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Population Assessment, Mapping and Flowering Response of *Rhododendron arboreum* Sm. – A Keystone Species in Central Himalayan Region of Uttarakhand, India

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ABSTRACT

There has been significant increase in temperature and decline in winter snowfall in the Himalayan region that have greatly influenced the tree growth and accelerated the forest degradation rate. We conducted a study in the central Himalayan region of Uttarakhand with respect to population status of *Rhododendron arboreum*. This species is a keystone species of montane forest occurring from low altitude (1400 m) to sub-alpine zone (3300 m). Because of increase in average annual temperature, *R. arboreum* is showing precocious flowering pattern. A total of 43 populations were studied based on observational survey. The plant showed morphological changes in leaves and tree height based on altitude and sunlight received. It was found that lower zones (1400 – 1700 m) and lower–middle zones (1800 – 2000 m) have decreased and disturbed populations of *R. arboreum.* Most of these areas are now occupied by *Pinus roxburghii* which is a drought tolerant and adaptable species and has been expanding its range to middle altitude areas (2100 – 2400 m) and becoming a serious threat. However, anthropogenic factors are also responsible for the decline of *R. arboreum* population in low and lower – middle altitude areas. Remedial measures for maintaining healthy population of *R. arboreum* have been discussed.

Key Words: Conservation; Distribution; Garhwal; Global Warming; Kumaon; Phenology; Population Decline; Threats.

INTRODUCTION

Forests are an important component of ecosystem and play an important role by providing a variety of ecosystem services (Lindberg et al. 1997, Krieger 2001, Nasi et al. 2002, Sing et al. 2015). A large number of plant species are required for the proper functioning of ecosystem services (Isbell et al. 2011). Rapid industrialization and high demands of the society are posing a hurdle in forest growth and productivity. A large number of forests are shrinking and showing loss of dominant tree species due to drought and temperature induced stresses (Andregg et al. 2012, 2013). Most often these tree species are foundation or keystone species which directly or indirectly governs the ecosystem functioning. Mature, scattered and large trees are regarded as the keystone structure due to their potential role in the functioning of ecosystem (Jim 2005, Manning et al. 2006, 2009, Fischer et al. 2010, Hall and Bunce 2011, Stagoll et al. 2012).

The temperature in Himalaya has increased by 1.6 °C (Bhutiyani et al. 2007) and the Himalayan forests are facing risk of degradation (Pandit et al. 2007, Chaturvedi et al. 2011, Gopalakrishnan et al. 2011). Due to climate change, Uttarakhand has experienced an increase in mean annual temperature and decline in rainfall (Mishra

2014), advancement of flowering and fruiting time of plant species (Rawat 2013), upward shift of vegetation (Bharti et al. 2012, Singh et al. 2012, 2013), decrease in mean annual greenness (Mishra and Chaudhuri 2015), forest degradation and fragmentation (Krishna et al. 2009, Kaur et al. 2012, Nandy et al. 2011, Sahana et al. 2016, Sharma et al. 2016) and glacier fragmentation, recession and decrease in glacier area (Kumar et al. 2008, Bhambri et al. 2011, Bahuguna et al. 2014). According to a report, Uttarakhand had lost around 268 km^2 of forest area, which is second highest in the country and open forest area had increased by 272 km^2 (FSI 2015).

Uttarakhand falls under the central Himalayan region of India, which is one of the global biodiversity hotspot (Mittermeier et al. 2004, Convention on Biological Diversity India 2009), having a total area of 53,484 km^2 out of which total forest area is 37,999.53 km^2 (71.04%) forest area (Uttarakhand Forest Statistics 2012–13, 2014–15). However, the actual forest area under forest department is 25,863.18 km^2 (48.35%) (Uttarakhand Forest Statistics 2012–13, 2014–15) and had decreased to 24,240 km^2 (45.32%) (FSI 2015). Although the concept of social forestry in the form of '*Van Panchayat*' and sacred groves is prevalent in Uttarakhand, people still depend on forest for most of their needs like fuel-wood, fodder, medicinal plants etc. *Rhododendron arboreum* Sm. is an important tree species distributed in the hilly areas of the State and is regarded as a keystone species. *R. arboreum*, locally called as '*buransh'* (Hindi) or '*guransh'* (Nepali), is a multipurpose tree species providing wood for fuel and making agricultural implements. Flowers are used in making of juice, squash, pickles and bark and flowers are used for medicinal purpose. It also harbours large amount of phytomass of lichens, bryophytes, pteridophytes, orchids and gives refuge to birds and animals making a micro-ecosystem. Looking at the benefits dispensed by *R. arboreum* to the environment and to the local communities, it can be regarded as an ecological keystone species (Paine 1969) as well as a cultural keystone species (Garibaldi and Turner 2004, Cristancho and Vining 2004). Cultural keystone species have a chief role serving as a marker for the society or a cultural group apart from providing essential ecosystem services (Garibaldi and Turner 2004, Cristancho and Vining 2004). The wood of *R. arboreum* is used as fuel-wood for domestic cooking purposes (Bhatt and Sachan 2004, Kumar and Sharma 2009, Singh et al. 2010) and features among the most preferred species for fuel-wood (Singh et al. 2010). There is high consumption (95.2%) of fuel wood in the rural areas of Uttarakhand Himalayan region (Dhanai et al. 2014). As the altitude increases the fuel wood and fodder consumption values of the areas also increase. There is rapid deforestation going on and together with climate change it will become a serious problem in future (Singh et al. 2010, Dhanai et al. 2014, 2015).

Presently, there is no available report regarding the population status of *R. arboreum* in Uttarakhand. Although, some niche modelling studies have been conducted in Nepal (Vetaas 2000, 2002) and China (Ranjitkar et al. 2014). The present study was undertaken with the objective to assess the population of *R. arboreum* in the state of Uttarakhand to determine the factors which are causing its decline in the forest area.

