*Tropical Ecology* **59**(2): 287–295, 2018 ISSN 0564-3295

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# Expansion of *Rhododendron campanulatum* krummholz in the treeline ecotone in Tungnath, Garhwal Himalaya

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**Abstract:** Sensitivity of alpine treeline ecotone to climate change and upward shift of plants due to warming have been reported from many parts of the globe. However, such research in the climate sensitive western Himalaya is still in infancy due to paucity of past climatic and vegetation distribution data to detect the change. In this paper we determined the expansion of *Rhododendron campanulatum* krummholz using seedling population and growth characteristics along an altitudinal transect rummimg from the upper forest limit to treeline ecotone and beyond it in Tungnath (i.e., 3242 m asl), Uttarakhand. In the studied transect (altitudinal gradient of 3511–3665 m asl) in 2017, a total of 17 trees and 36 seedlings of *R. campanulatum* were found growing. Almost half of the trees were devoid of any seedlings around their canopies. Height and circumference at collar height of both the adults and seedlings were positively correlated ($P <$ 0.05). Taking the mean distance of seedlings from the mother tree (2.8 m; range = 0.50–4.72 m) and mean age of the seedlings (2–9 yrs; mean = 3.9 yr; reckoned by the number of internodes) the rate of expansion of *R. campanulatum* population was computed about 1.4 m $yr^{-1}$ Occurrence of mature individuals at the mountain top without any seedlings indicates that as no space left for upward movement of plants, the interspaces between the krummholz are being filled by the regenerating individuals. This may leave little grazing grounds for the migratory livestock and change ecosystem properties. It may be further pointed out that due to rise in atmospheric temperature (@ 0.11 °C $yr^{-1}$ in the past two decades) and continued biotic stress of grazing and tree lopping, *R. campanulatum*, a non-palatable species of wider niche width might preponderate at the expense of herbs and other treeline species in future and may bring out compositional changes in treeline vegetation and carbon storage.

**Key words:** Climatic warming, krummholz expansion, *Rhododendron campanulatum*, seedling population, treeline ecotone, Western Himalaya.

**Guest editor:** S.P. Singh

## Introduction

The high altitude limit of forests and trees, commonly known as timberline, and treeline respectively represents one of the most conspicuous vegetation boundaries (Körner 1998). Natural treeline ecotones are sensitive biomonitors of past and recent climate change (CC) and variability (Kullman 1998), and are well suited for monitoring its impact (Becker *et al.* 2007; Kullman 1998). Sensitivity and response of alpine treeline ecotone to climate change (CC) is increasingly being discussed among scientists (Holtmeier 2009), and by the general public (IPCC 2007). Upward shifts of plants due to warming have already been reported from many parts of the globe (Cannone *et al.* 2007; Kelly & Goulden 2008; Schickhoff *et al.* 2015), including Himalayan region (Dubey *et al.* 2003; Gaire *et al.*

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**Fig. 1.** *R. campanulatum* krummholz beyond the treeline ecotone in Tungnath alpine meadow.

2011; Padma 2014; Panigrahi *et al*. 2010). In Parvati valley, Himachal Pradesh rate of upward movement of Himalayan blue pine (1.9 m $yr^{-1}$ on south and 1.4 m $yr^{-1}$ on north slope) was reported using dendrochronological technique (Dubey *et al.* 2003). In the central Nepal, Gaire *et al*. (2014) reported upward shifting of *Abies spectabilis* (@2.61 m $yr^{-1}$ since 1850 AD); however, they found the upper distribution limit of *Betula utilis* to be stagnant in the past few decades. Liang *et al*. (2011) found little change in the fir (*Abies georgei* var. *smithii*) tree line position in the Tibetan plateau after 200 yrs of warming.

