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„Heat stress effects on reproductive success and phenology in two different forest types near „Thermenlinie" in Austria"

verfasst von / submitted by

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“Je größer aber ein Mensch ist, desto mehr neigt er dazu,

vor einer Blume niederzuknien.”

-

Gilbert Keith Chesterton

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1 Abstract

Global warming does not affect the different parts of the world in the same intensity. For Europe a projection of up to 5.5°C till the end of this century is expected, leading to yet unknown ecological responses and consequences. A considerable amount of scientific research was conducted already about this topic on global scale, however, local scale observations are lacking for many areas. Extraordinary high temperatures around Vienna in the early years of this century pushed some species to a threshold of their heat tolerance. To get an overview if drought events affect vegetative and reproductive performance of plants, in this work the vegetative and generative course as well as species performance of two similar forest communities was evaluated. For this purpose, in the years 2015 and 2016 data of two plots with different aspects in the Vienna Woods, close to the south-western border line of Vienna, were recorded and analysed.

For the local scale at least, it could be shown that in the year 2015 summer flowering species had problems to build normally developed reproductive organs (seeds, fruits). Further-on, in the following year 2016, spring flowering species showed tendencies to start flowering earlier than expected..

Elevated temperatures through the year led to early yellowing and leaf dropping in some species, others seemed not to be able to withstand heat peaks, mounting in problems in building normally developed seeds. Species with both, conspicuous vegetative and generative responses showed a general preference to colder and/or more humid habitats raising the question whether in further scenarios plant community changes might happen on local scale.

Key words
Phenology, heat stress effects, reproduction success, temperature change

2 Introduction

Climate change and its impact on organisms and ecosystems is a pervasive global scale topic in the last decades (Dullinger et al., 2012; Parmesan, 2006; Walther, 2010). Different studies are emphasising a rapidly increasing raise in temperature (Hansen et al., 2010; Hartmann et al., 2013). In Hansen et al., (2006) a warming of global surface temperature of about 0.6°C since 1975 and 0.8°C in the last century was found, not only highlighting a general increase of temperature in the 19th century but stressing a raise in temperature per decade.

Global warming, however, is not affecting all parts of the world with the same intensity. A greater impact on the northern hemisphere was demonstrated (J. Hansen et al., 1996). For Europe there is a projection of 1-5.5°C for the end of this century (Swart, 2008). Furthermore, Lindner et al. (2010) expect that the water limitation of systems and extreme weather events, especially drought risk, will be an important threat in future scenarios. Therefore, the ecological response to this phenomenon was in the focus of scientific research (Parmesan, 2006; Walther et al., 2002). To track these ecological responses, phenology – the practice "of observing life cycle phase or activities of plants and animals in their temporal occurrence throughout the year" (Lieth, 1973) - is one of the preferred indicator methods to reflect climate change as it is sensible to temperature events as much as easy to record (Menzel et al., 2006). For Cleland et al. (2007), phenology might still be an aspect of plant ecology that is overlooked. Walther (2010) emphasises with respect to community responses to climate change to "not only focus on the actors (i.e. individuals, species) in ecological systems, but also intensify efforts to understand the dependencies and strengths of the linkages between them, addressing dynamic aspects and complex interactions."

Although in many studies a response of plant communities and single species to climate change is detected, mostly in variables of early leaf unfolding and early flowering (Menzel et al., 2006), there is a lack of studies dealing with the overall behaviour of different plants over a longer period of time.

On a local scale it might be very important not only to know whether global warming extends the vegetation period and thus productivity (Crabbe et al., 2016), but also whether extreme events, such as drought, might supress single species in a plant community, leading to a

different species composition with an altered performance in productivity (Bréda et al., 2006), water holding capability etc.

This thesis aims at providing an overview of the vegetative and generative course of different forest species and at identifying vulnerable species with regard to warmer temperatures. For this purpose the investigation was conducted in the eastern part of the Vienna Woods. The Vienna Woods, with a total area of 115 000 Hectare - 70 000 hectare forest (Mrkvicka, 2011) - is positioned in the transition zone of the west-middle-European climate and sub-continental pannonian climate (Fischer & Mazzucco, 2011). Organisms and ecosystems in this transition zone, may probably, strongly respond to climate effects. The hilly landforms, with different aspects as well as different forest types are thought to be a suitable investigation area. Therefore, the research questions are as follows:

1. Are there any shifts in phenology between two differently exposed forest plots within and between the years 2015 and 2016?
    - Do species have the same phenology in south and north exposed plots?
2. Is there a shift in flowering phenology in 2016 in the two plots compared to literature?
3. Is there an impact of drought stress on early yellowing, abscission or dysfunction of fruits?
4. How is the recruitment of the tree and shrub layer?
    - Is rejuvenation going on and if so which species seem to be successful in reproduction.
5. Can indicator values be used to predict the performance of the species of the herb layer?

3 Material & Methods

3.1 Investigation area, geology and sample plots

The investigation area that was chosen is located in the eastern part of the Vienna Woods and lies in a transition of oceanic and a continental climate with an average annual temperature (Wien Mariabrunn, ZAMG) of 9,2°C and an average total amount of rainfall of 740mm per year (1971-2000).

Fig. 1: Position of the two recording plots – down: Oak forest (PL1), up: Oak-hornbeam forest (PL2). In the overview picture (right upper corner) the transition from the Vienna Woods to the city boarder is clearly visible. In the eastern part of the plots the „Perchtoldsdorfer Heide“ is prominent.

This area is part of the North-Eastern Limestone Alps with calcareous bedrock, whereas the northern, bigger part of the Vienna Woods mainly consists of flysch. The two investigated plots are within a mixed oak forest and situated close to the market town Perchtoldsdorf and the south-western city boundary of Vienna.

Two plots were selected with a distance between them of about 0.85 kilometres. The plots were chosen from similar altitude and a similar species composition with a distinct tree-, shrub-, and herb layer.

The first plot (PL1), representing an oak forest, lies in the middle of a slope (427mAA) with an inclination of ~25° and is exposed to southeast by south. The size is about 420m^2 (>20 x 20). The plot contains a total number of 70 species.

Fig. 2: Oak forest (PL1) in June 2015, vegetation cover in the herb layer about 80% *Melittis melissophyllum*, partly flowering, partly vegetatively in the foreground.

Fig. 3: Oak-hornbeam forest (PL2) in May 2016, vegetation cover in the herb layer almost 100%, *Allium ursinum* is very prominent in the foreground.

The second plot (PL2) lies at an altitude of 404mAA, is less steep (~20°) and north exposed. The canopy of this oak-hornbeam forest plot is quite dense. It has a similar quadratic size of 400m^2 and with 58 species a slightly lower species richness.

Table 1: Information summary of the investigated plots.

	PL1	**PL2**
Coordinates	N 48°07'13.8'' E 16°14'26''	N 48°07'40.7'' E 16°14'35.8''
Elevation [mAA]	427	404
Slope (°)	25	20
Aspect	South-east by south	North
Total cover [%] **May 2016**	90	100
Forest type	Oak forest	Oak-hornbeam forest

Geology and soil

In general, the southern part of the Vienna Woods consists of limestone and dolomite. It lies within the eastern boarder of the Northern Limestone Alps. In greater detail, this part of the Vienna Woods is very heterogeneous with complex layering and constitution of soil types. The bedrock of both plots is "Hauptdolomit" and marl whereas the situation of the northern plot (PL2) is very complex with different layers packed together. The soil of PL1 is weathered to a rather shallow brownish Rendzina, yet with an A-horizon of about 10cm. The soil of PL2 shows a deeper, also brownish, Rendzina and with a bigger part of loam.

3.2 Data collection

The corners of the two different plots were marked with a warning tape at first to assure that they could be found easily; in addition the position of the plots was taken with a GPS (Garmin). To avoid artefacts due to weather aspects, the data of the sample plots were only collected on days with dry weather conditions.

Table 2: Description of the indicator values temperature and moisture according to Ellenberg et al. (1992); the translation of moisture was taken from Reintal et al. (2010) the category temperature was translated freely by the author, taking Reintal et al. (2010) as template.

	Temperature	Moisture
1	Indicator of cold conditions, restricted to high mountain locations	Indicator of extreme dryness, restricted to soils that often dry out for some time
2	Between 1 and 3	Between 1 and 3
3	Indicator of cool conditions, mostly found in subalpine locations	Dry-site indicator, more often found on dry ground than in moist places
4	Between 3 and 5 (mountainous species)	Between 3 and 5
5	Indicator of moderately warm locations (low to mountainous locations)	Moist site indicator, mainly on fresh soils of average dampness
6	Between 5 and 7	Between 5 and 7
7	Indicator of warm conditions	Dampness indicator, mainly on constantly moist or damp, but not wet soils
8	Between 7 and 9	Between 7 and 9
9	Indicator of extreme warm conditions	Wet-site indicator, often on water-saturated, badly aerated soils
x	Indifferent	Indifferent

3.2.1 Climate data of the investigation area

The meteorological data used were measured at the closest weather station to the sample plots in Wien Mariabrunn (227mAA; 48°12’24.84’’ N, 16°13’45.84'' E). The measurements between 1970 and 2016 provided by ZAMG (Zentralanstalt für Meteorologie und Geodynamik) Vienna consist of the monthly and annual information on average air temperature (°C), mean maximum air temperature (°C), absolute maximum air temperature (°C), and monthly amount of precipitation (mm).

Comparison of long-term values with the years 2015/2016, were plotted with Microsoft Excel.

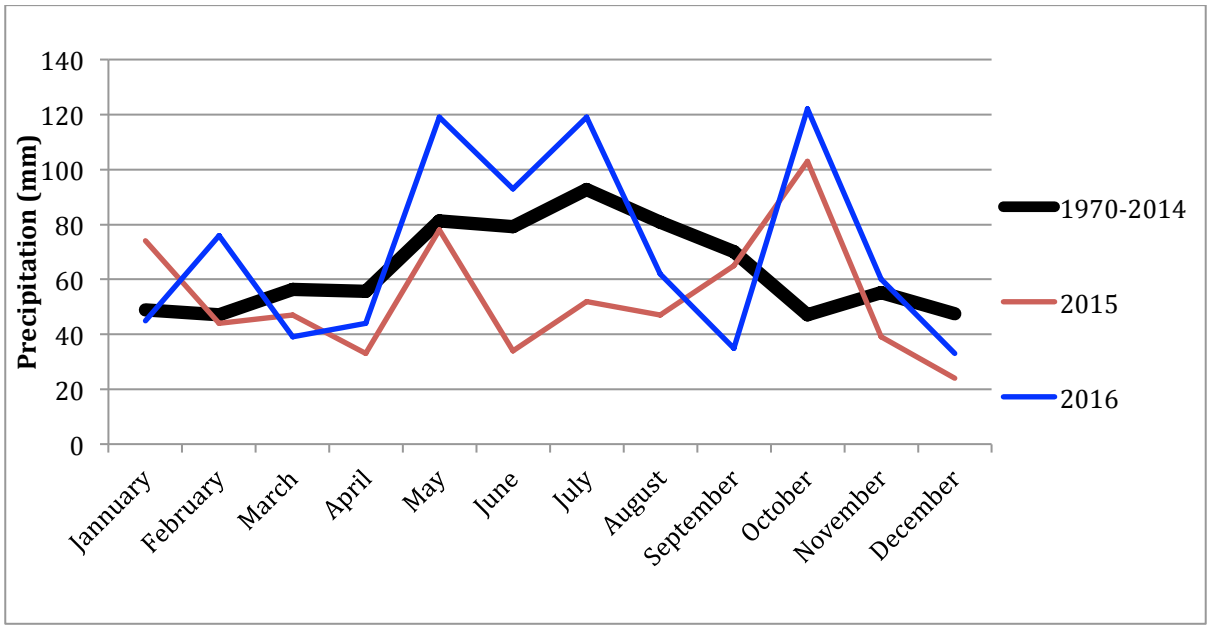


Fig. 4: Comparison of precipitation between long-term average, 2015 and 2016.

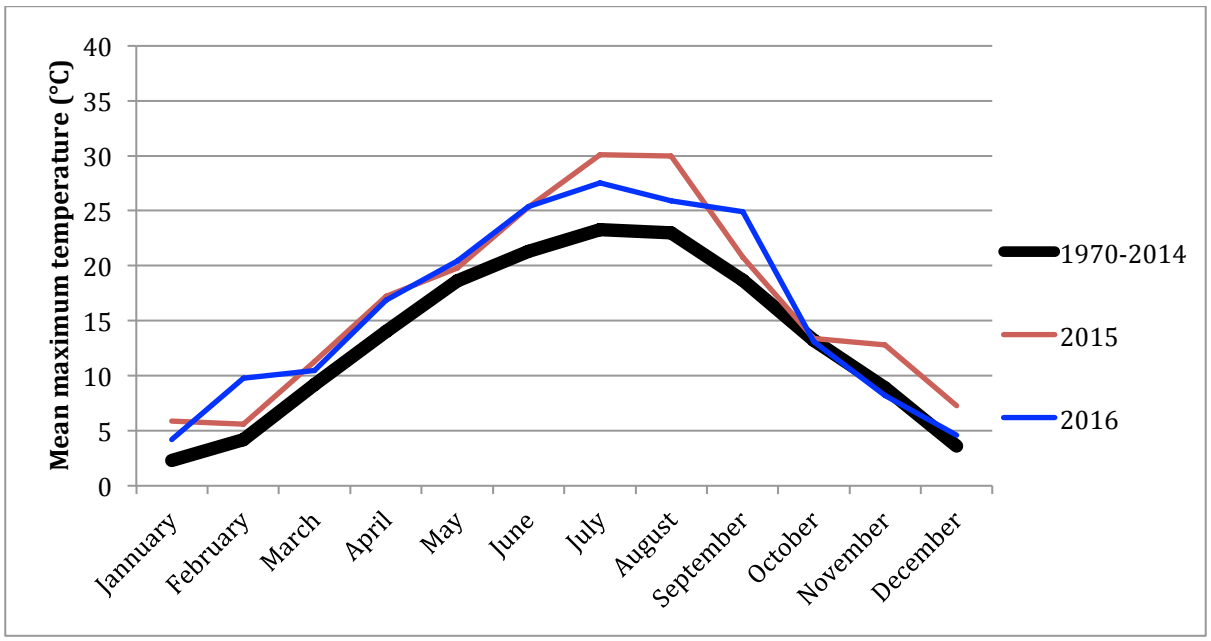


Fig. 5: Comparison of mean maximum temperature between long-term average, 2015 and 2016.