MATERIAL AND METHODS

Study Area

The Uttarakhand State (28° 44' to 31° 28' N Latitude and 77° 35' to 81° 01' East longitude) lies in the central Himalayan region of India. The state comprises of 13 districts grouped into two administrative divisions: Garhwal (north-west) and Kumaon (south-east) region (Uttarakhand State Action Plan for Climate Change 2012). Of the total area 93% (46035 km^2) is hill area and only 7% (7448 km^2) being plane area (Uttarakhand at a Glance 2013–14) and the altitude varies from 210-7817 m (Uttarakhand State Action Plan for Climate Change 2012). The average annual rainfall recorded in the year 2012 was 1631 mm and the average summer and winter temperature is 30 °C and 18 °C (Uttarakhand at a Glance 2013-14). On the basis of altitude there are five climatic zones, warm temperate (900-1800 m), cool temperate (1800-2400 m), cold zones (2400-3000 m), alpine zone (3000-4000 m), glacier zone (4000-4800 m), and perpetually frozen zone (above 4800 m) (Uttarakhand forest Statistics 2012-13). There physiographic zones are characterized into two broad types: i) non–montane zone consisting of 'bhabhar' (Shivalik foothills surface) and 'tarai' (marsh damp) areas and ii) montane zone consisting of sub-Himalaya (Shivalik hills and Doon valleys),mid-Himalaya (Lesser/Lower/Little/ Himanchal/ Mahabharat range Himalaya), greater-Himalaya (Higher Himalayas/'Himadri') and trans-Himalaya (Tibetan / Tethys Himalaya) (Figure 1) (Uttaranchal State of Environment 2004). There are eight major forest types in

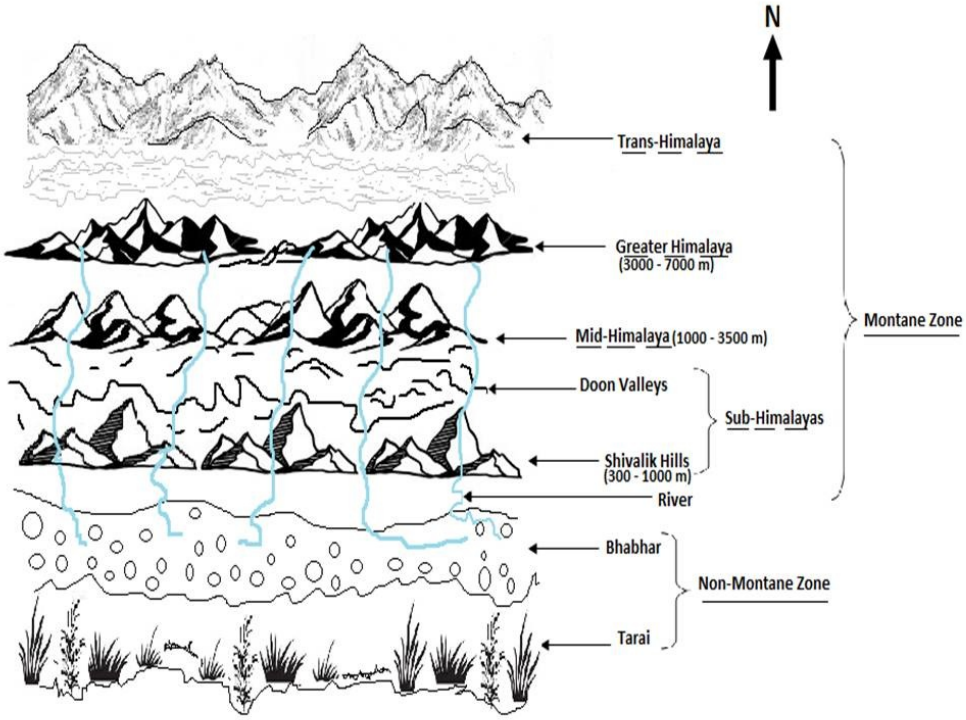

Figure 1. Diagrammatic representation of different physiographic zones in Uttarakhand (not to scale).

the state: tropical moist deciduous, tropical dry deciduous, subtropical pine, Himalayan moist temperate, Himalayan dry temperate, subalpine, moist alpine scrub and dry alpine scrub forests (FSI 2011). Higher zones also consists of pastures (2400-2800 m) and alpine meadows (>3000 m). The chief occupation of people is animal husbandry and agriculture which is generally rain-fed, however, the areas closer to drains ('nullah'/ 'gadhera'/'khaal'), spring ('dhara'), streams ('gaad') and river have access to irrigation.

Studied Species

R. arboreum Sm. belongs to the family Ericaceae (subgenus Hymenanthes, section Pontica, subsection Arborea) is present throughout the Indian Himalayan region and is an important species of mountain ecosystem occurring at an altitude of 1500-3300 metres. It is a tree and can attain a height of 5-12 m (Figure 2). The leaves are petiolate, oblong-lanceolate or oblong-oblanceolate, margin entire, apex acute (or sometime acuminate), base acute, adaxial surface glabrous, abaxial surface with 1-2 layered compact silvery indumentum. During March-April it bears reddish to dark pink flowers (15- 20), in a dense clustered terminal raceme ('truss') at

Figure 2. A tree of *Rhododendron arboreum* Sm. in natural habitat.

branch ends, which matures into brownish 2-2.5 cm cylindrically elongated fruits (capsule), dehiscing by septicidal mechanism splitting into four–five valves and releasing numerous small brown seeds.

OBSERVATIONS

The observations were made during the flowering season of *R. arboreum* Sm. i.e. (March - April) in 11 districts in the areas of its occurrence (Figure 3). The density of *R. arboreum* is low in subtropical Pine forest (1500-1700 m) but as the altitude increases its density also increases. From the forest canopy density map it is clearly evident that *R. arboreum* is a canopy forming species and goes to higher altitudes (Figure 4) It also occurs in Himalayan moist temperate, Himalayan dry temperate forest and goes up to subalpine zone (3300 m). Other common tree species found growing along with *R. arboreum* were *Quercus leucotrichophora* A. Camus*, Q. floribunda* Lindl. ex A. Camus*, Q. semecarpifolia* Sm.*, R. barbatum* Wall. ex G. Don , *R. campanulatum* D. Don.*, Taxus wallichiana* Zucc.*, Picea smithiana* (Wall.) Boiss.*, Cupressus torulosa* D. Don.*, Myrica esculenta* Buch.-Ham. ex D.Don.*, Cedrus deodara* (Roxb.) G.Don.*, Acacia catechu* (L.f.) Willd. *, Pinus roxburghii* Sarg.. A total of 43 locations were assessed in the 11 districts during the period 2013-2015. Generally the trees were found growing on slopes. Some areas (>2500 m) showed dominant *Rhododendron* cover but poor herbaceous ground cover and increased accumulation of litter and moist soil. The area type is characterized according to the dominant vegetation present there such as Oak–*Rhododendron* forest, *Rhododendron* forest, Pine forest and Oak–Pine forest. The study also included agricultural fields and pastures.

