

Chapter 8

International Phenological Observation Networks: Concept of IPG and GPM

Frank-M. Chmielewski, Stefan Heider, Susanne Moryson, and Ekko Bruns

Abstract International phenological observation networks are of great importance for many applications in phenology. Data from these networks generally have a high quality standard (genetically identical plants, standardized observation guidelines, etc.) and cover different climatic regions. In this chapter we introduce two networks, the International Phenological Gardens in Europe (IPG) and the Global Phenological Monitoring Programme (GPM). Both observation networks are coordinated by the Humboldt-University of Berlin (Germany). These networks allow a phenological monitoring across larger geographical areas. At the end of each paragraph, we show some examples how these data can be used for scientific applications. They are of great importance to describe relationships between observed climate variability/change and plant development and they can be used to develop or validate phenological models which are able to project possible future shifts in plant development.

8.1 Introduction

In the 1990s interest in phenological research and thus demand for phenological observations has increased, substantially. Mainly rising air temperatures in the end of 1980 and the clear phenological response of plants and animals to this increase have caused a growing interest in phenology by researchers and in public (e.g. EEA 2004; Parmesan 2006; Rosenzweig et al. 2007). Furthermore, the potential use of these data in other fields (see the relevant chapters in this book) like remote

F.-M. Chmielewski (✉) • S. Heider • S. Moryson
Agricultural Climatology, Department of Crop and Animal Sciences,
Faculty of Agriculture and Horticulture, Humboldt-University of Berlin, Berlin, Germany
e-mail: chmielew@agrar.hu-berlin.de

E. Bruns
Department of Networks and Data, German Meteorological Service, Offenbach, Germany

sensing, phenological modelling, agriculture and horticulture (Chap. 29), forestry, biodiversity, human health, and tourism has added value to phenological data and observations. Thus, climate and climate impact researchers have accepted the value of phenological data, and this renewed interest has increased demand for international cooperation in this area.

While the previous chapters mainly reported on different local, national, and regional phenological networks and cross-national analyses of these data, this chapter will introduce the only two *International Phenological Observation Networks* in the world.

The general advantage of these phenological networks is that the stations have identical standards. They require the observation of standardized, vegetatively propagated (genetically identical) plants. This is a great advantage if one considers that differences in the timing of the same phenological event (e.g. beginning of leafing or flowering) between two individuals may last several days or even some weeks. Differences in the maturity date of field crops (e.g. maize) or fruit trees can be even larger. Second, the definition of phenological stages is identical for all stations within the network and do not change over the years. Finally, the phenological stations are coordinated centrally, so that usually a high data quality is guaranteed.

The coordination of such networks is labour intensive and requires much dedication. Both networks, which are described below, have been coordinated by the Humboldt-University of Berlin for several years or decades. The central data collection and data management has been significantly improved in the recent years. General information about the monitoring network and real-time information on the current plant development can be found on the official webpages.

8.2 The International Phenological Gardens of Europe

The International Phenological Gardens (IPG) of Europe (<http://ipg.hu-berlin.de>) are a unique network for long-term phenological observations of plants representing the natural vegetation in Europe.

8.2.1 *Historical Aspects*

The idea to establish such an international monitoring network was initiated on the first meeting of the *Agrometeorological Commission* of the World Meteorological Organisation (WMO) in 1953. The aim of the new phenological network was to carry out large-scale and standardized phenological observations across Europe which are not influenced by the hereditary variability of the plants.

In the following years *Fritz Schnelle*, head of the Agrometeorological Division in the German Meteorological Service and *Erik Volkert*, University Professor of

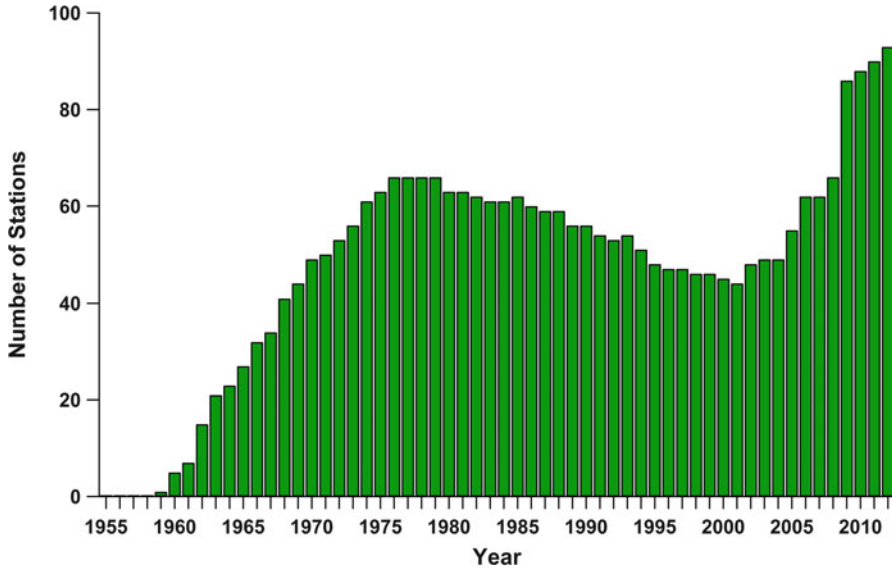


Fig. 8.1 Development of the IPG network between 1959 and 2012

Forestry, started to develop the concept for the International Phenological Gardens (Schnelle und Volkert 1957). At the beginning, they had to gather trees and shrubs from several places and institutions across Europe for the later propagation, find suitable places and institutions to establish phenological gardens, and draft an observation guide for the phenological observations. Simultaneously, they founded a parent garden at the *Federal Research Centre for Forestry and Forest Products* in Großhansdorf near Ahrensburg (Germany). This garden carried out the vegetative propagation and the plant dispatch for a long time.

