Chapter 2.6

THE GLOBAL PHENOLOGICAL MONITORING CONCEPT

Towards International Standardization of Phenological Networks

Ekko Bruns[1], Frank-M. Chmielewski[2], and Arnold J. H. VanVliet[3]
[1]*German Meteorological Service, Department Networks and Data, Offenbach, Germany;* [2]*Subdivision of Agricultural Meteorology, Institute of Crop Sciences, Faculty of Agriculture and Horticulture, Humboldt-University, Berlin, Germany;* [3]*Environmental Systems Analysis Group, Department of Environmental Sciences, Wageningen University, Wageningen, The Netherlands*

Key words: Global Phenological Monitoring, Network, Observation Program

1. BACKGROUND AND OBJECTIVES OF GPM

In the 1990s the interest in phenological research and thus the demand for phenological observations has increased substantially. Mainly, rising air temperatures in recent decades and the clear phenological response of plants and animals to this increase have caused the growing interest. Many studies have shown that the timing of life cycle events is able to provide a good indicator for climate change impacts (Schwartz 1994; Menzel and Fabian 1999; Chmielewski and Rötzer 2001, 2002). Furthermore, the potential use of these data in other fields like remote sensing (to calibrate and evaluate NDVI satellite information) has added value to phenological data (Reed et al. 1994; Carleton and O'Neal 1995; Schwartz 1999; Schwartz and Reed 1999; Tucker et al. 1999; Chen et al. 2000).

So, climate researchers have accepted the values of phenological data, and this renewed interest has increased demand for international cooperation in this area. In 1991, this demand was illustrated by a quote in the Proceedings of the International Conference on Climatic Impacts on the Environment and Society:

"*It is necessary for all of us to consider an establishment of a global phenological observation network for monitoring of changing climate and its impact to ecosystem*" (University of Tsukuba, Ibaraki, Japan January 27 – February 1, 1991).

The plans for establishing a new global phenological monitoring network were started by the "*Phenology Study Group*" of the International Society for Biometeorology (ISB) at a meeting in 1993 in Canada. The objectives of the Phenology Study group were:

- To promote a global dialogue among phenologists, by compiling information on phenological research and databanks,
- To use this global forum to encourage establishment and expansion of phenological networks, data exchange, and international cooperation,
- To encourage research that correlates phenological trends with climatic trends, especially in the context of global change monitoring,
- To explore methods of using phenology to stimulate public interest in science, especially among pupils and students.

At a second meeting in May 1995 (hosted by the German Meteorological Service in Offenbach), the Phenology Study Group drew up concrete benchmarks that facilitated network implementation. In 1996, the preparations of a Global Phenological Monitoring program (GPM) were completed at the 14th ISB Congress in Ljubljana, Slovenia. Phenologists from all over the world discussed the set-up of GPM. They agreed that the establishment a Global Phenological Monitoring program was an important tool to meet the objectives of the ISB Phenology Study Group. A main objective of GPM is to form a global standard phenological backbone that can link "local" phenological networks and encourage establishment and expansion of phenological networks throughout the world. GPM can actively increase cooperation. Furthermore, data generated by GPM provide a basis for communication, research, and public relations.

2. CONSTRUCTION AND SET UP OF GPM

During the design of the GPM program a number of details had to be considered, including the following issues:

- What climate-biosphere relations should GPM address?
- Which areas of the earth should be covered by GPM?
- What species should be included in the monitoring program?
- How should the GPM gardens obtain their plants?
- What specific site conditions could be tolerated?

– How should the observations instructions be formulated?

Each of these questions is examined in more detail in the following sections.

2.1 Climate-biosphere relations and geographical focus in GPM

The timing of phenological phases depends on numerous environmental conditions: temperature, precipitation, soil type, soil moisture, and insolation. However, in mid- and high latitudes, with vegetation-rest (dormancy) in winter and active growing period in summer, air temperature has the greatest influence on phenology (Fitter et al. 1995; Sparks et al. 2000; Chmielewski 2002). This is especially true for spring phenological phases (Figure 1).