The population was categorized as random, where the trees have random distribution, uniform, where the trees have uniform (even) distribution all along on the way, clumped, where the groups of 2-4 trees are found to be clumped (aggregated) together. The status of a population is described as, reduced 3-5 trees per 50 metres (m), disturbed 6-8 trees per 50 m, stable 9-14 trees per 50 m, healthy 15-20 trees per 50 m, and pristine >25 trees per 50 m. It was found that low altitude (1400-1700 m) areas showed poor population, lower middle altitude (1800-2000 m) showed average, middle altitude (2100-2300 m) showed good, upper middle altitude (2400-2600 m) very good and higher altitude areas (2700-3300 m) showed excellent population. However, some discrepancies were also found because other factors, such as area topography, soil erosion, human

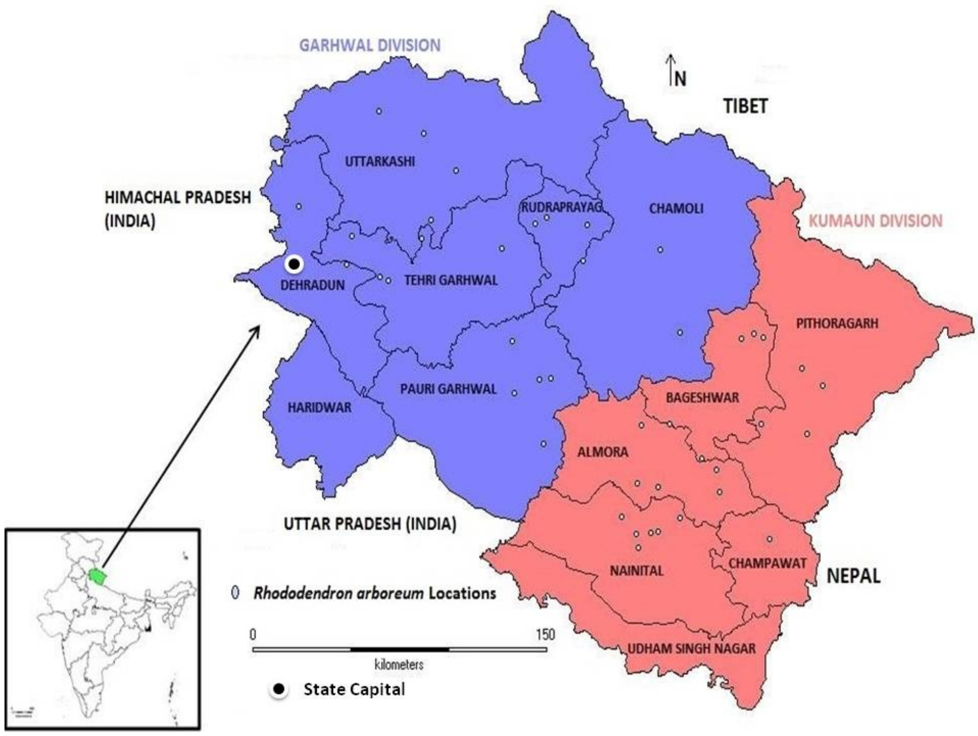

Figure 3. Study area showing assessed locations (green circles) in Uttarakhand state. Inset shows India with Uttarakhand state in green colour.

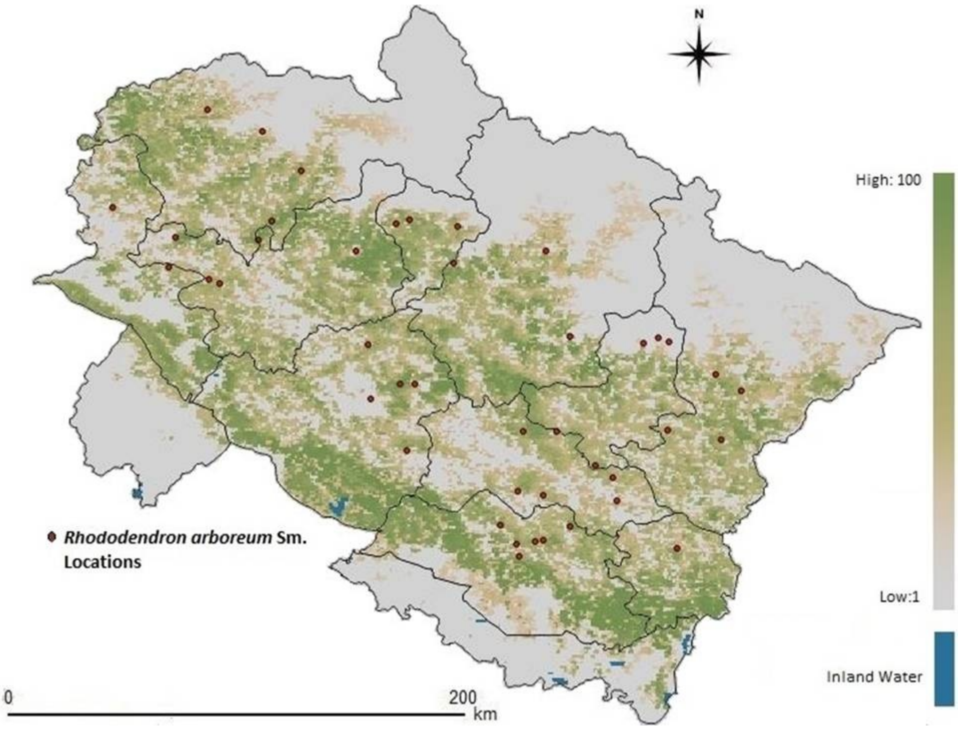

Figure 4. Map of Uttarakhand showing forest canopy density (1995-96) along with the different assessed population locations (red circles) [Forest canopy density data source: Global Forest Resources Assessment (FRA 2000); USGS- NASA Distributed Active Archive Center.]

