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Pollen allergy and the impact of a changing climate

While hay fever was almost unheard of in Switzerland 100 years ago, at present, around 20 percent of the Swiss population suffers from pollen allergy. Importantly, climate change is causing an earlier onset and increased intensity of the pollen season for many allergenic plants. Climate change also fosters the spread of highly allergenic invasive plants like ragweed. Furthermore, the combined exposure to air pollution and pollen may worsen allergic reactions through increased sensitivity and increased pollen allergenicity. Scientists of the Swiss Commission for Atmospheric Chemistry and Physics provide an overview of pollen, hay fever, and how climate change is affecting both.

Pollen Allergy

Pollen allergy, hay fever, and allergic rhinitis are all terms that are used to describe an allergic reaction to pollen from wind-pollinated plants. Typical manifestations of pollen allergy include nasal symptoms (sneezing and itching, a runny or blocked nose) and ocular symptoms (itchy or watery eyes),[1] sometimes accompanied by fatigue and skin disorders (eczema). In people with allergic asthma, a reaction to pollen may also cause severe breathing difficulties, in the most extreme cases requiring hospitalisation. In addition to decreasing the quality of life and sleep, allergic reactions cause systemic inflammation, which may lead to a cascade of other long-term reactions in the body. For example, people with pollen allergies may be predisposed to developing high blood pressure in the long term.[2] A growing number of studies show that on days with high pollen concentrations, cardiovascular[3] and respiratory[4] hospitalizations also increase.

Sensitization vs symptom phases

For a person to develop a pollen allergy, they first need to be exposed to a particular allergen to which their immune system overreacts because it erroneously identifies it as a threat. Over time, their immune system develops a memory for that particular allergen, thus preparing the body for more effective combat upon subsequent exposures. This is the sensitization phase. The symptom phase occurs once the immune system is 'trained' and reacts to the allergen at each exposure, causing an allergic reaction. Symptoms may worsen and, in time, people may become sensitised to additional allergens.

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Increased prevalence of allergies: The hygiene hypothesis

The revised 'hygiene hypothesis' suggests that being exposed to a low diversity of microbes may result in a different development of the immune system. The body then mistakenly overreacts when it encounters relatively harmless pollen. The Swiss SCARPOL study,[5] and many others worldwide, have shown that children growing up on farms have lower rates of pollen allergy, asthma and allergic sensitization. While it seems clear that rural/agricultural exposure at an early age has a protective effect, many questions remain regarding the type, duration and age during exposure at which the protective effect occurs.

The importance of pollen allergy in Switzerland

While pollen allergy was almost unheard of in Switzerland 100 years ago (just 0.8% of the population was estimated to be allergic in 1926), prevalence has since increased dramatically and is estimated to be around 20% of the Swiss population at present. Some studies suggest that hay fever prevalence has stabilised in Switzerland since the 1990s,[6] but only a few studies have representative or long-term data. A recent review shows little evidence for such a plateau in surrounding countries.[7] The increase in allergy prevalence is also a worldwide phenomenon, and while it shows large geographic variability both in children and adults, it is not limited to developed countries in 'the West'.

Allergy sufferers describe a worse quality of life during the pollen season, including wanting to withdraw from social activities and feeling insecure about their appearance (due to swollen eyes, sneezing, etc). For many, their allergies feel trivialised and often the symptoms are insufficiently treated (fig. 1). While pollen allergies are common, many people never obtain a formal diagnosis either from a physician or a specialised allergologist. Among the 303 people who self-identified as pollen-allergic and took part in a recent Swiss study, only 65% were ever diagnosed by a medical doctor.

In addition to the effects on quality of life, the economic impact is substantial. In Switzerland, estimates range from 1–4 billion Swiss Francs per year, including both direct costs for medication or hospitalisation and indirect costs related to lower productivity and missed school/work days.[8, 9]

Sources of airborne pollen

Many different flowering plants produce allergenic pollen, for example trees, grasses, or other herbaceous plants (fig. 2). However, the exposure needs to be regular and at a high enough level for a person to become sensitised. This means that a certain type of pollen needs to be abundant enough in the air for it to become a cause of allergy in a specific geographical area. Once a person is allergic, however, exposure to even a small amount of the corresponding allergenic pollen or a cross-reacting pollen can provoke symptoms.

