India needs phenological stations network

C. P. Kushwaha and K. P. Singh

Phenology (derived from Greek *phaino*, meaning to show or appear) is the study of periodicity in the life-cycle events of plants and animals which are influenced by seasonal variations in weather factors (e.g. temperature and precipitation). Extreme sensitivity of life-cycle events to inter-annual variations in meteorological conditions make phenological studies of great importance in addressing critical questions related with global modelling, monitoring and climate change[1]. Although climate change is being recognized at a global scale, changes at the regional level are more variable and difficult to predict[2]. At the regional level, the impact of climate change may be assessed by establishing causal relationships between phenological events of living organisms and seasonal weather parameters. Study of phenology is also becoming increasingly more relevant for sectors like forestry, agriculture, socio-economics and public health. Potential applications of phenological information in the context of global change have been variously discussed[3,4]. Thus, phenology has emerged as an important integrative measure to assess the impact of climate change on ecosystems. Long-term phenological records originating from the plant and animal observation networks provide a useful measure of changes in the species-level biological responses to variations in climate at specific sites[5]. The need for the establishment of a network of regional phenological stations in India has been recognized[6]. At a time when the probable impact of climate change is being widely discussed and the XI Five-Year plan is being implemented, it would be timely to assess the ecological significance and potential benefits of a network of phenological stations.

Global distribution of phenological network

Carolus Linnaeus (regarded as the father of modern plant taxonomy) established the first known plant phenological network in Sweden in the middle of the 18th century. His monumental book, *Philosophia Botanica*, describes methods for compiling annual plant calendars of leaf opening, leaf fall, flowering and fruiting together with climatological observations[7]. Most of the modern phenological networks, however, were established in the middle of the 20th century (Table 1). Presently, about 50 International Phenological Gardens (IPGs), which are a part of the network across Europe, regularly monitor a large number of species[8]. The International Phenological Metadatabase (developed by the European phenological network) provides information on active and historical phenological networks of the world. Almost 95% of total active phenological networks are located in only three continents, namely Europe, North America and South America (Table 1). A small fraction of the phenological networks is represented by Australia and Oceania. These networks are funded by governments, institutions, research agencies, private associations and the European Union. It is obvious that Asia and Africa completely lack phenological networks and most phenological observation networks extend through temperate ecosystems, while tropical ecosystems are grossly under-represented.

Besides the ongoing phenological networks, several on-line phenological recording programmes (e.g. *Nature's* calendar of UK phenology network, Alberta Plant Watch, Global phenological monitoring network, Netherlands phenology network) are also operating in these continents/ countries. These programmes engage workers (e.g. students, general public, guides, scouts, etc.) to report on-line calendar dates of a wide range of phenological phenomena from different localities (e.g. appearance of frogspawn; nest building by bird; appearance of fungi; appearance of insects and their mating; flowering time, fruit ripening, bud burst, appearance of leaves, leaf fall in various species). The on-line phenological recording programmes emphasize the need for the documentation of various life-cycle events of indicator and native plant species. These programmes also record the beginning and duration of flowering in plants that release large quantities of allergenic pollen causing allergic reactions with sensitive people and animals. Thus, the internet serves as an efficient and cost-effective method to record phenological events from a wide variety of localities.

Need for a phenological network in India

India is endowed with great variations in climate and vegetation. Policies for the location of phenological stations in the country may take into account climo-vegetational diversity and include larger designated areas like forests and major agricultural complexes (fruit and crop-growing regions). The phenological stations network should encompass all bio-geographical regions with focus on natural vegetation and the surrounding agricultural, horticultural and other important systems. The existing network of Biosphere Reserves, National Parks and Sanctuaries may be utilized for establishing phenological stations, and even the available meteorological stations can be considered for the purpose. In several temperate countries the recording of phenological activities is associated with the meteorological services. Besides recording various plant categories (e.g. forest trees and bushes, non-cultivated herbaceous plants, grasses, field crops, fruit crops), the network should also monitor economically important insects (like bees) and disease-causing organisms. Just as the widely distributed meteorological observation network has led to an immense increase in the knowledge of atmospheric phenomena, continuous collection of phenological information through well-positioned networks will significantly contribute to our understanding of biosphere functions. Apart from establishing phenological stations, the Ministry of Environment and Forests, Govt of India should initiate an on-line programme for the recording of phenological information from different localities of the country. General public, teachers, government officials, students and guides may be encouraged to report on-line dates of different phenological events from various locations through the internet.