settlements and agriculture etc. played a profound role in affecting the population. The seedlings (or saplings) generally get establish in eroded areas (Figure 5). Out of the 43 populations surveyed, 20 showed uniform distribution, 19 have random distribution, three have clumped-uniform distribution and one has random-uniform distribution pattern (Figure 6). Moreover, two populations have reduced status, 16 have disturbed status, 14 have stable status, seven have healthy status, and four have pristine status (Figure 7)

Figure 5. A sapling of *R. arboreum* established on an eroded slope.

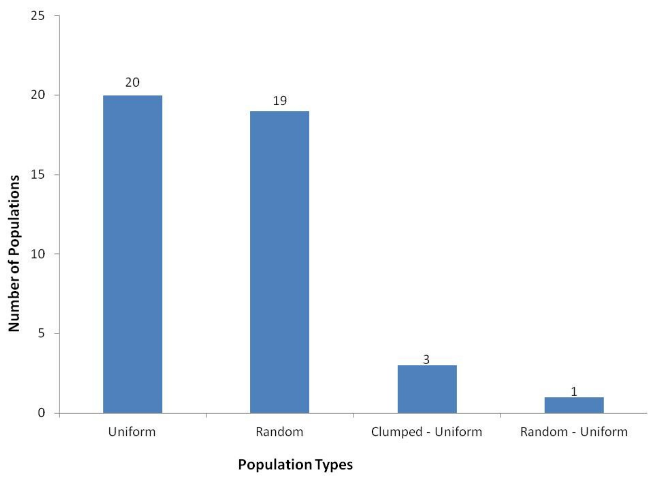

Figure 6. Types of population distribution in the study area.

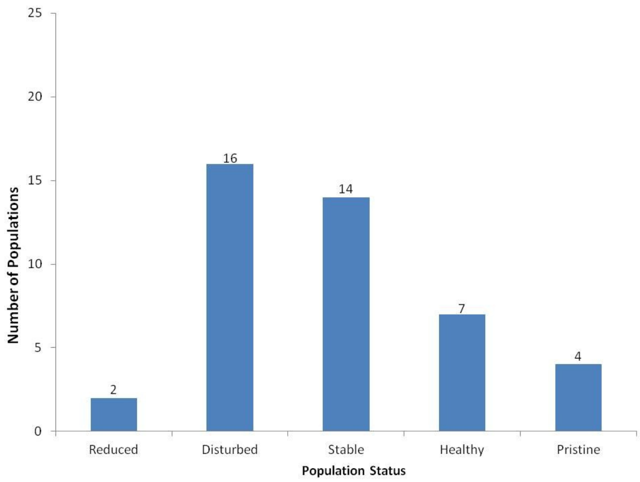

Figure 7. Types of population status in the study area.

Population Assessment

1) Kumaun Division

In Nainital district six locations were assessed, of which Kainchi Dham site depicted reduced population, Ramgarh and Takula had disturbed populations and three locations (Mukteshwar, Kilbury and Brahamsthali) had stable populations. In the Almora district six locations were inspected of which Sheetlakhet and Chowbattiya showed disturbed populations, Dhaulcchina and Pandavkholi had good populations and Binsar and Vriddh Jageshwar had stable populations. In Bageshwar district four populations were analyzed of which Kausani displayed disturbed population and Dwali-Phurkia, Dwali-Kafni, Jatoli-Kathelia had pristine populations. In the Champawat district Lohaghat population assessed with disturbed distribution. In Pithoragarh district four locations were examined of which one (Alam-Sirtola) had reduced population, two (Didihaat and Chaukori) had disturbed populations and Khuliya top had pristine population.

2) Garhwal Division

In the Pauri Garhwal district five locations were assessed of which three (Chobattakhal, Thailisain and Listiyakhet exhibited disturbed populations and two (Khirsu and Chaurinkhal) had stable populations. In Tehri Garhwal five locations were inspected of which Panthwari showed disturbed population, Dhanaulti, Sem Mukhem and Ghuttu had stable populations and Kaddukhal had healthy population status. In Dehradun district two locations were analyzed of which Chakrata displayed disturbed population and Landour had stable population. In Uttarkashi district four locations were surveyed of which Taluka depicted disturbed population, Charurangikhal and Barsu had stable populations and Janakichatti had healthy population status. In Rudraprayag district four locations were examined of which Gaurikund revealed disturbed population, Triyuginarayan had stable and Ransi-Gaundhar and Chopta had healthy population status. In the Chamoli district two areas were assessed of which Auli showed disturbed population and Wan-Doliadhar had healthy population status. Detailed information about the sites and the population status is given in Table 1.

Effect of Altitude on Plant Morphology

It was also found that trees growing in the shade of other trees, were small in stature and have large thin leaves, oriented perpendicular to sun rays while the trees growing in high light intensity i.e. open canopy or in higher altitude, were large in stature and had comparatively smaller and thicker leaves with parallel orientation to sun rays. Such observations are also reported by Fetcher et al. (1983). The trees when growing near a village or agricultural fields are shorter than the trees found in forest. Flowering in *R. arboreum* occurs first in the trees at low altitude areas and gradually progress to those at higher altitude areas. It has also been found that in the past flowering (flower opening) had been commencing in the third week of March; however it is now occurring during first–second weeks of March at low altitudes. Generally the flowering in a particular year is profuse and in the subsequent year it is comparatively less. As the altitude increases, the colour of flower becomes lighter. In the lower altitudes the flower are of red colour (1700-2100 m) but as the altitude increases the flower becomes dark pink, pink, light pink (2200-2500 m), lightest pink (2600-2800 m) and then finally approaches whitish pink (>2800 m), where flower is mostly white with shade of pink colour. Flower also shows different pattern of spots (nectar guides) on the corolla at different altitudes. The trees growing in shade showed less flowering as compared to those growing in open sunlight.

