PHENOLOGY AND CLIMATE CHANGE

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Contents

Summary

All organisms are dependent on the environment for their development and growth. Climate is one of the most important factors for life and has continuously fluctuated, due to natural forces, most well known since the last Ice Age. However, in recent years the climate has changed and a clear trend towards higher temperatures in most places on earth has emerged, to a great extent attributable to increased emission of anthropogenic greenhouse gases to the atmosphere. This temperature rise has been shown to influence phenology, periodical biological events, of organisms on earth. In most cases plants show earlier development, particularly in spring, and a longer growing season; as much as two weeks during the last three to five decades has been observed. Species respond to warmer temperatures at different rates which may result in mismatches in food webs. Higher temperatures also cause increased decomposition rates and change the nutrient status in all environments. This increases the growth of certain nutrient demanding species and changes the structure of a community, again influencing phenology of organisms. Most phenological data are collected from the Northern Hemisphere, and particularly from Europe, but recently information has also been available from the Southern Hemisphere. Examples of phenological responses to climate change are presented in the chapter, for both plants and animals from terrestrial and aquatic environments.

1. Introduction

Phenology is most often defined as the study of the timing of periodic (recurring) biological events (for instance timing of bud break of deciduous woody plants, flowering of various plants and migration of birds) in relation to the environment and in particular to climatic factors (especially temperatures). Sometimes even studies of abiotic recurring events such as the formation and melting of ice are included in the term. Others define this as seasonality. In the present chapter we will restrict phenology only to the timing of living organisms on land and in water (marine and freshwater), in relation to climate change, in particular to rising temperature. All types of organisms are included in the term; plants, fungi and animals (vertebrates as well as invertebrates). However, most phenological work has been carried out on higher plants, and more data are available from Europe than from other parts of the world.

Mark Twain said “climate lasts all the time and weather only a few days”, Robert Heinlein stated “climate is what you expect, weather is what you get” – both are correct and explain the difference between climate and weather. Weather is the physical state and the processes of the atmosphere at any given time at a certain location; climate is measured over longer time frames and usually over larger geographical areas.

The atmosphere, although crucial, is only one component of the climate system and interacts with the other climate subsystems and all organisms. Plants, for example, reduce wind velocity in the atmosphere near the ground, play a dominant role in the radiation budget and are part of the water cycle (evapotranspiration). Vegetation is a dynamic factor in the earth-climate system and has positive and negative feedback mechanisms to the biogeochemical and biogeophysical fluxes to the atmosphere. Probably the most prominent biogeochemical feedback is the interaction between vegetation and CO_2 concentration of the atmosphere.

In this chapter Climate Change is defined as any change in climate over time, whether due to natural variability or as a result of human activity, following the definition of the term by the IPCC (2007) e.g. in their WG II Fourth Assessment Report for Policymakers (Endbox 1). For some authors, however, Climate Change is restricted only to changes in temperature in recent years caused by human activity.

The difference between climate variability and climate change has a degree of arbitrariness and depends on the time scale considered. When looking at a time series of a meteorological element the fluctuations around the mean can be large, but when means of shorter periods stay constant we speak of climate variability. When we can discern an underlying (periodic) trend or an abrupt change in the variability we call this climate change.

Nearly all living organisms both on land, in the air and in water (marine as well as freshwater) are influenced in one way or another by changes in their environment. It is often necessary to also include the impact of climate change on organism diversity and physiology when discussing the relationships in phenology and very often species distribution is influenced. For example, some high alpine plant species cannot tolerate increased temperature and/or are stressed by other species invading upslope as the climate changes, and as a consequence they may be outcompeted or their phenological development delayed by shading. Similarly, fish preferring a cold climate may have to move pole-wards in the face of increased temperature and develop new spawning areas and thus change fisheries and aquatic communities.

In most parts of the world, change in temperature is the single environmental factor having the strongest influence on phenology, although in some areas change in precipitation is even more important for the timing of phenological events. Precipitation especially influences phenology in deserts and in areas with marked changes in extremely high precipitation. Secondary effects, at least in plants, may again be shown as a phenological delay through shading caused by increased numbers of competitors or slower development in denser and colder soil following increased precipitation. For plants, soil nutrients may also have some influence on phenology in addition to their impact on growth. A shortened growing season to maturation may be observed at higher latitudes with longer days in summer than at lower latitudes at similar temperatures, at least in the Northern Hemisphere.

