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The effects of climate change in Switzerland 1969–1996 on airborne pollen quantities from hazel, birch and grass

THOMAS FREI

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Records of different pollen were used to examine associations with weather parameters for the three different pollen: hazel (*Corylus* sp.), birch (*Betula* sp.) and grass (Poaceae).

As air temperature is expected to rise according to the forecasts from the Intergovernmental Panel on Climatic Change (IPCC) and as this factor has a great potential to affect the development of plants, the records of different pollen were used to understand possible associations.

The analysis of weather data for the studied period showed a significant increase in the annual mean temperature. From an aerobiology point of view it is most important to note that the temperature increase in winter (December) becomes most evident. As a consequence of this, hazel started earlier to flower. The flowering period which was originally in March thus shifted to January and February. Therefore the time period for hay fever patients shifted also partly to the traditional winter period. The starting season for birch and grass was not that much influenced by the temperature shift. However, regarding these two plants I also found that the warmer the weather preceding the flower period, the earlier the plants start to emit pollen. The total pollen count increased for the observed time period for all three investigated taxa. The reason for this increase is not obvious, but it is conceivable that the observed temperature rise may exert an influence. The observed pollen count increase goes hand in hand with the observed increase in pollen allergies. However, a direct link could not be ascertained yet.

The increase of temperature and the corresponding shift of the flowering time of plants whose pollen are of special interest in this connection has a medical significance since the period for hay fever sufferers becomes longer and can nowadays last from January (starting with hazel) until September (ending with mugwort) in Switzerland.

In addition, the analysis of weather data showed that the amount of precipitation did not change significantly over the observed time period, although precipitation increased slightly. A strong negative correlation between pollen number and the amount of precipitation was especially found for birch and grass.

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Given the current interest in climate change and thus in the effects of weather on phenology, it is of interest to see whether time series data can reveal associations with weather parameters. One phenological phase is of special interest since it influences human health directly: about 10% of the population in Europe suffer from hay fever caused by pollen release and pollen transport (D'Amato et al. 1991).

There is a great deal of evidence that global air temperature has changed during the twentieth century (IPCC, WGI, 1996). It has, however, proved difficult to identify the causes of these changes. Comparing the expected climatic effects of changes in the concentrations of carbon dioxide, sulphate aerosols and stratospheric ozone with the observed pattern of change in the atmosphere's temperature distribution provides the most convincing demonstration of the role of human actions (Santer et al. 1996). Climate change was already studied by the famous chemist Arrhenius (1896). He was already convinced that the temperature will rise as a consequence of the increase of CO₂. The temperature rise has indeed become a reality in the meantime and hence the behaviour of certain plants also started to change.

Global warming, induced by increasing concentrations of greenhouse gases in the atmosphere, has the potential to produce world-wide changes in precipitation as well as temperature (Rind et al. 1989, Vinnikov et al. 1990, Cubasch et al. 1992).

Humankind co-exists in the global environment with plants. Plants produce pollen, seeds and chemicals, some of which are a natural part of the atmosphere. Humans come in contact with or inhale these atmospheric particles, which are part of the air they breathe. Although pollen grains constitute only a small part of the viable particles in the atmosphere, they can be causative agents of allergic responses in susceptible humans. Aeroallergens can be deposited on the mucous membranes of the eyes, nasal and oral cavity and airways. Exposure to allergens like pollen leads finally to a release of mediators of the allergic response. This can trigger allergic rhinitis (hay fever), allergic asthma and atopic dermatitis (Roitt et al. 1985).

The allergenic contents of the atmosphere vary according to climate, geography and vegetation. Generally, there is an increasing frequency of pollen allergy, particularly in urban

areas. This increase of prevalence may have different causes, among them also air pollution (D'Amato et al. 1991).

The possible change of temperature in the winter season is of special interest with regard to those plants that flower in winter or spring time like hazel (*Corylus avellana*), alder (*Alnus*) and birch (*Betula* sp.). The flowering habit of these plants is also relevant from a medical point of view, since these plants can induce hay fever (D'Amato et al. 1991).

From a plant physiological point of view it is well known that the flowering of these plants is directly dependent on the corresponding air temperature (Frei 1995). This has now been studied again in detail for hazel, birch and grass.

