



Phenological shifts due to climate change and the associated conservation threats

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General Note



Article is recommended to print as color version in recycled paper. *Save Trees, Save Climate.*

ABSTRACT

Phenology a routine agricultural practice of past centuries has emerged fast as a very important discipline in global climate change research. Phenology can be a helping hand to various adaptation and mitigation efforts to counter or at least slow down the magnitude and range of conservation threats posed by global climate change. There are two ways by which plants respond to rising temperatures which depend upon the time at which warming occurs. Warming during chilling phase leads to delayed spring phenophases, as it takes longer to achieve the required chilling to complete endo-dormancy, while warming during forcing period causes earlier arrival of spring phenophases. Among animals birds have been studied extensively as far as the effects of warming on

phenophases is concerned. Majority of the studies have found early arrival of migratory birds and early start of breeding times. Extremely heterogeneous results have been found from different studies. Meta-analyses have helped overcome this problem and provided vital breakthroughs in understanding the effects of climate change on phenology of the organisms by combining and analyzing results from numerous studies across diverse taxa and different regions. The shifts have posed alarming extinction risks to different taxa throughout the globe with maximum damage expected to occur at higher latitudes and in regions with high number of endemic species mainly due to disruption of interactions between organisms. Thus there is an urgent need to constantly monitor the changing phenologies of organisms with special focus to be given on keystone species from higher latitudes and altitudes so that appropriate conservation efforts are taken in time.

Keywords: Climate change, phenology, meta-analysis, extinction, phenophase

1. INTRODUCTION

The hot debate whether climate change is a myth or a reality seems to be finally over courtesy the compelling evidences from diverse disciplines like ecology, phenology climatology and others which clearly show that climate change is occurring and already the effects can be felt on many forms of life as well as on factors like mean global air temperatures, and altered precipitation regimes. In its fifth assessment report the intergovernmental panel on climate change (IPCC) reported increase in mean global air temperatures by 0.85 degree Celsius over the period 1880 to 2012. According to the report the global mean sea level rose by 0.19 meters from 1901 to 2010 and the concentrations of green house gases carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) have increased by 40%, 150%, and 20%, respectively as compared to pre-industrial concentrations (IPCC 2013). Already a number of studies have highlighted the responses of species across diverse ecosystems and taxonomic groups to the changing climate (Fitter and Fitter 2002, Root *et al.*, 2003; Menzel *et al.*, 2006). Generally, there are three ways by which species have been found to respond to the rising temperatures. These include, changes in physiology, changes in timing of life cycle events or phenophases and changes in distribution and range shifts altitudinally as well as latitudinally (Walther *et al.*, 2002; Root *et al.*, 2003; Parmesan 2007). It appears that all the three effects would bring a state of imbalance at the ecosystem level in general and species level in particular. The first one could lead to altered metabolic functions and these would lead to reduced fitness in many species if not in all. Extinction risks from range shifts have been well documented in literature and the key factor involved here is the dispersal mechanisms of organisms under the pressure of rising temperatures that demands organisms to have strong dispersal capabilities to move to higher latitudes and sometimes higher altitudes to counterbalance the effects of warming. Indeed there is every chance that limits may be reached sooner or later in terms of dispersal abilities of organisms as well as in terms of availability of resources and space provided by the habitats. The net result would be that the new habitats would provide different interactions not always favorable to the organism (Walther *et al.*, 2002). Many studies have shown a strong correlation between rising temperatures and phenological shifts across taxonomic groups that include insects, plants, birds and grasses. It is now a well established fact that global warming has resulted in altered phenophases in these organisms. What remains unclear is that how the shifting of phases could impact the fitness of organisms. This review discusses the responses shown by plants and birds to rising temperatures across various regions as most of the studies have focused on these two groups. At last the possible extinction threats to the species and communities are also discussed. To start with, a brief history of development of phenology as an important discipline in climate change research is presented.

2. DEVELOPMENT OF PHENOLOGY AS A CLIMATE CHANGE SCIENCE

Phenology is the study of life cycle events like flowering, leafing and fruit set in plants and ones like hatching, migration and breeding in animals. Phenology is a very old discipline as records of phenological observations made hundreds of years ago are available. Some of these data sets have been used by researchers to study climatic conditions prevailing in the past. Sparks and Carey (1995) used phenological records of two centuries recorded by Marsham family to study effects of global warming on species while Chuine *et al.*, (2004) used grape harvest dates to reconstruct fluctuations in temperature since 1370 C.E. The agricultural and religious practices were the driving forces behind these recordings. During 16th, 17th and 18th centuries phenological calendars were made. However it was only during the 20th century that phenological studies gained much attention and phenology developed as a proper field of science. As a result, many phenological networks were set up that used volunteers as well as scientists to record phenology (Puppi 2007). The true value of phenology was realized in the later part of the 20th century when it began to be

recognized as an economical and effective tool in global climate change research. The phenological studies which earlier focused mainly on crop plants as a routine agricultural practice, has in recent times evolved as a vital discipline in climate change research.