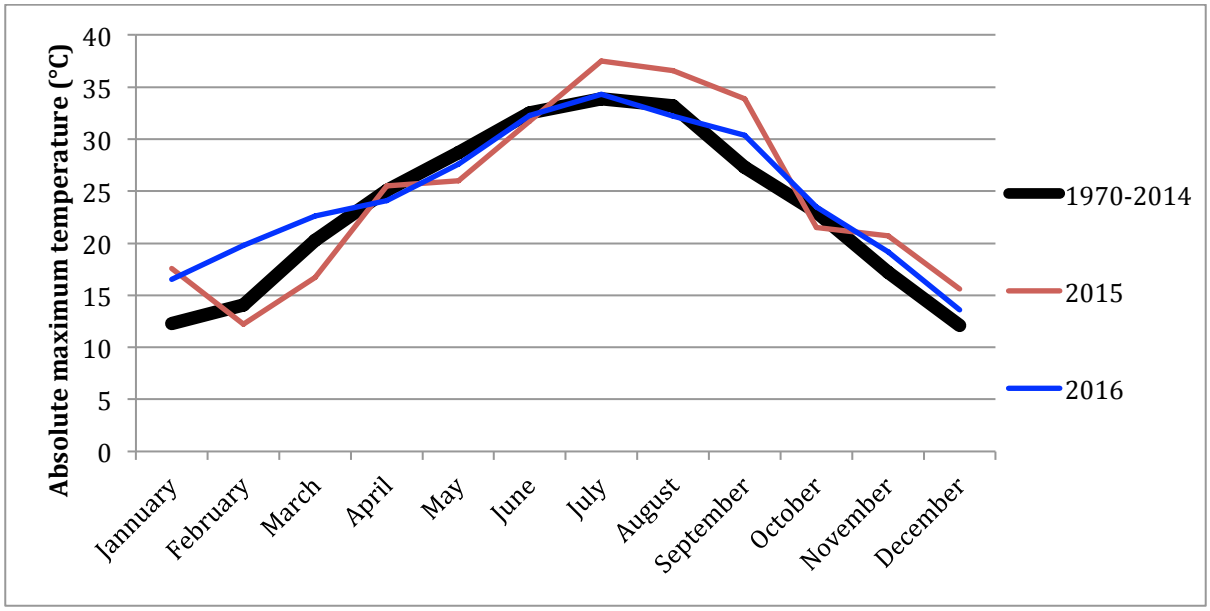


Fig. 6: Comparison of absolute maximum temperature between long-term average, 2015 and 2016.

3.2.2 Soil sample analysis

In September 2016, for every plot, four soil samples (PL1_1-4, PL2_1-4) with about one litre soil volume were taken randomly and analysed for pH, total amount of Carbon (%) and Nitrogen (%).

Soil samples were sieved using a 2 mm wire-mesh sifter. All visible roots were taken out. Amounts of about 50 g fresh soil were put into paper bags dried at 105°C over night for CN analysis.

For measuring the pH-value, the common Austrian Soil Science method has been used (ÖNORM DIN 19266). pH was determined in both water and 0.01 M $CaCl_2$ solution, using Inolab pH/ION 735 WTW for water and Schott pH-Meter CG840 for $CaCl_2$. 2,5 g of the fresh soil sample were placed into an eprovete, 12,5 ml of Aqua deion or 0,01 M $CaCl_2$ solution were added. After shaking a few seconds, the samples were stored in a cooling room (3-4°C) over night. Before analysis, the samples were shaken, allowed to stand for 15 minutes and then measured. The result was recorded after pH-value stabilized.

Total C and N was measured using a LECO C/N analyser (TruSec CN). For the analysis, approx. 0.25 g of oven-dried soil was weighed out onto small Aluminium plates, then closed and formed to a small drop to fit into the combustion cell. To avoid falsification during the

weighing process, five samples were taken out of a compartment drier, where the remaining samples were stored meanwhile. No replicates were made. Additionally to a standard curve, two standard soil samples were combusted after every 15 samples to secure stable measuring conditions and to be able to adjust the standard calibration values.

3.2.3 Observation intervals and vegetation relevés

Every 12 to 16 days between May and October 2015 and again from March to October 2016 the sample plots were analysed. A full species list and coverage estimation according Braun-Blanquet (Braun-Blanquet, 1964) was conducted initially. Species that could not be identified in the field were collected (from outside the plot if rare) to be analysed and determined subsequently with field guides (Fischer, Oswald, & Adler, 2008; Lauber & Wagner, 2012). According to Dierschke (1989) and modified by Klug et al. (2003) the phenological course was evaluated by classifying vegetative and generative stages of every species in the different layers. If species were represented by more than one stage at the same time, the most advanced stage was recorded. If it was not clear whether a seed was developed normally, a few generative parts of flowering individuals were taken and analysed with a binocular to determine development stages and/or functionality.

Forest-Type: Oak-Forest Date:
Weather:

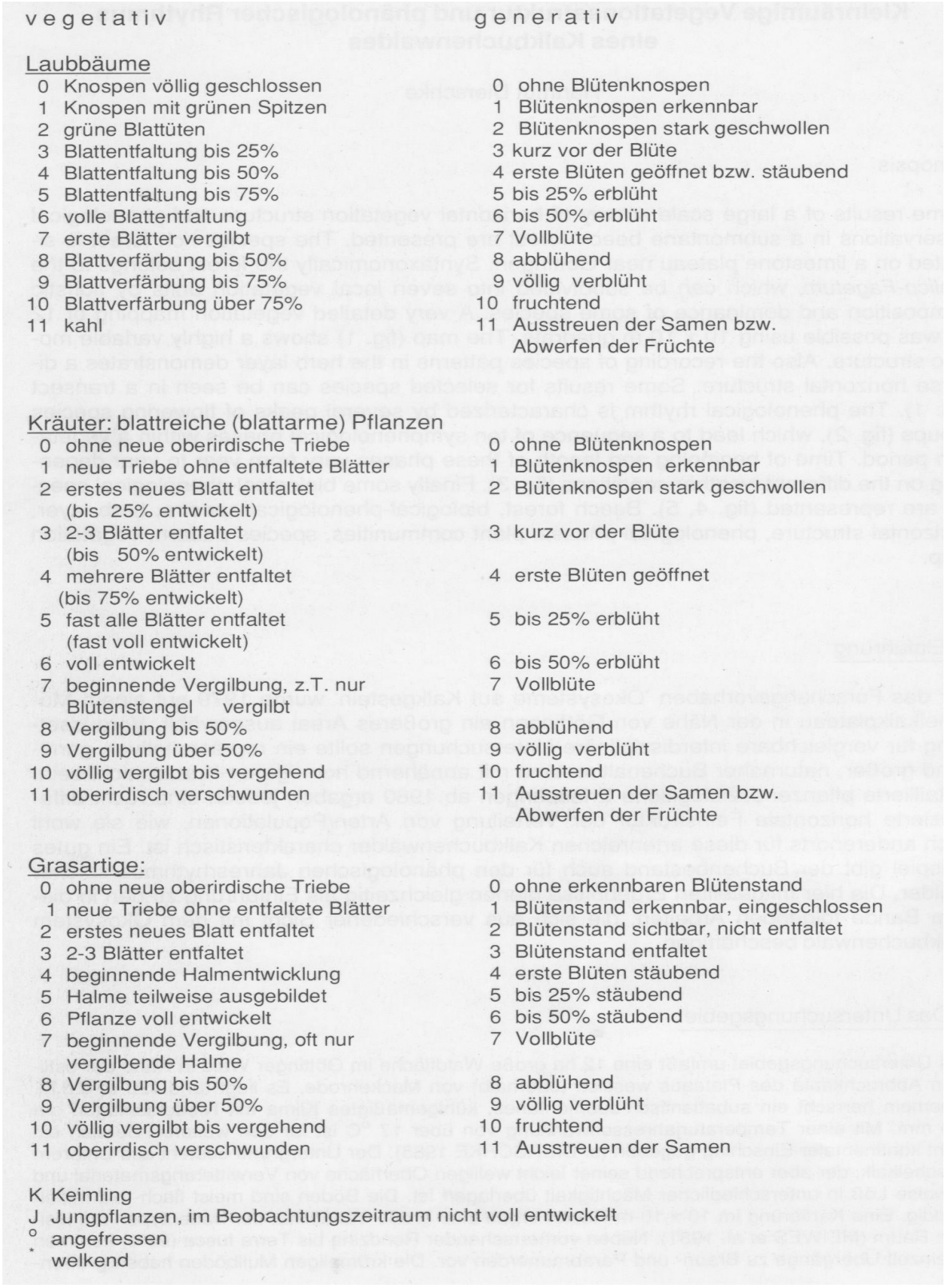
Species	Layer	Veg.	Gen.	additional Information
Acer campestre	T			
Acer pseudoplatanos	T			
Carpinus betulus	T			
Fraxinus excelsior	T			
Quercus cerris	T			
Quercus pubescens	T			
Q. pubescens X petraea	T			
Sorbus torminalis	T			
Tilia plathyphyllos	T			
Cornus mas	S			
Crategus laevigata	S			
Crategus monogyna	S			
Daphne laureola	S			
Sorbus aria	S			
Acer campestre	H			
Acer platanoides	H			
Acer pseudoplatanos	H			
Allium ursinum	H			
Arabis pseudoturitis	H			
Brachypodium sylvaticum	H			
Bromus ramous ssp. benekenii	H			
Buglossoides purpurocaerulea	H			
Buphtalmon sp.	H			
Anthericum ramosum	H			
Campanula rapunculoides	H			
Cardamine bulbifera	H			
Carex humilis	H			
Carex michelii	H			
Carpinus betulus	H			
Carpinus betulus	seedling			
Cephalantera damasonium	H			
Cephalanthera longifolia	H			
Clematis vitalba	H			
Clinopodium vulgare	H			
Cornus mas	H			
Crategus monogyna	H			
Cyclamen purpurascens	H			
Dactylis polygama	H			
Daphne laureola	H			

Species	LAYER	Veg.	Gen.	additional Information
Dictamnus albus	H			
Epipactis sp.	H			
Euonymus verrucosa	H			
Euphorbia cyparissias	H			
Fagus sylvatica	H			
Fraxinus excelsior	H			
Galium odoratum	H			
Glechoma hirsuta	H			
Hedera helix	H			
Hepatica nobilis	H			
Hieracium murorum agg.	H			
Hieracium sp. Vielblättrig	H			
Hippocrepis emerus	H			
Ligustrum vulgare	H			
Melica nutans	H			
Melica uniflora	H			
Melittis melissophyllum	H			
Mercurialis ovata	H			
Mercurialis perennis	H			
Muscari neglectum	H			
Neottia nidus-avis	H			
Peucedanum cervaria	H			
Polygonatum odoratum	H			
Primula veris	H			
Prunus avium	H			
Q. pubesicens x petraea	H			
Quercus cerris	H			
Rosa sp.	H			
Sanicula europaea	H			
Sorbus torminalis	H			
Tanacetum corymbosum	H			
Teucrium chamaedrys	H			
Tilia plathyphyllos	H			
Tilia sp. - hybrid	H			
Vincetoxicum hirundinaria	H			
Viola mirabilis	H			
Viola hirta	H			
Viola alba	H			
Campanula trachelium	H			

Fig. 7: Example of recording sheets of the oak forest (PL1).

The recording scale of Dierschke (1989) is organized, in detail, in a vegetative and generative scale and both of these scales are subdivided in the categories deciduous trees, herbs, and grass species. The vegetative scale, 0-11, starts for trees with fully closed buds, followed by different stages of leaf unfolding, stages of yellowing and the final stage (stage 11) is defined as leafless. The vegetative organization of herbal- and grass species starts with shoots, developing stages of how many leaves are unfolded, a stage of a fully developed plant and ending with yellowing stages till disappearing from surface (11). Analogous to the vegetative scale, the generative scale starts for all groups if flowering buds are detectable, followed by stages of bud swelling, stages of flower opening and withering of the flowers. The last two generative stages are “fruiting” and “dropping seeds”.