MATERIALS AND METHODS

Meteorological data

Meteorological data were collected at the meteorological station of Basel-Binningen, 316 m above sea level. The data from 1961 to 1990 were homogenised as described in Aschwanden et al. (1996).

Pollen data

Data from a Burkard Seven Day Recording Volumetric Spore Trap (Hirst 1952) with a sucking rate of 101 minute^{-1} were available for years for Basel (1969–1996). The pollen trap in Basel was moved in February 1977 from a building at 15 m above ground level to the roof of the Kantonsspital building 33 m above street level, over a distance of approximately 400 m. In order to be sure that the change of the trap did not influence the time series analysis the trend from 1969–1976 and from 1977–1996 was each separately investigated. In both periods the trend is independently positive it was sure

that the investigation over the whole time period was not influenced by the mentioned trap change.

The Kantonsspital building is 260 m above sea level. The distance between the pollen trap and the meteorological station is approximately 3 kilometres.

The collected pollen were analysed as described in Peeters and Zoller (1988). The pollen data from Basel were kindly provided by R. M. Leuschner for 1969 to 1992. Since 1993 the Swiss meteorological Institute is responsible for the pollen measurements all over Switzerland.

Hazel pollen data for 1975 are incomplete, therefore the mean of the years 1974 and 1976 was used in the analyses, except in the case of the number of days since the beginning of the year where 1975 has been omitted.

Hazel pollen data of January were incomplete for some of the earliest years since hardly any pollen were found in the corresponding year.

Statistical and graphical analyses

The statistical analyses and graphics were performed with the software STATISTICA, whereas the tables are EXCEL spreadsheets.

In order to stabilise the variance of the pollen counts, especially in view of the marked increase of pollen over the years, the annual pollen counts were log transformed when used in the regression against temperature and precipitation.

RESULTS

Trends in weather

The very first point to investigate was the behaviour of the annual temperature and the annual precipitation as recorded at Basel-Binningen from 1969 to 1996. Fig. 1 shows the

