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Variation in Phenology of Banj Oak (*Quercus Leucotrichophora*) Tree Across different Elevations in the Kumaun Himalayas, India.

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Abstract

Changes in phenological events have been caused by the present phenomenon of climate change. The elevation is another important factor which leads to the variations in phenological events. The Banj Oak plays holds a vital position as a keystone species in the moist temperate forests of the Central Himalayas, and contribute to human well-being by providing essential benefits such as biodiversity conservation, maintenance of soil organic matter, and the ability to retain water. Thus, this study aims to evaluate the various phenological events of *Q. leucotrichophora* tree species along the elevation gradients. The elevation gradients are low (1400-1600 m), mid (1700-1900 m) and high (2000-2200 m). At each elevation, three sites were selected for the detailed phenological study. The observations were made from bud initiation to seed fall. In general, leaf bud break and leaf fall were initiated earlier in low-elevation species. In comparison with the middle and high elevation, at low elevation the growth initiation occurred in February and March when the temperature had begun. Comparisons with previous studies have shown that some phenological events began to occur early. The study clearly indicates that climatic irregularities have influenced or altered the phenological events of species. It can be said that the phenological events changes with climatic factors, which are responsible for earlier or delayed phenophases. Understanding phenology and its variations can offer significant data. Consequently, this knowledge can be highly valuable for agricultural practices, which necessitate advanced information on particular stages of tree growth.

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Introduction

The Himalayan region is extremely vulnerable to the impacts of global warming and climate change, posing a significant threat to its forest ecosystem. Phenological plant events serve as an effective indicators of climatic variations.[1] The growing demand for indicators on climate change impacts, coupled with the distinct rise in air temperature across numerous northern hemisphere regions since the late 1980s, has led to an increasing interest in phenological data.[2] Phenology has arisen as a significant area of interest in ecological research.[3] Phenology, as defined by the International Biological Program (IBP), encompasses the examination of the timing of recurring biological events, the factors influencing their timing in relation to both living organisms and environment forces, and the interconnections between different phases within the same or different species.[4] Phenophases are the distinct stages of a plant's life cycle that undergo evolutionary changes over time. These phases encompass various events such as leaf emergence, leaf expansion, senescence, flowering, fruiting, and more, all of which are directly influenced by temperature, rainfall, and day length. These factors exhibit seasonal variations throughout the year. Thus, the phenological changes in plants are highly observable and serve as a sensitive indicator of climate change. With climate change, plant phenology has exhibited shifts in timing.[5] The phenology of plant species is heavily influenced by climatic conditions, particularly in higher altitude regions like mountain ecosystems.[6] Various environmental factors, including elevation, temperature, soil moisture, photoperiod, and snowmelt, play a substantial role in shaping flower phenology and ensuring the reproductive success of plant species.[7]

The Banj-Oak, a vital species in the moist temperate forests of the Central Himalaya, acts as a keystone species. It plays a crucial role in maintaining high biodiversity, soil organic matter, and water retention capacity, which directly contribute to human well-being. The phenological cycles, regeneration processes, and succession patterns of these forests are influenced by a combination of climate variability and human activities. As a result, phenology holds a significant importance in plant growth and development, strongly correlated with patterns of climate change. Phenological studies not only contribute to our understanding of plant species biology but also yield valuable information on ecological processes and the dynamics of plant communities. This knowledge is essential for comprehending how ecosystem services are provided and can greatly assist in guiding conservation efforts.[8,9]

Thus, the aim of this study is to analyze the phenological characteristics of *Quercus leucotric-hophora*, especially considering elevation, and to assess the impact of climate change.

Materials and Methods

Study Site

The study sites in the Kumaun Central Himalaya are situated within the geographical coordinates of approximately 29°22' and 29°27'N and 79°23' and 79°28'E. These sites are located at elevations ranging from 1400 and 2200 meters. At this elevation range, the oak (*Q. leucotrichophora*) form either pure or mixed stands. The whole area is divided into low elevation (1400-1600m), mid elevation (1700-1900m) and high elevation (2000-2200m) forests. The climate in this region is sub-tropical to temperate. The winter season in the area is characterized by extremely cold temperatures accompanied by light rain and substantial snowfall, typically occurring from December to January. Summers in this region are characterized by warm and dry conditions, extending from April to mid-June. The rainy season follows, characterized by mild warmth and humidity, and it spans from mid-June to mid-September. The highest recorded temperature reached 26.6 °C in June, while the lowest recorded temperature dropped to 3.8 °C in January.

Field Data Collection

At each elevation, three replicate sites were identified and selected. Five average sized, mature and healthy trees at each site (15 trees) were selected for phenological study. The phenophases observed were bud formation, bud bursting, leafing, flowering, leaf fall, acorn maturation and acorn fall. Each phenological event was observed at 15-day intervals during periods of low activity and weekly during periods of high activity.[10] The occurrence of about 5% of a phenophase in an individual is considered as initiation of a pheophase.

