



Documentation of the calculation of annual mean values and climate normals in phenology

This short report documents the method for calculating the annual mean values and the climate normals of phenology, presents the characteristics of the phenological data for Switzerland and shows the results of the changes in vegetation between the two normal periods 1961-1990 and 1991-2020.

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1 The Swiss Phenology Network and properties of phenological data

The Swiss Phenology Network currently comprises around 160 stations at which observers record the development of 26 different plant species. At these stations, they record the time of flowering, leaf development, fruit ripening, leaf discolouration and leaf fall of the respective plant species, the so-called phenophases. At MeteoSwiss, we refer to the combination of plant species and phenophase as phenoparameters, e.g. the flowering of dandelion. Detailed observation instructions help to ensure that the various phenophases and phenoparameters are precisely recognised and that the observations are carried out as uniformly as possible at all stations (Brügger and Vasella 2003).

The Swiss Phenology Network was founded in 1951 and comprised around 70 stations at the time (Jeanneret et al. 2011). Over the years, more and more stations have been added. However, stations have also been abandoned time and again. Of the stations that existed in 1951, 21 are still active today and therefore have very long data series (Fig. 2). The phenological stations are distributed over an altitude range of 200 to 1933 m and cover all regions and altitude levels of the country (Güsewell et al. 2018, Fig. 1, 3). The median altitude has changed slightly over time and has fallen from 788 m at the end of the 1950s to 640 m today. The altitude gradient of the phenology is around 2.5 - 3 days /100 m in spring and summer and - 0.5 days in autumn (Güsewell et al. 2018). When calculating simple mean values for the stations per year, the difference between the maximum height of 150 m between the stations would account for a difference of 3.75 – 4.5 days. Since 1975, the median altitude has been in the range of 635 - 675 m and the fluctuations are therefore of little significance for the average development of phenology.

The quality of the data series of the currently active stations was checked and outliers were marked and/or removed. The work of Auchmann et al. 2018 served as a basis for this. The results were further verified, processed and implemented by MeteoSwiss. Quality checks of the reported data are also carried out on an ongoing basis. The data from the active stations therefore form the basis for the climatological analyses of the phenology. Stations that were abandoned in earlier years have not yet been quality-checked. In future, they may supplement the calculation of annual averages, especially in earlier years.

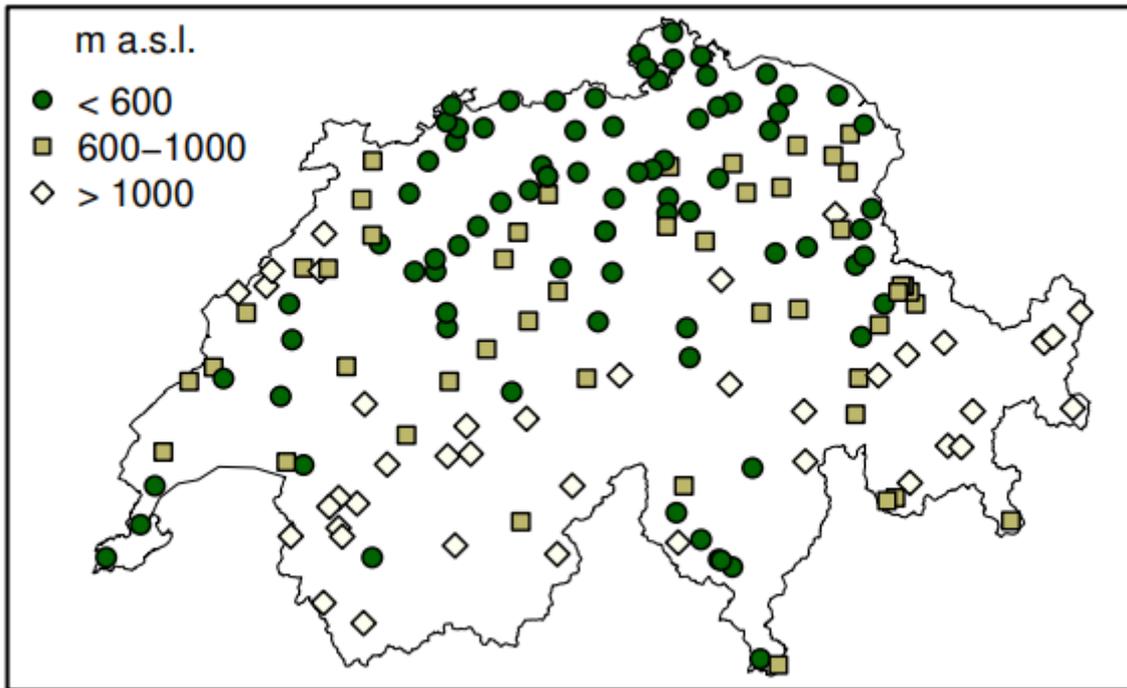


Figure 1: Location of active phenology stations and assignment to altitudinal layers (from Gusewell et al. 2018)

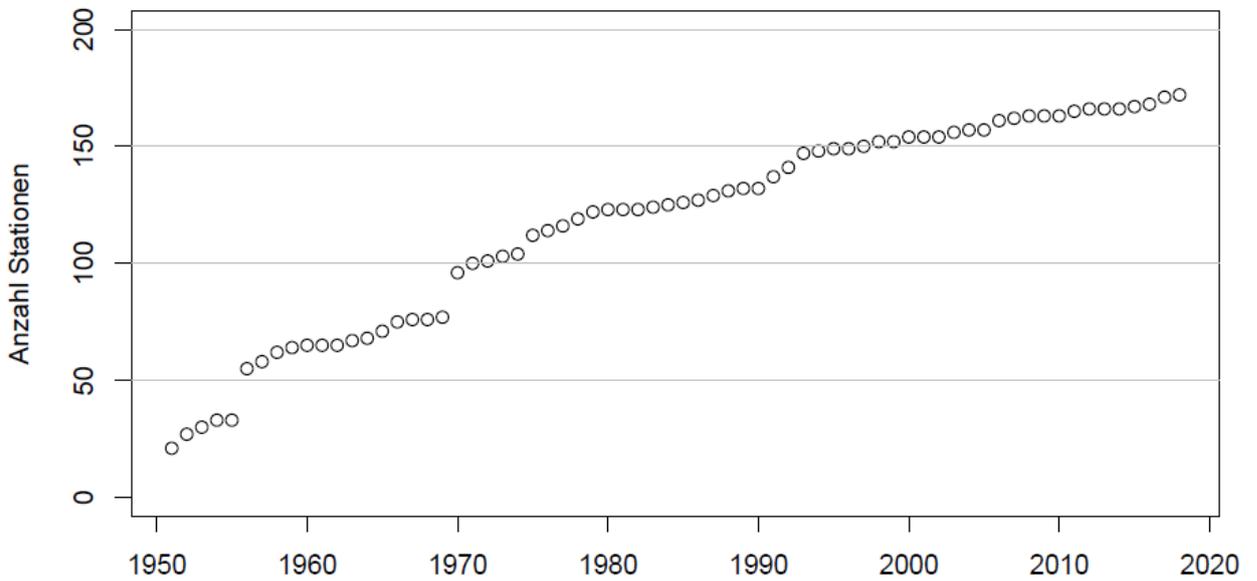


Figure 2: Development of the number of active phenology stations used for the mean value calculation.