To the twelve categories a 13th a further stage was added according Klug et al. (2003) defined as (translated) “early/violent loss of leaves/flowers” for vegetative and generative scale.



vegetativ	generativ
Laubbäume	
0 Knospen völlig geschlossen	0 ohne Blütenknospen
1 Knospen mit grünen Spitzen	1 Blütenknospen erkennbar
2 grüne Blattüten	2 Blütenknospen stark geschwollen
3 Blattentfaltung bis 25%	3 kurz vor der Blüte
4 Blattentfaltung bis 50%	4 erste Blüten geöffnet bzw. stäubend
5 Blattentfaltung bis 75%	5 bis 25% erblüht
6 volle Blattentfaltung	6 bis 50% erblüht
7 erste Blätter vergilbt	7 Vollblüte
8 Blattverfärbung bis 50%	8 abblühend
9 Blattverfärbung bis 75%	9 völlig verblüht
10 Blattverfärbung über 75%	10 fruchtend
11 kahl	11 Ausstreuen der Samen bzw. Abwerfen der Früchte
Kräuter: blattreiche (blattarme) Pflanzen	
0 ohne neue oberirdische Triebe	0 ohne Blütenknospen
1 neue Triebe ohne entfaltete Blätter	1 Blütenknospen erkennbar
2 erstes neues Blatt entfaltet (bis 25% entwickelt)	2 Blütenknospen stark geschwollen
3 2-3 Blätter entfaltet (bis 50% entwickelt)	3 kurz vor der Blüte
4 mehrere Blätter entfaltet (bis 75% entwickelt)	4 erste Blüten geöffnet
5 fast alle Blätter entfaltet (fast voll entwickelt)	5 bis 25% erblüht
6 voll entwickelt	6 bis 50% erblüht
7 beginnende Vergilbung, z.T. nur Blütenstengel vergilbt	7 Vollblüte
8 Vergilbung bis 50%	8 abblühend
9 Vergilbung über 50%	9 völlig verblüht
10 völlig vergilbt bis vergehend	10 fruchtend
11 oberirdisch verschwunden	11 Ausstreuen der Samen bzw. Abwerfen der Früchte
Grasartige:	
0 ohne neue oberirdische Triebe	0 ohne erkennbaren Blütenstand
1 neue Triebe ohne entfaltete Blätter	1 Blütenstand erkennbar, eingeschlossen
2 erstes neues Blatt entfaltet	2 Blütenstand sichtbar, nicht entfaltet
3 2-3 Blätter entfaltet	3 Blütenstand entfaltet
4 beginnende Halmentwicklung	4 erste Blüten stäubend
5 Halme teilweise ausgebildet	5 bis 25% stäubend
6 Pflanze voll entwickelt	6 bis 50% stäubend
7 beginnende Vergilbung, oft nur vergilbende Halme	7 Vollblüte
8 Vergilbung bis 50%	8 abblühend
9 Vergilbung über 50%	9 völlig verblüht
10 völlig vergilbt bis vergehend	10 fruchtend
11 oberirdisch verschwunden	11 Ausstreuen der Samen

K Keimling
J Jungpflanzen, im Beobachtungszeitraum nicht voll entwickelt
° angefressen
* welkend

Fig. 8: Phenological recording scale according to Dierschke (1989).

3.3 Data analysis and statistics

The data analysis focused on trends in climate (temperature, precipitation), the vegetative and generative processes, and the performance of species regarding temperature and moisture requirements as indicated by their indicator values. Indicator values were used as suggested from Ellenberg & Leuschner (2010) and Ellenberg et al., 1992, flowering periods were taken from Fischer et al., (2008) and resolved into weeks instead of months. Additionally, as the resolution of the flowering period is provided only roughly in this literature, the third week of the first month of the flowering period corresponding to the median of this month was taken as a reference for the expected onset of flowering for the comparison with the observed data. The first editing of the data was conducted with Excel, both through tables and charts.

For the testing of trends of meteorological data (times series), the non-parametrical Mann-Kendall test (McLeod, 2011; Mann, 1945) for monotonic trends in a time series, requiring only independency of the data set and based on the Kendall rank correlation, was performed (Gocic & Trajkovic, 2013).
As the data of the observed and given flowering starts of the species were not normally distributed, for both plots separately, a Mann-Whitney-Wilcoxon test (Lewis, 2010) was performed with the software RStudio to test if the observed data are different from the flowering starts given in Fischer et al. (2008). To test further if the different aspects of the plots have an impact on the generative courses, a χ^2-test was performed.
Finally, to analyse a possible correlation of early flowering behaviour of species and their habitat preferences (shown by indicator values), all species of the year 2016 that were undergoing a generative course were filtered first. Further on, the indicator value for temperature and moisture for all species were identified and finally all species with the same indicator values for the two categories were added into an indicator value category. The output was further analysed in RStudio and a Fisher´s exact test was performed, which is a non-parametric alternative to the χ^2-test for testing the independency of variables, especially powerful for small sample sizes and contingency tables bigger than 2x2.

3.3.1 Phenological data

The vegetative stages were compared using charts. The onset of flowering of those species of both plots that proceeded to a generative phase was compared to the flowering period given in Fischer et al. (2008). According to their performance, the species were separated into the categories “early flowering” and “flowering as expected”. The number of species was then related to their indicator values according to Ellenberg & Leuschner (2010) and Ellenberg et al., 1992.

4 Results

4.1 Climate data

The figures 9-12 (see below) show a trend line of the annual data of precipitation and temperature features, provided by ZAMG (Zentralanstalt für Meteorologie und Geodynamik). Between the years 1990 and 1998 some data are missing.

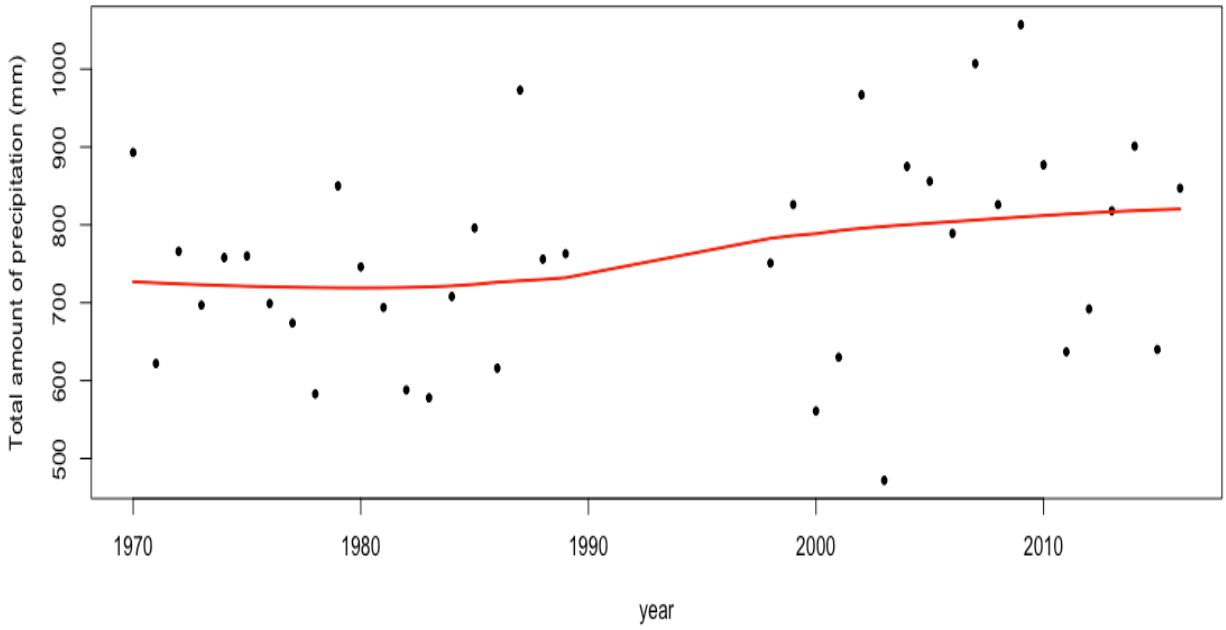


Fig. 9: Values of total amount of precipitation in the years 1970-2016 with a trend line added.

There are visually notable trends in the meteorological data from 1970 to 2016. However, for the total amount of precipitation per year, a trend was not significant (τ=0.181, n.s.).

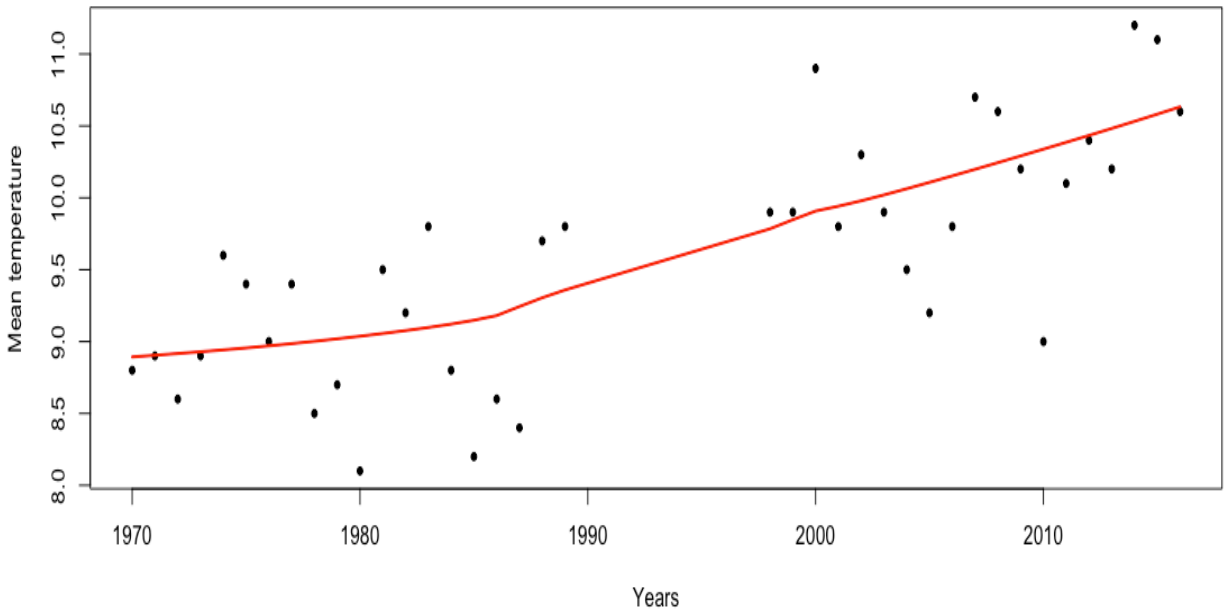


Fig. 10: Mean annual temperature values from 1970 to 2016 with a trend line added.

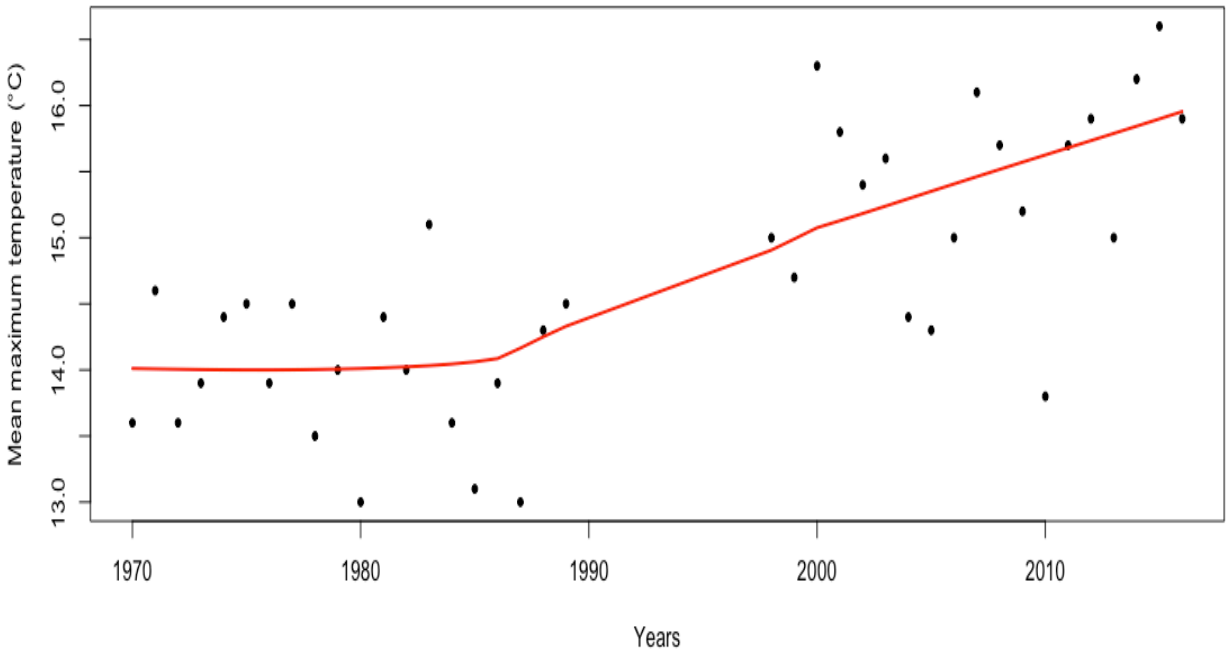


Fig. 11: Mean maximum temperature values from 1970 to 2016 with a trend line added.

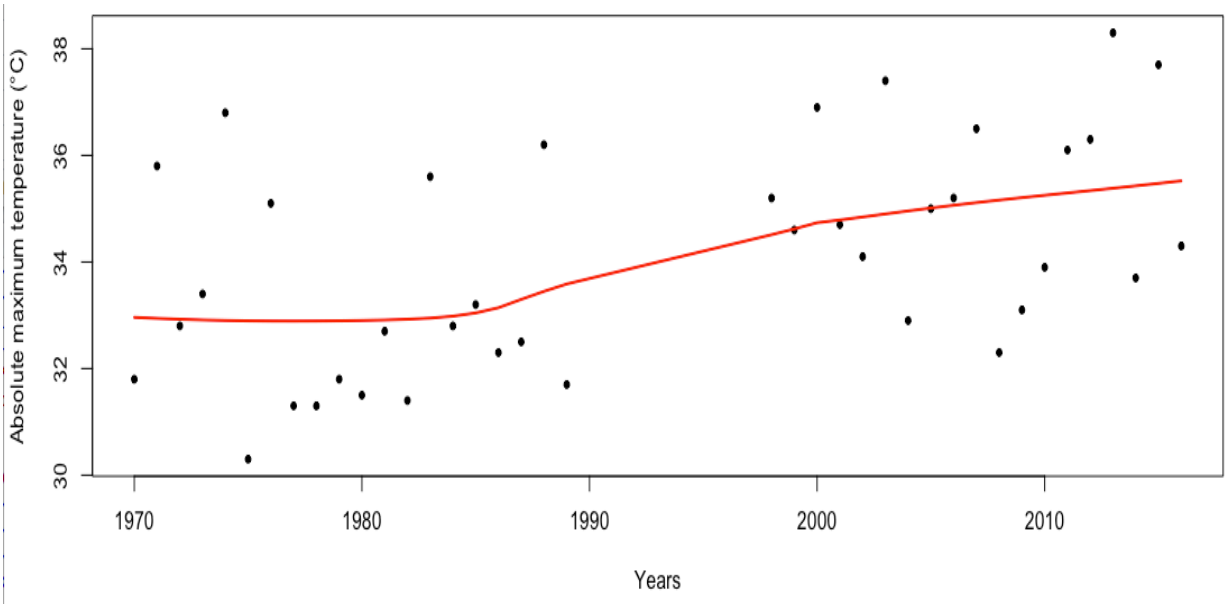


Fig. 12: Absolute maximum temperature values from 1970 to 2016 with a trend line added.

