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Conservation of Rhododendrons in Sikkim Himalaya: An Overview

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Abstract: A review of different conservation aspects of rhododendrons from the Sikkim Himalaya is retraced. Works done in the past and present on the various aspects of the regional rhododendrons vis-à-vis national and global research findings are presented and discussed for its contribution and effect to the understanding of the group. Rhododendrons which are classified as rare, endangered and threatened may be wiped out in near future from the biota, if proper management and conservation initiatives are not taken up. Chronologic primary and derived data on various aspects of regional rhododendrons, viz., species enumeration, species availability and distribution, general usage, identification of anthropogenic pressure, ex situ/ in situ and *in vitro* conservation initiatives, etc. are highlighted. The role of regional rhododendrons as keystone element in the context of Sikkim Himalaya is also presented for a better understanding of conservational issues at upper temperate and lower alpine region of Sikkim.

Key words: Anthropogenic threats · Sikkim Himalaya · Biodiversity · Conservation · Rhododendrons

INTRODUCTION

The genus *Rhododendron* belongs to family Ericaceae and was first described by Carl Linnaeus in 1737 in *Genera Plantarum*. The genus *Rhododendron* comprises of almost 1000 species throughout the world mostly concentrated within a short arc covering the highlands of Nepal, India and China (east of Yunnan and Sichuan) and Malaysia [1-3]. The genus *Rhododendron* is represented by eighty species in India [4-7]. In India the species of rhododendron is represented in the states of Arunachal Pradesh (61), Darjeeling in West Bengal (12), Himachal Pradesh (1), Jammu and Kashmir (3), Manipur (5), Mizoram (3), Nagaland (2), Sikkim (36), Tamil Nadu (1) and Uttaranchal (3). In the Sikkim Himalaya (the Sikkim Hills and Darjeeling Hills combined, ca. 10000 sq km) the rhododendrons are found between upper temperate and sub-alpine zone (1600-3600 m amsl). Very little information are available on the rhododendrons particularly in Sikkim Himalaya. Most of the scientific works in this genus has been done in Europe mainly in Edinburgh, Scotland [1, 8, 9]. After the work on Sikkim Himalayan Rhododendrons by Hooker [10] a complete gap prevailed in the study of the genus. The work was followed almost over a hundred years later by Pradhan and Lachungpa [6]. Over the years and in between these milestone compilations, small chapters by Gamble [4] and Cowan and Cowan [5] and later works by Parton [11]; Singh *et al*. [12]; Paul *et al*. [13]; Tiwari and Chauhan [14] have appeared. Various expeditions were done by the workers for enumeration of rhododendron and search of various species [15-17]. Survey of various threatened plants in the Sikkim Himalaya and the search of many species were also carried out [18-19]. Distribution and protected areas of rhododendrons in the Sikkim Himalaya is shown in Fig. 1. In the latest work Pradhan and Lachungpa [6] have assessed the entire area with total 36 species and a remarkable number of various subspecies, varieties and forms, this gives a more or less complete picture (Table 1). Various workers Pradhan and Lachungpa [6], Philipson and Philipson [8], Hooker [20] and Clarke and Hooker [21] describe the keys to identification of Sikkim Himalayan rhododendrons.

Sikkim is a small mountainous state in the Eastern Himalayan region extending approximately 114 km from North to South and 64 km from East to West, having a total geographical area of 7096 sq. km. The state is situated between 88°00' 58" and 88°55' 25" East and 27°04' and 28°07' 48" North. It is surrounded by vast stretches of Tibetan plateau in North; Chumbi valley and kingdom of Bhutan in the East; Darjeeling district of West Bengal in South and kingdom of Nepal in the West.

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Fig. 1: Location map of Sikkim, showing general distribution of rhododendron and five protected areas

The state has four districts, namely, East, West, North and South, with a population of 540493, having an average density of 76 persons/km^2, as per the census of 2002. This region is listed among the world's ten most critical centers for biodiversity and endemism with 150 species of mammals, 550 species of birds, 650 species of butterflies and moths, 33 species of reptiles, 16 species of amphibians, 48 species of fishes, 4500 species of flowering plants, 36 species of rhododendrons; 9 species of conifers, 450 species of trees, 430 species of orchids, 350 species of ferns and allies and 175 species of wild edible plants [6, 22-23]. The area experiences a heavy rainfall due to its proximity with the Bay of Bengal. Pre-monsoon rain occurs in April-May and Monsoon (South-West) operates normally from the month of May and continues up to early October. Average annual rainfall varies from 2000 mm at valleys to 4000 mm at the mountain ridges. The humidity remains very high during the rainy season (85-97%). In such a small area sharp climatic differences in different ecological zones have promoted a rich diversity and variations in the rhododendron species. Agriculture, high value cash crop farming and eco-tourism are the predominant livelihood options for the people of Sikkim, which has a diversity of ethnic groups such as the *Lepchas, Bhutias, Nepalese* and *Limbus*, representing distinctive and rich cultural diversity. Amongst them the Lepchas are the aboriginal inhabitants of Sikkim. These folks also play a major role in the survival and conservation of Sikkim Himalayan rhododendrons.