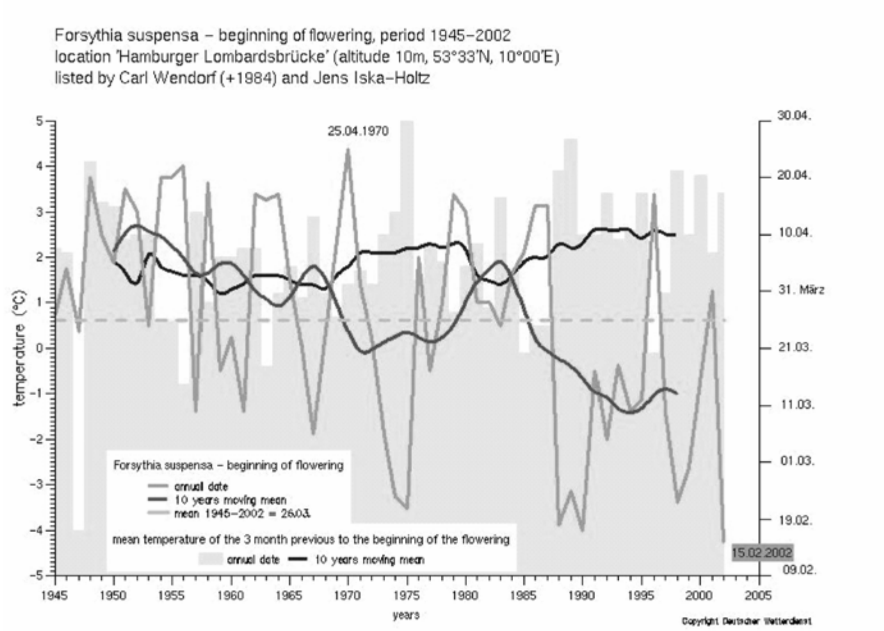

Figure 2.6-1. Beginning of flowering of forsythia 1945-2003 in Hamburg

Therefore, GPM focussed mainly on temperature impacts on the timing of life cycle events. The influence of temperature is not quite so pronounced for autumnal phases (Estrella 2000). In the arid and semiarid tropics and subtropics phenology is mainly driven by precipitation, because in these regions air temperature is never a limiting factor. Thus the global network will be mainly restricted to mid-latitudes (about 35° north to the Arctic Circle, and Tropic of Capricorn to 50° south).

2.2 Selection of species

The selection of plants is an important factor in determining the success of the monitoring program. A number of criteria were used to choose species:

- Plants should have phenological phases that are easy to recognize and observe;
- The start of the phases should be sensitive to air temperature;
- Plants should be economically important;
- Plants should have a broad geographic distribution and/or ecological amplitude;
- Plants should be easy to propagate and vegetative propagation of these plants should be common practice;
- The whole set of phenophases of the selected plants should cover as much as possible months with flowering stages during the growing season.

Based on these criterions 14 species were selected for the GPM-program (Tables 1 and 2). These species consist mainly of fruit trees (specified varieties), some park bushes, and spring flowers. The fruit species represent the so-called “Standard Program”, which is required for each GPM-garden that will be established. The “Standard Program” can be supplemented by the “Flowering Phase Program” (ornamental shrubs and snowdrops) to obtain the “Maximum Program”. Due to different environmental conditions it is not possible to have all plants in the program at all stations in mid- and high-latitudes.

2.3 Supply of plant species: GPM-parent gardens

A global network for plant observations depends on the quality of observation objects. Unhealthy plants will disturb the measurements. Furthermore, since genetic differences can influence the timing of life cycle events, a mechanism must be in place to guarantee the plant’s genetic identity. The best option is to work with one or several so called “parent gardens”, which are specialized in growing plants, and which are able to distribute the plant material. In 1996, the “*Müller-Platz*” nursery in Germany was engaged for this task, and now it acts as parent garden for

Europe. In the future, parent gardens need to be established in other regions of the world like Asia and North America.

