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VERTICAL DISTRIBUTION OF RHODODENDRON WITHIN THE HIMALAYAS: FIELD-BASED STUDY OF THE KEDARNATH WILDLIFE SANCTUARY

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Abstract: The Himalayas are one of one of the largest mountain ecosystems on the planet as well as their ecosystem is dependent on the altitude, climate, as well as topography (Shrestha *et al.*, 2012). Rhododendrons play a significant role in these ecosystems due to their ability to help to maintain forest structure the stability of soils, cycling of nutrients and habitat for wildlife (Xu *et al.*, 2019, 2019; Pandey *et al.*, 2019). The study investigated what the distribution vertically of species from Rhododendron on the Chopta-Tungnath trekking route within the Kedarnath Wildlife Sanctuary, Uttarakhand during a spring-time survey that was conducted between March 26 and 2025. The study examined the notion that Rhododendron species exhibit vertical segregation at higher altitudes, instead of being equally distributed throughout the slope of the mountain. The field observations were conducted from Sari village, which is located at around 2000m up and Chopta (2200 m) to Tungnath route at about 3200 m in a single trekking survey. The species were identified by ocular estimation as well as visual field observation. The results revealed an apparent pattern of altitudinal variation. In such respect trees were prevalent at lower elevations, while transitional forms emerged within the middle zones and shrubby forms became prominent at higher altitudes. These results support the notion that Rhododendron communities are segregated vertically across Himalayan elevation gradients, which is observed for a variety of other plant communities within mountain ecosystems.

Keywords: Rhododendron, Vertical segregation, Altitude gradient, Kedarnath Wildlife Sanctuary, Himalaya Spring survey, forest ecology

I. INTRODUCTION

The Himalayas are among the most complex ecological mountains on Earth. Their steep elevation gradients result in dramatic variations in temperature, moisture exposure, temperature, and plant structure in relatively small distances (Shrestha *et al.,* 2012). Due to this, Himalayan vegetation communities tend to alter quickly with elevation and a lot of species are confined to very narrow ecological zones. Rhododendrons are amongst the most distinctive woody plants in this region, and are closely associated with the altitudinal shifts (Xu *et al.,* 2019).

Rhododendrons are not just visually stunning they are also essential to the ecology in the Himalayan forests. They are involved in soil cover and the protection of slopes, retention of water and nutrient cycling, they also support pollinators as well as creating habitat for other species (Pandey *et al.,* 2019). In the majority of mountains, the rhododendrons can be often considered to be an important indicator of ecological conditions because their shape and distribution frequently reflect changes in the quality of habitat and climate. As the altitude increases the trees tend to get shorter, and then become smaller forms or shrubs that are more adaptable to the cold, windy conditions and shorter growth seasons.

The connection between the altitude and distribution of plants is particularly important in mountain regions that are fragile where the species have to tolerate high environmental gradients and where even small changes in climatic conditions could have significant ecological effects (Saikia *et al.,* 2017). In the Himalayas these gradients are further influenced by slope angle and soil type, as well as local disturbance. Recent research has also highlighted the importance of analyzing the distribution of plants within conserving contexts as climate change can change the appropriate elevational zones upwards in time (Banerjee *et al.,* 2022, Singh *et al.,* 2020). Rhododendron species, due to their high sensitivity to ecological change provides a wonderful chance to see the vertical structure in a clear way.

The study was prompted by observations made in the field on a hike across Kedarnath Wildlife Sanctuary, where the Rhododendron plant life appeared to change visually as the elevation. The main research question was to ask: is the distribution pattern of Rhododendron similar across all elevations? This hypothesis suggested that there should be a vertical segregation of Rhododendron just like other species of flora in the region. Based on field observations and field observations, this theory was proven. This article outlines the changes in a brief field-based style and highlights its conservation and ecological significance.

II. Short Literature Review

Research has previously demonstrated the Himalayan biodiversity is highly shaped by elevation and climatic variations. Shrestha *et al.,* (2012) identified their research on the Himalayas as an area experiencing extensive changes to the ecosystem caused by climate which is causing plant communities to respond rapidly to environmental changes. Xu *et al.,* (2019) stressed how the Hindu Kush Himalaya supports high biodiversity and essential ecosystem services, a lot of that depend on the health of mountain vegetation. In this larger

context Rhododendrons have been identified as being among the most significant culturally and ecologically plants in the region.

