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Review Article

Linking Climate Change with Global Phenology

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Abstract

At present, phenological studies achieved a prominent position in monitoring and predicting the timing of recurrent life cycle events. Phenology also provide a better understanding to manage and conserve environment. This article provides a useful information how pheonology, a multidisciplinary science plays an important role in conservational biology. We tried to explain changes in plant phenology caused by rising temperature, their impacts on species diversity and plant–animal interactions, and how conservation efforts could be improving in relation to plant resource organization. We listed the effects of phonological shifts and examine how phenological research can contribute to estimate and manage the land-use change and other natural and anthropogenic disturbances, such as fire, exotic and invasive species. Various instruments used for monitoring phenological activities at species-rich area are also discussed here.

Keywords: Phenology; Conservation; Pollinator; Frugivorous; Land-Use Pattern

Introduction

Phenology explores how the plants and animals will respond according to seasonal changes. In varying environmental conditions, the effect of rising temperature on plant phenophase [1] and animal [2] is extensively studied to know the variation in ecosystem dynamics resulting from a mismatch in the timing of interdependent phenophases [3]. Climate also affects the timing of flower colour and carbon flux of atmosphere [4]. Phenology is the best indicator of climate change as it is direct link between temperature and plant and animal development. The average global temperature has risen by 0.85°C which is also be proven by several number of phenological studies. This average global temperature is predicted to continue to rise and is predicted to continue to rise [5].

The phenology of many organisms is also affected by anthropogenic effects. Several studies showed [6] that the rising temperature change the species phenology earlier by several days to weeks. These studies are supported by experimental studies which link rising temperature to phenological shifts [7]. However, despite of rising temperature, plant phenology is also affected by day length, rainfall, nutrient availability and timing of snow melt [8] which are influenced by human activity. Abiotic ecosystem processes viz., soil moisture and nutrient pool influenced by plant species diversity [9]. These experiments were conducted on a smaller scale so the magnitude of nitrogen deposition and changing precipitation patterns was untested. Nitrogen deposition and changed precipitation regimes have also changed flowering time [10]. Rather than temperature, disturbances in species composition, abundance, or diversity also affect phenology which are influenced by human activities [11]. The role of biotic interactions on leafing, flowering and other phenological events is critical to understand.

Long-term phenological records of Northern Hemisphere shows a close relationship between rising temperature and earlier onset of leafing and flowering [1,12]. The conservation and management of natural systems can be improve with greater knowledge of the causes regulating and controlling plant cycles and differences across species, populations and communities [13]. Various vegetation monitoring techniques viz., digital photographs, satellite-derived phenology [4,14,15] can be applied worldwide to know the temporal shifts in vegetation.

Phenology helps in biotic conservation

Relation between leafing and herbivory

Study of leafing phenology, directly linked to ecosystem processes is very useful for conservation [13], understanding plant-water relations, primary productivity in terrestrial ecosystems, as well as gas exchange rates, biogeochemical cycling, dynamics of carbon sequestration [13] and defining the length of growing seasons and seasonal patterns of photosynthesis at local to global scales [15]. So leaf phenology provides key information for ecosystem process models that forecast responses to land-use change, atmospheric chemistry, and climate [15]. Any shifts on onset and end of growing season due to climate change may have consequences on net primary production. Premature leaf senescence in deciduous forests may induced by increased temperature and frequent drought, affecting the efficiency of nutrient resorption and length of growing seasons and impacts carbon uptake and ecosystem nutrient cycling [16], and therefore management practices [17]. Climate change, land-use change or use of insecticides shifts herbivorous insect phenology which in turn threaten plant population viability leading to increases in herbivore damage [18]. To avoid damage from insects, plants adopt many phenological strategies such as producing large, synchronous pulses of leaves to satiate herbivores and the timing of leafing peaks to the season with the lowest insect densities [19].

In agriculture, mismatch timing between highest insect density and their natural enemies due to climate change also decrease the effectiveness of biocontrol measures [20]. So it is necessary to have a detailed knowledge of phenological dynamics of folivorous animals and their host/target plants to conserve and manage of both herbivores and plant populations, and when designing pest control programmes in natural and agricultural ecosystems [15].

Relation between flowering and pollinator

In tropics, delimited flowering seasonality during springtime, typical of temperate and boreal ecosystems is generally absent. In tropics, animal-pollinated species has been estimated at 94% [21] where flowers with their aromatic compounds attracts females provides food for pollination services enabled strong and diverse adaptations in flower visitors, maintaining rich assemblages of highly specialized floral foragers, such as bees and humming birds.

Relation between fruiting and frugivorous

Frugivorous animals, affects seed dispersal and germination effectiveness [22] critically rely on fruits for their diet, population size, social behaviour, reproduction, and movements - depend on fruit abundance and seasonality [23]. Neotropical plant species contains high percentage of fruits which dispersed by frugivoures animals [24] whose population controlled by low fruit production or changes in fruit supply over time according to their nutritional content, morphology and colour [25], with consequences for their conservation and management [26]. Lower fruit availability effects vertebrate frugivores. Hunting for valuable animals also effects dispersal mechanism which in turn also affect seedling establishment [27]. This is especially serious for large-seeded plant species who are depended on these animals for their seed dispersal [28] e.g. defaunation of large-gaped frugivorous birds has been singled out as the main cause of rapid evolutionary change in palm seed size [27]. To conserve tropical communities, it is necessary to understand interconnection between accessibility of resources for primary consumers and seasonal variations in climate [29].