After several years of preparation, in 1957 *Schnelle* and *Volkert* officially founded the International Phenological Gardens of Europe. Only 2 years later, the first IPG at Offenbach (Germany) reported phenological observations from six plants (*Picea abies*: early/late, *Populus canescens*, *Robinia pseudoacacia*, *Salix aurita*, *Salix smithiana*). In 1960 three IPG in Vienna (Austria) and another IPG in Germany (Trier) were added to the network. In the following years the number of IPG increased rapidly to 66 stations in the mid-late 1970s (Fig. 8.1).

After the start of the network the coordinating institutions changed three times. From 1973 to 1977 the network was co-ordinated by the *Institute of Biometeorology* of the University at Munich. Between 1978 and 1995 the *German Meteorological Service* (DWD) was responsible for the phenological gardens. Unfortunately, during this time the number of stations steadily decreased. There are different reasons for this trend. Probably, some stations lost their interest in long-term phenological observations. However, the main reason was the increasing shortage in young plants to establish new gardens, because in the 1990s the original parent garden was no

longer able to manage the plant propagation and plant dispatch. When in 1996 the *Humboldt-University* of Berlin took over the coordination and the management, only 47 IPG belonged to the network. One of the first tasks of the new management was to find a new parent garden. In 1997, the young plants were first moved from the old parent garden in Großhansdorf to Ahrensburg (Germany), where a new site was established at the *JORDSAND* association. Finally in 2001, when the observation network comprised only 44 stations, the *Bavarian State Institute of Forestry* carried out the propagation of selected species from the IPG programme, so that by this the survival of the network was ensured. Some years later a further extension of the network was possible. The number of stations increased again. In 2009, when the Irish phenologists at the *Trinity College* Dublin decided to establish a national phenological network in Ireland, which was based on the IPG species, more than ten new stations joined the network.

The original IPG observation programme consisted of standard and expanded programmes. Both programmes comprise coniferous and deciduous trees. The *standard observation programme* includes 26 plants from the natural vegetation including different provenances (Table 8.1). In 2001 three further plant species (*Corylus avellana*, *Forstia suspensa*, *Syringa chinensis*) were added to this programme. Two of them are plants from the Global Phenological Monitoring Programme (see Sect. 8.3), in order to have a link between these two networks. Over and above this, some IPG also observe the *expanded programme*. This programme includes 23 other plants, but only three new varieties (*Picea omorica*, *Betula pendula*, *Fagus orientalis*). The remaining 20 plants are further provenances of the species in the standard programme.

Currently, the plant propagation is only focussed on 21 species which now belong to the IPG kernel programme (bold numbers in Table 8.1). New established IPG will be supplied only with these plants. Sometimes, due to climatic restrictions, it is not possible to grow all species of the programme at one site. In this case, the gardens have only a few plants in stock.

The phenological phases are recorded according to the BBCH-code (Meier 1997), which classifies plant growth stages of many of species according to a standardized system. The extended BBCH scale is an internationally recognized standard and can be applied to most of the plants.

In Germany, the phenological stages of fruit crops were described initially by the BBCH-code (Bruns 1995). Since the start of the EPN-project (European Phenology Network) in 2003, the acceptance of the BBCH-code increased in Europe and later worldwide. In this European project the BBCH-code was adapted to the observation programme of 11 national phenological networks in Europe and to the IPG programme, as well (Bruns and van Vliet 2003).

The BBCH system is an excellent illustration for the standardization of phenological observations and the IPG programme an outstanding example for the standardization of plant species which are observed.

Table 8.1 Plants in the IPG Standard programme, including the observed phenological stages 1 May shoot (BBCH 10), 2 leaf unfolding (BBCH 11), 3 St. John's sprout, 4 beginning of flowering (BBCH 60), 5 general flowering (BBCH 65), 6 first ripe fruits (BBCH 86), 7 autumn colouring (BBCH 94), 8 leaf fall (BBCH 95)