Numerous studies have revealed that the diversity and abundance of plants variations in Himalayas depend on the elevation and habitat structure. Saikia *et al.* (2017) discovered that their study showed that the eastern Himalayan Forest diversity is changing across the altitudinal zones. Dash *et al.* (2021) found that the plant layers in evergreen tropical mountain forests are significantly dependent on ecological gradients. Bhoyroo *et al.* (2013) added that the rate of reproduction and plant quantity may vary across altitudes due to changes in conditions for habitats and the ecology of pollination. These results collectively confirm the notion that mountain vegetation isn't always uniform across altitudes.

Research focused on Rhododendron has revealed that the genus has distinct spatial and environmental patterns. Lu *et al.* (2020) discovered the niche characteristics of Rhododendron communities, and demonstrated the relationship between their distribution and to elevation-related factors. Kuo *et al.* (2022) noted the fact that alpine vegetation on summits responds significantly to changes in climate which suggests that high-elevation vegetation community structures are determined by strict ecological boundaries. Similarly, Kolanowska *et al.*, (2020) proved that species distributions are affected by ecological niche suitability as well as the conditions of the climate. These studies offer a valuable context for our current field study, which is complemented by information from local sources like Kedarnath Wildlife Sanctuary.

III. MATERIALS AND METHODS

The research was conducted at Kedarnath Wildlife Sanctuary, Uttarakhand along the Chopta-Tungnath trekking route. The fieldwork was conducted in the spring between March 26 and 27 2025. It was a one-day survey and observations were taken on the paved route that runs from Sari village around 2000m up and up to Tungnath Temple at approximately 3200 meters.

The study was founded on observations from the field. Rhododendron individuals were identified visually by ocular analysis when walking on the trail. The identification was done in the field based on of their growth form, dimensions, leaf appearance flowering appearance, and general visual traits. Since the path was a trail for trekking instead of an established research plot the method was based on general patterns of distribution instead of precise estimates of abundance.

For the sake of a better understanding for ease of analysis, the transect was described as approximate elevational bands, so it was possible to track changes in the Rhododendron shape or dominance were observed upslope. The research focused on what the species appeared to be small tree, transitional forms or as shrubs. Also, attention was paid to whether the plants appeared widespread scattered or rare in every area. The purpose this study had was to record the natural elevational patterns there was no destructive sampling nor laboratory analysis was conducted. This study therefore is an observation made in the field of ecological the distribution of an elevation slope.