2.4 Site and planting conditions

Although temperature is the main forcing factor affecting plant development, other environmental factors also play a role. Therefore, to improve data analysis, a number of requirements for phenological garden site conditions were specified to standardize the monitoring program. With the focus on temperature, precipitation impacts were excluded by allowing irrigation in case of extreme water shortage. Another requirement was that the location 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 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 degrees 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, herbivory) or favourable influences (for example, artificial light), or other factors affecting the plants (shading). As such conditions are certainly not always met; minimum standards were defined (Tables 1 and 2).

Table 2.6-1. Standard GPM-Observation Program and minimum distances between plants

Species	*Variety*	*Rootstock*	*Minimum distance*	*Tree prop*
Almond	Perle der Weinstraße	St. Julien A	3.0	while taking root
Red currant	Werdavia	own-rooted	1.5	none
Sweet cherry	Hedelfinger	GiSelA 5	3.0	while taking root
Morello	Vladimirskaja	own-rooted	3.0	while taking root
Pear	Doyenne de Merode	OHF 333	3.0	while taking root
Apple	Yellow Transparent	Malus transitoria	2.5	permanent
Apple	Golden Delicious	M26	3.0	permanent
European chestnut	Dore de Lyon	seedling	detached	while taking root

The minimum distances (Tables 1 and 2) are only valid when plants have been placed taking into account the direction in which the different species of the GPM program are set relative to each other. Larger distances are desirable and consequently not an issue.

Table 2.6-2. Flowering Phase GPM-Observation Program and minimum distances between plants

Species	*Variety*	*Rootstock*	*Minimum distance*	*Tree prop*
Witch hazel	Jelena		2.5	no
Snowdrop	(genuine)	-	-	-
Forsythia	Fortunei	own-rooted	1.5	no
Lilac	Red Rothomagensis	own-rooted	2.5	no
Mock-orange	(genuine)	own-rooted	3.0	no
Heather	Allegro	own-rooted	0.5	-
Heather	Long White	own-rooted	0.5	-
Witch hazel	(genuine)	own-rooted	2.5	no

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 herbivory (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 give to wire-netting systems.

2.5 Observation instructions

Clear and understandable observation instructions help observers accurately monitor the plants and improve the quality of observations. GPM observers are asked to monitor the different phases of each species variety on only one plant. The other plants of the same variety serve to check the observation results, as well as being a reserve in case of loss. Thus, if a plant fails, another is ready to be used without any loss in the data quality. During the main growing season when temperatures are favourable, plants may develop at a tremendous rate. In order to obtain the exact date of the beginning of a phase, observations should be made at least 3-4 hours after the sun has passed zenith (midday). This helps to eliminate the possibility that phase onsets were missed during previous observations.

2.5.1 Definition of Phases

Phenological phases are recorded according to a BBCH[1] code, which classifies plant growth phases of a lot of species according to a standardized system. The BBCH scale is an internationally recognized standard in the agricultural sector, and is thus an excellent source of standardized guidelines (the BBCH system is explained more in detail in Chapter 4.4). BBCH-codes are available for all cultivated plants with economic importance. Consequently, the phases for apples, pears, cherries, and currants can be compared directly with their appropriate scales. For species that are not explicitly considered in the BBCH-scale, the general BBCH-scale can be used, which allows determination of phenological phases for all plants according to the standardised BBCH-code. The following descriptions of the phenological phases are a complement to the BBCH definitions. They are somewhat more "traditional" than the short BBCH definitions, giving more detailed descriptions (illustrations of the phases by means of either photos or sketches are included in GPM[2] web pages and literature).

The descriptions here and definitions in the BBCH monograph[3] should in no way contradict each other. Ultimately, the BBCH definitions are to be used.

