A preliminary proposal for an original classification of garden plants based on the study of their phenological periodicity and their side-runs

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Abstract

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A model group of garden plants (shrubs) was used to observe and evaluate phenological periodicity and new ways of its practical use in landscaping. The experiment focused on the aesthetically most impressive phenophases – full bloom and full coloration, and was conducted in three independent and separate localities over a period of 4 years. While observing and evaluating the selected group of plants, we also monitored and recorded concurrent attractive phenological events in other garden plants, seeking to verify the existence of certain "vegetation waves". The experiment demonstrated that in the research localities the course of phenological periodicity, including the course of individual side-runs, tends to be similar. Our preliminary results indicate that the "vegetation waves" indeed do exist. These findings suggest new solutions for the use of our selected plants, mainly for their theme combinations with wider groups of plants which tend to behave similarly in the same time points. As a result of our study, we propose 24 preliminary phenological groups of garden plants. Each of them characterizes a certain period of the calendar year which is considered aesthetically important by landscape architects. Plants were classified into these groups according to the preliminary mean onset time of the most attractive phenophases (full bloom and full coloration) in the most typical indicative species.

Keywords: landscaping; phenology; shrubs; use of plants; phenological groups

From the landscaping point of view the variability of plants throughout the year is a problem which remains largely unaddressed, despite its topicality and importance. This issue is dealt with quite rarely and mostly as part of different projects. The phenological periodicity of plants is most often studied along with ongoing changes or evolution trends in plant communities (Defila, Clot 2001; Faliński 2001; Bauer 2006) or along with the impact of climate change (Akunda, Huxley 1990; Kramer 1996; Röetzer et al. 2000; Chmielewski, Rötzer 2002; Schwartz 2003). The observation and evaluation of phenological periodicity, especially if conducted over the long term, may help us to better use particular plant species in landscaping. By conducting long-term phenological observations on a particular clearly defined area, we may inter alia discover a great many new creative solutions that arise from the yearly repetition of concurrent aesthetic activity of broader plant groups. During one single year, these plant groups (side-runs) form "vegetation waves" which repeat in regular cycles. In geobotany, this phenomenon was first described and thoroughly studied by Dierschke (1995). Long-term analyses of phenological events in garden plants, together with simultaneous and regular recording of their "vegetation waves" (side-runs), may have a significant influence on future creative principles in landscaping. To date, most Central European dendrology books and papers which cover our climate area, and which have therefore been used as references in practical landscaping (Gaida, Grothe 2000; Koblížek 2000; Úradníček et al. 2001; Bruns 2003; Horáček 2007), contain only summarized phenological data or roughly structured empirical findings by individual authors (monthly values, or their span only). Moreover, apart from a couple of sporadic exceptions (Bielawska et al. 1964; Supuka, Vreštiak 1984), these published values are indefinite in terms of geography and time. A striking volume of phenological data was collected by Hepper (2003), but practical comparison of results is difficult due to different climate course on the individual research sites. Nor Czech nor foreign authors take into account any links with the attractive phenological events in other taxa, despite the fact that in landscaping this wider context is of great importance.

Therefore, the aim of this research project was to observe selected phenological phases on a model set of garden plants throughout the whole year. In the same way, attention was simultaneously paid to their side-runs. Statistical evaluation of phenological features sought to verify whether a rich group of garden plants may be classified into certain aesthetically impressive and time-specific groups (vegetation waves), bearing in mind the long-established phenological seasons widely used in Czech practice (Petrik et al. 1986; Soukupová 2007).

The importance of identifying "yearly seasonality" on the basis of biological indicators (phenological indicative species) to satisfy the needs of botanists, farmers or other professionals is stressed by Dierschke (1995) and Schwartz (1998).

MATERIAL AND METHODS

The experimental part of this research project was conducted on 3 separate sites with a rich assortment of plants and with similar weather conditions throughout the years. These sites were: (1) Lednice (Château Park), (2) Brno (Mendel University Arboretum) and (3) Průhonice (Dendrological Garden); Czech Republic. The characteristics of these localities are described in detail by Bulíř (2009).

The model set of woody species was composed of 76 garden shrubs (Bulíř 2009) that were selected to always include some taxa which are impressive for their bloom or autumn leaf coloration in every phenological season, excluding winter (Soukupová 2007). The selected species also had to be sufficiently hardy in the conditions of all monitored areas. Furthermore, they had to be represented in their locations at least by 3 healthy individuals growing on average and standard sites. The plants were evaluated bearing in mind their genus and species.