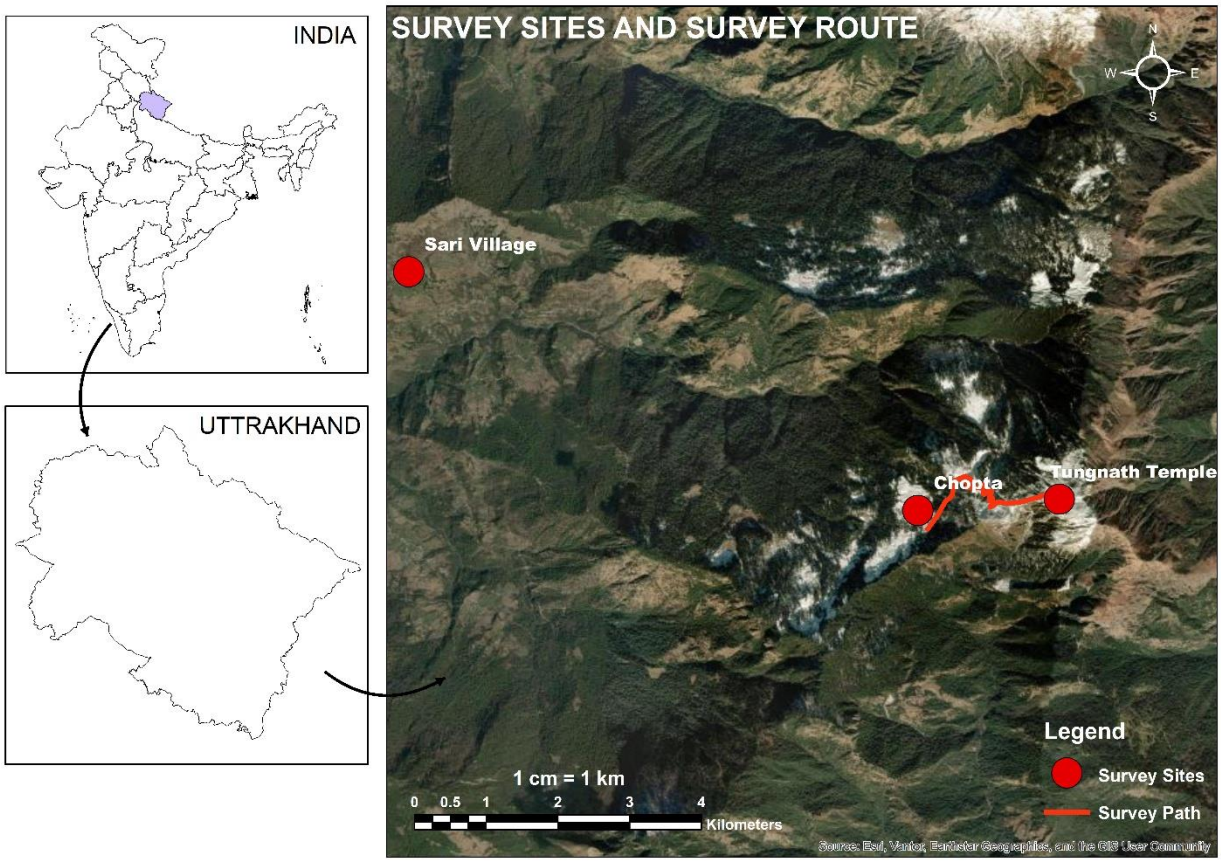

Figure 1. Survey Sites

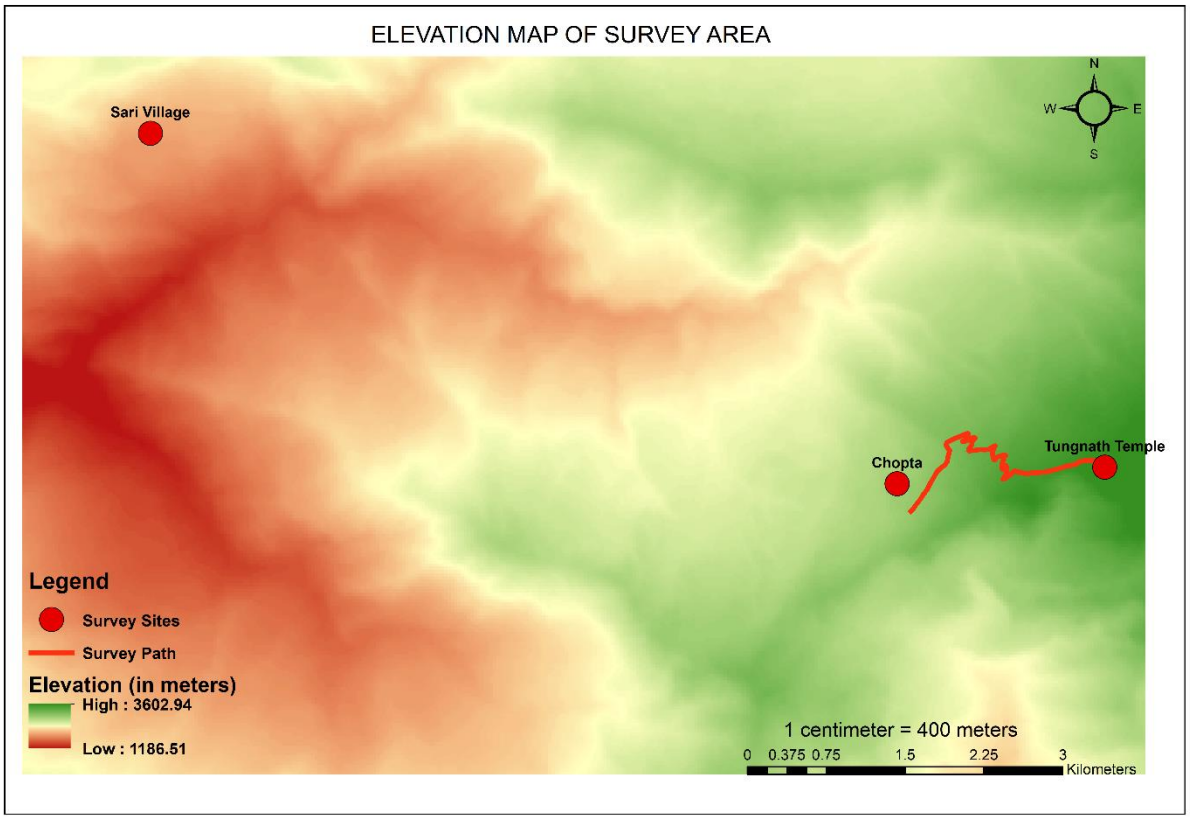

Figure. 2 Elevation map of Survey Area

IV. RESULTS AND DISSCUSSION

The study showed a clear vertical pattern of Rhododendron distribution. Rhododendrons were found across a large portion of the transect. However, their growth pattern and dominant position varied significantly with elevation. The distribution was not even and the pattern suggests that there is a segregation of ecological diversity across the gradient of elevation.

In lower elevations close to Sari village Rhododendrons generally were regarded as a tree-like species. They had a more matured trunk structure and a higher overall height. They were visible in the forest and were believed to be part of the upper montane forest layer. Particularly, flowering individuals were visible in the spring surveys which indicated a growing season. The lower zone was therefore home to the tallest and like a tree rhododendron.

In the middle of the transect, plants started to change the structure. The height of the individual slowly decreased and the form of growth changed to be less than a typical tree. The middle zone functioned as an ecological transition point between the lower-tree-dominated forest and the higher-growing vegetation dominated by shrubs. The change was gradual, rather than abrupt, indicating an ongoing ecological response to an increase in altitude.

At elevations of more than 2800 m, the Rhododendron group changed to more shrubby forms. They were smaller, less compact, and more for the colder and more open upper-mountain environments. Rhododendrons from trees became scarce in this region. The upper transect also was dominated by lower-growing forms of shrubs, rather than tall trees with wood. This was the most obvious sign of vertical segregation that was observed within the investigation.

In general, observations in the field showed that Rhododendron distribution changed dramatically with the altitude. Forms of trees were more prevalent in lower regions, while smaller varieties were seen throughout the middle zone and shrubs prevailed in higher zones. The results show that the Rhododendron communities of the Himalayas are arranged by the elevation.

The findings of this study confirm the idea that Rhododendron species have a vertical segregation across altitudinal gradients. This is in line with the more general ecological behaviour of mountain plants that typically respond to changes in temperature and variations in moisture as well as wind exposure and soil variations when altitude rises (Shrestha *et al.*, 2012; Saikia *et al.*, 2012; Saikia *et al.*,2017). In the current study, Rhododendron trees were widespread at lower elevations, but they became gradually smaller and less common upwards, before finally changing into shrubs at elevations above 2800 m.

This shift in vertical direction is important for ecological reasons. The tree forms typically require better conditions for taller growth as well as biomass accumulation and growth of the trunk. As the elevation rises the environmental stress increases and more small growth forms are typically preferred. Rhododendrons that are shaped like shrubs are more adapted to the cold, windy and short growing seasons as their smaller height

reduces the amount of sunlight and thus helps to conserve energy. This is why rhododendrons with trees became scarce close to the upper end of the transect, while the shrubby varieties became more prevalent.

