IMPACT OF CLIMATE CHANGE ON PHENOLOGICAL RESPONSES OF MAJOR FOREST TREES OF KUMAUN HIMALAYA

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INTRODUCTION

Climate change is a reality now and has emerged as a major issue across the globe. On an average the global temperature rose by 0.74 °C over the last hundred years (1906-2005), with more than half of this rise, i.e. 0.44 °C reportedly occurred in the last 25years (IPCC, 2007). Most of the observed increase in global average temperature since the mid 20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations (IPCC, 2007). Such changes in climate have already started affecting biological systems worldwide (Walther *et al*., 2002; Parmesan and Yohe, 2003). Significant upward shift of plant species have already been reported from many parts of the globe due to warming (Cannone *et al*., 2007; Kelly *and* Goulden, 2008). Several studies have detected effects of climate change (CC) on changes in species distribution (Permesan, 2006), the storage of carbon in plants and soils (Shaver *et al*., 2000), and the timing of life history or phenological events (Primack *et al*., 2004; Inouye, 2008). All these factors are known to play a role, alone or in combination, in triggering phenological, and a plethora of other changes such as fluctuations in pollinators, seed dispersal agents, predators and competitors (Lieberman, 1982). The flowering and fruiting at the wrong time, in advance or after the appropriate season, may lead to failure in finding mates, failure to match demands of growing offspring with temporal peaks in food resources (e.g. Visser *et al*., 1998), or failure by a pollinator to find pollen and nectar, or a flower to be pollinated. Climatologists believe that even with global warming of 1–2 °C, much less than the most recent projections of warming during this century, most ecosystems and landscapes will be impacted through changes in species composition, productivity and biodiversity (Leemans and Eickhout, 2004). Study of phenology has thus expanded beyond its practical origin-from documenting nature's patterns, to most recently for understanding the ecological consequences of CC (Post and Inouyem, 2008).

Himalayan mountains representing one of the 'Global Biodiversity Hotspots' have emerged among the most sensitive ecosystems under the global climate change scenario (Shrestha, 2009). These ecosystems, with their great vertical dimensions representing gradients of temperature, precipitation, and solar radiation form unique candidates to detect and analyze impacts of global change (Singh *et al*., 2011). Particularly, the plant species and community distribution range, and their phenologies are predicted to experience varying level of shifts across these gradients, and thereby act as potential indicators of change (Negi *et al*., 2012). The richness of endemic species with restricted distribution and life support values (goods and services) of this hotspot are highly vulnerable under the changing climate scenarios. Signatures of CC have already begun to appear in the Kumaun Himalayan region in the form of early flowering/fruiting of native trees such as *Rhododendron arboreum* (Gaira *et al*., 2014), shift in striking of monsoon (Kumar *et al*., 2007), long winter dry spells, increased frequency of forest fires during winter or early spring, etc. Unfortunately, poor availability of systematic long term data sets from the region has severely limited our capability to objectively define intensity of impacts and develop mitigation and adaptation strategies against the emerging reality of climate change (NAPCC, 2008). In this region a few studies have been devoted to understand the phenology of forests (e.g., Ralhan *et al*., 1985; Rawal *et al*., 1991; Negi, 1989; Negi and Singh, 1992**).** However, outcome of these studies could not be related to CC; as it was not a major issue those days. Therefore, studies need to be taken up to determine the impacts of CC both on major phenophases and leaf characteristics of dominant forest forming trees of the region to generate important insights into expected changes on various structural and functional features of forests and future scenario of goods and services generated by these forests. The present study was undertaken with an objective to determine the shift in phenophases (particularly leafing, leaf drop and flowering) in eight dominant forest forming tree species of Kumaun Himalayan forests and compared to the similar studies carried out in these forests about 3–4 decades ago (Ralhan *et al*., 1985; Negi, 1990). Altitude and aspects (South and North) were considered as the proxy of rise in atmospheric temperature across the four forest sites located in an altitudinal gradient of 300–2200m asl. in Nainital district of Kumaun Himalaya. The specific questions of this research were: (i) Whether atmospheric temperature and rainfall has changed since 1985 in the study area? and (ii) If yes, whether phenophases (leafing, leaf drop, flowering and fruiting) have been shifted?