Table 1. Continent-wise distribution of ongoing phenological networks. Values within parentheses represent the number of phenological networks. Data presented are synthesized from the information given in the website http://www.pik-potsdam.de/~rachimow/epn/html/frameok.html

Continent/network phenological	Distribution (country/state)	Operating since	Range of active sites in individual networks	Species monitored
Europe (34)	Austria, Italy, Norway, UK, Slovakia, Finland, Belgium, Spain, Switzerland, France, Czech Republic, Sweden, Germany, The Netherlands, Portugal	Before 1960 (11) 1960–90 (9) 1991–2000 (9) Since 2001 (5)	1–10 (10) 11–50 (10) 51–100 (5) 101–1000 (6) 1001–10,000 (3)	Natural vegetation, including trees; agricultural and horticultural plants; allergenic and non-allergenic pollens; birds; insects, and mammals.
North America (10)	Alberta, Panama, Massachusetts, Alaska, North Carolina, Colorado, New Mexico, Ohio, Grafton County, New Hampshire	Before 1960 (1) 1960–90 (6) 1991–2000 (3)	1–10 (4) 11–50 (4) 51–100 (1) 101–1000 (1)	Natural vegetation, including trees; agricultural and horticultural plants; allergenic and non-allergenic pollens; birds; insects, and mammals.
South America (3)	Brazil, Argentina, French Guiana, Suriname, Guyana, Amazon	1965, 1998, 2001	1–10 (1) 100–1000 (2)	Natural vegetation, including trees; agricultural and horticultural plants.
Australia and Oceania (1)	Australia	2003	101–1000 (1)	–
World (1)	Global	2003	101–1000 (1)	Natural vegetation, including trees; agricultural and horticultural plants.

Monitoring of tree phenology

Most existing networks listed in Table 1 record phenological events in natural vegetation, especially in trees. Being large perennial plants, trees show annual repetition of season-linked consecutive developmental stages which are collectively known as phenology[9]. It is evident that climate change will occur during the long lifespan of tree species and changes in phenology may be the major visible short-term response[10]. In fact, tree phenological observations have proved to be most effective impact indicators of climate change[11]. However, climate and phenology interactions in tropical Asian forests are poorly understood to enable quantitative prediction[10]. Dry tropical forests in India represent a mosaic composed of several phenological tree functional types in which cues for bud break of vegetative and flower buds and duration of deciduousness (leafless period) vary significantly[6]. In the dry tropics deciduousness results in minimized activity during the unfavourable season, and growth resumption with variable rates of resource use during the short favourable season[12]. Drought-induced leaf fall, increasing photoperiod/temperature and first significant rains have been reported to trigger bud break of vegetative buds[13]. In addition to these factors, decreasing photoperiod and episodic rain shower also function as cues for flower bud break. Tree phenological patterns are linked to many processes governing forest structure and functions, including length of growing season, water fluxes, primary production, nutrient budgets, C sequestration, food availability, population biology of pollinators, dispersers, seed predators and herbivores and interspecific competition among trees. To understand the impending impact of climate change on phenology of Indian tropical trees, phenological research and monitoring should focus around the following themes: duration of deciduousness (reciprocal to the growing season length), timing of vegetative bud break, leaf strategy, water relations, seasonal flowering types, interrelationships between vegetative and reproductive phenological events, patterns of resource use and asynchrony[6].

