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FLOWERING PHENOLOGY OF TREE *RHODODENDRON ARBOREUN* ALONG AN ELEVATION GRADIENT IN DIFFERENT SITES OF KUMAUN HIMALAYAS

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ABSTRACT
The present study carried out flowering phenology of tree rhododendron (*Rhododendron arboreum* Sm.) along elevation gradient in eight distinct ecological regions. Observations were carried out between 1650 m to 2460 m elevation in the Kumaun Central Himalaya. The distribution of tree rhododendron indicated that it is able to grow in a wide range of habitat with different environmental conditions. It is an under canopy tree species in central Himalaya. Crown density method was used for observation of flowering events of the selected species. Flowering timing and duration were determined within each site and along the elevation gradient in each study area. Our study showed results different between elevation to elevation in all the study sites. The early initial and peak flowering in lower elevation sites were probably due to the warm temperature. Winter temperature was the most important variable for initial and peak flowering dates. After temperature, soil moisture and rainfall was the most important factor for explaining initial flowering timing. The recent trend of early bloom may be due to the changing of climatic condition. The flowering timing of tree rhododendron was affected by different environmental conditions.

KEYWORDS: Phenology, *Rhododendron arboreum*, Initial flowering, Peak flowering, Climate change.

INTRODUCTION

Phenology is simplest terms, is the study of events of nature, in response to seasonal and climatic changes to the environment. The definition of phenology is "phenology is the study of timing of recurring biological events the causes of their timing with regards to biotic and abiotic factors and the inter-relation among phase of same or different species" (Lieth, 1974). The seasonality of photosynthesis in winter dormant/summer active ecosystems is also phenological in nature, as are the annual cycles of other ecosystem processes (*e.g.* Noormets *et al*., 2009). It involves the study of the response of living organisms to seasonal and climatic changes of the environment in which they live. Plants are adapted to the annual seasonal cycle and all the life – cycle stages are regulated by seasonal atmospheric changes. It is important to keep track of cyclical events such as appearance of buds, buds bursting, leafing, flowering, first bloom, pollination, fertilization, seed formation, seed development and dispersal of seeds from year to year, and to determine how they relate to the weather patterns. Flowering time is for many reasons a suitable trait for studies of distribution of genetic variation within and between populations. Traditionally flowering time variation has been an important component in studies of plant life history evolution. The timing of flowering is also most essential for species survival, and is shown in many studies to be highly correlated with plant fecundity (*e.g.*, O'Neil 1997, Kelly & Levin 2000, Stinson 2004). The most important proximal environmental cues determining flowering time are considered to be temperature and day length (Reeves & Coupland 2000). Flowering time distribution in plant populations can be shaped by numerous biotic and abiotic factors, such as pollinator activity (Lack 1982, Rathcke & Lacey 1985, Widen, 1991. Freeman *et al.,* 2003), selection for synchrony with members of same species and/or other species (1981, Rathcke & Lacey, 1985), herbivory (*e.g*., Juenger & Bergelson, 2000, Pilson 2000, Freeman *et al.,* 2003), temperature (*e.g*., Totland, Reeves & Coupland 2000) and drought (*e.g*., Dudley 1996, Heschel & Riginos, 2005). The final distribution of flowering time is a result of many factors acting together in a frame set by underlying genetic architecture (Coupland, 1995, Simpson *et al.,* 1999). Studies with *Arabidopsis thaliana* mutants have is covered multiple genetic pathways that lead to flowering (*e.g*., Reeves & Coupland, 2000, Mouradov *et al.,* 2002). Climate change is a shift in the "average weather" that a given region experiences. That the changes in the climate of the earth as a whole would mean "global climate change". The earth's natural climate has always been and still is constantly changing. These changes are measured by the change in all the features we associate with weather, such a temperature, wind patterns, precipitation and storms. The climate change seeing today different form previous climate change in both its rate and magnitude (Seth, 1980). With increasing warming, species and ecosystems are likely to shift from lower to higher altitudes and latitudes. Due to this the species would need to migrate upwards to survive. However the upward movement of alpine species occurring near the mountain peaks is likely to be restricted by the lack of space and soil. Some of the important alpine species of Himalaya that may face immediate extinction include oak (*Quercus semecarpifolia*) (Singh, 1997) and Rhododendron species. *Rhododendron arboreum* (Family Ericaceae) is an under canopy species occurring between 2000 m and 3000 m altitude in oak dominated forest. *R. arboreum* is distributed between 1000 m to 2500 m elevation in Kumaun Himalaya. The central Himalayan forests are rich in many tree species and Rhododendron is one of the important associated species from low to high elevation forests of the region. The Burash *(Rhododendron arboreum*) either form pure stand or associated with Oak (*Quercus leucotrichophora, Quercus floribunda, Quercus semecarpifolia*), deciduous species and Pine species etc. In the present study attempt has been made to monitor the timing of flowering phenology in *R. arboreum* from lower to higher elevation and comparison with earlier studies by Ralhan, 1982.