Various phenological observations may be recorded; this is often called the study of different phenophases. In higher plants on land the phenophases most observed are the timing of first bud burst (also called leafing or bud break), first flowering (in general when the first flower opens or releases pollen), full flowering, fruit ripening, leaf coloring (particularly in the boreal and temperate zones) and, finally, leaf fall. In fungi there are only a few studies carried out and mainly on the timing of the first and last appearance of their fruiting bodies. In animals, both land based and aquatic, the timing of mating, spawning, migration (e.g. in birds, in mammals (caribou) and fish (salmon), both to warmer and colder regions), nesting and hibernation provide important phenological information. In insects the time intervals between various stages in the life cycle and their first and last appearance dates are especially important.

It is important that each of the studied phenophases is clearly defined. Only in this way can results from various studies be compared. Daily observations are recommended but are often difficult to carry out in practice because of the amount of work involved. If the gaps between observations are too long, their usefulness is greatly reduced. If that is the case, it might be better to compare growth measurements at a certain date, e.g. weights or shoot lengths, often called phenometric studies. These are also easily compared with climatic conditions over several years at a single place (site) or between places of measurement. Such studies, as well as observations of phenophases, should preferably be done each time on a specific individual, and on an individual of average age, which is not living under extreme conditions within the study area. Sometimes the mean date of a number of individuals within a site is used. It is, of course, important to explain all methods used and to clearly define all observations made.

The IPCC (2007) clearly stressed that phenology in plants and animals is the simplest process showing a response to the recent climate change. Various taxa and species within a taxon, however, may show quite different responses to such changes.

1.1 History

1.1.1 Phenology

Observations of phenology in plants were carried out very early in history; e.g. in China, such knowledge is known from the last 3000-5000 years. Farmers in many countries used phenology to assist the timing of their work in the field, and even in the Christian Bible there are references to phenological observations.

The term phenology was first used in the mid-1800s by the Belgian botanist Charles Morren, but a plant calendar network had already been established by Linnaeus in 1751. This network, however, was rather short-lived; but from Kyoto, Japan, observations on full flowering of cherries are known for 80% of the years from 1400 A.D. until today, for scattered years even back to 705 A.D. In Europe, long series of plant phenology records are found in Switzerland, on leaf bud burst of horse-chestnut trees from the early 1800s to the present day and on full flowering of cherries from the late 1800s onwards. From the United Kingdom, the Marsham family phenological records are well known and encompass more than two centuries (1736-1958) on over 20 species of plants and animals. While some years are missing in these observations, and climatological data were not collected close to the phenological site, this is still a unique data set for comparisons between phenological observations and climate change.

For many years, the interest in phenology has been greatest, based on the number of observations, in Central Europe and particularly in Germany. By 1884 Ihne was reporting over 900 plant phenological sites from Germany out of a total of more than 1900 sites across Europe (of which more than 300 were in the United Kingdom and half as many in the small country of Switzerland).

To detect trends, long term phenological time-series are recommended (minimum of about 30 years) to make sure that extreme weather events do not influence the trends unduly. However, trend conclusions are often drawn from phenological studies covering relatively few years. This may be necessary because of current problems in financing long time-series. These data are also needed as early warning systems on the probable future influences of continuous global warming, at least partly caused by human activity through increased emissions of greenhouse gases (see Wallington et al (2004)).

1.1.2 Climate

Although spring temperatures generally have been higher and spring phenophases earlier in Europe, North America and also Japan, particularly since the mid to late 1980s, historically the same may have happened shortly after the last Ice Age about 10000 years before present. Six thousand years ago summer temperatures were 2ºC to 4ºC higher in both Europe and North America than the 1961-1990 average. The summer insolation was stronger by 4% during the warm period from 5-6000 to 2000 years B.C., called the Postglacial Climatic Optimum (see upper diagram Figure. 1). In this period several tree species invaded new regions, e.g. was spruce already at that time found as far North as Hudson Bay in North America. In Europe oak, hazel and other heat demanding deciduous tree species moved into Scandinavia, and pine forests were common in parts of the mountains of southern Norway which are treeless today.

