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ORIGINAL ARTICLE

Reproductive phenology and floral visitors in *Rhododendron arboreum* (Ericaceae) in a temperate forest of Garhwal Himalaya

Fenologia reprodutiva e disponibilidade de visitantes florais em *Rhododendron arboreum* (Ericaceae) em uma floresta temperada em Garhwal Himalaya

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Abstract

The study has been conducted in a temperate forest of north-west Himalaya, India at an altitude of 1600-2192 m asl to determine the reproductive phenological shift and the subsequent impact on pollination in *Rhododendron arboreum* in a temperate Himalayan forest. Phenological study and pollination observations in *Rhododendron arboreum* were carried out in two reproductive seasons (2016 and 2017) in a mixed broadleaved and conifer temperate forest. Floral morphology of *R. arboreum* was typically adapted to bird pollination and there was advancement of flowering by 5 days in first flowering and 9 days in termination of flowering in the year 2017 than that of the year 2016. The onset of flowering in *R. arboreum* was attributed mainly due to the scarcity of winter precipitation regardless of temperature variations. Ornithophily in assistance with entomophily would enhance the reproductive success by stimulating the magnitude of the visits through providing optimum resources.

Keywords: Phenology; Floral design; Bird pollination; Anthesis; Precipitation; Temperature.

Resumo

O estudo foi conduzido em uma floresta temperada do noroeste do Himalaia, Índia, a uma altitude de 1600-2192 m acima do nível médio do mar, para determinar a mudança fenológica reprodutiva e o subsequente impacto na polinização em *Rhododendron arboreum* em uma floresta temperada do Himalaia. O estudo fenológico e as observações de polinização em *Rhododendron arboreum* foram realizados em duas estações reprodutivas (2016 e 2017) em uma floresta mista temperada. A morfologia floral de *R. arboreum* foi tipicamente adaptada à polinização por pássaros e houve avanço da floração em 5 dias na primeira floração e 9 dias no término da floração no ano de 2017 do que no ano de 2016. Início da floração em *R. arboreum* foi atribuída, principalmente, devido à escassez de precipitação no inverno, independentemente das variações de temperatura. A ornitofilia, com assistência da entomofilia, pode aumentar o sucesso reprodutivo ao estimular a magnitude das visitas por meio do fornecimento ótimo de recursos.

Palavras-chave: Fenologia; Desenho floral; Polinização por pássaros; Antese; Precipitação; Temperatura.

INTRODUCTION

Floral phenological events are mostly governed by the prevailing environmental conditions which most often manage the flowering time (early and late flowering) in addition to the genetic control (when to flower is genetically fixed in flowering plants) (Martins et al.,

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2021). The regulation of flowering time in plants and its subsequent effect on pollination has received much scrutiny in recent years (Jung et al., 2017). Climatic fluctuations may disrupt the overlap in seasonal timing (i.e. phenology) of flower transition and pollinator flight activity, thus, altering the opportunity for interaction between the plants and animals (Harrison, 2000; Wall et al., 2003). Flowering phenology had a strong effect on plant reproductive success (Buide et al., 2002; McIntosh, 2002; Pias & Guitian, 2007; Liu et al., 2021). Changes in phenological events would cause the temporal disruption of species interactions, such as phenological mismatches among plants and their pollinators (Hegland et al., 2009; Visser & Both, 2005), possibly leading to an increase in extinction risks and loss of ecosystem services (Both et al., 2006; Memmott et al., 2007). The timing, intensity and duration of flowering decide the success of plant's reproductive cycle which in turn has impacted on the population of those animals, pollinators, and frugivores dependent on the flowering resources (Newstrom et al., 1994). There is an incomplete understanding of how interactions between plants and pollinators will be affected by the phenological shifts that accompany climate change (Hegland et al., 2009).

Several studies have investigated the consequence of climatic variability on flowering time (Gormsen et al., 2005; Primack et al., 2009; Blümel et al., 2015; Izawa et al., 2016). Such advancement is most often attributed to corresponding increase in temperature (e.g., Aono & Kazui, 2008; Khanduri et al., 2008; Primack et al., 2009, Amano et al., 2010). The rise of temperature leads to advancement in flowering time (reviewed in Anderson et al., 2012). The phenological responses in plants, particularly early flowering, are considered among the prominent biological indicator of climate change (Parmesan & Yohe, 2003; Root et al., 2003; Khanduri et al., 2008). Climate warming is considered as one of the strong reasons for pollination deficits (Saavedra et al., 2003); deficits are postulated to arise from phenological mismatches between plants and pollinators (Kudo et al., 2004; Memmott et al., 2007; Williams & Jackson, 2007).

