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## Forty years of symphenological research in a submontane calcareous beech forest under the influence of climate change

### Abstract

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An annual phenological survey was carried out between 1981 and 2020 in a mesic beech forest on limestone (*Hordelymo-Fagetum lathyretosum*) in Germany. Symphenological groups of species were defined according to concurrent flowering times. Using these groups, the vegetation period was subdivided into 9 phenophases, which are a refinement of the flowering waves introduced by Sandro Pignatti for European beech forests. For the three spring phases 2, 3 and 5 the starting time was analysed for a period of 40 years. Despite obvious fluctuations from year to year, the phases tended to start earlier, often in all phases in a synchronous manner. The extension of the vegetation period by 10-11 days is a striking sign of climate change. Finally, 60 years of cooperation and joint experiences of Sandro Pignatti and Hartmut Dierschke are briefly commented on.

**Key words:** biomonitoring, long-term data, phenophases, plant phenology, symphenological groups, Germany.

### Introduction

Starting with Lausi & Pignatti (1973), the first extensive results of symphenological studies were published for beech forest communities, collected by an European observation network (see also Marcello & Pignatti 1965; Pignatti 1972). Already in 1962, during the International Symposium on the Syntaxonomy of Beech Forests in Stolzenau, Pignatti suggested to analyze phenological observations in an European framework. He himself was influenced by A. Marcello from Venice, who carried out plant phenological research and thus provided the basis for Pignatti's work (Marcello 1954). Thus, soon after a call for international cooperation was started. Including the work of vegetation scientists from 14 countries, 1963 datasets were gathered for 204 plots from southern Sweden over central Europe to northwest Italy and eastern Catalonia, as well as south-east Europe. Results were collected in Trieste and electronically analysed using the local computer center. Many forest plots (33) belonged to the beech forest community *Melico-Fagetum*.

The datasets included observations for more than 500 species, 67 of which occurred in more than 10 plots (see also Lausi & Pignatti 1973). The symphenological investigations were concentrated on flowering waves, as well as on periodicity of beech leaves, each very complex and across large latitudinal and altitudinal gradients. This laid the foundations for a scientific branch dealing with annual vegetation rhythms: symphenology (Marcello 1953a; Dierschke 1994).

In contrast to the study of Lausi & Pignatti (1973), I (HD) followed a geographically narrow attempt for a phenological survey since the 1970s, starting with the observation of single stands in the surroundings of Göttingen (Germany). Since 1981, the efforts were concentrated on a single large forest area hosting a mesophilous beech forest stand over limestone. Here, rule-based phenological sequences were identified and generalized. Concerning their concurrent start of flowering, several symphenological species groups were distinguished, used for defining 9 phenophases (Dierschke 1982). The period since 1981 covers times of starting and increasing climate changes, which had an impact on temporal shifts of the phenophases (Dierschke 2000; Heinrichs & al. 2018; Dierschke & Becker 2020). This work summarizes methods and results.

### Symphenological groups and phenophases of deciduous forests

The general course of flowering in the herb layer of species-rich beech forests is known since a while (see e.g. Ellenberg 1939). A large-scale summary was first published by Lausi & Pignatti (1973), a recent update was given by Leuschner & Ellenberg (2017). Lausi & Pignatti (1973) recognized several flowering waves of concurrently flowering species. Dierschke used these waves for refining symphenological species groups (species with concurrent flowering; Dierschke 1983, 1994, 1995) and specified them for deciduous forests of central Europe (Dierschke 1982, 1989a).