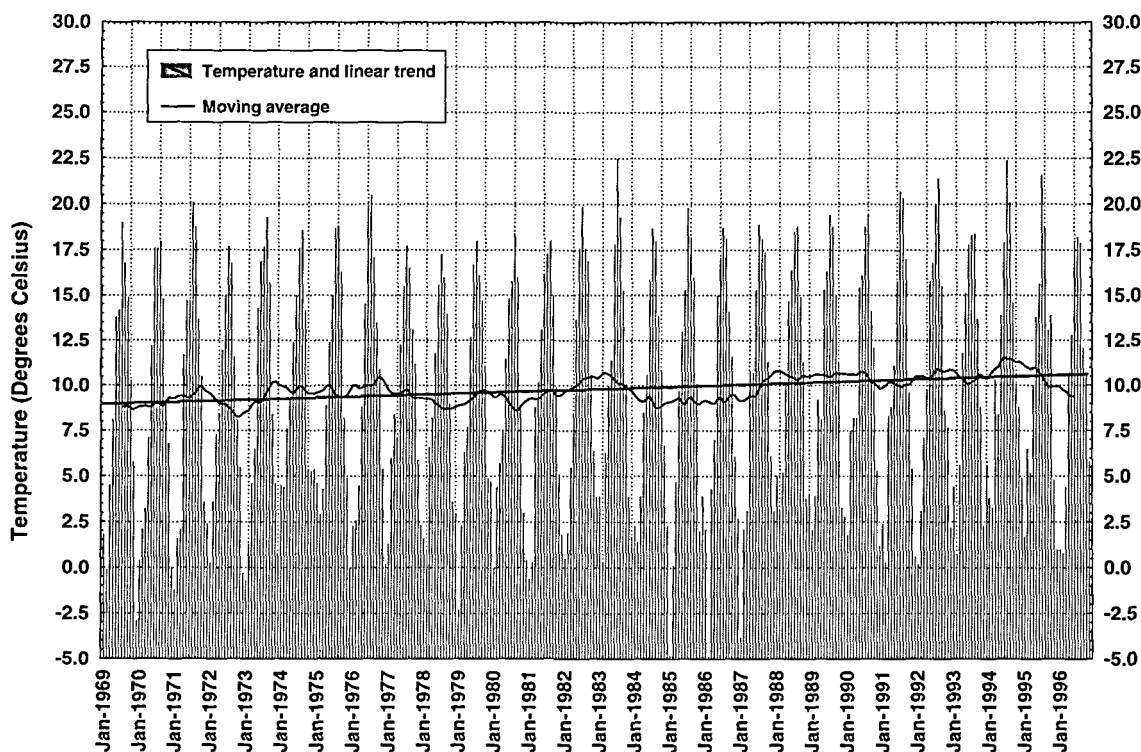


Fig. 1. Monthly mean temperature with linear trend and 12 months moving average, as measured at the meteorological station in Basel-Binningen (from January 1 to December 31).

average annual temperature distribution over the mentioned time period with a trend line as well as a 12 months moving average curve fitted to the data. Moreover, the fact that since 1988 the average annual temperature was mostly higher than 10.0°C is very remarkable (the 12 months moving average, however, fell slightly below 10°C in 1991 and 1996). Such a

consecutive period with an average annual temperature higher than 10.0°C had not been observed before. The standard temperature value for the international climate period 1961–1990 was 9.5°C, compared to 9.8°C for the investigated period 1969–1996. By studying the seasonal variations of the temperature it becomes evident that the

Table I. Statistical summary of some weather trends*.

Temperature and precipitation from 1969 to 1996; Regression on the basis of 28 observations; Independent variable: years; Dependent variables: temperature-precipitation; * P-value < 5%.

Month	Temperature			Precipitation		
	Slope	Coefficient of Determination	P-Value	Slope	Coefficient of Determination	P-Value
January	0.0437	2%	45.0%	−0.1630	0%	81.2%
February	0.0193	0%	33.2%	−0.5960	3%	40.8%
March	0.0765	10%	11.0%	0.2806	1%	61.1%
April	0.0629	14%	5.2%	0.0890	0%	91.9%
May	0.0415	5%	24.9%	1.3457	7%	18.6%
June	0.0492	10%	10.6%	−0.6252	2%	51.0%
July	0.0773	16%	3.4%*	0.5418	2%	43.4%
August	0.0742	24%	0.8%*	−0.8224	3%	36.3%
September	0.0050	0%	88.2%	1.9962	23%	1.0%*
October	0.0840	18%	2.3%*	1.2114	10%	10.2%
November	0.0128	0%	73.1%	−0.2539	0%	76.0%
December	0.0836	12%	7.1%	1.1351	11%	8.8%
Annual mean	0.0525	40%	0.0%*			
Annual amount				4.1393	9%	12.6%