DISCUSSION

Populations of *R. arboreum* in the lower altitude (1400-1700 m) and lower mid altitudes (1800-2000 m) are in

Table 1. Location of sites surveyed to assess the population of *R. arboreum* Sm.

Region/ District	Place	Altitude (m)	Area Type	Associated Species	Population Distribution	Population Status
Kumaun (Kumaon) Division						
1. Nanital	a) Kainchi Dham	1465-1650	Oak - Pine forest	*Pinus roxburghii, Quercus leucotrichophora*	Random	Reduced
	b) Ramgarh	2000-2085	i) Rhododendron-Oak forest ii) Agricultural fields	*Quercus leucotrichophora,* *Myrica esculenta*	Random	Disturbed
	c) Mukteshwar	2200-2300	Rhododendron-Oak forest	*Q. leucotrichophora,* *Q. floribunda*	Uniform	Stable
	d) Takula	1750-1800	Broad Leaved Mixed forest	*Q. leucotrichophora,* *M. esculenta, P. roxburghii*	Random	Disturbed
	e) Kilbury	2200 - 2300	Rhododendron-Oak forest	*Q. leucotrichophora, P. roxburghii,* *Cedrus deodara*	Uniform	Stable
	f) Brahamsthali	2500-2600	Broad Leaved Mixed Forest	*Q. leucotrichophora, Q. floribunda,* *Cedrus deodara*	Uniform, Random	Stable
2. Almora	a) Binsar	1841-2400	i) Pine forest ii) Rhododendron-Oak forest	*P. roxburghii* *Q. leucotrichophora, Q. floribunda,*	Uniform	Healthy
	b) Dhaulcchina	1800-2100	Broad Leaved Mixed forest	*Q. leucotrichophora,* *Q. floribunda, P. roxburghii*	Uniform	Stable
	c) Vriddh Jageshwar	2100-2250	Broad Leaved Mixed Forest	*Q. leucotrichophora, O. floribunda, P. roxburghii*	Uniform	Healthy
	d) Sheetlakhet	1700-1850	Broad Leaved Mixed forest	*Q. leucotrichophora, Myrica esculenta,* *Cupressus torulosa. Acacia catechu*	Random	Disturbed
	e) Pandavkholi, Doonagiri	2070-2454	i) Rhododendron-Oak Forest ii) Pasture	*Q. leucotrichophora, Q. floribunda*	Uniform	Stable
	f) Chowbattiya, Ranikhet	1800-1980	Broad Leaved Mixed forest	*Q. leucotrichophora, Myrica esculenta*	Random	Disturbed
3. Bageshwar	a) Kausani	1634-1700	i) Broad Leaved Mixed forest ii) Agriculture field	*Q. leucotrichophora,* (*Camellia sinensis*)	Random	Disturbed
	b) Dwali-Phurkia	2700-2879	Rhododendron forest	*Q. leucotrichophora, Quercus sp.,* *R. barbatum, R. campanulatum*	Uniform	Pristine
	c) Dwali-Kafni/Kaphni	2700-3350	Rhododendron forest	*Q. floribunda, Q. semecarpifolia, Picea spp.,* *R. barbatum, R. campanulatum, Taxus wallichiana*	Uniform	Pristine
	d) Jatoli-Kathelia (on Sunderdhunga way)	2368-2650	Rhododendron-Oak forest	*Q. floribunda, Q. semecarpifolia, C. deodara,* Acer spp., *Juglans* sp.	Uniform	Pristine
4. Champawat	a) Lohaghat	1600-1773	i)Oak - Pine forest ii)Agricultural field	*Q. leucotrichophora, M. esculenta, P. roxburghii,* *Cupressus torulosa, Acacia catechu*	Random	Disturbed
5. Pithoragarh	a) Didihaat	1670-1730	i) Oak - Pine forest ii)Agricultural fields	*Q. leucotrichophora, P. roxburghii, M. esculenta*	Random	Disturbed
	b) Chaukori	1950-1900	Rhododendron-Oak forest	*Q. leucotrichophora, Q. floribunda, M. esculenta,*	Random	Disturbed
	c) Khuliya/Khaliya Top Munsiyari	2120-3130	Rhododendron forest	*Q. leucotrichophora, Q. floribunda, R. barbatum,* *R. campanulatum*	Clumped, Uniform	Pristine
	d) Alam-Sirtola (on Chiplakedar way)	1430-1500	Broad Leaved Mixed forest	*Q. leucotrichophora, M. esculenta*	Random	Reduced
Garhwal Division						
1. Pauri Garhwal	a) Chowbattakhal	1650-1700	Oak-Pine forest	*Q. leucotrichophora, P. roxburghii*	Random	Disturbed
	b) Khirsu	1780-1800	Rhododendron-Oak forest	*Q. leucotrichophora, M. esculenta*	Uniform	Stable
	c) Chaurinkhal /Chorikhal	2100-2200	Rhododendron-Oak Forest	*Q. leucotrichophora, Q. floribunda, M. esculenta*	Uniform	Stable
	c) Thailisain	1630-1800	Oak-Pine forest	*Q. leucotrichophora, M. esculenta*	Random	Disturbed
	d) Listiyakhet, Dhumakot	1900-1980	Oak-Rhododendron-Pine forest	*Q. leucotrichophora, Q. floribunda,* *M. esculenta, P. roxburghii*	Random	Disturbed
2) Tehri Garhwal	a) Kaddukhal	2400-2640	Rhododendron-Oak Forest	*Q. leucotrichophora, Q. floribunda,*	Uniform	Healthy
	b) Dhanaulti	2100-2150	Rhododendron-Oak Forest	*Q. leucotrichophora, Quercus spp.,*	Uniform	Stable
	c) Panthwari (on Nagtibba way)	1800-1880	Rhododendron-Oak forest	*Q. leucotrichophora,*	Random	Disturbed

