Int J Biometeorol (2008) 52:667–674
DOI 10.1007/s00484-008-0159-2

ORIGINAL PAPER

# Climate change and its impact on birch pollen quantities and the start of the pollen season an example from Switzerland for the period 1969–2006

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Received: 17 December 2007 / Revised: 17 March 2008 / Accepted: 19 March 2008 / Published online: 15 May 2008


**Abstract** As published by the Intergovernmental Panel on Climate Change (IPCC) global warming is a reality and its impact is huge like the increase of extreme weather events, glacier recession, sea level rise and also effects on human health. Among them allergies to airborne pollen might increase or change in pattern due to the invasion of new allergic plants or due to different behavior of plants like earlier flowering. In this study we used the longest Swiss airborne pollen data set to examine the influence of the temperature increase on the time of flowering. In the case of Basel, where pollen data for 38 years are available, it was shown that due to a temperature increase the start of flowering in the case of birch occurred about 15 days earlier. Apart from a shift of the start of the flowering there is also a trend towards higher annual birch pollen quantities and an increase of the highest daily mean pollen concentrations. Due to global warming and because symptoms may appear earlier in the year people suffering from a pollen allergy might face a new unaccustomed situation.

**Keywords** Global warming · Temperature · Pollen allergy · Phenology

## Introduction

The planet's climate is constantly changing. The global average temperature is currently in the region of 15°C. Geological and other evidence suggests that, in the past, this average may have been as high as 27°C and as low as 7°C.

The greenhouse effect refers to the role played by gases which effectively trap energy from the Sun in the Earth's atmosphere. Without them, the planet would be too cold to sustain life as we know it. The most important of these gases in the natural greenhouse effect is water vapour, but its concentrations are changing little and it plays almost no role in recent human-induced greenhouse warming. Other greenhouse gases include carbon dioxide, methane and nitrous oxide, which are released by modern industry, agriculture and the burning of fossil fuels. Their concentration in the atmosphere is increasing - the concentration of carbon dioxide has risen by more than 30% since 1800. Temperature records go back to the late 19th Century and show that the global average temperature increased by about 0.6°C in the 20th Century IPCC (2001, 2007). Sea levels have risen 10–20 cm - thought to be caused mainly by the expansion of warming oceans. Most glaciers in the temperate regions of the world and along the Antarctic Peninsula are in retreat; and records show that the Arctic sea ice has thinned by 40% in recent decades in summer and autumn. If nothing is done to reduce emissions, current climate models predict a global temperature increase of 2–4.5°C by 2100 IPCC (2007). Even if greenhouse gas emissions are dramatically cut now, the effects would continue because parts of the climate system, particularly large bodies of water and ice, can take hundreds of years to respond to changes in temperature. It also takes decades for the greenhouse gases to break down.

Globally more extreme weather events are therefore expected, with heat waves getting hotter and more frequent. Additionally more flooding is expected from storms and rising sea levels. Climate change will also affect human health through multiple pathways, including direct effects and

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indirect effects that operate through changes in the range of disease vectors, water quality or air quality (increase of airborne pollen or new allergenic pollen in certain regions).

Since the beginning of systematic recordings in 1864 and until 2000 the annual mean temperature has increased in Northern Switzerland (Basel) by 1.5°C Begert et al. (2005). The past 15 years were among the warmest in the past 500 years and the four warmest years ever were all recorded after 1990 Casty et al. (2005).

Trees in cool and temperate regions are assumed to adapt to annual climatic variations that characterize these regions. To maximize growth, the trees extend the active growth period as long as possible. To achieve this, trees regulate the timing of bud burst and flowering during spring. Several theories and models have been presented to describe the phenological development of trees from the beginning of dormancy to bud burst. The importance of temperature for the tree's biological process has been proved Hänninen (1995); Häkkinen et al. (1998); Häkkinen (1999). 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 Emberlin et al. (2002). Therefore a change in the annual temperature has a direct effect on the tree physiology and hence on pollen release Rasmussen (2002); Spieksma et al. (2003); Clot (2004).

Generally, it has been observed for a long time now that allergies caused by different pollen increased dramatically during the last decades in all industrial societies Wüthrich (1989); D'Amato et al. (1991). The reason for the increase of allergies is caused by various factors, among them is also an increase or a change in airborne pollen distribution Frei (1998, 2000).