Rhododendron Species Diversity: The rhododendron habits of the terrestrial species were found to be of dwarf tussocks, small shrub or robust bushes which may sometimes form impenetrable thickets at places. A greater number of species grow as the epiphytes and only a few species grow to tree proportions (*Rhododendron arboreum, R. barbatum, R. falconeri, R. hodgsonii*)

Table 1: Rarity status of Sikkim Himalayan rhododendron

S. No.	Species	Altitudinal range (m)	Maximum height	Capsule size	Habitats and field characters	Status
1.	*R. arboreum* Smith Scarlet Arborescent Rhododendron N- Lali Gurans	1700-3400	15 m	30 mm long x 7 mm, wide oblong-cylindric	Tree, distributed from Kashmir through Nepal, Sikkim, Darjeeling, Bhutan, Arunachal Pradesh, Burma and S.E. Tibet.	Vulnerable
2.	*R. cinnabarinum* Hook.f. Cinnabar Rhododendron N-Sano Chimal	1900-4000	2 m	10-12 mm long, scaly	Branched shrub, growing in mixed rhododendron forests in association with *R. thomsonii, R. campanulatum,* etc. and distributed from Nepal, Sikkim, Bhutan, and Darjeeling.	Out of danger
3.	*R. dalbousiae* Hook.f. Lady Dalhousie's Rhododendron N - Lahare Chimal	2000-2600	2 m	20-25 mm long x 8-12 mm	Epiphytic shrub, parasitical on the trunks of large trees of *Michelia* and *Quercus*; Nepal, Sikkim, Darjeeling, Bhutan and Arunachal Pradesh.	Out of danger
4.	*R. grande* Wt. Large Silvery Rhododendron N- Patle Korlinga	2000-3000	10-15 m	35-40mm long x 10-12mm	Tree, distributed from E. Nepal, Sikkim, Darjeeling and Bhutan.	Threatened
5.	*R. griffithianum* Wt. Lord Auckland's Rhododendron N - Seto Chimal	2000-3200	3-5 m	30 mm long	Small tree, oak forest or in bamboo thickets in association with *R. grande*, *Magnolia globosa;* E. Nepal, Sikkim, Bhutan, S.E. Tibet and Arunachal Pradesh.	Out of danger
6.	*R. lindleyi* T. Moore Dr. Lindley's Rhododendron N-Sano Lahare Chimal	2000-3000	2-3 m	50 mm long	Epiphytic shrub, found epiphytic on trees and rocks, distributed from E. Nepal, Sikkim, Bhutan, Manipur, Burma and S.E. Tibet.	Out of danger
7.	*R. edgeworthii* Hook.f. Edgeworth's Rhododendron N- Edgeworth ko Chimal	2000-4000	1-4 m	20-25 mm long	Epiphytic shrub, distributed from Sikkim, Darjeeling, Bhutan, S.E. Tibet, N.E. Burma, and Yunnan in China.	Out of danger
8.	*R. triflorum* Hook.f. Three-flowered Rhododendron N- Pahenle Chimal	2300-4000	2-3 m	10-12 mm, cylindrical	Shrub inhabits open slopes and grows in association with *R. thomsonii* and other species.	Threatened
9.	*R. vaccinioides* Hook.f. Vaccinium-like Rhododendron N- Khiaune-pate Gurans	2400-3000	1 m	20-25 mm long x 2-4mm broad	Epiphytic shrub inhabits moist rocks and shady places, distributed from Nepal, Sikkim, Darjeeling, Bhutan, S. Tibet to N. Burma.	Out of danger
10.	*R. virgatum* Hook.f. Twiggy Rhododendron N- Hanginae Gurans	2500-3300	1.5 m	10-12 mm long, densely scaly	Erect twiggy shrub, grows gregariously on freshly exposed steep slopes in Chungthang, Lachung and Lachen.	Out of danger
11.	*R. camelliiflorum* Hook.f. Camellia-flowered Rhododendron N-Chia-phule Gurans	2500-3500	1-2 m	12-15 mm long	Straggly shrub, found on open rocky situations, distributed from Pakistan through Western and Central Himalayas.	Out of danger
12.	*R. leptocarpum* Nuttall Slender-fruited rhododendron N - Jhinophale Gurans	3000-3500	1-2 m	15 mm long x 4-5 mm	Epiphytic shrub, Growing in association with *R. dalhousiae* and *R. camelliiflorum*; Choka village in Sikkim, Shingba and Tobrang in N. Bhutan, and Mande La and Sakden in E. Bhutan, S.E. Tibet, China, N.E. and Arunachal Pradesh.	Endangered
13.	*R. maddeni* Hook.f. Major Madden's Rhododendron N - Major Madden ko Chimal	2500-4000	1.5-2.5 m	25-30 mm long, oblong-cylindric	Shrub, Epiphytic on trees, very rare in thickets by the Lachen and Lachung rivers at Chungthang in Sikkim and Bhutan.	Endangered
14.	*R. lepidotum* Wall.ex. G. Don. Scaly Rhododendron N - Bhale Sunpate	2500-5000	1-1.5 m	6-8 mm long x 4-6 mm broad	Resinous shrub, open rocky situations; Western and Central Himalaya to S.W. China.	Out of danger
15	*R. glaucophyllum* Rehder Glaucous-leaved Rhododendron N - Takma Chimal	2700-4000	1-1.5 m	2 mm long	Shrub, prefer open rocky moss-covered ridges and undergrowths of *Abies densa*; Sikkim Himalaya: Lachung, Lachen and Chola; E. Nepal, Bhutan, S.E. Tibet and Arunachal Pradesh.	Out of danger
16.	*R. falconeri* Hook.f. Dr. Falconer's Rhododendron N- Korlinga	3000-3500	10-15 m	5-10 mm long covered with branched hair	Tree, distributed from Nepal, Sikkim, Darjeeling, Bhutan and Arunachal Pradesh.	Threatened
17.	*R. niveum* Hook.f. Snow-leaved Rhododendron N - Hiun-pate Gurans	3100	2.5-5 m	6 mm long, green	Rocky valleys and ridges growing; Yakchey in North Sikkim; endemic to Bhutan and Sikkim.	Endangered
18.	*R. barbatum* Wall. ex G. Don. Bristly Rhododendron N- Lal-Chimal	3000-3700	6-10 m	20-25 mm long, oblong-cylindric	Tree, grows in association with *R. hogsonii* and other rhododendron species, distributed from Kumaon through Nepal, Sikkim, Darjeeling and Bhutan.	Out of danger
19.	*R. ciliatum* Hook.f. Ciliated Rhododendron N - Junge Chimal	3000-3800	1-1.5 m	9-12 mm long	Dwarf, Lithophytic shrub Marshy situations, well exposed to sunlight; Lachung and Lachen in Northeast Sikkim, Eastern Nepal through Sikkim and Bhutan.	Threatened
20.	*R. hodgsonii* Hook.f. Hodgson's Rhododendron N- Gulabi Korlinga	3000-4000	3-7 m	40-45 mm long	Branched Tree, distributed from Nepal through Sikkim, Darjeeling and Bhutan.	Out of danger
21.	*R. campanulatum* D. Don Bell-flowered Rhododendron N- Nilo Chimal	3000-4000	4-6 m	22-25 mm long broad, cylindric	Shrub, distributed in Nepal, Sikkim, Darjeeling, Bhutan Arunachal Pradesh.	Out of danger
22.	*R. baileyi* Balf.f. Bailey's Rhododendron N- Bailey ko Chimal	3000-4800	2 m	8 mm long, scaly	Terrestrial evergreen Shrub, distributed in Tibet, Bhutan and Sikkim.	Threatened
23.	*R. setosum* D. Don Bristly Rhododendron N- Tsallu Gurans	3000-5500	0.5 m	6 mm, small	Shrub, Highly aromatic, growing in association with other high altitude species like *R. nivale*, *R. lepidotum,* etc., distributed from Eastern Nepal, Sikkim and Bhutan.	Threatened
24.	*R. anthopogon* D. Don Bearded Rhododendron N- Dhupi Gurans	3000-5000	45 cm	3-4 mm long	Aromatic shrub, widely distribute species from Kashmir, Nepal, Sikkim, Dzongri, Arunachal Pradesh and S.E. Tibet.	Threatened
25.	*R. campylocarpum* Hook.f. Curve-fruited Rhododendron N - Bango-phale Gurans	3200-4000	1.5-5 m	20-25 mm long x 4 mm wide, cylindric	Shrub, distributed from Eastern Nepal through Sikkim, Darjeeling, Bhutan, Arunachal Pradesh and Burma.	Out of danger