3. DIFFERENT FACTORS DETERMINE PHENOLOGY

The first thing to ascertain in order to designate phenology as a climate change science is whether it is really dependent on climatic factors, and if it were, then to what degree these factors affect the phenophases. Literature is filled with studies that provide conclusive evidences regarding the relationship of temperature with plant phenophases as will be discussed in detail later in the paper. However, temperature is not the only factor that controls plant phenology. There are various other factors involved too. Photoperiod, solar radiation and rainfall have been found to be very important determinants of plant phenology (Friedel *et al.*, 1993; Ruml and Vulic 2001; Kflay Gebrehiwot, 2017). Soil temperature is another vital parameter that determines plant phenology but to lesser extent than air temperature (Wielgolaski 2001). Similarly water content, nutrient supply and soil type have been found to shape phenophases (Wielgolaski 1999; Poonam Kumari & Arvind Kumar Nema, 2018). Thus it is apparent that plant phenology is not the function of temperature alone but a range of other factors are also involved. However phenological responses to temperature are better understood than responses to precipitation and other factors (Root *et al.*, 2003) and the role of temperature in occurrence of early spring phenophases in plants has been found to be more significant than that of the photoperiod (Laube *et al.*, 2014).

In birds breeding time and migration are two life cycle phases that have been studied extensively in relation to climate change. Climate has an impact on bird mobility through its influence on food availability. Availability of both plant food as well as animal food (through the effect of climate on behaviour and survival of animal prey) is largely determined by climatic conditions (Elkins 1983; Visser *et al.*, 1998). Food type, feeding method and the ability to move away from adverse environmental conditions determine the magnitude to which a particular bird species is affected by climate (MacMynowski & Root 2007). Breeding in little penguins (*Eudyptula minor*) has been found to be linked to temperature of sea surface (Chambers 2004). Similarly reduced rainfall and mild warming due to climate change has been found to result in earlier egg laying in helmeted honeyeater (*Lichenostomus melanops cassidix*) (Chambers *et al.*, 2008a)

4. SPRING EVENTS ARE OCCURRING EARLIER IN PLANTS

Most studies that have evaluated plant responses to global warming have shown progressive advances in spring phenology of the plants. Analysis of phenological data of IPGs (International Phenological Gardens) from 1969-1998 showed earlier onset of growing seasons by 8 days correlating well with warming during early spring throughout the European continent (Chmielewski and Rötzer 2001). Chmielewski *et al.*, (2011) applied five phenological models to apple in order to calculate the beginning of blossom, all the models showed earlier blooming. Analysis of the datasets from 1965 to 2001 from 72 locations in North Eastern USA for lilac plants, grapes and apples showed advances in spring phenophases ranging from 2 to 8 days due to climate warming (Wolfe *et al.*, 2005). In a similar study from the Southern Hemisphere, advance of full bloom events in apple and pear in South Western Cape, by a margin of 1.6 days per decade with an increase in temperature being +0.45 degrees Celsius per decade was recorded (Grab and Craparo 2011). In Chestnut advances in first flowering dates by 1.6 days per decade for the period from 1963 to 2008 was reported (Guo *et al.*, 2013). Romanovskaja and Bakšienė (2009) summarized the effects of climate change on apple in Lithuania from 1961 to 2006 and found earlier flowering by 4-5 days than the long term average during the last decade. Thus it can be seen that plants belonging to different taxonomic groups and found across diverse regions have responded to warming temperatures by advancing their spring phenologies.

5. SOME STUDIES HAVE FOUND DELAYED SPRING EVENTS IN PLANTS

Although there is no doubt that majority of studies have recorded earlier onset of spring events, however there are some studies which have found the delayed onset of spring events. Yu *et al.*, (2010) studied spring phenology of meadow Steppe vegetations in Tibetean plaeteau and found delayed greening of grassland although initial years of the study reported earlier onset of spring. An analysis of plant phenological datasets showed a trend towards later blooming in certain species (Cook *et al.*, 2012). Pistachio (*Pistacia Vera* L.) also showed delayed flowering in Tunisia (Elloumi *et al.*, 2013) while as leaf unrolling in mountain birch showed delay in Russia (Kozlov and Berlina 2002). A study on apple (*Malus domestica*) showed later bud release which could lead to a trend towards delayed blooming in Mediterranean regions (Legave *et al.*, 2013).