Plant no.	Botanical name	English name	1	2	3	4	5	6	7	8
111	<i>Larix decidua</i>	European larch		x		x	x		x	x
121	<i>Picea abies</i> (early)	Norway spruce	x			x	x			
122	<i>Picea abies</i> (late)	Norway spruce	x			x	x			
123	<i>Picea abies</i> (northern)	Norway spruce	x			x	x			
131	<i>Pinus silvestris</i>	Scotch pine, Fir	x			x	x			
211	<i>Betula pubescens</i>	White birch		x		x	x		x	x
221	<i>Fagus sylvatica</i> 'Har'	Common beech		x		x	x	x	x	x
222	<i>Fagus sylvatica</i> 'Düd'	Common beech		x		x	x	x	x	x
223	<i>Fagus sylvatica</i> 'Tri'	Common beech		x		x	x	x	x	x
231	<i>Populus canescens</i>	Grey poplar		x		x	x	x	x	x
235	<i>Populus tremula</i>	Trembling poplar		x		x	x	x	x	x
241	<i>Prunus avium</i> 'Bov'	Wild cherry		x		x	x	x	x	x
242	<i>Prunus avium</i> 'Lut'	Wild cherry		x		x	x	x	x	x
251	<i>Qercus petraea</i> 'Zell'	Sessile oak		x	x	x	x	x	x	x
256	<i>Qercus robur</i> 'Wol'	Common oak		x	x	x	x	x	x	x
257	<i>Qercus robur</i> 'Bar'	Common oak		x	x	x	x	x	x	x
261	<i>Robinia pseudoacacia</i>	Common robinia		x		x	x	x	x	x
271	<i>Sorbus aucuparia</i>	Mountain ash		x	x	x	x	x	x	x
281	<i>Tilia cordata</i>	Small-leaved lime		x		x	x	x	x	x
311	<i>Ribes alpinum</i>	Alpine currant		x		x	x	x	x	x
321	<i>Salix aurita</i>	Roundear willow		x		x	x		x	x
323	<i>Salix acutifolia</i>	Pussy willow		x		x	x		x	x
324	<i>Salix smithiana</i>	Smith's willow		x		x	x		x	x
325	<i>Salix glauca</i>	Grey leafed willow		x		x	x		x	x
326	<i>Salix viminalis</i>	Basket willow		x		x	x		x	x
331	<i>Sambucus nigra</i>	Common elder		x		x	x	x	x	x
411	<i>Corylus avellana</i>	Common hazel		x		x	x	x	x	x
421	<i>Forsythia suspensa</i>	Forsythia		x		x	x		x	x
431	<i>Syringa vulgaris</i>	Common lilac		x		x	x		x	x

Bold plant numbers indicate the 21 plants from the current kernel program

8.2.2 The Network Today

Today, the network ranges across 28 latitudes from Scandinavia to Macedonia and across 37 longitudes from Ireland to Finland in the north and from Portugal to Macedonia in the south (Fig. 8.2). The IPG network now consists of 93 stations in 19 countries of Europe (stand 2012). All IPG are placed in similar surroundings, usually mainly plain surfaces with meadows and some trees. They are hosted by institutions such as universities, botanical gardens, meteorological services, forest research centres, etc. In the vicinity of each garden is usually an official meteorological station.

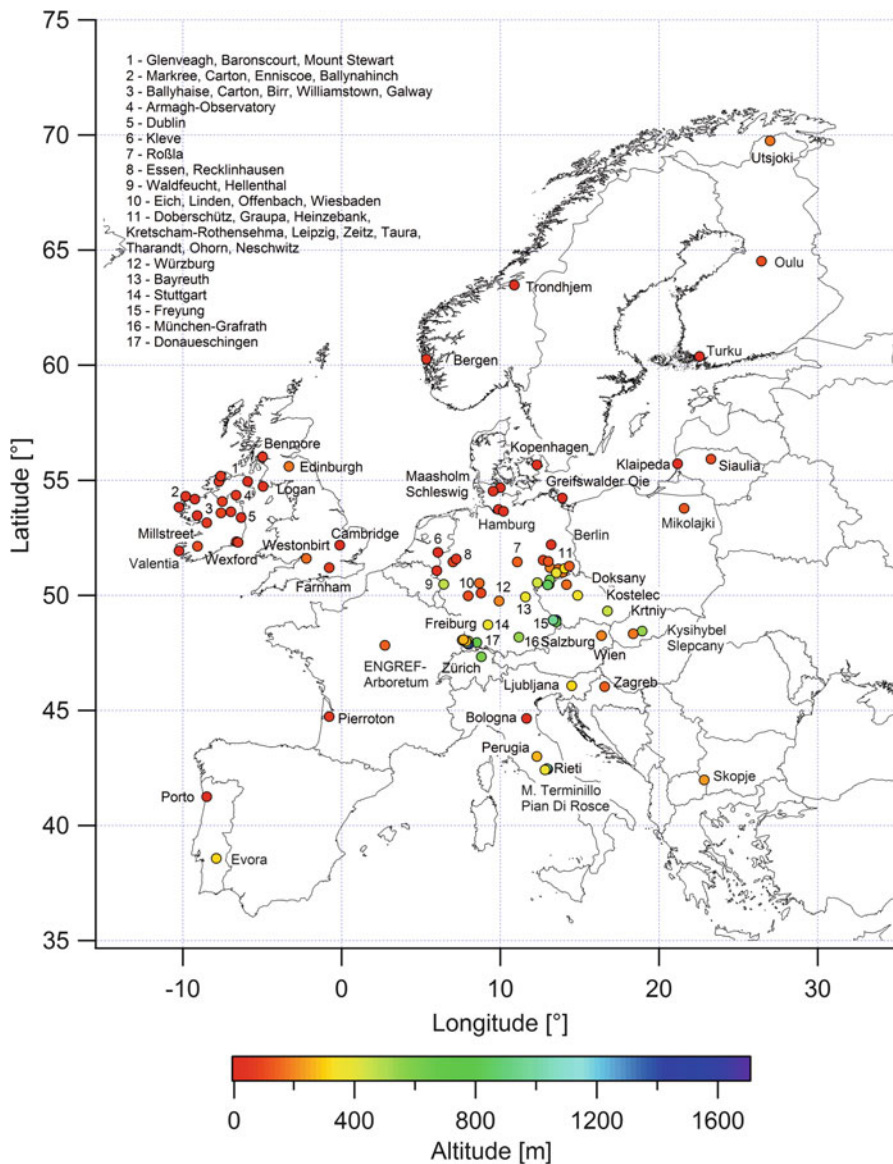


Fig. 8.2 Sites of the International Phenological Gardens of Europe (IPG), 2012

All observations are gathered and stored in the IPG database. The observations can be transmitted over the internet. In the members section of the IPG homepage the user can manage their station, add site information for the public (climate conditions, soil types, etc.) and can edit their observations. It is possible that a “super user” can serve several stations in a region. Additionally, the homepage gives everyone detailed information on the observed plants, the exact definition of the phenological