A short overview of the phenophases and relevant indicators are given in Table 1. The names of the phases are combinations of a woody and a herb species. While the *Corylus-Leucojum*-phase (1) is not easily separable because of the few flowering species, the *Acer-Anemone*-phase (2) starts with a well-recognizable flowering wave of light-depending early spring bloomers (start of spring; Fig. 1 and 2), reaching a flowering maximum in the *Prunus-Ranunculus auricomus*-phase (3) (Fig. 3) and coming to an end when completely unfolded leaves of the trees lead to shady conditions (phase 4). During the *Sorbus-Galium odoratum*-phase (5) a transition towards full shade in the herb layer takes place, where the flowering of *Allium ursinum* can be prominent (Fig. 4). In early summer (phase 6), a new wave of flowering starts in constant shade, but with a constantly decreasing number of flowering plants. Almost all spring geophytes have disappeared, and summer plants now dominate the fragmentary herb layer. In late summer, the *Hedera-Solidago*-phase (9) brings only a few newly flowering species. Following vegetative changes like autumnal colours and defoliation of woody species, the last two phases, autumn (10) and winter (11) can be separated.

Start and duration of phenophases shift with weather changes, especially due to the course of temperatures from late winter to early spring. Thus, start and duration of the phases are different from year to year, and make sensitive indicators for changes in weather and climate. In particular, the spring phases 1-5 shift parallel to continuously rising annual temperatures, and can be used as climate indicators (Dierschke 2000).



Fig. 1. Phenological research area: ca. 145 years old beech forest. *Acer platanoides-Anemone* phenophase (11.04.2011).



Fig. 2. Part of the phenological permanent plot in phenophase 2. *Anemone nemorosa* and *A. ranunculoides* in flower, big leaves of *Allium ursinum*.



Fig. 3. *Prunus-Ranunculus auricomus* phenophase. Herb layer with flowers of *Anemone nemorosa*, *Euphorbia amygdaloides* and *Lathyrus vernus* (20.04.2011).

### Survey area and methodology

In 1980 within a species-rich, 145–150 years old beech forest east of Göttingen, a larger permanent plot was installed for phenological investigations (Fig. 1).

It is located at the coordinates N 51° 32' / E 10° 03' near the edge of a limestone plateau, at about 420 m, under suboceanic to submontane climate conditions (mean annual temperature 7.4° C, sum of precipitation 709 mm; see also Heinrichs & al. 2018; Dierschke & Becker 2020).

The forest can be identified as *Hordelymo-Fagetum lathyretosum* following Dierschke (1989b) as part of the former *Melico-Fagetum* (see also Leuschner & Ellenberg 2017).

For a better recognition of the indicator species in the dense herb layer, tags with labels were placed (Fig. 2). To integrate as many species as possible, beside the inner part of the forest a light forest edge along a path was also surveyed.

Since 1981, phenological surveys were carried out continuously.

A specific key was developed for woody species, herbs and grasses, defining 11 stages of vegetative and generative development (Dierschke 1972, 1989c, 1994).

For every day of the survey, vegetative and generative stages of all species were