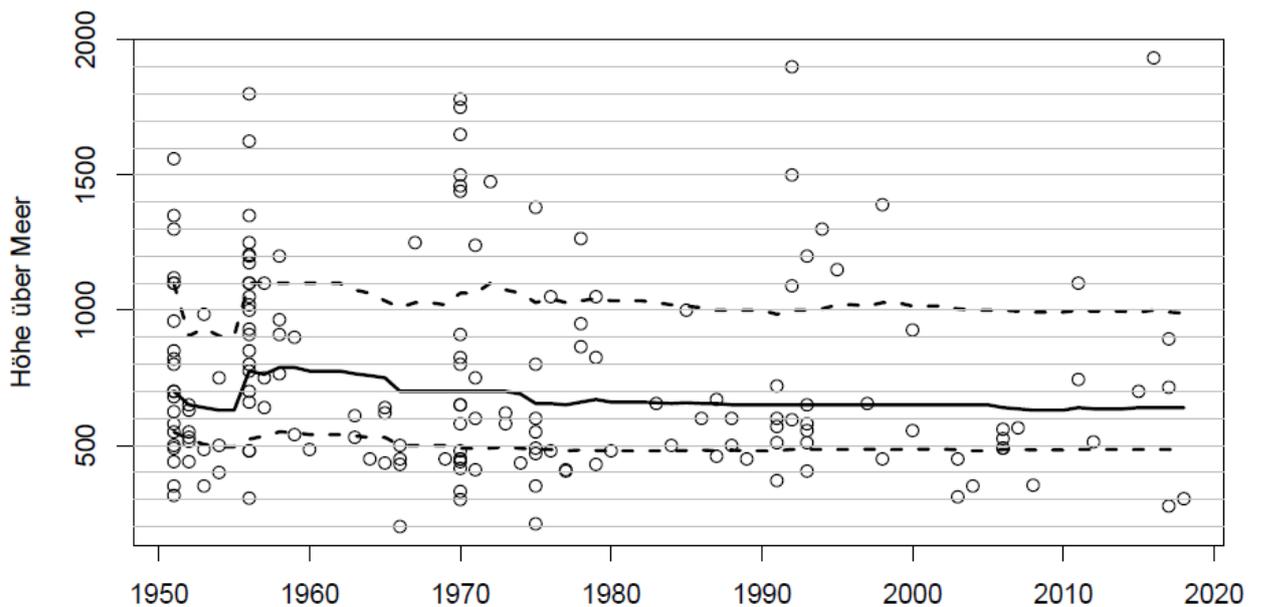


Figure 3: Height distribution of active phenological stations (median and percentiles 0.25, 0.75). The circles show the stations added in the respective years.

Phenological data are observational data and not exact measurements. They have various uncertainties that can hardly be quantified. The observers' assessment of the state of vegetation remains subjective to a certain extent, despite precise instructions. A single phenological phase can exhibit great variability in a small area, as the genetic variability of the plant species, the microclimate and the location influence its development. It is therefore important to observe always the same plant, which should represent an average development at the location. Individual time series are often incomplete and have data gaps, which further complicates their analysis. Changing the observer and the observed plant can cause inhomogeneity in the data series. Inhomogeneities of the data series were analysed (Auchmann et al. 2018), but it is hardly possible to correct the inhomogeneities.

By calculating the mean values of several phenological time series over a geographical area, the problem of uncertainty, gaps and the changing number of stations is reduced in phenology (Schaber et al. 2010). The new combined time series has less noise and therefore provides more robust and reliable information on vegetation development, but at the expense of local resolution.

For further detailed descriptions of the phenological data, please refer to the publications by Güsewell et al. (2018) and Auchmann et al. (2018).

2 Calculation of annual averages and climate normals

Annual mean values of the individual phenological phases are calculated for the climatological description of vegetation development. As the phenological development in Switzerland can mainly be distinguished for different altitude levels and less for geographical regions (Güsewell et al. 2018), the mean values are calculated for the whole of Switzerland and additionally for different altitude levels. Climate normal periods are defined in order to compare the development of a year with the long-term average, i.e. the climatology. The

same 30-year normal periods are used in phenology as in climatology: 1961-1990 and 1991-2020. A comparison of the annual phenological data with the normal value shows whether a year shows early or late vegetation development. The normal period 1961-1990 is used for comparison with the long-term climate development and that of 1991-2020 for comparison with today's climate.

2.1 Method of calculation

For the mean calculation of phenological data, the use of mixed linear models is proposed, in which the years are included as fixed effects and the stations as random effects (Schaber et al. 2010). A mixed linear model was also used by Gusewell et al. (2018) for analysing interannual variation and for trend calculation of annual phenological means.

To account for the influence of the non-constant mean altitude of stations in the Swiss phenology network since 1956, a mixed linear model was used in which the years and a station-specific altitude increment were modelled as fixed effects and the stations as random effect.¹

$$Y_{is} = J_i + q(h_s - h_{ref}) + \alpha_s + \varepsilon_{is}$$

Y_{is} : Observation in year i and station s

J_i : Year i (fixed effect, as a categorical variable)

$q(h_s - h_{ref})$: altitude gradient q calculated by the model, and difference of the station altitude h_s from a reference altitude h_{ref} for the selected altitude layer (fixed effect)

α_s : Station (random effect)

ε_{is} : Residuum

The analyses were made with R using the lme function from the nlme package (R Core Team 2021). This was used to calculate annual mean values for each phenological phase and for each altitude level and averages for the normal periods 1961-1990 and 1991-2020. Standard errors of the annual means were calculated and are discussed in the Results chapter.

