



The effects of climate change on the birch pollen season in Denmark

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Abstract

During the last two decades the climate in Denmark has become warmer and in climate scenarios (IPCC, 2001) it is foreseen that the temperature will increase in the coming decades. This predicted future increase in temperature will probably affect both the flowering of plants and the dispersion of pollen in the air. In this study the already observed effects on the birch pollen season are studied. Trend analyses of the birch pollen season for two stations in Denmark more than 200 km apart give similar results. In Copenhagen there is a marked shift to an earlier season – it starts about 14 days earlier in year 2000 than in 1977, the peak-date is 17 days earlier and the season-end is 9 days earlier. For Viborg the trend to an earlier season is in general the same, but slightly smaller. During the same period there has also been a distinct rise in the annual-total amount of birch pollen, peak-values and days with concentrations above zero. Rising mean temperatures during winter and spring can explain the calculated trends toward earlier pollen season. Models for estimation of the starting date based on Growing Degree Hours (GDH's) give very fine results with a correlation coefficient around 0.90 and rms error around 4.2 days. For annual-total there is a significant positive correlation with the mean temperature in the growing season the previous year.

1. Introduction

In 1977 continuous monitoring of airborne pollen was started in Denmark. Today routine monitoring of pollen is performed at two locations in Denmark; Copenhagen in Zealand and Viborg in Jutland. The results of the daily pollen monitoring have been reported to the public from 1979 for alder (*Alnus*), hazel (*Corylus*), elm (*Ulmus*), birch (*Betula*), grass (Poaceae) and mugwort (*Artemisia*). These pollen types are considered to be of the greatest allergological importance in Denmark (Dirksen and Østerballe, 1980). Since 1981 forecasts of the predicted concentrations of pollen in the air the following day have been performed for birch, grass and mugwort.

During the last two decades the climate in Denmark has become warmer, and in climate scenarios (IPCC, 2001) it is foreseen that the temperature will increase further in the coming decades. This

predicted future increase in temperature will probably affect both the flowering of plants and the dispersion of pollen in the air. In this study the already observed effects on the birch pollen season are studied, especially with focus on the start of season and the size of season, as an accurate prediction of these is most important for the medication of allergic patients. Birch pollen is known to be a major cause of pollen allergy in Denmark and pre-dominates the pollen registrations in the spring.

The prevalence of pollen allergy in Denmark seems to be an increasing problem. Thus one study showed an increase from 6.5% in 1987 to 10.3% in 1997 (Keiding, 1997), while another study showed an 50% increase in prevalence from 1989 to 1997 (Linneberg et al., 1999). A definite explanation of the observed increase was not given, but increasing awareness of symptoms may partly explain the increase. The increase in prevalence has also been observed in other

European countries, and several hypothesis have been discussed such as the role of air pollution and the so-called unhealthy 'western lifestyle' (D'Amato et al., 1991; Novak et al., 1998; Von Mutius et al., 1998).

Another obvious reason for the increase in the prevalence could be an increasing amount of pollen. Increasing trends in annual sums of birch pollen have been reported for other countries (eg. Emberlin et al., 1993; Spieksma et al., 1995; Jäger et al., 1996; Frei, 1998; Frei and Leuschner, 2000). But in general the observed trends were relatively small and insignificant except for Switzerland (Frei, 1998), where the observations showed a yearly increase of nearly 4% of birch pollen and also increases for other pollen types. He concluded that this increase probably together with the 'western style of life' was critical for the increasing prevalence of pollen allergy.

Concerning the starting date there are several studies on this issue (Hocevar and Segula-Ilic, 1990; Andersen, 1991; Frenguelli et al., 1992; Spieksma et al., 1995; Jäger et al., 1996; Emberlin et al., 1997; Hallsdóttir, 1998). In general the analyses show a clear correlation with the temperature in the pre-season and the starting date of the season. Thus Spieksma et al. (1995) for several stations found a high correlation between the starting date and the mean temperature of the forty days preceding the mean starting date (e.g. $r = -0.84$ for Vienna, $r = -0.72$ for Stockholm). Hallsdóttir (1998) found an even better correlation using an accumulated thermal sum up to 15 May, just prior to the earliest start of the birch pollen season in Reykjavík. Hocevar and Segula-Ilic (1990) also found that global radiation could improve the result for some stations, while precipitation and wind velocity did not significantly improve the results.

Unfortunately the definition of the starting date of the pollen season is not obvious, and it has been defined in several different ways e.g.: 'the sum-75 method' stating that the season starts when the accumulated daily sum reaches 75, 'the date when the accumulated sum reaches 2.5% of the annual total' (Emberlin, 1997); 'the first day with a pollen amount exceeding 1% of annual total, providing this was not followed by more than six consecutive days with zero values' (Jäger et al., 1996), 'the first day when the sum reaches 1% of the logarithmic mean of annual total' (Spieksma et al., 1995). The different definitions have different advantages and drawbacks, e.g. the '2.5% of annual total' means that the determination of starting date only is possible after the season, while using a

fixed threshold value may imply that the season does not start at all in small seasons.

Frei (1998) instead used the peak-date in his study of the relation between temperature and the flowering. He found a high significant correlation ($r = -0.85$, $p < 0.05$) between mean temperature of February-March and peak-date of birch pollen.

2. Material and methods

Pollen sampling is performed with Burkard Traps in Copenhagen, Zealand, at the Danish Meteorological Institute (55°43' N, 12°34' E) and in Viborg, Jutland, at Viborg-Kjellerup Hospital (56°27' N, 9°24' E). The traps are placed 15 and 21 meters above ground level, respectively. The distance between the two stations is about 220 km.

Meteorological data used for Copenhagen are taken from the synoptic stations at Værløse (55°46' N, 12°19' E), Kastrup Airport (55°39' N, 12°40' E) and Tune (55°35' N, 12°08' E). Data have been quality controlled and in this study mean data for the three stations have been used. The distances from the synoptic stations to the pollen station in Copenhagen are 15 km, 12 km and 28 km respectively.

Standard methods are used for the counting of pollen (Käpylä and Penttinen, 1981). Pollen grains are counted in 12 transverse stripes at a magnification of $\times 640$ and pollen are identified to generic genus.

The birch pollen data used in this study cover 24 years (1977–2000) for Copenhagen and 21 years (1980–2000) for Viborg. The start-date of the season is here defined as the date of which the accumulated sum reaches 2.5% of the total yearly number. The peak-date is defined as the date with highest daily concentration (peak-value) and the duration of season is here defined as number of days with accumulated counts between 2.5% and 97.5%.