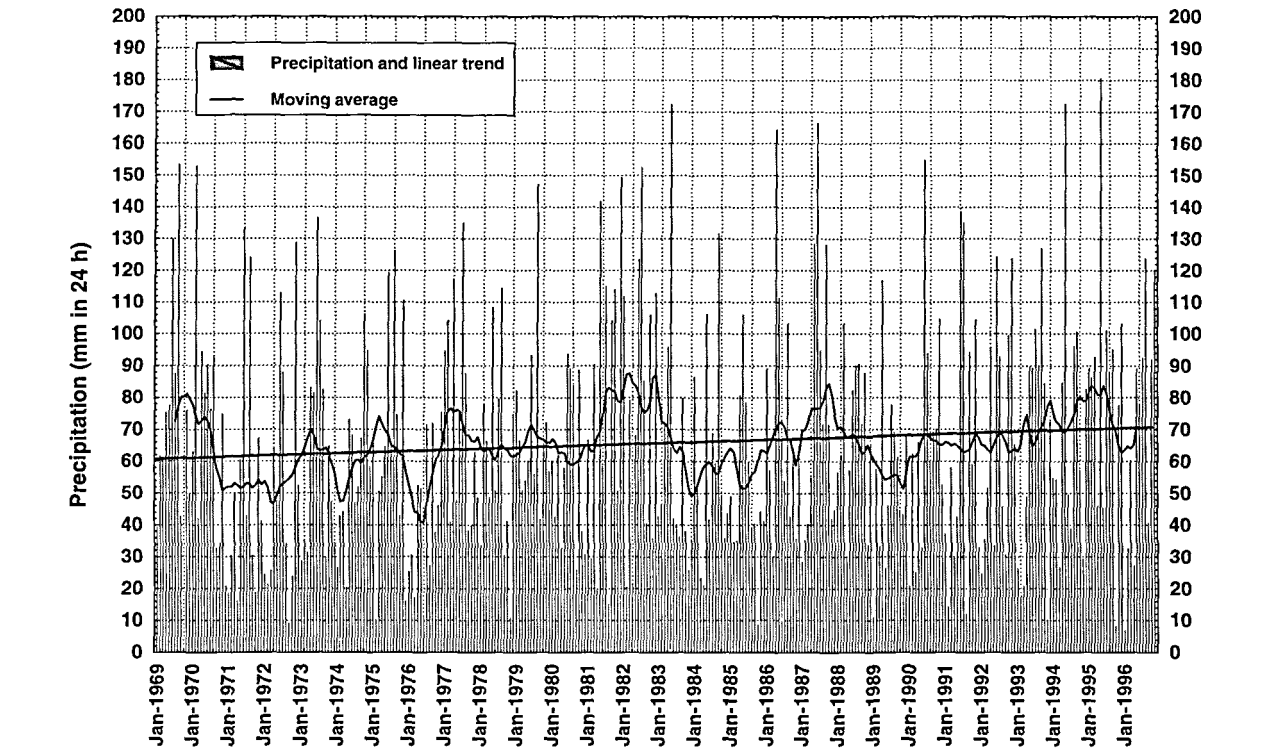


Fig. 2. Monthly precipitation with linear trend and 12 months moving average, as measured at the meteorological station in Basel-Binningen.

winter period became warmer the very last years as also observed by the Intergovernmental Panel on Climate Change 1995 (IPCC, WGI, 1996). Statistical analysis shows in Table I the different behaviour of the individual months. From an aerobiology point of view it is most relevant that the month of December has changed and shows a trend to become warmer.

The annual precipitation for the investigated time period did not reveal a relevant change. Fig. 2 shows the precipitation distribution over the mentioned time period with a trend line as well as a 12 months moving average curve fitted to the data. As shown in Table I the statistical analysis revealed that the annual amount of precipitation did not change significantly over the observed 28 years but there was a somewhat more marked change in the case of the month of September.

Behaviour of pollen release and pollen transport

The number of days before maximum daily pollen occurrence shows a trend towards earlier pollen release during later years (Table II). In the case of hazel this is statistically significant ($p=0.015$).

As shown in Fig. 3a,b,c, there is a strong negative correlation between the air temperature of the preceding months and the date of daily maximum pollen presence for all three different kinds of pollen.

A different approach was to compare the total annual count of the three pollen types, hazel, birch and grass (Table II) and the behaviour of the monthly temperature and precipitation. The relationship between the annual count of pollen and the two weather parameters, temperature and precipitation, was statistically analysed as shown in Table III. This revealed a surprising result for the three different pollen: the hazel pollen count correlates positively with air temperature (Fig. 4a), the birch pollen count does not correlate with air temperature but negatively with precipitation and has probably its own biological rhythm (Fig. 4b) and grass pollen count correlates positively with air temperature (Fig. 4c).

DISCUSSION AND CONCLUSIONS

Given that the time series data in this study are relatively few, the clear associations, found between annual amounts of pollen, period of flowering and weather is surprising.

Period of flowering and weather associations

As temperature plays a key role in the development of plants one can argue that with a possible temperature rise the period of flowering should be advanced.

Indeed it was found in this study that the temperature rise during the last 27 years led to a change in the flowering behaviour, especially for plants that are mainly temperature dependent like hazel (Frenguelli et al. 1993) and flower early in springtime. The linear regression of the number of days from the beginning of the year to the day of maximum daily occurrence of pollen against the temperature of the preceding months (see Fig. 3 as to which months were chosen) resulted

Table II. Annual pollen counts and number of days to maximum daily occurrence of pollen, covering the period from 1969 to 1996, including slope of regression line, correlation coefficient and probability level.