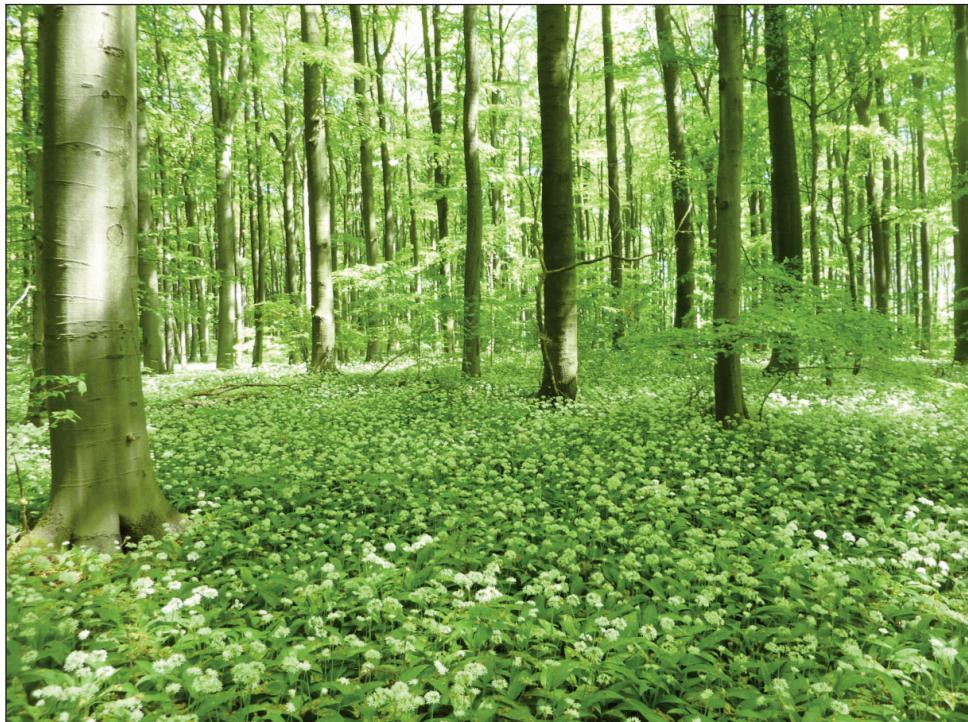


Fig. 4. *Sorbus-Galium odoratum* phenopase with flowering aspect of *Allium ursinum* (9.05.2011).

noted, once a week in the first years, after more variable periods later on. Species were assigned to symphenological groups according to their start of flowering (Table 1). Phenological phases were defined in days of the year. The results comprise observations for the years 1981-2020 for the three characteristic phases of spring (2, 3 and 5). Fig. 5 shows the starting time of these three phases, compared to the mean values of all 40 years.

The plot was produced using R version 4.03 (R Core Team 2020). A Kruskal-Wallace test using groups of five and ten years was performed using the R package ‘pgirmess’ (Giraudoux 2018).

Some basic statistical values for the period of 40 years are shown in Table 2.

Table 1. Spring and summer phenophases of species-rich deciduous forests and their flowering herbaceous species in the research area

1 *Corylus avellana*-*Leucojum vernum*-Phase

*Hepatica nobilis*, *Leucojum vernum*

2 *Acer platanoides*-*Anemone nemorosa*-Phase

*Anemone nemorosa*, *A. ranunculoides*, *Asarum europaeum*, *Corydalis cava*, *Mercurialis perennis*, *Primula elatior*, *Pulmonaria obscura*

3 *Prunus avium*-*Ranunculus auricomus*-Phase

*Euphorbia amygdaloides*, *Lathyrus vernus*, *Oxalis acetosella*, *Ranunculus auricomus* agg., *Viola reichenbachiana*

4 *Fagus sylvatica*-*Galeobdolon luteum*-Phase

*Alliaria petiolata*, *Cardamine bulbifera*, *Carex sylvatica*, *Galeobdolon luteum*, *Ranunculus lanuginosus*, *Stellaria holostea*

5 *Sorbus aucuparia*-*Galium odoratum*-Phase

*Allium ursinum*, *Arum maculatum*, *Galium odoratum*, *Geranium robertianum*, *Polygonatum multiflorum*, *P. verticillatum*, *Veronica montana*, *Vicia sepium*

6 *Cornus sanguinea*-*Melica uniflora*-Phase

*Aconitum vulparia*, *Geum urbanum*, *Impatiens parviflora*, *Melica uniflora*, *Phyteuma spicatum*, *Sanicula europaea*

7 *Ligustrum vulgare*-*Stachys sylvatica*-Phase

*Aegopodium podagraria*, *Hordelymus europaeus*, *Lilium martagon*, *Stachys sylvatica*

8 *Clematis vitalba*-*Galium sylvaticum*-Phase

*Brachypodium sylvaticum*, *Campanula trachelium*, *Circaeа lutetiana*, *Dactylis polygama*, *Galium sylvaticum*, *Hypericum hirsutum*

