

Designing new automatically generated pollen calendars for the public in Switzerland

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Abstract Pollen calendars are one of the most comprehensible means to inform allergy sufferers or medical professionals about the mean presence of allergenic pollen during the course of the year. They have been produced with a variety of methods and were distributed with great success since the beginning of pollen monitoring. Current technologies, longer data series and changing user demands allow to develop new calculation methods. For designing the new pollen calendars of Switzerland, the following requirements were formulated: The pollen load levels in the calendars should correspond to the levels used in pollen forecasts. A pollen load level in the calendar should show the time window in which it potentially occurs. Further requirements were an automatic generation of the calendars, a regular update and the possibility to provide calendars for single stations, regions or specific pollen species. The data analysis is based on mean daily pollen concentrations of the last 20 years of all 14 pollen-monitoring stations in Switzerland for the 15 pollen types most relevant for allergies. For each day of the year, the 90% quantile of

the daily pollen concentrations is determined in a moving 9-day time window over 20 years of data. The calculated concentrations are converted afterward into a pollen load level. The new method is flexible because various parameters can be selected freely: the reference period, the size of the moving time window, the quantile value and the thresholds for pollen load levels. Adjusting these parameters, also pollen calendars for fewer than 20 years can be calculated. However, a sensitivity analysis showed that a reference period of 20 years provides much more stable pollen calendars than shorter reference periods.

Keywords Pollen load levels · Operational · Airborne · Allergenic · Timing

1 Introduction

Pollen calendars show in a generalized and easily understandable way the mean yearly development of the pollen season for the main allergenic pollen species in a selected geographical area (Spieksma 1991). They are therefore one of the most comprehensible tools for informing the public about the seasonal occurrence and the intensity of the presence of allergenic pollen taxa. They were distributed with great success since the beginning of pollen monitoring (Stix and Ferretti 1974; Nilsson and Palmberg-

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Gotthard 1982). Based on pollen calendars, allergists can plan treatments and allergy sufferers are prepared for taking their medication or plan their recreation activities or holidays. Being informed about the possible presence of pollen types in the air helps preventing allergy symptoms. Besides daily pollen forecasts or forecasts of the start dates of the pollen season, pollen calendars are therefore one of the helpful tools for allergy management.

Pollen calendars can be found on the Web sites of pollen-monitoring networks and are used by patient organizations, by pharmaceutical companies and figure in medical information brochures. Pollen calendars are also published in scientific papers for characterizing the pollen season of a location with a new pollen trap or for comparing the pollen season between different regions (Spieksma 1991; Martínez-Bracero et al. 2015; Calderón-Ezquerro et al. 2015).

There are several methods for drawing pollen calendars. Scientific publications follow mostly the method of Spieksma (1991), which was adopted from the method of Stix and Ferretti (1974). Daily pollen concentrations are summed over 10-day periods and averaged over the years under consideration. A month is represented by three ten-day periods. The calendar is drawn with a logarithmic scale. In calendars for the public a more qualitative classification is used, like “main flowering,” “pre flowering” and “post flowering” (Germany¹), or “possible presence” and “systematic presence” of pollen (Belgium²), or “main release period” and “peak period” (Great Britain³), or pollen load levels “low,” “medium,” “high,” “very

high” (South Tirol,⁴ Austria,⁵ Italy⁶ and Catalonia and Tenerife⁷). The methods for calculating these pollen calendars for the public are mainly not published, except for the German pollen information service (PID). PID defines the main flowering period as the inner 80% of the seasonal pollen index (SPI), i.e., the main flowering starts on the day when 10% of SPI is reached. The start dates of the main flowering period of each year are then averaged over the calendar period (Kühne and Bergmann 2008). In Switzerland, a pollen calendar for whole Switzerland has since long time been available on the Web site of the Federal Office of Meteorology and Climatology MeteoSwiss (www.meteoswiss.ch). Until now, it was based on weekly mean pollen concentrations and was drawn manually. For this reason, updating this pollen calendar was very time-consuming.

For public users, it is a benefit if the periods in pollen calendars are classified in the same pollen load levels which are used in pollen forecasts. These levels are familiar, and the users most probably are able to assess their symptom reactions for each pollen level. The thresholds of the communicated pollen levels “low,” “medium,” “high,” “very high” are based upon daily mean pollen concentrations and are different for different groups of pollen taxa. They were empirically determined depending on the allergic reaction of the allergy sufferers to measured pollen concentrations. An overview of studies which determine pollen load thresholds is given by de Weger et al. (2013). Thresholds of pollen load levels used in Switzerland are published on the Web site of MeteoSwiss⁸ (Table S1).

¹ Stiftung Deutscher Polleninformationsdienst: <http://www.pollenstiftung.de/pollenvorhersage/pollenflug-kalender/> retrieved November 1, 2017.

² Belgian Aerobiological Surveillance Network: <https://airallergy.wiv-isp.be/content/pollen-and-fungal-spores-calendar> retrieved November 1, 2017.

³ MetOffice: <https://www.metoffice.gov.uk/public/weather/pollen-forecast/#?tab=map&map=Pollen&fcTime=1509447600&zom=5&lon=-4.00&lat=55.71> retrieved November 1, 2017.

⁴ Landesagentur für Umwelt Bozen, Südtirol: <http://umwelt.provinz.bz.it/luft/pollenflugkalender.asp> retrieved November 1, 2017.

⁵ pollenwarndienst.at <https://www.polleninfo.org/AT/de/aktuelle-belastung/pollen-countdown.html> retrieved November 1, 2017.

⁶ Rete Italiana di Monitoraggio Aerobiologico: http://www.pollnet.it/default_it.asp retrieved November 1, 2017, and Associazione Italiana Aerobiologia: <http://www.ilpolline.it/category/calendari-pollinici/> retrieved November 1, 2017.

⁷ Laboratori d'Anàlisi Palinològiques: <http://lap.uab.cat/aerobiologia/en/> retrieved November 1, 2017.

⁸ Thresholds for pollen load levels of Switzerland: <http://www.meteoswiss.admin.ch/home/climate/swiss-climate-in-detail/pollen-season%20.html> retrieved November 1, 2017.

The course of the pollen season varies remarkably from year to year, either in start dates or in intensity. For example, the start of the birch pollen season varies from mid-March to mid-April and the daily pollen concentrations can vary between very high and almost no pollen on a rainy day. Given this large variability, the calculation of an average pollen season is not very useful, because the presence of pollen and the peak periods will be leveled out to some degree.

We conducted a short oral user survey to learn about their expectations regarding pollen calendars. It revealed that the users prefer to get the whole time period, in which for example high pollen loads are possible, and do not expect to see mean pollen seasons. This is an additional argument against the use of average pollen seasons, but for a method in which a certain pollen level in the calendar covers the period in which this level occurred in a defined number of years within the reference period. Thus, the users are provided with the time windows in which a given pollen level can potentially occur.