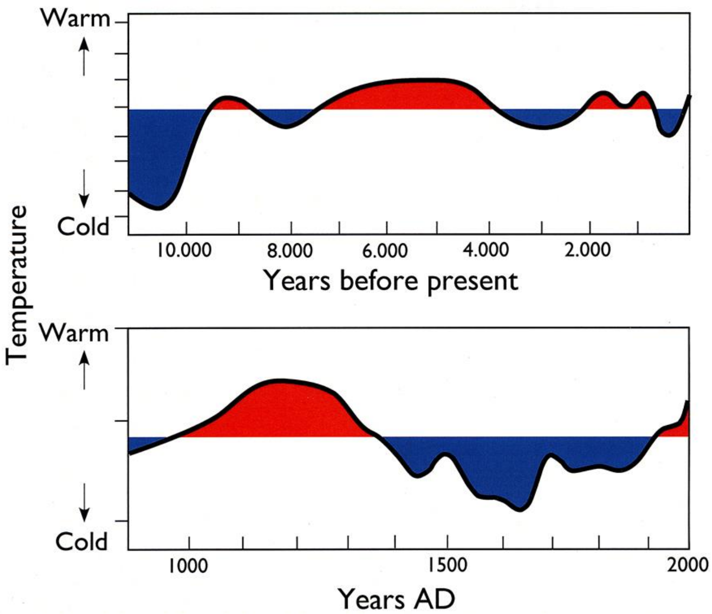
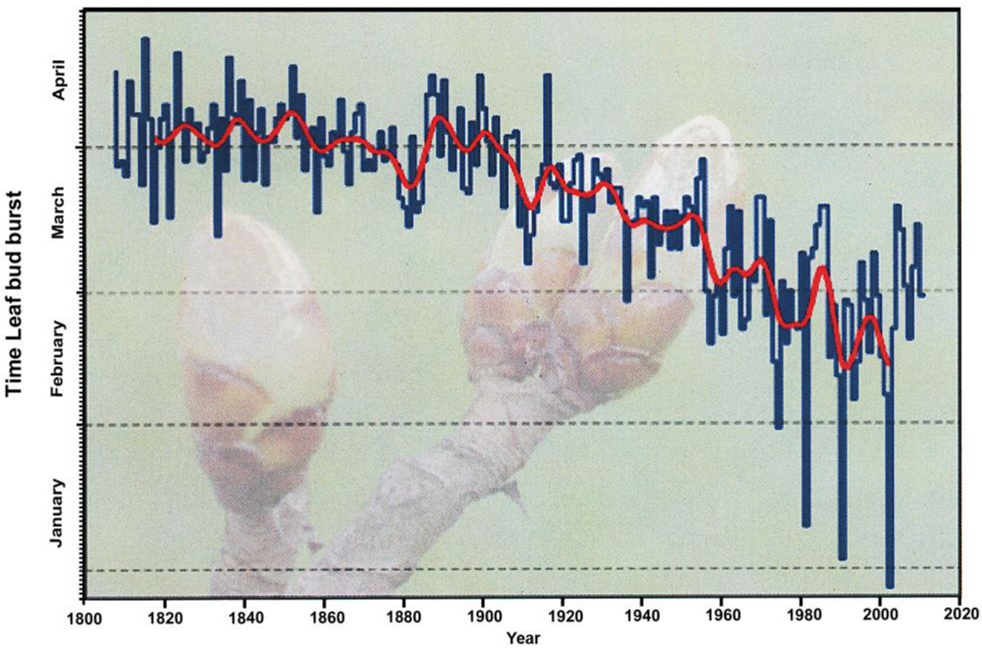


Figure 1.Global climate change since the last Ice Age (upper diagram) and in the last 1000 years (lower diagram). Please note the different scales. Based on Gates 1993.