The daily pollen data are averaged over five days, and for the main trend analysis an overlapping mean of five years has been used. Trends are examined at significance levels of $p < 0.001$ (***), $p < 0.01$ (**) and $p < 0.1$ (*). For the statistical analysis the Numerical Algorithm Group (NAG) library is used.

3. Results

3.1 *Trend analysis of the birch season*

Trend analyses of start-date, peak-date, annual-total, and peak-value of the birch pollen season in Copenhagen and Viborg are shown in Figures 1a–d. Data have been smoothed over five years.

For the start-date, Figure 1a, the trend analysis for the two stations are quite similar. In Copenhagen the yearly trend is -0.62 days per year and is significant ($p < 0.01$), while the trend for Viborg is smaller, -0.52 days per year, and statistically less significant ($p < 0.1$). During the 20-year period from 1979 to 1998 the start of the birch pollen season in Copenhagen has become earlier by about 12 days, cf. Table 1, from about 29 April in 1979 to about 17 April in 1998. In Viborg the change is about 10 days from 29 April to about 19 April.

For the peak-date, Figure 1b, the significance is quite clear ($p < 0.001$) for both stations. The trend lines are also nearly identical for the stations showing a shift in Copenhagen to a 14 days earlier season, from about 10 May in 1979 to 26 April in 1998. For Viborg the trend is slightly smaller and the change is from about 9 May to 27 April. Comparing the annual values of the start-date and peak-date, Figure 1a–b, there is a marked difference around 1990. For the start-date both stations have a distinct minimum, while for the peak-date there is no minimum for Copenhagen, and Viborg has a small minimum around 1988. The difference is caused by a decisive change in weather during the season 1990. This year the weather during the winter and early spring was extraordinarily mild, and the season started already in the beginning of April with maximum temperatures around 15°C and pollen concentrations of about 400 pollen per m^3 on 4 April. But a passing cold front gave a drop of 8°C in the temperatures and temporarily low pollen concentrations. More than two weeks later the weather again became warmer and the pollen concentrations increased rapidly reaching a peak-value of about 500 pollen per m^3 on the 23 April.

For the annual-total, Figure 1c, there is a large positive and statistically significant trend in Copenhagen increasing the annual amount with more than 230% during the 20-year period. The calculated mean season in Copenhagen increased from 2075 in 1979 to about 6910 in 1998. The yearly trend is about 254, which is smaller than the calculated trend of about 300 pollen/year for the shorter period, 1977–

1996 (Hodal and Rasmussen, 1997). In Viborg the increase is about 200% during the 20-year period increasing the calculated annual total from 1385 to about 4155.

The annual total is in general considerably larger for Copenhagen than for Viborg and on average about 60% more birch pollen are recorded in Copenhagen. Such large differences between Danish stations have been observed in earlier studies. Comparisons between Copenhagen and Odense ($55^{\circ}23' \text{N}$, $10^{\circ}22' \text{E}$) for the period 1982–1990 showed that 90% more birch pollen were recorded in Odense (Rasmussen, 1990).

For the daily peak-values a significant and large positive trend is observed in Copenhagen, with a calculated change of more than 500% from 1979 to 1998. In Viborg the calculated change is much smaller, 113%, and the trend is less significant ($p < 0.1$).

The large increase in the size of the birch pollen season can be one explanation of the observed large increase in allergy to pollen in Denmark (Keiding, 1997; Linneberg et al., 1999).

In Table 1 statistical data are also shown for the duration of the season, the number of days with birch pollen concentrations larger than zero, between 30–100 and above 100. All of them show increasing and generally statistically significant trends.

For all results presented above, the data have been smoothed over five years, but in general the results based on the raw unsmoothed data are similar. Figure 2 shows the trends of different percentiles of accumulated daily number (1%, 2.5%, 5%; 50%, 95%, 97.5% and 99%) of the birch pollen season in Copenhagen. The three first percentiles can be used to define the start of season, cf. the introduction on different definitions of start-date, and the three last parameters to define the end of season.

It is seen that the mean trend of the start-dates is around -0.68 days per year, and there is no essential difference in the trends whether we choose 1%, 2.5% or 5%. Except for 1981 and 1988 the spread in the different start-dates is small, and in mean the difference is only 4.5 days between the 1% and 5% percentiles. For the end-dates the mean trend is about -0.56 days per year. The spread is larger than for the start-dates with a mean difference of 10.6 days between the 95% and 99% percentiles. The largest trend, -0.81 , is observed for the 50% percentile, implying a shift of about 18.5 days from 1977 to year 2000.

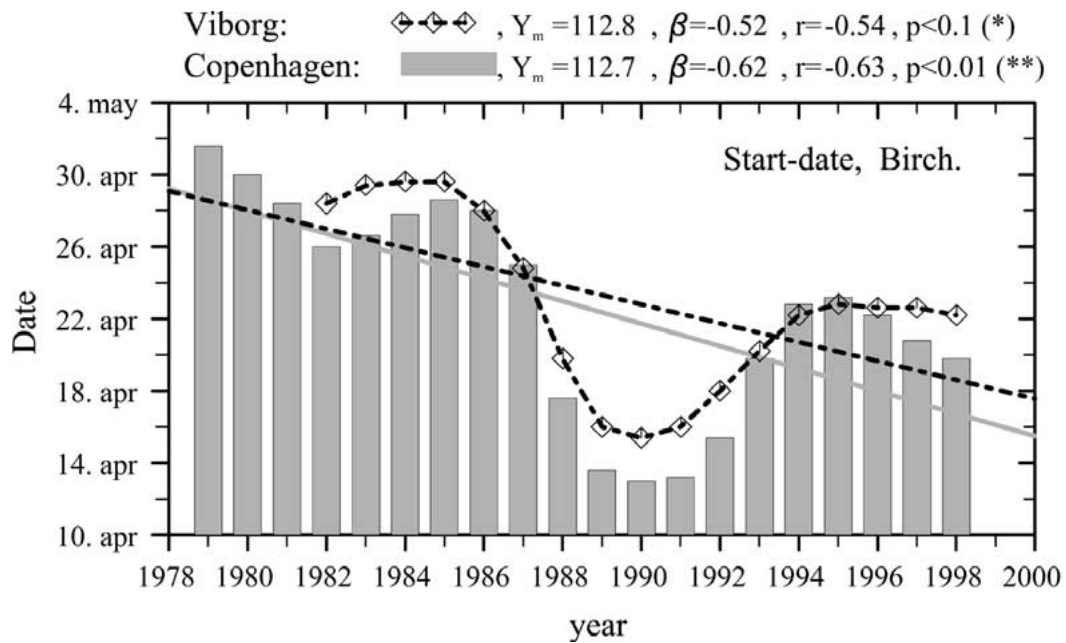


Figure 1a. Start-dates and calculated trends of the birch pollen season for Copenhagen (1977–2000) and Viborg (1980–2000). Data have been averaged over five years. Y_m is the mean value (day number), β is the annual trend (in days), r is the correlation coefficient and p is the significance of the trend.