Against this background we investigated to what extent the global climatic developments have affected conditions on the local level. As an example we have examined a long time series of Birch pollen recorded at the meteorological station of Basel-Binningen. It covers the period from 1969 to 2006, a total of 38 years and is therefore well suited for this purpose. This investigation encompasses the trends in the pollen counts, the highest daily mean pollen concentrations and especially the start of the pollen season. Furthermore, a regression of the start of the pollen season (days from the beginning of the year) against temperature in the period from 1st February to 15th March was performed.

## Materials and methods

### Meteorological data

Meteorological data were collected at the meteorological station of Basel-Binningen, 316 m above sea level. The air temperature is measured 2 m above ground according to the recommendations of the World Meteorological Organisation. The data were homogenized as described in Begert et al. (2005).

Meteorological data for the overview of the climatological trend in Switzerland is comprised of the twelve climatological reference stations: Basel, Bern, Château d'Oex, Chaumont, Davos, Engelberg, Genf, Lugano, Säntis, Sils/Segl Maria, Sion and Zürich which represent all climatological regions and different orographical locations. For this survey the time series 1864–2006 were analyzed.

### Pollen data

Pollen data from Burkard Seven Day Recording Volumetric Pollen and Spore Trap Hirst (1952) with a sucking rate of 10 l minute$^{-1}$ were available for 38 years for Basel (1969–2006). The pollen trap in Basel is located at the Kantonsspital building, 260 m above sea level. The distance between the pollen trap and the meteorological station is about 3 kilometres.

In our investigations the start of the pollen season has been defined as the day when sum of the daily counts reaches 2.5% of the annual pollen count and the end of the pollen season when the sum of daily counts reaches 97.5% of the annual pollen count whereby the pollen season encompasses 95% of the pollen recorded in the whole year (Goldberg et al. 1988).

### Statistical and graphical analyses

The statistical analyses and graphics were performed with the software S-PLUS. In addition to the linear regressions a loess smoother with a bandwidth of 1/5 has been inserted into the long time temperature series. This locally weighted regression smoothing, in which weights are assigned using the tri-cube weight function, helps in identifying short-term fluctuations within the overall trend. When the graphics were prepared, a spline smoother and various kernel smoothers were also used tentatively, but they did not give better results than the loess curve for a visual examination of the time series.

## Results

### Data

Table 1 is a summary of all used meteorological and pollen data from the station Basel.

### Temperature time series

Figure 1 shows the overall trend in Switzerland of the annual mean temperature 1864–2006 based on 12 homo-