Region/ District	Place	Altitude (m)	Area Type	Associated Species	Population Distribution	Population Status
	d) Sem Mukhem	2140-2500	i) Pasture,			
			ii) Rhododendron-Oak Forest	*Q. leucotrichophora, Q. floribunda*	Uniform	Stable
	e) Ghuttu	1800-1930	i) Agricultural Field,			
			ii) Rhododendron-Oak forest	*Q. leucotrichophora, Q. floribunda, M. esculenta, Pinus roxburghii*	Uniform	Stable
3) Dehradun	a) Landour	1900-2070	Broad leaved Mixed forest	*Q. leucotrichophora, Quercus sp., Cryptomeria sp., Pinus roxburghii*	Uniform	Stable
	b) Chakrata	1900 - 1940	Broad Leaved Mixed forest	*Q. leucotrichophora, Q. floribunda*	Random	Disturbed
4) Uttarkashi	a) Chaurangikhal	2180-2350	Rhododendron-Oak Forest	*Q. leucotrichophora, Quercus spp.,*	Uniform	Stable
	b) Barsu	2150-2300	i)Agricultural fields			
	(on Dayara meadow way)		ii) Oak-Conifer forest	*Q. leucotrichophora, Quercus spp., C. deodara*	Random	Stable
	c) Taluka	2000-2060	I) Coniferous forest,	*C. deodara, C. torulosa*	Random	Disturbed
			ii) Agricultural area			
	d) Janakichatti	2480-2830	Broad Leaved Mixed forest	*Q. floribunda, Q. semecarpifolia, Picea spp. Taxus wallichiana,*	Uniform	Healthy
5) Rudraprayag	a) Gaurikund	1900-1920	Broad Leaved Mixed forest	*Q. leucotrichophora, Q. floribunda*	Random	Disturbed
	b) Ransi-Gaundhar (on Madhmaheshwar way)	1830-3030	Pine-Rhododendron-Oak forest	*Q. leucotrichophora, Q. floribunda, P. roxburghii*	Clumped, Uniform	Healthy
	c) Chopta	2650-2690	Rhododendron forest	*Taxus wallichiana, R. barbatum*	Uniform	Healthy
	d) Triyuginarayan	1900 - 2100	Rhododendron-Oak forest	*Q. leucotrichophora, Q. floribunda, M. esculenta*	Uniform	Stable
6) Chamoli	a) Auli	2520-2860	i) Pasture,			
			ii) Rhododendron-Oak Forest	*Q. leucotrichophora, Q. semecarpifolia, Q. floribunda, C. deodara*	Random	Disturbed
	b) Wan-DoliaDhar (on Vedni Bugyal way)	2500-3270	i) Forest,	*Q. leucotrichophora, Q. semecarpifolia, Q.floribunda, Edgeworthia, Taxus wallichiana, R. campanulatum*	Clumped, Uniform	Healthy
			ii) Alpine Meadow			

* above Mean Sea Level

feeble state mainly due to anthropogenic induced pressure and because of Pine trees (*P. roxburghii*), which is a desiccation tolerant, fast colonizing and rapid water absorbing species, thus, very little water is available to other species for growth. The increase in temperature is also supported by the dendrochronological investigations on high altitude conifers of western Himalayas, which had shown an increase in mean annual temperature by 0.6°C and winter temperature by 1°C in 20th century (Yadav and Singh 2002, Yadav et al. 2004). Due to global warming the Himalayan mountain region is viewing changes such as i) increase in winter temperature (Bhutiyani et al. 2010, Dimri and Dash 2012), ii) increase in rainfall and decrease in snowfall (Duan et al. 2006, Bhutiyani et al. 2010, Dimri and Dash 2012), iii) early onset of spring (Bhutiyani et al. 2010), iv) precocious flowering (Rawat 2013, Ranjitkar et al. 2013, Gaira et al. 2014, Shah et al. 2014, Singh 2014), v) altered leaf phenology and change in duration of growing season (Khanduri et al. 2008, Singh et al. 2010, Shrestha et al. 2012), vi) tree line shift (Singh et al. 2012, 2013, Schickhoff et al. 2015) and plant range expansion (Dubey et al. 2003, Telwala et al. 2013, Schickhoff et al. 2015), vii) forest degradation (Pandit et al. 2007, Chaturvedi et al. 2011, Gopalakrishnan et al. 2011), and viii) melting and receding of glaciers (Hasnain 2002, Prasad et al. 2009, Mehta et al. 2011, Pandey et al. 2011) leading to increased river flow and drainage.

Pandit et al. (2007) speculated that only 10% of the dense forest would remain in the Indian Himalayan region by the year 2100 and western Himalayan forests will suffer extreme loss with regards to both area and density decreasing to 30.7% and 16.8% respectively. The most vulnerable regions in the Himalaya would be sub-alpine and alpine regions, the Himalayan dry temperate and moist temperate forests (Singh et al. 2010, Chaturvedi et al. 2011, Gopalakrishnan et al. 2011, Singh et al. 2012, 2013, Telwala et al. 2013, Schickhoff et al. 2015). According to Aitken et al. (2008) the forest trees will face either of the three fates due to climate change i.e. persist by migration to other areas, adapt to the conditions prevailing in the current location and extirpation.

Plant Morphology

The regeneration rate of *Rhododendron* is low because fewer saplings mature into trees due to competition and harsh environmental conditions (Figure 5, Figure 8a). *R. arboreum* prefers acidic soil for growth (Wurzburger and Hendrick 2007, Stehn et al. 2011, Li et al. 2015) and the acidic environment is created by the degradation of acidic litter of *R. arboreum* (Maithani et al. 1998). We found that altitude and light has a profound effect on growth of *R. arboreum*. Probability of growth of this species increases with the increase of altitude. With the increase of altitude the species richness decreases and hence the inter-specific competition also decreases (Choler et al. 2001, Bruun et al. 2006) and *R. arboreum* becomes a dominant species at altitude >2500 m. The reason for difference in leaf size and tree stature in different altitude can be attributed to the varying amount of solar radiation received by the trees growing in shade and exposed areas. The thicker leaves have greater mesophyll thickness and increased surface area of chloroplast facing the intercellular air spaces (Hanba et al. 2002). Thus the plant growing in sunny areas have developed the strategy of small and thick leaves to reduce transpiration during drought stress imposed by winter snow. Moreover, the smaller leaves at sunny sites could have low leaf temperature thus escape overheating (Niinemets and Kull 1994). The plant escapes direct sunlight by orienting the leaves parallel to sun rays in order to reduce transpiration while the shade plant maximize light reception by orienting the leaves perpendicular to solar radiation (Fetcher et al. 1983).