Table 1: Continued

26.	*R. decipiens* Lacaita Deceiving Rhododendron N- Jhukaune Korlinga	3300-3800	2.5-3 m	10 mm long	Medium tree, found in Singalila Ridge, Lachung Lachen.	Threatened
27.	*R. thomsonii* Hook.f. Dr. Thomson's Rhododendron N - Dr. Thomson's ko Gurans	3300-4500	3-5 m	7-8 mm long, glabrous	Large shrub, Open situations or forms mixed shrubberies with other rhododendron; Nepal, Sikkim, Bhutan and Darjeeling.	Vulnerable
28.	*R. pendulum* Hook.f. Pendulous Rhododendron N-Jhundinae Chimal	3300-4000	1-1..5 m	10-12 mm long, broadly ovate	Epiphytic shrub grows in sheltered Abies forest, distributed in Lachung and Yumthang in North Sikkim.	Rare
29.	*R. pumilum* Hook.f. Dwarf Rhododendron N-Purke Gurans	3500-4500	50-200mm	10-15 mm long, ovate	Faintly fragrant shrub, dwarf, grows in the alpine region, reported from E. Nepal, Sikkim and Bhutan.	Endangered
30.	*R. wallichii* Hook.f. Dr. Wallich's Rhododendron N-Wallich ko Chimal	3500-5000	3 m	25-35 mm long, slightly curved, glabrous	Shrub found between Lachung and Yumthang north Sikkim and distributed in Nepal, Bhutan and Assam.	Out of danger
31.	*R. wightii* Hook.f. Dr. Wight's Rhododendron N- Wight ko Gurans	3500-4500	3-5 m	40-50mm long x 7-8mm broad	Small tree, distributed from Nepal, Sikkim, Bhutan, and N. Burma.	Rare
32.	*R. sikkimense* Pradhan and Lachungpa Sikkimese Rhododendron N-Sikkimae Gurans	3700	3-5 m	6-7 mm long, silvery-haired	Terrestrial shrub grows on sandy soil and found in open exposed area in Northeast Sikkim.	Endangered
33.	*R. fulgens* Hook.f. Brilliant Rhododendron N-Chimal	4000-5000	2-5 m	5 mm long, slightly curve	Small tree, distributed from Nepal through Sikkim and Bhutan, Assam.	Rare
34.	*R. lanatum* Hook.f. Wooly Rhododendron N- Bhutle Gurans	4000	3 m	6 mm long x 8 mm, broad, cylindrical	Small tree inhabits rocks and gullies of Mountains in Nathula, Dzongri in Sikkim.	Out of danger
35.	*R. aeruginosum* Hook. f. Aeruginose Rhododendron N- Nilo-pate Chimal	4500-5000	1.5 m	4 mm long	Shrub grows on open rocky places at Lachung and Yumthang in Northeast Sikkim.	Threatened
36.	*R. nivale* Hook.f. Snow Rhododendron N- Hiun Gurans	4500-6000	1-1.5 m	4 mm long, scaly	Cushion-like shrub, Odoriferous, distributed fro western Nepal, through Sikkim and Bhutan.	Threatened

[N – Vernacular names in Nepali]

attaining heights up to 10-15 m (Table 1). Surprisingly large morphometric variations may be observed between the same species and this trend often transcends to the population level too. Rhododendrons form dominating species all along the cool temperate, subalpine and alpine zones in the Sikkim Himalaya. For many subalpine species, snow cover is prerequisite for survival during the harsh environmental conditions that prevail during alpine winters [24]. It supports a wide range of plant and animal diversity. It is a keystone element and if disturbed can degrade habitats that threaten associated biodiversity. The subalpine to alpine transition zone that includes timberline is the most fragile ecosystem in the Himalaya. Rhododendron is the only group of plants that has continuum in the aforesaid ecotone and beyond doubt maintains the biological sustenance in this fragile zone.