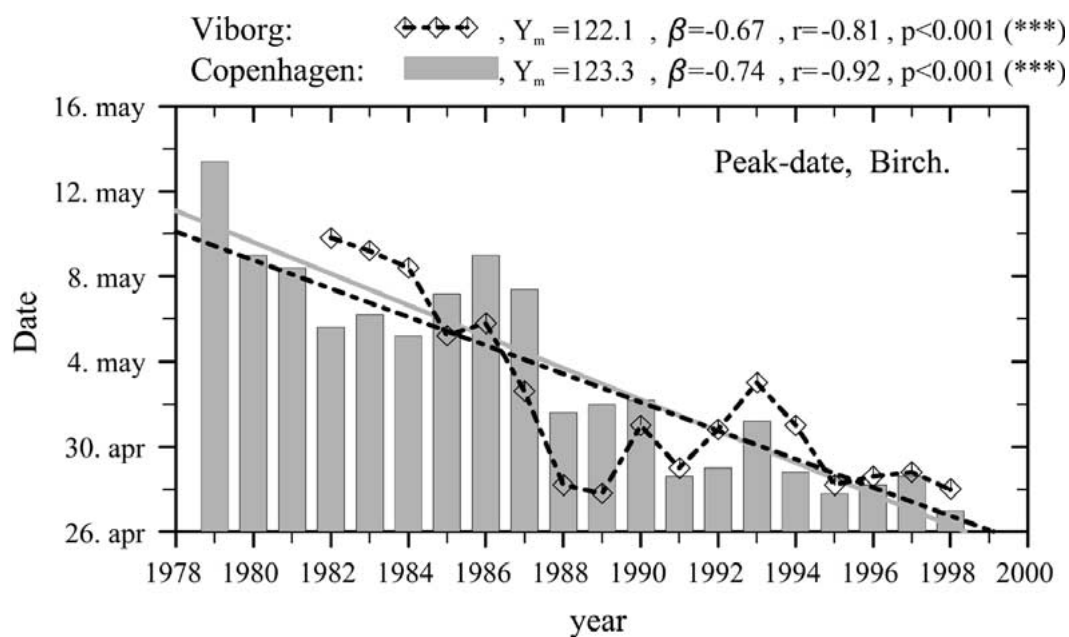


Figure 1b. As Figure 1a, but for peak-dates.

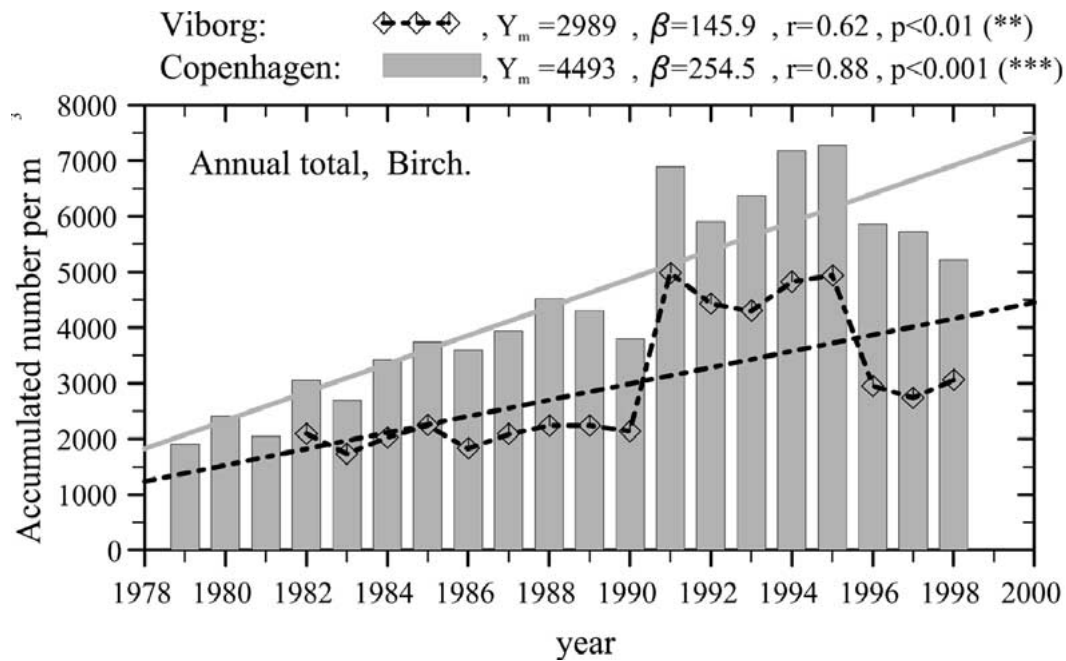


Figure 1c. As Figure 1a, but for annual-totals.

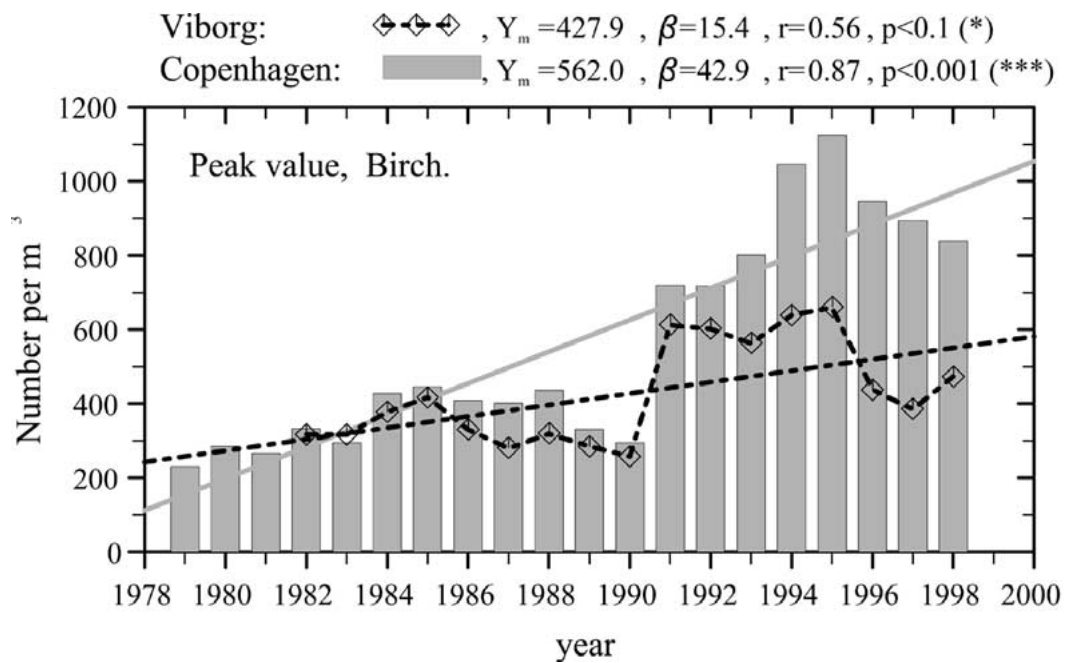


Figure 1d. As Figure 1a, but for peak-values.