The remaining of a particular phenophase in less than 5% will be assumed as completion of particular phenophase.[10]

Results

The study was conducted during 2019-20. The natural habitat range of *Q. leucotrichophora* primarily extends to altitudes ranging from 1000 to 2200 meters. At lower elevations, it coexists with *Pinus roxburghii Sarg*. commonly known as chir pine, which is a predominant tree species. *Q. leucotrichophora* can be found growing in pure stands or alongside other deciduous and coniferous tree species. Some notable associates with species at lower to middle elevations include *Myrica esculenta* Ham. Ex. D. Don, *Pyrus pashia* Buch. Ham., *Quercus glauca* Thunb., etc. At mid to high elevations, it associates with species such as *Lyonia ovalifolia* (Wall) Drude, *Quercus floribunda* Lindl, *Rhododendron arboretum Smith*, *Cedrus deodara* (Roxb.) G. Don, etc.

Across the elevations, the tree diameter and height of *Q. leucotrichophora* tree were measured at a height of 1.37m. The tree diameter ranged from 124 to 141 cm at low elevation, at mid elevation ranged from 120 to 136 cm and at high elevation, ranged from 114 to 124 cm. Similarly, the height ranged from 19.2 to 24.5 m at low elevation, 16.6 to 24.0 m at mid elevation; and at high elevation ranged from 15.6 to 20.5 m (Figure 1). ANOVA indicated that the tree diameter (cm) and height (m) decreased significantly ($p<0.05$) with increasing elevation (Table 1).

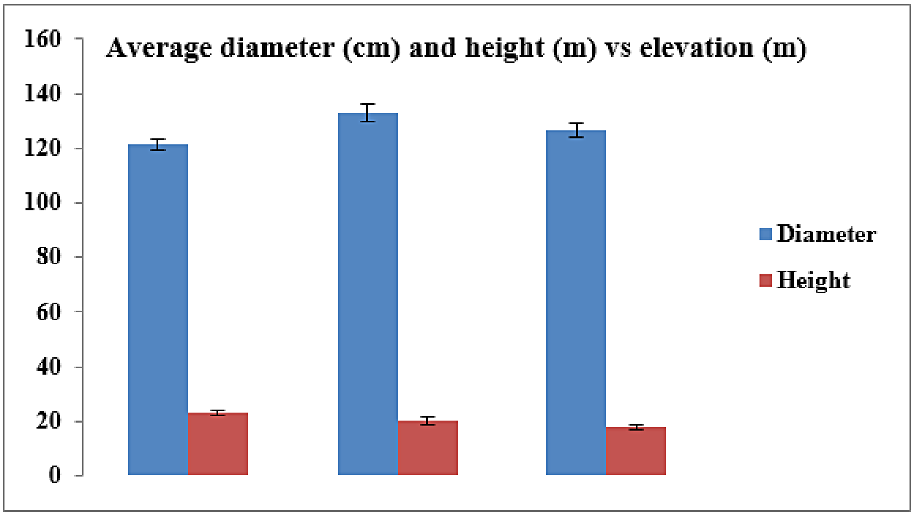

Fig. 1: Average diameter (cm) and height (m) of Q. leucotrichophora along the elevation gradient (Low, Mid and High).

Table 1: Analysis of Variance (ANOVA) for tree characteristics of *Q. leucotrichophora.*

Character		Sum of Squares	Df	Mean Square	F	Sig.
Diameter	Between Groups	361.200	2	180.600	4.894	.028
	Within Groups	442.800	12	36.900		
	Total	804.000	14			
Height	Between Groups	67.567	2	33.784	5.371	.022
	Within Groups	75.480	12	6.290		
	Total	143.048	14			

Phenological Characteristics

Bud formation in *Q. leucotrichophpora* initiates in the first week of February and extends until the first week of March at lower elevations. At mid elevation, it begins in the second week of February and persists until the second week of March. In contrast, at higher elevations, bud formation commences in the second week of March and lasts until the second week of April. Consequently, bud formation occurs earlier at lower elevations and is progressively delayed at higher elevations.

Bud bursting in *Q. leucotrichophora* begins in the third week of February and extends until the second week of March at lower elevations. At mid elevations, it initiates in the fourth week of February and persists until the fourth week of March. In contrast, at higher elevations, bud bursting commences in the third week of March and lasts until the second week of April.

Leafing starts in the first week of March and continues until the first week of April at lower elevations. At mid elevations, it begins in the second week of March and extends until the first week of April. At higher elevations, leafing starts in the first week of April and continues until the fourth week of April. During the rainy season, a second flush, accounting for approximately 30% of the leaves, typically occurs.