For the purposes of observing and recording side-runs in the different phenophases of our woody species, the research covered all taxa growing in the studied localities, including herbs.

Basic weather data were obtained from the closest meteorological stations. More detailed data and in-depth information on weather were obtained from the Czech Hydrometeorological Institute (ČHMÚ 2004, 2008; Kiesenbauer 2008).

The phenological phases were observed using the modified method of Čhmú (1987) and Coufal et al. (2004), which was adapted to landscaping needs by Bulíř (2009). Regular phenological observations took place in the years 2001, 2002, 2005 and 2006 in intervals of 6–8 days. In the aesthetically attractive months (April, May, October), the intervals were shortened to 4–5 days. The onset of a phenophase was defined as a situation when more than 50% of individuals of the same species fulfilled the requirements described for the development phase concerned. Only the aesthetically most impressive phenophases were observed – full bloom and full leaf coloration.

Apart from the course of phenological periodicity in the model woody species, we also followed their side-runs and sought to verify the existence of "vegetation waves". A side-run may be defined as a situation, where a particular plant species reaches an attractive phenophase at the same time or almost at the same time as other plants. The side-runs were always recorded separately for individual calendar years. In the first year of our observations, and also later, when processing the data, we always took note of those which were identical at least in two observed localities. The same rule was applied in the second monitoring period, however, this time certain preference was simultaneously given to taxa which had reached the phenophase concerned already in the first year of our observation. This rule was analogically applied also in the following years. The objective of this observation and recording principle was to find a combination of plants which behave identically in a particular time point and whose identical behaviour repeats in the following year(s) and confirms the existence of "vegetation waves".

The side-runs were recorded for both observed phenophases in summary tables which were drafted for individual model species. Data in these tables

Table 1. Part of results obtained from the evaluation of phenological data for 2001, 2002, 2005, 2006

Full bloom		Summary			Lednice			Brno			Průhonice		
No.	taxon	$\bar{x}$, day No.	$\bar{x}$, date	$s_{\bar{x}}$ days	$\bar{x}$, day No.	$\bar{x}$, date	$s_{\bar{x}}$ days	$\bar{x}$, day No.	$\bar{x}$, date	$s_{\bar{x}}$ days	$\bar{x}$, day No.	$\bar{x}$, date	$s_{\bar{x}}$ days
1	*Aesculus parviflora* WALT.	195	14 Jul	2	192	11 Jul	1	196	15 Jul	1	199	18 Jul	0
2	*Amelanchier lamarckii* F.G. SCHR.	116	26 Apr	2	116	26 Apr	0	115	25 Apr	3	119	29 Apr	3
3	*Amorpha fruticosa* L.	167	16 Jun	2	165	14 Jun	0	167	16 Jun	0	171	20 Jun	1
4	*Aralia elata* (MIQ.) SEEM.	237	25 Aug	3	236	24 Aug	5	234	22 Aug	3	247	4 Sep	0
5	*Berberis thunbergii* DC.	124	4 May	3	121	1 May	3	121	1 May	4	129	9 May	0
6	*Berberis vulgaris* L.	130	10 May	3	129	9 May	4	126	6 May	3	136	16 May	1

$\bar{x}$ – median of phenophase onset, $s_{\bar{x}}$ – mean selection error

were further classified into trees, shrubs and herbs. In case of herbs, only the phenophase of full bloom was considered, mainly due to its aesthetic value.

The summary statistical evaluation focused on the period of phenophase onsets. Considering the chosen interval for field observations, mean values were identified using a median ($\bar{x}$). The evaluation was done separately for each research area and was later complemented with a summary value from all localities so that partial elements would be evaluated in broader geographical context (first 3 altitudinal vegetation zones in the Czech Republic) and on the basis of a larger number of input data. Data described on the basis of median were assigned a mean selection error ($s_{\bar{x}}$).