Table 1a. Statistical data for the birch pollen season in Copenhagen, cf. Figure 1a–d.

Parameter	Mean	Trend (year)	Correlation coefficient	Change (1979–1998)	Change in % (1979–1998)	Significance of trend
Start-date	23. April	−0,62	−0,63	−11,8		$p < 0.01$
Peak-date	03. May	−0,74	−0,92	−14,1		$p < 0.001$
End-date	20. May	−0,39	−0,74	−7,4		$p < 0.001$
Duration	28,7	0,23	0,36	4,4	16,5	n.s.
Total	4.493,4	254,48	0,88	4.835,1	232,9	$p < 0.001$
Peak-value	562,0	42,86	0,87	814,3	526,1	$p < 0.001$
Days >0	56,9	1,43	0,82	27,2	62,8	$p < 0.001$
Days 30–100	9,0	0,19	0,60	3,6	50,5	$p < 0.01$
Days > 100	11,4	0,32	0,75	6,1	73,0	$p < 0.001$

Table 1b. Statistical data for the birch pollen season in Viborg, cf. Figure 1a–d.

Parameter	Mean	Trend (year)	Correlation coefficient	Change (1979–1998)	Change in % (1979–1998)	Significance of trend
Start-date	23. April	−0,52	−0,54	−9,9		$p < 0.1$
Peak-date	02. May	−0,67	−0,81	−12,7		$p < 0.001$
End-date	19. May	0,09	0,21	1,7		n.s.
Duration	28,3	0,61	0,70	11,6	53,7	$p < 0.01$
Total	2.989,4	145,85	0,62	2.771,2	200,1	$p < 0.01$
Peak-value	427,9	15,37	0,56	292,0	112,8	$p < 0.1$
Days >0	51,4	1,77	0,84	33,6	105,3	$p < 0.001$
Days 30–100	8,5	0,29	0,83	5,5	103,0	$p < 0.001$
Days > 100	7,0	0,19	0,70	3,6	73,7	$p < 0.01$

For all percentiles there is a minimum around 1990 and generally a maximum for 1985 caused by mild respectively cold weather during winter and early spring. In 1997 the end of season is relatively late probably caused by long range pollen transport from Mid-Scandinavia (Hjelmroos, 1991; Wallin et al., 1991; Hodal and Rasmussen, 1998).

3.2 Trend analysis of the temperature

The birch pollen season is influenced by meteorological parameters such as temperature, precipitation, cloud cover, wind velocity and humidity. Analyses of the correlation between these different meteorological parameters and the birch pollen season show that especially the temperature is important, cf. the introduction.

Figure 3a shows the calculated trend of quarterly and yearly mean temperatures in Copenhagen. The calculated trends are generally small and not statistically significant, except for the first quarter with a

yearly trend of 0.13 °C and a low significance ($p < 0.1$).

Figure 3b shows the total calculated change in monthly mean temperatures in Copenhagen from 1977 to 2000. There is a large increase for the months January to April with the largest change, +4.60 °C, for February. For the other months the changes are relatively small and of different sign.

The marked rise in temperature for winter and spring explains the marked shift to an earlier birch pollen season. This can be seen clearly from Figure 4 showing the relation between starting date and the mean temperature for February–March with a significant negative correlation, $r = -0.74$.

3.3 Growing Degree Hour (GDH) and start of season

Several models have been developed for the prediction of the start of season mainly based on the accumulation of mean temperature for a selected period in the pre-season, cf. the introduction and Figure 4.

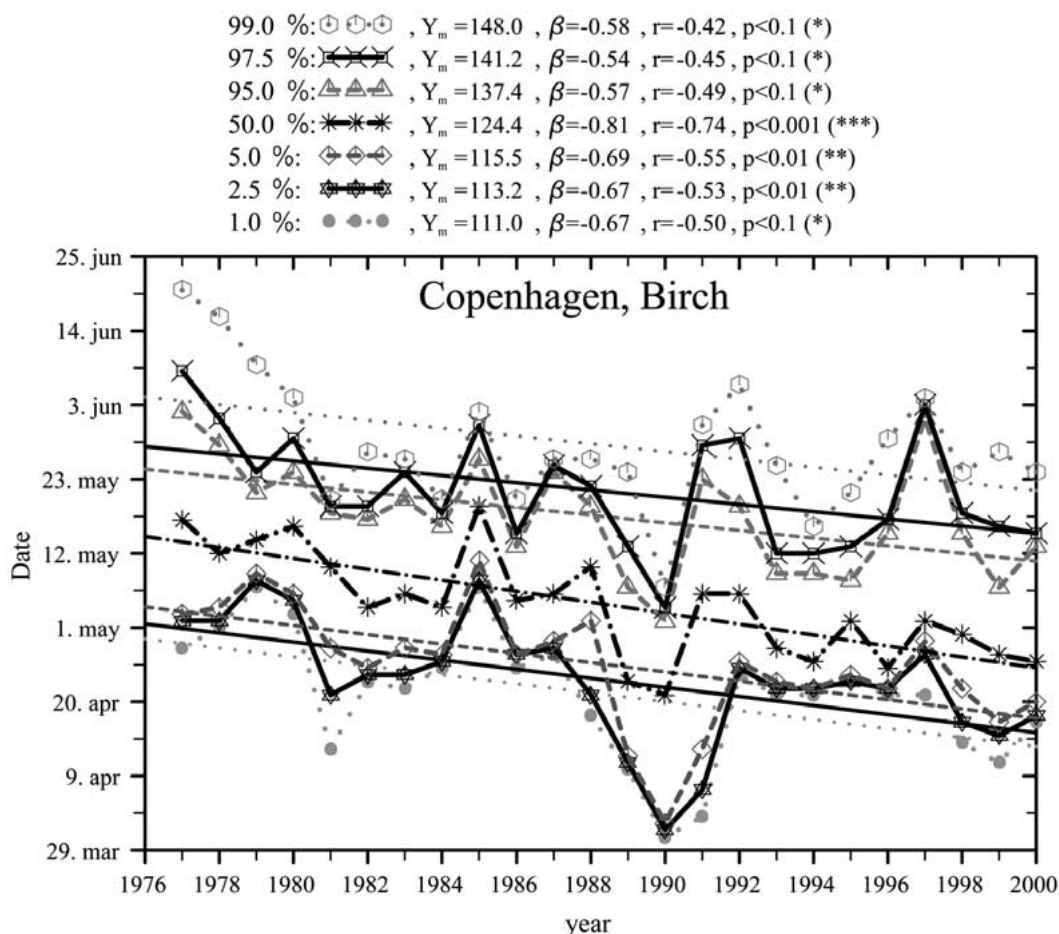


Figure 2. Trends of different percentiles of accumulated daily number for the birch pollen season in Copenhagen, 1977–2000. For symbols see Figure 1a.