Pollen is often considered to originate from natural sources, however, in many regions plants are strongly influenced by human activities. They are planted as part of urban green spaces or as ornamentals in private gardens, as well as in agricultural fields, or even in forests.

Impact of weather on the pollen season

The annual cycle of plants and thus the pollen season is closely linked to weather. Temperature, water availability, humidity and wind all play major roles, with weather patterns governing the intensity, timing and duration of pollen seasons. High temperatures in the months prior to the pollen season generally accelerate plant development and the start of flowering. During the season, pollen emission is favoured by higher temperatures, sunshine and medium humidity, while it is stopped by precipitation.

Temperature and water availability also potentially influence the intensity of the pollen season. In the case of trees, the

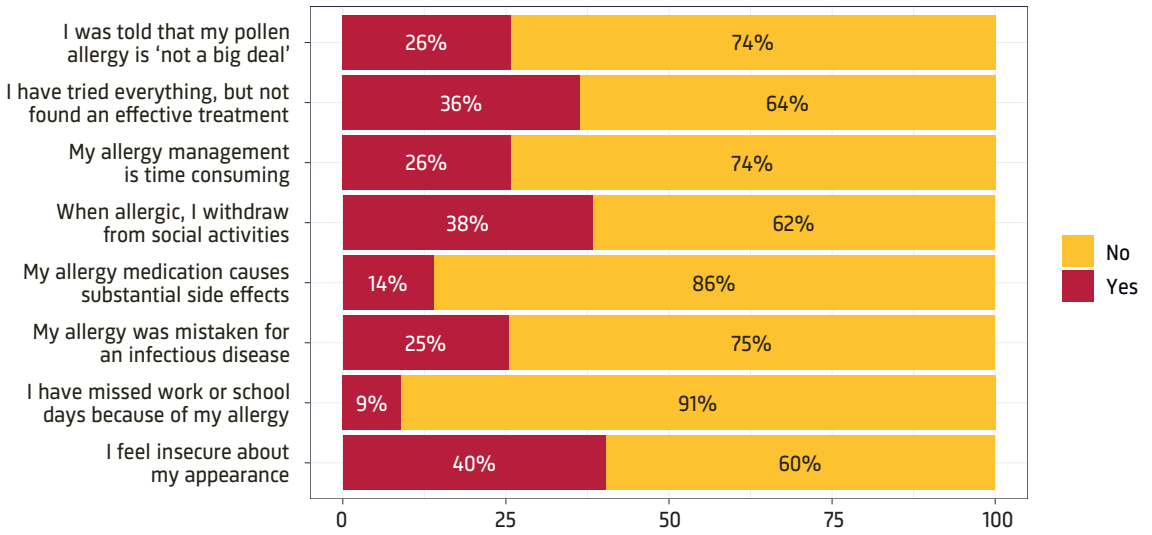

Figure 1: How people experience their pollen allergy: social, psychological and economic impacts. Results from a recent study in the Basel area of Switzerland. Source: Marloes Eeftens