RESULTS AND DISCUSSION

The summary of obtained phenological data and outputs shows that the onsets of phenological phases in individual years differ considerably. Apart from genetically determined factors, this is mainly due to different average temperatures and rainfall and to their distribution in time. All the above-mentioned phenomena are fully in accordance with the course of climatic elements in the given localities (ČHMÚ 2004, 2008; Kiesenbauer 2008). The influence of temperature and precipitation on the onset of observed phenophases is clearly in line with what was proved by a number of authors who studied the variability in plants against the background of ongoing climate change (Kramer 1996; Röetzer et al. 2000; Faliński 2001; Chmielewski, Rötzer 2002; Schwartz 2003; Bauer 2006). A more in-depth preliminary overall comparison of our own results (Table 1) from individual years and localities clearly suggests that the selected research areas are a source of very similar or occasionally almost identical phenological outputs (especially the localities of Brno and Lednice). In this case the estimated difference, which cannot be easily identified while respecting the principles set for this experiment, may be approximately 1 day, or perhaps 2 days in very early spring and late autumn. However, the estimated difference in the onset of different phenophases between the localities of Lednice and Brno cannot be supported with any solid evidence. More marked spring delay or autumn acceleration were observed on the vegetation in Průhonice, where the differences are obvious and clear despite no diversion from our original method. Compared to Brno and Lednice, the difference registered in spring and autumn phenophases in Průhonice accounts for standard 2 to 3 days, in some woody species even for a whole week. In very early spring and late autumn this difference is even more marked, while during full summer and late spring the values tend to approximate those of the two other localities. During the summer season, the difference between them is hardly perceptible (Bulíř 2009). Deviations begin to appear again with the onset of early autumn, growing proportionally with the lapse of time. Comparing our data with the values of phenological gradients published by Petrík et al. (1986) and Špánik, Šiška (2004), in case of Průhonice these values were confirmed.

Comparing the partial observation periods (years 2001, 2002, 2005, 2006) in between them, we may conclude that the course of vegetation periods was similar in years 2001 and 2002 on the one hand, and in years 2005 and 2006 on the other. Compared to long-term temperature values (ČHMÚ 2004, 2008; Kiesenbauer 2008), all these years ranked very high above the average. In Brno and Lednice the precipitation was also above the average, exceeding the long-term values during all years of the experiment, particularly

Table 2. Part of recording of phenological side-runs in phenological phase full bloom and summary of localities

Aesculus parviflora WALT.		
Shrub layer	Tree layer	Herb layer
Year 2001		
Berberis wilsoniae Hemsl. et Wilson	*Ailanthus altissima* (Mill.) Swingle	*Achillea filipendulina* Lam.
Calycanthus floridus L.	*Castanea sativa* Mill.	*Astilbe* × *arendsii* Arends
Colutea arborescens L.	*Catalpa bignonioides* Walter	*Astrantia major* L.
Hydrangea arborescens L.	*Gleditsia japonica* Miq.	*Campanula glomerata* L.
Philadelphus pubescens Loisel.	*Tilia cordata* Mill.	*Coreopsis verticillata* L.
Potentilla fruticosa L.	*Tilia tomentosa* Moench	*Erigeron speciosus* (Lindl.) DC.
Rosa rugosa Thunb.		*Lysimachia cletroides* Duby
Sorbaria aitchisonii Hemsl. ex Rehd.		*Monarda didyma* L.
Spiraea × *bumalda* Burvénich		*Telekia speciosa* (Schreber) Baumg.
		Yucca filamentosa L.
Year 2002		
Calycanthus floridus L.	*Catalpa bignonioides* Walter	*Astilbe* × *arendsii* Arends
Colutea arborescens L.	*Gleditsia japonica* Miq.	*Coreopsis verticillata* L.
Holodiscus discolor (Pursh) Maxim.	*Tilia cordata* Mill.	*Erigeron speciosus* (Lindl.) DC.
Hydrangea arborescens L.	*Tilia tometosa* Moench	*Heuchera brizoides* Lemoine
Lonicera japonica Thunb.	*Tilia* × *euchlora* K. Koch	*Hosta fortunei* (Bak.) L.H. Bailey
Potentilla fruticosa L.		*Lysimachia cletroides* Duby
Rosa rugosa Thunb.		*Monarda didyma* L.
Sorbaria aitchisonii Hemsl. ex Rehd.		*Telekia speciosa* (Schreber) Baumg.
Spiraea × *bumalda* Burvénich		*Yucca filamentosa* L.

in 2002. Lack of rainfall as compared to the long-term standard was registered only in Průhonice.

