Effect of Climate Change on Banj Oak (*Quercus leucotrichophora* A. Camus) Dominated Forest in Kumaun, Central Himalaya

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Research Article

Abstract

Background: Phenology is the study of growth of buds; leaf flushing, anthesis, fruiting and leaf fall in relation to seasons or years with climatic factors. Phenological events of three trees and shrubs species were made during 2008-2009 in a banj oak (*Quercus leucotrichophora* A. Camus) dominated forest located between 1700-2200 m elevation in Kumaun Himalaya. After winter dormancy the growth initiation occurred when temperature began to rise continuously and resulted in bud break.

Materials and methods: Monthly counts of leaves, flowers, fruits and shoot measurement were made on 150 tagged twigs on ten individuals of each species for initiation, completion and duration of different phenological events.

Results: In most species, leaves emerged during spring time (February-March). Across all species, peak number of leaves per shoot (0.34-1.03), peak leaf area per shoot (9.56-52.27 cm^2), shoot extension growth (3.43-25.46 cm) and shoot extension period (16-28 weeks) varied considerably.

Conclusion: Comparisons with earlier studies indicated that certain phenological events have started to occur early. However, some phenophases did not show any shifts.

Keywords: Phenology; Climate change; Litter fall; Kumaun Himalaya.

1. Introduction

The third assessment report from the IPCC projected that the earth's average surface temperature will increase by 1.4 to 5.8°C between 1990 and 2100, if no major efforts are undertaken to reduce the emissions of greenhouse gases. This is significantly higher than what the panel predicted in 1995 (1.8-3.5°C). The predicted impact of warming in the Himalayan will be much higher [1]. The general phenological aspects of leafing, flowering and fruiting in tropical tree species are fairly known [2-8]. However, few reports are available on phenological studies in forest ecosystems of Central Himalaya and north eastern India [9-13].

Global climate change may force variation in timing, duration and synchronization of phenological events in tropical forests [14]. Tropical trees are expected to respond variously to changes in rainfall and temperature because they differ widely in respect to adaptations to seasonal drought and cues for bud break of vegetative and flower buds [15]. Several studies have shown significant variation (advanced or delayed) in onset dates of flowering and fruiting responses in tree species as a result of climatic change [16,17]. Probably the climate change impact can be better assessed at the level of functional types based on the duration of deciduousness and timing of onset of the reproductive phase (first visible flower). The need for functional types has been emphasized to evaluate and predict the nature of vegetation responses to future global change [18].

If the phenological changes in a species are not at the same pace as the climatic shifts it will lead to a mistiming of several seasonal activities [19]. In the present study we have tried to compare the shifts in timing of major phenological events in three tree and three shrub species of *Quercus leucotrichophora* A. Camus dominant forest. Comparisons are based on earlier studies on phenology on the some species at the same site [20].

2. Materials and Methods

2.1 Study area

The study was conducted in Nainital forest division of Kumaun Himalaya. The study site was located between 1700-1840 m. the studied tree species were banj oak (*Quercus leucotrichophora*) with *Myrica esculenta* Ham. ex D. Don and *Rhododendron arboreum* Smith occurring in the under canopy. The phenophase were also recorded for the following three shrub species *D. cannabina* Wall., *D. salicifolia* (D.Don) Rendle and *R. ellipticus* Smith.

2.2 Soils

The soils are residual, originating from slates, phyllites, sandstone, and limestone of the Krol series. Sand predominates in the soil (60-80%), while the silt and clay contents are 10-20% and 5-10%, respectively. Organic matter ranges between 10.0 % and 18.5% and available C between 2.6% and 3.8%, the soil pH ranges between 5 and 6 [21].

2.3 Climate

The climate is characterized by a summer monsoon and the year has four distinct seasons viz., monsoon (July to September), post-monsoon (October to November), winter (December to January) and summer (April to mid-June). Climatic data for 2008-2009 were obtained from the State Observatory at Nainital. The average annual rainfall was 159.98 mm of, 60% of which was occur in the rainy season and the mean daily temperature ranged from -2.0°C to 30.5°C (Source: ARIES, Nainital).