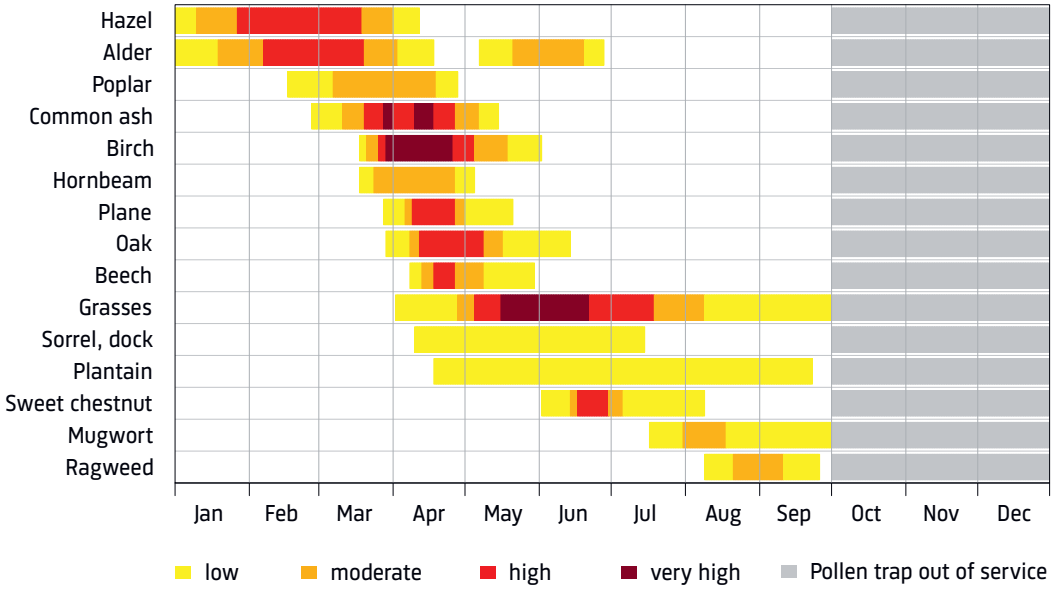

Figure 2: The pollen calendar for Switzerland informs allergy sufferers when certain allergenic pollen is typically abundant, which may help determine to which type(s) of pollen people react. However, only medical doctors can provide full diagnoses. The pollen calendar is also useful to plan trips/holidays in order to avoid pollen exposure. Source: MeteoSwiss

weather conditions in the year before flowering influences how many buds form and thus how much pollen the tree can release. For grasses, it is the availability of water before and during the growing season that determines how many flowers and how much pollen is produced. If there is sufficient soil moisture, pollen concentrations are particularly high during long, sunny periods.

Weather also plays an important role in the atmospheric dispersion of pollen. In turbulent and windy conditions, pollen can be transported much further than in calm weather situations. Because pollen grains are relatively large particles, they are typically not transported as far as other aerosol types. But when the conditions are favourable, pollen can be transported several hundreds or even thousands of kilometres.

Environmental factors affecting allergic disease

In addition to the genetic heritability of allergy, there are several environmental factors which have been associated with the development of pollen allergy. Avoiding initial exposure to an allergen is the most obvious strategy to prevent sensitization. However, this is becoming increasingly difficult because of climate change, which is facilitating the spread of highly allergenic species, such as ragweed. Models predict that sensitization to ragweed will increase in Europe from 33 million people in 2016 to 77 million by 2041–2060, simply because more people will be exposed to the pollen of this invasive plant.[10] Controlling the spread of ragweed in areas where it is currently still uncommon, as has been successfully done in Switzerland since 2006, may help to alleviate the future allergy burden.

Air pollution and the development of allergy

Several epidemiological studies have indicated that air pollutants (e.g., particulate matter, ozone, or nitrogen dioxide) are associated with higher risks of allergic rhinitis.[7] However, these studies have been cross-sectional and causality therefore cannot be assured. Nevertheless, toxicological studies suggest that inflammatory responses to air pollutants can increase the permeability of the airway epithelium, a protective inner 'skin', allowing easier access of allergens to the immune system[11] and potentially providing a physiological pathway for air pollution to impact the development of allergies.

Air pollution and pollen allergenicity

From a public health perspective, both pollen and air pollutants have been shown to independently have adverse

Urban vegetation and exposure to allergens

An interesting example of how exposure can cause allergies comes from eastern Switzerland. In the late 1990s, close to 100 alder trees (specifically *Alnus x spaethii*) were planted along the main throughway in Buchs, Sankt Gallen. This tree is known for its winter resistance, and flowers very early in the year, sometimes as early as Christmas. Researchers investigated allergic symptoms and blood serum samples in a random sample of 54 students before (1986) and 46 students after the trees were planted (2006), and found that while none of the students tested positive in 1986, 11% were sensitised to alder pollen in 2006. Moreover, of the 12 former students who agreed to be re-tested two decades later, 25% had developed a sensitization to alder pollen since the trees had been planted. The alder trees in Buchs were removed in 2014 because of issues with the large amounts of leaf litter and replaced with low-allergenic sweetgum trees. Likewise, more and more Swiss cities are taking into consideration allergenicity when planning urban green spaces.

effects on respiratory health, particularly asthma. Some studies suggest that the combined exposure to both air pollution and pollen may induce even stronger effects. The damage to the lung epithelium caused by air pollutants may make the airways more susceptible to airborne pollen. But so far, evidence for such amplifying effects between pollen and air pollutants is weak.[4]