2.2 Selection of height levels

As in the analysis by Gusewell et al. (2018), the following altitude levels were defined: below 600 m, 600 - 999 m, above 1000 m, and additionally below 799 m and above 800 m. An average value was also calculated for the whole of Switzerland (swissmean). The altitude levels make it possible to analyse whether the inter-annual patterns differ at different altitude levels. The altitude levels were chosen based on the station distribution and the similar size of the altitude intervals. In the case of dandelion flowering, for example, 48 reporting stations are included in the < 600 m level on average from 1961-2020, 38 stations in the 600 - 1000 m level and 31 stations in the > 1000 m level. The altitude levels were also based on the vegetation levels in Switzerland, which are defined by the occurrence of certain trees/plants

¹ The height of the stations was integrated into the calculation of the phenological standard values from September 2024. The previously published standard values were based on the model proposed by Schaber et al. (2010) with the year as a fixed effect and the stations as a random effect.

and forest communities. The choice of the 800 m limit corresponds approximately to the limit of the colline zone (foothill zone), which is defined by the upper occurrence of oaks.

A rounded number based on the mean altitude and the median altitude of the stations in the relevant altitude layers was selected as the reference altitude in the mean value calculation (Table 1).

Altitude layer	Average height of the stations	Median height of the stations	Reference height
Swissmean	759 m	627 m	700 m
< 600 m	462 m	450 m	450 m
600 - 999 m	755 m	750 m	750 m
> 1000 m	1316 m	1250 m	1250 m
< 799 m	526 m	500 m	500 m
> 800 m	1174 m	1100 m	1100 m

Table 1: Defining the reference height per height layer.

2.3 Selection of data series

Only data series from quality-controlled, active phenology stations with at least 20 years of data in the two normal periods 1961 - 2020 were used. Each altitudinal layer was assessed separately. A calculation of annual mean values is meaningful due to the existing number of phenology stations from 1956 onwards.

2.4 Selection of phenoparameters

Climate normal values were only calculated for phenoparameters with data from at least 10 stations per year over the entire period from 1961 to 2020. Since the number of observed phenoparameters decreases with altitude and only 24% of the stations are located above 1000 m, normal values were only calculated for 7 phenoparameters in the altitude layer above 1000 m over the two normal periods. Below 600 m, normal values could be calculated for 26 phenoparameters (out of a total of 28 phenoparameters from 1951 to the present) (Table 1). There is too little data for the calculation of both normal periods for the parameters vine blossom and grape harvest, which only have more than 10 reporting phenostations from 1968/69 and more than 20 stations from 1976.

Phenoparameter	swissmean	< 600 m	600-1000 m	≥ 1000 m	< 800 m	≥ 800 m
Apple tree - flowering (50%)	x	x	x		x	x
Autumn crocus - flowering (50%)	x					x
Cherry tree - flowering (50%)	x	x	x		x	x
Coltsfoot - flowering (50%)	x	x	x	x	x	x
Common rowan - fruit maturity (50%)	x					x
Common spruce - needle emergence (50%)	x	x	x	x	x	x
Cuckoo flower - flowering (50%)	x	x	x		x	x
Dandelion - flowering (50%)	x	x	x	x	x	x
European beech - leaf colouring (50%)	x	x	x		x	x
European beech - leaf drop (50%)	x	x	x		x	
European beech - leaf unfolding (50%)	x	x	x		x	x
European elder - flowering (50%)	x	x	x		x	x
European larch - needle emergence (50%)	x	x	x	x	x	x
European red elder - flowering (50%)	x					x
Field daisy - flowering (50%)	x	x	x	x	x	x
Hay harvest - start	x	x	x	x	x	x
Hazel - flowering (50%)	x	x	x		x	x
Hazel - leaf unfolding (50%)	x	x	x	x	x	x
Horse chestnut - flowering (50%)	x	x	x		x	
Horse chestnut - leaf colouring (50%)	x	x	x		x	x
Horse chestnut - leaf drop (50%)	x	x	x		x	
Horse chestnut - leaf unfolding (50%)	x	x	x		x	
Large leaved lime - flowering (50%)	x	x			x	
Pear tree - flowering (50%)	x	x	x		x	
Small leaved lime - flowering (50%)	x					
Wood anemone - flowering (50%)	x	x	x		x	x

Table 2: Phenoparameters for which both normal periods 1961-1990 and 1991-1920 can be calculated.

3 Results

For the selected phenoparameters, annual mean values from 1956 and the normal values 1961-1990 and 1991-2020 (as "day of year", doy) are calculated. They are available for download in tabular form:

<https://www.meteoswiss.admin.ch/climate/climate-change/vegetation-development.html>

The standard error of the annual mean values is discussed below and the change in vegetation development between the two normal periods is summarised. This summary was published in the blog post "[Tracking changes in vegetation development](#)" (in German, French, Italian) on 24 March 2023.

3.1 Discussion of the standard error

The standard errors of the mean values are not part of the output file. They are discussed here using the example of dandelion flowering (Figures 4, 5). As the number of phenological stations has increased over time, the uncertainty of the calculated annual means is greater in earlier years than from 1970, when the number of stations increased significantly. The standard error is greater for the altitudinal layer above 1000 m than for the other altitudinal layers, as it has the lowest number of stations and a greater variability of observations, because the stations extend over an altitude of around 800 m. For the dandelion, the standard error across all stations is between 0.87 and 1.36 days and above 1000 m between 2.07 and 2.92 days (Table 2). The same order of magnitude of the standard error also applies to all other phenoparameters.

Consequently, the very early years 1961, 2007, 2011, 2014, 2017 and 2020 all have a comparable mean date for dandelion flowering across all stations in Switzerland (doy 102-104).

