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# A concise review on multifaceted impacts of climate change on plant phenology

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**Abstract**
The recorded data on climate change over the past century indicate the increase in temperature. Important Biological events, including changes in plant/vegetation/crop phenology, have been investigated globally and found to be intimately as well as inextricably linked with climate change. Timing of life cycle events in relation to environment is phenology. Plants are finely tuned to the seasonality of their environment, and shifts in the phenology provide some of the most compelling evidence that species and ecosystems are being influenced by global climate change. Increase in temperature plays a vital role in germination, vegetative growth flowering and fruiting of plants. Climate change also perturbs the phenology of crop plants intimately linked with socioeconomic livelihood and should be given particular focus in future research. Concomitantly phenology may be linked with ecosystem as well as community dynamics. Future studies should aim to quantify and understand the effects of earlier leaf unfolding and later leaf fall on temperature, soil moisture, and atmospheric composition and dynamics. Moreover, long term data of climate change and its interrelationship is required to predict impact of climate change on phenology and vice versa. Also, modern tools like remote sensing may also play a crucial role in the present context.

**Keywords** climate change; community dynamics; flowering; livelihood; remote sensing.

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## 1 Introduction to Climate Change

Gobal climate change is in extricably linked with sustainable development (Rai and Rai, 2013a) Global climate change is of prime concern at global scale in present era of Anthropocene (Zhang and Liu, 2012). In the present era of science and technology, due to the rapid pace of industrialization and urbanization, quantity of natural resources as well as quality of global environment has been altered seriously (Rai, 2008a; Rai, 2008b; Rai, 2009; Rai and Tripathi, 2009; Zhang and Chen, 2011; Rai, 2012; Wu and Zhang, 2012; Rai and Rai, 2013a; Tuankrua et al., 2014). According to Environmental Protection Agency-USA, (USEPA), with increasing population, more and more countries are facing the problem of global environmental change originating from large expansion of industrial sector. Hand in hand, population growth will cause a rapid increase in number of industries preparing agro-chemical to sustain agriculture as well as will uplift the industrial demand for resources (Rai and Rai, 2013a; Rai and Rai, 2013b). Researchers believe that anthropogenic global warming has either already begun or will become manifest in the very near future, with average global temperatures predicted to rise by 1.5-4.5°C by the middle of next century (IPCC, 1990; IPCC, 2007; Rai and Rai, 2013b). Despite an incomplete understanding of the processes at work, there is considerable agreement that this warming will be the result of increased releases and atmospheric accumulation, since the industrial revolution, of carbon dioxide ($CO_2$), nitrous oxide ($N_20$), methane ($CH_4$) and chlorofluorocarbons (CFCs) the primary greenhouse gases (GHGs). Anticipation in some quarters of a host of negative consequences of such warming has led to ever louder calls to initiate strong policy actions to curtail GHG emissions (Rai and Rai, 2013b). Recent evidence and predictions indicate that climate changes are accelerating and will lead to wide-ranging shifts in climate variables. There will be changes in the mean and variance of rainfall and temperature, extreme weather events, food and agriculture production and prices, water availability and access, nutrition and health status (Rai and Rai, 2013b).

## 2 Phenology and Climate Change

Grinnell (1917) first elucidated the role of climatic thresholds in constraining the geographic boundaries of many species, followed by major works by MacArthur (1972). The temperature led to fever of earth by $0.6^0$ C during the two phases i.e. between 1910 and 1945 and 1976 onwards, the rate of second being just double of the first (Walther et al., 2002). Range-restricted species, particularly polar and mountain top species have been the first groups in which entire species have gone extinct due to recent climate change (Parmesan, 2006). Tropical coral reefs and amphibians have been most negatively affected (Parmesan, 2006).

Plant growth requires sufficient light, water, oxygen, mineral nutrients, and suitable temperature. These apparently simple demands actually involve a large number of environmental factors and physiological processes, such as meteorological factors (light, photoperiod, temperature, precipitation, humidity, wind, as well as gases), edaphic factors (topography, slope, exposure, and soil properties), as well as biotic factors (such as pests, diseases, and competition) (Menzel, 2002). Phenological onset of spring correlates very well with air temperature of the preceding months (Menzel, 2002). Phenology is perhaps the simplest way by which to track changes in the behaviour of species. Various indications of shifts in plant and animal phenology have already been reported for the boreal and temperate zones of the northern hemisphere (Menzel, 2002).