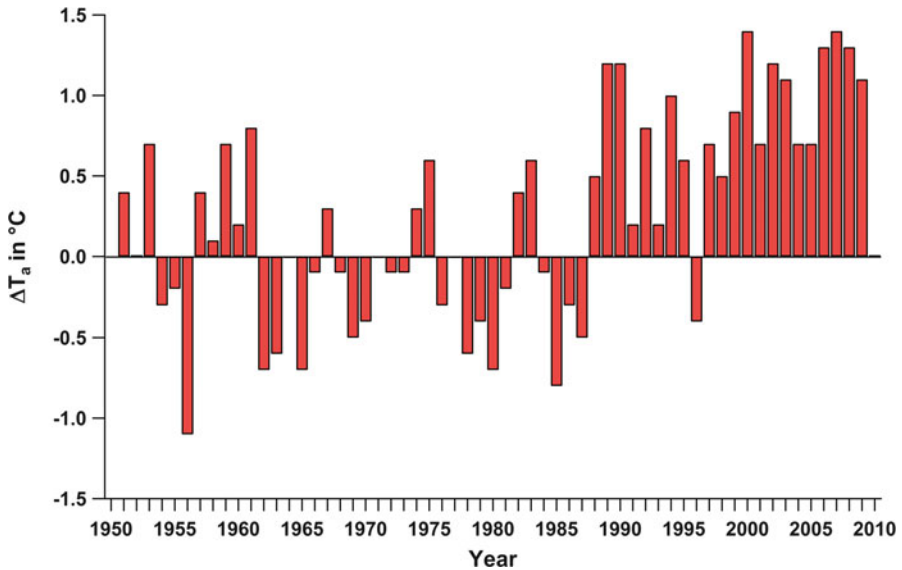


Fig. 8.3 Deviations of the mean annual air temperature (ΔT_a) in Europe (70°N–40°N, 10°W–25°E), 1950–2010 to the reference period 1961–1990 (E-OBS Data, Haylock et al. 2008)

stages (BBCH-code), and the number of active stations, including their climate conditions and average phenological data. For each year, beginning in 1959, the timing of phenological phases across Europe can be animated. Shown are deviations among all stations in timing of a phenological event from very early to very late.

8.2.3 Applications

The observational data of the International Phenological Gardens were used in many studies to detect regional or local differences in the timing of phenological events (e.g. Schnelle 1977, 1986; Schmittnägel 1983; Lauscher 1985; Sandig 1992; Seidler 1995) or trends (e.g. Menzel and Fabian 1999; Menzel 2000; Menzel et al. 2006), to present relationships between temperature variations and the beginning, end or length of growing season (e.g. Chmielewski and Rötzer 2001, 2002; Atkinson 2002; Donnelly 2002; Köstner et al. 2005; Rödiger 2012), for different modelling purposes (e.g. Kramer 1996; Menzel 1997; Rötzer et al. 2004) or to verify phenological models (e.g. Chuine 2001; Caffarra and Donnelly 2011), and to calculate phenological maps for Europe (Rötzer and Chmielewski 2001).

The strong relationships between air temperature and plant development in mid- and high-latitudes make phenological observations to sensitive indicators that can be used to evaluate possible biological impacts of climate change. Since the end of the 1980s, clear changes in air temperature have been observed in Europe (Fig. 8.3)

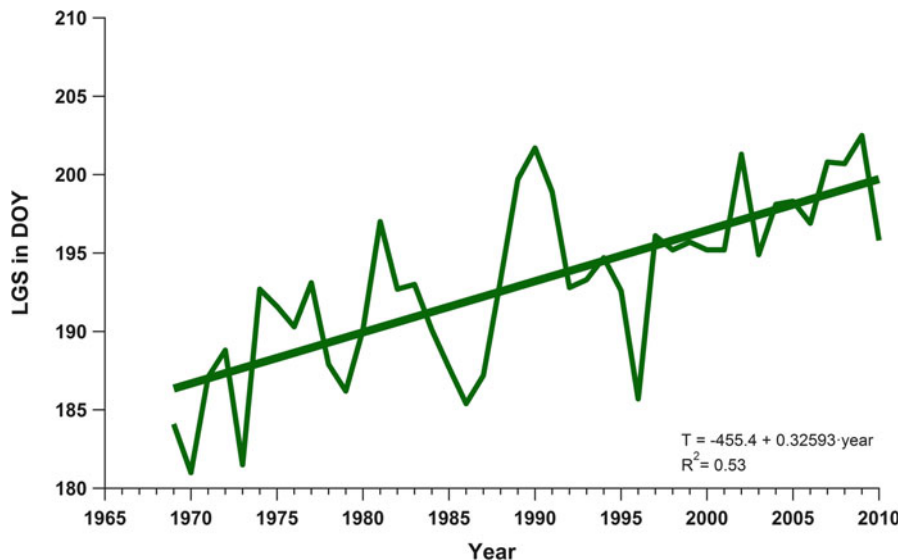


Fig. 8.4 Observed changes in the length of growing season across Europe between 1969 and 2010. The growing season length here is the average time between leaf unfolding and leaf colouring of selected IPG species (see description in text)

and in many other parts of the world. Mainly the temperatures in winter and in early spring – which are decisive for the spring plant development – changed distinctly. Most recent years were warmer than the long-term average.