MATERIALS & METHODS

Study site

The study sites are located between (29˚22' and 29˚27' N and 79˚23' and 79˚28' E) in the Kumaun Central Himalaya. Flowering phenology of *Rhododendron arboreum* along an elevation gradient covering the local distribution ranges of the tree *R. arboreum* were chosen in Patwadagar (PTD), Kailakhan (KLK), Bhowali (BHL), Pangot (PNG), Tiffon Top (TFT), Birla (BRI), Kilbury (KLB) and China Peak (CHP) at Nainital district of Kumaun Himalaya. The study sites were located between 1650 to 2460 m altitudes. The observation sites represent cool temperate and sub – tropical to temperate climate types, and mid to heavy snowfall occurs during January to February in high elevation sites. Metrological recording shows annual precipitation range between 1072 to 2600 mm, with the humidity percentage is range between 30 to 80%. The mean maximum temperature varies from 15.5˚C to 21.5˚C and minimum temperature varies between 7.0˚C to 10.0˚C. It was high in June and low in January (ARIES, Nainital). Typical vegetation is mixed broad-leaf forest, composed mainly of species like *Quercus leucotrichophora, Shorea robusta, Pinus roxburghii, Acer oblongum, Quercus floribunda, Cupressus torulosa, Cedrus deodara, Alnus nepelensis, Quercus semecarpifolia* and *Myrica esculenta* from low to high elevation.

Field Data Collection

On each site, randomly ten to twelve phenotypically superior trees were selected and marked for the flowering phenological events of *R. arboreum* along the elevation gradient. The superiority characters for tree were taken as healthy trees, free from buttresses, well developed crown and middle aged trees approaching maturity. Soil sample were collected before flowering began from observation plots at all the study site. Sample was done at two different depths (0-15 cm and 15-30 cm) from observation site. All soil samples from each plot were mixed to arrive at one set of soil parameters per plot. Soil samples were sending to laboratories for determination of organic material, moisture content and pH. Details site characteristics are presented in Table 1.

Phenological observation

The phenological events were observed from bud bursting to seed formation. For this, frequent field visits were made to observation the different phenological events. Data on the season of flowering phenology for 75 trees from eight sites in the study area were used for analysis. The different phenological events were observed in 10 days interval during low activity period and weekly at peak activity period for each phenological event. The phenological data compare with the past study of the phenology and the influence of climate change on phenological events was determined.

TABLE 1. Site characteristics in the Study area

Site	Ele	Lat	Long	Lit	Can	Asp	Snow fall	SM	pH	Other feature
PTD	1650	29º22’11	79º27’76	25	57	South	NA	7.1	5.9	LM
BHL	1850	29º39’04	79º48’85	60	54	East	Little	6.0	7.2	SH
PNG	1890	29º25’22	79º25’46	50	50	North	Medium	23.8	8.5	LM
KLK	1900	29º22’39	79º28’44	40	52	East	Little	16.4	6.2	HD
BRl	2120	29º39’01	79º46’72	70	70	East	Heavy	21.6	5.9	HD
KLB	2140	29º25’18	79º26’16	100	80	North	Heavy	54.4	6.3	SH
TFT	2150	29º38’35	79º40’85	90	50	West	Heavy	22.4	6.2	M
CHP	2460	29º38’07	79º23’70	80	75	North	Heavy	18.3	6.5	SU

Ele elevation (m), Lat latitude (°), Long longitude (°), Lit litter (%), Can canopy coverage (%), Asp Aspect, SM soil moisture, M moist, LM less moist, HD human disturbance, SH shady, SU sunny.