Year	Annual count of pollen			Number of days to maximum daily occurrence	
	hazel	birch	grass	hazel	birch
1969	239	1293	4690	68	116
1970	794	6718	3381	81	113
1971	619	7274	4282	95	106
1972	563	3498	3295	63	95
1973	540	4306	4688	83	117
1974	565	4628	6923	77	93
1975	755	1414	7036	n.a.	104
1976	970	12,910	8165	62	93
1977	2010	3335	6995	38	82
1978	290	2035	6320	60	100
1979	463	3581	5033	72	104
1980	708	8368	8998	40	106
1981	600	1670	4165	67	94
1982	335	5805	8135	60	107
1983	2620	1150	6965	27	107
1984	1220	9415	5615	36	115
1985	280	3475	10,550	68	97
1986	1135	5540	3845	81	123
1987	890	10,570	5165	61	108
1988	775	3905	10,340	35	109
1989	1445	9320	14,470	49	90
1990	1670	6640	8300	39	81
1991	1965	10,740	9915	66	101
1992	1020	6500	5865	60	103
1993	1450	8330	11,125	22	111
1994	1494	6996	8954	34	89
1995	1938	5386	9422	38	95
1996	1346	14,596	5210	84	111
Slope of re-gression line	40.664	188.610	175.185	-1.112	-0.174
Correlation coefficient (r)	0.544	0.438	0.530	-0.465	-0.136
Probability level (p)	0.003	0.020	0.004	0.015	0.491

in statistically significant regression coefficients ($p<0.05$) for hazel and birch examined. The corresponding correlation coefficients were relatively high in the case of hazel and birch, but lower in the case of grass.

In this study we showed that the trend analysis for the time period 1969–1996 reveals that the average annual temperature rose from 8.9°C to 10.5°C. The day number on which the maximum pollen release occurred was advanced by 31 days in the case of hazel and by 5 days in the case of birch. This observation was much less clear for grass. Two main factors are responsible for the different behaviour of grass: grass normally starts to flower in May and therefore the temperature amplitude is much smaller than in February. In addition May belongs to those months with a lot of precipitation and therefore the beginning of grass pollen release may be delayed due to this factor.

The question could be raised why the maximum daily pollen count of each year was used in order to determine the

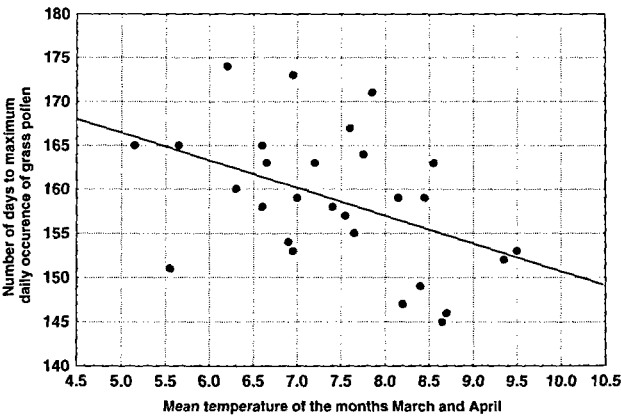
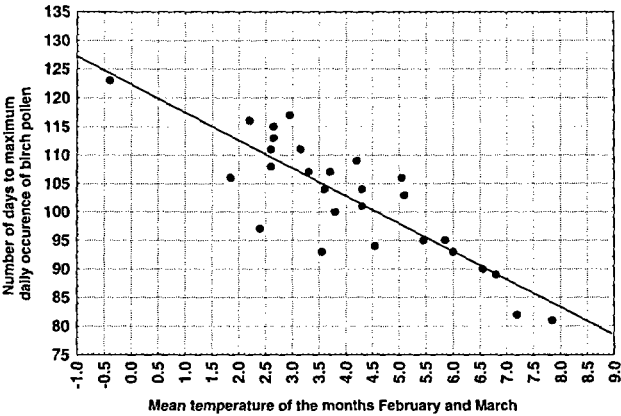
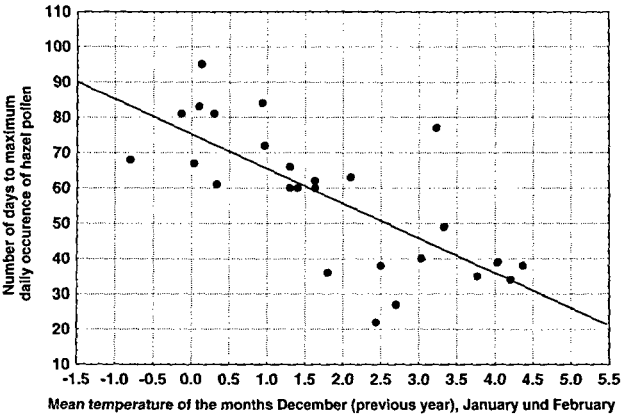