Flowering commences in the second week of March and continues until the first week of April at lower elevations. At mid elevations, it starts in the fourth week of March and extends until the third week of April. At higher elevations, flowering begins in the second week of April and continues until the fourth week of April. Pollination takes place during March and April at all elevations, followed by immediate seed setting. However, the acorns from the current or next growing season are always present on the trees.

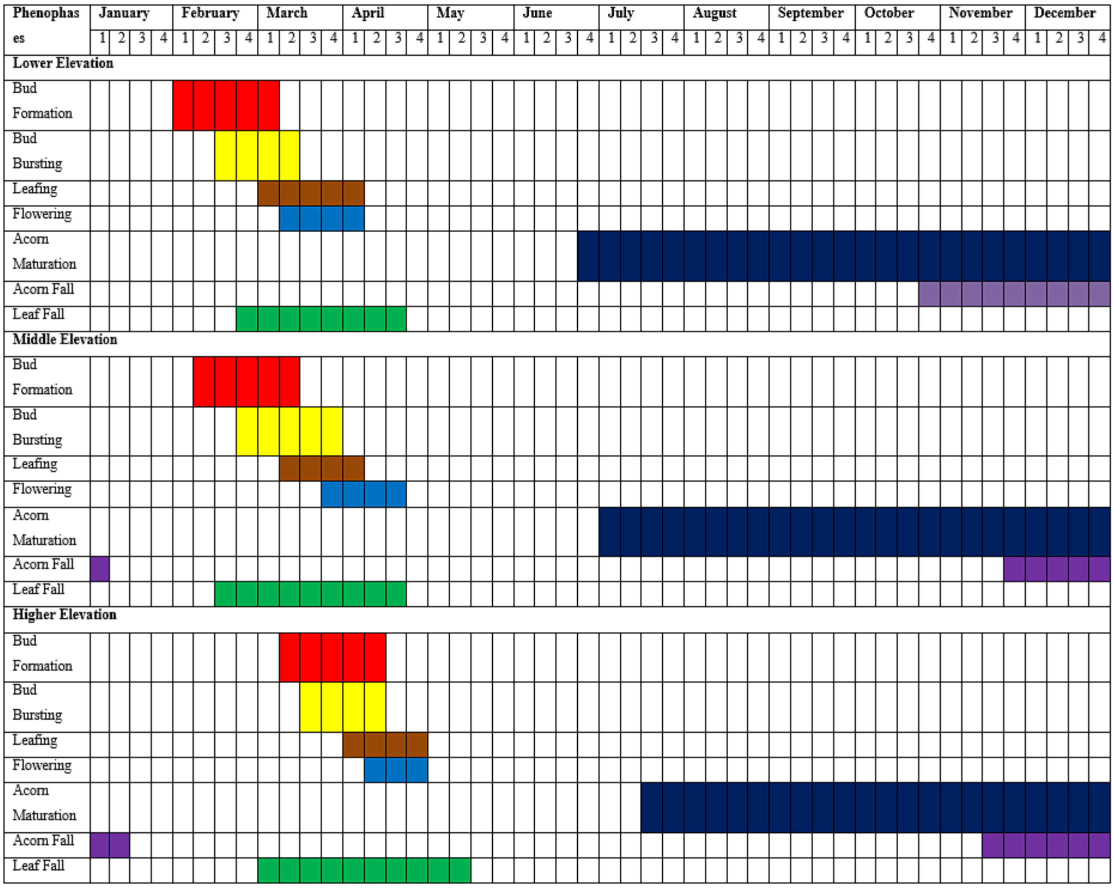

Fig. 2: Timing of phenological events in all the elevation of Q. leucotrichophora A. Camus in different weeks of each month; 1= Week 1, 2=Week 2, 3= Week 3, 4= Week 4.

Leaf fall begins in the fourth week of February and continues until the third week of April at lower elevations. At mid elevations, it starts in the third week of February and extends until the third week of April. At higher elevations, leaf fall commences in the first week of March and lasts until the second week of May.

Acorn maturation begins in the fourth week of June and continues until the fourth week of December at lower elevations. At mid elevations, it starts in the first week of July and extends until the third week of December. At higher elevations, it begins in the third week of July and continues until the third week of December.

Acorn fall in *Q. leucotrichophora* begins in the third week of November and continues until the fourth week of December at lower elevations. At mid elevations, it starts in the fourth week of November and extends until the first week of January. At higher elevations, it begins in the third week of November and lasts until the second week of January (Figure 2).