SL = Sprouting of leaves (bud break: BBCH 07, bud burst: BBCH 53):

The buds begin to open in at least 3 places on the object under observation. In the case of flower buds (bud burst) the green leaf tips enclosing flowers are visible; in the case of leaf buds (bud break) the first green is visible.

UL = Beginning of the unfolding of leaves, first leaf surfaces visible (BBCH 11):

In at least 3 places on the object under observation, first leaves have pushed themselves completely out of the bud or leaf sheath and have unfolded completely, so that the leaf stalk or leaf base is visible. This phase is sometimes only recognizable by bending back the young leaf. The individual leaf has taken on its ultimate form, but has not yet reached its ultimate size.

BF = First flowers open, Beginning of flowering, blossom (BBCH 60):

In at least 3 places on the object under observation the first flowers have opened completely.

Exceptions:

Snowdrops (*Galanthus nivalis*): the first 3 flowers have opened at the plantation. The flower is considered open only when the outer leaves have spread and the stamens are visible.

Heather (*Calluna vulgaris*): on 3 places of the plantation the first flowers have opened completely.

FF = Full flowering, General flowering, Full blossom (BBCH 65):

Approximately 50% of the flowers are open.

EF = End of flowering, blossom (BBCH 69):

This phase occurs when the flowers have faded. In some existing networks "flowers have faded" is equated with "approximately 95 % of the total petals have fallen". This rule is some different in formulation to the BBCH69 definition but in practice "de facto" identical.

RP = Fruit ripe for picking (for apple, pear, sweet cherry, morello, red currant, BBCH 87):

The fruits show the colouring characteristic for their variety and can be removed easily from the fruiting lateral.

Exception: Premature ripening should not be reported.

RP = First ripe fruits for almond, European chestnut (BBCH 86[4]):

The first ripe fruits fall from the tree naturally.

Exception: Premature ripening should not be reported.

CL = Colouring of leaves (BBCH94[4]):

Approximately 50 % of the leaves have taken on the colors of autumn. colouring of leaves, caused by drought, should not be reported.

FL = Leaf fall (BBCH95):

Approximately 50 % of the leaves have fallen off. Falling of leaves, caused by drought, should not be reported.

3. ESTABLISHMENT OF THE GPM NETWORK

There are two ways to establish the Global Phenological Monitoring network: setting up new gardens, or adapting existing networks to the proposed standardization. In recent years, both approaches have been pursued.

3.1 Setting up new GPM-gardens

The first GPM network garden was started in 1998 at Deuselbach (Germany). It is located at a measuring station of the *Federal Environmental Agency*. Further gardens quickly followed (at the beginning only in Germany), but now also in other countries of the northern hemisphere. The current network includes 15 gardens located in Asia, Europe, and North America (Table 3). More gardens are required before the data can be effectively analysed. At the moment the data from the German GPM-stations are gathered at the Humboldt-University of Berlin. In the near future is to decide how the network will be administrated in terms of data storage and access.

Two existing networks give an idea of the number of stations required for acquiring observational data from genetically homogeneous plants, i.e. the European IPG network[4] and the lilac/honeysuckle network[5] in the USA. Both networks currently consist of approximately 50 sites and both networks do not cover all of their respective continents. Based on the experience of these networks (and other factors like region, climate, and altitude gradation), we propose at least 75 stations for Europe. It will be an especially effective network if the stations are optimally distributed between Gibraltar and the Ural Mountains. Numbers of needed stations for other continents have yet to be assessed.