2.4 Site selection

Site for the studied species were similar as reported by Negi [20]. In the forest site 1ha permanent plot was established. Within 1ha permanent plot ten individuals of each of the canopy, subcanopy and shrub species were randomly selected for collecting seasonal data on shoot elongation and diameter changes.

2.5 Phenological recording

Phenological records on leaf emergence and leaf drop were made from December, 2007 to December, 2009 in banj oak dominated forest where trees and shrub of a given species were extensively distributed (Table 1). The site were visited at a weekly interval during the phenophase was observed in 5-10% individuals of a species, it was considered to have initiated and the species was considered to be in the phenophase as long as that phenophase was represented by at least 5-10% individuals [20].

2.6 Measurement of shoot length

One healthy lateral branch from each stratum viz., upper, middle and lower was marked. To assess the shoot elongation, the distance from the mark to the end of the shoot was measured to the nearest millimeter approximately fortnightly starting from late winter of 2007 for a period of two years [20,22].

2.7 Measurement of shoot diameter

The diameter changes for marked branches were measured by vernier calliper in two directions at right angle to one another to compensate, to extent, for any eccentricity in the shoots. The observations for diameter changes were made each month at approximately the same time of the day on each reading date to reduce effect of thermal expansion and hydration for period of eighteen months from March, 2008 to August, 2009 [20,22].

2.8 Leaf area

On each individual two representative canopy branches, one largely with sun leaves in an upper crown position and other largely with shade leaves in a lower crown position, were labled with permanent metal tag. Thus in total ten branches each for lower and upper crown position were marked. Leaves for each of the species were collected randomly on each of the sampling date (at weekly intervals from bud-break to full leaf expansion and at monthly intervals during the leaf senescence) from the marked twigs. All collected leaves of individual species were sketched on graph paper to measure the leaf area [20,22].

2.9 Flowering and fruiting

The flowering period of a species was the duration (days) from the initiation of flowering to the completion of flowering amongst its individual. Fruiting period of species was also the duration (days) from the first fruit formation to the last amongst its individual.

2.10 Litter fall

For studying litter production in banj oak forest three plots of 31.5 × 31.5 m^2 were established. The litter was measured by placing five litter traps (1 × 1 m^2) on the forest floor. Each trap was 2 mm mesh nylon, supported by wooden sides with 25 cm height. Litter from these traps was collected separately in paper bags and brought in to laboratory where the sample was sorted out in to three main categories viz. (i) leaf litter (ii) wooden litter (<2 cm Diameter) and (iii) miscellaneous litter and dried in shade. Litter sampling study was done during May, 2008 to April, 2010 [23,24].

Table 1. Periodicity of leaf recruitment and their number per shoot in studied species.

Species	% Leaf Population Produced in 1st Month of Bud-Break	Leaf Recruitment Rate (per Shoot Day^{-1}) in 1st Month of Leafing	Peak Leaf Pool Size (Number per Shoot)	Leaf Number per cm Shoot at Peak Leaf Pool Size
Trees				
M. esculenta	92	0.41	14.3 ± 0.72	1.03
Q. leucotrichophora	83	0.23	8.16 ± 0.34	0.62
R. arboreum	81	0.20	7.88 ± 0.54	0.51
Shrubs				
D. cannabina	78	0.26	8.73 ± 0.72	0.81
D. salicifolia	89	0.22	7.21 ± 0.22	0.97
R. ellipticus	76	0.24	8.4 ± 0.86	0.34

3. Results

3.1 Changes in leaf appearance

The months of leafing in 2009 were warmer than in 2008, i.e., the mean maximum temperature in February-March were 11.8 and 14.5°C, respectively in 2009 compared to 9.0 and 13.0°C in 2008. In 2009 the greater proportion of species showed leafing earlier due to the early rise in temperatures of February and March. Also, wet conditions during February-March of 2009 (45.1 and 14.8 mm rainfall in 2009 compared to 38.7 and 7.3 mm in 2008) triggered earlier leaf initiation in that year. 3 species (viz. *Quercus leucotrichophora, Rhododendron arboreum* and *Rubus ellipticus*) showed leafing 1-5 weeks earlier due to the early rise in temperature in February and March, 2009.