RESULTS

In the entire eight study site, flowering phenology of *Rhododendron arboreum* along the elevation gradients flowering commenced in mid-December and lasted until the last week of May. At 1650 m elevation, the mean duration of the flowering phases was 34.1±1.03 days. At 1850 m elevation, the mean duration of the flowering phases was 45.5±0.93 days. At 1890 m elevation, the mean duration of the flowering phases was 36.3±1.52 days. At 1900 m elevation the mean duration of the flowering phases was 39.1±0.52 days. At 2120 m elevation, the mean duration of the flowering phases was 40.7±1.21 days. At 2140 m elevation, the mean duration of the flowering phases was 38.8±0.93 days. At 2150 m elevation, the mean duration of the flowering phases was 45.1±2.01 days. At 2460 m elevation, the mean duration of the flowering phases was 49.8±1.43 days. The overall flowering duration was shorter at 1650 m elevation and longer was at 2460 m elevation. The mean duration of the flowering phases over all individual was 16 days longer at 2460 m elevation than the 1650 m elevation. The initial flowering, peak flowering and end of flowering time at different elevation in all the study site are given in table 2.

TABLE 2. Flowering dates of tree rhododendron averaged for each observation site along the elevation gradient in the study area.

Flowering	Elevation							
	1650m	1850m	1890m	1900m	2120m	2140m	2150m	2460m
Initial	30 Jan	15 Feb	25 Feb	5 Feb	15 Feb	22 Feb	20 Feb	10 Feb
Peak	20 Mar	10 Apr	10 Apr	25 Mar	20 Mar	5 Apr	10 Apr	5 Apr
End	02 May	28 May	30 May	20 May	20 May	26 May	30 May	31 May

In some observe trees peak flowering duration was very short with all branches blooming at the same time and most flowers shed simultaneously. In other trees peak flowering duration was substantially longer. Flowering pattern and duration varied from tree to tree within each site and elevation to elevation (Fig. 1, 2, and 3). In some trees, all branches were in bloom simultaneously; while in other bloom was staggered. Simultaneous flowering shortened bloom duration, while in the latter case it was extended (Fig. 2). The mean initial flowering dates occurred during the second and third week of February (Table 2 and Fig. 3). Peak flowering started from second week of March until the late April (Table 3 and Fig. 4). End of flowering started from second week of May until the first early June (Table 2). At all the study sites, initial flowering dates were generally delayed with increasing elevation, but due to high variation among individual trees, there was no significant trend. In addition to slight delayed in initial bloom, flowering periods were contracted at high elevation.

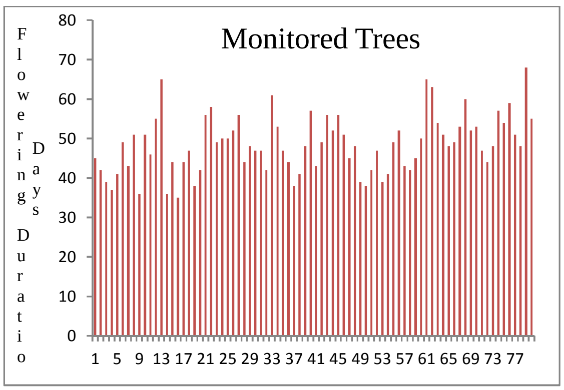

FIGURE1. Flowering Duration (per Tree)