The upward trends in the temperature features mean temperature (τ=0.539; p<0.001), mean maximum temperature (τ=0.475, p<0.001), and absolute maximum temperature (τ=0.336; p<0.01) are all highly significant.

Table 3: Statistical p-values for the analysis of a long-term trends for the abiotic factors: precipitation and different temperatures values.

Abiotic factors	P-values
Precipitation (mm)	0.10762
Mean temperature (°C)	1.9073×10^{-6}
Mean maximum temperature (°C)	2.7537×10^{-5}
Absolute maximum temperature (°C)	0.0027987

4.2 Soil conditions

The analysed soil samples show that the north exposed plot (PL2) has a slightly higher pH-value than the south-exposed PL1. The amount of carbon in the soil samples varies within the plots and, on average, the amount of carbon is higher in PL1 than in PL2. Taking the very similar amount of Nitrogen into account, C:N ratio of PL2 is 1:13,1 compared to 1:15,6 of PL1.

Table 4: Overview of the results of the soil analysis: pH, total carbon and total nitrogen of PL1 and PL2.

	pH $CaCl_2$	pH H_2O	C (%)	N (%)
PL1_1	7,16	7,87	7,96	0,546
PL2_1	7,29	7,87	10,72	0,884
PL1_2	7,2	7,68	15,31	0,98
PL2_2	7,18	7,65	13,26	0,954
PL1_3	7	7,46	15,45	0,96
PL2_3	7,21	7,73	10,8	0,795
PL1_4	7,07	7,6	11,54	0,74
PL2_4	7,28	7,97	7,75	0,606
PL1_average	7,1075	7,6525	12,565	0,8065
PL2_average	7,24	7,805	10,6325	0,80975

4.3 Phenology

4.3.1 Oak forest (PL1) in the course of the year 2016

The, approximately 25m high, tree layer was dominated by oaks (*Quercus cerris*, *Quercus pubescens*, *Quercus petraea*) co-occurring with *Fraxinus excelsior*, *Tilia platyphyllos, Acer campestre* and *Sorbus torminalis*. There was only one individual of *Tilia platyphyllos*, however, as it was quite in the middle of the plot and a large individual, it covered a big part of the plot area. The coverage of the tree layer was quite high (80%) yet the ground-layer received a lot of light, especially due to the big, loose crowns of the *Quercus spp.*

The sparse shrub layer was between 1.5m and 4m high, consisting of *Cornus mas, Crataegus laevigata, Crataegus monogyna* and *Sorbus aria*. The herb layer of PL1 was quite open (40% coverage) in the springtime. Although it became denser towards the summer, the coverage through the year was still rather low (60% coverage). Early flowering plants such as *Primula veris, Viola hirta, Mercurialis perennis, Mercurialis ovata, Daphne laureola* and *Hepatica nobilis* started their generative cycle first, followed by *Pseudoturritis turrita*, *Cardamine bulbifera*, *Carex michelii* and *Muscari neglectum*. Those were followed by *Sanicula europaea*, *Melica uniflora*, *Melica nutans* and *Buglossoides purpurocaeruleum*, forming

together a high number of flowering individuals. The final guild of generative plants was formed by summer flowering species like *Dictamnus albus, Cephalanthera longifolia, Cephalanthera damasonium* and *Peucedanum cervaria*.

4.3.2 Oak-hornbeam forest (PL2) in the course of the year 2016

The highest trees of the tree layer reached up to 20 meter, dominated by *Carpinus betulus, Quercus petraea* and *Fraxinus excelsior.* Additionally, single individuals of *Pyrus pyraster, Acer campestre, Acer platanoides, Fagus sylvatica, Tilia platyphyllos* and *Ulmus glabra* were present. The coverage of this layer conformed to the other plot yet the light availability was low due to the north exposition of the slope as well as the dense treetop of *Carpinus betulus.* Only three species, *Cornus mas*, *Acer campestre* and *Crataegus laevigata* profiled the shrub layer. *Cornus mas* and *Crataegus laevigata* could be detected among the first flowering species. From spring up to the summer months, the herb layer was very distinct mainly because of *Allium ursinum* and *Mercurialis perennis,* covering up to 90%. Together with other flowering species like, *Hepatica nobilis, Primula vulgaris, Daphne laureola* and *Euphorbia amygdaloides* the generative phase started notably early. Other species like *Anemone ranunculoides* and *Lamium maculatum* were in their vegetative phase at this point, producing their first flowers only two weeks afterwards. By the end of May the highly abundant species *Allium ursinum* started yellowing and *Galium odoratum* and the grasses species *Melica uniflora* and *Melica nutans* started replacing it. Towards the summer months, the number of flowering species was not as high as it was at PL1. At this period, the flowering species consisted of *Campanula trachelium, Campanula rapunculoides, Campanula persicifolia, Bromus benekenii* and *Brachypodium sylvaticum.*

4.3.3 Comparison of the flowering starts of PL1 and PL2 in the year 2016

The number of shared species of the two plots is 32 and is much higher compared to only 13 common species that were flowering on both plots.

Most of the species flowering in the two plots showed analogous flowering behaviour, however, a few species flowered earlier in plot 2 (Fig. 13).

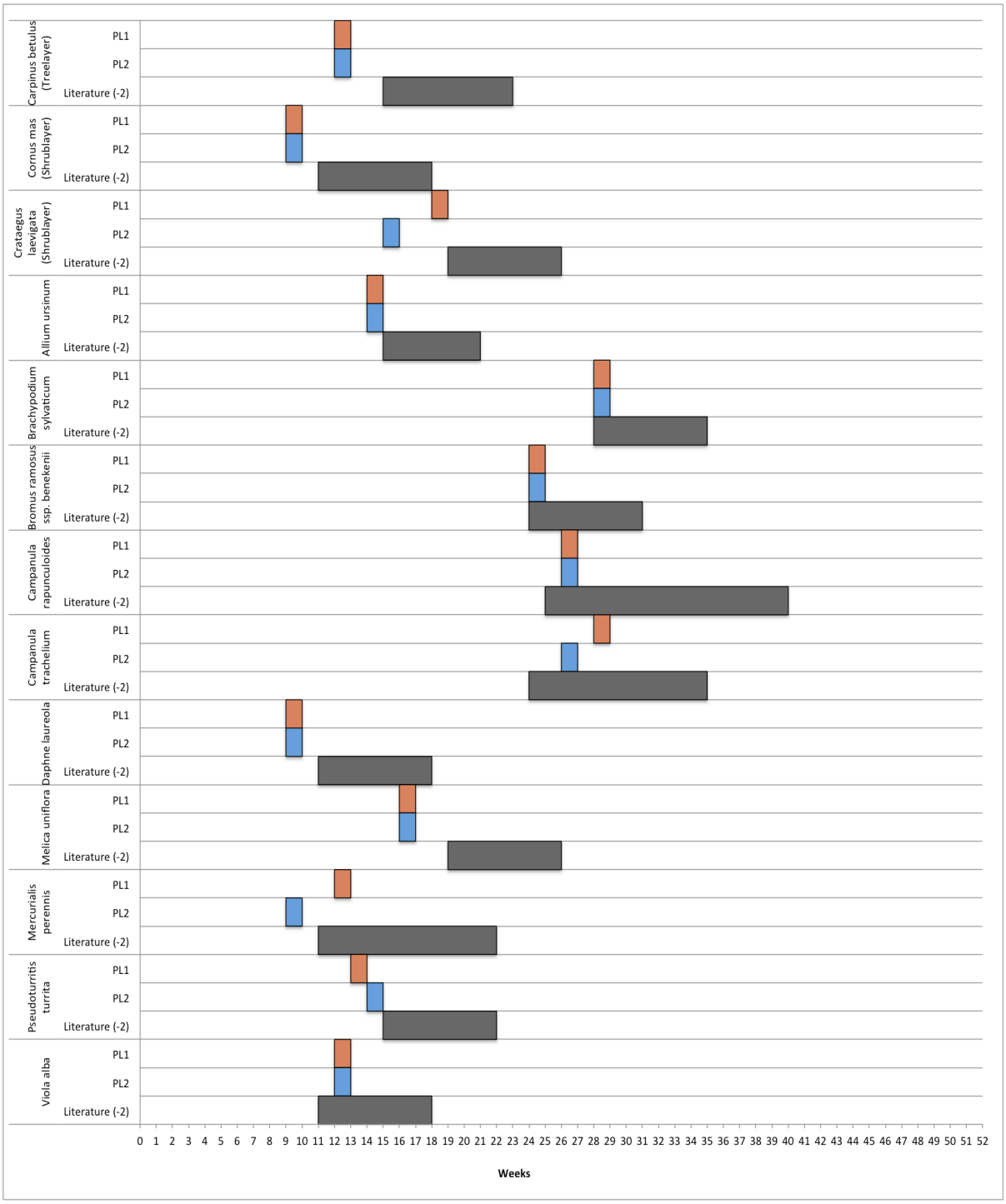


Fig. 13: Start of flowering of common species of PL1 (=orange) and PL2 (=blue) in 2016 versus flowering period (=grey), given by Fischer et al. (2008).

4.3.4 Comparison of vegetative stages of the two plots in the year 2016

Figure 14, 15 and 16 show the yearly vegetative course, divided in tree-, shrub-, and herb layer of the two plots in the year 2016. For the tree layer and the shrub layer of both plots no striking differences could be detected, only *Carpinus betulus* in the tree layer started leaf unfolding quite early in the oak-hornbeam forest compared to the oak forest.

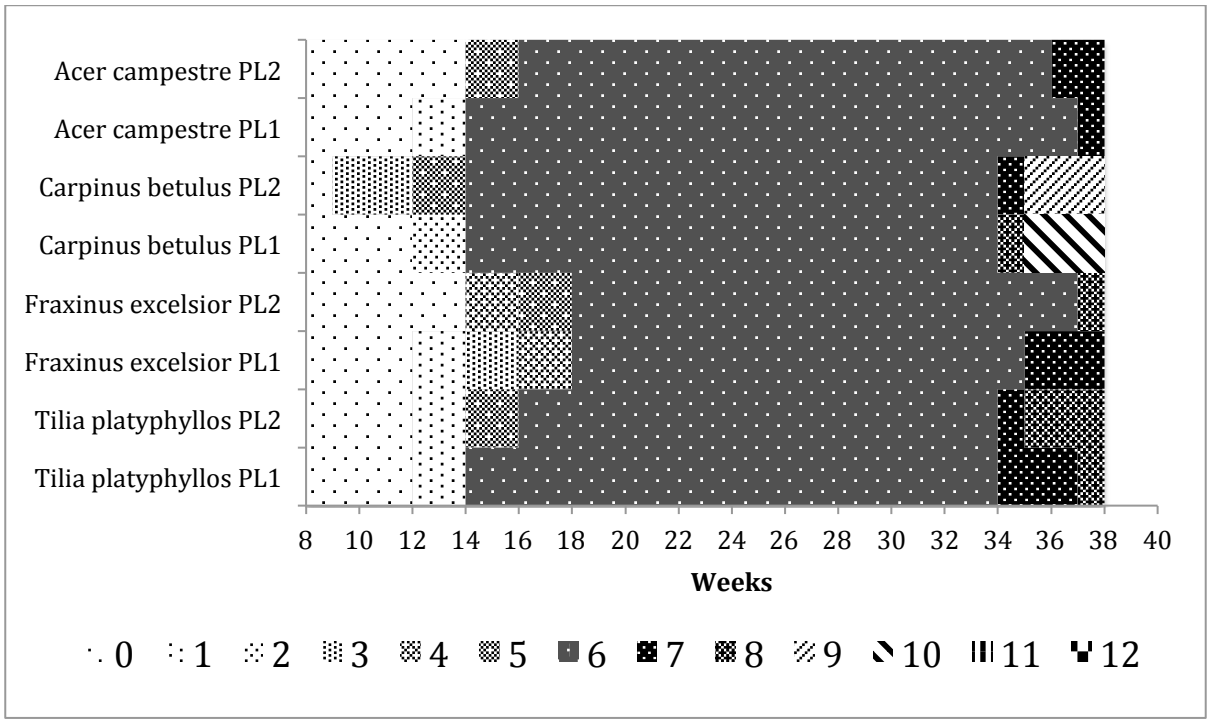


Fig. 14: Comparison of the vegetative phenology of common species of PL1 and PL2 - tree layer 2016.