The trees of *R. arboreum* growing in the vicinity of villages and houses were found short in stature thus indicating the anthropogenic pressure of fuel-wood extraction, collection of leaves for fertilizer, fodder and bedding of animals, flower extraction for juice preparation and hindering the expansion of roots due to construction of houses, roads and agricultural field. Generally, the species grows on slopes and provides refuge to herbaceous vegetation thereby helping in slope stabilization (Figure 8b). However, under its high density (>2500 m altitude) we found poor ground vegetation which can be attributed to i) acidic environment created by the leaf litter, ii) less nutrients and moisture available, due to slower degradation rate of leaf litter and iii) unavail-ability of direct sunlight (more diffused light) due to closed canopy. The reason for having poor population and average population at low (1400-1700 m) and lower middle (1800-2000 m) altitude area are expansion of human settlements and agriculture, presence of *Pinus roxburghii* which rapidly absorb water and nutrients thus creating drier conditions, and rapid urbanization, while middle altitude (2100-2300 m) and upper middle altitude (2400-2600 m) areas exhibited stable and healthy population status due to comparatively higher moisture and less anthropogenic activities and subsequently pristine population status was found at high altitude (2700-3300 m).

Flowering Pattern

The flowering period is also influenced by altitude. The flowering at low altitude occurs first on the onset of

Figure 8. a. Land slide in a mountain with less vegetation and b. Stabilized habitat in *R. arboreum*-dominated mountain slopes.

spring while at high altitude flowering commence later on the onset of warm period. In most parts of the Himalayan region the flowering of *R. arboreum* is reported to be occurring precociously, because of increase in average temperature (Ranjitkar et al. 2013, Gaira et al. 2014, Shah et al. 2014, Singh 2014). A possible explanation for precocious flowering could be that temperature increase due to global warming leads to ozone depletion and increase in ultraviolet rays entering the atmosphere (Caldwell et al. 2003, Paul and Gwynn-Jones, 2003, Pfeifer et al. 2006), which is causing early flowering in the mountain plants (Ziska et al. 1992). UV rays are responsible for increased production of flavonoids, which are the main photo-protective and colour imparting pigments in flower. *R. arboreum* can tolerate fluctuations in temperature and could spread to other areas as a result of global warming (Vetaas 2002, Ranjitkar 2013, Ranjitkar et al. 2013, 2014). However, the change in flowering phenology because of global warming would lead to disruption of plant-pollinator interactions which would lead to extinction of pollinators and decline in plant population (Memmott et al. 2007). And the decline of plant will lead to decrease in number of species of different phylum they support. The reason for profuse flowering in alternating years is due to the time taken by phenolic compounds of the rhododendron litter to degrade (Maithani et al. 1998). High acidic litter and low temperature slow down the microbial activity to release the nutrients. In the year of full utilization of nutrients which had released from the previous year accumulated litter, profuse flowering occurs, while less flowering occurs in the following year due to available limited resources. Thus, the flowering was found to be under the control of altitude, temperature, amount of insolation received, soil moisture and nutrients availability. Altitude and temperature regulate the timing and pattern (early or late) of flowering and soil moisture and nutrients regulate the intensity of flowering, while the factor of insolation regulates both aspects of flowering. The trees growing in shade i.e. receiving less insolation, showed less flowering together with paler coloured flowers, and as the altitude changes the insolation intensity changes hence the plant produce different coloured flowers. Recently, Tewari et al. (2016) reported increase in floral bud size is positively correlated with increase in twig water potential and soil moisture.

Factors Causing Decline in *R. arboreum* Population

1) Abiotic Factors

Although *R. arboreum* is a tolerant and hardy species with wide ecological amplitude, still there are some factors behind the loss of this species at low and mid altitude forests. Generally the abiotic and biotic factors together act as negative force to reduce the ability of the plant to establish in large number. However, biotic factor have the major role leading to species decline. Anthropogenic activities such as construction of roads and dams make the mountain foundation fragile which initiate the soil erosion and landslide (Figure 8a). Uttarkhand Himalaya and the surrounding region are highly susceptible to seismic catastrophe (Joshi et al. 2013, Kumar et al. 2014, Mishra 2015, Mridula and Wason 2016) because it falls in the 10% and 20% probability of exceedence of peak ground acceleration 100 gals and 200 gals (Joshi et al. 2013). On disfiguring the topography of mountain due to road and dam construction, the soil erosion accelerates during rainy season and trees have an inherent chance to get uprooted during rainfall and soil erosion (Figure 9). Forest fire is also a factor responsible for large scale destruction of forest. During the year 2014 around 930.33 hectare land in Uttarakhand was affected by forest fire (Uttarakhand Forest Statistics 2014). Sharma and Rikhari (1997) reported that nearly 45% of *R. arboreum* saplings were destroyed by fire in Binsar Wildlife sanctuary in 1995. Fire reduces the number of seedling and sapling density in frequent fire areas (Joshi et al. 2013). Contrary to this Peterson et al. (1994) stated that fire has very less effect on the growth

Figure 9. Plant roots exposed due to soil erosion

Figure 10. Factors responsible for open canopy: a) Agriculture fields all over the mountain, b) Human settlements with sparse vegetation, and signs of soil erosion.

Figure 11. Grazing pressure on the mountains: a. animal grazing in a pasture and b. animal grazing on mountain top.