Table 2.6-3 Established GPM gardens

Country	*Number of sites*	*Locations*
China	1	*Beijing*
Estonia	1	Jögeva
Germany	9	Blumberg, Brunswick, Deuselbach, Erbeskopf, Geisenheim, Linden Schleswig, Tharandt, Zingst
The Netherlands	2	Amsterdam, Wageningen
Slovakia	1	Banska Bystrica
USA	1	Milwaukee

3.2 Adaptation of existing networks: linking networks

The second way of establishing the GPM network is by adapting existing networks into the new network. In the last years, the GPM program expanded because several existing networks added some GPM plants to their own program. In 2001, the "Red Rothomagensis" lilac variety (also used in the USA) and the "Fortunei" forsythia variety were incorporated into the International Phenological Gardens program (from the GPM program). At the same time the first "link gardens" were laid out in Schleswig, Deuselbach and Tharandt (Germany). These are gardens in which both the IPG and the GPM assortments are planted. The link between IPG and GPM will continue, and the present three combined IPG/GPM gardens (as of 2002) will be followed by others. In autumn 2000, the *Wageningen Agricultural University* distributed bulbs of the snowdrop clone, which is also contained in the GPM program, to 700 observers in the Netherlands. In 2002, a standardized phenological garden plan was introduce into the GLOBE program for schools (http://www.globe.gov). The suggested garden consists of the "Flowering Phase Program" of GPM, as these stages are easy for students to observe. Thus, schools around the world can now help to extend the GPM program, fulfilling one of the aims of the original ISB *Phenology Study Group*: "To stimulate public interest in science, especially among pupils and students".

Finally, some countries have considered using concepts from the GPM program to set up their own national networks. Scientists from Beijing University would like to build up a phenological observation network in botanical gardens across China, in which GPM will play a central role. At present the GPM assortment is being propagated at the *Beijing Botanical Garden*. If these network plans are successful, it will be the first time that a national organization has adopted the full GPM program.

By standardising observations, it becomes possible to link the different networks. Standardisation can be applied to the species included in the programs, to the stand of the observation objects (for example solitaire plant or stand of a forest/woodland) as well as to the observation area (for example maximum distance from the reference point), even to the object (for example year for year the same individual) and to the definitions used for phenological stages. In recent years, progress has been made in standardizing definitions for phenological stages in Europe, based on European Phenology Network (EPN) activities. EPN has applied BBCH-methodology to the definitions used in twelve phenological networks in Europe so far. This analysis has made it possible to identify to what extent the existing networks are compatible among each other and with the GPM program.

In addition to the EPN standardisation activities, several other developments have contributed to these efforts. For example, the Meteorological and Hydrological Service of Croatia modified their phenological program in 1996, orienting itself more towards the German program, which necessarily meant higher compatibility with BBCH. In 2000, the Central Institute for Meteorology, Austria, proceeded in the same way, and with the same effect. The Dutch phenological network (revived in February 2001) also modelled itself on the German program, so that Dutch plant phases are in complete agreement with those of Germany, and (due to the phase selection) are almost completely in agreement with BBCH. The Canada Plantwatch program was expanded in 2002 and an instruction booklet was published. More plant species were added and phenophases modified to better match European protocols and the BBCH system. *MeteoSwiss* will be bringing out new instructions which are preponderant identical to the German instructions. In all, six European networks will then be working de facto according to compatible rules, where phenological phases overlap. In the Swiss guide the phenological phases will be compared to the corresponding *BBCH* codes for the first time in national instructions and at least that is the intention of the *Slovak Hydrometeorological Institute* in 2003. This list is not complete, but documents the tendency toward greater standardization, which is not limited to Europe, but also applies to the North American continent, and China. Before the development of the BBCH scales (in the 1990s) and prior to GPM, there were no internationally recognized standards (apart from Zadoks et al.'s (1974) cereal grain scales).