3.2 Leaf demography

In the first month following the bud-break, the tree species had produced 81-92% of total number of leaves. The leaf recruitment rate (number of leaves appearing in a shoot unit per day) in the first month of leafing ranged from a minimum of 0.20 in *R. arboreum* to maximum 0.41 in *M. esculenta*. The peak leaf pool size per shoot ranged between 7.88 (*R. arboreum*) to 14.3 (*M. esculenta*). Leaf density (number of leaves per cm shoot length) at the peak leaf pool size ranged from 0.51 (*R. arboreum*) to 1.03 (*M. esculenta*).

In comparison to trees, shrub species produced 76-89% of total number of leaves in the first month following the bud break. The leaf recruitment rate of shrub species was found lower compared to tree species. It ranged from 0.22 (*D. salicifolia*) to 0.26 (*D. cannabina*). Peak leaf pool size per shoot ranged between 7.21 in *D. salicifolia* to 8.73 in *D. cannabina*. Leaf density (number of leaves per cm shoot length) at the peak leaf pool size ranged from 0.34 (*R. ellipticus*) to 0.97 (*D. salicifolia*) (Table 1). The initiation of leaf expansion in tree species commenced from second week of February (*R. arboreum*) and continued till second week of March (*Q. leucotrichophora* and *R. arboreum*). The rate of leaf expansion was found maximum for *R. arboreum* (1.24 cm^2 day^{-1}) followed by *M. esculenta* (0.81 cm^2 day^{-1}) and *Q. leucotrichophora* (0.65 cm^2 day^{-1}). In shrub species, leaf expansion commenced from first week of February (*D. salicifolia*) to second week of April (*D. cannabina*). Leaf expansion rate was found maximum for *D. cannabina* (0.54 cm^2 day^{-1}) compared to *D. salicifolia* (0.34 cm^2 day^{-1}) and *R. ellipticus* (0.27 cm^2 day^{-1}).

3.3 Flowering and fruiting

Q. leucotrichophora and *R. arboreum* flowered during late winter to early spring seasons (January and February) and *M. esculenta* flowered during the rainy season (August). The duration of flowering was observed to a maximum of seven weeks in *R. arboreum*. In the remaining species the flowering period ranged between five to six weeks. When comparison was made in 2009 it occurred earlier by four weeks in *Q. leucotrichophora* and *R. arboreum* and delayed by one week in *M. esculenta*. In *R. arboreum* visible fruits occurred just after the competition of flowering. In the remaining species fruits were visible after six months period in *M. esculenta* and after one year in *Q. leucotrichophora* (Figure 1).

In shrubs *R. ellipiticus* flowered during late winter (January) and *D. cannabina* and *D. salicifolia* flowered during the early spring (February). The flowering period ranged abound four weeks in all shrub species. Differences were also recorded in regard to the time of flower initiation between the two years of study. In 2009 it occurred earlier by one week in *D. salicifolia* and delayed by same period in *D. cannabina.* However, *R. ellipticus* was unaffected by this year to year variation in flowering. In *D. cannabina* and *D. salicifolia* fruiting was took place just after flowering, i.e., April. *R. ellipticus* differed from other species in which fruiting occurred in February (Figure 1).