The above reports indicate that response of plants to warming generally depend upon the individual species to express early or delayed spring phenophases. In addition, there have been cases where same species has shown earlier onset during one time period but delayed onset during the other. For example, in chestnut, advances in first flowering dates by 1.6 days per decade for the

period from 1963 to 2008 were reported (Guo *et al.*, 2013). However the study also found that high temperatures during chill accumulation phase delayed first flowering dates. Similarly Yu *et al.*, (2010) studied spring phenology of meadow Steppe vegetations in Tibatean plaeteau from 1982 to 2006 and found advanced spring phenological events for initial years but found delayed responses from mid 1990s in spite of continued warming. These findings seem to be puzzling although satisfying explanations have been put forward in this regard. However, the fact remains that the cases of later onset of spring phenophases have been found to be less pronounced and generally show heterogenous patterns (Walther *et al.*, 2002). The onset of the spring phenophases generally is dependent upon two processes both of which depend upon temperature. One is the accumulation of chilling for attaining a state of endo-dormancy and the other one being the attainment of appropriate amount of heat needed to convert buds into flowers and leaves. If temperature increases during chill accumulation phase then delayed flowering and leafing would occur due to late fulfillment of chilling for endo-dormancy while as increase in temperature during second phase (also called forcing phase) would result in earlier occurrence of spring events (Guo *et al.*, 2013, Laube *et al.*, 2014).

6. SHIFTS IN BIRD MIGRATIONS AND BREEDING

Extensive research studies on animal phenophases like migration and breeding have been carried out vis-a-vis changes in temperature and other climatic factors. Majority of these studies have been carried out on the start of breeding time and spring arrival in migratory birds. Most of these studies show earlier occurrence of these events while some show delayed response to climate change. Crick *et al.*, (1997) examined the breeding time of 65 bird species in United Kingdom from 1971 to 1995 and found that 78% of the species started breeding earlier and on an average, breeding started 9 days earlier within individual species. Breeding in Great Tits was found to occur up to 10 days earlier than in 1970 in the United Kingdom and Germany (Winkel & Hudde 1997; McCleery & Perrins 1998). Mexican Jays (*Aphelocoma ultramarina*) in Arizona started nesting 10 days earlier between 1971 and 1997 (Brown *et al.*, 1999). Earlier breeding by 5-9 days between 1959 and 1991 was also recorded in tree swallows (*Tachycineta bicolor*) (Dunn & Winkler 1999). Since 1903, 39 bird species arrived significantly earlier in New York (Oglesby & Smith 1995). In Wisconsin, Bradley *et al.*, (1999) found earlier arrival of 8 bird species over past 61 years. Fall migration in European passerines has been occurring later in the season (Gatter 1992; Bezzel & Jetz 1995) which may be attributed to longer growing season (caused by climate change) providing resources for longer duration than before. Recently a study on 413 bird species distributed across five continents found advanced spring migration by 2.1 days per decade and 1.2 days per °C. The study reported more advances of migration time in case of short-distance migrants as compared to long-distance migrants (Usui *et al.*, 2017). In Australia changes in avian arrival timings have been reported with mostly earlier spring arrival being the general trend (Beaumont *et al.*, 2006; Chambers 2008b). Thus birds have been found to alter the timing of their arrival in spring and have found to have changed breeding time. These shifts will have drastic effects on the composition of ecosystems as will be discussed later.

7. RESULTS FROM META-ANALYSES

The problem with studies that include one or a few species is that it can be argued that the observed effects are specific to those species. Similarly for studies carried out in particular regions the results are valid only for those locations. Meta-analysis is a research tool that overcomes such limitations by combining results from numerous studies carried out in different geographical locations, representing taxonomically different species and studies for which data has been collected for diverse time periods. Many such studies have been carried out to unveil some remarkable patterns relating to species responses to climate change. A meta-analysis on 542 plant and 19 animal species covering 21 European countries showed an advance of spring by an average of 2.5 days per decade for the period from 1971-2000 (Menzel *et al.*, 2006). Parmesan and Yohe (2003) carried out a detailed assessment on the studies regarding phenological shifts. They included studies spanning from 16 to 132 years covering 677 species and found that 62% species showed advanced spring phases, 9% showed delayed spring phases while 27 % showed no shifts in phenology. The phases they considered included frog breeding, bird nesting, first flowering, tree bud-bursts, arrival of migrant birds and butterflies. In a meta-analysis of a wide range of species including animals and plants, the mean response across all species responding to climate change was a shift in phenological events of 5.1 days earlier per decade over the last 50 years (Root *et al.*, 2003). In china, which represents substantial part of the northern hemisphere biodiversity, a study of 112 species belonging to diverse taxonomic groups like trees, shrubs, herbs, birds, amphibians and insects showed a mean advance of 2.75 days per decade across all the taxonomic groups. Interestingly herbs and amphibians showed profound advancements than others (Ge *et al.*, 2015). One of the largest meta-analysis on phenological implications of climate change in the southern hemisphere found advance of spring events particularly in Australia and New Zealand. The study however did not report any substantial trends in terms of taxonomic groups and regions (Chambers *et al.*, 2013). These studies highlight the fact that springs events are occurring earlier in most of the cases but

we should not overlook the fact that delayed spring events are also occurring in parallel. We suggest more and more of such studies to be carried out to improve our understanding of trends in phenological responses shown by organisms to climate change.