The amount of allergens in pollen grains varies considerably from plant to plant and in different environmental conditions. High-stress growing conditions and elevated ozone concentrations may increase the allergenicity of tree pollen.[12] In particular, polluted urban environments pose challenging growing conditions for plants and this increased stress may drive plants to produce pollen with higher levels of allergens or pro-inflammatory substances. In skin-prick tests, patients reacted more strongly to pollen with higher allergenicity. Indeed, a recent study found that asthma hospital admissions were more strongly related to the allergen levels of the pollen, than to the pollen level itself.[13]

Impacts of climate change on airborne pollen levels

Climate change affects the onset, length and intensity of pollen seasons for many plants.[14] Globally, a trend to an earlier start of the pollen season has been observed. In Switzerland, this trend is clearly linked to warmer winter and spring temperatures. The hazel and alder pollen seasons now often begin in January instead of February. Over the past 30 years, the hazel and grass pollen seasons have, on average, started around two weeks earlier for both species,[16] while their and other herbaceous pollen seasons also tended to become longer (fig. 3). These changes have extended the total duration of the pollen season in Switzerland.

With increasing atmospheric carbon dioxide, plants produce more pollen because of more favourable growing conditions.[15] In Europe and Switzerland, a significant increase in tree pollen abundance has been measured in the last 30 years.[16] This might also be linked to the increase surface of forested areas or ornamental trees. However, the amount of grass pollen has not changed significantly and levels of certain other herba-