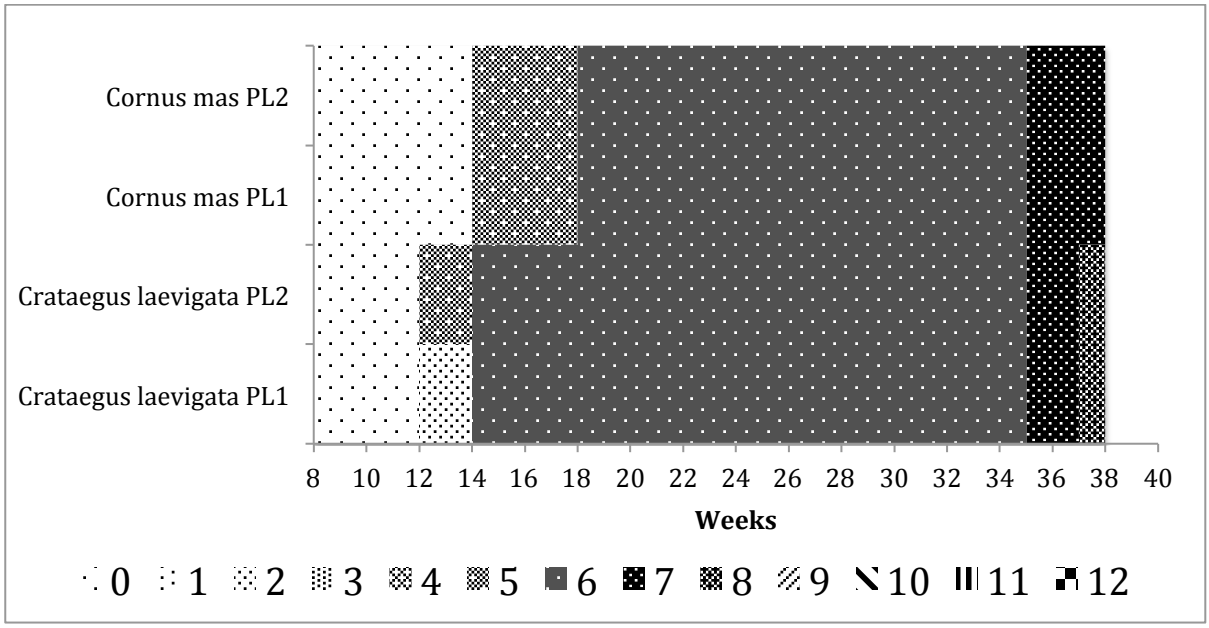


Fig. 15: Comparison of the vegetative phenology of common species of PL1 and PL2 - shrub layer 2016.

The common herb species of the two plots showed, in general, a similar behaviour in the course of vegetative phenology. The three species *Campanula ranunculoides, Galium odoratum* and *Tanacetum corymbosum* showed advanced development in the oak forest. Some species, like *Allium ursinum and Bromus benekenii* showed a prolonged vegetative phase in the oak-hornbeam forest compared to the oak forest. These two species started leaf unfolding and developing earlier and retract later. *Cyclamen purpurascens* was recorded to start its vegetative development earlier in the oak-hornbeam forest. Apart from *Tanacetum corymbosum*, the species show a preference to moderately moist and/or temperature (Table 5).

Table 5: Overview of species with deviating vegetative course of the two plots with their indicator values for temperature [T] and moisture [M].

Species	Plot	Indicator value [T]	Indicator value [M]
Campanula ranunculoides	PL1	6	4
Galium odoratum	PL1	5	5
Tanacetum corymbosum	PL1	6	3
Allium ursinum	PL2	X	6
Bromus benekenii	PL2	5	5
Cyclamen purpurascens	PL2	6	5

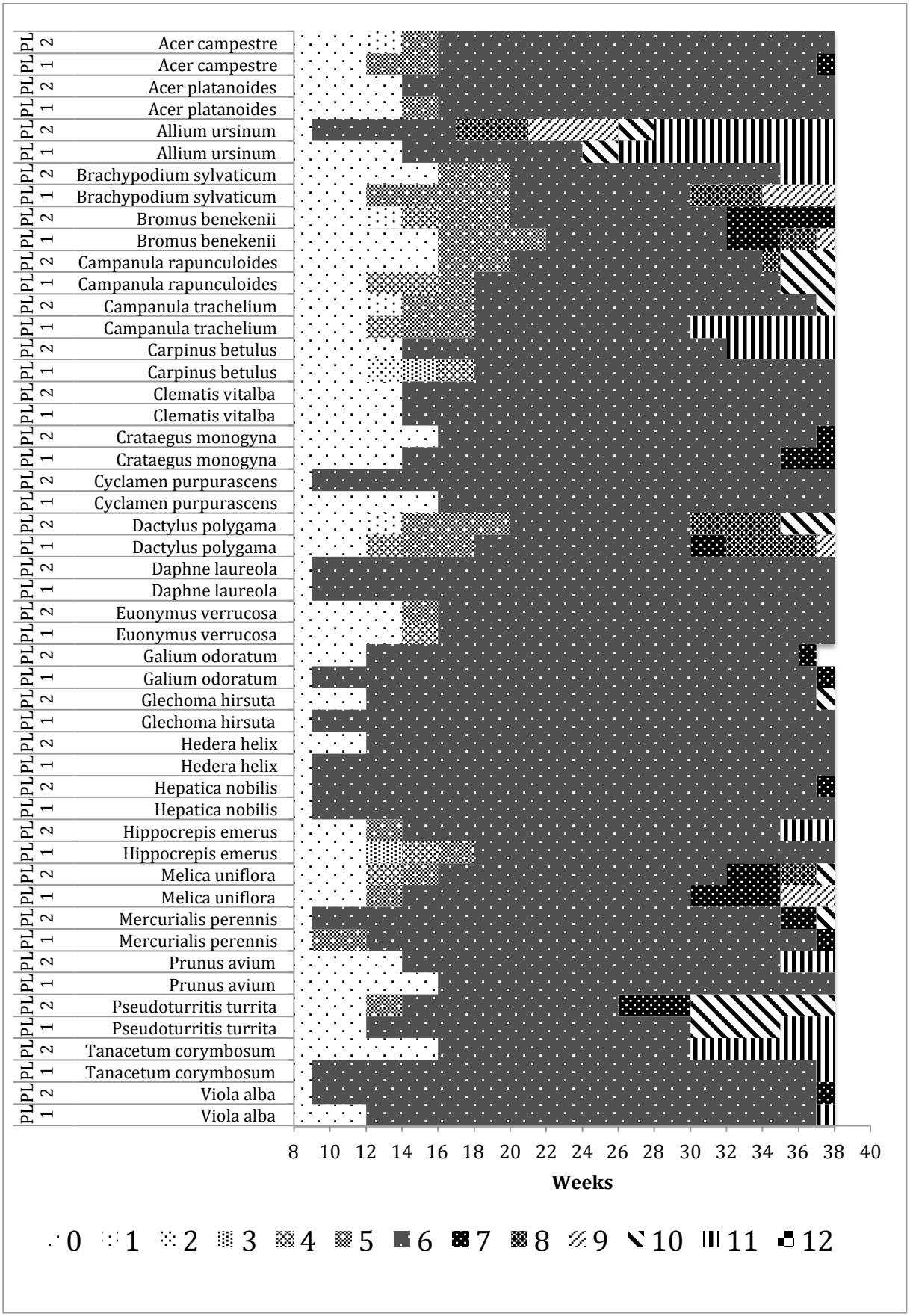


Fig. 16: Comparison of the vegetative phenology of common species of PL1 and PL2 - herb layer 2016; PL=Plot; 1=Oak forest, 2=Oak-hornbeam forest.

4.3.5 Vegetative and generative stages in 2015

In the year 2015 the annual precipitation was 640mm (760mm from 1970 to 2014). It was a dry year, and with the second highest maximum of temperature in the last 40 years, a very hot year. Most of the tree species in both sample plots seemed to withstand the heat, not showing any early yellowing or problems with seed development. Three conspicuous tree species are, however, *Fagus sylvatica*, dropping up to 80% of its leaves and *Tilia platyphyllos* together with *Carpinus betulus* showing signs of yellowing during the hottest month July. *Fagus sylvatica* and *Tilia platyphyllos* have the indicator values IV^T (Indicator value temperature): 5 and IV^M (Indicator value moisture): 5. *Carpinus betulus* has IV^T 6 and IV^M "indifferent". The other tree species, which were not affected by the heat and drought, have IV´s showing tendencies to either dryer and/or warmer habitats. Getting to the shrub layer, only a few species with evident stress could be detected. Similar as for the tree layer, some species of the herb layer with an IV^T 5 and IV^M 5, especially grasses like *Brachypodium sylvaticum, Melica nutans, Melica uniflora, Bromus benekenii* seemed to exceed their ability to deal with dry and/or hot conditions as they, although flowering, produced only stunted seeds.

4.3.6 Comparison of 2015 and 2016

The data collection in the year 2015 could start only in May. As the collecting period is not equal with 2016, it was only possible to compare the months between May and October between the two years, both vegetatively and generatively. In the year 2015 some species became stressed, showing this by leaf dropping, early yellowing (PL2: *Fagus sylvatica, Tilia platyphyllos*) or dysfunctional seeds (PL1 and PL2: *Brachypodium sylvaticum,PL2: Melica uniflora,* PL1: *Bromus benekenii)* whereas in 2016 seeds were fully developed together with a lack of notable early yellowing processes of any species. Anyway some different behaviour in flowering and fruiting could be recorded. In 2015, *Quercus petraea* was fruiting but in 2016 it did not even flower. *Carpinus betulus* was flowering, even abundantly, in 2016 only in the oak-hornbeam forest, yet only a very few fruits were developed. In contrast to that, in 2015 *Carpinus betulus* made no fruits at all. *Tilia platyphyllos* was the only tree species flowering and fruiting in both years and both plots. Still, it has to be mentioned that the amount of fruits was much lower in 2016. For the herb layer the only striking differences between the two years were the already above mentioned grass-species, whereas the shrub layer cannot really

be compared between the two years, as the species *Cornus mas* and *Crataegus laevigata* are supposed to flower earlier than the start of the recording period in 2015.

4.4 Early flowering species in 2016

4.4.1 Observed onset of flowering start compared to literature

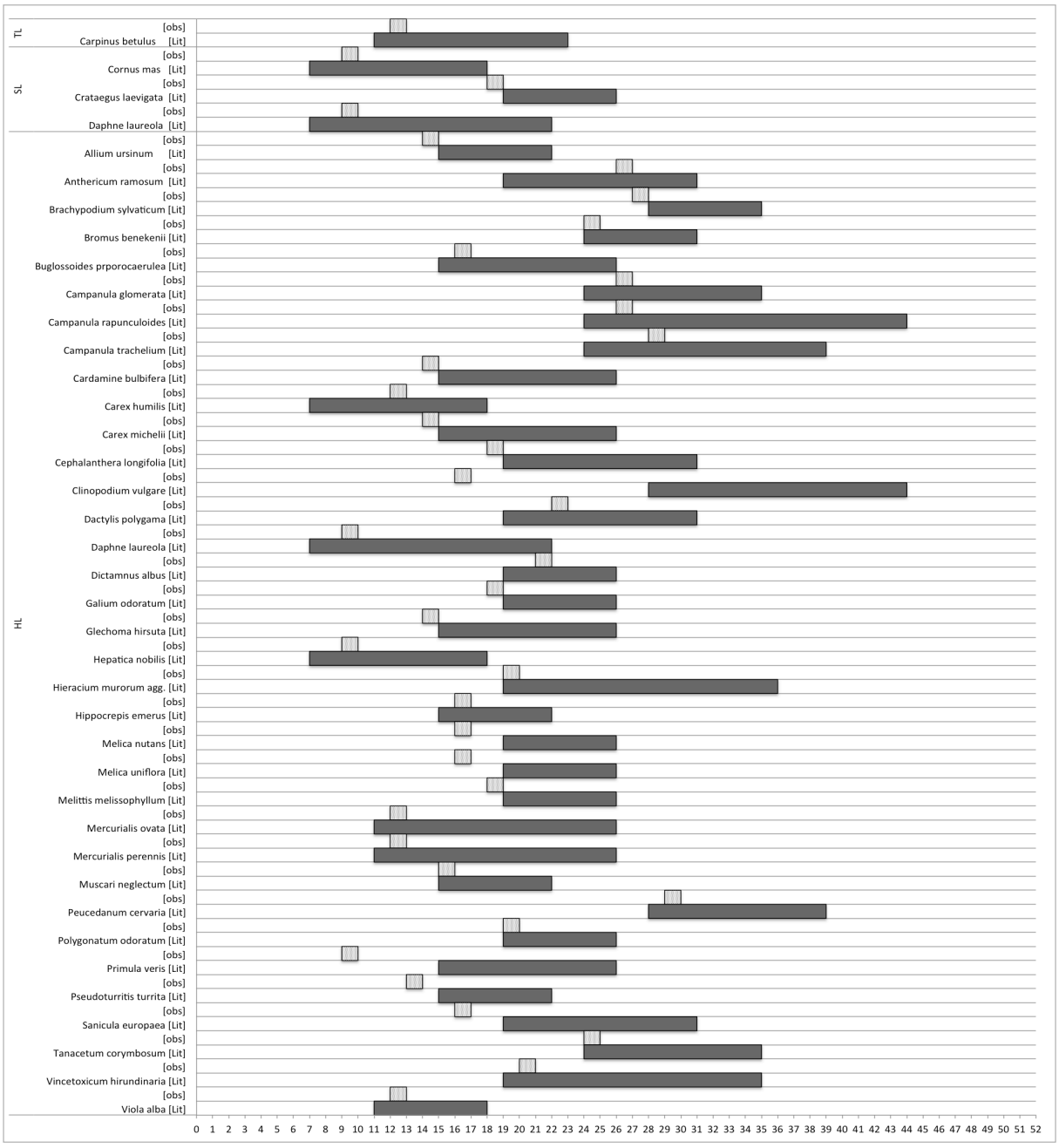


Fig. 17: Observed start of flowering in the oak forest (PL1), 2016 compared to flower period according to Fischer et al. (2008); TL=Tree layer, SL=Shrub layer, HL=Herb layer; obs=observed; Lit=Literature (after Fischer et al. 2008); light grey bar=observed start of flowering time, grey bar=flowering period according Fischer et al. (2008), x-axis: weeks in the year 2016.