In a general sense, the rhododendrons are essentially terrestrials in nature. Under suitable environment the epiphytes are always found growing on the soils albeit the ground is a raised earth, rocks or sloping. The epiphytic species of the group were found as *R. camelliiflorum, R. dalhousiae, R. edgeworthii, R. griffithianum* (to some extent), *R. leptocarpum, R. lindleyi* and *R. vaccinioides*. For these the major phorophytes are species of *Castanopsis, Quercus, R. arboreum*, etc. Generally, trees with a longer lifespan and rough bark were found to be preferred as phorophytes.

Some of the species which also grow on rocks are *R. fulgens, R. lepidotum, R. nivale, R. pendulum, R. setosum, R. camelliiflorum* and to some extent *R. anthopogon* and *R. baileyi.* At favourable location, it seems, almost all species take to the rocks as refuge. Species which require shade to a varying degree are *R. lanatum* (under *Abies* sp.), *R. fulgens, R. decipiens, R. wallichii, R. wightii and R. campanulatum* (all under mixed community of dominant *Abies* sp.). All other species may be classified as 'outdoor' because they grow quite well in the open. Most of the bush/bushlets are found on open sloping terrain. The slopes offer somewhat well-drained condition and thus less moist situation, where a few species make their home, e.g. *R. virgatum, R. pendulum*, etc. The epiphytic rhododendrons which are found sometimes growing on soil are generally restricted to the sloping terrain where water-logging is less experienced (as is the situation on a tree environment). The shrubs favour level grounds, the river-terraces being their favourite retreats. At Barshey Rhododendron Sanctuary, *R. falconeri* though grows in marshy locality, never steps into the marsh but choose the adjacent grounds which are less moist. Similarly, the *R. ciliatum* at

Yakchay grows on marshy places and at the adjacent non-marshy sites *R. niveum* covers the remaining ground. As all marshy places are usually on even grounds the species that grow here were seldom found growing on the slopes. The 36 species of rhododendrons in the Sikkim Himalaya showed barrel-shaped altitudinal distribution [12]. Nine different altitudinal distribution ranges were categorized between 1500 m and 6000 m. *R. arboreum* is a common species that showed distribution from 1500 m elevation up to 4000 m, while other species of wide ecological amplitude ranging from 2500 m up and 6000 m were *R. anthopogon* and *R. setosum*. The highest number of species occurrence was recorded between 3000-3500 m. The species availability decreases drastically from 4500 m upwards and 2500 m downwards. Species concentration increases with the latitudinal progression from south to north. Rhododendron forests are attractive destination for large number of visitors but the increasing influx is exerting more pressure towards its survival. It provides habitat for a variety of wildlife including avifauna.

Rhododendrons throughout the world have shown a widely varying ecological representation linked with its conservational status, which correspond to its growing condition or locality. A case in point is *Rhododendron ponticum*, which at one extreme represents the gregarious habit to the extent of growing to weed proportion over the English landscape whereas at the other end *Rhododendron maddeni* has become an endangered species through time in the Sikkim Himalaya. As the situation differs by each location type an entire set of action measures taken and the results vary accordingly. Singh *et al*. [12] for the first time brings up a dataset to understand a much endangered species of the Himalayas and discusses the mechanisms involved to resurrect it and reintroduction in the wild.

Morphological Traits: The genus *Rhododendron* belongs to Division *Angiospermae*, Sub-division *Dicotyledoneae*, Class *Metachlamydeae* (*Sympetalae*), Order *Ericales,* Family *Ericaceae* and Subfamily *Rhododendroideae.* The major characteristics of the genera are; the plants are mostly shrub or tree, flowers are actinomorphic, bisexual, pentamerous, hypogynous, corolla gamopetalous, stamens obdioplostemonous and inserted on a nectar secreting disc, free and usually not epipetallous, pollen in tetrads, ovary many, small seeds with endosperm and frequently roots are associated with mycorrhiza. Pollen tetrad description of different rhododendron species containing normal information on microsporogenesis and microspore tetrads based on rotational and transitional views of tetrads was described by Kumar *et al*. [25]. Variation in size of pollen tetrads and morphology in some rhododendron species were most remarkable.

Various workers Pradhan and Lachungpa [6], Philipson and Philipson [8], Hooker [20] and Clarke, Hooker [21] and Cullen and Chamberlain [26] describe the keys to identification of Sikkim Himalayan rhododendrons. The rhododendron flowers have an enormous range of colour, shapes and size in their wild forms and its horticultural values are internationally known. Apart from their aesthetic use worldwide, several species of Sikkim Himalayan rhododendrons have ethnic uses from times immemorial and whose survival in the wild is threatened. Micro- and macro-morphological studies of rhododendron species showed that the testa and the endosperm dimensions and especially the ornamentation pattern on the outer periclinal walls of some species are distinct (Table 1). Seeds of rhododendron are clearly distinguished from their outer micro- and macro-morphological variability from species to species. Rhododendron seeds are dull with rough spermoderm surface [27]. Mainly on the basis of the shape and texture of leaves, colour of petals, number of stamens and capsule walls, Pradhan and Lachungpa [6] recognized section, series and subseries of genus *Rhododendron*. Seed morphological data support the taxonomic relationships of different species of genus rhododendron by having longer and wider seeds with longer endosperms. There is wide variation in the seed dimensions, macro and micro-morphological features in some species of rhododendrons [27]. Also, the capsules of *R. dalhousiae* are larger in diameter than those of other species, which is associated with a large seed size in this species.