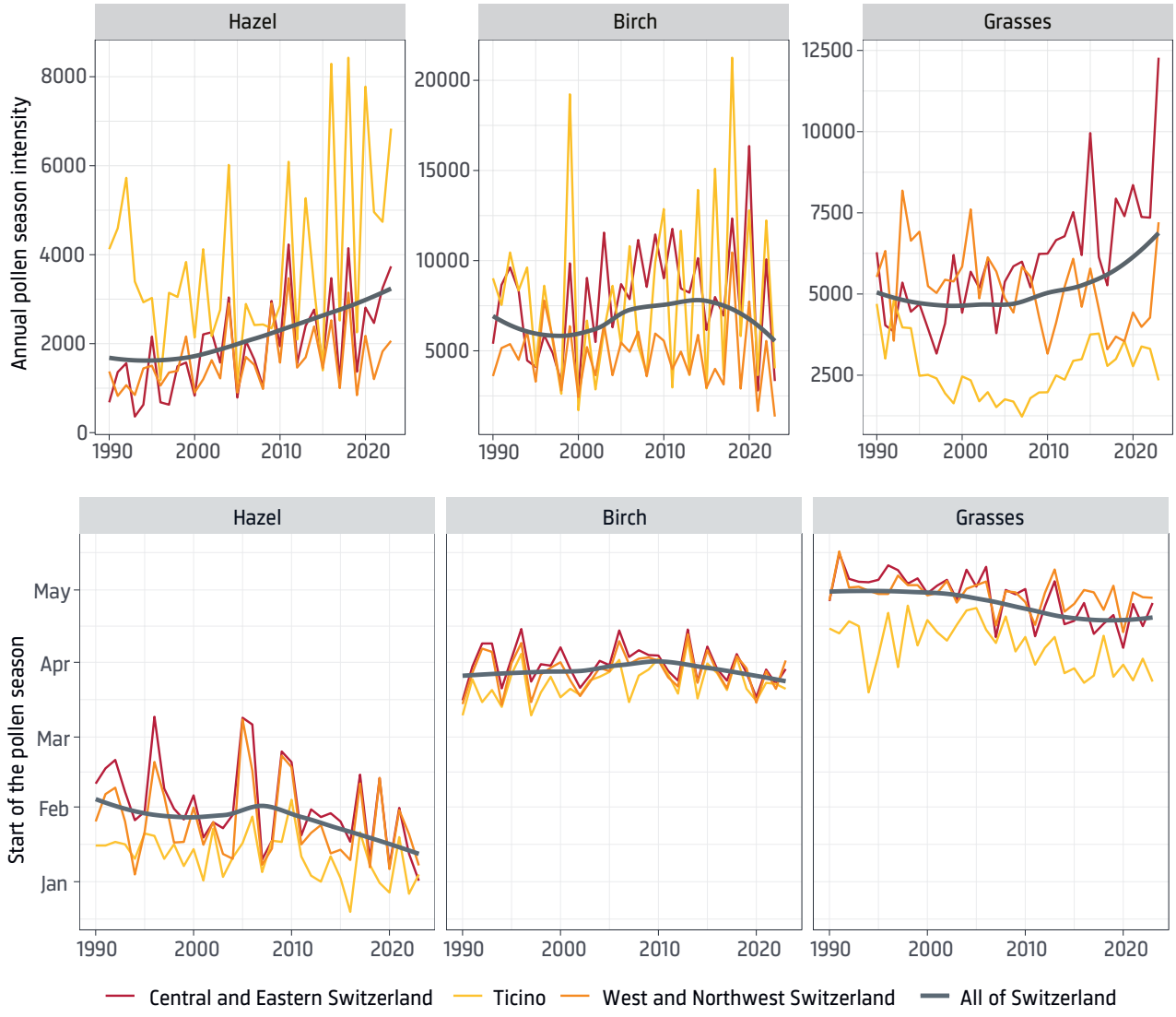

Figure 3: The intensity (the total of all pollen over the season, top) and start (bottom) of the pollen seasons for Hazel, Birch, and Grasses are changing in Switzerland, with tendencies towards more pollen and earlier start dates. Source: Marloes Eeftens

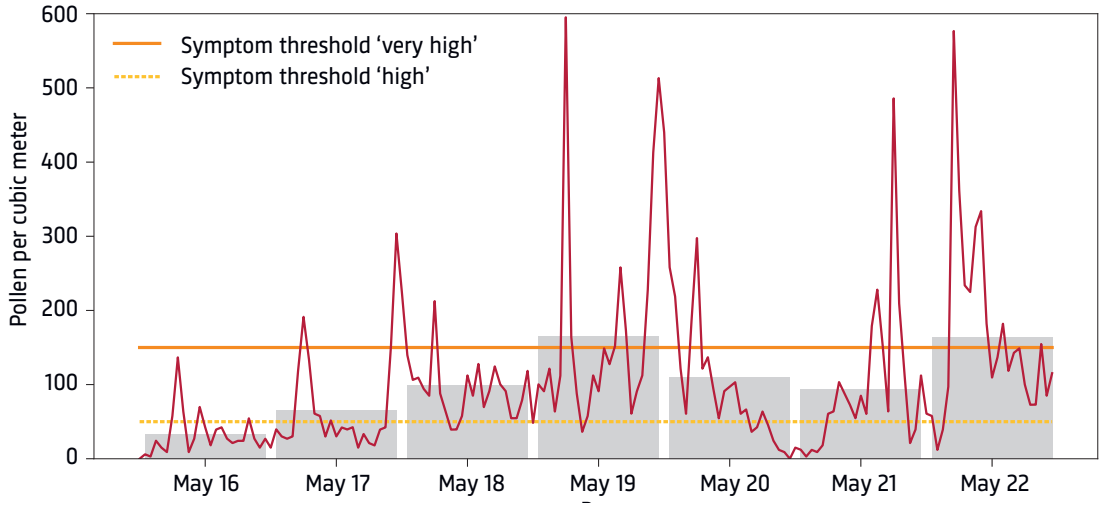

Figure 4: The real-time grass pollen observations (red line) provide current hourly values, which is for allergy sufferers much more useful than daily averages being made available 3–9 days later as was usual with manual observations (grey bars). The automatic observations are also integrated in real-time into the MeteoSwiss forecast model to produce more accurate forecasts. Source: MeteoSwiss

ceous pollen have even decreased. The latter is, however, rather the result of reduced vegetated areas with more intensive agricultural land use and increased urbanisation.

In the long term, plant distributions are expected to shift with climate change. Some allergenic plants will move into new areas, for example from the Mediterranean to Central Europe or further up into the Alps. Others may also decrease in certain regions as conditions make their survival impossible. Even if plant distributions do not change, the pollen season may change, for example, long dry periods in summer tend to reduce grass pollen concentrations and shorten the flowering season.

To sum up, in the future, people with pollen allergies are likely to be exposed to higher pollen concentrations over longer periods.

Pollen information: From measurement to forecast

Pollen monitoring in Switzerland started from 1969 onwards under the impulsion of medical doctors using a manual method developed in the 1950s.[19] This method has been widely used across the world for decades and entails a microscopic analysis of samples that have been taken over the previous week. The weekly drum is divided into seven pieces to provide daily average values which are made available with a delay of 3–9 days.

