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Phenological events along the elevation gradient and effect of climate change on *Rhododendron arboreum* Sm. in Kumaun Himalaya

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Phenological events of rhododendron (*Rhododendron arboreum* Sm.) were monitored along elevation gradients in distinct ecological settings. The observations were carried out between 1500 and 2500 m elevation in Central Himalaya. The phenological events, i.e. bud formation, bud bursting, leafing, flowering, fruit formation and seed formation were recorded. Phenological duration and synchrony of all these phenophases were determined within site and along the elevation gradient in each study site. Our observations showed high synchrony throughout the elevation gradient, especially for peak flowering. Temperature, rainfall, age of the observed trees and site characteristics were related to initial and peak flowering dates. The circumference varied from 35.0 ± 2.73 to 140.0 ± 2.88 cm; similarly, height varied from 5.0 ± 1.02 to 16.5 ± 1.41 m. All the phenological events began early at low elevation and were delayed at higher elevation. *R. arboreum* had a sharp flowering peak from January to March. Wet season flowering was rare, and seed formation occurred in summer. The climatic conditions affected the phenological characters of *R. arboreum*.

Keywords: Climate change, elevation gradient, phenology, *Rhododendron arboreum*.

RHODODENDRON *arboreum* Sm. (local name – Burans, family – Ericaceae) is one of the most important small, evergreen and a major under canopy tree species in the Central Himalayan forests. It is widely distributed from 1000 to 2500 m elevation in Kumaun Himalaya. Common associates of this tree are about 16 trees and 19 shrubs. At low elevation, it mixes with chir pine and broadleaf species, while at high elevation it remains either as under canopy species in *Quercus semecarpifolia* forest or dominates as canopy species in some location near timberline. *R. arboreum* is distributed from subtropical to temperate forests. The subtropical forests are located along an altitudinal gradient and exhibit limited day length variation within the annual cycle. However, temperature, particularly at higher elevation approaches those of temperate latitudes. Phenological observations provide

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a background for information on functional rhythms of plants and plants communities. Much phenological research has been concerned with the influence of climatic variables upon crop plants[1]. Most of the studies on plant phenology have been carried out in tropical forests to describe community-level pattern of leafing, flowering and fruiting[2–5].

Global climate is probably the most important determinant of vegetation pattern and has significant influence on the distribution, structure and ecology of forest and forest ecosystem. It is therefore logical to assume that changes in climate would alter the configuration of the forest ecosystem. Climate change has led to shifts in phenology in many species distributed widely across taxonomic groups. Most species react differently to climate change; the outstanding question is how future climate change will affect the phenology of the whole ecosystem under different climate change scenarios. Climate is probably the most important determinant of vegetation patterns globally and has significant influence on the distribution, structure and ecology of forests. India is a land with a wide range of variation in climatic, altitude and physiography. The wide variety in physical features and climatic situations has resulted in a diversity of habitats such as deserts, deciduous, evergreen and moist forests, mangroves and alpine grasslands. There is considerable divergence of opinion about the magnitude of climate change predicted for the Indian region and its effect on plants. Both climatic models and observational studies give conflicting views regarding the effect of climate change on vegetation. There is now ample evidence which shows that over the past decades, the phenology – the timing of seasonal activities such as timing of flowering or breeding[6] of many plant and animal species has advanced and that these shifts are related to climate change[6–10]. What is, however, less clear is how we should interpret these shifts in phenology. The observed changes in phenology may be a positive sign because species are apparently adapting to changing climatic conditions, or they may be a negative sign because they show that climate change is, indeed, impacting living systems[8].

Phenology is the study of nature of plant events in response to seasonal and climatic changes to the environment. If the phenology of a species shifts at a rate different from that of the species that make-up its ecological conditions, it will lead to variation in its seasonal activities[11], or to use an alternative terminology, to a mismatch in phenology[12]. Such tropical decoupling of food-web phenology may have severe consequences, including biodiversity loss[11]. The dominant evergreen forest species, occurring between 350 and 2150 m in Kumaun Himalaya have concentrated leaf drop and simultaneous leafing during the warm, dry period of the year. About half of the species showed multiple leafing. All species had a sharp flowering peak in summer season (March to May). In high mountainous regions, flowering phenology changes along elevation gradients, with plants at lower elevation typically flowering earlier than those of the same species growing at higher elevations[13,14]. Ecologically, high elevation environments include alpine and montane areas with temperate climate, where the annual lifecycle of plants is determined by weather-related events, such as snowmelt, soil thawing and fulfillment of chilling requirements[15–17]. Global climate change is affecting phenology in these high elevation environments[15]. The climate of the region is influenced by summer monsoon. The functional behaviour of vegetation represents a transition between strongly seasonal temperate and tropical forests[18]. Thus, the objective of the present study was to document the phenological events and identify the effect of climate change on phenological events of *Rhododendron arboreum*, with particular reference to elevation on leafing, flowering and fruiting.