Rhododendrons

A key-stone element of the biodiversity: Sikkim falls in one of the 'biodiversity hotspots' [28-29] and one of the world's most critical centres of biodiversity and endemism [30-31]. The forests represent diverse plant communities and vegetation types corresponding to variations of climatic and edaphic factors.The study of the impact of the rhododendron species on other species has its significance to ecosystem processes, succession and forest management, thus rhododendron is considered a 'Keystone element' in the Himalayan context. Over the Sikkim Himalayan landscape also the rhododendron plays a pronounced role as a keystone species and especially at the sub-alpine zone it provides the ecological stability to the vegetation communities and associated niche and also

to the community continuum. Rhododendrons form dominating species all along the cool temperate, subalpine and alpine zones in the Sikkim Himalaya. It supports a wide range of plant and animal diversity. It is a keystone element so that if disturbed may degrade habitats that threaten associated biodiversity. Restoration of rhododendrons and their conservation in nature promotes the existence of other biodiversity components. It provides feeding guild for wide range of birds in an altitudinal gradient. The subalpine to alpine transition zone that includes timberline is the most fragile ecosystem in the Himalaya. Rhododendron is the only group of plants that has continum in the aforesaid ecotone and beyond doubt maintains the biological sustenance in this fragile zone. Nutrient and water fluxes between the associated species are filtered and possibly impacted by these genera [32]. Furthermore, rhododendrons are the most abundant in the sites with the highest potential for forest productivity, which increases the importance of the influence that rhododendrons have on the forests. Consequently, critical adjustment in forest management protocols and forestry practices may be required based on the mechanisms by which rhododendrons has the impact on associated biodiversity [33]. Population viability analysis in this study for different species have revealed that the loss of even a single individual from a small population could adversely affect the population structure and viability and push many species toward extinction (e.g., *R. leptocarpum*).

Rhododendrons and the People Use Patterns: Many of these rhododendron species have a major uses for the local people ranging from landscaping to making household goods, accent and woodland planting. The instance of country-made liqour from *R. arboreum* flowers may be encountered in the Singalila ridge in the Darjeeling Himalaya. The flowers are collected and processed fresh. For this particular purpose, it is learnt that, the Forest Department, demarcates certain areas for flower harvest each year. Also picking of flowers from single tree amounts to about 60% only and the rest of the blooms are left out on the tree to mature into seeds. The collection of *R. anthopogon* and *R. setosum* for incense purpose is an age-old custom but stress is severe now. The twigs and older branches are also included. Though uprooting is seldom found the practice of incense collecting is a threat of considerable dimension to the species and the environment of the region. The tiny leaves of *R. nivale* have the fragrance that can be used for aesthetics [10, 20]. *R. setosum* emits a strong heady aroma that causes painful headaches at high altitudes. The leaves could be distilled for aromatic oils with possible uses in perfumery and cosmetics [6]. The vegetative parts of *R. thomsonii* are found to be highly poisonous. Leaves and pollen of *R. cinnabarinum* and *R. grande* are poisonous to grazing animals. Apart from their aesthetic use worldwide, several species of Sikkim Himalayan rhododendron have ethnic uses. The leaves of *R. anthopogon* are mixed with those of juniper to provide incense that is widely used in Buddhist monasteries. The fruits are the favorites of birds, which also disperse the seeds. Other uses are in packing of apples and butter (leaves of *R. decipiens* and *R. falconeri* are used) and making small household implements (tool handles, pack saddles, etc.). In the latest work Prakash *et al*. [34] has analysed the non-toxic edible *Rhododendron* species with high amounts of phenols and promising antioxidant activity may be utilized in the development of nutraceuticals and functional foods whereas other non-edible toxic species can be used for the isolation of desired phytochemical to develop health care product. Further, the present studies hold promise to identify sources of phytochemicals with potential antioxidant and free radical scavenging activities.

Threats and Constraints: Forest natural resources are influenced to a greater extent by both natural and anthropogenic disturbances, resulting in habitat degradation and consequent depletion of flora and fauna of the protected areas. Within the last few decades the rhododendron of this region has been experiencing a marked increase in anthropogenic pressure and due to this the likelihood of its survival has come under close scrutiny. It was observed that till the middle of the 1980's rhododendrons never did show any discernible signs of disturbance in the wild. Later, the origin of human interference over its habitat spread its tentacles in 3 major areas, viz., (i) Increase of settlements at the fringe areas giving rise to increase in population, ii. Construction of road networks and (ii) Surge in tourist influx. Although not working in unison these factors independently were enough to wreck havoc in and around the rhododendron habitats. Escalation in population called in for increased firewood supply and the newly-built roads helped to bring in the rhododendron woods with minimum efforts on larger trucks. Earlier, the woods had to be ferried in by man or the beasts but the changed situation meant no good for the plants. Moreover, the road construction and repair jobs incessantly relied on rhododendron logs for heating and melting the hundreds of coal-tar barrels and the work force garrisoned nearby also took its share of the

Table 2: Protected areas of Sikkim Himalaya

Name of protected area	Area (Km^2)	District	Altitudinal range (m)	Significance
Barsey Rhododendron Sanctuary	104.00	West	2200-4100	Well known for its unique abundance of rhododendron trees and shrubs. Part of Barsey Rhododendron sanctuary has a tri-junction where Singalila National Park of Darjeeling and eastern Nepal meet. *R. arboreum, R. cinnabarinum, R. falconeri, R. barbatum, R. campanulatum* and *R. hodgsoni* are most common rhododendrons that are found in the sanctuary.
Fambonglho Wildlife Sanctuary	51.76	East	1524-2749	This sanctuary near Gangtok town, East Sikkim is a true representative of the sub tropical ecoregion and is rich in R. *dalhousiae,* bamboo forests and Oaks (*Quercus* sp.),. It is also a notified sanctuary and a tourist destination.
Kyongnosla Alpine Sanctuary	31.00	East	3292-4116	Situated around the area adjoining the Chhangu lake along the Nathula road at a distance of about 31 km east of Gangtok in East Sikkim. The sanctuary is rich with a wide variety of rhododendrons and rare and endangered medicinal plants.
Maenam Wildlife Sanctuary	35.34	South	2400-3263	Located in the South Sikkim is a true representative of the Sub tropical ecoregion and is very rich in *R. griffithianum* and *R. dalhousiae.* It is also a notified sanctuary and a popular tourist destination.
Shingba Rhododendron Sanctuary	43.00	North	3048-4575	This sanctuary above Lachung village, North Sikkim is a true representative of the temperate ecoregion. *R. niveum* the state tree of Sikkim *e*xists only in a small scattered population along with *Abies webbiana* Lindl. and other rhododendrons in protected areas. It is also a notified sanctuary and a popular destination for trekkers.

rhododendron woodlands. The inflow of tourists marked the next phase of damage to the rhododendrons where the habitat was infringed openly, flowers were picked and seedlings trampled underneath. Where the first two factors were responsible for direct damage to the existing plants the last one contributed in fixing up the plant's regeneration system for good.