Rhododendron arboreum Sm., (Ericaceae), Rose tree, locally known as Burans (in Hindi) is an evergreen tree or a small tree with a showy display of bright red flowers. It is a very valuable tree species both ecologically and economically (Tiwari & Chauhan, 2006; Singh & Chatterjee, 2022). The squash/juice made from its flower is very popular in westerm Himalayan region and is considered as a significant resource of livelihood improvement alternative (Singh & Chatterjee, 2022). Therefore the flowers are being harvested by the local inhabitants, non-governmental organizations and small scale entrepreneurs of the region which ultimately lead to a biotic pressure on this species. However, *R. arboreum* is categorized as a least concern species by the IUCN Red List of Threatened Species in 2018. *R. arboreum* has medicinal properties in pharmacology as (i) Anti-inflammatory and Anti-conceptive activity (ii) Hepatoprotective activity (III) Anti-diarrhoeal activity (Verma et al., 2010), (iv) Anti-diabetic activity (Bhandary & Kuwabata, 2008), (v) Antioxidant or Adaptogenic activity (Dhan et al., 2007; Swamidasan et al., 2008). *R. arboreum* is distributed from subtropical to temperate forests at an altitude of 1200-3500 m (Chauhan, 1999). *Rhododendron arboreum* is the National flower of Nepal and the State tree of Uttarakhand state, India. At low elevation, it mixes with *Pinus roxburghii* Sarg. and broadleaf species such as *Myrica esculenta* Buch.-Ham. ex D. Don, *Quercus leucotrichophora* A. Camus, *Lyonia ovalifolia* (Wall.) Drude, while at high elevation it remains either as under canopy species in *Quercus semicarpifolia* Sm. forests or dominates as canopy species in some locations near the timberline, while in low to mid hills altitudes it remains an under-canopy species in *Q. leucotrichophora* and *Q. floribunda* Lindl. ex A. Camus forest (Gaira et al., 2014). The flower of *R. arboreum* varies in color from a deep scarlet to red with white markings, pink to white. In *R. arboreum*, the floweing occurs during March to May and occasionally takes place in January (Troup, 1921). The annual mean maximum temperature has been reported to be responsible for the shift in flowering dates of *R. arboreum* (Gaira et al., 2014). Versatile flowering time may disrupt the plant pollinator interactions and entire community structure. This study was designed to reveal the year-to-year variability in the pattern of the flowering of *R. arboreum.* An attempt has also been made to convey the information of potential pollinators and their responses to phenological mismatches.

MATERIAL AND METHODS

Study area

Study site is located in the campus of College of Forestry, Ranichauri, Uttarakhand, India, which is situated in 30^0 18' North and 78^0 24' East with an elevation of 1600-2192 m above the sea level (Figure 1). The study was conducted in two reproductive seasons of 2016 and 2017 (second fortnight of December 2015 to June 2017). As per agro meteorological department of College of Forestry, Ranichauri, the maximum mean monthly temperature of the study area ranges from 25.9 ºC to 15.1 ºC in May of 2016 and the corresponding minimum from 11.5 ºC to 2.4 ºC in January of 2017. The study area has received a maximum rainfall of 415 mm in July of 2016 (Figure 2). July and August are the rainy months when maximum rainfall occurs in the study region (Upadhyay et al., 2015). Fifty sample trees of *R. arboreum* were selected randomly for taking various phenological observations during the study.