The study site is located between 29°22′–29°23′N and 79°26′–79°28′E in the Central Himalaya. It falls in subtropical to temperate climate condition. Winter is usually very cold with slight rain and heavy snowfall (December to January); summer is warm and dry (April to mid-June), and a rainy season is slightly warm and humid (mid-June to mid-September). The soil of the area represents meadow soil, brown forest soil and red loam. pH of the soil ranges from 5.0 to 6.4. The average rainfall is about 1352 mm and average humidity is about 55%. The mean annual temperature is 18.5°C. In the present study we have selected a total of eight sites located between 1500 and 2500 m altitudinal range.

On each site, 10–12 phenotypically superior trees were randomly selected and marked for the phenological events. The superiority characters for the tree were taken as healthy trees, free from buttresses, well-developed crown and middle-aged trees approaching maturity. The circumference or girth at the breast height of the selected trees was measured using a measuring tape and converted to diameter as follows

$$C = \pi D, \quad D = C/\pi.$$

where C and D refer to circumference and diameter respectively.

The height of the selected trees was measured using the Ravi multimeter. The phenological events were observed from bud formation to seed formation. For this, frequent field visits were made to record observation on different phenological events – bud formation, bud bursting, leafing, flowering, fruiting and seed formation. The different phenological events were observed at 15 days interval during low activity period and weekly during peak activity period for each phenological event. The phenological data were compared with those of earlier studies on phenology.

Among growth parameters, circumference and height of rhododendron were studied (Table 1 and Figure 1).

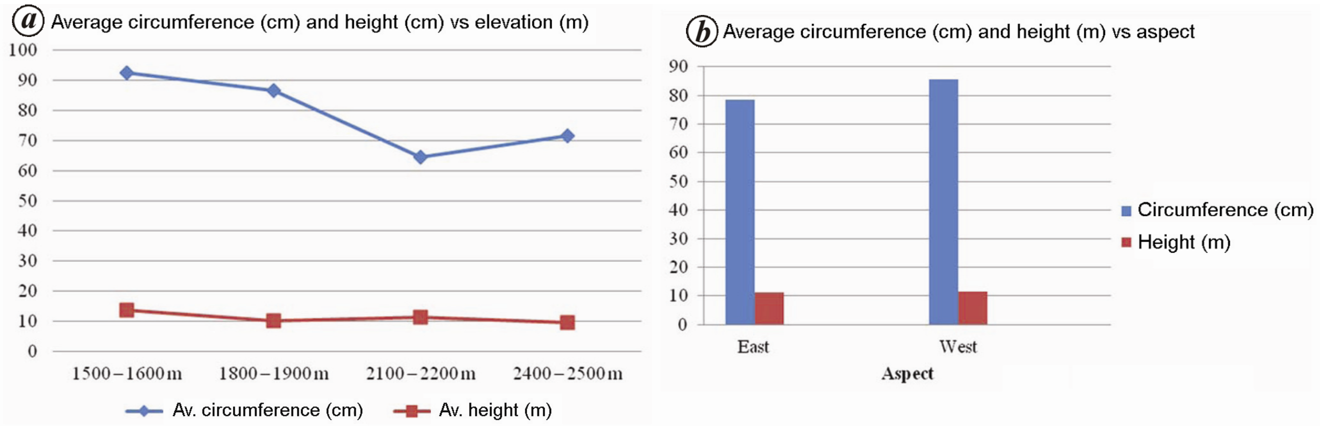

Figure 1. Average circumference and height of rhododendron along the elevation (***a***) and aspects (***b***).