9 *Hedera helix*-*Solidago virgaurea*-Phase

Without new flowering plants in the research area

## Results

The start of the phenological phases of spring (2, 3 and 5) depends, beside internal vegetation rhythms, on the weather of the previous months, especially on temperatures. Figure 5 shows striking changes from year to year. A precise analysis shows a continuously earlier start for all phases compared to the 40-year mean. In Table 2, some critical statistical values are presented. Comparing the ten-year means of the

first two decades for the *Acer platanoides-Anemone*-phase (2), an advance of 8 days can be observed. In later decades, the advance is less striking. In total, an earlier start of 11 days (from 9<sup>th</sup> April to 30<sup>th</sup> March) can be recognized for the period 1981-2020, which is similar to that of the *Prunus avium-Ranunculus auricomus*-phase (3), (9 days earlier, 26<sup>th</sup> to 17<sup>th</sup> April), and the *Sorbus aucuparia-Galium odoratum*-phase (5) (11 days, 22<sup>nd</sup> to 11<sup>th</sup> May). The amplitude of the variance in starting dates is highest in phase 2 with 43 days, as a result of cold temperature setbacks in some years (12<sup>th</sup> March to 24<sup>th</sup> April). In phases 3 and 5, the amplitude is 39 days (7<sup>th</sup> April to 16<sup>th</sup> May, and 26<sup>th</sup> April to 4<sup>th</sup> June). Shifts of the starting dates of the three phases usually happen simultaneously, i.e. the beginning of phase 2 is crucial for the start of the following spring phases. Some shifts to a later start of phases 3 and 5 are due to earlier cold air events in that year.

Even more striking is the comparison of the starting dates of each phase within the decades when the number of later or earlier starts are considered. From 1981 to 1990, late starting dates dominate (phases 2 and 3 in seven years, phase 5 in eight years), along with harsh winters with long-lasting snow covers. This was the case especially for the years 1983/84 and 1986/87. The latest start of phase 2 was in 1984 (24<sup>th</sup> April). In recent years, late starting dates were rare, with the exception of 2006. Already in the period 1991-2000, 4 to 5 years had an earlier start of phase 2, while in 2001-2010, 6 earlier years were recorded, and in the last decade 7-8 earlier years. Because the changes of the starting day from year to year were strong, there was no statistically significant trend for 5- and 10-year periods.

Table 2. Some dates of the beginning of phenophase 2, 3 and 5.

<b>Phenophase</b>	<b>2</b>	<b>3</b>	<b>5</b>
Mean beginning date within 40 years	93,1	114,0	135,8
Latest beginning	115,0	137,0	156,0
Earliest beginning	72,0	98,0	117,0
 Mean beginning dates for decades			
1981-1990	100,3	119,9	142,9
1991-2000	92,2	114,9	136,7
2001-2010	90,2	113,1	133,4
2011-2020	89,6	108,1	130,6

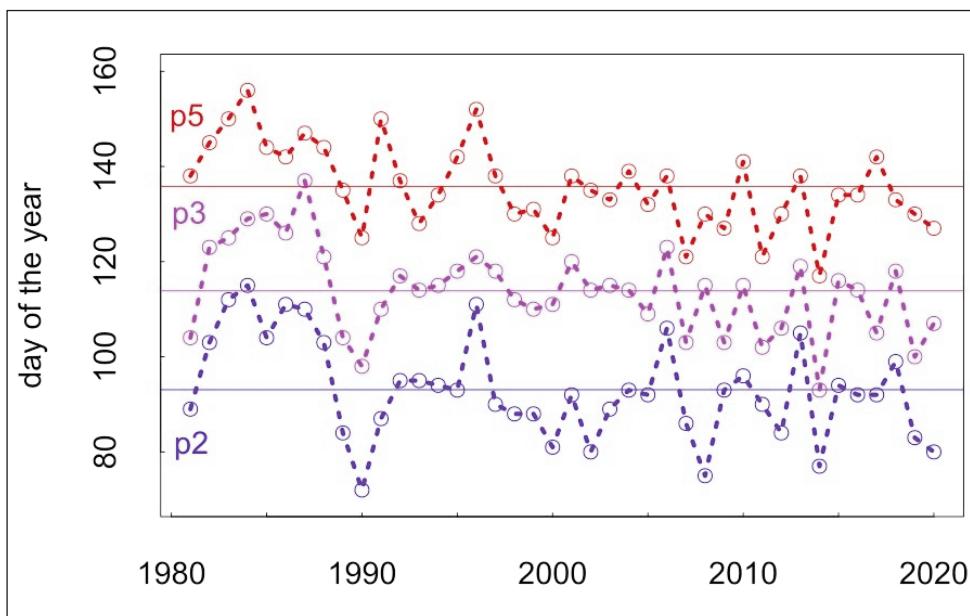


Fig. 5. Beginning of the phenophases p2, p3 and p5 and mean values 1981-2020.