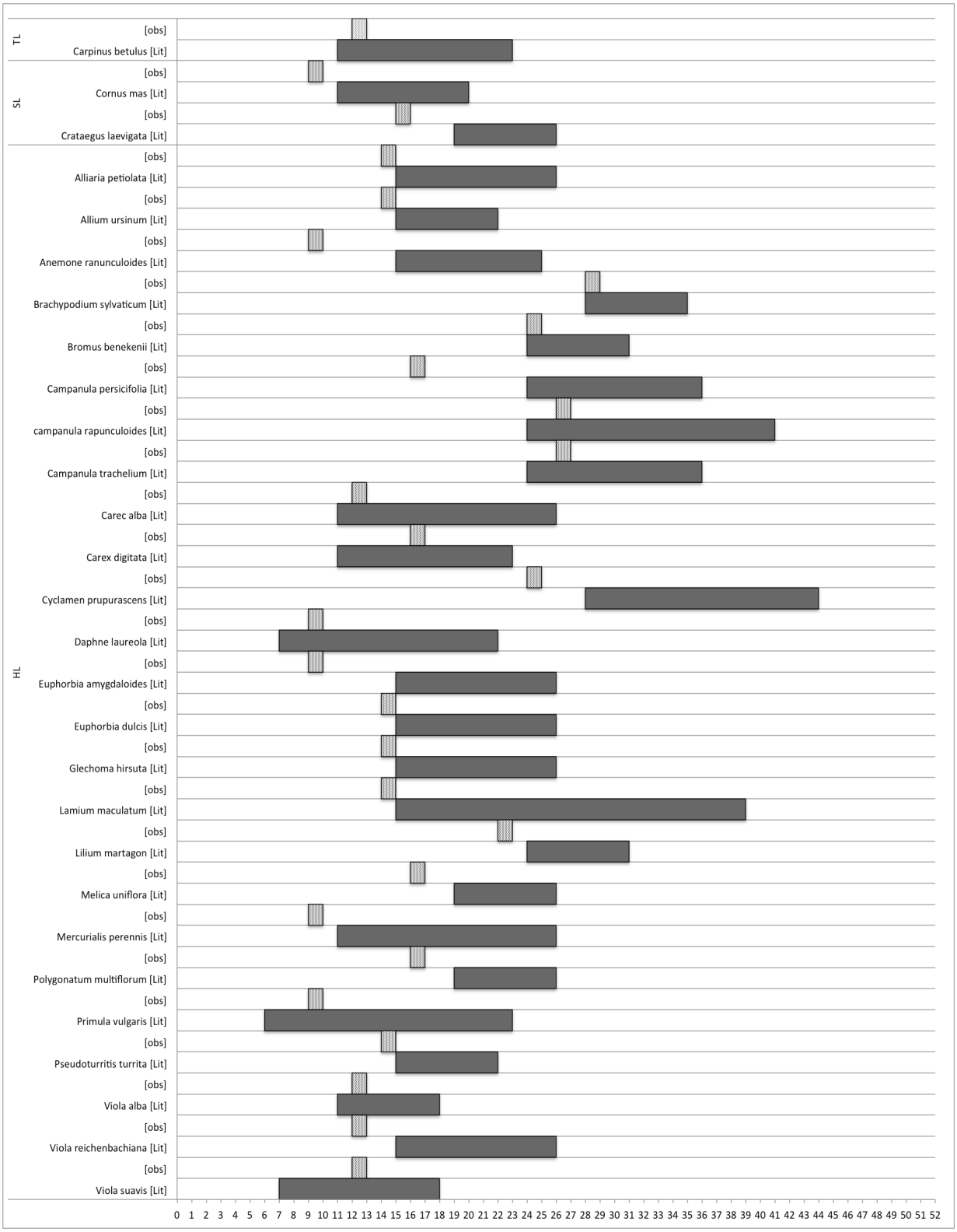


Fig. 18: Observed start of flowering in the oak-hornbeam forest (PL2), 2016 compared to flower period according to Fischer et al. (2008), 2016; TL=Tree layer, SL=Shrub layer, HL=Herb layer; obs=observed; Lit=Literature (after Fischer et al. 2008); light grey bar=observed start of flowering time, grey bar=flowering period according Fischer et al. (2008), x-axis: weeks in the year 2016.

Figure 17 and 18 show the observed flowering start of the species with a generative stage versus their flowering period. Some species start flowering early compared to the flowering time given for plants in literature for Austria (Fischer et al., 2008 = expected). Most of the species with an observed flowering start earlier than the one given in literature are species that have their flowering period starting early, respective in springtime.
Although a number of species flowered earlier than expected, the mean numbers of weeks when the first flowers appeared are not significantly different between the groups "early flowering" and "flowering as expected" tested with the Mann-Whitney-Wilcoxon test neither for Plot 1 (W=738, n.s.) nor for Plot 2 (W=349, n.s.).

4.4.2 Early onset of flowering and aspect of the plots

Comparing the two plant communities and their generative course it could be shown that not only the species composition but also the amount of early flowering species between the plots is different. In the oak forest (PL1), which is south exposed, 14 species flowering earlier than expected, could be detected compared to 29 species that were flowering within the expected range. In the oak-hornbeam forest on the other hand 19 early flowering species compared to only 9 species flowering as expected could be recorded. The $\chi 2$-test ($\chi 2=5.4432$, $p<0.05$) revealed a significant difference between the plots and their flowering course.

4.4.3 Flowering species and their indicator values

Among the flowering species, those with a preference for cooler and/or moister habitats (IV^T: 5; IV^M: 5-6) belong predominantly to the early flowering species. In general, there is a tendency that species with a preference to warm or moderately warm conditions did not flower outside their expected flowering period.
Comparing the indicator value temperature of the two plots, it shows a quite similar picture, yet plants preferring moderately warm to warm conditions (IV^T 6) perform strikingly different (Fig. 19a and 20a). This trend and similarity is not as clear for the indicator value moisture. In absolute numbers, the biggest number of early flowering species belong to category 5, yet there are many normally flowering species as well. In category 6, which represents species with the highest moisture preference in the plots, only early flowering species for both plots were detected. Overall, the plots show rather different results related to moisture values. In

PL2 the number of early flowering species is even bigger than the number of normally flowering species.

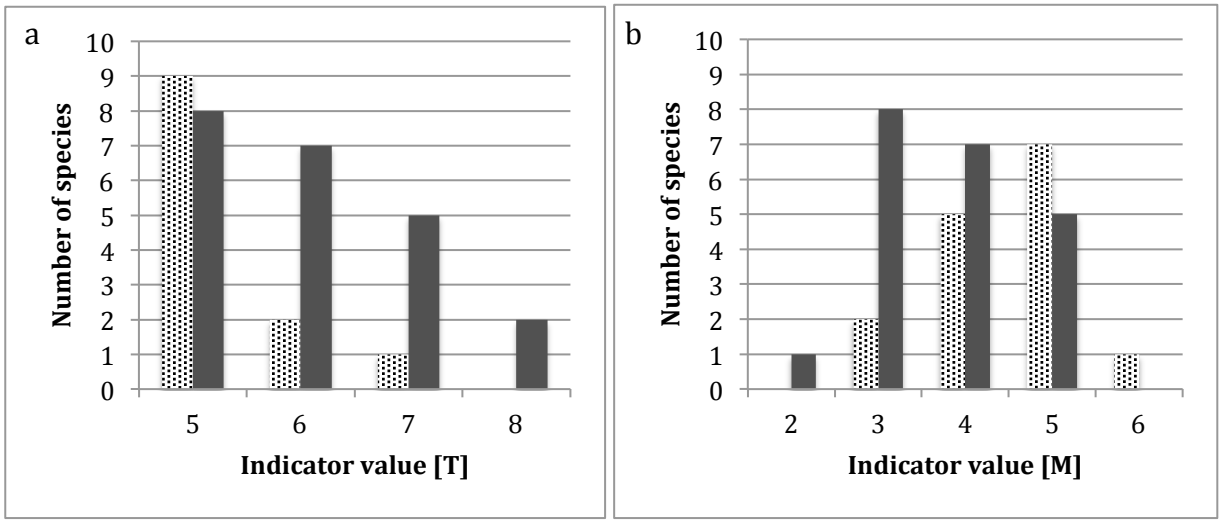


Fig. 19: Number of early flowering species/species flowering as expected assigned to their indicator values (a) for temperature [T] and (b) for moisture [M] in PL1 2016, scattered bar=early flowering species, filled bar=not early flowering species.

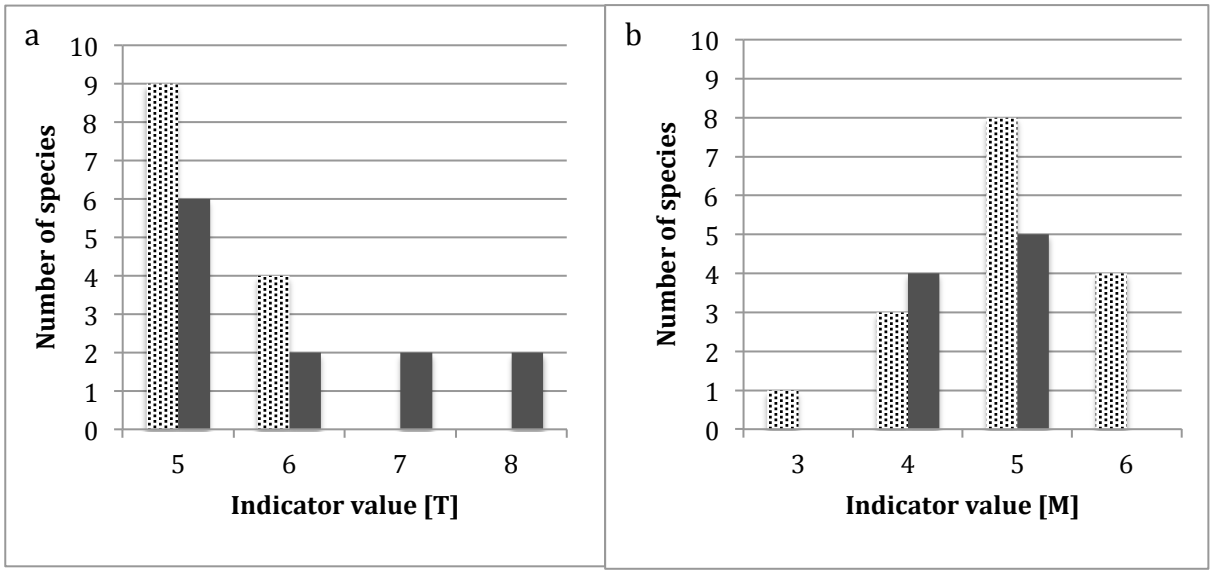


Fig. 20: Number of early flowering species/species flowering as expected assigned to their indicator values (a) for temperature [T] and (b) for moisture [M] in PL2 2016, scattered bar=early flowering species, filled bar=not early flowering species.

Plants of indicator values 4 and 5 behave similar between the two plots, yet, the values 3 and 6 are very unlike (compare Fig. 19b and 20b). In PL1 the indicator value 3 characterizes a high number of normally flowering species compared to only 1 early flowering species in

PL2. On the other hand PL2 shows some early flowering species with the indicator value 6 while there is only 1 in PL1.

The flowering pattern of species when grouped according to their indicator values suggests that there may be a correlation between plants of certain indicator values and their flowering performance (Fig. 19-20). However, testing this with Fisher´s exact test over all categories in a plot did not show any significant relationship (Table 6).

Table 6: Results of test for correlation between performance of flowering (early/ as expected) when species are grouped according to their indicator values for temperature and moisture (Fischer´s exact test).

Sample plot	Category of the Indicator value	Fisher´s exact test P-value
PL1	Temperature	0.2337
PL1	Moisture	0.189
PL2	Temperature	0.5464
PL2	Moisture	0.267

4.5 Recruitment of the tree- and shrub layer in the year 2016

Most of the tree and shrub species of the two plots were reproducing, yet the abundance of the species was very different in the plots. In the oak-hornbeam forest the number of seedlings per species was very low, several times only one individual could be found. Only a high number of seedlings of *Tilia platyphyllos* could be recorded in the year 2016, yet seemingly not many seedlings could establish the years before. Contrasting to that, in the oak forest the seedling abundance, especially of *Acer campestre, Sorbus torminalis* and *Quercus cerris,* was very high.

Table 7: Overview of the recruitment of different tree species (X=present) within the plots. The grey highlighting of "X" indicates a high abundance of seedlings of the respective species. Empty space indicates that recruitment of this species is missing in the respective plot.

Species	**Oak forest: PL1**	**Oak-hornbeam forest: PL2**
Acer campestre	X	X
Acer platanoides	X	X
Acer pseudoplatanus	X	X
Cornus mas		X
Crataegus laevigata	X	X
Crataegus monogyna	X	X
Euonymus verrucosa	X	X
Fagus sylvatica	X	
Fraxinus excelsior	X	X
Juglans regia		X
Prunus avium	X	X
Quercus cerris	X	
Quercus petraea	X	X
Sorbus torminalis	X	
Tilia platyphyllos	X	X
Number of species	13	12

5 Discussion

Thresholds of temperature limits in vegetative and generative stages and recruitment in the tree layer

The deviations in the vegetative course of some species indicated stress (e.g. leaf dropping, yellowing) in the oak-hornbeam forest in the year 2015 matching with the peak of absolute temperature maximum and very low precipitation. Day 19 of July 2015 was the warmest day of the year (37,1°C). At the weather station Wien Mariabrunn (the only available dataset for this purpose close to the plots, ZAMG) between 16th and 25th of July 2015 the temperature maximum was only one day not above 32°C and only 3.4 mm rainfall occurred, indicating dry conditions. In the data record, 9 days after the temperature peak, *Fagus sylvatica* had already dropped leaves. As described in Leuzinger et al. (2005), *Fagus sylvatica* does not tolerate excessive flux rates and, therefore, restricts transpiration rates, equitable with a rather weak response to drought stress, matching the observations. In contrast, the *Quercus* spp. did not show any signs of drought stress and performed well, especially *Quercus petraea*. This is in line with the findings of Leuzinger et al. (2005), that *Q. petraea* keeps transpiration rates high during drought events, showing resistance and normal performance. Another reason for the different performances of the sessile oak and common beech might be found in different root systems, explained by the findings of Leuschner et al. (2001), who showed a deeper reaching coarse root system in *Q. petraea* than in *Fagus sylvatica*.