Somewhat colder periods followed the end of the Postglacial Climatic Optimum, in periods also much drier, causing e.g. the lakes in northern Africa to drop from a high level about 6000 years ago towards the dry conditions today. In more recent periods, there were again relatively high temperatures in the Northern Hemisphere, e.g. in the Middle Ages from about 1000 A.D. to 1400 A.D., after which the so-called Little Ice Age started and lasted to about 1850 (see lower diagram Figure.1). During this cold period many forest species disappeared in northern areas, and in mountain districts, e.g. in southern Norway, the tree line was lowered by more than 200 m. From the end of the Little Ice Age (which is well into man's so-called second industrial revolution on increased trapping of manmade gases in the atmosphere, (see Wallington et al (2004)), increasing temperatures and earlier spring phenophases were generally detected in various parts of the World, particularly from near the end of the 20th century (see later in this chapter).

There may be several reasons for climate change and thus also for phenological changes. Historically, it is proposed that relatively abrupt temperature changes may have been caused by large volcanic eruptions, and also that sunspots, concentrations of magnetic fluxes at the solar surface, may be influential. In the Fourth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC 2007) it is stressed that a "likely substantial anthropogenic warming over the past 50 years averaged over each continent except Antarctica has had a discernable influence on many physical and biological systems", thus also on phenology (see the curves in Figure. 2 for observations of first leaf bud burst in horse-chestnut in the city of Geneva in the 200 years from 1800 and first flowering of cherries from 1894 in a Swiss rural district).



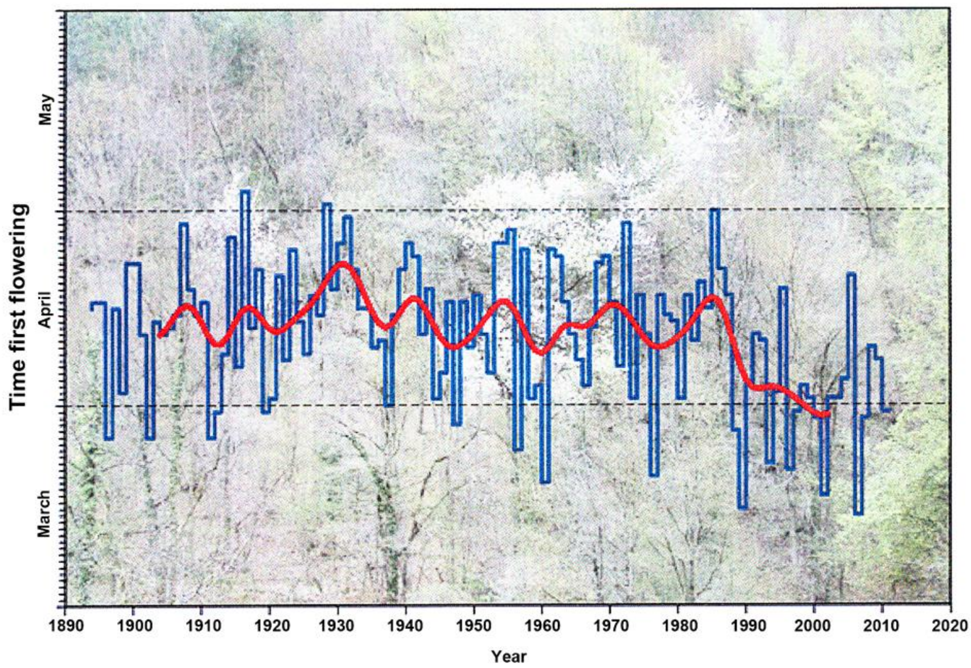


Figure 2. Earlier dates for leaf bud burst of horse-chestnut (*Aesculus hippocastanum*) in the Swiss city of Geneva since the beginning of the 1900s (top), probably mainly an anthropogenic temperature effect in a growing city, while the earlier dates for flowering of cherries (*Prunus avium*) in a Swiss rural district from the late 1980s (bottom) may be a result of global climate change. Based on MeteoSchweiz 2011 (http://*www.meteoschweiz.admin.ch/web/de/klima/klima_schweiz/phaenologie/ Phaenobeobachtungen_seit_1808.html)*

2. Climate Change in Recent Decades

2.1. Changes in Near Surface Climate

One of the outstanding features of climate is its high variability. The causes of this variability can be divided into internal and external forces. External climate variability is triggered by external "disturbances" like volcanism, plate tectonics, solar activity, variations in the earth-sun geometry or anthropogenic greenhouse gas emissions. Prominent examples of externally caused climate variability occurred in the ice ages and under current global warming.

