from East Lothian, found that species advanced most by a warm winter and spring in 1989 were those that tended to flower early anyway. Similarly Fitter et al. (1995) using 30 years of data for Oxford, showed similar tendency for early species to be more advanced by warm springs than late species. This pattern of responses means that spring events in temperate and subarctic Europe will become more spread-out in a warmer climate.

Sites in the current analysis have experienced a range of temperature fluctuations and trends that can be used to examine actual responses in the start of the pollen season to indicate further potential. In most cases the rate of adjustment has slowed after an initial trend towards warming, indicating that the point has been reached on the thermal-warmth/chilling curve when more warmth is required to compensate for lack of adequate vernalisation.

This research has contributed to the understanding of actual and potential responses to environmental controls, and helps to elucidate the triggers and limits that control phenological events. Current opinion on climatic change is that global warming will continue but the resultant rates and patterns of temperature changes are uncertain. In this scenario it is useful to know the likely responses in the phenology of species, especially those with direct implications for health. In the case of the birch there is increasing awareness of the importance of this genus for allergy. This is especially because of the cross-reactivity of the main allergen (Bet v 1) with several foods, including apples and other stoned fruits via profilin, and its cross-reactivity with a variety of allergens from other spring-flowering trees such as the alder, hazel and hornbeam (Dreborg and Foucard 1983; Merrett 1997). In the light of the results of the current analyses it will be necessary to amend pollen calendars and local predictive models for birch pollen seasons to incorporate the recent changes in the timing of the start. It will also be necessary to assess the implications of earlier seasons for allergy sufferers. More work is needed on other taxa to investigate responses in the pollen seasons to climate change, not only in the timing of the start of the seasons but also in their duration and severity.

Acknowledgements The authors would like to thank the following: Dr. A. G. Peeters and the Swiss Society of Aerobiology for pollen data for Zurich 1982–1993, Mike Savage, Department of Bacteriology, St. Mary's Hospital, Paddington, London, for pollen data until 1984, the Royal Meteorological Institute of Belgium and the many technicians and assistants who have helped with the pollen counting at the various sites.

References

- British Aerobiology Federation (1995) Airborne pollens and spores, a guide to trapping and counting. ISBN 0-9525617-0-0
- Cannell MGR, Pitcairn CER (1993) Impacts of the mild winters and hot summers in the United Kingdom in 1988–1990. Department of the Environment, HMSO London
- Cannell MGR, Smith RI (1986) Climatic warming, spring budburst and frost damage on trees. *J Appl Ecol* 23:177–191
- Dreborg S, Foucard T (1983) Allergy to apple, carrot and potato in children with birch pollen allergy. *Allergy* 38:167–172
- Emberlin J, Mullins J, Corden J, Millington W, Brooke M, Savage M, Jones S (1997) The trend to earlier birch pollen seasons in the UK. A biotic response to changes in weather conditions? *Grana* 36:29–33
- Erdtman G (1954) An introduction to pollen analysis. *Chronica Botanica*, Waltham, Mass
- Fitter AH, Fitter RSR, Harris ITB, Williamson MH (1995) Relationships between first flowering data and temperature in the flora of locality in Central England. *Funct Ecol* 9:55–60
- Hirst JM (1952) An automatic volumetric spore trap. *Ann Appl Biol* 39:257
- Hörak F, Jaeger S (1979) Die Erreger des Heufiebers. Urban & Schwarzenberg, Munich
- Margary ID (1926) The Marsham phenological record in Norfolk 1736–1925, and some others. *Q J R Meteorol Soc* 22:27–54
- Mann ME (2001) Climate during the last millennium. *Weather* 56:91–102
- Merrett TG (1997) Quantification of IgE both as total immunoglobulin and as allergen specific antibody, vol 2. In: Kay AB (ed) Allergy and allergic diseases. Blackwell Science, ISBN 0-86542-867-0, pp 1012–1037
- Mullenders W (1974) Aeropalynological research in Belgium. In Charpin JV, Surinyach R, Frankland AW (eds) Atlas of European allergenic pollens. Sandoz, Paris pp 95–102
- Murray MB, Cannell GR, Smith RI (1989) Date of budburst of fifteen tree species in Britain following climatic warming. *J Appl Ecol* 26:693–700
- Nilsson S, Persson (1981) Tree pollen spectra in the Stockholm region Sweden 1973–1980. *Grana* 20:179–182
- Sparks TH, Carey PD (1995) The responses of species to climate over two centuries: an analysis of the Marsham phenology record 1736–1947. *J Ecol* 83:321–329
- Spieksma F Th, Emberlin J, Hjemroos M, Jaeger S, Leuschener R (1995) Atmospheric birch (*Betula*) pollen in Europe: trends and fluctuations in annual quantities and the starting dates of seasons. *Grana* 34:51–57