**Table 1** Summary of the meteorological and pollen data for Basel 1969–2006

| Year | Number of days until onset of the Birch pollen season | Highest daily mean count of Birch pollen | Annual Birch pollen count | Annual mean temperature | Annual temperature anomalies relative to the 1961–1990 mean (9.6°C) | Annual temperature anomalies relative to the 1931–1960 mean (9.4°C) |
|---|---|---|---|---|---|---|
| 1969 | 107 | 679 | 1293 | 9.0 | −0.6 | −0.4 |
| 1970 | 109 | 1679 | 6618 | 9.2 | −0.4 | −0.2 |
| 1971 | 101 | 1225 | 7274 | 9.3 | −0.3 | −0.1 |
| 1972 | 86 | 543 | 3498 | 8.9 | −0.7 | −0.5 |
| 1973 | 97 | 833 | 4306 | 9.2 | −0.4 | −0.2 |
| 1974 | 85 | 850 | 4628 | 10.0 | 0.4 | 0.6 |
| 1975 | 105 | 182 | 1414 | 9.7 | 0.1 | 0.3 |
| 1976 | 90 | 1640 | 12910 | 10.0 | 0.4 | 0.6 |
| 1977 | 76 | 650 | 3335 | 9.9 | 0.3 | 0.5 |
| 1978 | 97 | 265 | 1935 | 9.0 | −0.6 | −0.4 |
| 1979 | 100 | 591 | 3581 | 9.5 | −0.1 | 0.1 |
| 1980 | 97 | 1010 | 8268 | 8.9 | −0.7 | −0.5 |
| 1981 | 91 | 280 | 1670 | 9.6 | 0.0 | 0.2 |
| 1982 | 101 | 600 | 5705 | 10.3 | 0.7 | 0.9 |
| 1983 | 88 | 200 | 1150 | 10.3 | 0.7 | 0.9 |
| 1984 | 106 | 1800 | 9415 | 9.5 | −0.1 | 0.1 |
| 1985 | 95 | 355 | 3275 | 9.0 | −0.6 | −0.4 |
| 1986 | 108 | 1020 | 5340 | 9.4 | −0.2 | 0.0 |
| 1987 | 106 | 2110 | 10570 | 9.5 | −0.1 | 0.1 |
| 1988 | 102 | 885 | 3905 | 10.5 | 0.9 | 1.1 |
| 1989 | 87 | 1800 | 9320 | 10.6 | 1.0 | 1.2 |
| 1990 | 79 | 1345 | 6640 | 10.9 | 1.3 | 1.5 |
| 1991 | 84 | 1420 | 10740 | 10.0 | 0.4 | 0.6 |
| 1992 | 99 | 1150 | 6400 | 10.7 | 1.1 | 1.3 |
| 1993 | 91 | 860 | 8230 | 10.2 | 0.6 | 0.8 |
| 1994 | 76 | 1590 | 6888 | 11.5 | 1.9 | 2.1 |
| 1995 | 94 | 908 | 5282 | 10.5 | 0.9 | 1.1 |
| 1996 | 103 | 3040 | 14596 | 9.4 | −0.2 | 0.0 |
| 1997 | 76 | 1230 | 8602 | 10.6 | 1.0 | 1.2 |
| 1998 | 89 | 1640 | 5326 | 10.6 | 1.0 | 1.2 |
| 1999 | 93 | 2906 | 11070 | 10.7 | 1.1 | 1.3 |
| 2000 | 91 | 456 | 4432 | 11.4 | 1.8 | 2.0 |
| 2001 | 86 | 1048 | 7702 | 10.6 | 1.0 | 1.2 |
| 2002 | 78 | 516 | 5942 | 11.2 | 1.6 | 1.8 |
| 2003 | 85 | 1056 | 4664 | 11.4 | 1.8 | 2.0 |
| 2004 | 77 | 1516 | 8104 | 10.6 | 1.0 | 1.2 |
| 2005 | 89 | 754 | 4634 | 10.4 | 0.8 | 1.0 |
| 2006 | 102 | 880 | 6170 | 10.9 | 1.3 | 1.5 |

geneous data sets and also the trend of the temperature in Basel in the same period.

The temperature level of the two time series is different, but their pattern is nearly identical. The upward trend is very clear. This is already well known, but in order to highlight the short-term trends during this period a loess curve has been added. We performed the nonparametric Mann-Kendall test for trend and obtained a slope of 1.1°C/100 years for Switzerland and a slope of 1.3°C/100 years for Basel (p-value in both cases $<0.001$).

The Mann-Kendall test for trend has also been applied to the temperature of the period 1969–2006 corresponding to the pollen time series of Basel. The slope obtained for this period is 0.49°C/10 years in the case of Switzerland and 0.51°C/10 years in the case of Basel (p-value in both cases $<0.001$).

The slopes have also been calculated by performing a linear regression and the results were practically the same. The reason for this near-identicalness lies in the fact that these data sets closely approximate the normal distribution.