Other models are based on the accumulation of Growing Degree Hours (GDHs) (e.g. Andersen 1991; Frenguelli et al. 1992). The hypothesis, or experience, is that the trees after having achieved a certain number of GDHs starts to pollinate – the pollen season is beginning. The problem is to find the optimal initial date for the accumulation and to relate meteorological and astronomical parameters to the GDHs.

Concerning the initial date it is common to use a fixed date for starting the accumulation (often 1 January), while other more complicated models (Andersen, 1991; Frenguelli et al., 1992) start the accumulation after a dormancy period. We will here use the simple method with a fixed date.

There are several definitions of GDH. The most simple one just accumulates the number of hours the temperature exceeds a threshold value or base temperature. Other models accumulate the difference

between the actual temperature and threshold/base temperature (i.e. $GDH = \sum(T - T_0)$ for $T > T_0$, and T_0 is the base temperature). This method, which will be used here, implies a close relation between temperature and GDH, and for low base temperatures a direct relation between temperature and GDH exists. The models, however, can be refined/complicated by optimal temperature functions and by including e.g. the length of day, hours of sunshine and stress-factors (e.g. drought).

In Figure 5a the optimal values of GDH's for the birch pollen season in Copenhagen are shown for different initial dates and different base temperatures. Optimal values are e.g. about 7.700 for a model with initial date 1 January ("0101") and base temperature 0 °C, and 3.000 for a model with initial date 1 April ("0401") and base temperature 0 °C. For higher base temperatures the optimal GDH values

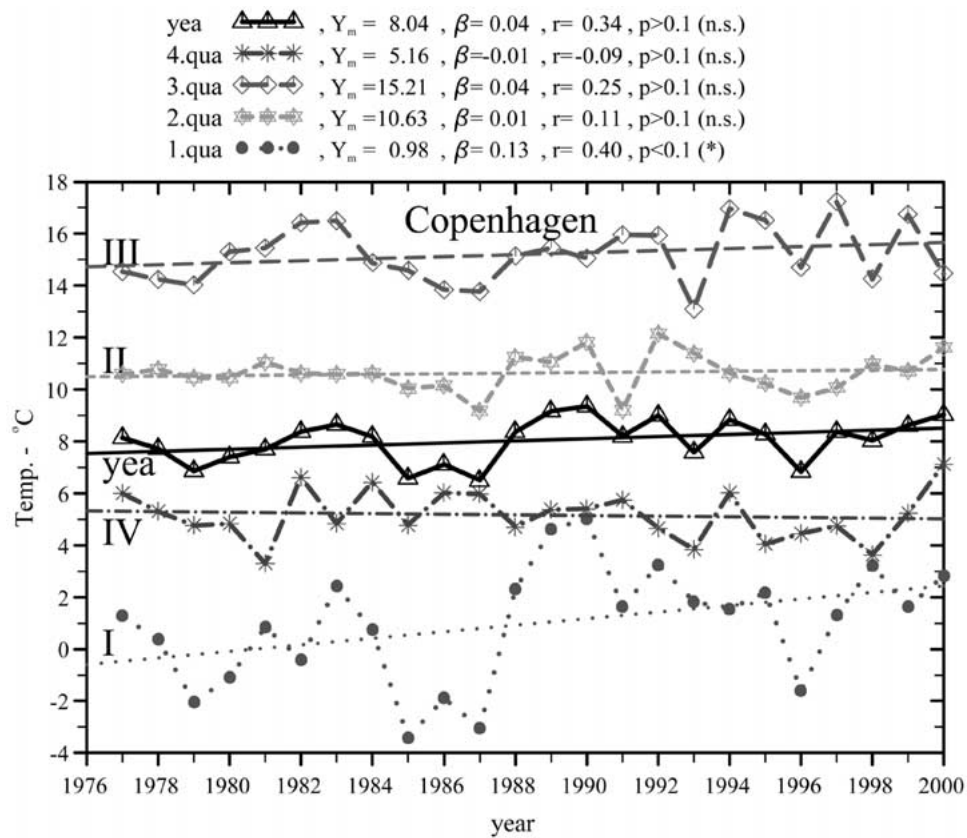


Figure 3a. Trends of the quarterly and yearly mean temperatures for Copenhagen, 1977–2000. For symbols see Figure 1a.

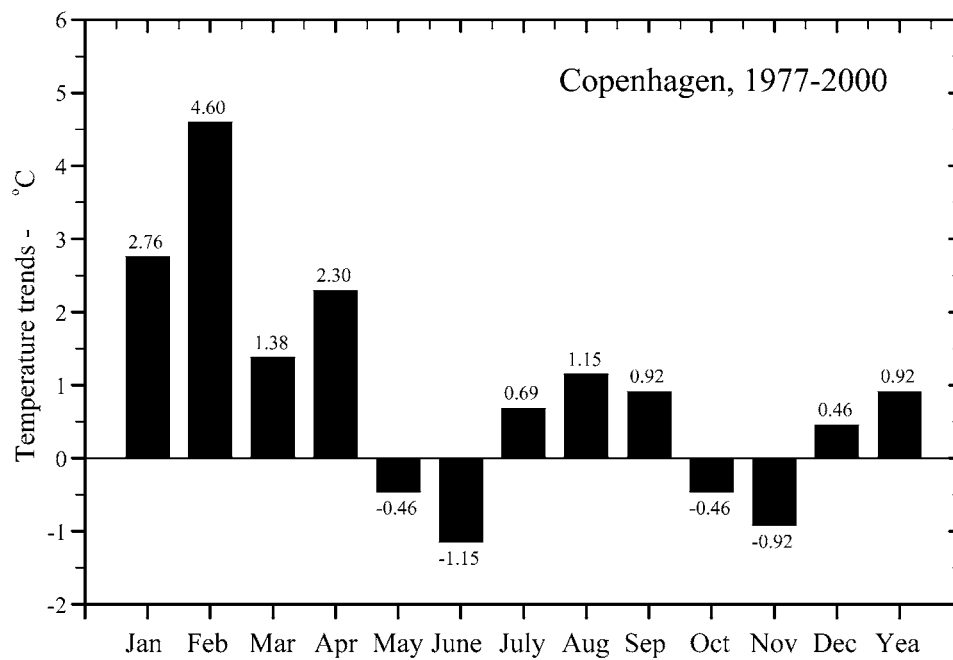


Figure 3b. Total trends of mean monthly temperatures for Copenhagen, 1977–2000.