Gewöhnlicher Löwenzahn – Blüte (50%) alle Stationen, 1956–2023

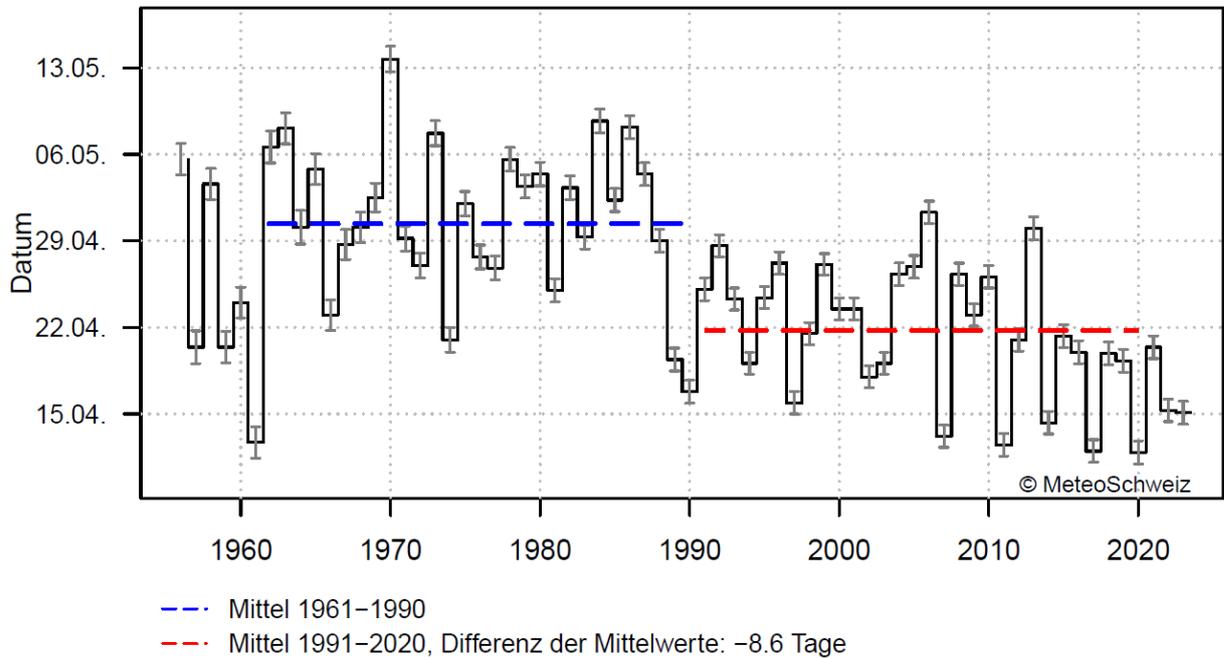


Figure 4: Annual mean values of dandelion flowering for the whole of Switzerland with standard errors shown. Blue line: mean 1961-1990, red line: mean 1991-2020. Difference of the mean values -8.6 days.

Gewöhnlicher Löwenzahn – Blüte (50%) oberhalb von 1000 m, 1956–2023

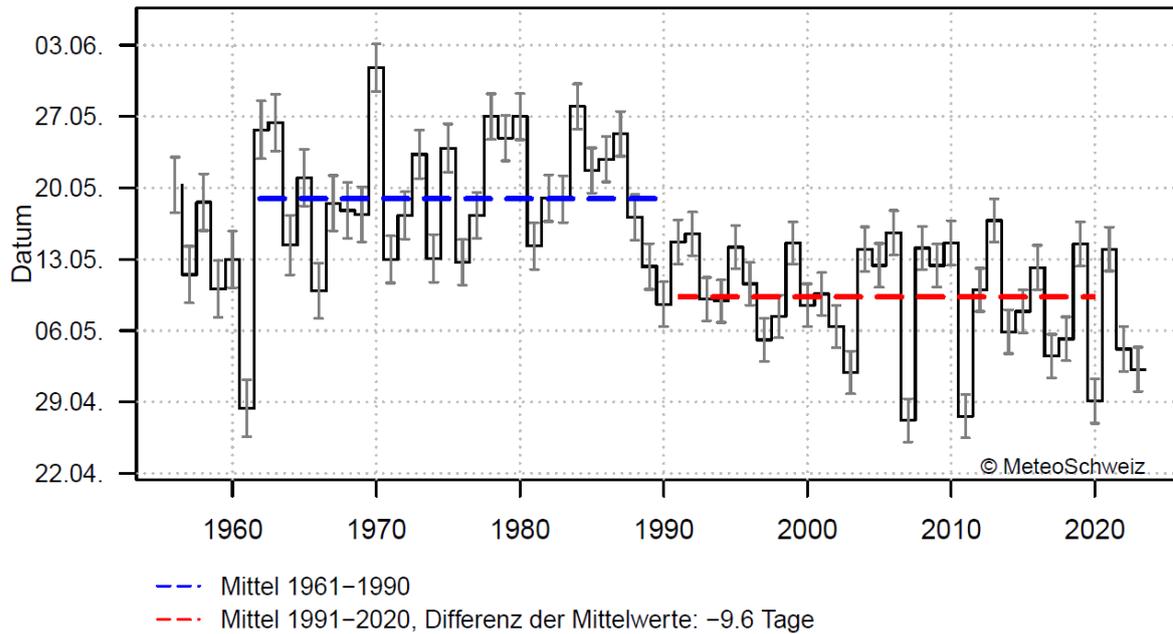


Figure 5: Annual mean values of dandelion flowering for altitudes above 1000 m with standard error shown. Blue line: mean 1961-1990, red line: mean 1991-2020. Difference of the mean values -9.6 days.

Table 3 (next page): Dandelion full flowering: comparison of annual mean values, standard errors and number of stations for the whole of Switzerland with all stations (left) and only the stations above 1000 m (right).

Dandelion full flowering, average for all stations			
year	day of year	standard error	number of stations
1956	126	1.27	51
1957	110	1.33	46
1958	124	1.25	53
1959	110	1.27	51
1960	114	1.24	54
1961	103	1.28	50
1962	127	1.30	48
1963	128	1.26	52
1964	120	1.36	43
1965	125	1.25	53
1966	113	1.23	55
1967	119	1.21	57
1968	120	1.22	56
1969	123	1.16	64
1970	134	1.03	88
1971	119	1.02	91
1972	117	1.01	93
1973	128	1.01	93
1974	111	1.00	95
1975	122	0.98	100
1976	118	0.97	104
1977	117	0.96	107
1978	126	0.95	112
1979	123	0.94	115
1980	124	0.94	113
1981	115	0.95	110
1982	123	0.95	110
1983	119	0.95	110
1984	129	0.96	109
1985	122	0.94	115
1986	128	0.94	116
1987	124	0.93	120
1988	119	0.94	116
1989	109	0.93	119
1990	107	0.92	121
1991	115	0.92	121
1992	119	0.89	137
1993	114	0.89	137
1994	109	0.88	140
1995	114	0.89	138
1996	117	0.90	129
1997	106	0.90	131
1998	112	0.90	131
1999	117	0.87	144
2000	114	0.89	134
2001	113	0.89	136
2002	108	0.89	135
2003	109	0.89	137
2004	116	0.91	127
2005	117	0.92	124
2006	121	0.92	124
2007	103	0.90	132
2008	116	0.90	131
2009	113	0.90	131
2010	116	0.90	129
2011	103	0.91	128
2012	111	0.91	126
2013	120	0.92	124
2014	104	0.92	121
2015	111	0.92	124
2016	110	0.93	120
2017	102	0.92	123
2018	110	0.93	117
2019	109	0.92	121
2020	102	0.93	119
2021	110	0.92	123
2022	105	0.92	123
2023	105	0.93	118