During the last few decades, the Himalayas have experienced approximately 2–3 times greater rise of atmospheric temperature than the global average (Liu & Chen 2000; Shrestha *et al.* 1999; Xu *et al.* 2009), and the increase is greater (0.07 °C $yr^{-1}$) in winter, than in summer (0.03 °C $yr^{-1}$) (Shrestha *et al.* 2012). Also, increasing warming rate with altitude, peaking between 4800 m and 6200 m altitudes has been reported (Singh *et al.* 2011; Wolfe 1979). It has been stated that in the face of CC, most ecosystems and landscapes will be impacted through changes in species composition, productivity and biodiversity (Leemans & Eickhout 2004). The Himalayan region presents the highest timberlines and treelines in the world diverse in tree species composition (Shi & Wu 2013). At present, the common thinking is that as a response to rise in atmospheric temperature timberlines are currently advancing to higher altitudes and moving further north (Parmesan & Yohe 2003), thus impacting the species with restricted niche widths and loss of habitats and even species extinction (Subedi 2009). However, there are also many anomalies, due to local and regional conditions (terrain type, orographic influences, herbivory, disease), and the anthropogenic influences (Cairns & Moen 2004), which have been reported as much as over 80% of treelines in Himalayas (Schickhoff 2015). Empirical data, however, based on filed observations is seriously lacking to support or defy the upward movement of plants in the western Himalayan treeline ecotone.

In this study undertaken on *R. campanulatum* krummholz in and around treeline ecotone at Tungnath, Western Himalaya, we have hypothesised that *R. campanulatum* krummholzs are expanding its population (both vertically and laterally), and occupying the space available in the alpine meadow rapidly as an impact of global warming. The specific research issues were: (i) regeneration status (density of seedlings) of *R. campanulatum* beyond the treeline ecotone, and (ii) filling of the interspaces between the krummholz patches by the regenerating *R. campanulatum* seedlings in the alpine meadow.

**Fig. 2.** *R. campanulatum* seedlings growing about 5 m distance from the mother bush in the Tungnath alpine meadow.

## Study area

Details of the study site and vegetation are given in Pradeep Singh *et al.* 2018 (this Issue). *R. campanulatum* is a shrub or small tree or sub-tree (up to 8 m high; referred to as tree hereafter) that bears spectacular bell shaped flowers during April–May, followed by fruiting in June and seed dispersal subsequently (Bisht *et al.* 2014). It is a timberline krummholz (crooked wood) species and provides a biogeographical example of a sub-dominant taxon, which ranges from subalpine to cold temperate zones (Tiwari & Chauhan 2006). It is one of the few species of *Rhododendron* that forms dense, pure stands in the timberline zone of the Central and Western Himalaya (Vetaas 2002). In the study area its density ranges from 360 to 2840 ind./ha; Rai *et al.* 2012), signifying that this species is an important constituent of tree line ecotone. In the study site *R. campanulatum* krummhols are found in isolated patches with 50 m to 500 m gaps between them along the NW slopes (Fig. 1), up to the highest point of Tungnath alpine meadow (3665 masl). In Tungnath, none of the seedlings/saplings of other tree species were found growing in the alpine meadow beyond the treeline ecotone except for the *R. campanulatum* (Fig. 2). It has been reported that rhododendrons may survive global warming *in situ* because of high temperature tolerance, but the long-term effect on their regeneration is uncertain (Vetaas 2002). *R. campanulatum* is not grazed as it is an unpalatable species (Negi *et al.* 1993), so its regeneration status is expected to be largely determined by warming. However, cutting of its mature sticks for fuelwood is rampant due to its inflammable character by the migratory graziers leading to disturbance in its natural growth and succession. Also, heavy grazing at this site has been reported leading to dominance of less palatable herbs and grass species such as *Anemone* spp., *Poa alpina*, *Polygonum* spp., *Ranunculus hirtellus* etc. (Nautiyal *et al.* 2004), which might influence the regeneration of *R. campanulatum*.

## Materials and methods

This study was initiated with literature search relating to the distribution of *R. campanulatum* in Tungnath reported by earlier workers. It revealed the highest altitude of occurrence of this species

