

Climate Change and Phenology

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Global climate change is a reality, a continuous process that needs to be taken seriously, even though there are large uncertainties in its spatial and temporal distribution. The recent IPCC fourth assessment report reveals that unprecedented climate change, associated disturbances and other global change drivers are likely to exceed the resilience of many ecosystems. This would result in the increased risk of extinction of 20–30% of plant and animal species if increases in global average temperature exceed 1.5–2.5°C as reported by IPCC fourth assessment report. The report also projected major changes in ecosystem structure and function, species' ecological interactions, and species' geographic ranges, with predominantly negative consequences for biodiversity and for ecosystem goods and services, due to increasing temperature and associated atmospheric CO₂ concentrations.

Climate is one of the most important factors controlling the growth, abundance, survival and distribution of species as well as regulating natural ecosystems in a variety of ways. It is evident that natural systems are changing due to changing global climate in the timings of phenological events, changes in species abundance and range, shifts in habitat, changes in species composition of communities, extinction of species, fragmentation of habitat and changes in the structure and functioning of habitats and ecosystems are the most important ecological changes occurring in response to climate change. There is evidence that regional changes in climate have already affected biological systems around the world. Among all the studies and evidence on changing natural ecosystems considered by the IPCC third assessment report on climate impacts, major findings come from changes in phenological events. Therefore, important changes in biological systems are changing the timing of seasonal events (phenology) of plants and animals, leading to loss of synchrony between species and the availability of food and disrupting the rhythm of natural ecosystems. As with the global impact of climate change on ecosystems, it is inevitable that climate change may affect many of our species, habitats and ecosystems. Major changes in the Bangladesh may include changes in phenology and shifts in species range, species abundance and the habitat requirements of species. Numerous phenological studies around the world have indicated that phenological events have changed in both plants and animals; for example, earlier flowering, advancement of peak appearance of butterflies, birds laying eggs earlier, birds migrating earlier, amphibians spawning earlier, fish breeding earlier, etc.

Phenology – nature's calendar

Phenology is generally described as observation of the life-cycle phases of plants and animals and their relationship with the environment, especially climate. It involves investigation of the response of living organisms to seasonal and climatic changes in the environment in which they live. Seasonal changes include variations in temperature, rainfall, precipitation, humidity, wind, duration of sunlight, soil temperature, atmospheric circulation (The El Niño Southern Oscillation, The North Atlantic Oscillation, and The Arctic Oscillation), frost and other life-driving factors. Leaf flush, leaf unfolding, flowering, bud burst, fruit ripening, colour change and leaf fall, as well as the timing of birds'

migration and nesting, appearance of insects, and spawning of amphibians are all examples of phenological events or phenophases.

Most types of plants and animal growth requires sufficient light, water, CO₂, O₂, mineral nutrients, and temperature. These simple demands involve a large number of environmental factors and physiological processes such as meteorological (light, photoperiod, temperature, precipitation, humidity, wind, as well as gases) and edaphic factors (topography, slope, exposure, and soil properties), as well as biotic factors such as pests, diseases, and competition. Therefore phenophases are regulated mainly by climatic factors, and to a much lesser extent by inner factors of the organism (e.g. genetic regulation, plant hormones). The basic pattern and its plasticity are genetically determined and then modified by the environment. However, temperature is considered the driving factor determining phenological phases because the commencement of each development period for plants requires certain critical and accumulated temperatures.