Dandelion full flowering, average of stations ≥ 1000 m			
year	day of year	standard error	number of stations
1956	140	2.71	17
1957	132	2.77	16
1958	139	2.77	16
1959	130	2.77	16
1960	133	2.77	16
1961	118	2.77	16
1962	146	2.84	15
1963	146	2.78	16
1964	134	2.92	14
1965	141	2.77	16
1966	130	2.71	17
1967	139	2.71	17
1968	138	2.71	17
1969	137	2.71	17
1970	152	2.31	27
1971	133	2.31	27
1972	137	2.31	27
1973	143	2.37	25
1974	133	2.34	26
1975	144	2.37	25
1976	133	2.24	30
1977	137	2.24	30
1978	147	2.24	30
1979	145	2.24	30
1980	147	2.26	29
1981	134	2.29	28
1982	139	2.29	28
1983	139	2.29	28
1984	148	2.21	31
1985	142	2.21	31
1986	143	2.21	31
1987	145	2.19	32
1988	137	2.24	30
1989	132	2.24	30
1990	129	2.19	32
1991	135	2.17	33
1992	136	2.13	35
1993	129	2.12	36
1994	129	2.08	38
1995	134	2.12	36
1996	131	2.10	37
1997	125	2.12	36
1998	127	2.10	37
1999	135	2.07	39
2000	129	2.08	38
2001	130	2.10	37
2002	126	2.07	39
2003	122	2.10	37
2004	134	2.17	33
2005	132	2.15	34
2006	136	2.19	32
2007	117	2.12	36
2008	134	2.12	36
2009	132	2.12	36
2010	135	2.17	33
2011	118	2.12	36
2012	130	2.12	36
2013	137	2.13	35
2014	126	2.15	34
2015	128	2.12	36
2016	132	2.17	33
2017	124	2.13	35
2018	125	2.15	34
2019	135	2.17	33
2020	119	2.19	32
2021	134	2.15	34
2022	124	2.19	32
2023	122	2.17	33

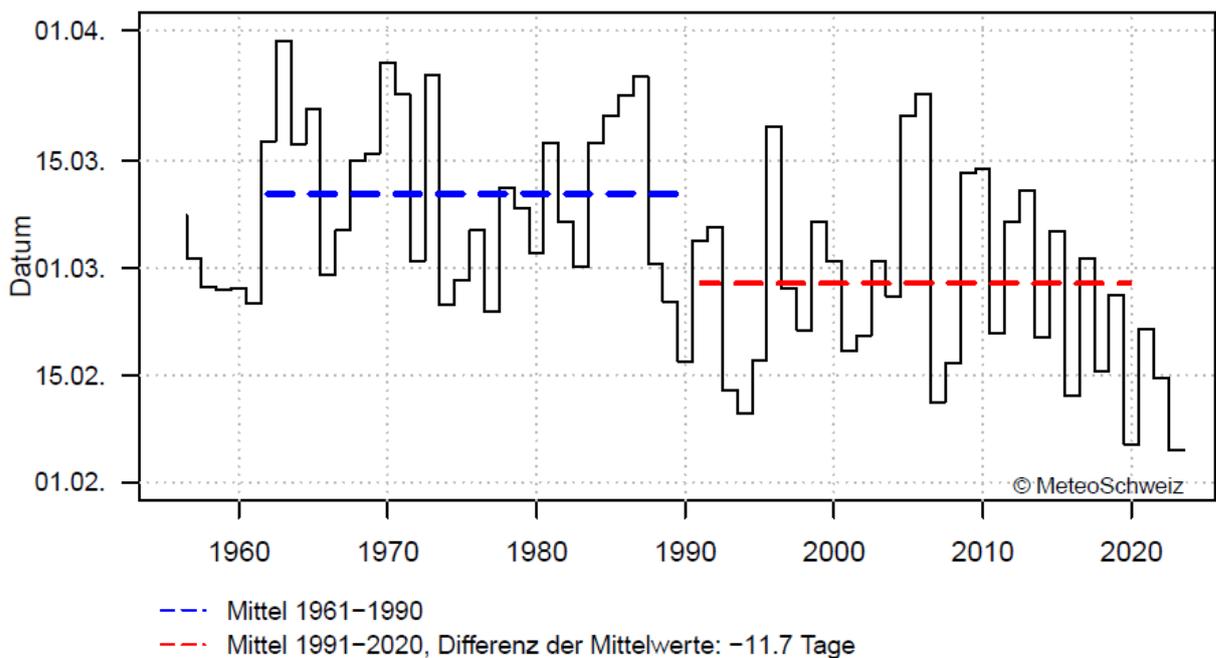
3.2 Spring begins 4 - 10 days earlier

The flowering of hazel bushes shows a strong advance of 12 days between the two normal periods 1961-1990 and 1991-2020. Early flowering has been particularly frequent in recent years.