These new requirements lead to the following goals for the development of the new pollen calendars for public users in Switzerland:

- Automatic generation with regular updates
- Possibility to plot calendars for single stations, regions or pollen types
- Based upon daily data of pollen concentrations
- Use of the same pollen load levels as in pollen forecasts for showing the allergy risk
- Provide the time windows in which a given pollen level may potentially occur
- Usable for a few years of data as well as for longer time series

2 Method

2.1 Data

Since 1993, the national pollen network of Switzerland is operated by the Federal Office of Meteorology and Climatology MeteoSwiss. However, many of the Swiss pollen stations started to operate before that date under the head of the Swiss working group on aerobiology. The network consists of 14 pollen stations (Fig. 1), and each equipped with a Hirst-type Burkard pollen trap (Hirst 1952). The preparation of

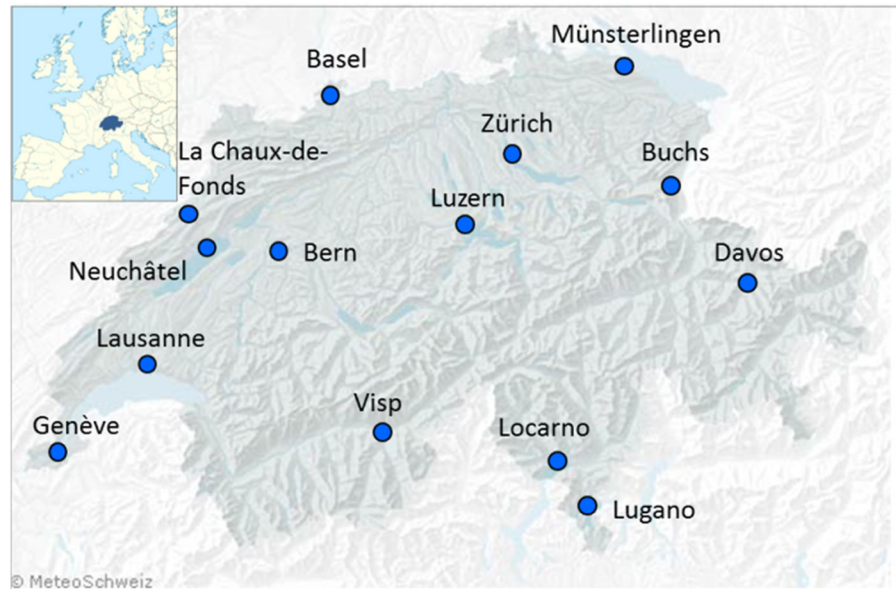
pollen slides and the analysis of the data followed standard methods described by Mandrioli et al. (1998) and Galán et al. (2014). Pollen grains were microscopically identified at a 400× or 600× magnification, and the slides were examined along two longitudinal transects. For calculating new pollen calendars, the 20-year period 1997–2016 was selected, so that the most recent station (Lausanne), with a monitoring start in 1997, would also reach 20 years of data.

The 15 most important allergenic pollen taxa of Switzerland are presented in the calendar. These are the same taxa for which forecasts are broadcasted during the pollen season. Pollen calendars are drawn for single stations, for three main regions and for whole Switzerland. The assignment of the pollen stations to regions of Switzerland follows the regionalization of the Swiss pollen network of Gehrig (2012) (Table 1). In contrast to this regionalization, the pollen trap of Basel was included in the regional calendar of central and eastern Switzerland, in order to cover also lower altitudes that have a slightly earlier pollen season. In western Switzerland, the pollen trap of Genève covers these milder regions. The two mountain stations La Chaux-de-Fonds and Davos are not used for the calendar of whole Switzerland, because this calendar should mainly cover the lower elevations, where most of the people are living. The station of Visp in the Valais is included in the calendar of whole Switzerland, but not in the regional calendars, because the pollen season of the Valais differs clearly from the rest of the regional pollen calendars.

2.2 Calculation method

A pollen load level in the calendar should cover the period during which this level occurred in a defined number of years within the reference period. To this end, selecting a quantile value is suitable. The quantile value α separates the data in such a way that the fraction α of the data is smaller and the fraction $1 - \alpha$ is bigger than the quantile value. For example, for a 90% quantile ($\alpha = 0.9$), 90% of the data are smaller and 10% are bigger than the quantile value (Stahel 2008). For the new calendars of Switzerland we determined for each day of the year the 90% quantile of the daily pollen concentrations in a moving 9-day time window over 20 years of data (Fig. 2). Thus, the calculated pollen concentration was surpassed only on

Fig. 1 National pollen network of Switzerland



10% of the days in the time window (that is, for 18 out of 180 values). The concentration values (pollen/m³) that correspond to the 90% quantile are converted afterward into a pollen load level (low, moderate, high, very high) according to the thresholds used by default for all pollen communications in Switzerland (Table S1). The advantage of using a moving 9-day time window is that the number of values for the quantile calculation is increased, which allows for smooth results also in the case of shorter reference periods. Additionally, using a moving 9-day time window guarantees a greater robustness against very unusual years with very early or late pollen season start and end dates or against high daily variations caused by changing weather conditions, because pollen loads will have an effect on the calendar only when they were reached in at least 10% of the days in the time window. As an example, Fig. 3 shows the resulting pollen load level for the calendar compared to the variability of the whole 20 years of birch pollen concentrations in Zurich.

After the transformation into pollen load levels, some deviant single 1- or 2-day values are still present. In order to automatically smooth these values, the data of the pollen calendars are smoothed with a 5-day moving filter for removing the single 2-day values and then with a 3-day moving filter for removing the single 1-day values.

Daily pollen data frequently have smaller or larger gaps of missing data, especially at the beginning of the year or due to trap failures during the pollen season. For the calculation of quantile values, missing values are ignored. To prevent calendar values with an insufficient base of data, we defined a maximum quota of missing values within the moving time window (e.g., 50%) in order for daily values to be calculated.

The calculation of the pollen calendars was programmed with R (cran.r-project.org). The number of days of the moving window (e.g., 5, 7, 9 or more days) and the selected quantile (e.g., 90, 80% quantile) can be specified. For a 20-year period, the choice of a 9-day moving window and a 90% quantile showed to be the most appropriate for identifying the pollen season, because the calendar is smoothed reasonably and, by optical comparison with the yearly data, reflects the pollen season well. For drawing regional or country-wide pollen calendars, the quantile value for the day of the year was calculated by collecting the daily concentrations of all stations of the region in the 9-day time window and used them as base for calculating the quantile value, i.e., 180 values multiplied by the number of stations.

Table 1 Assignments of pollen stations to greater regions of Switzerland

Region	Pollen stations
Central and Eastern Plateau	Basel (273 m a.s.l.), Buchs (445 m a.s.l.), Luzern (460 m a.s.l.), Münsterlingen (410 m a.s.l.), Zürich (556 m a.s.l.)
Western Plateau	Bern (560 m a.s.l.), Genève (380 m a.s.l.), Lausanne (570 m a.s.l.), Neuchâtel (490 m a.s.l.)
Ticino	Locarno (366 m a.s.l.), Lugano (273 m a.s.l.)
Switzerland	All of the above stations plus Visp (650 m a.s.l.), not included, are Davos (1600 m a.s.l.) and La Chaux-de-Fonds (1040 m a.s.l.)