The many rhododendrons which were relatively few in numbers earlier have become suddenly scarce (*R. leptocarpum, R. pendulum*), population at places have turned acutely localized (*R. ciliatum, R. glaucophyllum, R. niveum, R. virgatum*), the stands are markedly shrinking (*R. cinnabarinum, R. hodgsonii* and *R. lanatum*) and at certain locations entire populations have completely vanished (*R. decipiens* at Yumthang valley, *R. maddeni* at the Rate chhu catchment). *Rhododendron pumilum,* a much localized species from the Yumthang valley has not been observed for quite a long time despite repeated intensive scouting. It is presumed now that the species might be heading for extinction; a greater probability is that it could already be extinct. Chronologically, all these events are of much recent date but the pace of its occurrence is of much significance and in the conservation aspect this might be fairly unsettling. Regeneration status of most of the rhododendrons has been found to be below par [12]. There have been efforts to study the impacts of anthropogenic pressures on the protected area ecosystems at local and regional level by different workers.

The forests represent diverse plant communities and vegetational types corresponding to variations of climatic and edaphic factors but the main variable still is anthropogenic for the region. This is now an established fact everywhere and in the region signs of this particular interference are showing up at some important locations. The rhododendron growing area falling on the established trekking/touring routes are the one which are prone to get disturbed. Flowers are picked up but the rare ones are prime objects to be preserved on the trekking routes. The disturbances are mainly in the form of picking of flowers, pollarding, uprooting and changing the natural habitat chemically and mechanically. Usually the trekkers on Singalila ridge (Meghma-Sandakphu trail) and to Dzongri (Yuksam Thansing trail) are so much preoccupied with their long and arduous route that uprooting a plant and bringing it back home is a trying prospect. They can hardly manage to cut and use fresh rhododendrons to light a fire. Additional procedure on the rhododendron comes from the pack animals of various expeditions. Apart from this route is also used by hundreds of grazing animals, chiefly the yaks and the graziers. The Sikkim Himalaya is still dependant to a large extent on natural fuel resource supply and in the countryside it is rather obligate rather than an option. Rhododendrons are always a prime target because of its easily burning qualities and therefore exploited at length wherever it is growing in the Sikkim Himalaya. The conservation initiatives of the government are highly commendable where large areas have been set aside as protected areas (Table 2). The two rhododendron sanctuaries, viz., at Shingba and Barsey, are exclusively declared as protected areas keeping in view the commitments towards conservation of rhododendron species. Normally, if other hardwoods are available the rhododendrons are seldom used as fuelwood by the locals. The migratory clusters and sheep/yak herders usually employ woods of resinous trees which are easily flammable even when fresh. Stockpiling of hardwoods is rarely found in these groups of people. However, shrinking supplies of the hardwoods may easily make rhododendrons the next obvious target in sight. The neighboring villages at Lachung and Lachen also play a

role in the anthropogenic pressure mainly in the form of fuelwood collection. Species of *R. hodgsonii*, *R. wightii* and *R. decipiens* are the principal targets and the cut stumps in the habitat stands as evidence to this effect. These rhododendrons which are major fuel source among the genus are found within the elevations 2700-3600 m. At present the rhododendrons of the region have reached a stage where many species are found as rare and endangered. At the time of baseline assessment many species were found at varying degree of threat within their habitat.

Research Initiatives in Rhododendron Regeneration: Various reports are available on the rhododendrons research and development internationally [3, 35], however so far much more information has been accumulated till now over this genera (mostly Azalea group) in regards to it's growing condition, reproductive methods, taxonomy, breeding etc. [36], but actual study on rhododendron regeneration and conservation issue in the Sikkim Himalaya is almost non existent. Though floristically rich, the genus *Rhododendron* in the region is one of the most neglected groups of plants in terms of scientific inquiry so far. It has been experienced that on each individual species behaved differently to a set of treatments, whether it is *in vitro* applications or through conventional methods. The rhododendron species are propagated by vegetative means as well as through seeds. The success in micropropagation of rhododendron is limited due to several problems. The rhododendron species often secrete substances into the medium which inhibit the growth, development and differentiation of the expalnt *in vitro.* The rate of vegetative propagation is very slow in many rhododendron species and seed germination in nature is also very poor.

Conventional Propagation: Rhododendron propagation via conventional method is generally carried out by seeds and vegetative methods. Rhododendrons here usually grow under a moist environment with plenty of soil moisture, humidity and at the locations above 2800 m spend about 3 months under the snow. The winters with severe drop in temperature at localities above 2800 m produces permafrost type of situation. A physiological drought condition is thus always experienced by these plants at such locations. The species which experience and grow over regular snow-slide and avalanches are *R. niveum* and *R. thomsonii*. The soil in most of the rhododendron growing spots showed high nitrogen content. It has now been established that phosphorus is extremely essential for the proper growth of the seedlings of rhododendrons. All plants must have access to the same essential resources to be able to grow and reproduce. For plants growing in cold environments, low temperature is considered to restrict growth more strongly than it restricts photosynthesis [37].