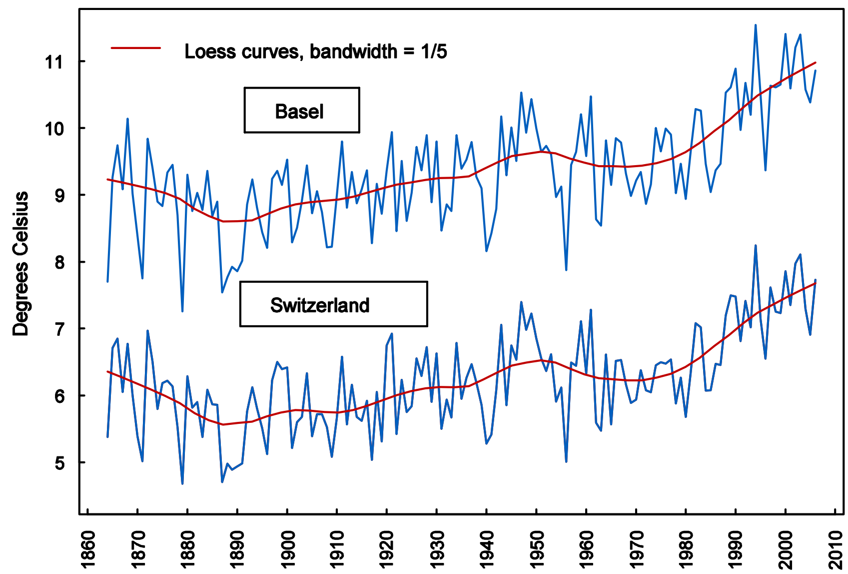


**Fig. 1** Annual mean temperature 1864–2006. Basel and Switzerland (average of 12 meteorlogical stations)

Additionally the temperature anomalies in Basel relative to the mean 1961–1990 are shown in Fig. 2. This graph may serve for comparisons with similar graphs of other countries or regions. Table 1 also includes the anomalies relative to the mean 1931–1960 so that a direct comparison with the anomalies relative to the mean 1961–1990 can be made.

## Annual counts of Birch pollen in Basel

Figure 3 shows the total annual counts and the highest daily mean count of the Birch pollen. The quantities fluctuate strongly which is a result not only of changes in the pollen release but and foremost, of the weather influences. As a consequence, the pollen quantity in the air does not always correlate with the flowering and the subsequent pollen release. Moreover, part of the pollen may stay in the air for more than one day. Depending on the weather during the flowering period this can have the effect that the annual pollen counts diverge considerably from the effective pollen release.

Linear regression lines have been added to the graph. They show that there is a slight upward trend over the whole period of 38 years. We applied the nonparametric Mann-Kendall test for trend to this time series and obtained the following results: tau 0.22, slope 97.76, intercept 3967.2 and p-value 0.056. Therefore, the trend towards higher pollen counts is at the limit of statistical significance.

Furthermore, we also applied the sequential Mann-Kendall test for time series (progressive analysis by means