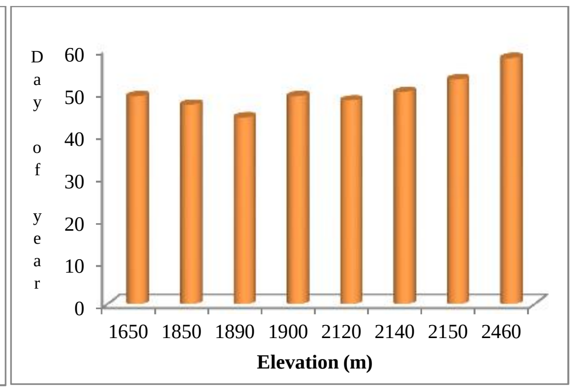

FIGURE 2. Initial Flowering (per tree)

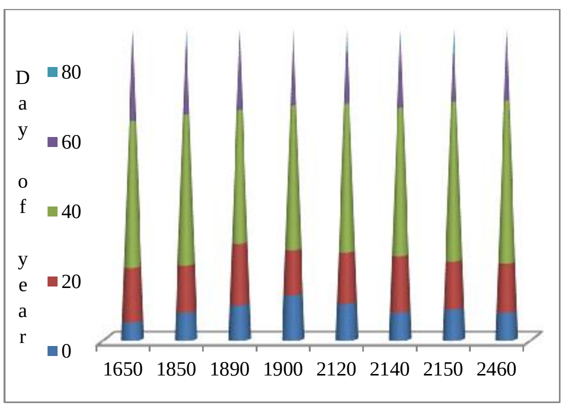

FIGURE 3. Average Initial Flowering (Density)

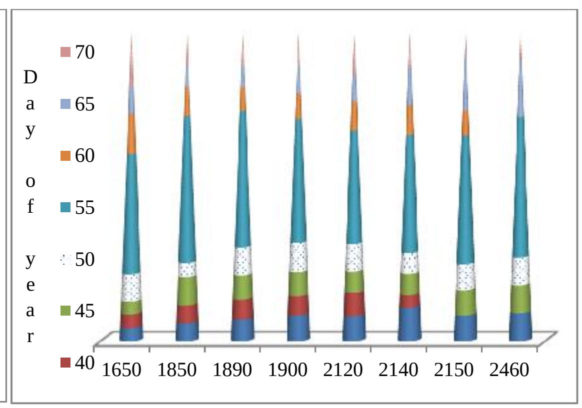

FIGURE 4. Average Peak Flowering (Density)

DISCUSSION

Plant phenology is strongly controlled by climate and has consequently become one of the most reliable bio-indicators of ongoing climate change. Climate change has affected the phenology of a wide range of species but it remains difficult to interpret these shifts and to explain the variation among species and even among populations with in species. Differences in temporal responses of plant phenology to recent climate change are due to differences in the sensitivity to climate among events and species. Plants are finely tuned to the seasonality of their environment, and shifts in the timing of plant activity (*i.e.* phenology) provide some of the most compelling evidence that species and ecosystems are being influenced by global environmental change. In the present study, our observation showed earlier bloom at lower elevation site, and longer flowering periods with increasing elevation. The current study results are in line with earlier studies describing delayed flowering and contractions in bloom duration with elevation for different species (Crimmins *et al.,* 2009; Rusch, 1993). Occasional deviation from this pattern along our elevation gradients may have been caused by variation in micro-environmental factors (Gimenez-Benavides *et al*., 2007). The result different between the all study sites, winter temperature and rainfall was the most important control on initial and peak flowering events in all sites. The distribution of Rhododendron indicates that it is able to grow in a wide range of habitats with different environmental conditions. In spite of differences in the timing of the first and peak bloom dates among trees within each of the study sites was high. This was probably due to longer flowering periods by individuals at higher elevations compare to those at lower elevations, which ensured overlap even with late-blooming trees everywhere. The recent trend of rising winter-spring temperature and the detected bloom-advancing effect of high temperatures 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 (Luo *et al*., 2007). Previous studies have demonstrated that plant communities have shifted their phenology in recent decades (Ralhan, 1985a and 1985b) but there is a lack of consistency with respect to the phenological events analyzed. The flowering phenology of *R. arboreum* is differs from place to place in the present study. This indicated that the flowering phenological events changes, because the temperature and moisture present in the soil (Ralhan, 1985a and 1985b). The leafing and flowering is a simultaneous process, after the bud bursting (within 18 – 25 days), the initial flowering was reported from 30 January, at 1650 m elevation, while at other elevation it was delayed (3 – 4 week). The peak flowering was reported from 20 March, at 1650 m elevation. We have compared the flowering period of *R. arboreum* with the earlier study made by Ralhan (1982). He reported a first flowering in *R. arboreum* during 15 March and appeared 2 – 3 flowers per tree during this period. Variation in flowering time suggests adaption to the length of the growing season. The important determination of flowering time, temperature, rainfall and day length has strong latitudinal gradients. In high-altitude Speterstulen population this can be due to short growing season availed for seed maturation, as e.g., in the alpine Rhododendron (Kudo, 1993). Besides the need of trees at lower elevations to complete their seed production process in a shorter time than trees of the same species at higher elevations, this evolutionary principle may be responsible for the observed flowering patterns. Probably due to the longer prevalence of warm temperature, less or no snow fall and less humidity present in soil in lower elevation compare to higher elevation. Soil temperature is an important factor, in the present study soil temperature was high in lower elevation than the higher elevation, and it decreased with increasing elevation. Soil temperature showed a significant correlation with flowering phenology, confirming results by Dahlgren *et al*. (2007), who worked on *Actaea spicata.* This probably reflected the strong correlation between soil temperature and air temperature (Chudinova *et al*., 2006), which has been identified as the strongest driver of phenology since selection for early initiation of flowering was strongest in the environmental with the shorter growing season and in the colder year, it is likely related to the climatic factors, directly via pollinations.