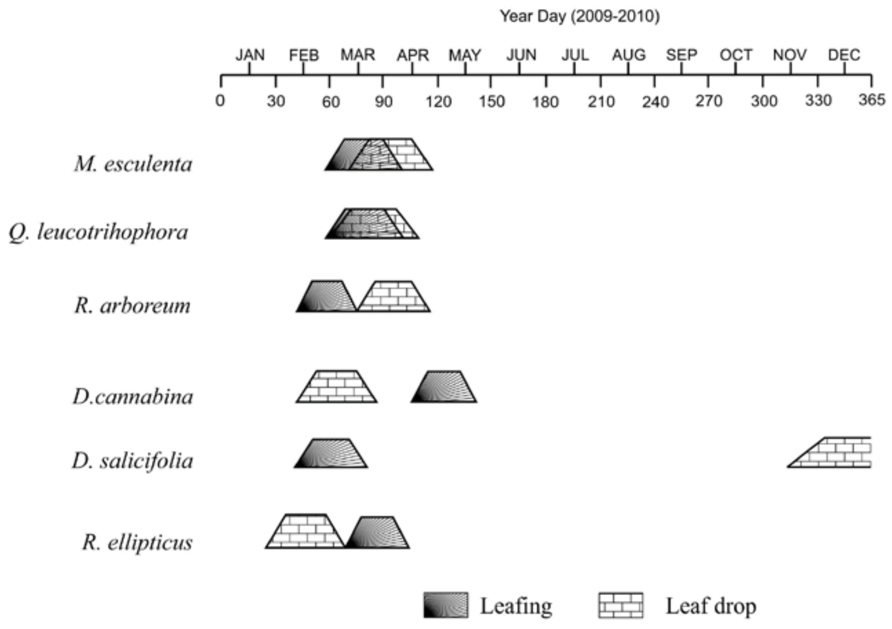
3.4 Shoot demography

In *Q. leucotrichophora* and *R. arboreum*, 90% shoot elongation was completed during rainy season (July and August) and in *M. esculenta* it was completed by the end of rainy season (i.e., September and October). The amount of shoot elongation ranged between 8.45 cm in *M. esculenta* to 25.46 cm in *R. ellipticus.* The average percentage of the shoot elongation realized in the first month of bud break was higher for *Q. leucotrichophora* (72.89%).

In *D. cannabina,* 90% shoot elongation was completed by June, prior to the commencement of rainy season, in *D. salicifolia* it was completed during rainy season (July and August) and in *R. ellipticus* it was completed by the end of rainy. The amount of shoot elongation ranged between 20.18 cm in *D. salicifolia* to 25.46 cm in *R. ellipticus.* The average percentage of the shoot elongation realized in the first month of bud break was higher for *D. salicifolia* (53.05%) (Table 2).

Of the total diameter increment, the percentage increment in one month from bud-break ranged between 65.32% in *Q. leucotrichophora* to 80.89% in *R. arboreum*. Of the total diameter increment, the percentage realized in one month from bud-break found maximum for *R. arboreum* (80.98%) and minimum for *Q. leucotrichophora* (65.32%).

Compare to trees, in shrub species the percentage increment in one month from bud-break ranged between 44.52% in *R. ellipticus* to 71.55% in *D. cannabina*. Of the total diameter increment, the percentage realized in one month from bud-break found maximum for *D. cannabina* (71.55) and minimum *R. ellipticus* (44.52%) (Table 2).