The mountain stations Davos (1600 m a.s.l.) and La Chaux-de-Fonds (1040 m a.s.l.) are not included in the calendar for whole Switzerland nor in the regional calendars

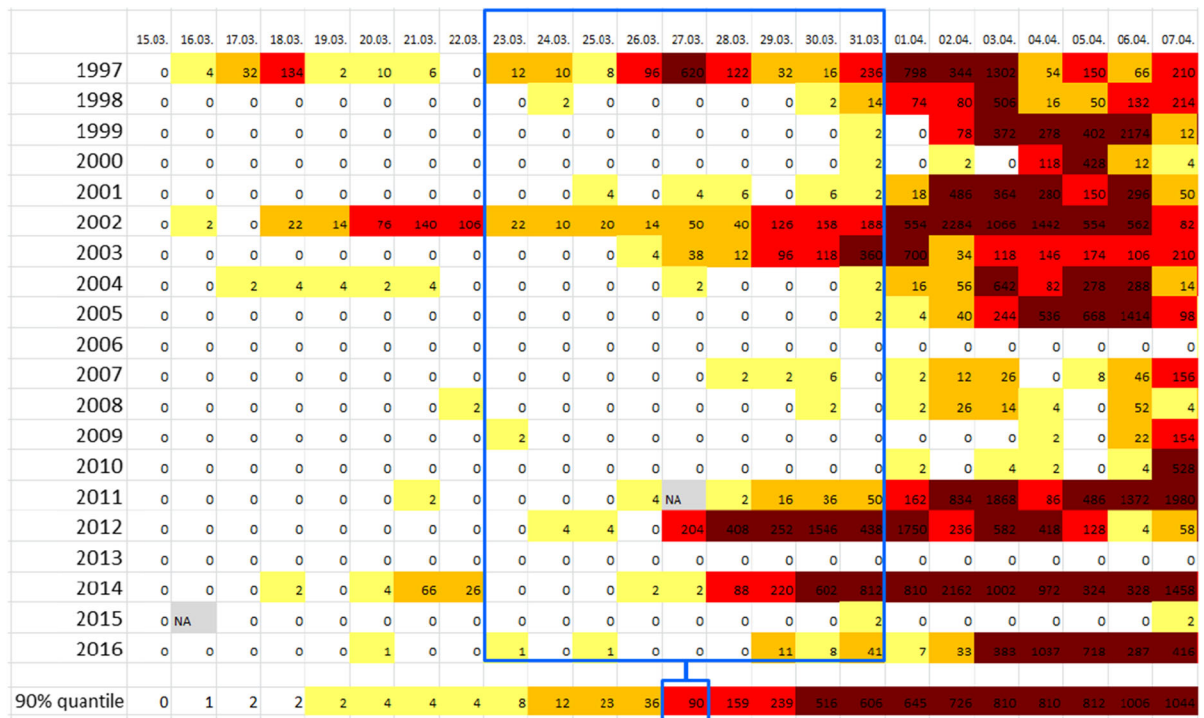


Fig. 2 Presentation of the calculation method for pollen calendars using the example of *Betula* pollen in Zurich. The 90% quantile value of the daily pollen concentrations is determined in a moving 9-day window (blue), i.e., the 90% quantile is calculated from 180 daily concentrations. As an

example, on the 27 March, the central date of the 9-day window, the 90% quantile is 90 pollen/m³. This concentration is then transformed into the pollen load level “high.” Colors for pollen load levels: low: yellow, moderate: orange, high: red, very high: dark red, NA: gray

3 Results and discussion

Pollen calendars for each monitoring site, the regions and whole Switzerland are available on the Web site of the Federal Office of Meteorology and Climatology MeteoSwiss (<http://www.meteoswiss.ch/pollen-calendar>). Here we present the characteristic of the pollen season in Switzerland with the three regional

pollen calendars (Fig. 4) and with the calendars of some selected allergenic pollen types (Figs. 5, 6).

3.1 Regional pollen calendars

The division of Switzerland into different regions and the assignment of the pollen-monitoring stations to the regions are presented in Table 1. The pollen of hazel

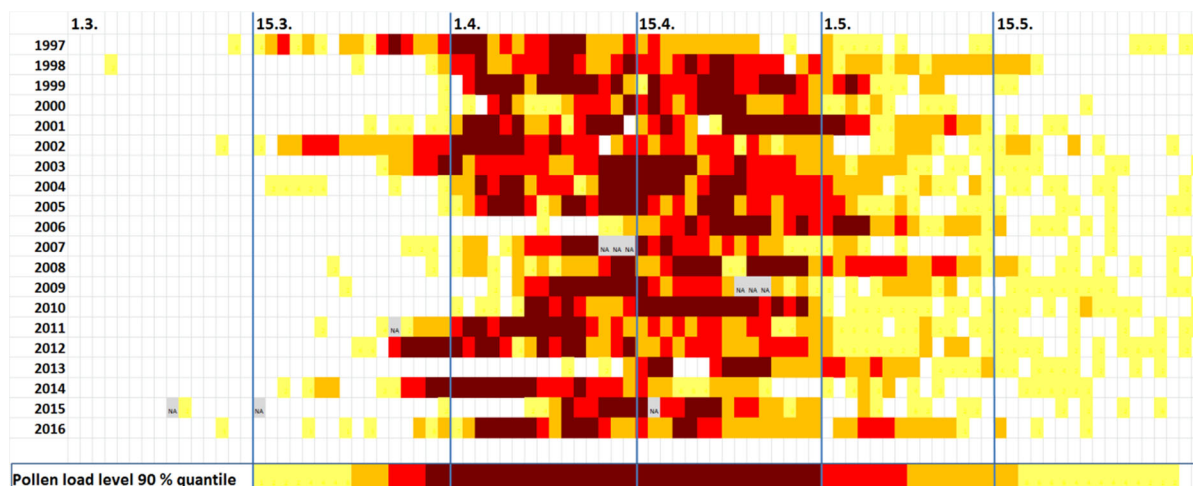


Fig. 3 Resulting 90% quantile pollen load level using the example of the *Betula* pollen season 1997–2016 in Zurich. Colors for pollen load levels: low: yellow, moderate: orange, high: red, very high: dark red, NA: gray

(*Corylus*), alder (*Alnus*), ash (*Fraxinus*), birch (*Betula*), grasses (Poaceae) and mugwort (*Artemisia*) are the most important pollen types for allergies in Switzerland. The pollen season starts in Switzerland in January with the flowering of *Corylus* and *Alnus*, followed in March and April by *Fraxinus* and *Betula*. Poaceae are dominant in May to mid of July, while *Artemisia* is mainly present in the Valais from mid-July to mid-September. The pollen from hornbeam (*Carpinus*), oak (*Quercus*) and beech (*Fagus*) is considered to be moderately allergenic, but is important because of cross-reactions with *Betula* pollen. Ragweed (*Ambrosia*) pollen is mainly present in Ticino (south of the Alps) and in the region of the Lake of Geneva. In the rest of Switzerland *Ambrosia* pollen originates mainly due to long-range transport. Plane (*Platanus*) pollen is measured in monitoring stations located in towns, but the allergenicity of the pollen is considered to be low. In Ticino chestnut (*Castanea*) pollen is present in very high concentrations, while in the rest of Switzerland only low pollen loads are recorded. A bit less important for allergies is pollen of poplar (*Populus*), sorrel (*Rumex*) and plantain (*Plantago*) with a low-to-moderate allergenicity.