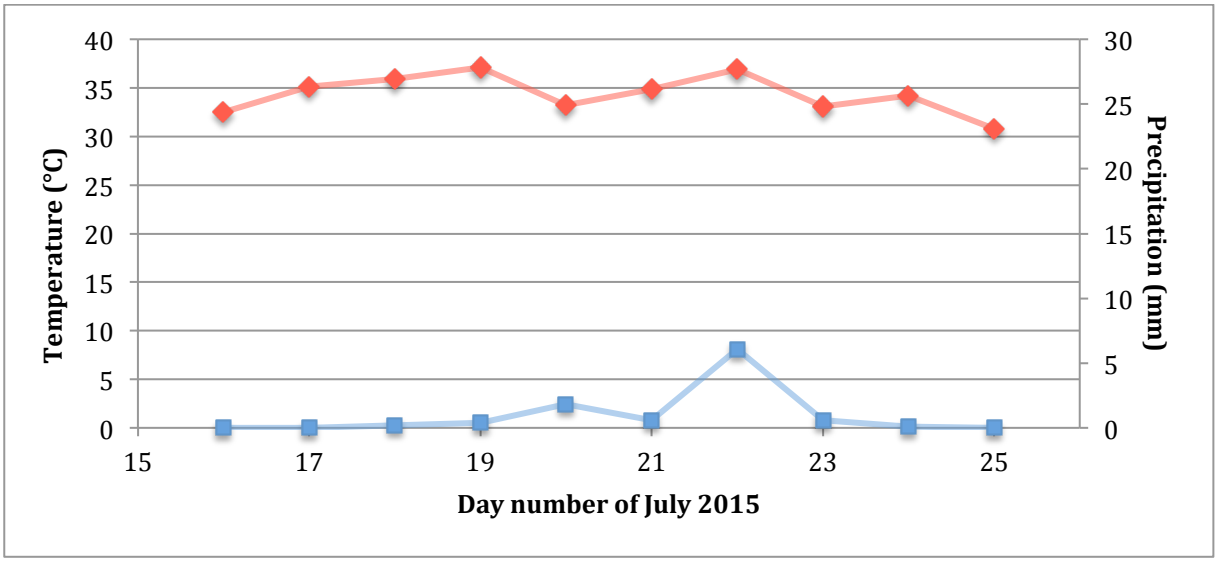


Fig. 21: Daily absolute maximum temperature (°C) and daily precipitation of July 2015, day 16 to 25 - Period with highest temperature values and very low precipitation values respectively in 2015; red= temperature values, blue= precipitation values.

Seemingly not that severely affected, *Tilia platyphyllos* started yellowing simultaneously at the end of July, recovering again two weeks later when the weather cooled down. The individual of *T. platyphyllos* in the oak forest did not show any yellowing, although this site was south exposed. Clear reasons for this cannot be identified whereas it might be, that the rather solitary and comparatively taller individual in the oak forest had less competition, therefore a more developed root system and subsequently maybe a better water supply.

As *Acer campestre* did not show any signs of stress (e.g. early yellowing, leaf dropping), but *T. platyphyllos* did, my findings show a contrast to Leuzinger et al. (2005) who found *T. platyphyllos* to be rather drought resistant and *A. campestre* less. Additionally, in my plots, the recruitment of *A. campestre* was very high, yet higher in PL1 than PL2, indicating a good overall reproduction. In the years of the data records, however, no reproductive organs were found in *A. campestre* contrary to the yellowing, fruit developing, *T. platyphyllos* respectively. Therefore, the whole recruitment in *A.campestre* originates from the years before data collection. It seems that *T. platyphyllos* is capable to produce fruits more successfully during drought stress than *A. campestre*, but recruitment performance is lower.

Carpinus betulus showed first signs of yellowing, but also developed seeds. This might indicate that this species got into drought stress at temperature peak, but the quite effective strategy for the water budget compensated the stress to a level that the tree could still develop fruits. The recruitment of *C. betulus* was low too. Matching somewhat with the finding of this work, Leuzinger et al. (2005) found that *C. betulus* cuts down transpiration rates during drought but responds quickly once moisture is available again. Some of the tree and shrub

species of the stands, like *Cornus mas* and *Sorbus aria*, failed to develop seeds or even flowers, which is in line with the findings of Bréda et al. (2006) that tree water deficits might result in reduced bud production.

Interestingly, although *Sorbus torminalis* showed a very high amount of seedlings in the oak forest plot, in the two recording years, no flowers or fruits were detected. Stephenson (1981, p. 261) hypothesizes that if resources are limited then "pollinated flowers and juvenile fruits abscise until fruit and seed number matches the available resources" and that "the proportion of juvenile fruits and seeds that mature is dependent upon extrinsic factors, such as weather conditions and seed predation, and the ability of the maternal parent to provide the resources necessary for growth and development" raising the question of a possible nutrient deficiency at the site.

In general, there is a recruitment success in most of the trees and shrubs. However, species with high seedling abundance are mostly species with a preference for warmer temperatures and/or a lower moisture demand (relatively low indicator value of moisture).

Tilia platyphyllos is deviating with an indicator value of temperature of 6 and an indicator value of moisture of 6, but as the single individuals in both plots were very vital/old, they might be more resistant against drought stress, resulting in a possible ability to still produce fruits.

It is known, that for some tree species there is a specific dynamic that in some years individuals are producing large amounts of seeds and in others nearly none. This phenomenon, which is called "Mastjahre", has not been taken into account for this thesis. Next to temperature stress this might also play a role why some species did not really produce seeds.

Early flowering species and withering of seeds – threshold of heat tolerance during reproduction of the herb layer

As illustrated by the present findings, it is obvious that species have different thresholds for heat stress tolerance for both, vegetative and generative stages. Data of heat stress effects during the generative stage as well as reproduction limits on single species level are, however, mostly available from crops. Some, especially grass-like, species in the hot year 2015 could not finish their generative cycle, only producing aborted seeds. As the affected species had their flowering time within the very hot and dry months of 2015 and as all of them prefer rather cool habitats, it is most likely that they actually faced their heat stress tolerance

threshold for reproduction, matching with the findings of Angadi et al. (2000) that for a successful reproduction the flowering stage is the most vulnerable phase affecting the quantity and functionality of seeds, respectively.

In this thesis, only early flowering species or species with problems of building a normally developed seed were regarded. It is possible that other species became stressed as well, aborting either single flower buds or simply producing a smaller number of seeds. This would be in line with Warner & Erwin (2005) who suggested that in between the smallest negative impact on the generative stages and 100% bud abortion there is a stage that leads to single bud abortion.

Comparing 2015 and 2016 against the long-term values, the mean maximum temperature was raised in both years, whereas only in 2015 the absolute temperature maximum was much higher than the long-term values. As the stress signs (yellowing, abscission) were much more prominent in 2015, absolute temperature maximum seems to have a big impact on reproduction. It is difficult to conclude whether the temperature peaks were the only influencing factors or if duration of the exposure was also important, as suggested in Warner & Erwin (2005).

In this work, phenological changes could be detected rather for spring flowering species. Summer flowering species on the other hand seem not to react by changing their phenology so much but some might have faced their heat stress threshold.

Table 8: Overview of sensitive species and their stress response in the year 2015.

Taxon	Layer	Stress response in 2015	Plot
Carpinus betulus	Tree layer	Yellowing	PL2
Fagus sylvatica	Tree layer	Dropping leaves	PL2
Tilia platyphyllos	Tree layer	Yellowing	PL1
Cornus mas	Shrub layer	No fruits developed	PL1 and PL2
Brachypodium sylvaticum	Herb layer	Ovary withered	PL1
Dactylis polygama	Herb layer	No fruits developed	PL1
Hordelymus europaea	Herb layer	No fruits developed	PL2
Melica uniflora	Herb layer	Seeds withered	PL2

Sensitive species and indicator values

Species with an onset of flowering in the months March and April seem to have a tendency to flower earlier as suggested (e.g. Fischer et al., 2008), whereas species with a flowering start in summer, flowered mostly within their usual flowering period, but in the year 2015 some of them had problems to complete their generative cycle. The mean maximum temperature values were high in both years compared to the long-term values, yet, the summer month were particularly high.

Species that were regarded as early flowering according to Fischer et al. (2008) belonged mostly to the group of spring flowering species and not to the group of summer flowering species. The reason for the early onset of species flowering in March and April is possibly due to warmer temperatures during the month of onset and the temperatures in the preceding one or two months (Menzel et al., 2006).

For the statistical analysis, abundances of the different species were not taken into account. Every occurring species was treated with the same weighting for the statistics even if only single individuals (e.g. *Tanacetum corymbosum*) were present, opposed to species with many individuals (e.g. *Allium ursinum*). This situation, however, leads to a big impact of a few species on the statistics, especially of those with a rather extreme indicator value. The species *Pseudoturritis turrita* is the most weighing example. It had only a low number of individuals, was identified to be in the category early flowering and has indicator value 7 for temperature and 3 for moisture. It could be very useful for research questions similar to this work and maybe others, to think about a proper weighting of species' abundance to be able to reduce outlier effects.

All in all, if dealing with heat stress tolerance and topics related to performance under extreme weather conditions, indicator values could be used to a get a first impression of how species of the herb layer might perform. Further on, as temperature changes proceed, the question of which species will be affected most might come up as well, another field in which indicator values can help to get a pre-selection of sensitive species.

Effects of exposition and surroundings on the phenological course of plant species

Although one could have expected a bigger temperature stress for species of the oak forest with a southern aspect, the different signs of stress are similar for the two plots. With statistical analyses, it could be shown that in general in the oak-hornbeam forest more species were flowering early, yet no signs of stress like withering or unsuccessful generative cycles were detected. The forest communities of the plots are similar, yet, the number of species that were occurring in both plots and showing a generative stage, was rather small. This low number makes it difficult to detect deviations in the phenological course as well. Moreover, on the lower edge of the slope, only about 50 metres away from the oak forest plot, a rather moist habitat with many individuals of *Fagus sylvatica* was growing, possibly creating a moister microclimate, which buffered the temperature peaks of the site and decreasing the heat potential during this period at the plot. This might weaken the heat effects of the southern aspect to an extent that possible effects were compensated and therefore could not be detected clearly.

At the time of the maximum vegetation cover it was difficult to detect species with very low abundances, leading to the possible bias that some rare species were detected late or maybe even overseen.

Further on, some species showed very high abundances in the plots but deviating flowering behaviour between the individuals. Intraspecific competition, temperature or different water/nutrient availability within the plots might have affected their phenology. An example for this was *Allium ursinum* as it occupied nearly the whole plot in the oak-hornbeam forest. The individuals grew at different conditions, experiencing possibly different deficiencies and stress factors within one plot. Compared to this, in the oak forest only very few individuals of *Allium ursinum* were found, which had a rather synchronous behaviour. This phenomenon could only be found for the generative but not for the vegetative phenological course.

Taking the vegetative course into account, it could be shown that between the plots, some species showed differences, yet, most species had a very similar behaviour. Possibly, the resolution of the recording intervals was too coarse. Summing up, the two plots with different aspects show differences in their phenology, especially in terms of onset of flowering periods, yet it is not clear if the reasons for this are due to the aspect of the plots or species composition of the plant community.

In the light of the vegetative phenological course, differences between the two plots and expositions are not strikingly big. Interestingly not many plants actually dropped their leaves or showed signs of exceeding their heat stress tolerance, opposed to the findings of Klug et al. (2003). The suggested modification of the recording scale with a 13th category of Klug et al. (2003) was only used for one species in the tree layer – *Fagus sylvatica*.

Possible future scenarios for similar forest communities

As climate change proceeds, there is by now no definite idea how the two forest communities (PL1, PL2) could respond to changing drought and temperature regimes, yet it is assumed that neophytes might benefit from the expected climate change (Dukes & Mooney, 1999; Rabitsch & Essl, 2010). A vague insight or possible negative future trend could be given by the example of an already degraded oak forest: a probably "relictic" forest community of Laaer Wald in Vienna, Favoriten (= Monte Laa). A species list was recorded in October 2017 and is compared here to the, still intact, forest communities of the two forest plots investigated in this thesis (PL1, PL2).
Comparing the three plots, it is obvious that the degraded forest community shows a very low number of species, which, however, may also partly be due to the late recording date (above ground organs were already abandoned in plants of spring and early summer). Secondly the number of neophytes is quite high, giving a possible clue of shifting benefits for adaption and colonization towards neophytes. Although it is a very bold trial to make a forecast how community might change in future, it might still emphasize the risk and threat of changing climate regimes to local forest communities.
Two prominent species, which are among others associated with semi-dry grassland or dry forest and also occurring in the degraded oak forest, are *Mahonia aquifolium* and *Ailanthus altissima*. In Central Europe these species are both rated to have a high potential in reproduction and profit from climate change is expected (Nehring et al., 2013). They are already observed to spread on the edges of "Perchtoldsdorfer Heide", near the observed plots of this theses as well as in other (semi) dry grasslands and black pine forests (pers.com, J. Greimler, 2017).

Table 9: Overview of the species list of Plot 1, Plot 2 and the degraded oak forest on Monta Laa.