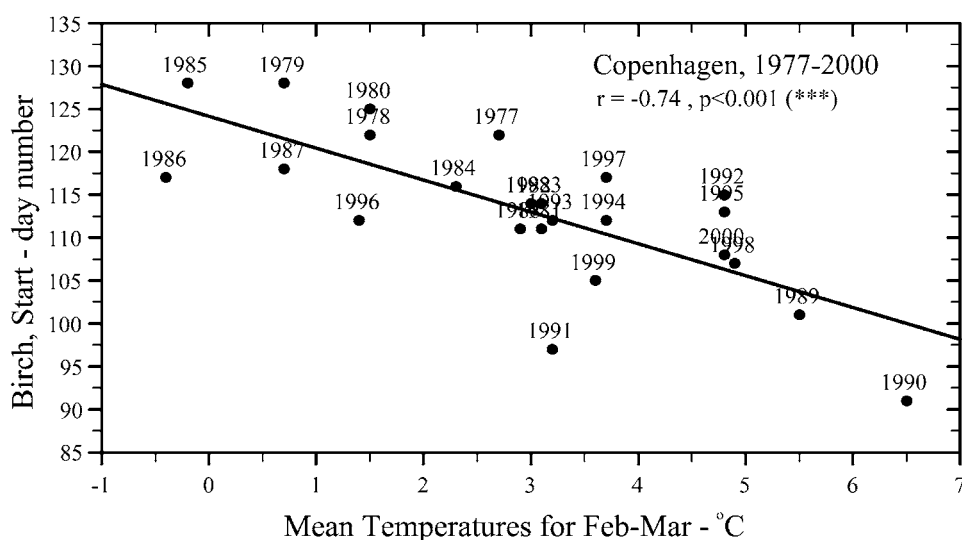


Figure 4. Correlation between mean temperatures for February–March and the start-date of the Birch pollen season in Copenhagen, 1977–2000.

for the different initial dates converge. The optimal values are determined by a least square fit of data from 1977–2000.

Figure 5b shows the rms errors for modelled start-dates for Copenhagen, 1977–2000, for different initial dates and different base temperatures, utilising the GDH-values from Figure 5a. The lowest rms error, about 4.2 days, is for the model with initial date 1 March and the largest error, 12 days, is for the model with initial date 1 January and a base temperature 0 °C.

Figure 5c shows the corresponding correlation for different initial dates and different base temperatures. The highest correlation, around 91%, is found for the models with initial date 1 January and base temperature 6.5 °C and for the model with initial date 1 February and base temperature around 6.0 °C.

Figure 6 shows the observed and predicted start-date of the birch season for Copenhagen using two GDH-models, one with initial date 1 January and base temperature 6.5 °C, and the other with initial date 1 March and base temperature 5 °C. The optimal GDH's are 1000 and 1400 respectively. It is seen that the two models in general give the same result, except for 1990, when the winter and early spring was extraordinarily mild. Here the model with initial date 1 January predicts a much too early start of the season, probably because the temperature is not the only parameter determining the starting of season. Otherwise the fit in general is quite good except for 1981 and 1988 with errors between 8 and 11 days. The season 1981 was special as the amount were extraordinary

small in large part of Europe (Goldberg et al., 1988; Spielsma et al., 1995) and in Denmark the total was only 60 against a mean of nearly 5000, cf. Table 1.

These small amounts make modelling uncertain. For the season 1988 the total amount of pollen also was small, only 692, and probably a very strong cold front passing late 20 April is a cause to the small amount. From gentle southerly winds, sunny weather and temperatures up to around 20 °C the weather changes dramatically with a temperature drop by up to 15 degrees and gale force wind with strong gusts during the passage. Just before the cold front passage the birch season was beginning and the measurements showed 12 pollen pr. m³ on the 20 April. Probably the concentrations would have increased dramatically if the warm weather had continued for the next 2–4 days, but the change to colder weather temporarily stopped the season until around 1 May, when the weather again became warmer. The small total amounts measured in 1988 could partly be due to the cold front passage destroying pollen ready for pollination. However, another explanation could be that the small amounts were due to the poor weather and less growth during the previous summer 1987, cf. next section.

The concept of GDH modelling can also be used for predicting e.g. peak-date and end of season.

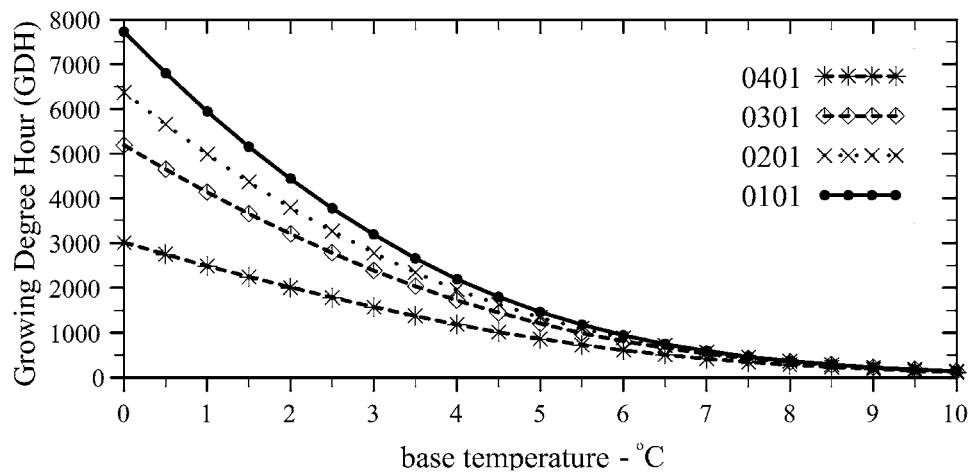


Figure 5a. Optimal values of GDH for different initial dates and different base temperatures for birch pollen in Copenhagen, 1977–2000.