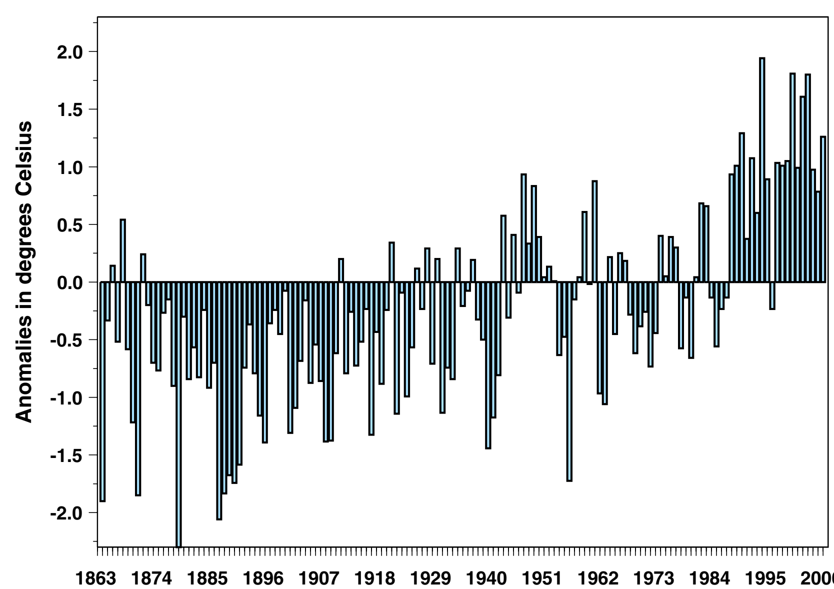


**Fig. 2** Annual mean temperature anomalies in Basel 1864–2006 relative to the mean 1961–1990

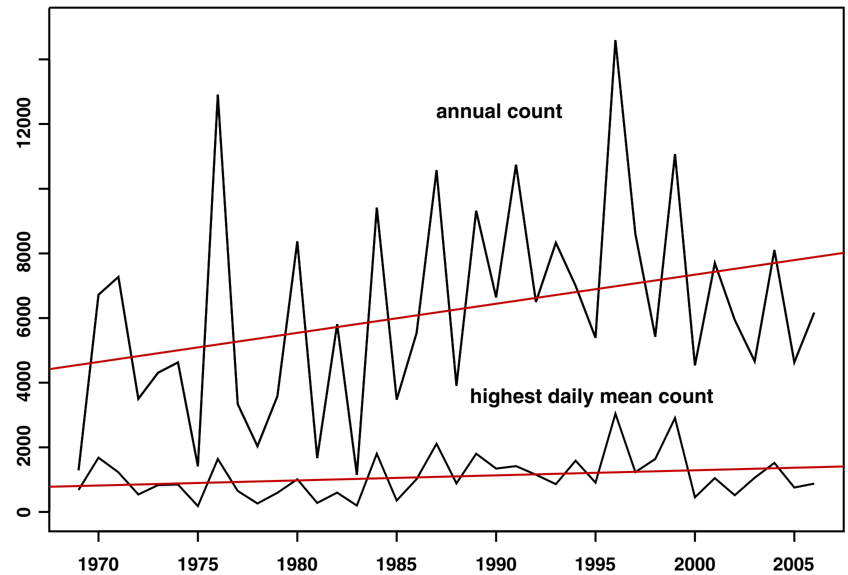


**Fig. 3** Birch pollen: annual count and highest daily mean count Basel, 1969–2006

of the statistic u(t)) Sneyers (1990) and we found that the lines of the progressive and the retrograde series of the normalized tau cross at two points (years 1982 and 1991) thus indicating approximate potential turning points. One of the lines (the progressive one) exceeds the confidence limit at the level 1.96 but only after the crossing points and at the end it is slightly below the confidence limit. Therefore, we have to assume that the trend turning points are not significant, whereas the overall trend has still to be corroborated by future analyses when additional years will be available.

## Highest daily mean Birch pollen count in Basel

As can be seen from Fig. 3 the pattern of the highest daily mean pollen count in each year is similar to the pattern of the total annual pollen count. This similarity was to be expected but maybe not to such an extent. From the perspective of a person who is allergic to birch pollen the strong variation of the maxima from one year to the other and also the high levels attained in 1996 and 1999 are certainly of particular interest.

The Mann-Kendall test for trend on the other hand is not really conclusive because the p-value of this test is 0.18. The other results are: tau 0.17, slope 12.4 and intercept 717.8.

## Earlier start of the pollen season

Figure 4, a scatter plot of the start of the birch pollen season against the years, shows a trend towards earlier season starts. There are high fluctuations from one year to the other