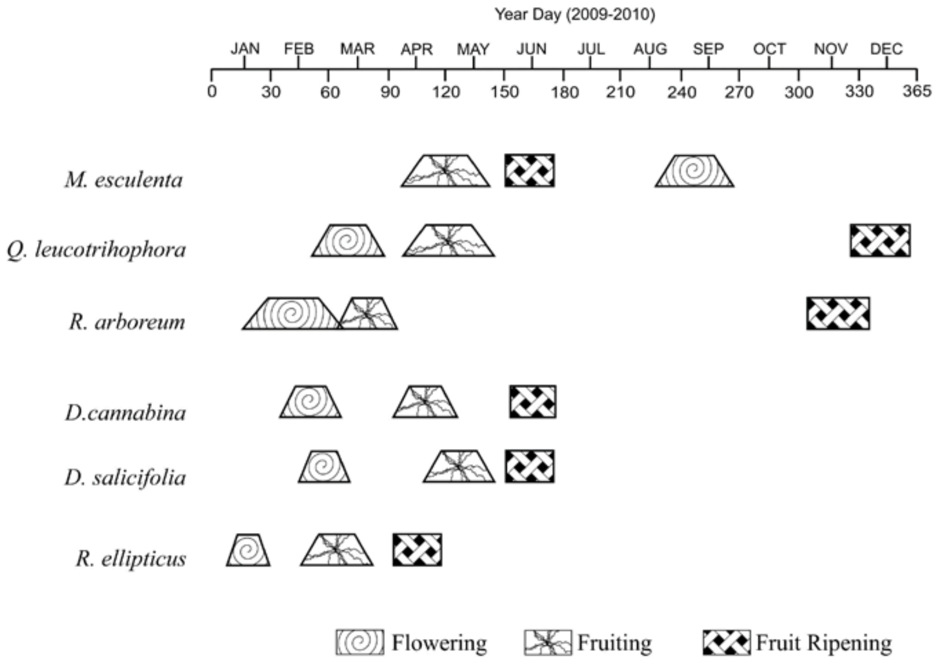


Figure 1. A calendar of flowering, fruiting and fruit ripening for the tree and shrub species. The left hand side of the bar indicates initiation of the phenophase and the right hand side represents end of the phenophase.

Table 2. Different parameters of shoot length and diameter of tree and shrub species.

				Rate (cm^{-2} day^{l})	
Species	**Date of Bud Break**	**Full Length of Shoot (cm)**	**Net Gain in Diameter (mm)**	**Shoot Elongation**	**Shoot Diameter**
Trees					
M. esculenta	12-April	8.45 ± 0.62	4.97 ± 0.09	0.043 ± 0.01	0.026 ± 0.001
Q. leucotrichophora	11-March	20.43 ± 1.09	4.89 ±0 .21	0.119 ± 0.002	0.021 ± 0.002
R. arboreum	8-May	10.44 ± 0.47	3.67 ± 0.12	0.098 ± 0.02	0.033 ± 0.001
Shrubs					
D. cannabina	3-March	20.22 ± 2.25	4.71 ± 0.26	0.187 ± 0.03	0.044 ± 0.01
D. salicifolia	13-March	20.18 ± 1.78	6.66 ± 0.41	0.12 ± 0.02	0.04 ± 0.002
R. ellipticus	4-February	25.46 ± 2.53	4.38 ± 0.36	0.089 ± 0.001	0.019 ± 0.02

3.5 Litterfall

The leaf fall was greatest in the spring (February-May) season (47.29%), followed by the monsoon (19.33%), winter (19.13%) and post monsoon seasons (14.26%). The contribution of leaf litter to total annual litter production was highest during summer months; the leaf litter accounted for 18.47% (May) to 12.53% (June) of the respective total monthly fall (Figure 2).

The contribution of wood litter to total annual litter production was highest during summer seasons; the wood litter accounted for 13.74% (June) to 10.14% (May) of the respective total monthly fall. The wood fall was greatest in the summer season (36.92%), followed by the monsoon (28.86%), winter (24.4%) and post monsoon seasons (9.81%).

The contribution of miscellaneous litter to total annual litter production was highest during winter seasons; the miscellaneous litter accounted for 12.3% (January) to 6.15% (December) of the respective total monthly fall. The miscellaneous fall was greatest in the winter season (36.69%), followed by the post monsoon (23.57%), monsoon (22.96%) and summer season (16.6%). The mean monthly temperature (°C) was significantly correlated with leaf litter fall (r=0.873), wood litter fall (r=0.737) and miscellaneous litter fall (r=0.803) per month. The mean monthly rainfall (mm) also showed significant correlated with leaf litter fall (r=-0.628), wood litter fall (r=-0.858) and miscellaneous litter fall (r=0.554) per month.