These observed changes in temperature correspond well to changes in the circulation pattern over Europe (Chmielewski and Rötzer 2001). The increased frequency of positive phases in the North Atlantic Oscillation (NAO) since 1989 led to milder temperatures in winter and in spring, because of the prevailing westerly winds from the Atlantic Ocean during this time of the year. Cold spells were predominant only in the last two winters (2009/10, 2010/11).

These climate changes led to clear reactions in flora and fauna. Between 1969 and 2010, the average length of growing season in Europe, here defined as the average time between leaf unfolding and leaf fall of the IPG species 211, 241, 242, 271 or 324, and 311 (see Table 8.1), has extended by 14 days. This corresponds to a significant trend of 3.26 days/decade (Fig. 8.4). In accordance with climatic changes, mainly since the end of the 1980s, longer periods now occur. Between 1989 and 2010, 19 out of 22 years had an extended growing season, compared to the long-term average from 1969–2010.

In Europe the growing season lasts on average 193 days ($s = 5.5$ days) with large regional differences (Rötzer and Chmielewski 2001). The longest period can be found in the southern part of France and in the coastal regions of southern

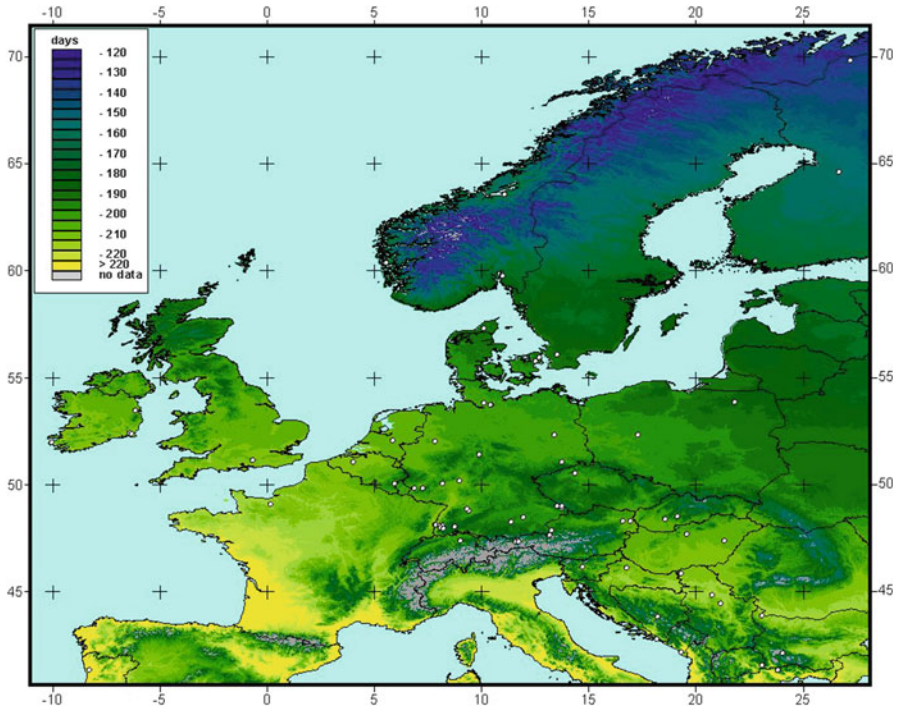


Fig. 8.5 Average length of growing season across Europe (Rötzer and Chmielewski 2001)

Europe (Fig 8.5). These findings were confirmed by Lebourgeois et al. 2010. They calculated for France a growing season length between 180 and 190 days in the east and more than 210 days in the west and south-west.

In large parts of Ireland, southern England, the Netherlands and in Belgium, and most parts of France, Hungary and southern Europe (except in the mountainous regions) the growing season lasts between 200 and 220 days. In Scotland, Denmark, Germany, Switzerland, Austria, the Czech Republic, Slovenia and Poland, and in the southern part of Sweden, the growing season lasts more than 180 days, but less than 200 days. Shorter growing seasons, with less than 180 days, are calculated for high altitudes and for nearly all of Scandinavia. High regions in Scandinavia as well as the areas north of the Arctic Circle show growing seasons under 150 days. These growing season lengths correspond to the average duration of snow cover (180–222 days) in most northern regions of Scandinavia.

8.3 The Global Phenological Monitoring Program

The Global Phenological Monitoring (GPM) Programme (<http://gpm.hu-berlin.de>) was originally an initiative of the ISB Phenology Group and is still in development. A further successful establishment of this network requires the efforts of phenologists

from different parts of the world. Currently, the aim of the study group is to establish a *Global Phenology Programme* by using, analysing and linking data from existing monitoring networks worldwide. First examples of this initiative are the European Phenology Network (van Vliet et al. 2003) and the Pan European Phenological database PEP725 (Koch et al. 2010). This is a welcome development, but can never substitute for a standardized global monitoring programme such as GPM or IPG. Some advantages of this network are highlighted at the end of this chapter.