## Discussion

### *Symphenological species groups*

In plant communities, species groups with common behaviour can be distinguished, such as the sociological species groups used in syntaxonomy (Dierschke 1994). Often used are also ecological species groups as indicators for stand conditions (for forests: Leuschner & Ellenberg 2017). Chronological changes in vegetation development can be characterized and detected by symphenological species groups, which aggregate species with nearly similar phenology (Dierschke 1994). Both vegetative and generative developments are used as criteria. Vegetative criteria are e.g. leaves turning green in spring, full leaf development in the canopies, as well as autumn colouring and defoliation at the end of the vegetation period. A characteristic sign of vegetation development is the concurrent flowering of herb species, as shown in the present study. Its analysis shows, especially in species-rich forests, a typical, annually-repeating sequence of phenophases (Dierschke 1982). Within each phase, the species usually reach their full flower development, while their whole flowering period may extend also into the following phases, so that the sum of flowering species is higher in each phase.

When these phases are generally known, symphenological species groups can be compiled over large areas as well. Altogether, it became obvious that they keep stable across large spatial and long time-scales, being well suitable to separate certain phenophases (Dierschke 1982, 1994). It is interesting that phenophases initially observed in forests do

also occur in open habitats, especially in several grassland communities (Dierschke & Briemle 2002). So, for central Europe 1577 plant species of low to middle altitudes, corresponding to the beginning of their flowering time, were assigned to nine phenophases which were first identified in forests (Dierschke 1995). For deciduous forests, 340 species applied in this context. In the herb layer, 7 species start flowering in phase 1, 33 in phase 2, 22 in phase 3, 20 in phase 4, 46 in phase 5, 37 in phase 6, 26 in phase 7, 38 in phase 8, and 4 in phase 9. In summary, in spring (phases 1-5) the forests host 95 newly flowering species, in early summer (phases 6-7) 63, in high summer 38, and in early autumn only four. Altogether, nature offers an extensive inventory for phenological characterization and separation of different time periods, whereas in every forest stand only a small proportion occurs (table 1). The flowering order of phenological groups is rather constant across large areas and altitudes (Leuschner & Ellenberg 2017), so that even landscapes with a diverse vegetation mosaic can be classified by seasons according to the order of geophenophases (Dierschke 2015).

#### *Flowering waves and phenophases*

The rhythmic phenological changes in the course of the year are very obvious and long-known for species-rich deciduous forests; already Ellenberg (1939) roughly separated three main flowering phases in northwestern Germany. His phenological spectrum contains a phase of 9 spring green species, and 2 phases of early and late flowering summer green species, with 21 and 13 species respectively. In addition, there is a group of 14 winter green species most of which flower in spring. This corresponds approximately with the three flowering waves described by Pignatti (1972) and Lausi & Pignatti (1973) for the European beech forests: a heliophilous wave in April/May, followed by a first and a second wave of shade tolerant species in June and July. Our own finely separated phases (Table 1) can be assigned accordingly. The first heliophilous phase by Lausi & Pignatti (1973), during which trees are still bare, corresponds to our phases 1-4. Phase 5 is a transition to early summer, the forest ground being shady, but many species could benefit from the previous availability of light. This applies to the spring geophytes of our study area; *Allium ursinum*, *Arum maculatum*, *Polygonatum multiflorum* and *P. verticillatum*. *Allium ursinum* belongs to the first species sprouting in spring, developing leaves and flower buds in phases 3-4.