There is growing evidence that the global climate is changing (e.g., Easterling et al., 2000; Inouye et al., 2002), and a matching concern for the consequences this will have for natural ecosystems. Although evidence is accumulating for biological responses to the changing climate (Hughes, 2000; Inouye et al., 2002), the response of many species to variation in climate remains largely unpredictable. Inouye et al. (2002) observed multifaceted factors altering the timing of flowering in relation to climate change.

Timing of life cycle events in relation to environment is phenology and inextricably linked with the climate change. ‘Phenology is the study of the timing of recurrent biological events, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species’ (Lieth, 1974; Badeck et al., 2004). According to Spark “Phenology is a pastime with a considerable history. Once considered the harmless activity of a select few country gentlemen and clerics, it has now taken on a new importance since its value as (probably) the oldest written biological record has been recognised” (Menzel, 2002).Climate warming has advanced the biological spring and delayed the arrival of biological winter (Peñuelas et al., 2009). These changes in the annual cycle of plants and the lengthening of the green-cover season have many consequences for ecological processes, agriculture, forestry, human health, and the global economy (Peñuelas et al., 2009). A longer growing season as a result of climate change will in turn affect climate through biogeochemical and biophysical effects (Peñuelas et al., 2009).

Seasonal availability (phenology) of floral resources, and variation in their abundance, can be of great ecological significance (Inouye et al., 2002). Phenology is a dominant and often overlooked aspect of plant ecology, from the scale of individuals to whole ecosystems. The timing of the switch between vegetative and reproductive phases that occurs in concert with flowering is crucial to optimal seed set for individuals and populations (Bernier, 1988; Cleland et al., 2007).

Without long-term phenological data, it is very difficult to predict reliably the likely impacts of climate change on biodiversity (Khanduri et al., 2008). During the past 100 years of modern academic investigations on plant phenology (Clarke, 1893; Robertson, 1895; Lechowicz, 1984; Rathcke and Lacey, 1985; Borchert, 1992; Hanninen, 1995; Kikuzawa,1995; Lechowicz, 1985; Reich, 1995; Khanduri et al., 2008), two main lines of research have been developed: (i) environmental research addressed to the relationship of the timing of plant development stages to abiotic factors such as photoperiod (Hammer and Bonner, 1938; Panje and Srinivasan, 1959; Heide, 1992; White, 1995; Guo et al., 1998; Khanduri et al., 2008) and climatic constraints including temperature averages (Sorenson, 1941; Lindsey and Newman, 1956; Holway and Ward, 1965; Vasek and Sauer, 1971; Fitter et al., 1995; Khanduri et al., 2008), temperature accumulations (White, 1995; Jackson, 1966; Sparks and Carey, 1995; Khanduri et al., 2008), and moisture, and (ii) evolutionary research, addressed to the genetic basis and natural selection of plant phenology (Kochmer and Handel, 1986; Ollerton and Lack, 1992; Geber and Dawson, 1993; Khanduri et al., 2008).

Autumn events like leaf fall and colouring are delayed due to climate change and may find implications in species distribution as well as interactions, ecosystem productivity, community structure and conservation of biodiversity (Bertin, 2008).

Variation among species in their phenology is an important mechanism for maintaining species coexistence in diverse plant communities, by reducing competition for pollinators and other resources (Rathcke and Lacey, 1985; Cleland et al., 2007).

The timing of growth onset and senescence also determine growing season length, thus driving annual carbon uptake in terrestrial ecosystems (Gu, 2003; Cleland et al., 2007).

Plants are finely tuned to the seasonality of their environment, and shifts in the timing of plant activity (i.e. phenology) provide some of the most compelling evidence that species and ecosystems are being influenced by global environmental change (Cleland et al., 2007). Researches demonstrated shifting phenology at multiple scales, including earlier spring flowering in individual plants and an earlier spring green-up' of the land surface revealed in satellite images (Cleland et al., 2007).

Global climate change could significantly alter plant phenology because temperature influences the timing of development, both alone and through interactions with other cues, such as photoperiod (Bernier, 1988; Partanen et al., 1998; Cleland et al., 2007)

The phenology of a species is typically evolved through natural selection to match the environmental conditions to maximize its fitness (Stenseth and Mysterud, 2002).

In tropical ecosystems, phenology might be less sensitive to temperature and photoperiod, and more tuned to seasonal shifts in precipitation (Reich, 1995; Morellato, 2003; Sanchez–Azofeifa et al., 2003; Cleland et al., 2007).