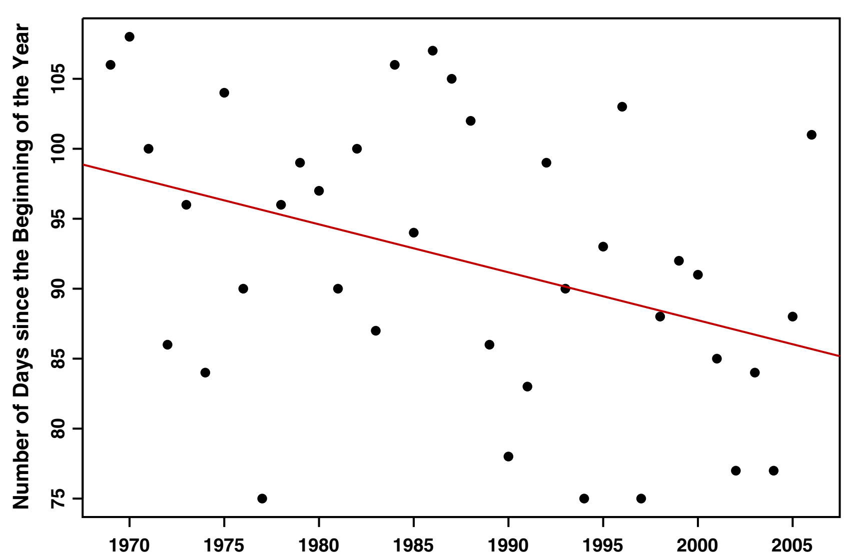


**Fig. 4** Start of the birch pollen season in days since the beginning of the year Basel, 1969–2006

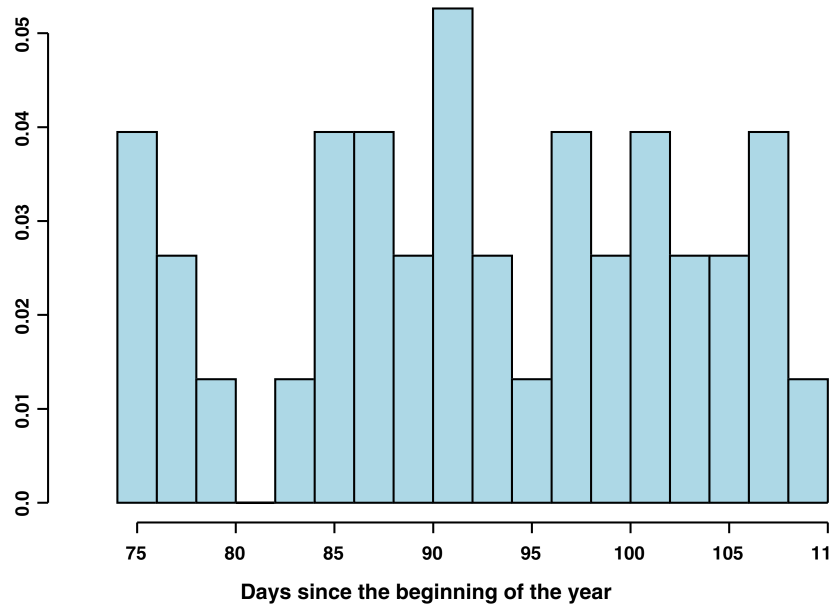


**Fig. 5** Histograms of the start of the birch pollen season (relative frequency) Basel, 1969–2006

but the trend is nevertheless clear enough. We applied the nonparametric Mann-Kendall test for trend and obtained the following results: tau −0.260, slope −0.4, intercept 99.3, p-value 0.022. According to these results the shift towards an earlier pollen season in the period 1969–2006 (38 years) is about 15 days. We have also analyzed the season starts of a number of other pollen types and of several recording stations. In nearly all the cases there is a clear trend towards an earlier onset of the pollen season.

As expected, a linear regression of the season start data against time gives similar but not identical results: correlation −0.38, slope 0.34, intercept 98.71, p-value 0.018. According to the Kolmogorov-Smirnov Goodness-of-Fit test the data are normally distributed (2-tailed asymptotic significance 0.845) but the variance is relatively large. This is the main reason why the results are noticeably different. As has already been mentioned, there is hardly any difference regarding the trend between these two methods when the long temperature time series are analyzed (same slopes). The histogram of the days since the beginning of the year until the start of the Birch pollen season (Fig. 5) gives an idea how the data are distributed. The earliest onset of the pollen season occurred 75 days