Very little information is apparently available on the germination of rhododendrons. At the present, no long term storage methods are suggested for the seeds of rhododendrons, so it is important to examine their desiccation response in order to obtain preliminary information for their storage and conservation [38]. It is now widely accepted that the physiological quality of seed, defined in terms of percentage, rate and uniformity of germination, has a major impact on the efficiency and production. Seed germination refers to the resumption of metabolic activities upon inhibition of seeds followed by radical emergence and subsequent seedling growth. Small seeds (like that of rhododendrons) require suitable medium supplemented with nutrient and carbohydrates source for vigorous *in vitro* seed germination and growth. Physical parameters such as light and temperature also determine the success or failure of a species on a particular locality, which in turn depends mostly on the germinability of the seeds of a particular species. Seed germination of the same species may also vary with the time of collection and parental environment [39]. The plants of this genus generally prefer acidic soil [1, 26]. Seed germination and its behaviour in Sikkim Himalayan plants were investigated using soil from forest (Rate chhu, East Sikkim) as well as non-forest areas, including sterilized soil [40]. Results obtained from various soil treatments indicated the presence of certain germination factors in the rhizosphere soil of rhododendrons, which seem to be of microbial origin. The role of rhizoflora, positive or negative on seed germination and subsequent plant growth of some important tree species of Indian Himalayan region has been reported recently [41-42]. The rhizosphere which is often characterized with stimulated microbial activity provides a natural consortium of microorganisms and may be used as a source of inoculums for raising healthy seedlings of forest species. A tree rhizosphere is likely to develop a microenvironment continuously under the effect of the root exudates, soil characteristics and climatic factors, giving an opportunity for development of a specialized rhizoflora. Such rhizosphere (e.g., tea) has been reported to be colonized by greater antagonistic populations providing a natural site for isolation and selection of promising microbial inoculants [43]. Diversity and colonization of arbuscular

mycorrhizal fungi associated with species of rhododendrons found on an altitudinal range from 1500 to 4500 m amsl in Kumaun region of Indian Central Himalaya have recently been studied [44]. An appropriate amount of rhizosphere soil preferably from the corresponding taxa, may carry all the microorganisms including mycorrhizae and prove to be an excellent source of "inoculum" to colonize nutritionally poor soils at degraded sites.

There are very few reports of vegetative propagation of rhododendrons species occurring in the Himalayan region. One of the key problems in rhododendron species is that the plants are not good at coppicing. Adventitious root formation is a key step in vegetative propagation and losses occur often because the cuttings do not form roots. Phenolic compounds either alone or in combination with auxins and abscisic acid have also been reported to stimulate adventitious root formation in cutting of several plant species [45-46]. Rhododendrons are generally propagated by vegetative propagation. This is the well established method of reproducing a young plant exactly similar to its parent. If the rare and endangered species are to be conserved, cutting, grafting and layering needs to be resorted too. Great improvements have been made in the case of rooting of cutting, but only for Azaleas and some species, other than Sikkim Himalayan rhododendrons. Propagation through direct rooting of the cuttings were found effective in *R. griffithianum* and also successful in the case of *R. arboreum*, *barbatum*, *campanulatum*, *ciliatum*, *hodgsonii* and *grande*. The tender branchlet cuttings were more vigorous in root production in comparison to the mature branches. Recently some success has been obtained in inducing roots in *R. grande* and *R. dalhousiae* using air wet technique [47]. Layering and airlayering are often the best way for the propagation because this is more rapid and more successful in wet condition and where there is plenty of organic matter that does not dry out readily. The best advantage of this is that the root system of the parent plant is not damaged or disturbed.

***In vitro* Micropropagation:** Most of the rhododendron produce seeds which are too small and do not readily germinate in soils. Thus mass multiplication of disease free planting material is a general problem. In this regard the micropropagation holds significant promise for true-to-type, rapid and mass multiplication under disease free conditions. In recent years, tissue culture has emerged as a promising technique to obtain genetically pure elite populations under *in vitro* conditions rather than working on indifferent populations. Tissue culture has now become a well established technique for culturing and studying the physiological behavior of isolated plant organs under precisely controlled physical and chemical conditions. The *in vitro* propagation through meristem culture is the most economical and viable method for clonal propagation. The first successful micropropagation protocol has been achieved for an important Sikkim Himalayan rhododendron, *R. maddeni* Hook.f. [48-49]. Cotyledonary nodal part was used for shoots multiplication on Anderson media with antioxidants containing low concentration of 2iP and IAA. Kumar *et al*. [48] (2004) described a method for propagations and direct rooting of shoots under *in vivo* using expanding bud explants. Pre-treatment for at least 10 days in a medium supplemented with IBA increased the number of roots produced per shoot. Although Murashige and Skoog's medium [50] has been widely used for *in vitro* shoot proliferation of many different plant species, it has been reported to be toxic to rhododendrons. A low salt concentration medium developed by Anderson [51-53] has been successfully used for shoot establishment and proliferation for a wide range of rhododendron species with a requirement for some modification of the medium strength for some species. Among cytokinins, Zeatin and Isopentenyladenine (2iP) have been commonly used in micropropagation of rhododendrons [53-56]. However these are costly and are used at high concentration; moreover, certain cultivars do not respond well to these cytokinins [55]. Adventitious shoot regeneration of rhododendron species has been induced from various tissues including ovaries [57-58], stamens [59], stem segment [60-63], shoot tips [63] and leaf explants [54, 64-65]. Among all sources of explants, leaf tissues and stem segments are the most preferred as they are available in large quantities throughout the growing season. Most explants will initially develop callus and then adventitious shoots are observed within 3-6 months [57, 62-64, 66]. The influence of dark treatment on callus induction has been reported to increase the frequency of shoot regeneration of rhododendrons [57-58]. Phenolics substances have been found to inhibit *in vitro* growth of pathogenic fungus [67]. In many species phenolics leach into the medium from the cut surfaces of the explants, these phenolics turn dark brown on oxidation and are detrimental to the cultures. This problem is very common in case of woody species like rhododendrons, particularly when explants are taken from mature trees. Although a number of studies have been reported on rhododendron regeneration, most dealt with subgenus *Azalea* but only

a few dealt with rhododendrons. The overall success of tissue culture raised plants depends upon successful transplantation in the field. Such plants are generally characterized with lower photosynthetic efficiency, malfunctioning of stomata and marked decrease in particular waxes [68].