During flowering, its leaves begin to wilt already, parallel to those of several other spring geophytes (see also Heinrichs & al. 2018). So we consider this first phase with shade of the canopy (5) as the end of spring. Generally, the beginning of the phases is often influenced by the start of the second phase (Fig. 5). The second shade-tolerant flowering wave of Lausi und Pignatti (1973) is almost congruent with our phases 6-7, which are mostly dominated by flowering hemicryptophytes. Phase 8 makes the long summer phase, only vaguely separable in Lausi & Pignatti (1973) and also in our studies. Already Dierschke (1982, 1994) described such flowering waves for the *Melico-Fagetum*, where in spring (phase 1-5) 22 species were flowering, in early summer (6-7) further 9 species, and in high summer only 4 species.

### *Phenophases, biomonitoring und climate change*

The dependency of annual periodicity of plant development from weather conditions was recognized already in earlier times. According to Schnelle (1955), Karl von Linné (Linnaeus) can be considered as the founder of systematic phenological observations and of phenology itself as a discipline. Starting in the mid of the 18<sup>th</sup> century, he established a phenological observation network in Sweden (for the historical development of plant phenology see Schnelle 1955, Dierschke 1994). In Germany, observation networks were established, maintained and analysed by the German weather service (*Deutscher Wetterdienst*, e. g. Kolbe & Kaiser-Weiss 2015). Plants can be used as bioindicators for the sum of weather events, also for displaying climate changes over longer time. For German observers, form-sheets with species lists are provided, on which the development of certain stages like leaf unfolding, start of flowering, full flowering etc. are noted. Data analysis for certain times and/or areas can deliver starting dates for phenological phases (Schnelle 1955). Such events are visualised for many contributing regions of the continent in the data viewer of the pan-European phenology database (<http://www.pep725.eu/>), where also updated publications can be downloaded.

The approach followed by Dierschke uses symphenological species groups for this kind of climate monitoring. Not every species has the same reaction in each year, so that several synchronously flowering species can give more robust results for monitoring weather and climate changes (Dierschke 2000). However, this approach is less innovative than originally thought, as according to Schnelle (1955), already Marcello (1953a-b) proposed the use of species groups in Italy in the 1940s and perhaps even introduced the term symphenology. Obviously influenced by Marcello, Lausi & Pignatti (1973) recognized symphenological species groups, analysing their start of flowering over large areas of Europe in a pioneer attempt of a large-scale symphenological monitoring. Wilmanns (in Dierschke 1972) had called upon an international symphenological observation network for standard plant communities already in 1970. Unfortunately, this approach was not followed, and up to now nothing comparable was installed. Observation plots do not necessarily have to be far from settlements, and can be even installed in botanical gardens. Dierschke (2016) showed that starting times of phenological groups in the Old Botanical Garden in Göttingen and in his own private garden are similar to those of a permanent plot in a distant forest, although they start earlier due to lower altitude and sheltered urban conditions.

The complex influences on periodic vegetation rhythms are not fully understood yet: as a basis for phenological phenomena and their deviations, Leuschner & Ellenberg (2017) mention the temperatures of soil and soil water, day length and genotypes, beside the course and the sum of air temperatures. After 40 years of phenological observations in our survey area, the spring phases 2-5 started 10-11 days earlier.

The start of the *Acer platanoides-Anemone nemorosa*-phase (phase 2) was often decisive for the later course (Fig. 5). Decadal means (Table 2) started earlier in the first years (even 8 days between the first and the second decade for phase 2). Since 1989, a period of mild winters and an early beginning of the vegetation period begun (Dierschke 2000). So the earliest beginning of phase 2 from 1981-2020 was on March, 12<sup>th</sup> 1990, with correspondingly early starts of the following phases. Later, the trend of continuous warming proceeded (Schönwiese 2020), but the tendency to earlier phenophases became weaker, perhaps because the length of days limits this development. Also, drought damage in the previous vegetation period might have played a role.

Further studies used the phenological data from our research area (already Dierschke 2000). According to Heinrichs & al. (2018), between 1981-1990 and 2008-2017 the growing season for *Allium ursinum* was extended from 51.5 to 57.2 days in this area. Further data and interpretations can be found in Dierschke (2016), and in Dierschke & Becker (2020).