The pollen season of the regions north and south of the Alps differs clearly. In Ticino, south of the Alps, the pollen seasons of all pollen species start earlier and the intensity of the pollen season differs for many species from the one north of the Alps. The *Betula*, *Alnus*, *Castanea* and *Ambrosia* pollen season is more

intense, while the Poaceae pollen intensity is much lower than north of the Alps. On the Swiss Plateau, north of the Alps, two regional pollen calendars were made, following the regionalization in a western and a central and eastern part of Switzerland by Gehrig (2012). The calendars of these two regions do not differ for all pollen types. For *Betula* pollen the differences are small. Also the pollen seasons of *Corylus* and *Fraxinus* are very similar. Small differences arise from the slightly longer *Alnus* pollen season and the more intense season of *Alnus viridis*, measured in May and June, in central and eastern Switzerland. The start of the Poaceae pollen season is again very similar, although the period of very high pollen loads is shifted slightly toward later dates in western Switzerland. In western Switzerland, *Fraxinus* pollen is detected earlier in the year, probably due to long-range transport from France. Clearer differences are visible for *Carpinus*, *Fagus*, *Quercus*, *Artemisia* and *Ambrosia*. These differences are systematic in all stations for *Quercus*, which shows a longer and more intense pollen season in western Switzerland, and for *Artemisia* and *Ambrosia* with higher pollen load levels. *Fagus* and *Carpinus* vary also between the stations of one region; therefore, the regional calendars show these differences rather by chance. For *Fagus*, the stations of Neuchâtel, Bern, Basel, Luzern and Zurich have more intense seasons; for *Carpinus*, these are Basel, Bern, Genève and Zurich. Because of the different season characteristics

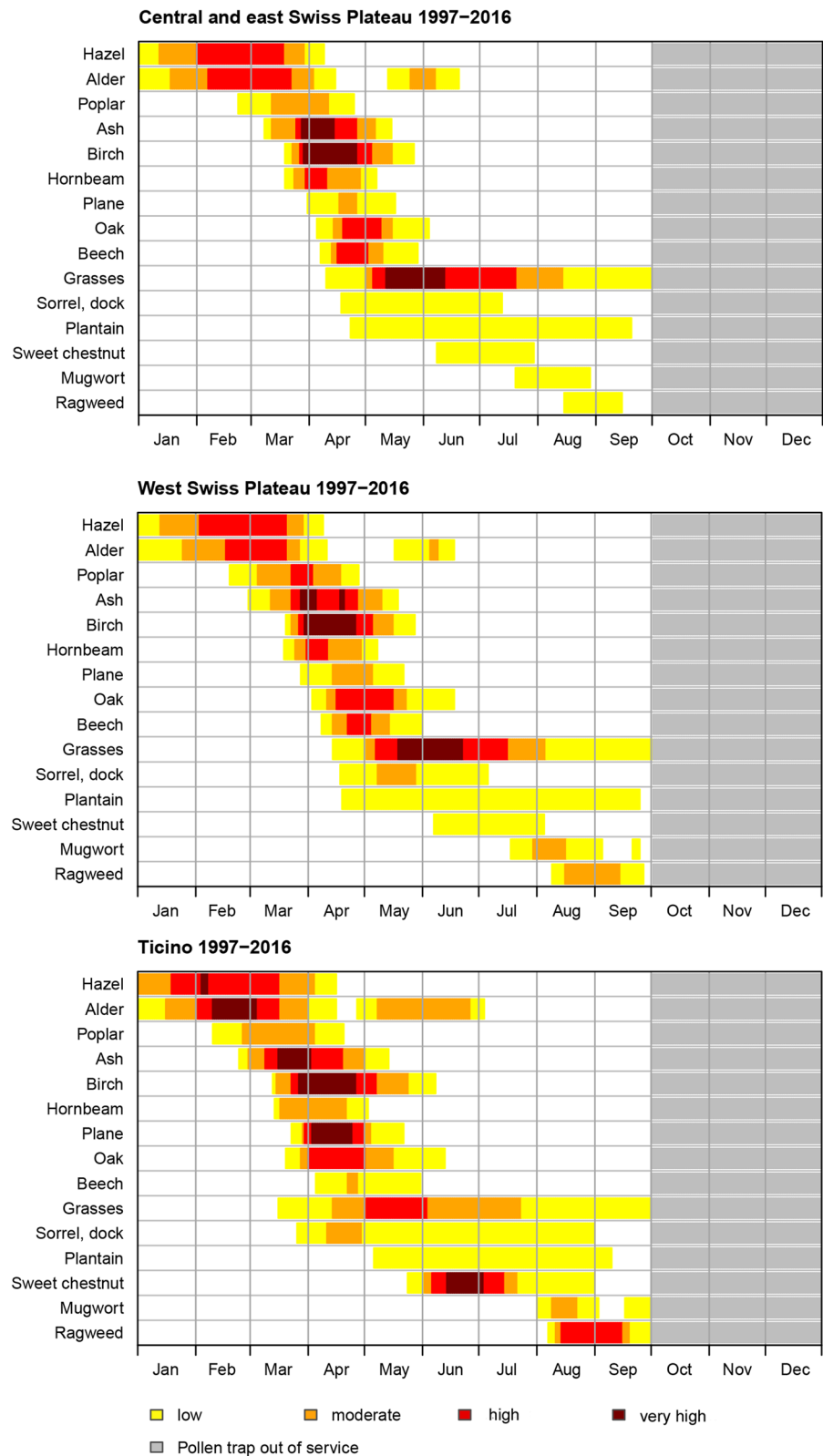
Fig. 4 Regional pollen calendars of Switzerland

Fig. 5 Pollen calendars of *Corylus* (hazel), *Alnus* (alder) and *Fraxinus* (ash) pollen for all monitoring stations of Switzerland