The contribution of leaf fall to total annual litter in respective month was highest during summer months; the leaf litter accounted for 78.7% (April) to 84.0% (May). The wood fall contribution was highest during monsoon months; the wood litter accounted for 31.7% (August) to 27.1% (September) and highest during winter by Miscellaneous litter. The miscellaneous litter accounted for 6.7% (December) to 19.2% (January).

4. Discussion

In the studied species the growth initiation occurred in month of February and March when temperature had started to increase. *R. arboreum* and *D. salicifolia* were among the first to show growth initiation, in the

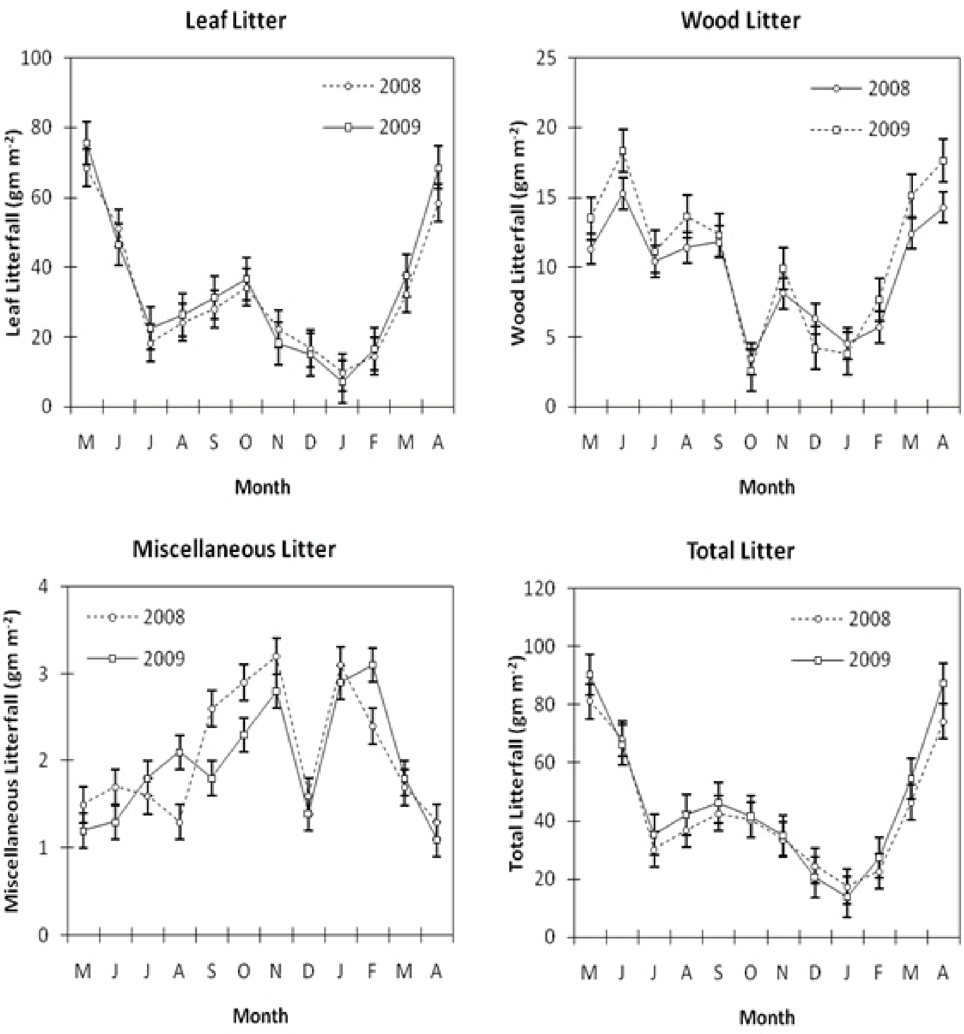


Figure 2. Monthly leaf, wood, miscellaneous and total litter fall (g m^{-2}) in banj oak forest.