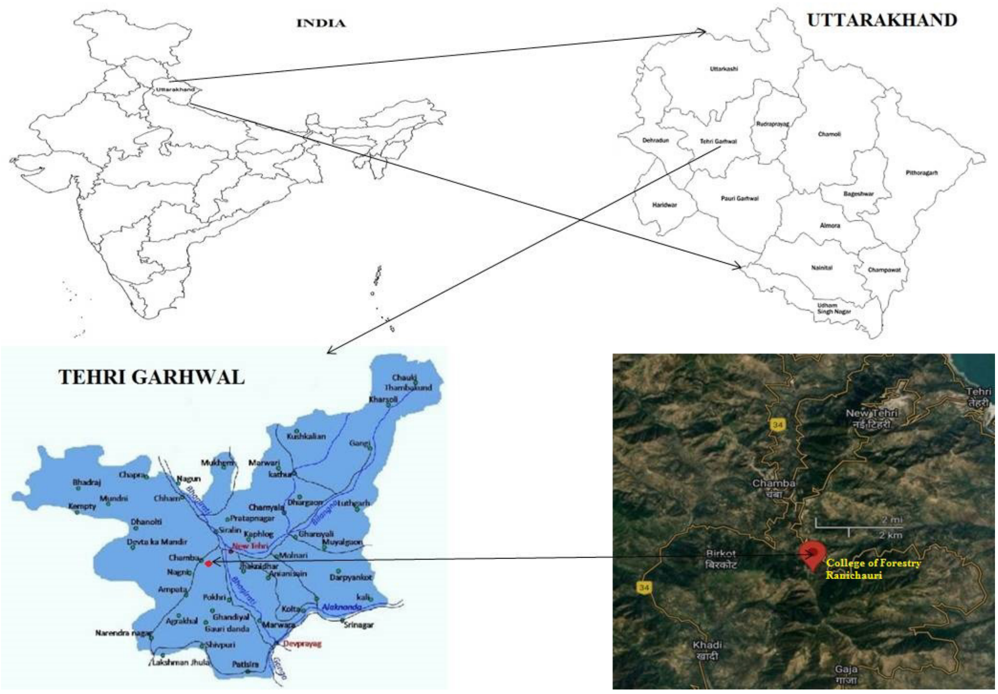

Figure 1. Location map of the study area

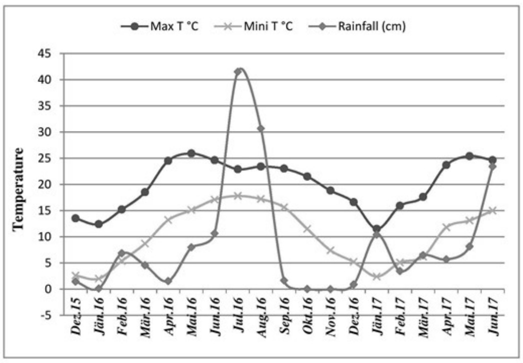

Figure 2. The trend of temperature (Maximum and Minimum) and Rainfall variation in two flowering season of *R. arboreum* on December 2015 to June 2017, Ranichauri, Tehri Garhwal (1600-2192 a asl). Source: Meteorology Department, College of Forestry, Ranichauri.

Floral morphometrics

Ten flowers were chosen randomly and harvested from a tree with a total of fifty flowers from five trees selected randomly in a population. The flower size and shape with corolla, stamen and pistil size were measured manually in a laboratory and the average value for each flower traits was recorded. The cluster of flowers (inflorescences) were also assessed and counted using ten clusters in a tree with a total of fifty clusters from five selected trees. The counting of flowers in a cluster was done directly on selected trees.

Anthesis

Anthesis, by definition the opening of flowers to display the reproductive sex organs (Kalisz et al., 2004), was examined in randomly selected ten inflorescences of five trees. Inflorescences were tagged with colour tags prior to the initiation of flower buds and recorded the stages of developments (Figure 3A to 3F). Observations on anthesis were recorded after every 2 h interval from morning (06:00 h) to evening (16:00 h) in a day during the study period till the culmination of anthesis in all the selected inflorescences in all sampled trees. The flowers opened in each observation period were marked with a permanent marker to avoid error due to duplication and over counting. Air temperature and relative humidity were also recorded with the help of thermohygrometer.