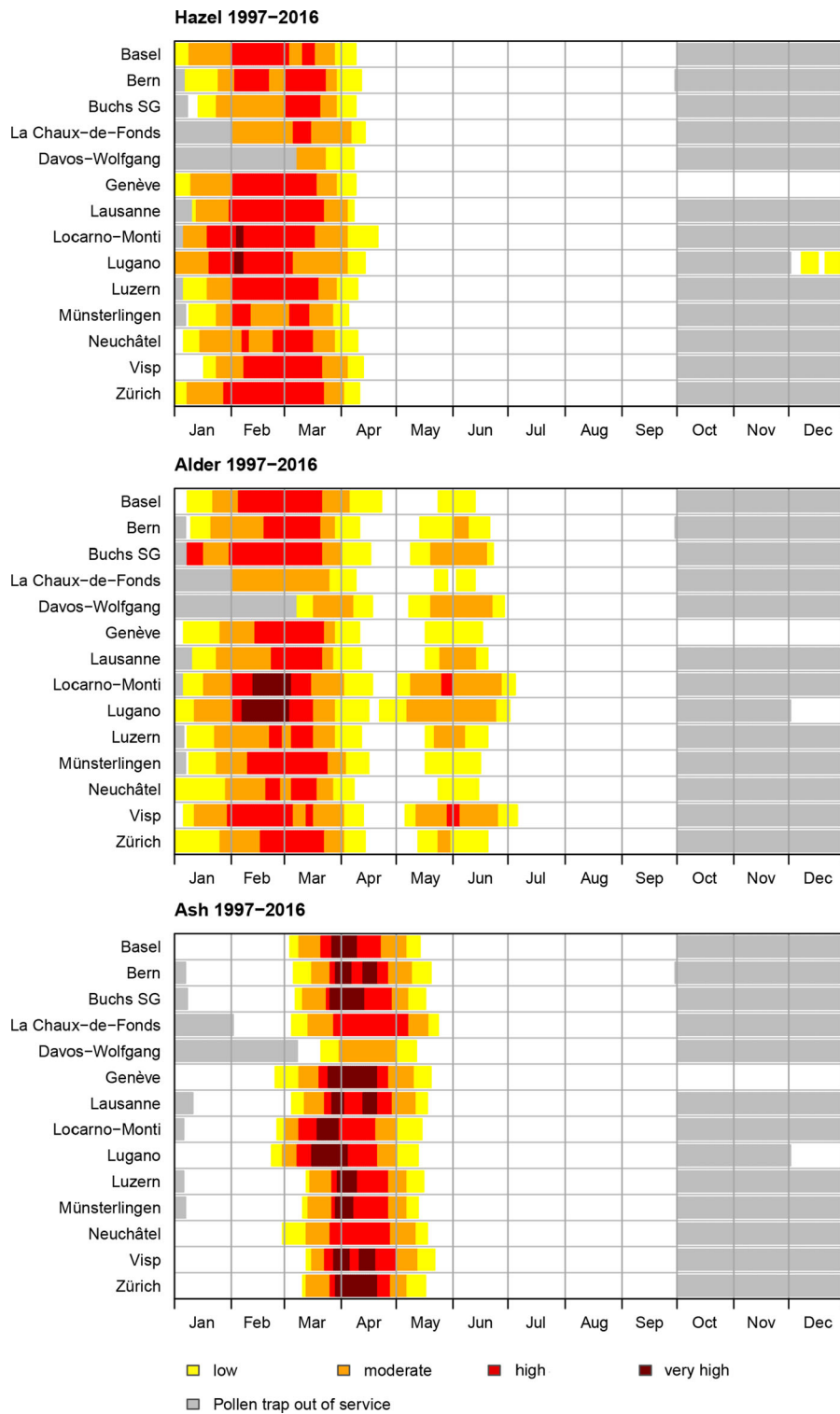
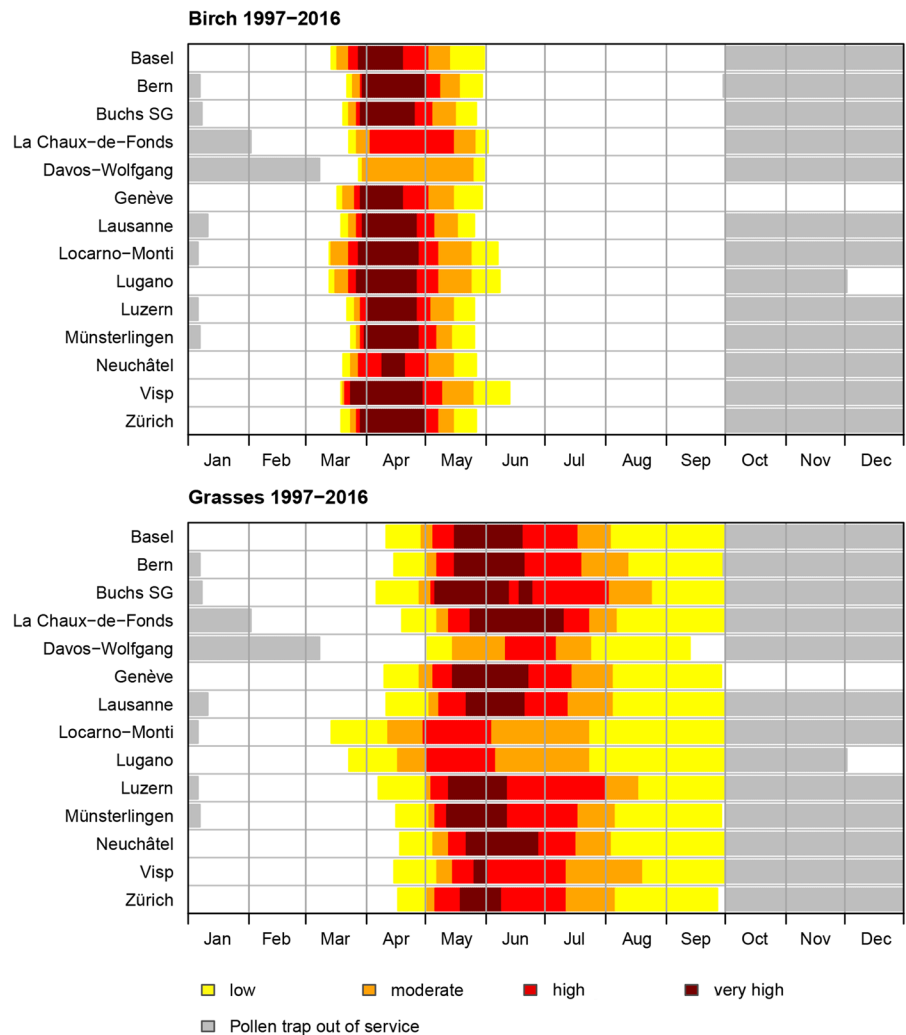


Fig. 6 Pollen calendars of *Betula* (birch) and Poaceae (grasses) pollen for all monitoring stations of Switzerland



of *Quercus*, *Artemisia* and *Ambrosia*, the separation of the Swiss Plateau into two pollen calendars is reasonable. The more local the pollen information, the better the benefit for the allergic persons.

3.2 Pollen calendars of selected allergenic species

3.2.1 Hazel (*Corylus*)

The pollen seasons of the different monitoring stations are quite variable (Fig. 5). North of the Alps, high *Corylus* pollen concentrations start mostly in February and can last until March. In Ticino (Lugano, Locarno), low concentrations are measured already in December, and the increase to high loads starts in mid-January.