Fig. 3. Number of days from beginning of year to the day of maximum daily occurrence of pollen against temperature (sorted in ascending order): a. Hazel ($r=0.728$, $p<0.05$); b. Birch ($r=0.854$, $p<0.05$); c. Grass ($r=0.448$, $p>0.05$). The temperature mean of 1974/1975 (December to February) is excluded, as the *Corylus* pollen count of 1975 is incomplete.

position of the flowering period within the calendar year. An alternative would certainly have consisted in defining the pollen season according to the method of Lejoly-Gabriel (1978), in which case the number of days until the date of the beginning of the flowering period could have served as a comparative basis. In preliminary analyses carried out in this respect it became evident that both methods have there

Table III. Regression data (log-transformed annual pollen count against temperature and precipitation).

Years: 1969–1996;
Temperature: Degrees Celsius;
Precipitation: mm in 24 h;
Independent Variables: temperature and precipitation;
Dependent Variable: annual pollen count;
Number of observations: Birch and Grass – 28; Hazel – 27.
Temperature basis:
Hazel: mean of December (previous year), January and February
Birch: mean of February and March
Grass: mean of March and April
Precipitation basis:
Hazel: mean of December (previous year), January and February
Birch: mean March and April
Grass: mean of May and June

Pollen x axis	Temperature		Precipitation		Multiple Regression Temperature and Precipitation Coefficient of Determination
	Slope	P-value	Slope	P-value	
Hazel	0.0770	2.0%	0.0016	53.2%	20%
Birch	0.0049	88.0%	0.0071	3.3%	16%
Grass	0.0677	1.7%	0.0020	15.6%	27%

strong and weak points, but basically the results lead to the same conclusions. It may also be mentioned that several authors have different views as to how the beginning of the pollination period should be defined. The widely recognised method of Lejoly-Gabriel has undoubtedly its merits, but in years with highly irregular pollen counts, if strictly followed, can lead to results that are not always satisfactory. This is the main reason why the maximum daily pollen count was chosen.

Total annual amount of pollen and weather associations

Studying the distribution of the annual amount of hazel pollen it becomes evident that those years whose winters were warm produced more pollen. The reason for this behaviour of the plants is not clear. On the other hand, it is quite clear that hazel is a plant that reacts mainly to temperature (Frenguelli et al. 1993).

In the case of birch it was also found in an European study of birch pollen distribution at four different places (Spiekma et al. 1995) that birch often shows a biannual rhythm with one year of big pollen release and the following year with a smaller pollen release. This biological rhythm overrides the influence of temperature. However, the trend analysis still shows an increase in birch pollen all over the years.

Grass pollen seems to respond mostly to precipitation. This is very reasonable since grass pollen amounts are highest in the air in May and June. These two months also have the highest amounts of precipitation. Grass pollen occurrence is therefore very much dependent on the current weather situation. Intense precipitation reduces the air content of pollen