4. CONCLUSIONS

In recent years, the Global Phenological Monitoring network has steadily increased in size. Set-up issues have been thoroughly explored, and sites successfully implemented in different parts of the world. GPM has demonstrated that it can play a significant role in standardization of phenological networks, as the BBCH-coding system is being adopted by other phenological networks. The first phase of the GPM network also improved cooperation between groups all over the world, and formed the basis for several successful initiatives, such as reviving the Dutch phenological network and the European Phenology Network. GPM will continue to contribute to the further expansion of existing networks, and the establishment of new networks, both to improve the use of phenological information, and improve cooperation and communication between the many actors involved in phenology. The program is now poised for future expansion into other parts of the world. Hopefully, GPM will be just as successful in gaining acceptance from phenologists internationally, as BBCH has been in worldwide agricultural experiments.

NOTES

[1]BBCH = **B**iologische Bundesanstalt, **B**undessortenamt, **Ch**emische Industrie (Federal Biological Research Centre for Agriculture and Forestry, Federal Office of Plant Varieties, Chemical Industry)

[2]http://www.dow.wau.nl/msa/gpm/

[3]BBCH-Monograph, 1997, Blackwell Science, p 622

[4]The reference numbers BBCH86 and BBCH94 were defined for this purpose. They fit into the context and do not violate the BBCH principle.

[5]http://www.agrar.hu-berlin.de/pflanzenbau/agrarmet/ipg.html

[6]http://www.uwm.edu/~mds/enanet.html

REFERENCES CITED

Carleton, A. M. and M. O'Neal, Satellite-derived land surface climate 'signal' for the Midwest U.S.A., *International Journal of Remote Sensing,16*, 3195-3202, 1995.

Chen X., Z. Tan, M.D. Schwartz, C. Xu, Determining the growing season of land vegetation on the basis of plant phenology and satellite data in northern China. *Int. J. Biometeorol 44*, 97–101, 2000.

Chmielewski, F.-M., Trends in the seasons. *BAMS, 10*, 1464-1465, 2002.

Chmielewski, F.-M. and T. Rötzer, Response of tree phenology to climate change across Europe. *Agricultural and Forest Meteorology, 108*, 101-112, 2001.

Chmielewski, F.-M. and T. Rötzer, Annual and spatial variability of the beginning of growing season in Europe in relation to air temperature changes. *Clim. Res. 19, 1*, 257-264, 2002.

Estrella, N. On modeling of phenological autumn phases. In: Menzel, A.: Progress in phenology: Monitoring, data analysis, and global change impacts. Conference abstract booklet, 49, 2000.

Fitter A.H., R.S.R. Fitter, I.T.B. Harris, M.H. Williamson, Relationships between first flowering date and temperature in the flora of a locality in central England. Funct Ecol 9, 55–60 41, 155–160, 1995.

Menzel, A. and P. Fabian, Growing season extended in Europe. *Nature, 397*, 659, 1999

Reed, B.C.; J.F. Brown; D. VanderZee, T.R. Loveland, J.W. Merchant, D.O. Ohlen, Variability of land cover phenology in the United States. *J Veg. Sci. 5*, 703-714, 1994.

Sparks T.H., E.P. Jeffree, C.E. Jefree C.E., An examination of relationships between flowering times and temperature at the national scale using long-term phenological record from the UK. *Int J Biometeorol 44,* 82–87, 2000.

Schwartz M.D., Monitoring global change with phenology: the case of spring green wave. *Int. J. Biometeorol. 38*, 18–22, 1994.

Schwartz M.D., Advancing to full bloom: planning phenological research for the 21st century. *Int. J. Biometeorol. 42*, 113–118, 1999.

Schwartz M.D. and B.C. Reed, Surface phenology and satellite sensor-derived onset of greenness: an initial comparison. *Int. J. Remote Sens. 20,* 3451–3457, 1999.

Tucker , C.J., D.A. Slayback, J.E. Pinzon, S.O. Los, R.B. Myneni, M.G. Taylor, Higher northern latitude normalized difference vegetation index and growing season trends from 1982 to 1999, *Int J Biometeorol 45*, 191-195, 1999.

Zadoks, J.C., T.T. Chang, C.F. Konzak, A Decimal code for the growth stages of cereals, *Weed Res. 14*, 415-421, 1974.