**Fig. 3.** Growth mesurements on *R. campanulatum* seedlings in the Tungnath alpine meadow.

(tree species line) at 3500 m asl. June 1977 (Semwal & Gaur 1981), and mature krummholz of this species forming abrupt treeline at 3000 and 3250 m asl. in Tungnath (Sundriyal & Bisht 1988). Thus to investigate the rate of expansion of its population in the interspaces of its krummholz during the time span of past about 40 yrs (taking 1977 as base year following Semwal & Gaur 1981), we placed a vertical belt transect (20 m wide and 150 m long) along a representative slope (altitudinal gradient 3511 to 3666 m asl) representing *R. campanulatum* in NW aspect of Tungnath alpine meadow beyond the treeline ecotone in August 2017. With respect to biotic disturbance (in terms of grazing and cutting of *R. campanulatum* mature shoots) this transect was least disturbed. Census of seedlings (< 15 cm height) was carried out around each of the bushes found within this transect (Fig. 3). This method of belt transect plots (20 m wide and 250 m long), which included treeline as well as tree species limit has also been used in Central Nepal (Gaire *et al.* 2014), and also in western Himalaya using 100 $m^2$ plots by Dubey *et al.* (2003). Within this transect, measurements on all the trees of *R. campanulatum* and seedlings growing around them were taken for their altitude, height, circumference at collar height (Cch; 10 cm above ground), number of internodes per individual, number of leaves per seedling, etc. A metal measuring tape (0.5 mm least count) and a micrometer (0.1 mm least count) were used to measure the plant height and diameter at collar height (10 cm above ground). Number of internodes (as a proxy of one year growth to determine the age of the plants; one internode = 1 yr age) was counted for these seedlings (Fig. 4). Internode numbers and length have been used as a measure of growth and life span determination of *R. campanulatum* (Barquero 2009), and also other plants (Wills 2003; Zalamea *et al.* 2008). As *R. campanulatum* has a distinct branching pattern with circular swellings formed at the junction (node) of each annual growth increment, the nodes were visible and could be counted from the leader shoot to the base of the main stem to give an estimate of aboveground plant age (Fig. 4). In some instances bark was removed at the swelled spot to verify the presence of nodes. However, after a certain age with increase in stem diameter the internodes are fused with the nodes, thus the number of internodes could be counted only up to a maximum of 9. Counting nodes is a simple non-destructive technique to determine plant age.

**Fig. 4.** A seedling showing number of nodes (marked with pen 1–7 along the leader shoot).

The number of modules (e.g., internodes, leaves etc.) produced over a plant's life span provides an estimate of its age, thus has been used to determine the age of plants, and has opened the possibility to reconstruct their past growth and dynamics (Taylor & Zisheng 1993). It has been pointed out that age determination using tree ring limits is considered inappropriate for young seedlings (Durate *et al.* 1999). Data for all the measured parameters were pooled for statistical analyses following Snedecor & Cochran (1980).

## Results and discussion

In the study altitudinal transect of Tungnath alpine meadow the height of the trees (17 trees recorded) ranged from 0.65 to 2.63 m, circumference from 14 to 30 cm, and number of clumps from 4 to 26 per individual (Table 1). There existed a positive relationship between tree height and circumference ($r = 0.459$; $P < 0.05$). Tree height vs. number of clumps ($r = 0.092$), and altitude vs. tree height ($r = 0.045$) were found weakly negatively correlated. Around these trees a total of 35 seedlings of varying heights (range = 1.6–10.2 cm) were found within a distance ranging from 0.45–4.72 m from the centre of these trees (Table 1). Age of these seedlings (reckoned by number of internodes) ranged from 2 to 9 yrs. Seedling height and circumference were positively correlated ($r = 0.625$; $P < 0.05$). Seedling number vs. altitude was found negatively related ($r = 0.317$; NS), indicating that with increasing altitude cold conditions limit the seed germination and seedlings survival (Tranquillini 1979). No relationship occurred between height of seedling and distance from the tree, and between altitude and age (number of internodes) of the seedlings indicating that *R. campanulatum* did not follow any definite pattern of regeneration that may owe to continued biotic interference. Seedling height and number of leaves/seedling were also found unrelated. Vetaas (2002) reported that extreme chilling temperature limits the survival of *R. campanulatum*. Climate in high altitudes of the western Himalayan region is poorly studied due to logistic difficulties in maintaining observational networks and often supplemented through tree ring studies (Yadav *et al.* 2004).

In ten of the total 17 trees growing towards the higher part (3546–3666 m asl) of the studied transect, only 3 trees were represented by one seedling each, and in the rest of the seven trees no

**Table 1.** Growth characteristics of mother bushes and seedlings of *R. campanulatum* along an altitudinal gradient in Tungnath alpine meadow (Cch= circumference at collar height).