8. CONSERVATION THREATS DUE TO THE PHENOLOGICAL SHIFTS CAUSED BY GLOBAL WARMING

Although shifting the timing of life cycle events helps species to keep synchrony with abiotic factors which are periodically recycled through ecosystems but that may pose devastating conservation threats. Serious effects on biodiversity can result from altered phenologies due to enhanced asynchrony in ecological interactions like plant-insect and predator-prey interactions leading to reduced fitness and ultimately extinctions (Parmesan 2007). For example, the disrupted synchrony between winter moth (*Operophtera brumata*) hatching and oak bud burst has led to a mismatch between peak in food availability and peak food demands of Great Tit (*Parus major*) nestlings, leading to serious population declines (Visser and Holleman 2001, Visser *et al.*, 1998). Similarly in a study of 1420 pollinator and 429 plant species, phenological shifts resulted in reduced resources for pollinators accompanied by reduced overlap between plants and pollinators ultimately leading to extinction of both plants and their pollinators (Memmott *et al.*, 2007). In Illinois USA, the study of effects of climate change on plant-pollinator interactions over a period of 120 years has shown lack of interactions between plants and pollinators accompanied by 50 percent extinction of bee species attributed to shifted phenologies (Burkle *et al.*, 2013). Situations where pollinators are cued by temperature and plants by photoperiod would result in asynchrony in mutualistic interactions of plants and their pollinators (Cleland *et al.* 2007). Disruption of interactions may affect species directly as well as indirectly and more serious effects are expected in case of species with greater roles in a community. Imagine a community in which phenological shifts due to climate change create a mismatch between occurrence of plant flowering phenophase and pollinator (bird and/or insect) arrival or emergence in a form suitable for pollination. The result would be lack of pollination for plant and reduced food availability for pollinator, and consequently reduced fitness for both. The case would get worse if either or both are highly specific for each other. The risk would be amplified if either of the two would be a keystone species. The matter would get even worse if such a situation arises in a biodiversity hotspot. Thus hotspots belonging to geographical regions that are most vulnerable to climate change like mid and high latitudes should be constantly monitored for shifting phenologies (Gupta, 2015).

Migrating birds normally find enough food and resources in the places they visit. Their untimely arrival, however, may result in population decline due to lack of availability of sufficient food as has been reported in case of the Flycatcher, *Ficedula hypoleuca*, which has led to significant declines in its population (Both & Visser 2001). Although earlier arrival at breeding grounds may be beneficial as it facilitates multiple clutches and more reproductive output but there are always chances of declines in food availability for nestlings arising out of mismatches in food availability timings (Perrins 1970; Visser *et al.*, 1998; Both & Visser 2001). 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 & Lacey 1985). Among plants, any climatic change that would result in different species to flower synchronously may lead to competition and if pollinators favor one over the other (e.g. due to more nutritious nectar), then one species can be drawn away with the other dominating leading to local extinction. Delays in spring arrival by migratory birds may lead to increased competition for nest sites.

Biological invasion is considered as a serious threat to biodiversity. Climate change has been found to amplify the effect of invasive species by favoring their extensive growth. Most of the invasive species require low chilling to complete endo-dormancy. Warming during winters may reduce fitness of high chill requiring native species due to incomplete fulfillment of chilling requirements. This results in delayed flowering and leaf emergence and if late spring frosts occur then low chill requiring invasive species will have tremendous advantages to exclude native ones (Laube *et al.*, 2014).

9. CONCLUDING REMARKS

The present review article gives an overview about the responses shown by organisms towards global warming besides highlighting the extinction risks associated with these shifts. In past several years a lot of research work has been carried out in different countries regarding impacts of climate change on spring phenologies of plants and birds. Phenological responses to climate change have been found to be quite heterogeneous but meta-analyses have proved very fruitful in our understanding regarding this. Generally spring phenophases have been found to occur earlier in most of the studies besides some studies showing later onset of these phases. The phenological shifts would lead to disruption of ecological interactions among organisms leading to extinction of one or both interacting species and other species that depend upon these interacting species. Since mid and higher latitudes are believed to be affected the most by climate change, phenological studies should be carried out in these regions especially in biodiversity hotspots of these areas to assess conservation threats and take conservation measures well in time.

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