Significance of phenology in climate change studies

It is now well documented that plant phenology has an important connection to climatic components. Numerous examples are evident, from the blossoming of cherry in Japan to the flowering of hawthorn in the UK or lilac in the USA, showing that global warming is significantly changing the seasonality of natural ecosystems. Due to its sensitive response to climate, ecologists are now using plant phenology as an indicator for environmental monitoring, particularly in detecting climate change. It is possible to model the relationship between phenophases and climatic elements due to the availability of long-term phenological data for a number of plant and animal species. Study of changes in the timing of plant phenophases in response to climate warming is important for two reasons. First, it demonstrates to the public and policy-makers that climate change is already happening even in response to the current modest increase in temperature; and second, it quantifies the extent of change in natural ecosystems that we can expect in the future. If we want to predict the future response of species to a changed climate, we need to explore how species have responded to climate in the past. The use of phenology as a sensitive bio-indicator presupposes quantitative analysis of changes in phenological time series and a known relationship with temperature or a comparable change in corresponding temperature series over time. Longer plant phenological records that go well beyond the period of instrumental meteorological records (e.g. records of cherry trees blossoming in Kyoto, Japan) can be used as proxy climate data for temperature. A French Climatologist reconstructed summer temperature variations from grape harvest dates from 1370–2003 in France, and a Chinese Climatologist reconstructed past winter temperatures in China using historical phenological events.

The experiences of the UK Phenology Network show that it is possible to communicate and disseminate climate change issues to the general public effectively and that phenology has shown itself capable of reconnecting people with nature. In an editorial comment, Menzel (a bio-climatologist) illustrates the value of phenology ‘ranging from ground truth for satellite data, education, public awareness, bio-indicator allowing cautious extrapolation of climate change impacts, to processes in vegetation climate feedback’.

Due to increased research interest in global environmental change and interannual climatic variability, long-term phenological data are becoming essential inputs to climate models. Phenological modelling plays a prominent role in regional ecosystem simulation models and atmosphere general circulation models. Phenological records and models are used in agricultural production, integrated pest- and invasive-species management, drought monitoring, biodiversity, forestry, wildfire risk assessment,

and treatment of pollen allergies. Therefore phenology has recently developed rapidly and globally as an environmental science discipline.

Tim Sparks, an eminent phenologist in UK illustrates the value of phenological data as follows: 'Historical data are a resource. They were collected at considerable effort in time and money. They do have value, and that value is too great to allow them to be left in obscurity or lost forever'.

Shifts in phenology do not just affect wildlife; they may have serious economic and social implications. It has been shown that phenology plays an important role in the carbon balance of terrestrial ecosystems and in climate and vegetation models. Recently, ecologists have used phenological models to predict the future carbon sequestration potential of boreal forests.

Findings from the shifting of plant phenophases are helpful for conservation and adaptive management of species as well as for the insect species dependent upon them. They may help in decision-making processes for conservation strategies and protected area management.

A brief history of phenology

Phenology is an ancient scientific discipline, the history of which dates back to the time of the hunter-gatherers. Monitoring seasonal natural events such as the date of spring blooming of a particular plant species is a centuries-old practice. Keeping records of plant phenology was both a hobby and a tradition for natural historians in many countries. Phenological calendars were used by the ancient Chinese and the Romans to guide agricultural operations, as well in the UK and Japan. The oldest phenological records of cherry trees blossoming were made in Kyoto, Japan and date back to 705 AD. The Chinese are thought to have kept the first written phenological records, starting around 974 B.C. Some Chinese phenological series stretch back to the sixteenth century or earlier.

In Europe, the Swedish botanist Carolus Linnaeus (1707–1778) systematically recorded plant flowering times at 18 locations in Sweden over many years in his work *Philosophia Botanica*. His careful notes also recorded the exact climatic conditions at the time. In Britain the long history of recording phenological observation goes back at least 250 years, with the oldest records dated 1703. Phenological recording was very popular in the UK in the Victorian era. The systematic collection of phenological records in Britain started in 1736 when Robert Marsham, near Norwich, began to collect 'indicators of spring', particularly flowering, leafing and bird migration dates. Five generations of the Marsham family recorded phenological observations at their estate from 1736 through to 1958, forming the longest phenological record by one family in the world. The Marsham phenological records were related to long-term climate records. Carolus Linnaeus and Robert Marsham now share the honour of being considered the 'fathers' of modern plant phenology'. The Royal Meteorological Society (RMS) commenced a countrywide phenological network from 1875–1947 to examine the relationship between meteorological events and the natural world. Eleven plant phenophases were consistently recorded during this period (1891–1948), and a further fourteen phenophases were recorded between 1929 and 1948. The output was documented each year in the *Quarterly Journal of the Royal Meteorological Society* as 'The Phenological Reports'. This network ceased after 1947 due to lack of coordination and the absence of an appropriate organisation to handle it. In 1905 the British Naturalists' Association started a phenological scheme that continues on a small scale to the current time. The Royal Botanic Garden, Edinburgh (RBGE) has a phenological dataset covering about half the 19th century with a shortlist of around 40 species, which is now preserved in the RBGE archives.