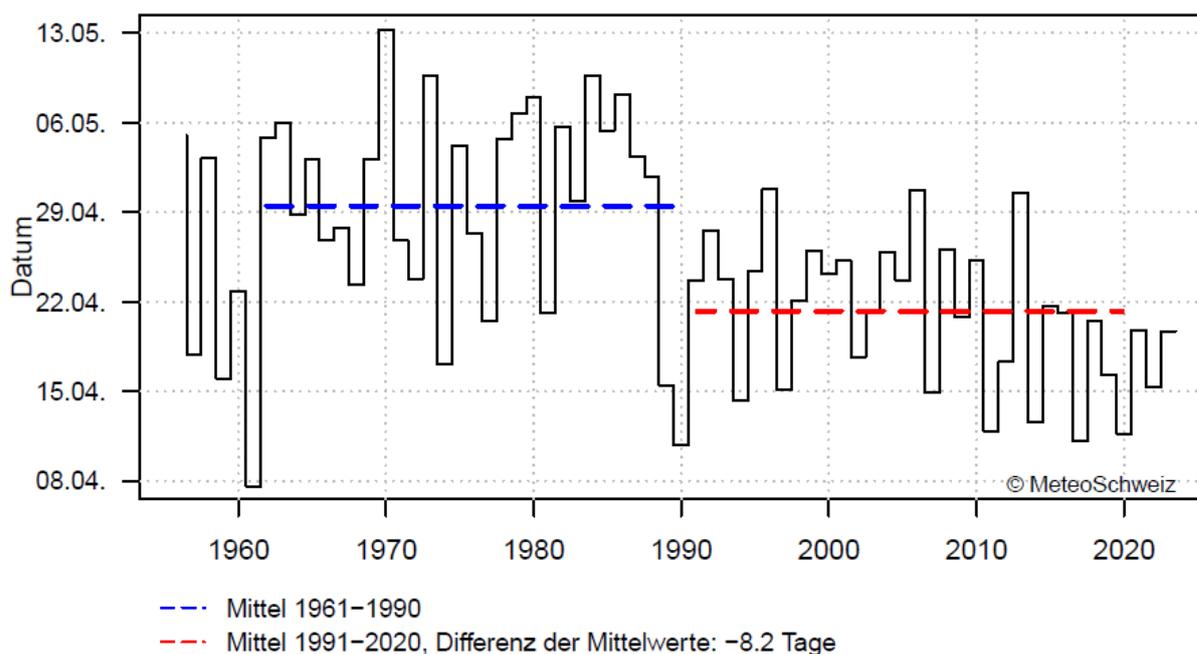
The flowering of fruit trees and of the herbs dandelion, wood anemone and cuckoo flower was 5 - 10 days earlier between the two standard periods. The temperature from February to April has the greatest influence on the timing of spring development. It rose by 1.4°C between the normal periods. In all data series, a strong advance of the respective phenological phase from 1989 onwards is noticeable, which is accompanied by an increase in the February to April temperature.

Leaf unfolding and needle emergence were slightly less early, by 4 - 6 days. We know that beech trees only react more strongly to warmer temperatures after a certain day length. This means that it is better protected from late frosts and does not sprout during a warm phase in early spring.

Haselstrauch – Blüte (50%) alle Stationen, 1956–2023



Kirschbaum – Blüte (50%) alle Stationen, 1956–2023



Buche – Blättentfaltung (50%) alle Stationen, 1956–2023

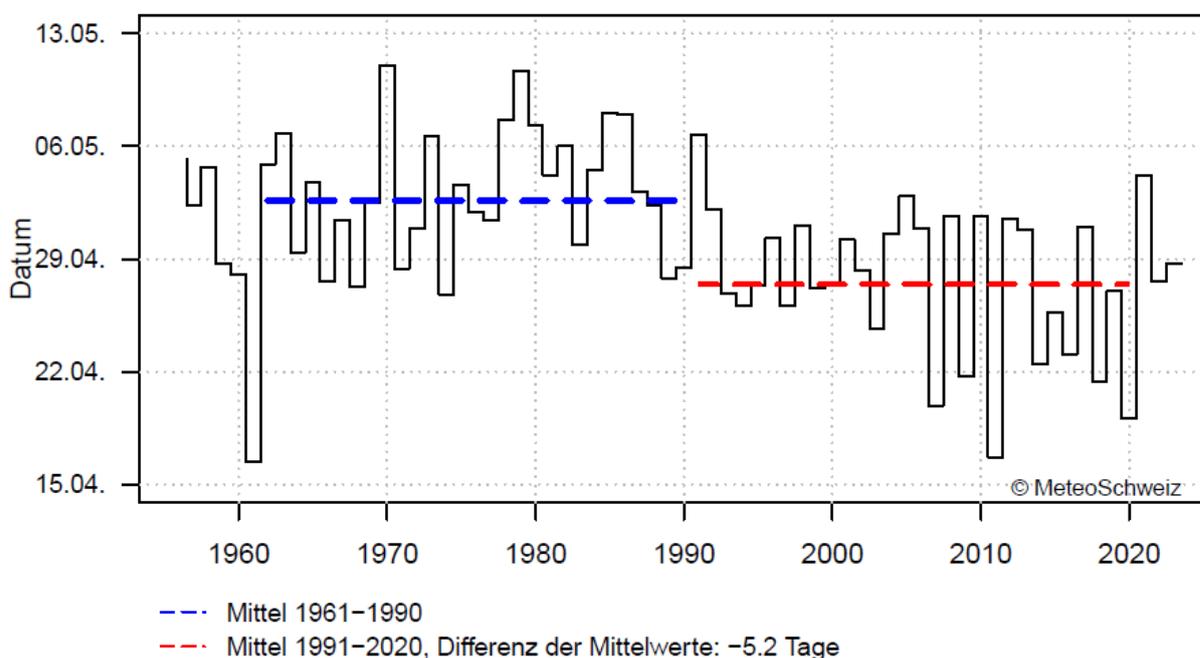


Figure 6: Annual mean values for the whole of Switzerland for the flowering of hazel (Haselstrauch) and cherry (Kirschbaum) and the leaf unfolding of beech (Buche).