While comparing the collected and statistically processed data (Table 1) with available bibliography, attention must be paid to the origin of these references, because this may determine the climate they cover. Logically, the length of the observations is also of much importance. Since in Czech bibliography we have extremely limited number of appropriate data, we may only compare very rough and summarized phenological characteristics such as bloom span in months. As far as the period and overall duration of autumn leaf coloration is concerned, there is no data available at all.

The majority of available data are included in publications which assess assortment of woody species for landscaping purposes (Gaida, Grothe 2000; Bruns 2003; Horáček 2007). Furthermore, if we compare the available data provided by individual authors, we find out that they differ in a great number of values. And if we add to this comparison our own collected data (Table 1), appropriately grouped and evaluated, in many cases these values will be yet totally different. It seems clear, that the data provided in available publications reflect a range of summarized long-term phenological values from a number of different ecological sites. None of these publications describes how the summary characteristics were obtained by the author in question.

On the other hand, the data obtained and evaluated in this project (Table 1) reflect a relatively short observation period. Nonetheless, unlike the quoted bibliography, they clearly characterize selected localities in given time points and under objectively described conditions. Therefore, our preliminary results, based on a sum of obtained knowledge, may be generalized and may be used to describe phenological behaviour in the first 3 altitudinal vegetation zones in the Czech Republic. And it is in these altitudinal zones where the widest range of plant assortment is used and where landscape architects most often work.

Moreover, the yearly records of side-runs (Table 2) taken along with simultaneous statistical evaluation of the onsets of observed phenophases (Table 1) seem to prove that the "vegetation waves" exist even in a very rich group of garden plants. Thus they confirm the results of studies which were already conducted on natural sites (Dierschke 1995).

Table 3. Configuration of phenological groups of garden plants

Phenological season	Phenological phase
1. very early spring	*Corylus avellana – Galanthus nivalis* *Cornus mas – Adonis vernalis* *Forsythia × intermedia – Scilla sibirica*
2. early spring	*Ribes alpinum – Waldsteinia geoides* *Spiraea × cinerea – Alyssum saxatile* (Tulipa) *Viburnum lantana – Lamium galeobdolon*
3. full spring	*Syringa vulgaris – Gentiana acaulis* *Spiraea × vanhouttei – Nepeta mussini* *Viburnum opulus – Iris germanica* (*Rhododendron × hybridum* – early)
4. early summer	*Kolkwitzia amabilis – Papaver orientale* (*Rhododendron × hybridum* – late) *Deutzia scabra – Digitalis purpurea* *Philadelphus pubescens – Hosta plantaginea*
5. full summer	*Spiraea bumalda – Lavandula officinalis* (Rosa) *Hydrangea macrophylla – Astilbe × arendsii* *Buddleia davidii – Helenium × hybridum*
6. late summer	*Aralia elata – Solidago canadensis*
7. early autumn	*Caryopteris × clandonensis – Anemone hupehensis* *Elsholtzia stauntonii – Sedum telephium* *Viburnum plicatum* (full coloration) – *Aster dumosus*
8. full autumn golden autumn	*Amelanchier lamarckii* (full coloration) – *Cimicifuga simplex* *Corylus avellana* (full coloration) – *Parrotia persica* (full coloration) *Berberis thunbergii* (full coloration) – *Cotoneaster horizontalis* (full coloration)
9. late autumn	*Deutzia scabra* (full coloration) – *Viburnum × carlcephalum* (full coloration) *Lonicera maackii* (full coloration) – *Symphoricarpos × chenaultii* (full coloration)
10. winter	dormancy

To a considerable extent, this may be explained by repetition of similar microclimatic conditions in the environment and by genetically determined similarity in the partial behaviour of the plant species (groups). The 4-year monitoring of side-runs suggests that if there is a remarkable time shift in the onset of certain phenophases (e.g. delayed onset of spring period) and the progress of these phenophases is faster, the side-runs tend to behave in a similar way. Thus, in case of a climatic and vegetation leap, a number of side-runs tend to occur at the same time (Bulíř 2009).

The analysis of our results may serve as a basis for a practical group classification of plants for landscaping purposes, with time being one of the key factors to be considered. Therefore, on the basis of all the knowledge learnt and following thorough analysis of our collected data, we propose new phenological groups of garden plants. Based on the preliminary mean onset time of their attractive phenological behaviour (full bloom and full coloration), plants are classified into concurrent phenological groups which may characterize certain stages of the calendar year.