Shifts in phenological activity and species interaction

Effects of temperature on plant phenology is not same for all species. It changes the duration of reproductive phase and timing of phenological activity at community level [28,30]. Any fluctuation in phenological activity in some plant species can also affect other plants through competition and/or facilitation for pollinators and seed dispersers [31]. Some studies show that phenology plays a crucial role in the stability and diversity of mutualistic communities [32] which is important for the conservation and management of plant–pollination interactions and mutualistic networks [33]. In this context, one potential threat from climate change is the temporal uncoupling of mutualistic species interactions [30,33]. Fluctuations in global temperature cause early/delay in flowering and fruiting time which in turn effects the primary consumer and seed dispersers results low recruitment and resource scarcity [33]. Ultimately, both the ability of animal partners to forage on changing host plants as well as the maintenance of viable services for host plants from these mutualistic partners will influence the severity of potential effects of phenological mismatches and the conservation of mutualistic networks [33].

Changes in phenology, climatic conditions and land-use pattern

Divisions and edge effects

Land-use changes result in habitat loss, causes declines in plant and animal diversity [34]. This activity produces variations in light, temperature and humidity conditions of that habitat. These variations effects phenological activity, plant-animal interactions and ecological services [35]. An increase in flowering and fruiting activity in natural habitats with increased sunlight, is reported in several studies [36]. However, in fragmented areas and those subjected to edge effects, this higher production in reproductive plant parts does not always favour the reproductive success and recruitment of native species from the original plant community [36]. This may be cause by new environmental conditions of fragmented area with loss of pollinators and seed dispersers [35].

Effects of fire on phenology

Fire determine vegetation physiognomy and species diversity [37]. It stimulated flowering and fruiting [38], seed germination [39], increase fruit production [40], and/or phenological cycle by shifting the flowering/fruiting date [40], but may also depress the availability of large-seeded fruits (Barlow and Peres, 2006). Regarding benefits, fire also reduce flowering and fruiting by destroying buds, flowers and fruits, affecting species that reproduce during the fire season [41] and/or favour invasive species [42].

Phenological study of fire-prone area helps to improve management practices and restoration strategies. High fire frequency results low flower and fruit production [41] results in low regeneration [43].

Phenological patterns and species interactions

The investigation of how native, exotic and invasive species cooperate could profit by recognizing plant phenology as a key attribute impacting their associations [44]. Invasive species cause decline in native species or local extinctions because they change the structure and function of native ecosystems [45]. The native and exotic species which are closely related compete for pollinators and seed dispersers, change fruit quality, quantity, dispersal of seed and so community structure and ecosystem functioning [46]. Exotic species can leaf, bloom and fruit at that time when natives were not and get benefits from a priority effect [44]. Compared to natives, exotic species have also longer leaf and fruit period which provide the advantages over natives by providing more adaptability to environmental changes with implications for management and conservation [44]. When disturbance promote biomass growth, native species act as invasive species; e.g. native liana hyper abundance resulting from increased temperature and CO_2 availability associated with global atmospheric change [47]. The trees which are liana supported therefore modified by light competition which affects vegetative and reproductive phase [48]. During scarcity of flowering trees, native lianas provide flower resources to pollinators [49]. Such area of should take into account for forest conservation and management.

Tools for observing phenological activities

Phenological databases

The phenological studies and observation in modern era not fit in current conservation strategies. Observers organized phenology results like a seed collection calendar [50]. So its required to add additional objectives like estimate relationship between fruiting phenology and seed germination, dormancy [51], and storage behaviour [52] in seasonal habitats for choosing better adaptable species, to make methods for breaking dormancy, and seed preservation. From herbaria we can reconstruct past historical patterns of plant phenology [53] which provide data on reproductive pattern of any species whose phenolgical information was is not available [54]. Now-a-days digital photographs were also used for the same purpose. Dendrochronology is also very useful to understand effect of climate change on tree growth rings and cambial activity [55]. The results are used to develop growth models and to understanding how climatic conditions affects growth and cambial activity. This information used to make better management and conservation plan [56].

Phenological monitoring

With increasing importance of climate change and global warming, phenological monitoring techniques are also developing. These techniques help in predicting upcoming effects of climate change and address applied environmental and conservation issues [57]. Beside traditional phenological observations, this information will promote scientists to use alternative methods like remote sensing based phenology from regional to global scales [58] and deployment of in situ digital cameras for continuous monitoring of multiple simultaneous sites, referred to as near-surface remote phenology [4]. In species rich tropical areas, sampling can be expensive and labour-intensive so alternative techniques can be used for phenological studies [14]. Pehno cams can be useful tools in such area which detect changes in leafing events according to changes in the red, green and blue (RGB) channels [15]. Orbital remote sensing is also another useful which records biophysical and biochemical vegetation parameters [58]. Remote sensing detects seasonal vegetation changes over a large range of spatial and temporal scales, and have been incorporated into conservation practices [59,60].

Conclusions and Recommendations for Future Research

Now it is necessary to use new technology and tools for observing phenology, because phenology enters in a new phase which need all these techniques for long term data collection. As already discussed that new predicting models are developing to study phenological shift at different scales in current climatic scenario, these mechanisms will help us to improve models capabilities. More advance studies are required to improve conservation and management policies at species and community level. We can also address the effects of rising temperature on local and global scale with geographical variations.

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