8.3.1 *Historical Aspects*

The plan for establishing a new Global Phenological Monitoring network were started by the '*Phenology Group*' of the International Society for Biometeorology (ISB) at the 1993 meeting in Canada. At a second meeting in May 1995 (hosted by the DWD in Offenbach), the Phenology Group drew up concrete benchmarks that facilitated the network implementation. In 1996, the preparations of a Global Phenological Monitoring programme were completed at the 14th ISB Congress in Ljubljana, Slovenia. Phenologists from all over the world discussed the set-up of GPM stations. They agreed that the establishment a Global Phenological Monitoring programme was an important tool to meet the objectives of the ISB Phenology Group.

In 1998 and 1999 three GPM gardens were established in Germany (Deuselbach, Blumberg, Tharandt). In 2000, they reported the first observation results. Two new international gardens were established in 2002 (one garden in Beijing/China and another one in Milwaukee/USA). Unfortunately, the GPM in China had to be already abandoned in 2006. Despite of intensive efforts, it was not possible to set up a new garden in this region. Further gardens in Germany, the Czech Republic, Estonia, Italy, Slovakia, and Turkey quickly followed (Fig. 8.6).

The data from the GPM-stations are gathered at the Humboldt-University of Berlin. For the GPM gardens a similar database was established, such as for the IPG network. The annual observations can be also submitted via internet. In the members and in the public section of the GPM homepage the features are the same as those available for the IPG network.

GPM focuses mainly on temperature impacts on the timing of life cycle events. Since in arid and semiarid tropics or subtropics phenology is mainly driven by precipitation, the global network will be restricted to mid-latitudes of about 35° north to the Arctic Circle, and from the Tropic of Capricorn to 50° south.

The selection of plants was an important factor in determining the orientation of the monitoring program. The focus in GPM should not be the same (natural vegetation) as in the IPG programme. A number of criteria were used to choose species:

- plants should be *economically important*,
- species should have a broad geographic distribution and/or ecological amplitude,
- plants should be easy to propagate and vegetative propagation of these species should be common practice,

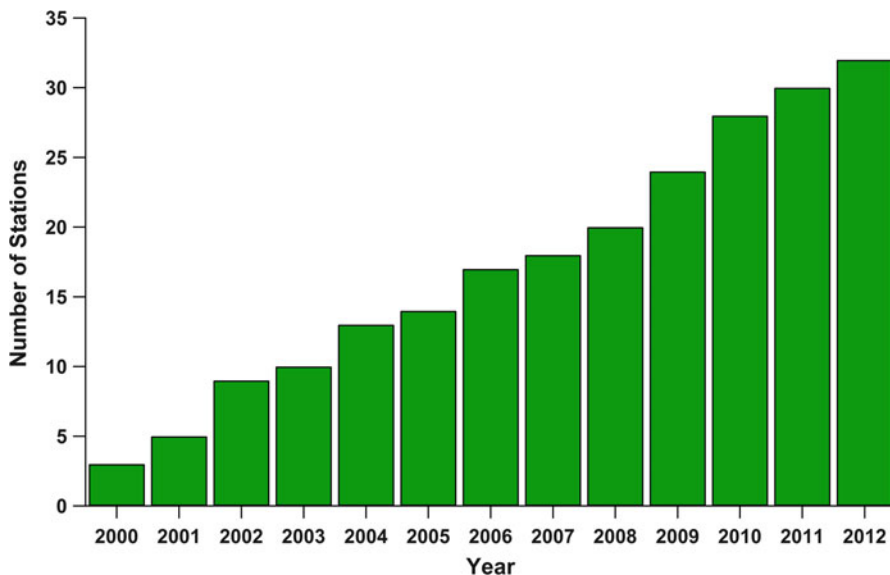


Fig. 8.6 Development of the GPM network between 2000 and 2012

- the start of the phases should be sensitive to air temperature, and
- plants should have phenological stages which are easy to recognize and to observe.

Based on these criteria, 16 plants were selected for the GPM observation programme (Tables 8.2 and 8.3). These species consist mainly of fruit trees (specified varieties), some park bushes, and spring flowers.

The fruit species represent the so-called ‘*Standard Programme*’, which is required for each GPM-garden that will be established. The Standard Programme can be supplemented by a ‘*Flowering Phase Programme*’ (ornamental shrubs and snowdrops). Due to different environmental conditions it is not possible to have all plants of the programme at all stations in middle and high latitudes. Thus, there are some gardens which only observe the standard programme and gardens which have a reduced number of species on-site. The minimum distance between trees shall be used for the same species. Larger distances are desirable and consequently not an issue.

Although temperature is the main factor affecting plant development, other environmental factors are also important. Therefore, to improve data analysis, a number of requirements for the phenological garden were specified to standardize the monitoring programme.

With the focus on temperature, precipitation impacts were excluded by allowing irrigation in case of extreme water shortage. Another requirement was that the location should be characteristic of the larger region around the observation area. Sites are to be avoided which, due to specific sun exposure (e.g. southern slope), shady side, topographical conditions, (e.g. frost hollow), or urban development, are

Table 8.2 Standard GPM-Observation programme and minimum distances (D) between the plants

Species	Variety	Latin name	Rootstock	D (m)
Almond	Perle der Weinstraße	<i>Prunus dulcis</i>	St. Julien A	3.0
Red currant	Werdavia, white cultivar	<i>Ribes rubrum</i>	own-rooted	1.5
Sweet cherry	Hedelfinger, type Diemitz	<i>Prunus avium</i>	GiSelA 5	3.0
Sour cherry	Vladimirskaja	<i>Prunus cerasus</i>	own-rooted	3.0
Pear	Doyenne de Merode	<i>Pyrus communis</i>	OHF 333	3.0
Apple	Yellow Transparent	<i>Malus x domestica</i>	Malus transitoria	2.5
Apple	Golden Delicious, type Golden Reinders	<i>Malus x domestica</i>	M26	3.0
European chestnut	Dore de Lyon	<i>Castanea sativa</i>	seedling	detached