Phenological indicative species are in the centre of these groups and are complemented with further species on the basis of regular side-runs. All these species together form plant groups the behaviour of which is characteristic for a certain time period. This is an elementary principle for classifying, in a practical and useful way, the great number of plants used in landscaping. It tries to reflect simultaneously occurring impressive phenological events (side-runs) depicted in wider plant groups.

The phenological groups of garden plants are conceived so as to cover aesthetically impressive behaviour of plants throughout the whole calendar year and in easily applicable time intervals. They are also proposed with respect to long-established phenological seasons (Soukupová 2007). Each newly defined group characterizes certain sub-season and carries the scientific names of respective indicative plants which are usually a combination of a "notable garden shrub" and of a "notable garden herb". Only the autumn season is an exception, since in Central Europe there are no flowering hardy herbs in this period of the year. Therefore, in autumn we use a combination of two "notable garden shrubs". The onset of full bloom or full coloration phenophases in indicative plant species marks the beginning of the most attractive period of a given phenological group. As regards notable garden shrubs, the phenological indicative species in this category were selected on the basis of the statistical evaluation of the mean onset time of the key phenophases in our 3 localities. In case of notable garden herbs, the selection was determined by the regularity of their presence in the side-runs of a given notable garden shrub. The time unit defining individual phenological groups ranges within the interval of 10 calendar days, however, during the vegetation period it tends to oscillate slightly. Thus, in full spring the interval is somewhat shorter due to the fact that vegetation develops faster. On the other hand, in full summer the length of the aesthetic effect of given phenological groups is longer, because the species flowering in this period generally tend to remain in bloom for longer time.

The configuration of plant groups (Table 3) is the first preliminary attempt to classify plants with regard to time of the most important phenological activity of the high number of different species used in landscaping. The configuration is proposed for long-established phenological seasons and for the most important phenophases of full bloom and full coloration.

CONCLUSION

This paper focused on new ways of using practical findings obtained from studying the variability of plants throughout the year. On a model group of garden plants (shrubs) we studied the dynamics of phenological periodicity. Simultaneously, we followed and recorded concurrent aesthetically impressive phenological events in other garden plants, and sought to verify the existence of "vegetation waves".

On the basis of our experiment we may conclude the following:

– the sum of collected and statistically evaluated phenological data clearly reflects the complex impact of individual environmental factors. Therefore, in case of our selected localities the data may be considered as fully integrated,
– the experiment demonstrated that the course of phenological periodicity, including the course of individual side-runs, tends to be similar in different localities,
– our yearly recordings of side-runs and simultaneous statistical evaluation of observed phenophases seem to confirm the existence of "vegetation waves". Like the observed phenophases, the "vegetation waves" follow the particular course of the weather,
– the continuous outcomes of our experiment conducted in the selected localities suggest that the collected phenological data may be tentatively integrated and applied in the first three altitudinal vegetation zones in the Czech Republic, which include areas where the widest range of plant assortment is grown and where landscape architects most frequently work.

The facts mentioned above are elementary pieces of knowledge for an applied classification of a voluminous group of garden plants into time-specific and aesthetically attractive sub-groups that will – to a certain degree of probability – recur in established phenological seasons.

In light of the above information we propose a preliminary scheme for classification of garden plants. The criterion for its definition was the mean onset time of the aesthetically most important phenophases (full bloom and full coloration) in typical indicative species. For the seasons of the phenological year we propose 24 phenological groups of garden plants. During vegetation period, each of these groups ("vegetation waves") fills a time interval of approximately one calendar decade. Such a period fully corresponds to landscaping needs.

As a matter of fact, the obtained sum of results and our conceived preliminary proposal for the classification of garden plants should be put into the context of a longer time period (climatological period). Considering the above, we may say that:

– our collected and evaluated data are in accordance with the climatologic characteristics, or in other words, they correspond to temperatures and precipitation values which rank above the average from a long-term point of view, as well as to their somewhat extreme behaviour that may be observed in a more detailed analysis of the climate,
– our data were being evaluated for a relatively short period of four years and need further follow-up. They should be updated in line with the results of long-term and taxonomy-wide research.

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