The observed pattern also agrees with previous studies that have shown the fact that the Rhododendron communities aren't random, but instead defined by niches and conditions. Lu *et al.*, (2020) demonstrated they found that the Rhododendron communities are linked to environmental and spatial gradients, and (Kuo *et al.*, 2022) highlighted that the vegetation in alpine ecosystems is extremely sensitive to changes in temperatures. The current field study provides the local proof from Kedarnath Wildlife Sanctuary that Rhododendron forms of growth change significantly in a short, but environmentally sharp elevation gradient.

The timing of the spring survey is equally important. March is a period of transition within the middle Himalaya where the lower and middle elevations start to show signs of growth and blossom after stress from winter. This allows Rhododendron patterns more visible particularly in areas where flowering plants can be seen within the landscape of forests. The seasonal context could explain why the tree patterns at lower elevations seemed to be more noticeable and active, whereas higher elevation plants were smaller and less floral in the window of survey.

From a conservation standpoint from a conservation perspective, these findings are important as they reveal that Rhododendron communities have distinct elevational bands instead of the same pattern of continuous elevation. This could have implications regarding the management of habitats, particularly in protected areas with a climate-sensitive character like Kedarnath Wildlife Sanctuary. If the warming trend continues and the elevational limits of these species could change upwards, thereby changing the structure of communities and compressing the habitat zones that are suitable for them (Banerjee *et al.*, 2022; Singh *et al.*, 2022; Singh *et al.*,2020). The apparent rarity of tree rhododendrons higher than 2800 meters suggests that these species are already close to their ecological limits in this region.

The study is restricted by its single-trek layout and observational methodology, but it nevertheless captures an important ecological pattern. Transect observations made using field technology are particularly beneficial in mountain ecosystems because it allows scientists to observe the changes immediately in slopes with gradients. Even without the quantitative plots the pattern we observe here is enough to suggest the Rhododendron distributions are vertically organized. Future research could expand on this with continuous plots and species-wise count and repeated surveys during the season.

V. CONCLUSION

The field-based study conducted by Kedarnath Wildlife Sanctuary shows that Rhododendron species have a very an exact vertical separation along the Chopta-Tungnath altitude gradient. The distribution of the species is not identical at every elevation. In fact, tree forms dominate lower elevations, while transitional forms show up at the mid-zone and the shrubby forms are more prevalent at higher altitudes. The tree rhododendrons are scarce at elevations above 2800 meters, whereas smaller and less compact forms are more suited to the mountainous upper zone.

The results confirm the notion that Rhododendron as well as other Himalayan plants is influenced by elevation. The study also demonstrates the significance for elevation to act as an eco-filter for mountain ecosystems. From a conservation point of view this study highlights the importance of protecting altitude-related habitats as ecological units since changes in the climate or land use could change the composition of species along the slope. Rhododendrons are, therefore, not just gorgeous elements in Himalayan woodlands, but are also important indicators of changes in the ecology.

Figure. 3 Rhododendron Shrub (No flowering at time of visit) on the way of hike to Tungnath (elevation 3000 m)

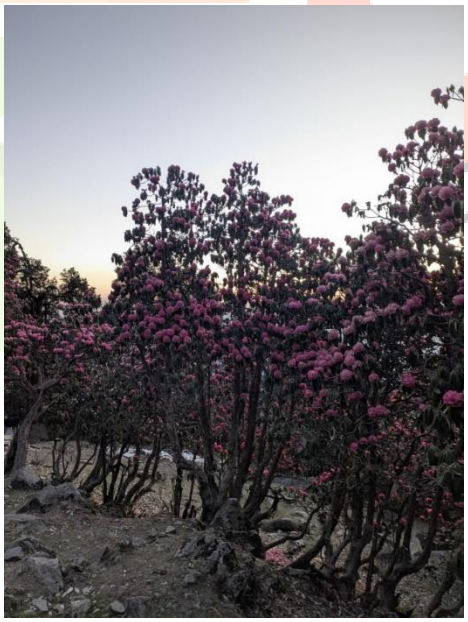

Figure. 4 Rhododendron small trees with Pink flowers at Chopta (elevation 2500m)

Figure. 5 Rhododendron Trees (with Bright red flowers) at Deoriatal Trek (elevation 2200 m)

Figure. 6 Rhododendron Tree (with bright red flowers) near Sari village (elevation 2000m)

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