Internal variability arises from interactions between the different climate sub-systems, for instance between the atmosphere and the hydrosphere in the El Nino/ Southern Oscillation phenomena. Here changes in the atmospheric pressure systems of South East Asia / South East Pacific and in the surface temperature regime of the tropical Pacific have not only influence on the regional but also on the global climate. Another example is the North Atlantic Oscillation (NAO) and the Northern Annular Mode (NAM). NAO/NAM exerts a dominant influence on winter surface temperatures across much of the Northern Hemisphere and on storminess and precipitation.

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Biographical Sketches

Frans Emil Wielgolaski was born in Norway in 1931. He received an M.Sc. in Horticulture from the Norwegian Agricultural University in 1957 and a degree in Botanical Ecology from the University of Oslo in 1964. After graduation he was a faculty member in the Botany Department, University of Bergen (curator Botanical Garden) and University of Oslo (assoc. prof. in ecology) until appointed professor in Botanical Ecology at the University of Tromsø in 1977, then from 1993 at the University of Oslo. He was plant research leader of a phenological project 1965-68 (> 60 sites) along a Norwegian western fjord (Sogn). Secretary General of the Norwegian International Biological Programme (IBP) 1968-75, administrative and scientific leader of IBP studies at the Norwegian mountain plateau Hardangervidda and member of IBP's International Steering Committee. He has written and edited several books, most recently in 2001, 2005 and 2008, and co-authored over 200 scientific publications, particularly on mountain ecology and plant phenology in relation to climate change, e.g. in collaborative EU projects.

Tim (Timothy) H. Sparks was born in the UK in 1959. He received an M.Sc in Applied Statistics in 1988, an M.Sc in Operational Research in 1993 and a Ph.D. in Environmental Sciences in 2001 (all from Sheffield Hallam University). After working in agricultural research he moved to ecological research at the Monks Wood Research Station in 1991 and stayed there until it was closed in 2009. He joined Coventry University in 2011 and is also a visiting professor at the Poznań University of Life Sciences and at the University of Liverpool, a visiting researcher in the Department of Zoology, University of Cambridge, and a Hans Fischer Senior Fellow, Technische Universität München. He has a wide range of interests associated with conservation, environmental change and the interpretation of data. He remains an advisor for the UK Phenology Network which he founded in 1998. He has co-authored > 300 publications, particularly in phenology and climate impacts.

Elisabeth J. Koch was born in Austria in 1952. She received a Ph.D. in meteorology from the University of Vienna in 1976. She has worked at the ZAMG (the national service for meteorology and geodynamics) in Vienna from 1976 and is now the head of the climatology section. Her interests in phenology include close contact with the national Austrian scheme, and internationally she has chaired many committees that have brought phenological scientists closer together. In 2006 she won the Austrian climate protection award sponsored by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management and the Austrian hail insurance company for her work in phenological research. At present (2010-2014) she is chairing an international project with the aim to deliver a pan European phenological research database (www.pep725.eu).She has co-authored > 150 publications, particularly in bio-climatology and phenology.

Marie Russell Keatley received her PhD in the flowering phenology of eucalypts from the University of Melbourne in 2000. She is a Senior Adjunct Fellow with the Dept. of Forest and Ecosystem Science, University of Melbourne, Creswick. She has co-authored over 50 scientific publications focusing on plant phenology and the application of statistical methods in phenology. In 2010, she co-edited and contributed to the book *Phenological Research: Methods for environmental and climate change analysis*. She was one of the proponents in the establishment of the National Ecological Meta Database (a web-based database for documenting existing long-term ecological datasets) which is hosted by the Australian Bureau of Meteorology. She is a founding partner of, and member of the Scientific Advisory Panel, for ClimateWatch – Australia's citizen science phenological observation network (www.climatewatch.org.au) and a member of the International Society of Biometeorology's Phenological Commission.