STUDY SITES AND METHODOLOGY

To study the response of atmospheric temperature and rainfall on phenological responses of trees mature and intact stands of Sal (*Shorea robusta)*, Chir pine (*Pinus roxburghii*) BanjOak (*Quercus leucotrichophora*) and Tilonj Oak (*Q. floribunda*) forests were selected for the study (2014–2016) across the representative forest sites with a variety of topographical, edaphic and climatic factors across an altitudinal gradient of 300–2200m asl in Kumaun Himalaya (Table 1). In each of the forest sites a dominant canopy tree species and a co-dominant sub-canopy tree species was taken up for detailed studies. In each of the selected forests two representative stands (one south facing and other north facing to account for the effect of sunshine) were selected and 100 mature individuals of the dominant and co-dominant tree species were marked for detailed phenological observations viz., date of vegetative bud break and leafing, duration of leafing, onset of senescence and leaf drop, flowering, fruiting and fruit maturation. These permanent marked forest stands were visited at bi-weekly interval during high phenological activity period and less frequently during the low activity period. During every field visit the numbers of marked trees of a given species were observed for all the phenophases described above. To address the climate change impacts the meteorological data was procured from Indian meteorology department, Pune as (a) All India 1^0x1^0 Rainfall data (Year 1901–2004), (b) All India temperature data (Year 1969–2009), and (c) Daily district normal meteorological parameters (Rainfall, maximum temperature, minimum temperature, mean temperature, relative humidity, wind speed). Aphrodite temperature data 0.25^0x0.25^0 (Year 1961-2007) and Aphrodite rainfall data (Year 1951-2007) was downloaded from the website for the study region.

Table 1. Location of the study sites and dominant tree species in the forests along an altitudinal gradient in Kumaun Himalaya

Sites	Elevation (m asl)	Latitude (N)	Longitude (E)	Canopy / Sub-canopy Tree Species
Chorgaliya	300	29^{0}17′32.7″	79°32′31.5″	*Shorea robusta* *Mallotus philippensis*
Patwadangar	1529	29°20'24.1"	79°26'27.7"	*Pinus roxburghii* *Myrica esculenta*
Kailakhan	1872	29°22'37.5"	79°28'47.6"	*Quercus leucotrichophora* *Rhododendron arboreum*
Barahpathar	2098	29°22'54.8"	79°26'27.8"	*Quercus floribunda* *Machilus duthei*
Ayarpatta	2200	29°23'08.9"	79°26'56.5"	*Quercus floribunda* *Machilus duthei*

Syntheses of the dataset revealed that during a time span of over 20 years the average annual atmospheric temperature rose by 0.005 °C and a decline in rainfall by 3.3 mm/yr was recorded in this period (Fig. 1). Started in third week of April. Leaf drop initiated in third week of May and peaked in second week of June. In *M. esculenta* (sub-canopy species) leaf bud break occurred in first week of May and peaked in second week of May, whereas flowering initiated in first week of September and peaked in second week of October. Fruiting started in last week of February and culminated in first week of April. Leaf drop initiated in March second week and peaked in third week of April and culminated in last week.

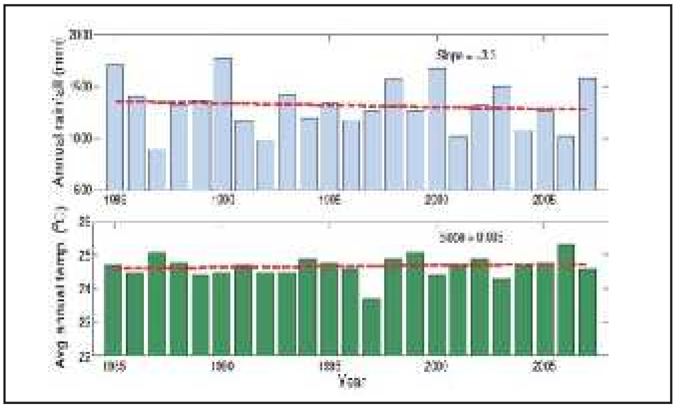

Fig. 1. Long-term (1985–2007) changes in annual rainfall and average annual temperature in the study area (*Source: IMD and APHRODITE*)