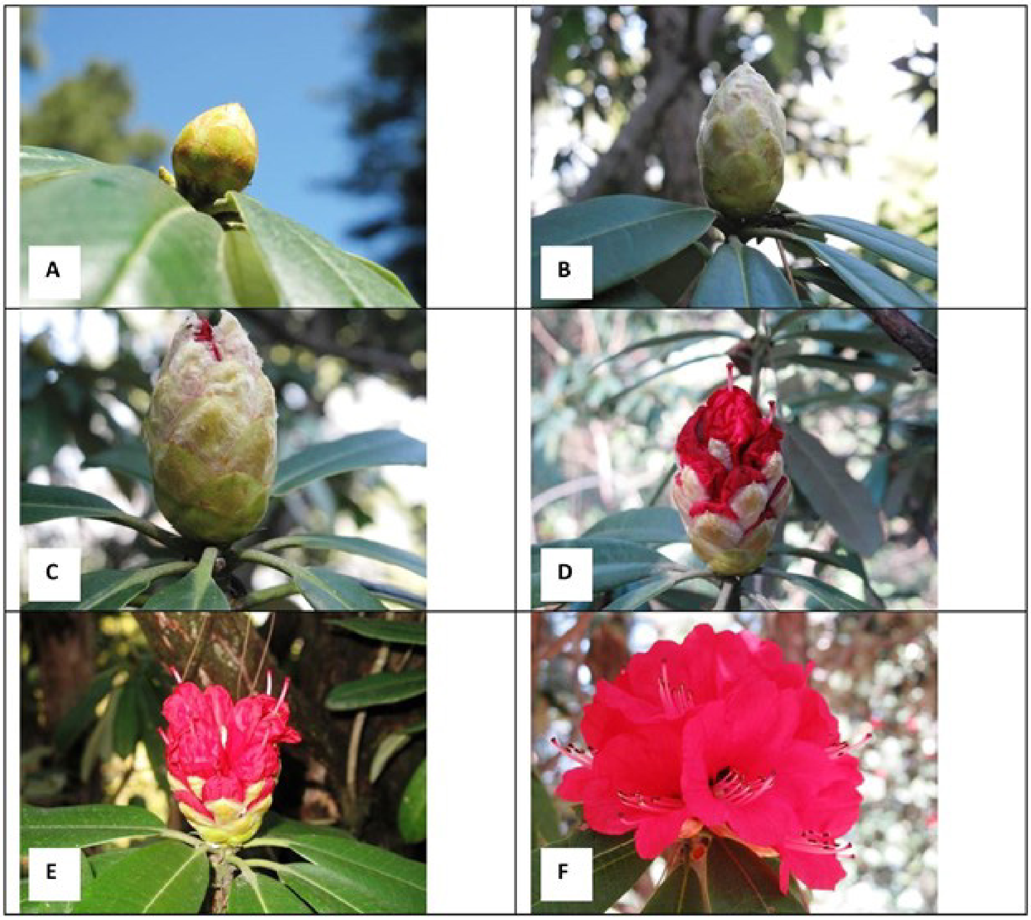

Figure 3. Different stages of anthesis of *Rhododendron arboreum*. A. Developing stage of inflorescence bud after a week of bud initiation, B. Developed bud 2 days before anthesis, C. Bud bursting and initiation of anthesis, D. Beginning and pattern of anthesis, clearly showing that the stigma extended first, E. progress of blooming, showing opening of flowers, F. A full bloomed inflorescence, showing clubbed pollen on dehisced anther surfaces.

Phenology

Phenological observations of *R. arboreum* were carried out from December 2015 to June 2017. The records of reproductive phenological activities were made every week during the flowering phase and at two weeks intervals during fruiting phase. Characterizations of the flower phenological measures were made following Opler et al. (1980) and Sharma & Khanduri (2007). When 10% of individuals of the population were apparent in a particular flower phenophase, then that phase was considered to have started. Similarly, when 10% of individuals remained in a particular phase, that particular phase was considered to have been completed. Phenological parameters viz., flower bud initiation, first flowering, duration of flowering, termination of flowering and fruit formation were carefully monitored. Phenological observations were taken from the fifty chosen trees in the study area that were marked with paint. Observations were recorded visually in flowering and non-flowering period. The timing of all the above-mentioned parameters was recorded and tabulated.

Flower visitor

Observations of flower visitors were recorded on sample trees throughout the day between 06:00 to 18:00 hours in consecutive reproductive episodes (2016-2017). Animal visitors who were visiting the inflorescences were observed for their activity viz., grooming, resting, mating, nesting, frequency of visit per inflorescence and relative abundance. Photographs of the pollinators were taken during the foraging period of the visitors from 6:00 to 18:00 hrs and used for further identification. Pollinators which remained unidentified, were identified with the help of 'The Book of Indian Birds' (Ali, 2002) and 'Birds of India' (Kazmierczk, 2000). Name of visitors, total number of visitors of a species visited, and time of visit and duration of the visits were recorded.

Statistical analysis

ANCOVA (Analysis of covariance) was used to check the existence of variation in the time of visit in a day and pollinator activity in the flowering seasons 2016 and 2017 (concomitant variable: time; dependent variable is: number of pollinators visiting the flower in the season of 2016 and 2017). Student t-test (test for difference of mean) was performed to test whether earlier flowering promoted decreasing or increasing the number of pollinator's visits in the flowering seasons. T- test was also applied to check the variations in total flower production of sample trees in two flowering seasons. Paired t- test was performed to assess the monthly mean temperature and rainfall variation in the two flowering episodes of 2016 and 2017. The effect of air temperature and relative humidity of the day on the number of opened flowers was analyzed using the TWO- WAY ANOVA, with time, temperature and relative humidity as fixed effects – independent variables. Log transformations of variables were done in order to improve the normality of residuals and to reduce heteroscedasticity (Sokal & Rohlf, 1995). The effect of the time period in a day on pollinator visits in two flowering season was also examined with TWO-WAY ANOVA. ANOVA were performed using the VassarStats online (Lowry, 1998).