Layer	Oak-Hornbeam forest	Oak forest	Degraded oak forest
Tree	*Acer campestre*	*Acer campestre*	*Acer campestre*
T	*Acer platanoides*	*Acer pseudoplatanos*	*Acer platanoides*
T	*Carpinus betulus*	*Carpinus betulus*	*Fraxinus excelsior*
T	*Fagus sylvatica*	*Fraxinus excelsior*	*Hedera helix*
T	*Fraxinus excelsior*	*Quercus pubescens x petraea*	*Prunus mahaleb*
T	*Pyrus pyraster*	*Quercus cerris*	*Quercus cerris*
T	*Quercus petraea*	*Quercus pubescens*	*Quercus pubescens*
T	*Sorbus aria*	*Sorbus torminalis*	*Quercus rubra*
T	*Tilia cordata x platyphyllos*	*Tilia platyphyllos*	
T	*Tilia platyphyllos*		
T	*Ulmus glabra*		
Shrub	*Acer campestre*	*Cornus mas*	*Crataegus monogyna*
S	*Cornus mas*	*Crataegus laevigata*	*Syringa vulgaris*
S	*Crataegus laevigata*	*Crataegus monogyna*	*Daphne laureola*
S		*Daphne laureola*	*Malus sp.*
S		*Sorbus aria*	
Herb	*Acer campestre*	*Acer campestre*	*Acer campestre*
H	*Acer platanoides*	*Acer platanoides*	*Ailanthus altissima*
H	*Acer pseudoplatanos*	*Acer pseudoplatanos*	*Alliaria petiolata*
H	*Alliaria petiolata*	*Allium sp.*	*Anthriscus cerrefolius*
H	*Allium ursinums*	*Allium ursinum*	*Clematis vitalba*
H	*Anemone ranunculoides*	*Anthericum ramosum*	*Crataegus monogyna*
H	*Brachypodium sylvaticum*	*Brachypodium sylvaticum*	*Dactylis polygama*
H	*Bromus benekenii*	*Bromus benekenii*	*Galium aparine*
H	*Campanula persicifolia*	*Buglossoides purpurocaerula*	*Geum urbanum*
H	*Campanula rapunculoides*	*Campanula glomerata*	*Hedera helix*
H	*Campanula trachelium*	*Campanula rapunculoides*	*Juglans regia*
H	*Carex alba*	*Campanula trachelium*	*Lamium maculatum*
H	*Carex digitata*	*Cardamine bulbifera*	*Leonurus cardiaca*
H	*Carpinus betulus*	*Carex humilis*	*Ligstrum vulgare*
H	*Clematis vitalba*	*Carex michelii*	*Mahonia aquifolia*
H	*Crataegus laevigata*	*Carpinus betulus*	*Quercus cerris*
H	*Crataegus monogyna*	*Cephalanthera damsonium*	*Quercus pubescens*
H	*Cyclamen purpurascens*	*Cephalanthera longifolia*	*Rubus sp*
H	*Dactylis polygama*	*Clematis recta*	*Sambucus nigra*
H	*Daphne laureola*	*Clematis vitalba*	

H	*Euonymus verrucosa*	*Clinopodium vulgare*	
H	*Euphorbia amygdaloides*	*Cornus mas*	
H	*Euphorbia dulcis*	*Crataegus monogyna*	
H	*Gagea lutea*	*Cyclamen purpurascens*	
H	*Galium aparine*	*Dactylis polygama*	
H	*Galium odoratum*	*Daphne laureola*	
H	*Glechoma hirsuta*	*Dictamnus albus*	
H	*Hedera helix*	*Epipactis sp.*	
H	*Hepatica nobilis*	*Euonymus verrucosa*	
H	*Hieracium sp.*	*Euphorbia cyparissias*	
H	*Hippocrepis emerus*	*Fagus sylvatica*	
H	*Hordelymus europaea*	*Fraxinus excelsior*	
H	*Juglans regia*	*Galium odoratum*	
H	*Lamium maculatum*	*Glechoma hirsuta*	
H	*Lilium matagon*	*Hedera helix*	
H	*Melica uniflora*	*Hepatica nobilis*	
H	*Mercurialis perenne*	*Hieracium murorum agg.*	
H	*Polygonatum multiflorum*	*Hieracium sp.*	
H	*Primula vulgaris*	*Hippocrepis emerus*	
H	*Prunus avium*	*Ligustrum vulgare*	
H	*Prunus spinosa*	*Melica nutans*	
H	*Pseudoturritis turrita*	*Melica uniflora*	
H	*Rosa sp.*	*Melittis melissophyllum*	
H	*Sorbus aria*	*Mercurialis ovata*	
H	*Stellaria media*	*Mercurialis perennis*	
H	*Tanacetum corymbosum*	*Muscaria neglectum*	
H	*Ulmus glabra*	*Neottia nidus-avis*	
H	*Viola alba*	*Peucedanum cervaria*	
H	*Viola reichenbachiana*	*Polygonatum odoratum*	
H	*Viola suavis*	*Primula veris*	
H		*Prunus avium*	
H		*Pseudoturritis turrita*	
H		*Quercus pubescens x petraea*	
H		*Quercus cerris*	
H		*Rosa sp.*	
H		*Sanicula europaea*	
H		*Sorbus torminalis*	
H		*Tanacetum corymbosum*	
H		*Teucrium chamaedrys*	

H		*Tilia platyphyllos*	
H		*Vincetoxcium hirundinaria*	
H		*Viola alba*	
H		*Viola hirta*	
H		*Viola mirabilis*	

Conclusions

To summarize the main findings of this works: I could observe and partly back up by statistics, that there are more frequent and extreme temperature values since 1970, intensifying towards the present. This leads to a pressure on some species in vegetative and generative phenology as well as in reproduction success. In the two investigated plots, summer flowering species seem to be affected in terms of heat/drought, facing their thresholds of heat tolerance and therefore can have problems in developing functional seeds whereas spring flowering species seem to be affected by warming temperatures in spring, reacting with an early onset of flowering, but no limitations of their reproduction success could be detected.

Recruitment for tree and shrubs species seems to be in line with their habitat preferences (given by their indicator values), leading to a better reproduction success for species with preferences for warmer and/or dryer habitats.

In this work it could be shown that indicator values can be used for roughly predicting the performance of species and also for highlighting sensible species. Although further observations will be needed, the information of this work may provide data for a later comparison as well as additional insights in the phenological dynamics on a small scale especially regarding on-going temperature stress and reproductive success in local plant communities.

Outlook and further needs/suggestions

As it was shown that spring phenology switches are happening, it could be very interesting to tie on this topic and try to see if correlations of temperature changes in the spring month and changing flowering phenology is going on. This work had a limited time frame when the observations were made. Especially for the topics phenology and climate change, long-term data and monitoring would be important to improve the data body.

It is very difficult to have an idea on what future events will bring, yet the performance of species will also much depend on how often and in which extent extreme weather events will occur.

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7 Zusammenfassung

Verschiedene Untersuchungen weisen darauf hin, dass eine globale Erhöhung der Temperatur unterschiedlich große Effekte auf Regionen in dem nächsten Jahrhundert haben wird. In Europa wird bis Ende dieses Jahrhunderts mit einem Temperaturanstieg von bis zu 5.5°C gerechnet, was zu schwer abschätzbaren ökologischen Folgen führen wird. Viele wissenschaftliche Arbeiten haben sich mit diesem Thema, vor allem im globalen Kontext, auseinander gesetzt. Wie die ökologischen Folgen für Regionen sind, wurde bisher jedoch nur spärlich behandelt. Für die Wiener Umgebung gab es Anfang dieses Jahrhunderts besonders trockene Jahre, mit hohen Temperaturen und wenig Niederschlag, was manche Arten an den Rand ihrer Dürrehärte gedrängt hat. Welchen Impakt extreme Trockenheit und Hitze auf vegetative und reproduktive Teile von Pflanzen haben, ist auf lokaler Ebene nicht ausreichend erforscht. Um mehr Erkenntnisse dieser Auswirkungen für die Wiener Umgebung zu erfahren, wurden in den Jahren 2015 und 2016 phänologische Daten gesammelt. Dafür wurden zwei Waldflächen mit unterschiedlicher Exposition aber ähnlicher Artenzusammensetzung ausgewählt und der vegetative und generative Verlauf jeder Art und in weiterer Folge im Zusammenhang mit den Faktoren Temperatur und Niederschlag ausgewertet.

Für die Versuchsflächen konnte gezeigt werden, dass in dem heißen Jahr 2015 im Sommer blühende Arten Probleme hatten, funktionsfähige Diasporen auszubilden (Früchte, Samen). Im Frühling blühende Arten hingegen reagierten tendenziell auf die wärmeren Tage im Winter damit, dass der Blühzeitpunkt nach vorne verschoben war.

Sehr hohe Temperaturmaxima während der Jahre führten dazu, dass die Blätter mancher Pflanzenarten frühzeitig vergilbten bis hin zu einem total Blattabwurf im Sommer, andere Arten konnten keine funktionsfähigen Samen ausbilden was ebenfalls auf den großen Hitzestress deutet. Es konnte gezeigt werden, dass Arten mit einer Präferenz für kühlere und/oder feuchtere Habitate, besonders häufig entweder früh blühten oder Probleme hatten ihren generativen Zyklus zu schließen. Diese Erkenntnisse werfen die Fragen auf, ob bei weiterer Temperaturerhöhung und häufigeren extremen Maximaltemperaturen Pflanzengesellschaften noch stärker reagieren, gewisse Arten verdrängt werden und sich womöglich die Artenzusammensetzung ändert.

8 Appendix

Table 10: Vegetation of the two plots in May 2015 ordered by layers and abundance; BB =Braun-Blanquet for coverage, *=species that were recorded after the vegetation survey, T=Tree-,S=Shrub-,H=Herb layer.

Oak-hornbeam forest			Oak forest		
Taxon	Layer	BB	Taxon	Layer	BB
Carpinus betulus	T	4	Quercus cerris	T	3
Fraxinus excelsior	T	3	Quercus pubescens	T	3
Quercus petrea	T	2	Tilia plathyphyllos	T	3
Tilia platyphyllos	T	2	Fraxinus excelsior	T	2
Fagus sylvatica	T	1	Acer campestre	T	1
Acer platanoides	T	1	Carpinus betulus	T	1
Acer campestre	T	1	Sorbus torminalis	T	1
Pyrus pyraster	T	1	Q. pubescens X petraea	T	1
Ulmus glabra	T	1			
Sorbus aria	T	+			
Cornus mas	S	2	Cornus mas	S	2
Acer campestre	S	1	Crategus laevigata	S	1
Crategus laevigata	S	+	Crategus monogyna	S	1
			Daphne laureola	S	1
			Sorbus aria	S	+
Allium ursinum	H	4	Buglossoides purpurocaerulea	H	2
Mercurialis perenne	H	3	Fraxinus excelsior	H	2
Melica uniflora	H	2	Tilia plathyphyllos	H	2
Acer campestre	H	1	Vincetoxicum hirundinaria	H	2
Alliaria petiolata	H	1	Acer campestre	H	1
Campanula trachelium	H	1	Brachypodium sylvaticum	H	1
Carex alba	H	1	Cardarmine bulbifera	H	1
Daphne laureola	H	1	Carex humilis	H	1
Galium odoratum	H	1	Daphne laureola	H	1
Hepatica nobilis	H	1	Euonymus verrucosa	H	1
Hordelymus europaea	H	1	Galium odoratum	H	1
Primula vulgaris	H	1	Hepatica nobilis	H	1
Viola sp.(suavis/odorata)	H	1	Ligustrum vulgare	H	1
Acer platanoides	H	+	Melica nutans	H	1
Acer pseudoplatanos	H	+	Melica uniflora	H	1
Carpinus betulus	H	+	Melittis melissophyllum	H	1
Clematis vitalba	H	+	Quercus cerris	H	1
Crategus laevigata	H	+	Sanicula europaea	H	1
Crategus monogyna	H	+	Viola mirabilis	H	1

Dactylus polygama	H	+
Euonymus verrucosa	H	+
Euphorbia amygdaloides	H	+
Glechoma hirsuta	H	+
Hedera helix	H	+
Juglans regia	H	+
Lamium maculatum	H	+
Lilium matagon	H	+
Polygonatum multiflorum	H	+
Prunus avium	H	+
Prunus spinosa	H	+
Pseudoturritis turrita	H	+
Rosa sp.	H	+
Sorbus aria	H	+
Tanacetum corymbosum agg.	H	+
Ulmus glabra	H	+
Viola reichenbachiana	H	+
Brachypodium sylvaticum	H	*
Campanula rapunculoides	H	*
Cyclamen purpurascens	H	*
Hippocrepis emerus	H	*
Stellaria media	H	*
Tilia cordata x plathyphyllos	H	*

Viola sp.	H	1
Acer platanoides	H	+
Acer pseudoplatanos	H	+
Anthericum ramosum	H	+
Bromus ramous ssp. benekenii	H	+
Campanula rapunculoides	H	+
Carpinus betulus	H	+
Cephalantera damasonium	H	+
Cephalanthera longifolia	H	+
Clematis vitalba	H	+
Cornus mas	H	+
Crategus monogyna	H	+
Dactylis polygama	H	+
Diptamnus albus	H	+
Euphorbia cyparissias	H	+
Fagus sylvatica	H	+
Glechoma hirsuta	H	+
Hedera helix	H	+
Hieracium murorum agg.	H	+
Hippocrepis emerus	H	+
Mercurialis perenne	H	+
Neottia nitus-avis	H	+
Peucedanum cervaria	H	+
Polygonatum odoratum	H	+
Primula veris	H	+
Prunus avium	H	+
Pseudoturritis turrita	H	+
Q.cerris	H	+
Tanacetum corymbosum	H	+
Teucrium chamaedrys	H	+
Allium ursinum	H	*
Carex michelii	H	*
Clinopodium vulgare	H	*
Cyclamen purpurascens	H	*
Epipactis sp.	H	*
Q. pubescens x petraea	H	*
Rosa sp.	H	*
Sorbus torminalis	H	*
Tilia cordata x plathyphyllos	H	*