RESULTS & DISCUSSION

This phenological study of about two years shows that all the eight tree species (both canopy and sub-canopy) varied considerably with regards to proportion of different phenophases at a given time, marginally along the aspects and widely across the altitudinal transect. In general, leaf bud break and leaf drop was initiated earlier in low altitude species as compared to high altitude species. Sub-canopy species generally initiated all the phenophases little late than the canopy species, may be partly due to low amount of sunlight and temperature. All the four major phenophases were found overlapping with each other. The species-wise description of various phenophases is given below: In *S. robusta* leaf bud break occurred during April first week to third week; flowering from second week of May and peaked in first week of June; fruiting started from second week of June and peaked in first week of July. Leaf drop started from last week of November and peaked in March first week. In *M. philippensis* (sub-canopy species) leaf bud break initiated in last week of April and peaked in second week of May, flowering initiated in July second week and peaked in August first week; fruiting started in last week of November and culminated in first week of February. Leaf drop initiated in February second week and peaked in third week of March. In *P. roxburghii* leaf bud break started in second week of May and peaked in first week of June. Reproductive phase started in first week of February and peaked in second week of March and fruiting. In *Q. leucotrichophora* leaf bud break started in second week of April, flowering initiated in second week of May and peaked in first week of June, and fruiting started in third week of June. Leaf drop started in third week of January and peaked in second week of March and culminated in first week of April. In *R. arboreum* (sub-canopy species) leaf bud break initiated in first week of April and leafing started in last week of April, flowering initiated in first week of December and peaked in first week of January, and fruiting initiated in last week of April and culminated in third week of June. Leaf drop initiated in March second week and peaked in second week of April and culminated in third week of May. In *Quercus floribunda* leaf bud break started in last week of April and peak leafing occurred in second week of May, flowering initiated in first week of June and peaked in last week of June, and fruiting started in second week of July. Leaf drop initiated in second week of March and peaked in first week of April and culminated in first week of May. In *Machilus duthei* (sub-canopy species) leaf bud break initiation occurred in last week of March and leafing peaked in second week of April. Flowering initiated in first week of June and peaked in second week of July. Fruiting started in first week of August and peaked in last week of August and culminated in last week of October. Leaf drop initiated in second week of March, peaked in second week of April and culminated in third week of May. In all the above species it was noticeable that all the phenophases initiated earlier at south aspect as compared to north aspect. Inter-annual comparison of the phenological records revealed that in 2016 leafing was initiated 10–12 days earlier as compared to April 2015. Also in 2014 leaf drop initiation was earlier by 10-15 days as compared to 2015 in all the species. Again in 2016 leaf drop was recorded earlier as found in 2014. A comparison of our phenological observations of leaf bud break with the past (1985–86; Negi, 1990) for the same tree species and forest sites indicated an advancement in growing season of 1.6 days/yr (1985-2015). As mentioned earlier, during a time span of over 20 years the average annual atmospheric temperature has increased by 0.005 °C and a decline in rainfall by 3.3 mm/yr in this region. Earlier initiation of phenophases as a response of temperature and rainfall in the present study sites in 1985 and 1986 has been reported by Negi, 1989. For example, at approx. 2000m altitude leaf initiation was advanced by a week in 1985 (spring temperature in March and April were 17.6 and 20.9 °C, respectively) as compared to that in 1986 (March: 14.8 °C and April:16.5 °C).

However, this annual shift in occurrence of phenophases was not observed in *Quercus floribunda*, *Litsea umbrosa*, *Acer oblongum* (species of higher altitude). Flowering was also advanced by 1–3 weeks (in Oak, Rhododendron, Pine, the dominant forest trees) in 1985 as compared to 1986. Khanduri *et al*., 2008 reported average advancement of 1.9 days per decade in spring events and average delay of 1.4 days per decade in autumn events in over 650 temperate species that has extended average loss by 3.3 days. Similar findings are published from other parts of the world. In Europe warming in the early spring over the last 30 yrs. (1969–1998) by 1°C led to an earlier beginning of growing season by 8 days (Chmielewski and Rötzer, 2000); Alps (1.5 d/yr; Sto¨ckli and Vidale, 2004) and China (0.8 d/yr; Piao *et al.*, 2006). In the Himalayan region some reports (e.g., Shrestha *et al*., 2012) have shown 0.19 d/yr advancement (25 yr. period 1982-2006; mean 0.06 °C/yr) in temp. rise. It can be pointed out that this phenological earliness is creating ecological mis-matches between interacting species and their abiotic environment thus disrupting key plant-animal interactions such as pollination, herbivore, insectivore etc. Asynchrony in fruiting will have implications on trophic level. Seed germination may hamper and forest regeneration may fail. Temporal mismatches are crucial for plant survival strategies, structure, functioning and composition of ecosystems, species and community distribution range that may cause shifts in ecosystem productivity, with implications for C budget.

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