Discussion

The selected *Q. leucotrichophora* trees decreased in diameter with increasing elevation. The height was greater at low elevation and decreased significantly at higher elevation ($p<0.05$). In the present study, the phenology of *Q. leucotrichophora* exhibited variations across different elevations. These variations in phenology were primarily influenced by changes in climatic conditions, including temperature, soil moisture, humidity, and rainfall, which varied from site to site. Among these factors, winter temperature emerged as the most significant variable impacting phenophases. Phenological events, including bud formation, bud bursting, leaf emergence, flowering, fruit development, and seed maturation, were consistently observed to happen earlier at lower elevations and progressively later at higher elevations. Tree phenology closely aligned with the prevailing temperatures at the respective elevations, resulting in earlier occurrences at lower elevations and delayed timing at higher elevations, reflecting the delayed temperature rise at higher elevations. Shift (advanced/delayed) in various phenophases due to climate change were also recorded for different tree species.[11] Examining phenology at the population level can significantly enhance our understanding of the potential threats to global biodiversity.[12] The IPCC has reported an approximate 0.74 °C increase in average global temperatures over the past century.[13] This climate warming trend has the potential to push numerous plant species to the brink of extinction within the next century, primarily by disrupting the timing of their life cycles, impacting individual survival, and altering species interactions.[14,15] Nevertheless, plants have the ability to respond to climate warming through adjustments in their phenology, distribution range, and physiological processes.[16]

Evergreen trees prevail in the forests of the Central Himalayas, typically characterized by a mean life span slightly exceeding one year.[17] Leaf formation and leaf drop coincide during the spring season (March to April) in the Central Himalayas, and the trees exhibit a leaf-exchanging type where they never become completely devoid of leaves.[18] Leaf formation and flowering are simultaneous processes after the bud burst (within 15-20 days), the flowering taking approximately upto two weeks at mid elevation compared to low elevation and at high elevation it delayed by five weeks compared to low elevation and by one week compared to mid elevation. In the present study, the temperature ranged during leafing and flowering was 8.6-23.1°C (GIC, Nainital). We have compared the flowering period of *Q. leucotrichophora* with an earlier study where the leafing started in March-August, leaf drop in April-May, flowering in March-April and fruiting started from September-January.[19] A study made on this species and observed that the leafing started in March-April, leaf drop in February-April and flowering in March-April and fruiting in April-June at 1200-3000m elevation.[20] Similarly, another study reported that that the leafing in *Q. leucotrichophora* started in March-April, leaf drop in March-May, flowering in March-April and fruiting in April-June at 1700-2000m elevation in Kumaun Himalayan region. The temperature ranged during this period was 7.7-19.5^{0}C. There is little or no variation in temperature during the leafing, flowering, fruiting, leaf drop period where it was 17.0-17.5^{0}C.[21] The leafing started in March-May, leaf drop in March-May, flowering in March-April and fruiting in October-January at 1200-2300m elevation (Table 2).[22] When flowering was compared between different aspects, it was greater in the west aspect because it is warmer and has more sunlight compared to the east aspect. In mountainous areas, the flowering phenology vary along the elevation gradient, with plants at lower elevations usually flowering earlier than those of the same species growing at higher elevations.[23]

Table 2: Comparative study of different phenophases of *Q. leucotrichophora.*

Leaf Fall	Leafing	Flowering	Fruting	Elevation (m)	Source
Apr-May	Mar-Aug	Mar-Apr	Sep-Jan	1850-2150	Ralhan (1985)
Feb-Apr	Mar-Apr	Mar-Apr	Apr-June	1200-3000	Negi (1989)
Mar-May	Mar-Apr	Mar-Apr	Apr-June	1700-2000	Kumar (2011)
Mar-May	Mar-May	Mar-Apr	Oct-Jan	1200-2300	Yadav & Bisht (2013)

The duration of various phenophases, including bud formation, bud bursting, leaf formation, flowering, and seed formation, was to be shorter at higher elevations compared to lower elevations. There was a slight decrease in the duration of flowering as elevation increased.[24] This decrease in the longevity of phenophases at higher elevations can be attributed to factors such as lower temperatures, reduced water stress, and lower soil moisture levels. The most prominent biological responses to environmental changes, particularly climate change, are alterations in the timing of recurrent seasonal biological events or phenology. Previous research has provided evidence that plant communities have undergone shifts in their phenology during recent decades.

Conclusion

The phenological observations conducted on *Q. leucotrichophora* in this study are valuable for comprehending biological responses. The study clearly indicates the influence of temperature on phenological events due to unpredictable shifts in climate and rising temperatures, and has consequently become one of the most reliable bio-indicators of climate change. The diversity of phenological patterns, highlighting variations in the timing of phenophases in the studied species, provides crucial insights into the developmental status and information about trees during a particular year. Research indicates that the most significant phenological responses, such as the peak period of emergence and budding of leaves, flowers, and fruits, occur during the pre-monsoon season (March, April, and May). In the present study, early winter temperature and soil moisture was an important influence for peak flowering.

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Conflict of Interest

The authors do not have any conflict of interest.

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