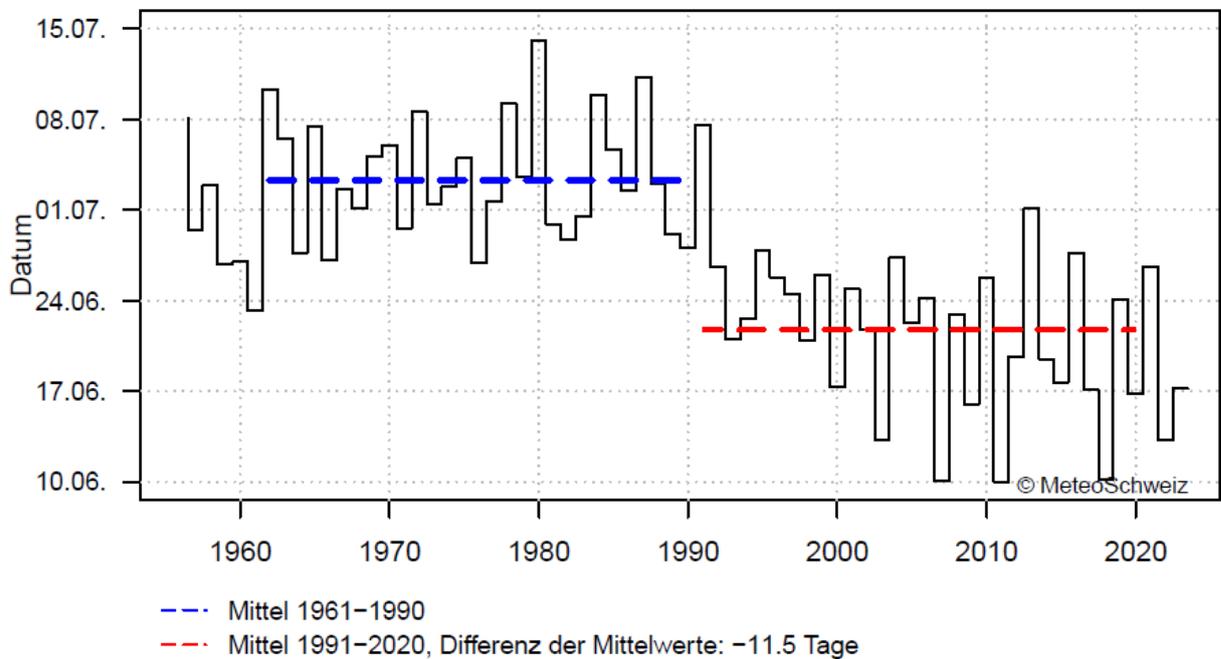
3.3 Strong advance by 10 - 12 days in early summer and summer

The early summer and summer phases include the flowering of daisies, European elder and large leaved lime trees. The average flowering dates of the current normal period 1991-2020 are 10 - 12 days earlier than in the period 1961-1990. The temperature of the most influential months, March to May and April to June, has increased by 1.6 °C and 1.8 °C respectively

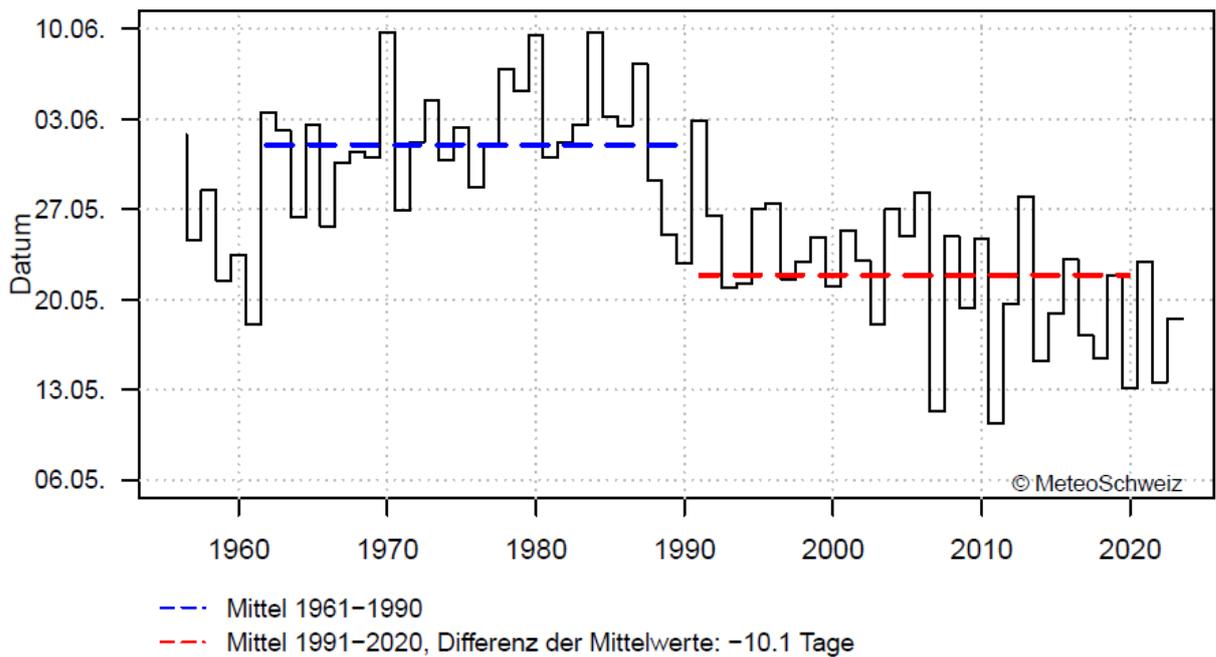
between the normal periods. The strong advance of the start dates from the end of the 1980s runs parallel to a marked increase in the temperature of these months.

The latest date for the flowering of the large leaved lime tree in the entire data series is 14 July 1980. In 1980, spring was a cool and poor in sunshine, and even at the end of May it was still snowing down to around 1000 m. Summery phases were also short in June. In the annual report of MeteoSwiss, June and July are described as follows: "The cold, wet weather caused great difficulties for agriculture, especially in the mountain regions. The higher altitudes recorded a vegetation delay of up to three weeks". The Swiss average temperature from April to June 1980 was 5.2 °C. The years 2007, 2011 and 2018 differ significantly from this with an average temperature from April to June of 10.4 to 10.7 °C and with the earliest flowering of the large leaved lime tree in the Swiss average on 9 and 10 June.