Benefits of a network of phenological stations

There are several useful applications of phenological observations and analysis of their records. For instance, assessment of climate change impact, forest management, agriculture, socio-economic development, biodiversity/ecology, tourism and sports and issues related to public health. The National Communications Report of India to the United Nations Framework Convention on Climate Change[14], shows that climate change is likely to impact all natural ecosystems as well as socio-economic systems. Climate-sensitive sectors (e.g. forestry, agriculture and fisheries) and natural resources (such as water, biodiversity and grasslands) play a significant role in the subsistence and livelihood of nearly 700 million rural people in India. In the agricultural sector phenological information may relate to the growth of crops and insects in an attempt to predict yields, bloom dates, and insect and disease infestations. Since ancient times, phenological observations have been used in scheduling agricultural work and current models based on meteorological and phenological data may significantly contribute to enhance cost-efficiency in the agricultural sector of India. Agro-meteorological forecasts enhance the efficiency of agriculture in several temperate countries (e.g. agro-meteorological forecasts of the Deutscher Wetterdienst, http://

www.dwd.de). In the forestry sector, phenological information may help in better management of forest ecosystems and determination of growing season length. In temperate regions growing season length is increasing due to the earlier onset of spring[15,16]. In Indian forests, existence of several tree functional types, differing in drought-related adaptations and length of deciduousness, poses uncertainty in determination of growing season length. All shifts in phenological phases, especially in the leaf period, have impacts on the climate system itself via feedback mechanisms of surface albedo, carbon-dioxide fluxes and evapotranspiration. Phenological information, which is easily perceived and recorded, can serve as a useful input in environmental education, public awareness, resource management and health programmes (e.g. allergic diseases). Apart from this, phenology may promote both scientific research in school children, and tourism and sports through information such as timing of snowfall and major flowering time. An advantage with phenological observations is that they are extremely suitable to illustrate and communicate climate-change impacts.

1. Schwartz, M. D., Ahas, R. and Aasa, A., *Global Change Biol.*, 2006, **12**, 343–351.
2. Climate Change 2001, Synthesis Report, Intergovernmental Panel on Climate Change, Geneva, Switzerland, 2001.
3. Schwartz, M. D., *Int. J. Biometeorol.*, 1999, **42**, 113–118.
4. Menzel, A., *Climate Change*, 2002, **54**, 379–385.
5. Sparks, T. H. and Carey, P. D., *J. Ecol.*, 1995, **83**, 321–329.
6. Singh, K. P. and Kushwaha, C. P., *Curr. Sci.*, 2005, **89**, 964–975.
7. Schnelle, F., *Pflanzenphanologie*, 1995, 299.
8. Chmielewski, F.-M. and Rotzer, T., *Agric. For. Meteorol.*, 2001, **108**, 101–112.
9. Borchert, R., Meyer, S. A., Felger, R. S. and Porter-Bolland, L., *Global Ecol. Biogeogr.*, 2004, **13**, 409–425.
10. Corlett, R. T. and Lafrankie, J. V., *Climate Change*, 1998, **39**, 439–453.
11. Donnelly, A., Jones, M. B. and Sweeney, J., *Int. J. Biometeorol.*, 2004, **49**, 1–12.
12. Kushwaha, C. P. and Singh, K. P., *J. Trop. Ecol.*, 2005, **21**, 47–56.
13. Rivera, G. *et al.*, *Trees*, 2002, **16**, 445–456.
14. India's Initial National Communications to the United Nations Framework Convention on Climate Change, Ministry of Environment and Forests, New Delhi, 2004.
15. Myneni, R. B. *et al.*, *Nature*, 1997, **386**, 698–792.
16. Menzel, A., *Climate Change*, 2003, **57**, 243–263.

ACKNOWLEDGEMENT. Financial support to C.P.K. from DST, New Delhi is acknowledged.

C. P. Kushwaha and K. P. Singh are in the Department of Botany, Banaras Hindu University, Varanasi 221 005, India.*
**e-mail: kpsingh.bhu@gmail.com*