The start dates and the timing of the peak periods of the *Corylus* pollen season show a higher yearly variability than the ones of the later flowering allergenic species (Table S1). A particular *Corylus* pollen season has often several peak periods, which are interrupted by long periods with very low pollen loads due to cold weather. This difference is due to the higher interannual variability in winter temperature than in summer temperature (Scherrer 2006). Therefore, the same problem with high variability arises also for *Alnus*, which is flowering at the same time period of the year. This high variability poses a difficulty when deducing a generalized pattern as needed for pollen calendars. For instance, north of the Alps, there is no indication for very high pollen load levels in the calendars, although in reality, such concentrations

were measured occasionally. But days with very high loads occur irregularly, and there is no station for which very high concentrations were measured regularly. This is the reason why the class of very high pollen loads is not present in the calendars for stations north of the Alps.

3.2.2 Alder (*Alnus*)

All pollen calendars of Switzerland show a two-phase *Alnus* pollen season (Fig. 5). From January until March *A. glutinosa* and *A. incana* are flowering and reach high pollen loads north of the Alps and very high loads south of the Alps. In May and June *A. viridis* flowers in the Alps above elevations of about 1400 m. Every year, this pollen is transported from the Alps toward the pollen stations at lower altitude and can lead to moderate concentrations. The closer the station to the source areas of the Alps, the more *A. viridis* pollen is measured. In Locarno and Visp, transported *A. viridis* pollen can even reach high concentrations. Another phenomenon occurs in Buchs, where the *Alnus* pollen loads can be high already at the beginning of January. This pollen originates from the nearby planted ornamental *Alnus x spaethii* trees, which frequently flower already at Christmas. They prolong the *Alnus* pollen season significantly and may lead to increased sensitizations to alder pollen (Gassner et al. 2013; Gehrig et al. 2015).

3.2.3 Ash (*Fraxinus*)

The *Fraxinus* pollen season starts mostly some days before the *Betula* pollen season (Fig. 5). Both pollen types lead to the important peak in hay fever symptoms in March and April (Dürr et al. 2008). This corresponds to the very high pollen loads recorded regularly in March and April on the Swiss Plateau, in Valais and in Ticino. In La Chaux-de-Fonds (1000 m), *Fraxinus* pollen reaches high loads in April. In Davos, all measured *Fraxinus* pollen originates from long-range transport and mostly only moderate concentrations are recorded. *Fraxinus* is the second most important deciduous tree in the forests of Switzerland and can grow up to elevations of about 1400 m (Brändli 1998). *Fraxinus* is also planted in towns, but not as frequently as *Betula*. Since 2008, the fungal disease of the ash dieback (*Hymenoscyphus fraxineus*) spreads in Switzerland and leads to the dieback of

branches or whole ash trees (Engesser and Meier 2012). In the years 2014 and 2016, the intensity of the *Fraxinus* pollen season was very low, most probably caused by this fungal infestation. A further weakening of the *Fraxinus* trees by this fungus would change the characteristics of the *Fraxinus* pollen season in the future.

3.2.4 Birch (*Betula*)

In Switzerland *Betula* pollen reaches high to very high concentrations from the end of March until the beginning of May (Fig. 6). The differences between the stations are low with some exceptions: Noticeable are the much less intense pollen season in the mountains (La Chaux-de-Fonds and Davos) and the very long pollen season in the cantons of Valais (Visp) and Ticino (Lugano and Locarno). In Visp, Lugano and Locarno, which all are situated in valleys with steep slopes and summits reaching more than 2000 m, the mountain wind transports *Betula* pollen after the end of the local flowering period in the valley from higher altitudes toward the valley bottom. In both regions, birch is a frequent tree in the forests. Birch is most frequently growing at elevations between 800 and 1200 m in forests, but can grow up to 2000 m in the western central Alps. North of the Alps, birch grows rather seldom in forests (Brändli 1998), but it is planted as ornamental tree frequently in towns and on cultured land. The pollen loads in towns are therefore high.

3.2.5 Grasses (*Poaceae*)

On the Swiss Plateau, moderate *Poaceae* pollen loads start at the beginning of May (Fig. 6). The increase to high concentrations occurs soon afterward, with only small variation in the timing within the stations north of the Alps. High pollen loads last until mid of July. The period and the length of very high pollen loads are variable and depend on the surrounding vegetation and land use of the monitoring stations. At the stations of Davos (1600 m) and in Ticino (Lugano, Locarno) the *Poaceae* pollen season is clearly less intensive than on the Swiss Plateau, north of the Alps. In Ticino, the *Poaceae* pollen season starts already in March with low concentrations and increases to moderate loads in mid-April. The period with high loads is already finished at the beginning of June, and very high

concentrations do normally not occur. In the mountain region of Davos, the Poaceae pollen season starts later, is short and reaches maximally high concentrations. La Chaux-de-Fonds (1000 m) belongs to the stations with the most intensive and longest Poaceae pollen season. Due to its higher elevation, the season starts later than on the Swiss Plateau, but especially very high pollen loads last remarkably longer than on the Plateau. The reason is that in the Jura mountain around La Chaux-de-Fonds, meadows are more frequent than on the Swiss Plateau.