The changes of shifting of flowering patterns form elevation to elevation, in the current study sites, the flowering patterns suitable to higher elevation sites, compare to lower elevation sites, because species and ecosystems are likely to shift from lower to higher elevation and the capacity of high elevation population to adapt to environmental change is higher than that of population at lower elevation. Due to this the species would need to migrate upward to survival. In the present study, early winter temperatures were the most influential factor for initial flowering phenology and late winter to early summer temperature and soil moisture was important influence factor for peak flowering.

REFERENCES

Chudinova, S.M., Frauenfeld, O.W., Barry, R.G. (2006) Relationship between air and soil temperature trends and periodicities in the permafrost regions of Russia. J Geophys Res111: F02008.doi:10.1029/2005JF000342

Crimmins, T.M., Crimmins, M.A., David Bertelsen, C. (2009) Flowering range changes across an elevation gradient in response to warming summer temperatures. Glob Chang Biol 15:1141–1152. doi:10.1111/j.1365-2486. 2008.01831.x

Coupland, G. (1995) Genetic and environmental control of flowering time in *Arabidopsis*. Tends in Genetics 11(10): 393-397.

Dahlgren, J.P., von Zeipe, L.H., Ehrlen, J. (2007) Variation in vegetative and flowering phenology in a forest herb caused by environmental heterogeneity. Am J Bot 94:1570–1576

Dudley, S.A. (1996) Differing selection on plant physiological traits in response to environmental water availability: a test of adaptive hypotheses. Evolution 50: 92-102.

Freeman, R.S., Brody, A.K. & Neefus, C.D. (2003) Flowering phenology and compensation for herbivory in *Ipomopsis aggregate*. Oecologia 136: 394-401.

Gimenez-Benavides, L., Escudero A., Iriondo, J.M. (2007) Reproductive limits of a late flowering high-mountain. Mediterranean plant along an elevational climate gradient. New Phytol 137: 367-382. Doi: 10. 1111/j. 1469-8137. 2006.01932.x

Heschel, M.S. & Riginos, C. (2005) Mechanisms of selection for drought stress tolerance and avoidance in *Impatiens capensis* (Balsaminacea). American Journal of Botany 92(1): 37-44.

Juenger, T. & Bergelson, J. (2000) The evolution of compensation to herbivory in Scarlet gilia, *Ipomopsis aggregata*: herbivore-imposed natural selection and the quantitative genetics of tolerance. Evolution 54(3): 764-777.