RESULTS AND DISCUSSION

Floral design and anthesis

R. arboreum is a floriferous species with red, hermaphrodite, exquisitely nectariferous flowers, crowded together in umbels at the tip of the shoots. Flowers are arranged in the racemose inflorescence with a hemispherical shape having the average diameter of $10.9 \pm 0.4_{(Mean\pm sd)}$ to $11.7 \pm 0.5_{(Mean\pm sd)}$ cm (N = 50). Flowers are bright red, pentamerous, bisexual, actinomorphic and arranged in a corymbose cluster with the average number of $15.5 \pm 1.6_{(Mean\pm sd)}$ to $19 \pm 1.9_{(Mean\pm sd)}$ flowers (N = 50). Calyx 5 in number, pale yellow colour, widely ovate and scarious. Corolla has an average length of $3.6 \pm 0.4_{(Mean\pm sd)}$ to $4.2 \pm 0.3_{(Mean\pm sd)}$ cm long (N = 50), 5 lobes, bright red, campanulate, recurved and inserted to the nectariferous disc.

Stamens are 10 in number of different lengths arranged in five pairs with pairs having the same length, consisting of five different lengths of stamens ranging from 1.7 to 2.2 cm, filaments are white, free, curved, inserted on the disc opposite to the petals, porcidial anthers i.e., tubular anthers opening by apical pores on the top (the characteristic of the Ericaceae family). Anthers are 2-celled; the thecae often saccate, cells dehisced apically by the pores, anthers inverted during the developmental phase so as to appear introrse when mature. The ovary is hypogynous, sessile, with a large number of ovules, single style, filiform, stigma capitate. Pistil length varies from $3.66 \pm 0.53_{(Mean\pm sd)}$ to $3.99 \pm 0.34_{(Mean\pm sd)}$ cm and nectar cells are present.

Floral design and display of *R. arboreum* is modified for accelerating outcross pollination especially by birds. Floral morphology had a strong positive effect on the bird pollination success. The contrivances such as large sized flower, differential length of the stamen, long pistil (pin type), deep bright red colour and ample nectar production have been constructed, thus offering the desirable condition for bird pollination in *Rhododendron*. Birds are large and require more energy than insects do. Thus, plants with bird-pollinated flowers tend to put more energy into nectar production and often produce larger flowers to accommodate their avian fauna (Khanduri et al., 2021). In general, large flowered species are out-breeders (Khanduri & Kumar, 2017; Khanduri et al., 2021) and small flowered are in-breeders (Khanduri, 2016). Therefore, the shape and size of the flower can influence reproductive output by affecting the behaviour of pollinator and rates of visitation (Galen & Newport, 1987; Haque & Ghoshal, 1981). Floral morphology of *R. arboreum* is more or less similar to related species in the genera, as reported in other studies such as *R. floccigerum* (Georgian et al., 2015) and *R. luteum* (Sawidis et al., 2011). It is important to expand our focus on understanding the morphology of the flower on pollination because it has long been recognized that the morphology of the flower has an important role in the success of pollination through vectors by inducing or suppressing the rate of visits.

We have analyzed the peak period of anthesis in a set of 50 inflorescences having a mean of 617 flowers each in every year. In our study, it is apparent that the peak period of anthesis observed between 06:00 to 08:00 hrs of the morning provided an insight that flower opening time in a plant in a day would likely be genetically fixed instead of being subject to slight variations arising from microclimatic conditions. The anthesis of the flowers started with the outer flowers first then moved inwards and required 2-4 hours for the complete blooming process. There was no significant effect of tree-to-tree difference in anthesis. However, a significant difference of time interval in a day on blooming was recorded (Table 1); which showed that there was a differential response to microclimate on flower opening.

The timing of flower opening is a critical life-history event because it determines the exposure of the plant reproductive organs to abiotic and biotic conditions that affect plant fitness (Brody, 1997; Elzinga et al., 2007; Sukumaran et al., 2020). Furthermore, the timing of flowering on animal-pollinated plant species is highly associated with the foraging time of pollinators to harbour maximum reproductive success (Kendall et al., 2022).

Table 1. TWO WAY ANOVA of the effect of time and tree to tree differences on anthesis in *R. arboretum* in two reproductive episodes 2016 and 2017

	SV	df	SS	MS	F- ratio	p-Values
2016	Time (6,8,10,12,14, and 16hrs)	5	660.60	132.12	38.60**	0.0001
	Trees	4	11.92	2.97	0.87^{NS}	0.46
	Error	20	68.50	3.40		
2017	Time (6,8,10,12,14, and 16hrs)	5	31002.90	6200.50	41.10**	0.0001
	Trees	4	572.46	143.10	0.95^{NS}	0.46
	Error	20	3019.50	150.90		

SV: Sources of variations, df: degrees of freedom, SS: Sum of squire, MS: Mean squire, NS: non-significant and ** found significant at both 5% and 1%.