Table 8.3 Flowering phase GPM-Observation programme and minimum distances (D) between the plants

Species	Variety	Latin name	D (m)
Witch hazel	Jelena	<i>Hamamelis x intermedia</i>	2.5
Snowdrop	Scharlokii	<i>Galanthus nivalis</i>	–
Forsythia	Fortunei	<i>Forsythia suspensa</i>	1.5
Lilac	Red Rothomagensis	<i>Syringa chinensis</i>	2.5
Mock-orange	(genuine)	<i>Philadelphus coronarius</i>	3.0
Heather	Allegro	<i>Calluna vulgaris</i>	0.5
Heather	Long white	<i>Calluna vulgaris</i>	0.5
Witch hazel	(genuine)	<i>Hamamelis virginiana</i>	2.5

All plants are own-rooted

known to have climatic anomalies, or where deviations from characteristic conditions can be expected. The plants should be planted on level ground (slopes of up to 3° in all directions are still acceptable). The trees and shrubs do not have to be planted in a specified order. The optimum growing site is open ground without obstacles, traffic routes, detrimental (for example, herbivores) or favourable influences (for example, artificial light), or other factors affecting the plants (shading).

If the observed plants are located near obstacles the following issues apply. The minimum distance from the base of any obstacle (building, tree, wall, etc.) should be at least 1.5 times the height of the obstacle (more, two times, from the edge of forested areas). The distance from a two-lane road should be at least 8 m, and from any larger (eight-lane) highway, at least 25 m. All plants must be protected against herbivores (consumption by wild or domestic animals) by a wire-netting fence or individually by an anti-game protective agent. So-called “plant protection covers” (e.g. tube protection and growth covers) are unsuitable, as they can accelerate growth considerably (heat congestion). Thus, preference should be given to wire-netting systems.

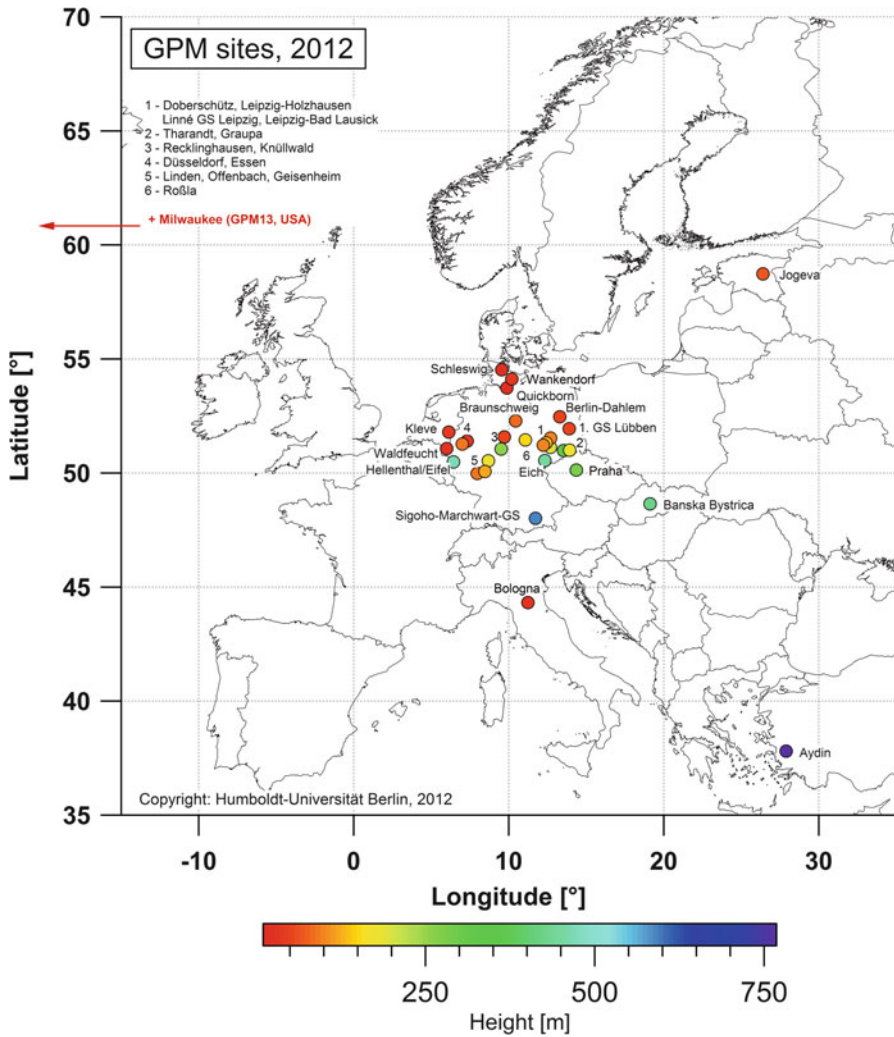


Fig. 8.7 Sites of the Global Phenological Monitoring program (GPM), 2012

8.3.2 The Network Today

Figure 8.7 shows the current distribution of the GPM-gardens in Europe. The only garden in the USA (Milwaukee) is not presented on this map. The current network includes 32 phenological gardens in 7 countries. One sees immediately that most gardens are located still in Germany. Additionally, three schools are involved in this network (*Linné Elementary School* in Leipzig, *First Elementary School* in Lübben, and the *Sigoho-Marchwart Elementary School* in Siegersbrunn). This is absolutely

desirable and a possibility to introduce students to science. Phenology is well-suited for this purpose, which meets the original goal of the ISB Phenology Group: ‘*To stimulate public interest in science, especially among pupils and students*’.