In their meta-study Menzel & al. (2006) analysed large datasets of phenological observations from all over Europe. For the period 1971-2000, earlier leaf unfolding and flowering of 2.5 days per decade applied, which suits to our observations until 2020. According to Menzel & al. (2006), most phases are correlated with mean temperatures of the last and the previous months. The results indicate changes in spring and summer phenology across the continent. Similar results were published by Kolbe & Kaiser-Weiss (2015), who analysed the period 1951-2012 for Germany. In spring and summer, clear correlations apply for the beginning of certain phases and air temperatures, including those from the previous months. Especially since 1981, earlier beginnings of the phases were visible. Ge & al. (2014) compared phenological observations from China, Japan and Switzerland, showing very similar trends across the three areas. The latter example shows, that effects are indeed global. Recent developments for phenological observations use automatic visual interpretation of either repeated camera monitoring or remote sensing with satellite data (Nijland & al. 2016; Bórnez & al. 2020; Misra & al. 2020). Such approaches are promising for delivering continuous large-scale measures, but need maintenance, calibration and ground validation by trained experts. Symphenological groups could be used also in this context.

### Personal notes of H. Dierschke

I know Sandro Pignatti since 60 years; initially we were affiliated as colleagues, later as friends. As a young student, in spring 1961 I worked for Reinhold Tüxen at the Federal Institute for Vegetation Mapping (*Bundesanstalt für Vegetationskartierung*) in Stolzenau. Just at this time a Symposium of the International Association for Vegetation Science (IAVS) about “anthropogenic vegetation” took place. More than 100 participants from 14 countries came together, from Italy L. Fenaroli, S. Gentile, V. Giacolini, E. Marchese-Poli and E. & S. Pignatti. That is where I met Erika and Sandro for the first time. Sandro impressed with a presentation on “*Polyplioide-Verhältnisse der anthropogenen Pflanzengesellschaften und Vegetationsserien*” (Pignatti 1966). Many further common conferences of the IAVS followed until 1969 in Stolzenau, then until 1981 in Rinteln and later in other places like Corrientes (1983), Bailleul (1985, 1994), Uppsala (1989), Warsaw (1990), Eger (1991), Shanghai (1992), Santa Cruz de Tenerife (1993), Nagano (2000), and Naples (2003), were Sandro repeatedly attracted attention by innovative ideas and activities. All his contributions in Stolzenau and Rinteln were published (Pignatti 1966, 1968 a/b, 1972, 1978, 1980, 1981; Pignatti & Pignatti 1966, 1982; Christofolini & al. 1970; Pignatti & al. 1977; Lausi & al. 1979). Several times he was a session president of the meetings, and in 1969 he gave the laudatory speech for Reinhold Tüxen’s 70<sup>th</sup> birthday. In 1988 he was the organizer of the 31. IAVS symposium in Frascati about “Spontaneous vegetation in settlements” with participants from 18 countries (Ubrizsy Savoia 1989). – We

spent together several long IAVS excursions, such as those in Japan (1974, 1984 and 2000), Argentina (1983), Southwestern Australia (1990), Eastern China (1992), etc. I also have a good memory of the well-organized excursions by Franco Pedrotti and his staff in central Italy in 1982, when we walked longer sections of the ways through the Apennines side by side.

As a successor of Heinz Ellenberg, Sandro Pignatti was president of the IAVS between 1986 and 1994. At the same time I was secretary general, and we worked together in a productive and friendly way. In 1991, Sandro was one of the initiators of a new international cooperation of vegetation scientists, the “European Vegetation Surveys” (EVS). He organized, led and inspired small and later larger meetings of geobotanists in the Orto Botanico in Rome for many years. I was part of this from the beginning in 1992 to 2009. Also in this case, short to several day long excursions in the wider surrounding were special events. My last meeting with Sandro was in Rinteln in 2012, when he was honored with the Reinhold-Tüxen-prize. After sixty years of friendship, I am happy to dedicate this article about the phenology of beech forests to him.

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