Very old phenological time series in Europe include cherry flowering in the Alpenvorland of Switzerland dating back to 1721, bud burst of horse chestnut in Geneva, Switzerland, dating back to

1808, and grape harvest dates from France back to the Middle Ages. The first International Phenological Network was set up by the *Societas Meteorologica Palatina* in Mannheim, Germany. In Germany, the first European Phenological Network was founded by Professor Hoffmann of Giessen University and his student, Ihne, in 1882 and continued until the Second World War.

After the 1990s phenological research gained momentum in the context of research into global change, and a large number of research findings were published on the impacts of climate change on phenological events. As a result some nature-based organisations shifted their focus and deployed their efforts to phenological research. The UK Phenology Network (UKPN) coordinated by the Woodland Trust and the Centre for Ecology and Hydrology, was started in 1998 with the aim of creating a large-scale network of phenology recorders and to search for and preserve historical data. Currently there are more than 20,000 registered volunteer recorders throughout the UK who have already recorded over one million observations from both plants and animals. BBC TV, in association with the Woodland Trust, began a nature programme, *Springwatch*, in 2003. It invited viewers to record first springtime sightings of various animal and plant species across the UK. The UKPN now claim that their phenology database contains nearly two million records stretching across 300 years. Following its increasing popularity and viewer response, the BBC has started another programme, *Autumnwatch*. Both *Springwatch* and *Autumnwatch* currently use Internet technology to receive records of phenological events. In 2000, a new initiative, 'The Kew 100', began with the aim of annually recording the first-flowering and mid-flowering dates of 100 plants in Kew Gardens.

Recently, in UK, the Woodland Trust, UKPN, Centre for Ecology and Hydrology, UK Forestry Commission and BBC *Springwatch* and *Autumnwatch* have been promoting phenological aspects of climate change. Searches for important sources of phenological data from naturalists' diaries, obscure books and manuscripts are ongoing through the initiatives of these organisations. Moreover, a number of dedicated amateur naturalists, botanists, scientists, and university researchers are also collecting phenological data from both plants and animals across the UK and are trying to preserve historical records, examining species response to climatic variation and forging international collaborations. Britain has a legacy of phenological recording and one can now examine the phenophase-temperature relationships of many species.

Implications for impacts of Climate Change on Phenology in Bangladesh

There may be very little study on the impacts of climate change on the phenology of the flora and fauna of Bangladesh. Studies carried out in this areas in Southeast Asian regions are either Fragmentary or inconclusive. There are some grey literature on the impacts of climate change on biodiversity and ecosystem of the country. We have different types of ecological zone in Bangladesh which are habitat for a variety of species of flora and fauna. Due to climate change, phenology of those species may be change that needs to be investigated. It is now evident that delaying or advancing of season is happening and extreme weather events and climate variability are magnifying it. Delay or advance of the arrival of summer, rainy and winter season in Bangladesh may disrupt the natural rhythm or synchrony of the ecosystem.