3.3 The selection of the reference period

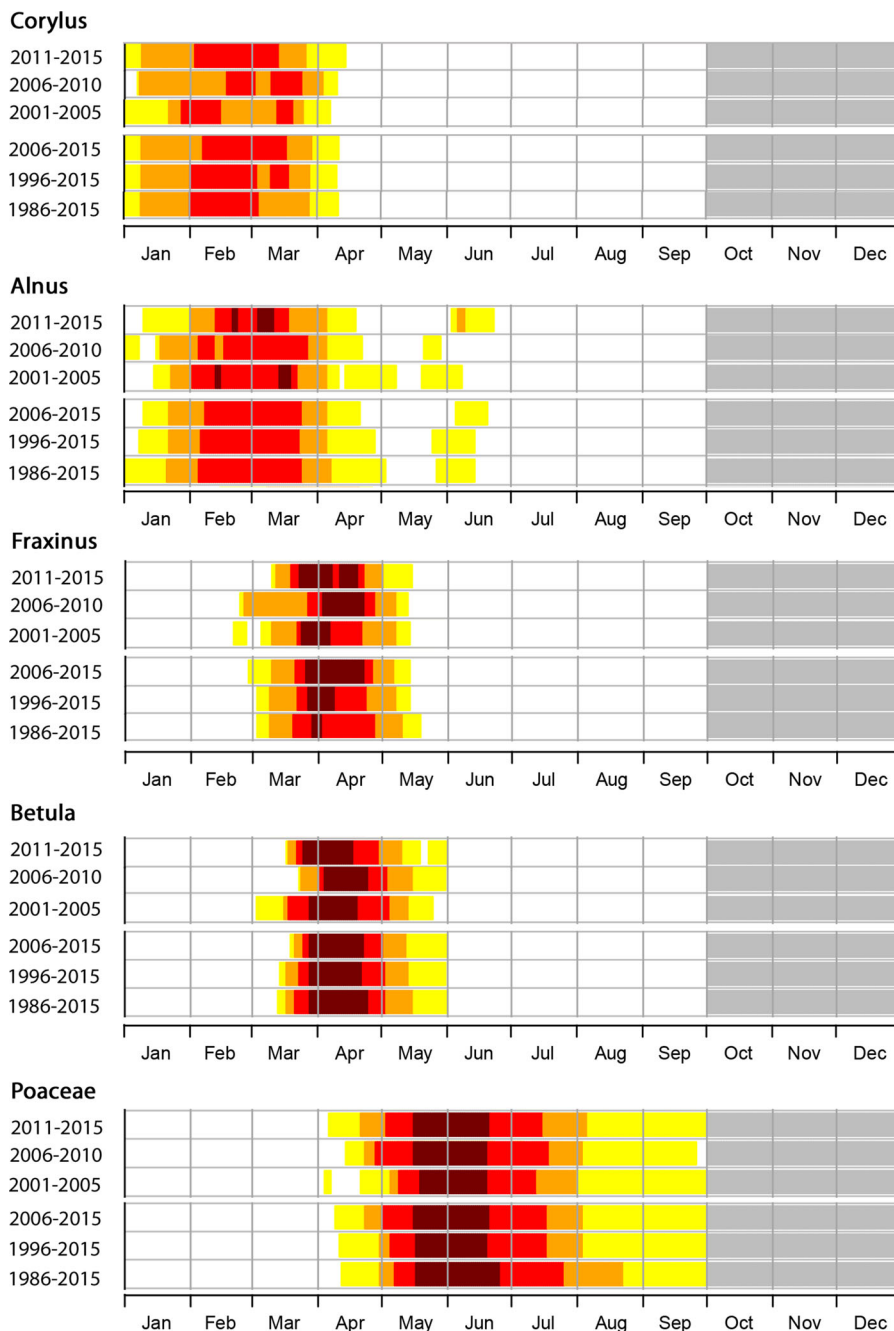
According to the recommendations given by Galán et al. (2017), pollen calendars are a graphical representation of the annual characteristics of major airborne pollen or spores recorded in a given location, which is an average of several years of data. (A minimum of 5 years is generally recommended.) The pollen seasons usually show a high yearly variability in the start dates, in the duration and in the intensity. To represent the whole characteristic of the pollen season at a given location, it is therefore necessary to include several years of pollen data for a pollen calendar.

To investigate the influence of the length of the reference period, we calculated pollen calendars with different reference periods for the monitoring station of Basel and most allergenic pollen taxa (*Corylus*, *Alnus*, *Fraxinus*, *Betula*, Poaceae) (Fig. 7). Three 5-year calendars (2011–2015, 2006–2010 and 2001–2005) are compared with a 10-year calendar (2006–2015), a 20-year calendar (1996–2015) and a 30-year calendar (1986–2015). Next to the interannual variability, long-term changes due to climate change or land use are further factors which have to be taken into account when making pollen calendars. To investigate the role of long-term trends, we estimated linear models $y = a \times x + b$ for the start dates, the number of days with high and very high concentrations and for the API_n (annual pollen integral) (Supplementary Online Information Table S1, Fig. S1, Fig. S2). The API_n is the integral over 1 year of mean daily pollen concentrations (pollen day/m³) (Galan et al. 2017) and was before presented as the annual or seasonal pollen index (API or SPI). The thresholds for the number of days with high and very high pollen concentrations are the same as used for the

pollen calendars (Table S1). During the 30-year period 1986–2015, there was no significant linear trend in the start dates of these pollen types. The API_n shows a significant decrease in Basel for *Betula* ($p = 0.029$) and Poaceae ($p = 0.018$), while for the other pollen species no significant change was found (Table S2).

The 5-year calendars show much bigger variations in the start dates and in the timing and length of the peak periods for *Corylus*, *Alnus*, *Fraxinus* and *Betula* than the long-term calendars of 10–30 years. For *Alnus* and *Corylus*, the great yearly variability of the start dates and peak periods of the pollen season reflects well in the 5-year pollen calendars. The long-time calendars show a more stable start date, but the peak period can still differ, especially for *Corylus*. The start dates of the *Fraxinus* pollen season have a variability of more than 1 month. Exceptional early start dates in February can occur and are due to long-range transport of pollen. The 5-year pollen calendars do not level out this variability neither for start dates nor for the timing of the peak pollen season. The 10–30-year-long pollen calendars are much more stable and show a comparable start date and length of the pollen season. Interestingly, there is a remarkable difference in the period of very high pollen loads of these long-term calendars. During the period of 1986–2015, the number of days with very high pollen loads has increased significantly (linear trend $p = 0.044$), but not the number of days with high pollen loads (linear trend $p = 0.312$) (Table S1). The API_n showed an increasing tendency during the same period, but without a significant linear trend ($p = 0.072$) (Table S1). This change is well visible when comparing the three long-term calendars, where the 30-year calendar has a much shorter period with very high loads than the calendar which covers the last 10 years. In the case of *Fraxinus*, the 30-year calendar does not reflect well the pollen season which users currently have to expect, because it includes too many years with lower pollen loads than occurring in recent years. The start dates and the timing of the peak period of the *Betula* pollen season vary over about a month, which is reflected in the short-term calendars. The three long-term calendars are again more stable and show a comparable timing and duration of the *Betula* pollen season. The Poaceae pollen season is less variable in the start dates or in the timing of the peak period. Nevertheless, the 5-year calendars show a difference in the start dates, but the peak season with

Fig. 7 Pollen calendars for Basel with different length of the reference period. For each pollen taxa, three 5-year calendars are compared with a 10-, 20- and 30-year calendar



very high pollen loads and the end of high loads are very similar. Although more stable, the three long-term calendars differ in two aspects. The 10-year calendar shows an earlier start of the Poaceae pollen season. While there is not significant linear trend of the start dates during the 30-year period from 1986 to 2015, there is a tendency for an earlier season start by

12 days in the period from 1996 to 2015 (linear trend, $p = 0.07$). Calculated APIn values reveal that in the long term, the Poaceae pollen season intensity has decreased since 1986. Additionally, the number of days with high pollen loads decreased from 47 to 30 days (linear trend, $p = 0.006$). Also the number of days with very high pollen loads decreased, but not

significantly ($p = 0.089$). These findings imply that also in the case of Poaceae, the 30-year calendar does not reflect exactly the current pollen season.