Crop production is particularly sensitive to climate change (Craufurd and Wheeler, 2009). Temperature is a major determinant of the rate of plant development and, under climate change; warmer temperatures that shorten development stages of determinate crops will most probably reduce the yield of a given variety. Earlier crop flowering and maturity have been observed and documented in recent decades, and these are often associated with warmer (spring) temperatures (Craufurd and Wheeler, 2009). For example, the yield of wheat declined by 5–8% (Wheeler et al., 1996; Craufurd and Wheeler, 2009) or 10% (Mitchell et al., 1993) per $1^0$C rise in mean seasonal temperature. The timing of anthesis and grain maturity was earlier at warmer temperatures in both studies, thus shortening the duration of growth and reducing grain yield (Craufurd and Wheeler, 2009). Earlier flowering and maturity have been observed and documented in crop plants (Williams et al., 2004; Hu et al., 2005; Menzel et al., 2006; Tao et al., 2006; Estrella et al., 2007), as well as in natural communities (Fitter and Fitter, 2002), over the last 50 years from phenology networks and individual records. Menzel et al., (2006), for example, report that 78% of all observations in 21 European countries showed earlier flowering, with an advance in phonological events of 2.5 d per decade on average (Craufurd and Wheeler, 2009).

Climate change also affects trophic interaction at various levels in an intricate complex manner. In many cases higher temperatures have been shown to speed up plant development and lead to earlier switching to the next ontogenetic stage (Menzel and Fabian, 1999; Badeck et al., 2004). Menzel and Dose (2005) show that timing of cherry blossom in Japan was highly variable among years, but no clear trends were discerned from1400 to 1900. A statistically significant change point is first seen in the early 1900s,withsteady advancements since 1952.Based on its well-known variation with the annual course of weather elements, plant phenology might be expected to be one of the most responsive and easily observable traits in nature that change in response to climate (Badeck et al., 2004).suggest that this ontogeny–phenology landscape provides a flexible method to document changes in the relative phenologies of interacting species, examine the causes of these phenological shifts, and estimate their consequences for interacting species (Yang and Rudolf, 2010). But the plethora of records also stems from the strong sociological significance of the change of the seasons, particularly in high-latitude countries affected (Parmesan, 2006).

Community and ecosystems respond in an intricate complex way towards the change in climate (Walther, 2010). Even in cases where climate is considered the dominant trigger that drives the phenology of species, different species may respond to different climatic parameters (e.g. Visser and Holleman, 2001; Walther, 2010).

Numerous ecological studies have now pointed to an important general pattern of species responses to climate change around the world: on average, seasonal life-history events such as leaf unfolding, flowering, insect emergence, or the arrival of migratory birds are occurring earlier than they have in the historical past (Dunn and Winkler, 1999; Walther et al., 2002; Parmesan and Yohe, 2003; Gordo and Sanz, 2005; Yang and Rudolf, 2010). Despite this prevailing trend, however, it has also become evident that species within the same community often show variable phonological responses to climate change (Visser and Both, 2005; Miller-Rushing and Primack, 2008; Both et al., 2009; Yang and Rudolf, 2010).

For example, an unusually warm spring in northern Japan lead to substantial phenological advances in the flowering of several spring-ephemeral plants relative to their pollinating bees, resulting in dramatically decreased seed production of bee pollinated species (Kudo et al., 2004; Yang and Rudolf, 2010).

It has been shown that phenology plays a crucial role in the carbon balance of terrestrial ecosystems (Keeling et al., 1996; Badeck et al., 2004); in determining shifts in agricultural zoning (Fischer et al., 2002; Badeck et al., 2004); in vegetation feedback onto the atmospheric boundary layer (Schwartz and Crawford, 2001);in plant competition (Rathcke and Lacey, 1985); in pest and disease control (Penfound et al., 1945; Badeck et al., 2004); and in pollen flight forecasts (Traidl-Hoffmann et al., 2003; Badeck et al., 2004).

Environmental factors other than temperature also modify plant phenology. The second most important trigger of spring phenological phases is photoperiod length. This has been shown in experimental studies (Saxe et al., 2001; Badeck et al., 2004). The weight of this factor is species-specific. This has also been concluded from fits of phenological models to large data sets of phonological observations (Schaber and Badeck, 2003; Badeck et al., 2004).

The phenology of flowering by herbaceous wildflowers in mountain regions where there is significant snowfall is primarily a consequence of one environmental event, the disappearance of the snowpack (Inouye and Wielgolaski, 2003; Inouye, 2008). Global influences include ongoing changes in temperature and precipitation regimes, with high-altitude environments warming and receiving more precipitation as rain instead of snow (Beniston and Fox, 1996; Johnson, 1998; Inouye, 2008). Regional influences on snowpack in the western United States include the El Nino/Southern Oscillation (ENSO; Diaz et al., 2003; Inouye, 2008) and the North Pacific Oscillation (Pacific Decadal Oscillation; Grissino-Mayer et al., 2004; Inouye, 2008). Fig. 1 shows the intimate relationship between climate change and phenology.