Phenology

Various phenological events (average data) such as bud formation, bud bursting, first flowering, peak flowering period, flowering termination and fruit formation were observed and summarized in Table 2. The bud formation in the first reproductive season begun on 30 December 2015 and in the second reproductive season started on 24 December 2016. Bud bursting took place from 15 January in 2016 and 13 January in 2017. The first flowering in 2016 was witnessed on 28 January and on 23 January in 2017, thus it was 5 days earlier than in the reproductive season of 2016. The peak flowering was noticed during 24 February to 18 March in 2016, and 18 February to 16 March in 2017. The duration of peak flowering was for 24 days and 28 days in 2016 and 2017, respectively. The flower termination had occurred 9 days earlier in 2017. The fruit formation in the reproductive year 2016 started from 16 February to 31 March, a total of 44 days, and in 2017 it took the duration of 37 days. After the first flowering, fruit formation started within 15-20 days. The advancement of phenological events of *R. arboreum* in the reproductive year 2017 would likely be the differential response to changes in winter temperature and precipitation, which has also been reported in two distinct ecological niches (i.e., Gaoligong Nature Reserve (GNR) in China and in the Kanchenjunga Conservation Area (KCA) in Nepal) of *R. arboreum* (Ranjitkar et al., 2013). Cumulative variation in flower production in the two subsequent years 2016-2017 was assessed through t-test (test for difference in mean) which showed that there was no significant variation among sample trees (t= 0.190, p =2.306 and p= 3.355).

Table 2. Timing and occurrence of various reproductive phenological events of *R. arboreum* in the years of 2016 and 2017.

Phenological stages	2016	2017
Bud formation	30 December	24 December
Bud bursting	15 January	13 January
First Flowering	28-January	23-January
Peak Flowering period	24 February to March 18	18 February to March 16
Flowering termination	10-April	1-April
Fruit formation	16 February to March 31	19 February to 27 March

Phenological studies in the two consecutive reproductive years of 2016 and 2017 in a population of *R. arboreum* reflected a trend of gradual changes in the phenological events from one to next year. Phenological investigations at the plant population level may improve our understanding of the mechanisms of ecosystem response to climate warming (Oberbauer et al., 2013), which is expected to threaten global biodiversity greatly (Thomas et al., 2004; Dawson et al., 2011). The most striking result in our study was that the initial time of blooming which advanced up to 6 days on an average and termination of flowering had diminished a minimum of 9 days in the flowering season of 2017 when compared to the year 2016. Moreover, the flowering of *R. arboreum* was often occurring from March to May (Troup, 1921); and is now evidenced to occur between early February and mid March (Gaira et al., 2014). The trend of flowering as per the results of current study also revealed advancement of flowering between February and March of target species which could be due to the effect of climate change on plant phenology (Khanduri et al., 2008; Gaira et al., 2014). The temperature of Ranichauri (study location) has been found to increase by 0.013 ºC per year in maximum temperature (Upadhyay et al., 2015); that might also be reason of the advancement of the flowering of *R. arboreum*. It has also been observed in a study of North-Eastern Himalaya that the population of *R. arboreum* occurring at the lower altitude was induced to an earlier onset of flowering when compared to that of higher altitude (Malsawmkima & Sahoo, 2020). For most plant species, climate warming may lead to earlier flowering in spring and delayed flowering in autumn (Ibáñez et al., 2010). Furthermore, early flowering in plant species has been attributed to their greater responsiveness to temperature variations (Aono & Kazui, 2008) and its microhabitat (Buide et al., 2002). Our study strongly suggests that onset of flowering in *R. arboreum* was attributed mainly to the scarcity of winter precipitation and temperature variations. Similar findings were also obtained in the past, such as an advancement in flowering time by 88 – 97 days over 119 years based on herbarium and real-time field observations for *Rhododendron arboreum* (Gaira et al., 2014); 17–25 days advancement over the last 100 years for *Aconitum heterophyllum* (Gaira et al., 2011). Changes in plant phenological patterns have been associated with the species specific plant structural architecture, availability and transfer of nutrients (Sosebee & Wiebe, 1973), plant growth rates (Taylor Junior, 1972), temperature (Nuttonson,1955), and precipitation (Blaisdell, 1958).

The present study demonstrated that all the reproductive phenological events such as bud formation, bud bursting, first flowering, peak flowering, termination of flowering and fruit formation occurred earlier in the year of 2017 when compared to 2016. We found that advancement of reproductive phenological events of *R. arboreum* in the year 2017 would likely to be the differential response of the plant to the changes in winter temperature and precipitation. It is most likely that reproductive phenological shift (delaying or forwarding the circadian events in plants) could be considered as a reaction mechanism in plants, as it may vary among species according the action of climate driving forces such as precipitation and temperature. This pattern may be propitious for the plant sustenance and fitness because it may decrease energy loss; increase or decrease the pollination success and reproduction (Parmesan & Yohe, 2003).