So which is the best selection of the reference period? The 5-year pollen calendars are affected more by the interannual variation of the pollen season and do therefore not fully reflect the characteristics of the pollen season at the specific location. 10- and 20-year calendars are more stable and give a better representation of the pollen season. Given the availability of long-term pollen data, also longer reference periods might be an option. In climatology, 30-year normal periods are normally used (WMO 2011). With long-term calendars, particular attention has to be paid, however, to possible trends in the pollen data. In the presence of long-term trends in season start dates or pollen intensities, a 30-year calendar may not be the optimal selection. Our comparisons reveal that pollen calendars calculated from the most recent 10 or 20 years of data give a robust climatological overview of the current pollen season at a specific location. The 20-year reference period that was chosen for the new pollen calendars of Switzerland therefore represents an optimal compromise between the whole climatological representation of the pollen season and the available length of data series.

4 Conclusion

Pollen calendars have different user groups. They are either produced for the general public as a well comprehensible allergy information or they can be used in scientific studies as an overview of the generalized pollen season at different locations. The requirements for these user groups are different; therefore, we propose to choose different calculation and presentation methods. For scientific studies, the method of Spieksma (1991) is exact and very convenient, but for the public pollen calendars showing the familiar pollen load levels correspond much better to the needs of the users. A short oral survey of users revealed that users prefer to get the whole time period, in which for example high pollen loads possibly occur and do not expect to see a mean pollen season. These needs can be met by the method of using a quantile value of daily pollen concentrations over several years. These pollen calendars can be automatically calculated, and therefore, regular updates are easily

generated. They show the time period when a pollen load level is likely to occur, i.e., that it occurred during the reference period in at least 10% of the years. Thanks to using daily concentrations, smaller differences between monitoring stations may be discovered compared with the method of decadal sums (Spieksma 1991). Our proposed method compares to the decadal sums inasmuch as daily concentrations are also smoothed by using a 9-day filter. This smoothing helps that the calendar is well generalized and it guarantees a greater robustness against unusual years with very early or late pollen season start and end dates or against high daily variations caused by changing weather conditions. For an adaptation to different locations or reference periods, it is important that different parameters in the program can be selected flexibly and adapted to the data: the quantile value (e.g., 80, 90%), the length of the filter window and the length of the reference period. For a 20-year period, the quantile of 90% and a filter length of 9 days were found to be most appropriate and showed the best results. When using reference periods of 5 years, we should be aware that the resulting pollen calendars are still affected by interannual variability of the pollen season and do not present the whole characteristic of the pollen season. Calendars of 10 or 20 years are more stable and are therefore better suited to represent the whole variation of the pollen season. A special focus should be put on trends of pollen data, which alter the characteristic of the season and can become important in long-term calendars of 20 or 30 years. A regular update of the pollen calendars is therefore recommended.

References

- Brändli, U. -B. (1998). Die häufigsten Waldbäume der Schweiz. Ergebnisse aus dem Landesforstinventar 1983–85: Verbreitung, Standort und Häufigkeit von 30 Baumarten. Berichte der Eidgenössischen Forschungsanstalt für Wald, Schnee und Landschaft (p. 342).
- Calderón-Ezquerro, M. C., Guerrero-Guerra, C., Martínez-López, B., Fuentes-Rojas, F., Téllez-Unzueta, F., López-Espinoza, E. D., et al. (2015). First airborne pollen calendar for Mexico City and its relationship with bioclimatic factors. *Aerobiologia*, 32(2), 225–244.
- de Weger, L. A., Bergmann, K. C., Rantio-Lehtimäki, A., Dahl, A., Buters, J., Déchamp, C., et al. (2013). Impact of pollen. In M. Sofiev, K. C. Bergmann (Eds.), *Allergenic pollen: A*

- review of the production, release, distribution and health impacts* (pp. 161–215). Dordrecht: Springer.
- Dürr, C., Heimgartner, S., Gehrig, R., Caversaccio, M., & Helbling, A. (2008). Pollenallergie: Klinische Aspekte. Teil 1. Schweiz. *Medical Forum*, 8, 253–257.
- Engesser, R., & Meier, F. (2012). Eschenwelke wird noch bedrohlicher. Aktuelle Verbreitung und neuer Infektionssweg. *Wald und Holz*, 12(12), 35–39.
- Galán, C., Ariatti, A., Bonini, M., Clot, B., Crouzy, B., Dahl, A., et al. (2017). Recommended terminology for aerobiological studies. *Aerobiologia*, 33, 293–295.
- Galán, C., Smith, M., Thibaudon, M., Frenguelli, G., Oteros, J., Gehrig, R., et al. (2014). Pollen monitoring: minimum requirements and reproducibility of analysis. *Aerobiologia*, 30, 385–395.
- Gassner, M., Gehrig, R., & Schmid-Grendelmeier, P. (2013). Hay fever as a Christmas gift. *New England Journal of Medicine*, 368, 393–394.
- Gehrig, R. (2012). Die Repräsentativität der Pollenmessstationen des Schweizer Pollenmessnetzes. Arbeitsberichte der MeteoSchweiz (p. 237).
- Gehrig, R., Gassner, M., & Schmid-Grendelmeier, P. (2015). *Alnus x spaethii* pollen can cause allergies already at Christmas. *Aerobiologia*, 31(2), 239–247.
- Hirst, J. M. (1952). An automatic volumetric spore trap. *The Annals of Applied Biology*, 39(2), 257–265.
- Kühne, H., & Bergmann, K. C. (2008). New pollen calendars for Germany. In *Abstracts of the 8th European pollen symposium, bad lippspringe, 29–30 March 2008* (Vol. 17, p. 375).
- Mandrioli, P., Comtois, P., & Levizzani, V. (Eds.). (1998). *Methods in aerobiology*. Bologna: Pitagora Editrice.
- Martínez-Bracero, M., Alcázar, P., Díaz de la Guardia, C., González-Minero, F. J., Ruiz, L., Trigo Pérez, M. M., et al. (2015). Pollen calendars: a guide to common airborne pollen in Andalusia. *Aerobiologia*, 31(4), 549–557.
- Nilsson, S., & Palmberg-Gotthard, J. (1982). Pollen calendar for huddinge (Sweden), 1977–1981. *Grana*, 21(3), 183–185.
- Scherrer, S. C. (2006). *Interannual climate variability in the European and Alpine region*. Dissertation Swiss Federal Institute of Technology (ETH) Zürich No. 16338 (pp. 120). <https://doi.org/10.3929/ethz-a-005133273>.
- Spieksma, F. T. M. (1991). Regional European Pollen Calendars. In G. D'Amato, F. T. M. Spieksma, S. Bonini (Eds.), *Allergenic pollen and pollinosis in Europe* (pp. 49–65). Oxford: Blackwell Scientific Publications.
- Stahel, W. A. (2008). *Statistische Datenanalyse. Eine Einführung für Naturwissenschaftler* (5. Auflage). Wiesbaden: Friedr. Vieweg & Sohn Verlag.
- Stix, E., & Ferretti, M. L. (1974). Pollen calendars of three locations in Western Germany. *Atlas European des Pollens Allergisants*, 85–94.
- WMO. (2011). Guide to climatological practices. WMO-No. 100, 2011 edition. Chapter 4.8. Updated Jan 19, 2016 from http://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.php.