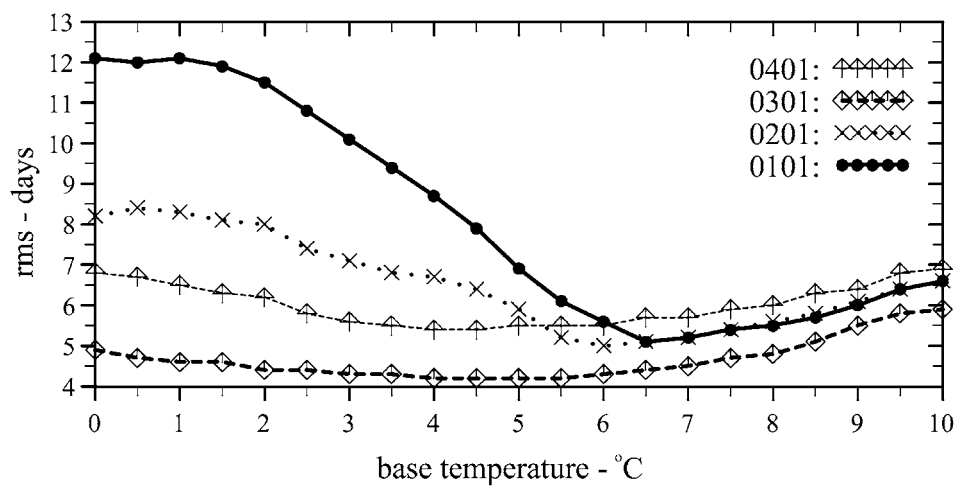


Figure 5b. RMS-errors for different initial dates and different base temperatures for birch pollen in Copenhagen, 1977–2000.

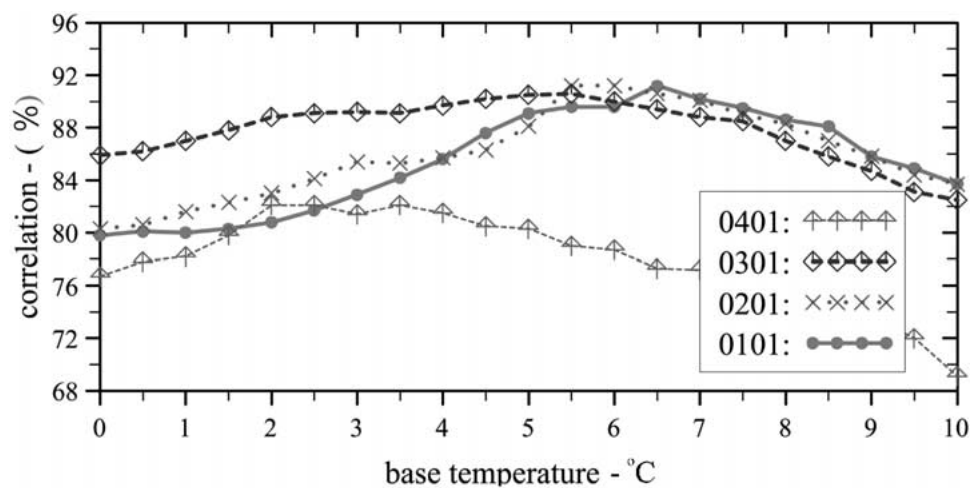


Figure 5c. Correlation's for different initial dates and different base temperatures for birch pollen in Copenhagen, 1977–2000.

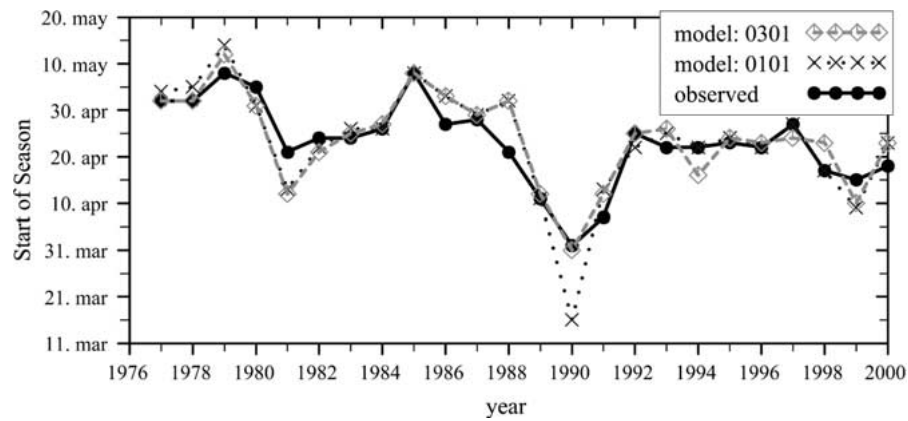


Figure 6. Observed and predicted start dates of the birch pollen season in Copenhagen, 1977–2000. The models are based on GDH's with initial dates 1 January ("0101") and 1 March ("0301"). Base temperatures are 6.5 and 5 °C and optimal GDH-values are 1000 and 1400 respectively.

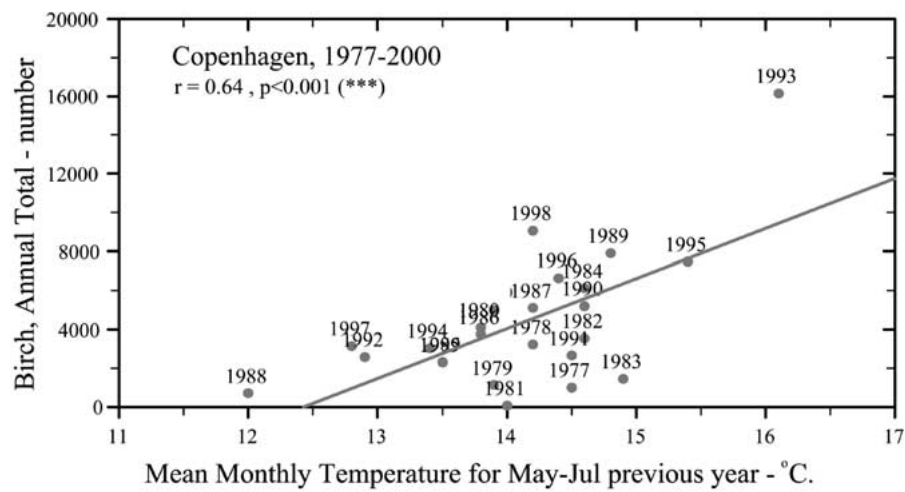


Figure 7a. Correlation between mean temperatures for May–July the previous year and the annual totals of the Birch pollen season in Copenhagen, 1977–2000.