Table 1. Average circumference and height of rhododendron at different sites

Site no.	Elevation (units)	Aspect	Circumference (cm)	Height (m)
1	1500–1600	East	65.0 ± 3.272	12.6 ± 0.718
		West	120.0 ± 2.496	14.0 ± 1.871
2	1800–1900	East	68.5 ± 3.15	10.0 ± 1.01
3		East	105.2 ± 2.156	10.86 ± 1.51
4		East	86.01 ± 2.95	9.5 ± 0.50
5	2100–2200	East	52.01 ± 2.95	13.5 ± 1.51
6		East	76.51 ± 2.95	13.01 ± 1.01
7		East	65.81 ± 3.95	7.5 ± 1.51
8	2400–2500	East	92.2 ± 3.125	10.0 ± 1.11
		West	51.3 ± 2.563	8.9 ± 1.231

At different elevations, i.e. 1500–1600, 1800–1900, 2100–2200 and 2400–2500 m, the mean circumference of the selected *R. arboreum* trees at breast height was 92.5 ± 2.884, 86.57 ± 2.752, 64.77 ± 3.283 and 71.7 ± 2.844 cm respectively (Table 1 and Figure 1). Overall, the circumference of *R. arboreum* trees varied from 35.0 ± 2.73 to 140.0 ± 1.96 cm, with a mean circumference of 87.5 ± 2.12 cm.

For elevations 1500–1600, 1800–1900, 2100–2200 and 2400–2500 m, the mean height of the selected *R. arboreum* trees at breast height was 13.8 ± 1.294, 10.12 ± 1.006, 11.34 ± 1.343 and 9.4 ± 1.170 m respectively (Table 1 and Figure 1). Overall, the height of *R. arboreum* trees varied from 5.0 ± 1.02 to 16.5 ± 1.41 m, with a mean height of 10.52 ± 1.12 m.

Various phenological events, i.e. bud formation, bud bursting, leafing, flowering, fruiting, and seed formation were observed and studied (Tables 2 and 3 and Figure 2).

At low elevation (1500–1600 m), the bud formation in *R. arboreum* started from 30 December and continues up to 25 February. In the mid-elevations (1800–1900 and 2100–2200 m) it started from 29 December and continued up to 17 March and from 6 January up to 21 March respectively. At high elevation (2400–2500 m), bud formation started on 11 January and continued up to 11 March. Thus bud formation started early at low elevation and was delayed at higher elevation.

At low elevation (1500–1600 m), bud bursting in *R. arboreum* started from 15 January and continued up to 5 March. In the mid-elevations (1800–1900 and 2100–2200 m), it started from 29 December and continued up to 22 March and from 21 January up to 26 March respectively. At high elevation (2400–2500 m), bud bursting started on 31 January and continued up to 21 March.

At low elevation (1500–1600 m), leafing in *R. arboreum* started from 25 January and continued up to 30 March. In the mid-elevations (1800–1900 and 2100–2200 m) it started from 14 January and continued up to 31 March and from 11 February up to 31 March respectively. At high elevation (2400–2500 m), leafing started on 31 January and continued up to 31 March.

At low elevation (1500–1600 m), flowering in *R. arboreum* started from 30 January and continued up to 20 March. In the mid-elevations (1800–1900 and 2100–2200 m) it started from 19 January and continued up to 31 March and from 16 February up to 31 March respectively. At high elevation (2400–2500 m), flowering started from 21 February and continued up to 31 March.

At low elevation (1500–1600 m), fruit formation in *R. arboreum* started from 15 February and continued up to 31 March. In the mid-elevations (1800–1900 and 2100–2200 m) it started from 4 February and continued up to 31 March and from 6 March up to 31 March respectively. At high elevation (2400–2500 m), the fruit formation started on 11 March and continued up to 31 March.

At low elevation (1500–1600 m), seed formation in *R. arboreum* started from 15 February and continued up to 31 March. In the mid-elevations (1800–1900 and 2100–2200 m) it started from 14 February and continued up to 31 March and from 6 March up to 31 March respectively. And finally at high elevation (2400–2500 m) the fruit formation started from 11 March and continued up to 31 March.

Table 2. Timing of various phenological events of rhododendron at different sites

Site no.	Bud formation	Bud bursting	Leafing	Flowering	Fruits formation	Seed formation
1	30 December–25 February	15 January–5 March	25 January–30 March	30 January–10 March	15 February–20 March	15 February–20 March
2	29 December–4 February	19 December–7 March	14 January–31 March	19 January–7 March	4 February–17 March	14 February–17 March
3	4 February–2 March	14 February–7 March	24 February–31 March	7–31 March	17–31 March	22–31 March
4	24 January–17 March	14 February–22 March	2–31 March	7–22 March	12–31 March	12–31 March
5	31 January–21 March	11 February–26 March	6–31 March	6–31 March	21–31 March	21–31 March
6	6 January–2 March	21 January–6 March	11 February–31 March	16 February–31 March	6–31 March	6–31 March
7	16 January–2 March	6 February–11 March	26 February–31 March	2–31 March	11–31 March	16–31 March
8	11 January–11 March	31 January–21 March	31 January–31 March	21 February–31 March	16–31 March	16–31 March