Table 3. A summary of comparative values of various phenologic events for studied species. Each value is represented as average week of initiation of a phenophase

Species	Leafing		Flowering		Fruiting		Fruit Ripening	
	Present study	Negi [20]	Present study	Negi [20]	Present study	Negi [20]	Present study	Negi [20]
M. esculenta	4th week (February)	1st week (April)	2nd week (August)	1st week (August)	1st week (April)	1st week (March)	1st week (June)	1st week (May)
Q. leucotrichophora	4th week (February)	4th week (March)	4th week (February)	2nd week (March)	2nd week (April)	3rd week (April)	4th week (November)	1st week (December)
R. arboreum	2nd week (February)	3rd week (April)	2nd week (January)	4th week (February)	2nd week (March)	1st week (April)	1st week (October)	1st week (June)

second week of February and *D. cannabina* was the last to exhibit its growth initiation (in mid April). Studies by Njoku [25], Lawton and Akpan [26] have also implicated day length and air temperature increase as the inducer of leaf flushing, which holds true for the present study area where peak activity of bud break and leafing took place during February-March when photoperiod and temperatures were increasing [4,27]. Further, the role of isolated rain showers to initiate leafing by replenishing water content has also been frequently emphasized [28]. In the study site, though the soil moisture continues to be low from October to mid-June, the long dry spells were frequently broken by isolated rain showers (average monthly rainfall is 41.9 and 11.2 mm in February and March), possibly facilitating leaf emergence during March-April.

The numbers of flowering species increased from January and by mid February majority of the species were flowering. In *M. esculenta* it was delayed until first week of August. In *Q. leucotrichophora* and two shrub species (*D. cannabina* and *D. salicifolia*) fruiting began in the first to third week of April. However, *R. ellipticus* was first to initiate fruiting in February. From the standpoint of time interval between fruitition to fruit ripening, in most of the species fruit ripened within two or three months of fruitiiton except *R. arboreum* in which fruit ripened occurred within 6 months and *Q. leucotrichophora* within 15 months. In majority of species shoot elongation began with the increase of temperature in mid-March to mid-April except *R. ellipticus* which had first emergence of shoot in February. In five species over 90% shoot elongation was completed during rainy season (July and August) except *D. cannabina* prior to the commencement of rainy season.

The available data indicates that the Himalayas seem to be warming several times more than the global average rate [29,30]. The temperature rise was more during the winter and autumn than during the summer; and that increases was larger at higher altitudes [30]. A study based on the analysis of data of 43 years (period 1965-2007) indicated that the maximum temperatures have increased by 1.1°C and minimum by 1.2°C temperature [31]. This study supported the result of Liu and Chen [30].

Climate change is clearly affecting plant phenology world wide [32-35]. Our results further confirm this observation. In present study leaf initiation of *M. esculenta* and *Q. leucotrichophora* had shifted by approximately 3-4 weeks in comparison to earlier studies [20]. *R. arboreum* showed approximately 7-8 weeks shifts in leafing. Flowering in *R. arboreum* was earlier by 5 weeks and fruiting had also shifted about 2 weeks earlier when compared with earlier studies conducted by Negi [20]. This shift in flowering can largely be explained by a 0.81°C increase in the mean January and February maximum temperature over the past 10 years. Only *M. esculenta* was unaffected by this phenological change. However, no previous studies were available to compare phenological activities of studied shrub species (Table 3).

5. Conclusion

To conclude, it is evident that the phenophases of species are responding to climate change, i.e., increasing temperature changing rainfall pattern. The changes in early-flowering species respond to enhanced February and March temperatures to a greater degree. Such changes in flowering times in response to future climate change might significantly affect hybridization, pollination biology, and population structures and regeneration on the studied species.

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