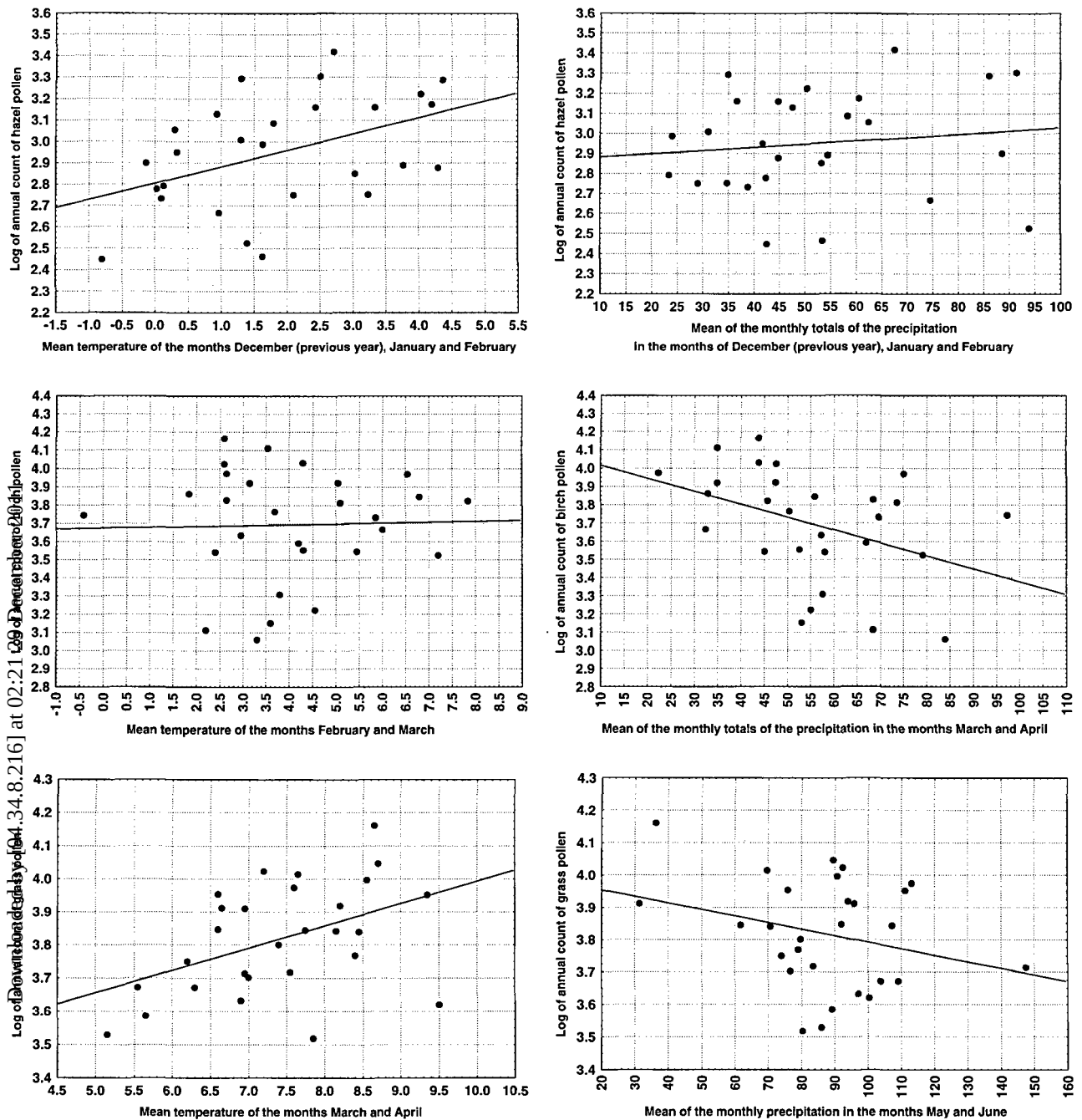


Fig. 4. Comparison of meteorological parameters with log of annual count of: a. hazel pollen (temperature: $r = 0.446$, $p < 0.05$; precipitation: $r = 0.126$, $p = 0.53$ [not significant]); b. Birch (temperature: $r = 0.030$, $p = 0.88$ [not significant]; precipitation: $r = 0.404$, $p < 0.05$); c. Grass (temperature: $r = 0.449$, $p < 0.05$; precipitation: $r = 0.276$, $p = 0.16$ [not significant]).

dramatically. In the case of grass pollen it is difficult to distinguish between pollen production by the plant and pollen release and transport that may be reduced very strongly by precipitation. It is possible that the increase in grass pollen amount might in fact have been even stronger if not counter acted by the meteorological conditions.

When the statistical results relative to Fig. 4 are compared, it becomes evident that there is a certain probability that the temperature of the months preceding the flowering period

may be one of the factors determining the annual pollen count, at least in the case of hazel and grass ($p < 0.05$ for both), but not in the case of birch ($p = 0.88$). The correlation coefficients, however, are not particularly high and in the case of birch practically nil. Precipitation, on the other hand, seems to influence only the birch pollen count ($p < 0.05$; negative correlation), whereas the figures for hazel and grass are statistically insignificant (hazel: $p = 0.53$; grass: $p = 0.16$). It has to be emphasised, however, that the regression results

are only an indication but at this stage not yet a clear proof of the assumed causal relationship.