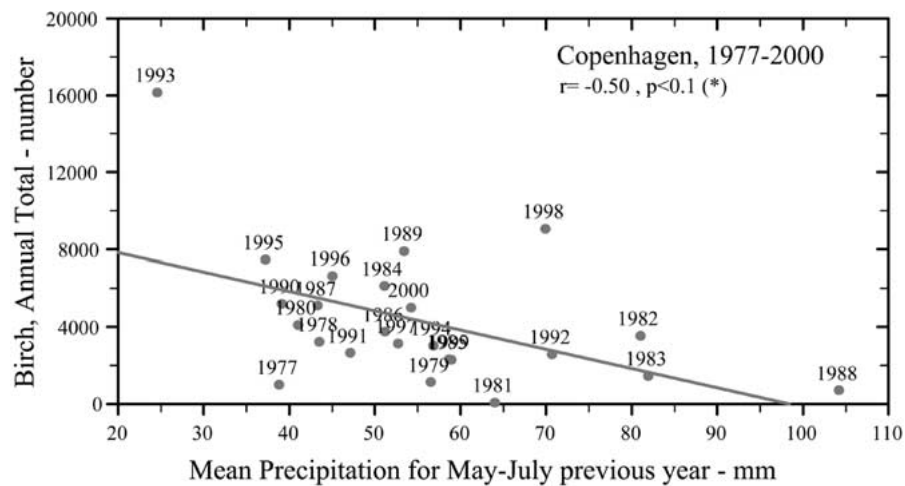


Figure 7b. Correlation between precipitation for May–July the previous year and the annual totals of the Birch pollen season in Copenhagen, 1977–2000.

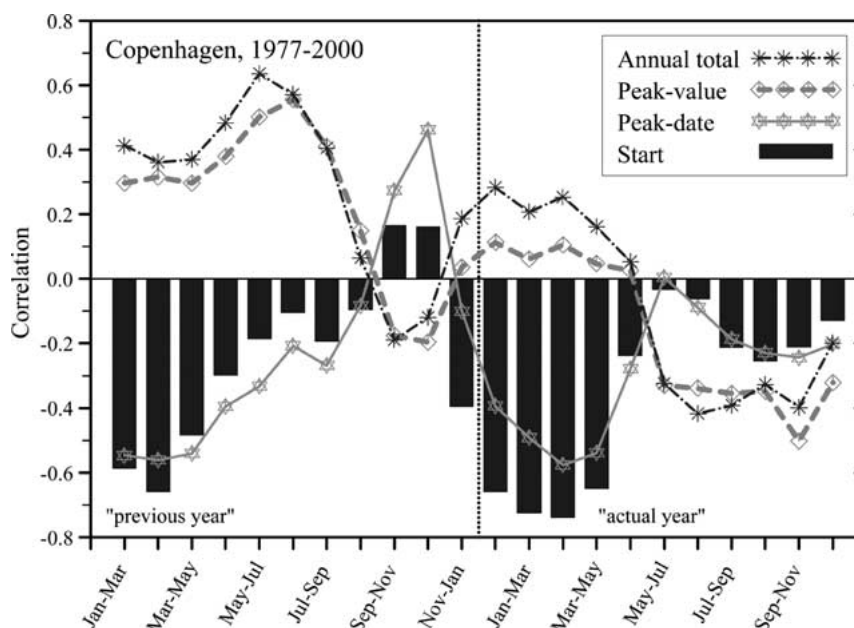


Figure 8. Correlation between mean temperatures during 3 months periods and start-date, peak-date, peak-value and annual-total of the birch pollen season in Copenhagen, 1977–2000.

3.4 Correlation between meteorological parameters and the annual-total

Concerning amount of pollen for birch there is a well documented biennial oscillation (Goldberg et al., 1984; Spieksma et al., 1995) as the individual trees have a general cycle with large pollination one year and poor pollination the next year and vice versa. A synchronisation of trees in an area can result in the observed two-year cycle. In Iceland, however, a three-year cycle is observed in Reykjavík (Hallsdóttir, 1998). This was explained by a climatic controlling mechanism, and a good correlation was found with the number of growth days (number of days with temperatures above 7.5 °C) in the previous year.

The biological factor complicates the analysis of the relation between meteorological factors and the size of season. Another complicating factor is the fact that the size of season is determined both of the primary production of pollen and of the dispersion during the season. The first one is mainly dependent on the temperature and precipitation in the pre-season while the dispersion depends on several parameters in the season e.g. wind, temperature, stability, mixing height and precipitation.

Figure 7a shows the correlation between mean temperatures for May–July the previous year and the annual-total. There is a positive and statistically

significant correlation ($p < 0.01$). It can be seen that 1977, 1979, 1981 and 1983 are all below the regression line – probably because of the biennial oscillation.

The correlation between the annual-total of birch pollen and the mean precipitation for May–July the previous year, Figure 7b, is negative ($r = -0.50$), but this negative correlation is probably due to the general negative correlation between temperature and precipitation.

Figure 8 shows the correlation between temperatures during 3 months periods and start-date, peak-date, peak-values and annual-totals of the birch pollen season in Copenhagen, 1977–2000. It is obvious that the start-date and peak-date depend on the temperature in the pre-season with the best relation for February–April with a correlation coefficient of -0.74 for the start-date and -0.58 for the peak-date. For annual-total and peak-values the best relation is found with the temperature for May–July and June–August in the previous year with correlation coefficients of about -0.64 and -0.55 , respectively.

4. Conclusion

The trend analysis of the birch pollen season in Copenhagen show a marked shift to an earlier season

– it starts about 14 days earlier in year 2000 than in 1977, the peak-date is 17 days earlier and the season-end is 9 days earlier. For Viborg the trend to an earlier season is in general the same, but slightly smaller. During the same period there has also been a distinct rise in the annual-total amount of birch pollen, peak-values and days with concentrations above zero.

The large increase in the size of the birch pollen season can be one explanation for the large increase in allergy to pollen in Denmark.

All trends are statistically significant ($p < 0.01$ or $p < 0.001$) for Copenhagen, except the duration of season. For Viborg the calculated trend of end-date is not significant and significance of start-date and peak-value is low ($p < 0.1$).

Rising mean temperatures during winter and early spring for the same period can explain the calculated trends toward an earlier pollen season.

Models for estimation of start-date based on Growing Degree Hours (GDH's) give very fine results with a correlation coefficient around 0.90 and rms error around 4.2 days.

For annual-total there is a significant positive correlation with the mean temperature in the growing season the previous year, while the correlation with mean temperatures in the actual season is weak and insignificant. The correlation between annual total and precipitation in the previous season is negative with low significance.

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