A future expansion of the network would be desirable. On the international scale import-requirements for plants are usually restricted. Within the European Union (EU), the export of plants without restrictions is possible. However, non-EU countries in Europe are already subject to more restrictions. For this reason it would be reasonable to establish *GPM parent gardens* at least in Asia, Australia, North and South America, which are specialized in growing plants, and are able to propagate and distribute the plant material. For Europe such a parent garden was established in Abstatt (Germany). The tree nursery ‘Krauß’ propagates the GPM plants successfully for several years. Plants can be ordered from anywhere in Europe. Since the fruit trees of the GPM are exactly defined (species, variety) it could be also possible to buy the plants on-site if they are really genetically identical. However, great care should be exercised here. This could be an option for countries with strong restrictions on imports of plants to at least partially join the monitoring programme.

In recent years, the Global Phenological Monitoring Programme has steadily increased in size. Set-up issues have been thoroughly explored, and new sites successfully implemented. GPM will continue to contribute to the further expansion of phenological gardens, to improve the use of phenological information and to improve cooperation and communication between the actors involved in phenology. The programme is now poised for future expansion into other parts of the world. However, this is only possible if there is an active support of phenologists outside of Europe.

8.3.3 Applications

The oldest GPM stations now have phenological records of more than 10 years. This allows for the first statistical analysis. However, the shorter time-series at many other stations limits use of the data.

Observations from GPM can contribute to investigations of possible impacts of climate variability or climate change on fruit crops. This is a very important task, because impact studies for perennial crops are limited compared to field crops (see also Chap. 29). For instance, the data can be used to analyse regional differences in the timing of phenological stages. It should be possible to explain these differences as a result of different climatic conditions. For example, the beginning of sour cherry blossom in Bologna (Italy) starts already on 12 April. Here, we have the warmest climate with an average annual air temperature (T_a) of 12.9 °C. In Jõgeva (Estonia) the annual mean is only 5.1 °C and the beginning of blossom only starts on 23 May (difference of 41 days). In Germany the beginning of sour cherry blossom starts on 24 April ($T_a = 9.2$ °C) and in Milwaukee (USA) on 10 May

Table 8.4 Validation of a phenological model for the beginning of sour cherry blossom (BB) on phenological observations of the GPM programme

GPM station	BB (number of years)	RMSE _{val} (days)
Braunschweig (D)	113.9 (7)	2.68
Berlin-Dahlem (D)	108.2 (5)	2.53
Geisenheim (D)	108.7 (7)	1.37
Offenbach (D)	103.0 (4)	2.43
Schleswig (D)	119.0 (8)	3.95
Tharandt (D)	121.3 (7)	4.36
Linden (D)	115.0 (8)	2.91
Graupa (D)	111.5 (5)	3.32
Praha (CZ)	111.8 (6)	2.87
Banska Bystrica (SK)	116.3 (8)	2.14
Milwaukee (USA)	130.0 (9)	3.89
Average across stations	114.4 (6.7)	2.95

RMSE_{val} root mean square error between calculated and observed data, variety ‘Vladimirska’, Model parameter: $t_0 = 244$ DOY, $C^* = 74.1$ CP, $T_{BF} = 1.0$ °C, $F^* = 567.4$ PTU, RMSE_{opt} = 2.19 days

($T_a = 7.8$ °C). This very rough estimation shows that there is indeed a clear response between climate and the beginning of cherry blossom.

Climate change will probably shift climate and growing zones worldwide. Phenological observations can help to forecast how the plants could respond to warmer environmental conditions, if phenological gardens already exist in warm climates such as in Turkey. GPM also has a great potential for modelling tasks. Plants in the international networks are standardized, so that the phenological observations are well-suited to develop models for the beginning of fruit tree blossom or picking ripeness. These blossoming models can later be used to evaluate the late frost hazard due to climate change in different parts of the world. Additionally, phenological observations are necessary to develop yield and water budget models for fruit crops.

Currently, most of the records are not long enough for modelling purposes, but they can already be used to verify phenological models. Matzneller et al. (2013) developed a phenological model for the beginning of sour cherry blossom for Germany based on phenological observations from the DWD. The model was developed for one important cherry growing region in Germany (Rhineland-Palatinate). For this modelling task a combined ‘Chilling Portion/Growing Degree Day Model’ with daylength factor was used (see Chap. 29). The model was verified at several *GPM stations*. The results show that at nearly all stations the model performed very well (Table 8.4), even when the model is used outside of Germany. This example clearly shows how important standardized phenological observations are for model development and validation.

The later validation of the same model on data from *experimental stations* in Germany, Hungary, Poland, and Michigan/USA lead also to reasonable results, but the average RMSE were higher (4.66 days), compared to the validation at the GPM programme (2.95 days). The phenological observations at these experimental

stations are certainly very precise, but the definition of the phenological stages varies between the sites. Variable definitions contributed to higher model error. Additionally, the cultivars differ from site to site, so that the calculations by the model are not easily comparable with the observations. The treatment and management of the fruit trees also differs from site to site, which led to larger differences between the modelled and observed values.

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