Figure 12. Examples of open canopy: a. Sparse vegetation on mountain and b. Canopy openness in Rhododendron forests

of competing species like *Pinus ponderosa* in Arizona, which shows *Pinus* species are better adapted to fire than other plant species. The snow factor leads to freezing induced desiccation in the plant and during spring season, when there is increase in transpiration rate due to increase in temperature and thus the plant suffers from drought induced injury because sufficient water is not available immediately (due to water in snow form and frozen soil).

2) Biotic Factors

Agriculture and human settlements are expanding due to alarming increase in population, which puts pressure on the ecosystem for their never ending needs (Figure 10a and 10b). Similarly livestock over-grazing remove the grass cover thus exposing soil and making it prone to erosion (Figure 11a and 11b). Although urbanization brings economic value and development to the area as a whole but at the expenses of large amount of agricultural land which is utilized and this ultimately puts pressure on the forest as people convert and encroach forest areas for agriculture purpose. Urbanization and infrastructural development should be carried out in plain areas where disaster risk is minimum and also taking into consideration the long term impact of the project on the local environment. Fuelwood removal from forest decreases the tree cover of the forest and makes the forest canopy open leading to habitat fragmentation of species (Figure 12a and 12b). Although creation of open canopy area serve as germination ground for establishment of other species (Hubbell et al. 1999) but these gaps also put negative pressure on the species diversity of ecosystem by creating habitat fragmentation and make the soil more prone to erosion. According to Hosonuma et al. (2012) in Asian continent the main drivers for deforestation are local/subsistence agriculture, commercial agriculture, mining, urban expansion, and timber extraction and logging, fuel-wood accounting for forest degradation. FAO (2015) reported that in India the total wood removal has increased from 248.22 million metre^3 (in 1990) to 434.77 million metre^3 (in 2011) while the annual increase in planted forest is only 3% (1990-2015). In Uttarakhand during the period 2014-2015 nearly 23,9521 cubic metres (m^3) of timber and 17,1266.33 m^3 of firewood was produced (Uttarakhand Forest Statistics 2014). Construction of dams and roads bring extreme change to the topography of the mountain, forest cover reduction and alter the species composition and thus should be done by thorough consideration. Drought tolerant and hardy species like *Pinus roxburghii* is expanding to upper elevation areas (Dubey et al. 2003), which hampers the establishment of other species like *Quercus* (Oak) species (Singh et al. 1984). *Pinus* rapidly extract water from soil while *Quercus* increase the water holding capacity of soil, thus promoting the establishment of species like *R. arboreum* (Singh and Pande 1989). According to Grace and Platt (1995) *P. plaustris* exerted a neighbourhood effect, in which the growth of juvenile plants even of the same species was affected. Singh et al. (2012) using satellite imagery had shown that in Uttarakhand the alpine region is experiencing shift in tree line above mean level of 388 ± 80 m. In some areas like Chamoli Garhwal district there is noteworthy upward shift of 1000 m. Singh et al. (2013) through niche modelling study shown that the fundamental niche of *Betula utilis*, a tree line species, is already occupied by other vegetation.

Measures to Counteract Population Decline

Some measure that could be employed at ground level to reduce the impact of destructive effect on *R. arboreum* population are as follows:

i) promote use of solar power generation,

ii) construct biogas plants so fuel-wood use will be minimized,

iii) promote the concept of community agro-forestry to reduce the extraction of fodder from the forest thus reducing grazing,

iv) reduce the fuel bank to forest fire, by adopting the flammable pine needles and other species leaf litter for manure making,

v) construction of dams should be minimized to maintain ecosystem functions,

vi) road construction in landslide prone areas should be discouraged instead bridges should be used to connect the mountains,

vii) encourage the farmers to adopt mixed cropping/ farming in order to maintain land fertility for longer period, to get additional income in form of honey, milk, wool etc. and also strengthen the local insect pollinator diversity,

viii) plantation of local, economically important, adaptable species in degraded forest areas and wastelands like *R. arboreum* Sm., *Quercus* species, *Myrica esculenta* , *Grewia optiva* J. R. Drumm. ex Burret, *Zanthoxylum armatum* DC., *Ficus* species, *Prunus* species, *Pyrus* species, *Celtris australis* L., *Desmodium oojeinense* (Roxb.) H. Ohashi, *Bauhinia* *variegata* L., *Juglans regia* L., *Elaeocarpus ganitrus* Roxb. ex G. Don., *Terminalia species, Alnus nepalensis* D. Don., *Syzygium cumini* (L.) Skeels., *Lyonia ovalifolia* (Wall.) Drude, *Thamnocalamus* species, *Azadirachta indica* A. Juss., *Emblica officinalis* Gaertn., *Dalbergia sissoo* Roxb., *Cedrela toona* Roxb. ex Rottler, *Alianthus excels* Roxb., *Melia azedarach* L., *Mangifera indica* L., *Punica granatum* L., *Saraca asoca* (Roxb.) Willd., *Cochlospermum religiosum* (L.) Alston, *Albizia lebbeck* (L.) Benth., *Morus alba* L., *Berberis* species, *Cinnamomum* species, *Erythrina* species, *Calamus* species, *Dendrocalamus* species etc. to check soil erosion and promote slope stabilization, and

ix) bring forest surrounding the villages under the concept of community forest governed by local communities ('Van Panchayat') (Baland et al. 2010).

CONCLUSION

R. arboreum is a widespread species in Uttarakhand region, but at low and mid altitude its regeneration is hampered due to anthropogenic effects. An unprecedented increase in temperature is altering the phenology and causing precocious flowering particularly at low altitude regions. These factors are creating a negative force which is detrimental to the survival and spread of the species at low altitudes and it is presumed that the populations of this species will be gradually reduced at the lower region and then the pressure would be mounted on the middle altitude region plants. More research through GIS and remote sensing together with quantitative survey is required to ascertain the population status in a close manner. As *R. arboreum* is a keystone species the effect on its population will surely have an impact on the ecosystem in a large way. Therefore, a coordinated effort should be taken by government sector and the local community, so as to prolong the species presence at low and mid altitude in a healthy manner.

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Author Contributions

A.M. designed and performed the study, wrote the manuscript. P.K.B. and D.P.S. wrote the manuscript. P.L.U. provided the inputs and customized the manuscript. We declare there are no competing interests.

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