It is interesting that some of the daily news papers are reporting about earlier blossoming of mango inflorescence in some parts of Bangladesh. The long-term implications of changes in the phenology of various species may be profound for different ecosystem in Bangladesh. It is generally required long term data to find out finger print of climate change. The World Meteorological Organization guideline is to use at least 30 years data to find out climate signals. Forest Department of Bangladesh, National Botanical Garden and Bangladesh National Herbarium have scanty and sporadic long term

phenological data on flora and fauna. Though it is already late, we should start immediately to collect phenological data every year from different ecological zone which will be an important source for interpreting climate signals from those data. On the other hand we have various climatic data e.g. air temperature, rainfall, sea surface temperature, soil temperature etc. and these are available in Bangladesh Meteorological Department. Therefore both climatic data and phenological data are required to detect climate change trends. We can also explore or investigate obscure phenological data source that may be collected by any of armature naturalist in our country. If we start now we can select some sensitive and indicator species in future that will be useful for detecting climate change. This is also required for conservation planning of our critical ecosystem that might be disrupted due to climate induced factors. Due to its (phenology) sensitivity to climate warming, the UK government has included phenology in its climate change indicators in 1999. We have yet to set any climate change indicator for Bangladesh. It is also urgent for us to set Climate Change indicators for Bangladesh. How such species will respond to longer and warmer summer/rainy season needs to be investigated? Some deciduous trees from the Sal forest may leaf earlier and produce flowers in advance than before. Sea level rise, increase of air and sea temperature and ocean acidification due to climate change may impact the phenology of mangrove plants and animals. These phenomena may also change the phenology of marine fish species which may ultimately shift the breeding ground. This may also result in the appearance of predators who feed on leaves of these trees and pollinators of the flowers earlier than expected. It is not possible to tell anything without scientific investigation and rigorous research work. The different responses may disrupt the complex linkages between different trophic levels in nature and disturb the ecological balance. An understanding of how vegetation responded to past climate is needed for predictions of response of plants to future climate change. Shifts in plant phenological events will disrupt ecosystem structure and the synchrony of natural ecosystems and may increase intra-specific competition. Some nectar-feeding butterflies and other insects are dependent on particular host plants for their survival. If plants flower or fruit earlier, these insects and fructivorous birds, as well as carnivorous animals that use the insects or birds for their food, may try to adjust their life cycles. Therefore there is a close relationship between host plants and such insect species. What will be the fate of these insect species if the phenological events of their host plants shift by a considerable amount? In this case important synchrony in the ecosystem may be disrupted, which may affect pollination and seed dispersal insects as well as all connections via food webs. On the other hand, the survival of some nectar-feeding insects and birds is dependent upon flowering and fruiting at a particular time. Some species may adapt to recent phenological change and others may not; this needs to be further investigated. Longer-lived woody tree species may not be able to evolve in response to climate change, as the changes projected may occur within the lifetime of a single individual. It is speculate that species with no phenological adaptability may experience greater stress or even extinction during prolonged climate change. Shrubs and herb may experience range shifts which are expected to be more rapid than those occurring in trees. Although changeable conditions are likely to favour the most adaptable species, they will be unfavourable for many specialised, rare or sensitive species.

We urgently need to develop a scientific database on chronology of major phenological events for our flora and fauna. This can be done with the help of the large number of botanists/ecologist/foresters/wildlife biologist in the university departments and colleges, who will generate data at the regional level through a close networking. The Ministry of Environment and Forests should initiate the work now for collecting phenological data every year from different forest and ecological zone. Those consecutive data would be useful in near future for country conservation

planning. It is also important for funding agencies to invest grants in this thrust area, so that the effect of predicted climate change on ecosystems and species is studied at regional and local levels, and steps for possible mitigation are planned in advance. Shifting of phenology does not just affect plants and animal life; they may have serious implications for our agriculture, forestry, fisheries sector. Farmers need to know timing of flowering, fruiting, seed ripening, harvesting, etc for managing sustainable yield. These may also affect food grain production of our country. Moreover, these issue was not properly reflected in the 'National Biodiversity Strategy and Action Plan' and also the National Adaptation Programme of Action'. Therefore this issue should be mainstream in the national conservation policy and planning. Shifting phenophases due to climate change are likely to create powerful selection pressures on plant species themselves, as well as on species at higher trophic levels that depend on these plants. Some ecologists warn that climate-induced changes in phenological events might affect community organisation and have influential consequences for ecology and evolution. Therefore long-term monitoring of plant ecosystems with climate change-integrated conservation strategies (CCS) is essential.

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