| *R. campanulatum* krummholz | Altitude (m asl) | Crown length (m) | Crown width (m) | Height (m) | Cch (cm) | No. of clumps | Seedling characteristics | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Distance from bush (m) | Height (cm) | Diameter (mm) | No. of nodes | No. of leaves |
| 1 | 3511 | 4.65 | 2.70 | 1.79 | 30.2 | 24 | 0.86 | 2.80 | 3.34 | 4 | 3 |
| | | | | | | | 0.92 | 1.60 | 2.45 | 2 | 3 |
| | | | | | | | 1.43 | 2.40 | 2.34 | 4 | 2 |
| | | | | | | | 1.80 | 8.30 | 3.09 | 9 | 3 |
| | | | | | | | 1.81 | 3.50 | 4.17 | 5 | 3 |
| | | | | | | | 1.83 | 3.00 | 4.25 | 4 | 3 |
| | | | | | | | 1.87 | 2.00 | 3.93 | 2 | 2 |
| | | | | | | | 0.68 | 10.00 | 7.61 | 7 | 3 |
| 2 | 3522 | 3.00 | 3.20 | 1.04 | 23.2 | 18 | - | - | - | - | - |
| 3 | 3534 | 3.64 | 2.45 | 1.35 | 20.5 | 13 | - | - | - | - | - |
| 4 | 3534 | 2.34 | 1.93 | 1.32 | 20.0 | 9 | 2.96 | 2.90 | 2.56 | 4 | 2 |
| 5 | 3539 | 5.02 | 4.05 | 1.45 | 20.1 | 9 | 0.80 | 1.80 | 2.00 | 2 | 3 |
| | | | | | | | 0.83 | 1.50 | 1.00 | 2 | 3 |
| | | | | | | | 1.00 | 3.60 | 2.63 | 4 | 3 |
| | | | | | | | 1.00 | 2.40 | 2.21 | 3 | 4 |
| | | | | | | | 2.42 | 4.90 | 3.65 | 4 | 3 |
| | | | | | | | 2.45 | 2.00 | 1.04 | 2 | 3 |
| | | | | | | | 2.20 | 2.90 | 2.49 | 4 | 2 |
| | | | | | | | 2.40 | 1.80 | 2.41 | 2 | 2 |
| | | | | | | | 3.14 | 2.80 | 2.00 | 2 | 5 |
| | | | | | | | 3.39 | 3.00 | 2.59 | 3 | 3 |
| | | | | | | | 3.15 | 5.13 | 5.03 | 3 | 4 |
| | | | | | | | 3.10 | 2.80 | 2.45 | 3 | 2 |
| | | | | | | | 2.99 | 2.60 | 4.00 | 4 | 3 |
| | | | | | | | 2.99 | 2.10 | 2.60 | 2 | 3 |
| | | | | | | | 4.72 | 3.40 | 3.22 | 4 | 3 |
| | | | | | | | 4.72 | 3.50 | 3.42 | 5 | 3 |
| 6 | 3543 | 1.51 | 1.09 | 1.06 | 14.3 | 9 | 0.50 | 5.00 | 4.87 | 6 | 3 |
| | | | | | | | 0.70 | 3.00 | 4.35 | 4 | 2 |
| | | | | | | | 0.71 | 3.50 | 4.81 | 5 | 5 |
| | | | | | | | 0.63 | 10.2 | 6.56 | 6 | 3 |
| 7 | 3546 | 2.30 | 1.70 | 1.14 | 15.2 | 9 | 0.45 | 2.70 | 3.30 | 3 | 4 |
| | | | | | | | 0.47 | 6.00 | 4.68 | 5 | 3 |
| | | | | | | | 3.92 | 8.60 | 6.21 | 6 | 3 |
| 8 | 3546 | 3.20 | 1.25 | 2.05 | 29.2 | 7 | - | - | - | - | - |
| 9 | 3546 | 2.80 | 1.70 | 2.10 | 23.0 | 6 | - | - | - | - | - |
| 10 | 3550 | 2.72 | 0.98 | 2.60 | 19.1 | 4 | - | - | - | - | - |
| 11 | 3574 | 2.74 | 1.36 | 2.08 | 35.2 | 17 | - | - | - | - | - |
| 12 | 3601 | 2.01 | 1.37 | 2.02 | 28.1 | 13 | - | - | - | - | - |
| 13 | 3604 | 2.23 | 1.15 | 0.97 | 18.0 | 7 | - | - | - | - | - |
| 14 | 3610 | 3.09 | 1.13 | 2.63 | 36.2 | 12 | 3.67 | 6.50 | 5.27 | 6 | 4 |
| 15 | 3630 | 1.60 | 1.01 | 1.20 | 25.2 | 18 | 4.64 | 5.50 | 4.86 | 3 | 5 |
| 16 | 3642 | 1.92 | 1.31 | 1.12 | 21.3 | 26 | 26.00 | 4.00 | 2.46 | 4 | 3 |
| 17 | 3666 | 0.93 | 0.65 | 0.65 | 15.0 | 19 | - | - | - | - | - |