This technology has been replaced by automatic devices which provide information in real-time and at much higher temporal resolution (hourly instead of daily) (fig. 4). Sixteen automatic instruments are currently operational across Switzerland as part of the Swiss pollen monitoring network (SwissPollen, run by MeteoSwiss). In a pioneering effort, real-time pollen data are integrated into the forecast model, similarly to what is done with weather observations, which has resulted in significantly improved forecasts over Switzerland. In the future, it may be possible to use such information to provide warnings, also in combination with other environmental stress factors such as air quality or meteorological events like thunderstorms.

Automatic devices also open the door to monitoring a range of other particle types, for example, fungal spores, large dust particles, or potentially even microplastics. Such advancements require significant efforts to develop identification software, but would provide information important for health, agriculture and research.

Climate Change in Switzerland

Over the past 150 years, anthropogenic emissions of greenhouse gases have dramatically increased, leading to unprecedented changes in the climate at all scales. In February 2024 the global monthly average temperature was, for the first time ever, 1.5 °C warmer than the pre-industrial period.[17]

Warming in Switzerland is double that of the global mean and the last decade (2014–2023) has been 2.7 °C warmer than the pre-industrial period.[18] The progressive warming has translated into an increased frequency and intensity of heat waves, while cold periods are occurring much less often. Heavy precipitation events are also much more frequent and intense.

As a result of these changes, many natural processes have been affected in addition to pollen. These include changes in the spread of vectors transmitting infectious diseases (e.g., ticks, mosquitoes) or high concentrations of dangerous air pollutants (e.g., resulting from more wildfires).

Strategies for allergy management

Personalized allergy management like medication, immunotherapy, and avoiding exposure may prevent or mitigate the symptoms of allergic individuals. However, with 20% of the population affected, mitigation strategies also need to target public health:

- **Limiting climate change:** The changing climate has already contributed to earlier and more intense pollen seasons in Switzerland, as well as changing habitats for highly allergenic invasive species. Mitigating climate change will slow these trends but will require large local, regional, and global action.
- **Active eradication:** Since the mid-1990s, legal measures have been in place in Switzerland to control the spread of highly allergenic, invasive neophytes such as ragweed. Thanks to early action and the continued commitment of cantons, municipalities, and the road and railway services, ragweed is effectively controlled throughout Switzerland since 2006.
- **Smart urban plan(n/t)ing:** Urban vegetation is important for keeping cities cool, providing shade and biodiversity, and generally increasing public health by offering space for leisure and physical activity. Urban trees are often selected for their tolerance to typical urban stressors, such as a lack of root space and polluted air and water. Planting them is an expensive and long-term investment, thus it is important to consider how they handle climate change and to choose low-allergen plants or low pollen producing plants to reduce pollen exposure.[20]
- **Environmental monitoring and public health warning systems:** Continuous evaluation and improvement of monitoring and warning systems can help to warn the allergic population of high pollen episodes in a personalised manner. Similar action plans have been implemented for heat waves.
- **Indoor air filtration:** Air filters can significantly reduce the levels of airborne allergens in public and private buildings but need to be sufficiently maintained (e.g., filters regularly exchanged).
- **Reducing air pollution:** As air pollution may increase the allergenicity of pollen grains and aggravate allergic reactions, reducing air pollution will have positive effects on the allergy situation as well as several other health conditions which would benefit from cleaner outdoor air.
- **Increasing biodiversity in urban areas:** It has been suggested that living in areas with a high biodiversity of plants, animals, microbiota, etc. and being in contact with nature may prevent allergic disease. Choosing a variety of indigenous plants in gardens, and protecting and increasing the biodiversity at local as well as at larger scales will have positive effects on the allergy situation and health in general.

On an individual level, the aha! Swiss Allergy Centre provide useful tips for allergy sufferers on their website: aha.ch.

Real-time measurements of the main allergenic pollen as well as forecasts for the coming days can be found on the MeteoSwiss website (meteoswiss.ch), on the MeteoSwiss smartphone application and on the Pollen-News application of the aha! Swiss Allergy Centre.

SDGs: The UN's International Sustainable Development Goals the UN

This publication of the Swiss Academy of Sciences (SCNAT) contributes to SDGs 3, 13, and 15:
'Ensure healthy lives and promote well-being for all at all ages', 'Take urgent action to combat climate change and its impacts', and 'Protect, restore and promote sustainable use of terrestrial ecosystems'.

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