Kelly, M.G. & Levin, D.A. (2000) Directional selection on initial flowering date in *Phlox drummondii*

(Polemoniaceae). American Journal of Botany 87: 382-391.

Kudo, G. (1993) Relationship between flowering time and fruit set of the entomophilous alpine shrub, *Rhododendron aureum* (Ericaceae) inhabiting snow patches. American Journal of Botany 80: 1300-1304.

Lack, A. (1982) Competition for pollinators in the ecology of *Centaurea scabiosa* L. and C*entaurea nigra* L. New Phytologist 91: 297-308.

Lieth, H. (1974) Purposes of a phenology book. Pp 3-19. In: (H. Lieth, ed.) Phenology and Seasonality Modeling. New York: Springer-Verlag. 444 pp.

Luo, Z, O. J. Sun, Q. Ge, W. Xu and J. Zheng (2007) Phenological responses of plants of climate change in an urban environment. *Ecological Research*; 22: 507 -0 514.

Mouradov, A., Cremer, F. & Coupland, G. (2002) Control of flowering time: interacting pathways as a basis for diversity. Plant Cell 14: 111-130.

Negi, GCS (1989) Phenology and nutrient dynamics of tree leaves in Kumaun Himalaya forest. Ph.D. thesis, Kumaun University, Nainital.

Noormets, A. (Ed.) (2009) Phenology of Ecosystem Processes. Springer, New York, 275 pp.

O´Neil, P. (1997) Natural selection on genetically correlated phonological characters in *Lythrum salicaria* L. (Lythraceae). Evolution 51(1): 267-274.

Pilson, D. (2000) Herbivory and natural selection on flowering phenology in wild sunflower, *Helianthus annus*. Oecologia 122: 72-82.

Ralhan, P.K. (1982) Phenology of plants in forest ecosystems of Kumaun Himalaya. Ph.D. thesis, Kumaun University, Nainital.

Ralhan, P. K., Sexena, A. K. and Singh, J. S. (1982) Analysis of forest vegetation at and around Nainital in Kumoun Himalaya. Proc. Indian. Natn Sci. Acad. B 48 No. 1 – 121 – 137.

Ralhan, P. K., Khanna, R. K., Singh S. P. and Singh, J. S. (1985) Phenological characteristic of the tree layer of Kumaun Himalaya forests. *Vegetation* 60:90– 101.

Rathcke, B.J. & Lacey, E.P. (1985) Phenological patterns of terrestrial plants. Annual reviews in Ecology and Systematics, 16: 179-214.

Reeves, P.H/ & Coupland, G. (2000) Response of plant development to environment: control of flowering by daylength and temperature. Current Opinions in Plant Biology 3: 37-42.

Rusch, V.E. (1993) Altitudinal variation in the phenology of Nothopha – guspumilio in Argentina. Rev Chil Hist Nat 66:131–141

Seth, S. K. (1980) Forest and forestry in Himalayan region. Proceedings of national seminar on resource development and environment in the Himalayan region. pp. 70 – 97. Department of Science and Technology, Govt. of India, New Delhi.

Simpson, G.G., Gendall, A.R. & Dean, C. (1999) When to switch to flowering. Annual Review in Cell and Developmental Biology, 99: 519-550.

Singh, S.P., Rawat, Y.S. and Garkoti, S.C. (1997) Failure of brown oak (*Quercus semecarpifolia*) to regenerate in central Himalaya: A case of environmental semi surprise. *Current Science* 73: 371-374.

Stinson, K.A. (2004) Natural selection favors rapid reproductive phenology in *Potentilla pulcherrima* (Rosaceae) at opposite end of a subalpine snowmelt gradient. American Journal of Botany 91(4): 531-539.

Totland Ø (1999) Effects of temperature on performance and phenotypic selection on plant tarits in alpine *Ranunculus acris*. Oecologia 120: 242-251.

Widen, B. (1991) Phenotypic selection on flowering phenology in *Senecio intergrifolius*, a perennial herb. Oikos 61: 205-215.