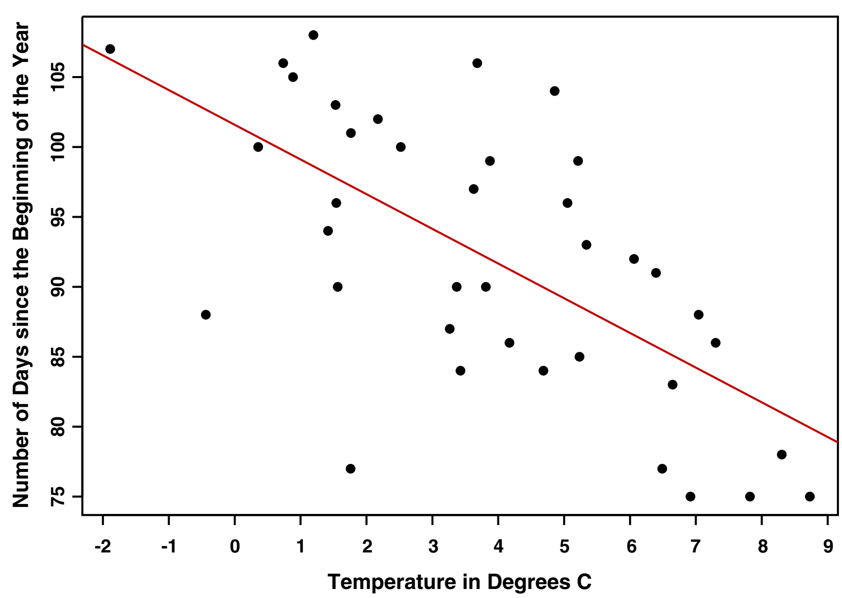


**Fig. 6** Mean temperature Febr 16–March 15 and start of the birch pollen season Basel, 1969–2006

**Table 2** Regression of season start against mean temperature, Basel-Binningen, 1969–2006

| Parameter | | Value | | | |
|---|---|---|---|---|---|
| Independent variable (predictor) | | Temperature, Basel-Binninge,n from 16 February to 15 March | | | |
| Dependent variable (outcome) | | Start of the Birch pollen season, Basel-Binningen | | | |
| *R* (correlation coefficient) | | 0.647 | | | |
| *R*-square (coefficient of determination) | | 0.419 | | | |
| Adjusted *R*-square | | 0.403 | | | |
| Standard error of estimate | | 7.715 | | | |
| Coefficients | Unstandardized coefficients | | Standardized coefficient | | |
| | B | SE | Beta | *t* statistics | *p* value |
| Constant (intercept) | 101.582 | 2.254 | | 45.060 | <0.001 |
| Annual mean of temperature (slope) | −2.480 | 0.487 | −0.647 | −5.096 | <0.001 |

after the beginning of the year, the latest 108 days after the beginning of the year (mean 92 days).

As the annual mean temperature during this period was steadily increasing we also performed various regressions in order to see how the annual temperature correlates with the season start of the birch pollen. For this purpose we used different temperature means and combinations thereof as the independent variable. As was to be expected the best results were obtained when the predictor was a relatively short temperature period quite near the onset of the pollen season. Based on these tests we have chosen the temperature period from 16th February to 15th March (Fig. 6).

Table 2 show the results of a regression of the season start against the mean temperature of the above-mentioned period. As can be seen from the p-value the regression is highly significant. The correlation coefficient is 0.65 and the adjusted R-square is 0.403. That means that 40.3% of the variability of the season start is explained by the temperature of the period mentioned above. The regression coefficient of −2.48 for the slope means that an increase of 1 degree of the temperature approximately results in a shift of the season to an earlier date by about 2.5 days.

The fact that the investigations focus on a single location in Switzerland could give reason to doubt that the conclusions also reflect changes that have generally occurred in other geographic regions in Switzerland. We have, therefore, also performed regressions for the Birch pollen time series on Zurich which is shorter (1982–2006). The results were similar and thus confirmed the validity of the developments and trends observed in Basel.

## Discussion

This study is based on data from the longest pollen data series in Switzerland (Basel 1969–2006) which is also one of the longest in Europe Emberlin et al. (2002); Spieksma et al. (1995). The study is unique in Switzerland since a pollen time series of 38 years could be analysed. The investigation showed clearly that the shift towards an earlier flowering of birch is directly linked to an increase of the temperature. The shift is especially pronounced since the late Seventies which is in accordance with the temperature increase of this period.

The global average surface temperature has increased over the 20th century by about 0.6° + /− 0.2°C and is projected to continue to rise at a rapid rate. However, the record shows a great deal of variability: Most of the warming has occurred during two periods (1910–1945 and 1976–2000) which is also the case for Switzerland (Fig. 1) and it is very likely that the 1990s were the warmest decade IPCC (2007).

Several studies have shown evidence of ecological impacts of this climate change Dose and Menzel (2004) like shifts in plant and animal phenology for the boreal and temperate zones of the northern hemisphere Menzel and Fabian (1999). Phenology like the described flowering of the birches is perhaps the simplest bio-indicator to track climate changes Ahas et al. (2002). Springtime phases like those of the birch flowering are particularly sensitive to temperature (Fig. 6, Table 2).

The annual total amount of birch pollen appears to have increased over the years. According to the Mann-Kendall test for trend the pollen count in Basel increased on average by 97.8 each year in the last 38 years.

Taken the findings of Bättig et al. (2007) temperature increase and extreme events in the time period of 2071–2100 will be even strengthened and the impact of the birch pollen season enhanced. Apart from a shift in flowering there is also a trend towards an increase of the annual total amount of birch pollen and an increasing trend in the extreme events as regards the highest daily mean pollen concentrations (Fig. 3).

As a result of the global warming people suffering from hay fever (pollen allergy) may have symptoms at an earlier time as in the past and the symptoms might also get more severe because of higher pollen quantities. It will, therefore, be important to assess the implications for birch allergy sufferers of earlier seasons and higher pollen quantities.

**Acknowledgement** We would like to thank Dr. Ruth Leuschner for making available the Basel pollen data.

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