Flower visitor observation

Birds of families Pycnonotidae, Zosteropidae and Turdidae i.e., Black Bulbul (Figure 4A), Oriental White Eye (Figure 4C) and Grey Winged Blackbird were found to be the major bird visitors in *R. arboreum*. Other floral visitors observed were Rufous sibia (Figure 4B), Great Barbet, Red Billed Magpie, Brown Fronted Woodpecker, Slaty Backed Flycatcher and Bumble Bee (Figure 4F). Most frequently observed bird visitors were *Hypsipetes leucocephalus* (in a large group of 8-39 individuals), followed by *Zosterops palpebrosus* (7-9 individuals) and *Turdus boulboul* (1-3 individuals). The recorded three bird species were found as potential pollinators in *R. arboreum* that help in pollination. Even though the morphology of the larger birds indicated that they were able to fit their head into the corolla of *R. arboreum*, in some instances the robbing and destructing behaviour of visiting species was also observed. *Psittacula himalayana* were also observed in large groups (Figure 4D, 4E), but they are generally visited for basking rather than feeding on flowers. Although they feed on flowers, they also were observed destroying the corolla of the flowers thereafter feeding on it, because their beak structure is not suitable for feeding on flowers. The maximum percentage of visits - 29.93% (2016) and 34% (2017) - were recorded between 06:00 to 08:00 hrs, followed by 27.89% (2016) and 32% (2017) during 16:00 and 18:00 hrs of the day. The difference in the total number of individuals visited in two flowering seasons of 2016 and 2017 was not significant (t=4.20, p= 2.776). Analysis by ANCOVA showed that there were no significant differences between number of pollinator visits and corresponding time of the day in the two flowering years of 2016 and 2017 (Table 3, F=0.34, d.f=1, p=0.57). ANOVA results also showed that there was a weak significant effect on pollinator activity at variable time interval in a day (F=2.758, d.f=5, p=0.145). Thus, inflorescences received most pollinator visits during the morning and evening hours of the day and rarely in the afternoon. From the detailed observations, it was apparent that the number of visits and bird activity was high in morning 06:00-08:00 hr, coinciding with the peak time of anthesis (Table 4).

Table 3. ANCOVA results of time of visit and pollinator activity in the flowering seasons 2016 and 2017.

SV	SS	df	MS	F	P
Time	216.75	1	216.75	0.34^{NS}	0.57
Error	5747.72	9	638.64		
total	5964.47	10			

SV: Sources of variations, df: degrees of freedom, SS: Sum of squire, MS: Mean squire, and NS: non-significant.

Table 4. Visitors observed on the flowers of the *R. arboreum* in the two reproductive episodes (2016 and 2017). NV: Name of the visitor, SN: Scientific name, F: Family, TN 2016: Total number of individuals visited in 2016, TN 2017: Total number of individuals visited in 2017 and D: Duration of one visit (mini-max) (in a sec)

NV	SN	F	TN 2016	TN 2017	D
Time interval 6:00 to 8:00					
Black Bulbul	*Hypsipetes leucocephalus*	Pycnonotidae	28	39	3-5
Rufous Sibia	*Heterophasia capistrata*	Timalinae	2	4	7-9
Red Billed Blue Magpie	*Urocissa erythrorhyncha*	Crovidae	0	1	5-6
Grey Winged Blackbird	*Turdus boulboul*	Turdidae	1	2	3-5
Slaty Headed Parakeet	*Psittacula himalayana*	Psittaculidae	10	13	120- 180
Oriental White Eye	*Zosterops palpebrosus*	Zosteropidae	3	7	2-3
Slaty Backed Flycatcher	*Ficedula hodgsonii*	Muscicapidae	0	1	2-4
Time interval 8:00 to 10:00					
Great Barbet	*Megalaima virens*	Megalaimidae	2	2	3-6
Oriental White Eye	*Zosterops palpebrosus*	Zosteropidae	4	6	1-2
Slaty Headed Parakeet	*Psittacula himalayana*	Psittaculidae	9	17	60-120
Grey Winged Blackbird	*Turdus boulboul*	Turdidae	0	1	3-6
Black Bulbul	*Hypsipetes leucocephalus*	Pycnonotidae	16	23	3-5
Brown Fronted Woodpecker	*Dendrocopos auriceps*	Picidae	4	2	11-Dec
Time interval 10:00 to 12:00					
Grey Winged Blackbird	*Turdus boulboul*	Turdidae	3	1	4-6
Black Bulbul	*Hypsipetes leucocephalus*	Pycnonotidae	16	8	4-5
Red Billed Blue Magpie	*Urocissa erythrorhyncha*	Crovidae	3	1	3-4
Time interval 12:00 to 2:00					
Oriental White Eye	*Zosterops palpebrosus*	Zosteropidae	1	5	2-3
Bumble bee	*Bombus spp.*	Hymenoptera	0	1	1-2
Time interval 2:00 to 4:00					
Rufous Sibia	*Heterophasia capistrata*	Timalinae	4	1	6-9
Time interval 4:00 to 6:00					
Great Barbet	*Megalaima virens*	Megalaimidae	6	2	3-4
Brown Fronted Woodpecker	*Dendrocopos auriceps*	Picidae	1	2	8-10
Oriental White Eye	*Zosterops palpebrosus*	Zosteropidae	2	9	1-2
Black Bulbul	*Hypsipetes leucocephalus*	Pycnonotidae	23	33	4-5
Slaty Headed Parakeet	*Psittacula himalayana*	Psittaculidae	9	17	120-150