seedlings were found under their canopy (Table 1). In contrast, some of the trees growing towards the lower altitude of the studied transect were represented by fairly high number of seedlings (max. 16) around them, and that requires to be studied to understand their reproductive success. Taking the mean distance of seedlings from the tree (2.8 m) and mean age of the seedling 3.9 yr (reckoned by the number of internodes) the rate of expansion of *R. campanulatum* population can be computed about 1.4 m $yr^{-1}$. This rate of expansion computed by us is comparable to the rate of upward movement of treeline for Himalayan blue pine (1.9 m $yr^{-1}$ on south and 1.4 m $yr^{-1}$ on north slope) reported by Dubey *et al.* (2003) in Parvati Valley, Himachal Pradesh and 2.61 m $yr^{-1}$ for *Abies spectabilis* in Nepal Himalaya (Gaire *et al.* 2014) using dendrochronological study. For the endemic herbs of alpine region of Sikkim Himalaya, the rate of range shift has been reported 2.75 m $yr^{-1}$ (Telwala *et al.* 2013). Considering the altitude of occurrence of this species at 3500 m asl. in June 1977 reported by Semwal & Gaur (1981), and the highest altitude of its occurrence in 2017 (i.e., 3665 m asl), it turns out that in an interval of about 40 yrs. (between 1977 and 2017) this species has moved up about 165 m @ 4.1 m $yr^{-1}$. However, it may be pointed out that Semwal & Gaur (1981) might have recorded only *R. campanulatum* bushes visible from a distance and ignored the seedlings/saplings, which have grown up now to a mature bush stage. In the Santa Rosa Mountains of Southern California, Kelly & Goulden (2008) reported that the average elevation of the dominant plant species rose by ~ 65 m between 1977 and 2006–07 @ 2.2 m $yr^{-1}$ along a 2314 m elevation gradient. Dendrochronological study in the treeline of high mountains of central Nepal Himalaya for dominant trees *Abies spectabilis* and *Betula utilis* since AD 1850 show that due to species-specific responses to CC differential pattern in regeneration and population is anticipated as climate continues to change throughout the century (Gaire *et al.* 2014).

The occurrence of only one tree at the top of Tungnath (3665 m asl) without any seedling in its vicinity, points out that this quite old tree (number of clumps, 19; but height only 0.65 m) had no further space left to recruit the seedling and regenerate even if temperature rise provided favourable conditions for growth. Looking at the climatic data of 1990–97 (mean = 9.0 °C) recorded during peak growing season (July–September) at this site by Nautiyal *et al.* (2001) as compared to that recorded during July–September 2017 (mean = 11.2 °C; Joshi *et al.* this issue) indicates that substantial rise in atmospheric temperature (@ 0.11 °C $yr^{-1}$; about twice than reported for the Himalayan mountains, Singh *et al.* 2012) has been taken place in the past over 20 yrs and it may have promoted the regeneration and expansion of *R. campanulatum* population.

## Conclusion

*R. campanulatum* is expanding in the interspaces of krummholzs both vertically and laterally and may occupy the alpine meadow in future under the influence of global warming. It may result in species loss as well as reduction in organic carbon layer (Speed *et al.* 2015). Preponderance and densification of this non-palatable species is expected in Tungnath at the expense of other treeline species, such as *Abies spectabilis, Betula utilis* and *Quercus semecarpifolia*, which are grazed by the migratory livestock. Therefore, long-term monitoring of treeline is important for understanding the future directions of compositional changes in the vegetation of treeline ecotone to have a clear mechanistic understanding to predict the potential impacts and changes by human activities in this fragile and eco-sensitive western Himalayan region (Negi *et al.* 2012).

## Acknowledgements

The first three authors are thankful to Director of the Institute, and Head, CBCM, GBPNIHESD for providing necessary facilities to write this ms. This research was funded by National Mission on Himalayan Studies, MoEF&CC, Govt. of India, New Delhi.

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(Received on 10.08.2018 and accepted after revisions, on 17.08.2018)