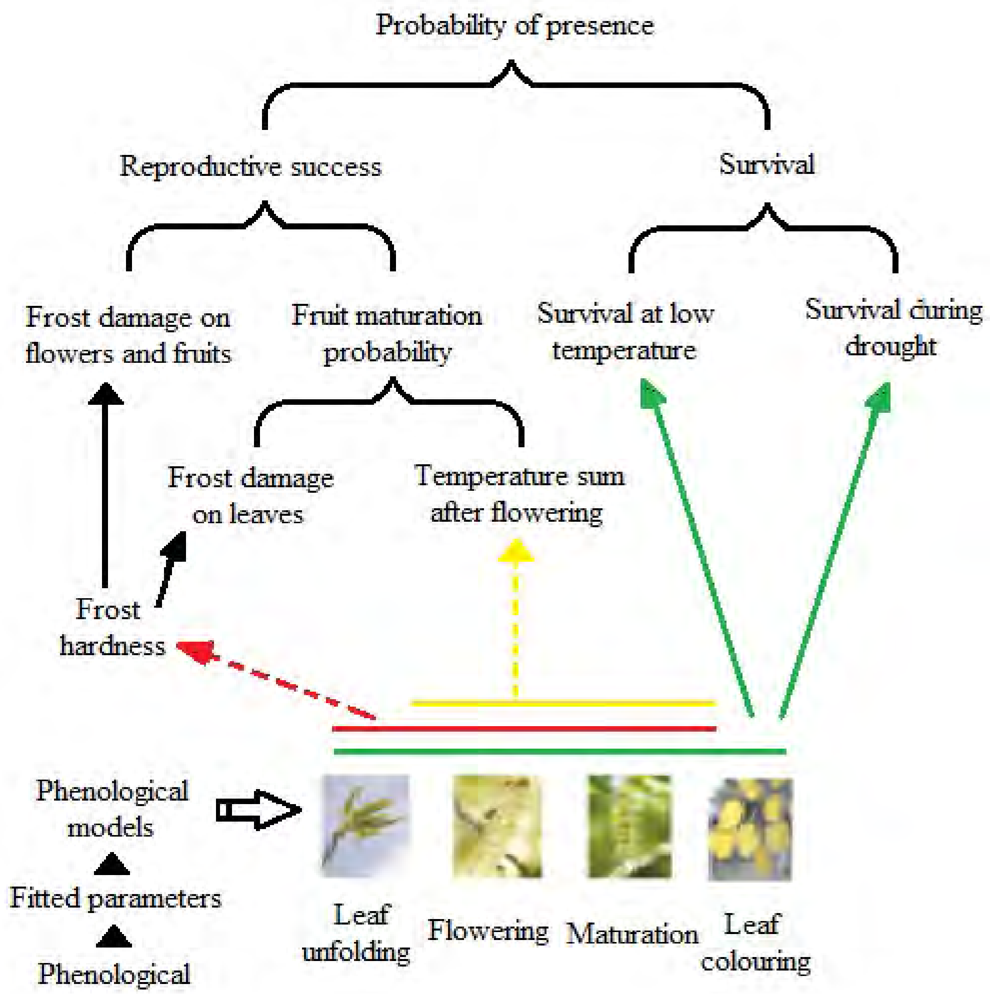


**Fig. 1** Intimate relationship between phenology and climate change (Redrawn after Cleland, 2002).

## 3 Knowledge Gaps, Future Perspective and Concluding Remarks

Efforts to scale from site-specific, species-level observations to predict regional phenological patterns are at the forefront of current phenological research. The POSITIVE project (Phenological Observations and Satellite Data: Trends in the Vegetation Cycle in Europe) used phonological models to make regional predictions of spring leaf-out based on ground-level observations of birch leaf unfolding, and compared these projections to satellite observations of spring green-up (Cleland et al., 2007).Future studies should aim to quantify and understand the effects of earlier leaf unfolding and later leaf fall on temperature, soil moisture, and atmospheric composition and dynamics; this information will help to improve the representation of phonological changes in climate models and thus increase the accuracy of forecasts (Peñuelas et al., 2009). On the other hand, all shifts in phenological phases due to climate and/or global change have global and particularly regional impacts on the climate system itself via feedback mechanisms of surface albedo, $CO_2$ fluxes and evaporation. Thus, there are several applications where phenological observations and analyses of their records are most valuable for the Global Change Community (Menzel, 2002).

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