Flower opening time has shown to be synchronous among focal trees of the populations studied which overlapped with the peak activity period of potential pollinator (birds) in the two flowering seasons. However, significant numbers of birds were also observed between 4 – 6 pm, and should be investigated about nocturnal perches in *R. arboreum* in future, as that has not been done so far. Our results showed that the cumulative impact of phenological shift would most likely be to enhance or shorten the total duration of the reproductive period. However, it has the least effect on the stages of its own clock, since regularity results in reducing the possibility of temporal mismatches between plant and pollinator phenology.

Moreover, we found that earlier flowering in *Rhododendron* in 2017 did not increase the number of pollinator visits but might have increased the frequency of visits (which was not recorded in this study), as a result of high peak flowering amplitude, increased flower display and more availability of total food resources. Past studies reported that earlier flowering led to greater pollination for plants (Rafferty & Ives, 2011). Increased flower abundance within a community may affect the reproductive success of plant species through increased visitation rates. As a result the pollinator behaviour and composition of the pollinator community was altered, which ultimately increases out-crossing rates and seed production (van Treuren et al., 1994; Johnson & Steiner, 2000; Hegland & Totland, 2005). Increased flower numbers enhance food availability which appears to be one of the most important factors governing the activity and population density of many pollinator species (Steffan-Dewenter et al., 2002; Westphal et al., 2003; Hegland & Boeke, 2006; Steffan-Dewenter & Schiele, 2008).

Figure 4. Floral visitors of *R. arboreum* (A: Black Bulbul feeding on *R. arboreum* flowers, B: Rufous Sibia feeding on *R. arboreum* flowers, C: Oriental White Eye perching on *R. arboreum,* D: Slaty Headed Parakeet feeding on *R. arboreum* flowers, E: Slaty Headed Parakeets perching on *R. arboreum* tree, F: Bumble bee feeding on *R. arboreum* flower.

Interestingly, we found that the number of species which visited the focal plant did not show much variation in the two flowering seasons; which was interpreted as that the onset of flowering did not disrupt the network of plant (*R. arboreum*) and pollinator (birds). One possible explanation for our result is that the advancement in flowering is due to climate change that seemed to have a substantial impact on the reproductive success in plants which often pollinated by poikilothermic (i.e. insects) animals than homeotherms (i.e. birds). In addition, birds are large and require more energy than insects, thus the advancement in flowering seems to have accelerated bird pollination. In contrast, shortening of total reproductive period would result in a gap between the supply of resources and requirements of birds. Therefore birds may be forced to opt for secondary food resources which disrupt total food web network of pollinators; which in turn would affect habitat loss and extinction of species. Bird distributional shifts have already been linked to climate change (Gregory et al., 2009; Niven et al., 2009; Chen et al., 2011). Unchecked climate change, combined with habitat loss, may lead to the extinctions of hundreds of bird species (Sekercioglu et al., 2008).

CONCLUSIONS

Along with temperature variability and anomalous rainfall pattern in the winter season. It is most likely that the reproductive phenological shift could be considered as a positive reaction mechanism in plants, as it may vary among species against the action of climate driving forces. Pollinator activity and reproductive success vary with total availability of food resources, as scarcity of food reduces the chances of pollinator visit which result in pollen limitation and reproductive failure. Our findings also suggest that there was a linear relationship between plant and birds with increasing temperature up to certain limit. Thus, our results provide additional evidence and explanation for the variable response of *R. arboreum* to climate change. Further research is needed to see whether the trend continues, and what might be the effect on the activity of birds in the population in future.

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