Table 3. Duration of phenophases in rhododendron across different sites

Phenophase	Bud formation	Bud bursting	Leafing	Flowering	Fruits formation	Seed formation
Time of occurrence	29 December–21 March	29 December–26 March	14 January–31 March	19 January–31 March	4 February–31 March	14 February–31 March
Duration	83 days	88 days	76 days	70 days	55 days	45 days

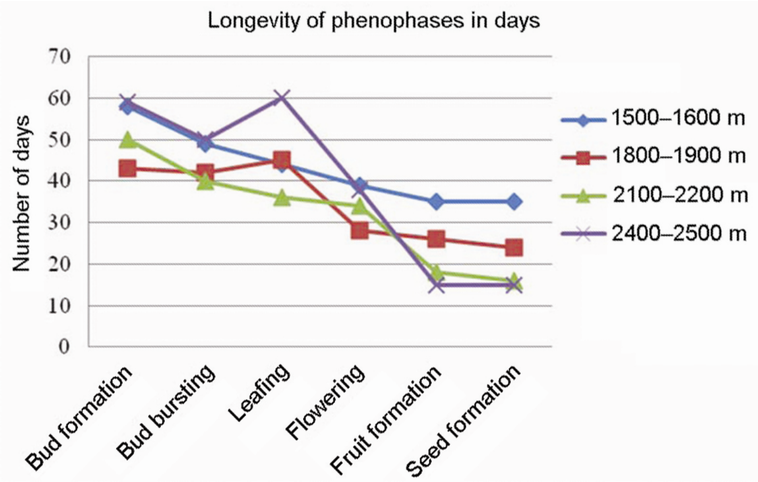

Figure 2. Longevity (in days) of various phenophases along the elevation.

Results differed between all the study sites, but winter temperature was the most important variable affecting the regression model for both initial flowering and peak flowering at all sites. After temperature, soil moisture was the most important variable for explaining initial flowering dates. The distribution of rhododendron indicates that it is able to grow in a wide range of habitats with different environmental conditions. The recent trend of rising winter–spring temperature and the detected bloom-advancing effect of high temperature during this period suggest that rhododendron might expand its distributional range in response to global warming. Global climate change is likely to alter the phenological patterns of plants due to the controlling effects of climate on plant ontogeny[19]. Changes in the timing of seasonally re-occurring biological events/phenology are most powerful biological responses to environmental change, particularly climate change. Previous studies have demonstrated that plant communities have shifted their phenology in recent decades[20,21], but there is a lack of consistency with respect to the phenological events analysed.

The circumference of the selected *R. arboreum* trees decreased with increasing elevation. The height was more at low elevation and decreased at higher elevation.

Similarly, the phenology of *R. arboreum* differed from site to site in the present study. This indicated that the phenological events changed, because of the temperature and moisture present in the soil[20,21]. Leafing and flowering is a simultaneous process, after the bud bursting (within 15–20 days), the first flowering occurred from 19 January at 1800–1900 m elevation, while at 2100–2200 m elevation it was delayed (6–7 March). We have compared the flowering period of *R. arboreum* with an earlier study[22] which reported first flowering in *R. arboreum* during 15 March, when 2–3 flowers appeared per tree during this period.

The variations in phenology of *R. arboreum* were due to the changes in climatic condition like, temperature, soil moisture, humidity and rainfall which varied from site to site. In the present study the tree parameters (circumference and height) were greater at low elevation and decreased at high elevation. Similarly, all the phenological characters (bud formation, bud bursting, leafing, flowering, fruit formation and seed formation) occurred early at low elevation and were delayed with increasing elevation. This may be because every character of the tree needs a particular set of temperatures for its growth and development. This optimum set of temperatures is met early at low elevation and later as elevation increases. When circumference, height and phenological events were compared between east and west aspect, they were greater in the west aspect because it is warmer and has more sunlight compared to the east aspect.

The longevity of various phenophases indicated that bud formation, bud bursting, leafing and flowering periods, were longer at high elevation, while fruit and seed formation periods were shorter at high elevation compared to low elevation. Overall, the various phenological events in *R. arboreum* vary from 45 to 88 days. The shortest period was for seed formation and longest for bud bursting. Bud formation started from 29 December when the temperature was low, while the seeds matured during May when the temperature remained high.

In *R. arboreum* trees the circumference, height and all phenological characters were more pronounced and early at low elevation and decreased with increasing elevation. All the phenological characters appeared early (within 65–75 days) compared to an earlier study[22]. These changes in phenological characters in *R. arboreum* may be due to changes in the temperature, rainfall pattern, soil moisture and other climatic conditions.

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