Sommerlinde – Blüte (50%) alle Stationen, 1956–2023



Wiesen-Margerite – Blüte (50%) alle Stationen, 1956–2023



Schwarzer Holunder – Blüte (50%) alle Stationen, 1956–2023

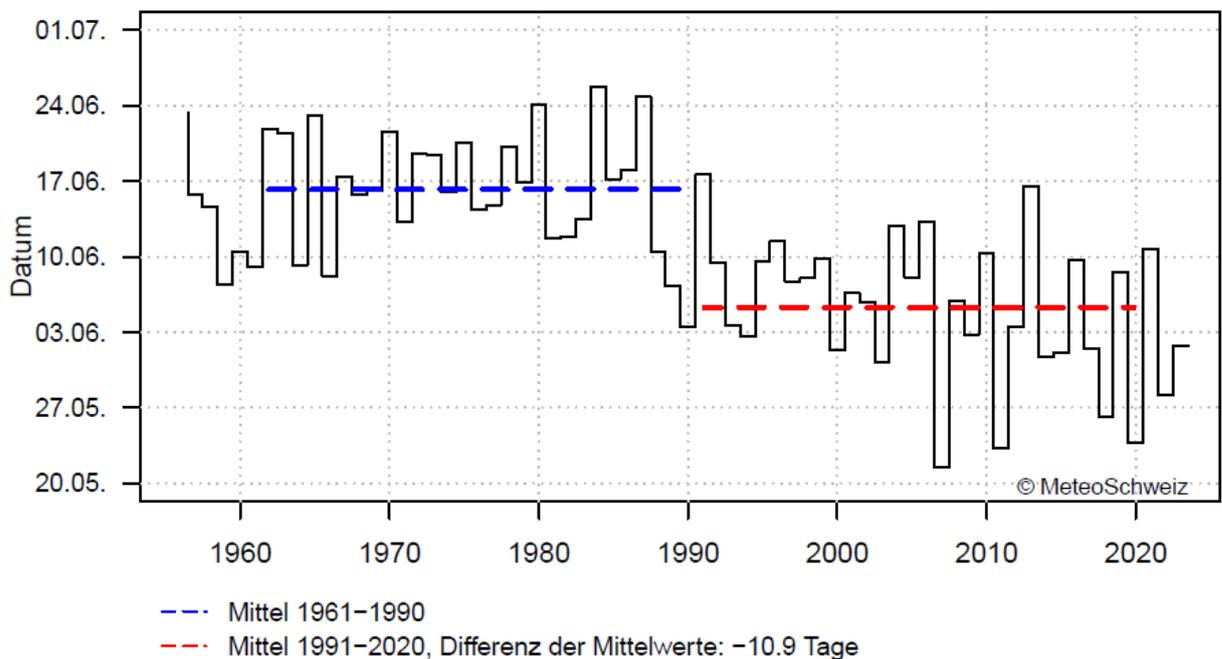


Figure 7: Annual mean values for the whole of Switzerland for the flowering of large leaved lime (Sommerlinde), filed daisy (Wiesen-Margerite) and European elder (Schwarzer Holunder).

3.4 Autumn hardly changes

The leaf colouration of the beech did not change significantly. The autumnal leaf colouration is triggered by the decreasing day length, which initiates the decomposition of chlorophyll and thus the emergence of yellow and red pigments. Temperature and dryness also play a role. Leaf discolouration occurs later if the months of August and September are very warm. A cool September usually leads to early leaf discolouration. A very warm, dry late spring and early summer can also cause the leaves to colour earlier.

The earliest leaf colouring occurred in 1996, a year with a particularly cool September with early snowfall down to around 1100 m and with temperatures below normal in all months from July to October. Because leaf colouration depends on various influencing factors, it is difficult to predict whether the trend towards late leaf colouration of recent years will continue as temperatures rise, or whether the increasing dryness in early summer and summer will lead to earlier leaf colouration.

Buche – Blattverfärbung (50%) alle Stationen, 1956–2023

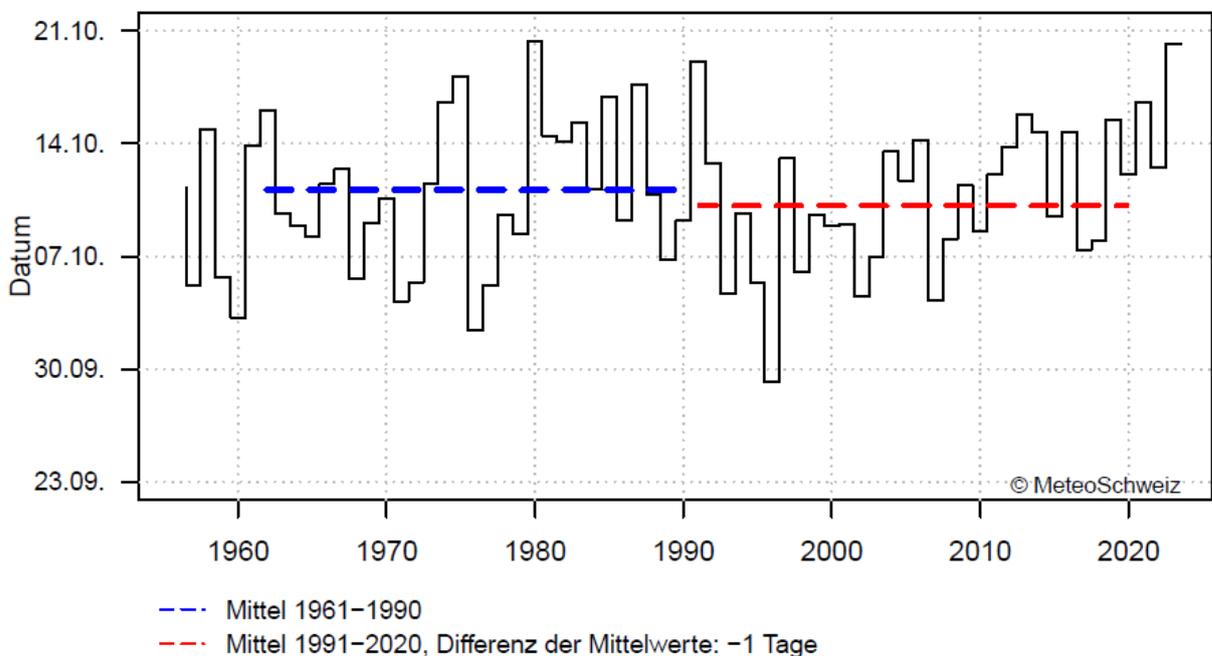


Figure 8: Annual mean values for the whole of Switzerland for leaf colouring of beech.

3.5 Effects of a changed phenology

The ever earlier appearance of flowering and leaf development can lead to a greater risk of late frosts. Studies from Switzerland have shown that the safety margin between the last frost and flowering and leaf development is still sufficiently large for our native plants and that they usually only sprout after the last frost. At higher altitudes, however, this safety margin has decreased. There were severe late frosts in 2017 on fruit and forest trees and on vines, in 2019 on beech trees at altitudes around 1000 m, in 2021 on fruit trees and in 2022 on fruit trees, especially in France.

Each plant species reacts differently to climate change. Animals also have their own rhythms, such as breeding or the hatching of insects, which are often also influenced by temperature. Existing food chains can become unbalanced with changing temperatures, so that, for example, during the rearing of young birds there are not enough caterpillars to feed on. A

change in the food supply for roe deer fawns was also observed because the vegetation grew earlier than the roe deer's mating season.

These examples clearly show how climate change can have a direct impact on the flora and fauna in Switzerland.

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