Pollen count and epidemiological observations

From an epidemiological point of view there are different observations made during the past years, among them the fact that the prevalence of hay fever sufferers has increased (Wüthrich 1989) and that tree pollen becomes more and more important as an inducing agent for hay fever.

As far as the dramatic increase of hay fever prevalence is concerned a lot of different hypotheses have been postulated (Rusznak et al. 1994). This study shows for the first time that for the longest existing time series of pollen counts in Switzerland there has been an increase in pollen release for all three investigated pollens. The annual increase of the pollen counts in this period was 4.6% for hazel, 3.8% for birch and 2.6% for grass. The fact that the area of grassland was reduced by motorway and construction projects during the study period makes the observed increase in the grass pollen count even more impressive.

However, by investigating only the time period from 1990 to 1996 it becomes evident that the pollen from hazel and birch increased also in that time period but the amount of grass pollen decreased. This might be a hint that tree pollen becomes more and more relevant for allergic diseases whereas grass pollen probably become less important.

It remains to be proven whether the increased pollen count really may be responsible for an increased hay fever prevalence. That the observed increase in the pollen count is responsible for the observed increased prevalence of hay fever remains to be proven. Another observation is that the hay fever prevalence at higher elevation is smaller compared to lower elevation (Wüthrich et al. 1994). We know that the pollen count at higher elevation is much smaller than at lower elevation too (Frei 1997). Finally it is also important to note that the increase in pollinosis during the last years was stronger than the increase of observed pollen. Therefore we conclude that other factors like the "western style of life" or air pollution increase must also play a crucial role in this process but that probably the combination of all these factors are most critical for triggering the allergic disease.

The point could be raised whether the increased pollen count of hazel might be due to additional hazel planted, but there is no hint whatsoever that this could be the case, all the more as there is no noteworthy nut production in this area. In the case of birch, it is still possible, however, that additional trees were planted, especially in parks, but there are no data available in this respect, and anyhow, no significant change has been observed in this respect. It is interesting to note that newer data from a different station in Switzerland revealed the same trend in pollen counts which leads to the conclusion that the observed increase of pollen did not take place exclusively in the neighbourhood of the chosen station.

Concerning hazel pollen one can argue that the flowering period became longer with the increased temperature. For birch pollen and grass pollen, however, this is certainly not true. It might be that a higher average temperature supports the flowering process of the plants. On the other hand it is

also possible that a higher CO₂ concentration influences the growth behaviour of plants and makes it possible that more pollen are produced and hence released and transported.

It is important to note that the observed correlation between pollen data and meteorological conditions might, at least partly, be due to their parallel trend over years, and the cause for changes in pollen activities might be anything that also shows a monotonic trend over the studied period. We shall interpret the results under the assumption that changes in meteorology will lead to similar changes in pollen activity in the future as they have done in the studied period – even if they were not a direct cause for these changes.

Global warming and human health

Originally it was believed that global warming has a major effect on ecosystems and hence indirectly on human beings. Recently it has also become evident that global warming has its effects on human health. Especially malaria, schistosomiasis and dengue are believed to spread with global warming (Stone 1995). Other studies also show a positive correlation between death rate and temperature or between asthma, bronchitis and temperature (Saez et al. 1995).

This study shows that global warming might also have an influence on the increase and spreading of allergies by an increase of pollen numbers and by a shift of the flowering period in the direction of winter (Emberlin 1994, Emberlin et al. 1997). A similar result was also found by Jäger et al. (1996) but the observed time period was much shorter and a correlation with weather parameters was missing. An additional threat may result from the observation that new plants like ragweed (*Ambrosia artemisiifolia*) enter Central Europe due to global warming (Rich 1994). Ragweed is known to be the main cause of hay fever in the United States of America (Lewis et al. 1991).

Therefore one can summarise the findings of this study by stating that global warming seems to influence the behaviour of different plants in such a manner that it becomes a direct threat to human health, especially with regard to allergies and asthma.

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