Conservation Initiatives for Rhododendron Species: Various reports are available on the rhododendrons research and development internationally, however, so far much more information has been accumulated over this genus (mostly *Azalea* group) in regard to its growing condition, reproductive methods, taxonomy, breeding etc., actual study on conservation issue in the Sikkim Himalaya is almost nonexistent. At the time of baseline assessment many species are found at varying degree of threat within their habitat. The natural habitats of the rhododendrons are threatened due to natural causes, deforestation, urbanization and other anthropogenic interventions [69-70]. Consequently, the rhododendrons are fast becoming rare or even endangered. To counter this, rare species, e.g., *R. fulgens, R. pendulum, R. wightii* and endangered species, such as, *R. maddeni, R. niveum, R. sikkimense, R. pumilum, R. leptocarpum* and an assortment of infraspecific forms need to be conserved under *in situ*/*ex situ* conditions as well as through *in vitro* propagules cryo-preservation.

In the fall of 1993, G.B. Pant Institute of Himalayan Environment and Development (GBPIHED), Sikkim Unit established the Pangthang Arboretum for temperate-subalpine trees of the Sikkim Himalaya and within it a separate section was given for *ex situ* conservation of the rhododendrons. This is the only *ex situ* conservation initiative on rhododendrons in India. The rare and endangered species are in the process of mass propagation by the Institute for their restoration in nature in near future. The regional rhododendron germ pool was thus established but a rather large-scale conservation challenge was still alive outside the rhododendron reserve. In between the different institutional works, GBPIHED has initiated an assessment of natural population and developmental studies of rhododendrons in Sikkim Himalaya [12, 25, 47]. Restoration of rhododendrons and their conservation in nature promotes the existence of other biodiversity components. The Government of Sikkim has also initiated the work for the rhododendron conservation; they have extended the protected areas as biosphere reserve, national parks and sanctuaries (Table 2), keeping in view the conservation of rhododendrons. The conservation initiatives of the government are highly praiseworthy, where large areas have been protected in the region and in sequel to this general awareness drive is now expressly needed.

Some of the rare and endangered species are now under *in vitro* research procedures like *R. maddenii, R. niveum,* etc. Under a collaborative programme of the G.B. Pant Institute of Himalayan Environment and Development, Sikkim unit (Pangthang-Gangtok) and Department of Forest, Government of Sikkim, a unique kind of rare and threatened plant Conservation Park, covering 2 hectare of area, was established in the Himalayan Zoological Park, Bulbulay-Gangtok. It is to be noted that the fragrant-flowered *R. maddenii,* is one of the rare and endangered rhododendron species and the first rhododendron which is not only *in vitro* propagated but also mass multiplied through tissue culture in India by GBPIHED, Sikkim. So far, only two populations have been reported for *R. maddenii* from Sikkim Himalaya. Biotechnological research on *R. maddeni* has been supported by central funding agencies since 1999 but still more work is required to reach the next level for conservation of Sikkim Himalayan rhododendron. In nature, the plant is a very slow growing woody shrub. Higher polyphenols and flavonoids exudation from the explants makes the sterilization and proper establishment of explants difficult. Forest Department has also been planting some of the rhododendrons in *Smriti Van* as a test trial of rhododendrons. This has given a positive sign towards conservation. In order to bring out sustainable rhododendron conservation and management, it is essential to adopt several different approaches for managing forests and Sikkim Himalayan biodiversity. There is also the need of greater involvement of communities and for models that decentralize management and conservation roles and responsibilities. Also, maintaining viable population of rhododendron species is a crucial factor in conservation. *In situ* conservation approach is a good management scheme which in time would facilitate gene flow towards the creation of natural hybrids, introduction of new genetic stock and translocation. This has been experimentally found to be useful in case of *R. niveum* in Lachung Valley of North Sikkim. Beyond the protected area network and *in situ* conservation, *ex situ* conservation seems to be a good approach for providing mass awareness to the general public and a research hub for staid workers [71]. Plant tissue culture and vegetative propagation are also best alternatives towards species management [25, 27]. Therefore special attention needs to be given for

propagation and conservation as systematic propagation would go a long way in achieving conservation. It is desirable to apply simple methods, e.g., seed germination or propagation via airlayering/cuttings as because these would be easy to perform in the field and are cost effective approach. Educating local people on the significance and beauty of the species and their variations in nature will be an enabling factor towards rhododendron conservation. Forest planner should take into consideration for planting rhododendrons that is of value to the locality in aesthetic enhancement, tourism importance and economic upliftment of the people. Use of biotechnological development for rhododendron conservation would be far more appealing to the inherently nature loving population of Sikkim Himalaya. It may be summarized that about a quarter of species of rhododendrons from Sikkim Himalaya which are under greater conservational threats is an eye-opener towards anthropogenic interference over the natural biota and its consequence in the Himalayan region. In a relative sense it may be argued that more interference would bring about still bigger disturbances to the rhododendron species and its habitat. Research activities may mitigate the impasse to a certain degree but overall success depends much on the conservation concept engrained in and championed by the local inhabitants and campaigning/monitoring by government institutions. Some of the species have already become scarce, for example, *R. leptocarpum* is endangered and reported to have only 16 surviving individuals at present in the region. It may be symptomatic of a greater problem and more species may follow a similar path of disintegration. Under this state of events it is high time that an effort in the active conservation of rhododendrons should be taken up before it is very late to save the existing rhododendron germ pool.

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REFERENCES

1. Chamberlain, D.F., 1982. A Revision of Rhododendrons, II subgenus Hymenanthes, Notes Roy. Bot. Garden, Edinburgh, 39(2): 1-480.
2. Leach, D.G., 1961. Rhododendrons of the World, Charles Scribners's Sons, New York.
3. Rotherham, I.D., 1983. The ecology of *Rhododendron ponticum* L. with special reference to its competitive and invasive capabilities. Ph.D Thesis, University of Sheffield UK.
4. Gamble, J., 1936. A Manual of Indian timbers, London.
5. Cowan, A.M. and J.M. Cowan, 1938. Trees of the Northern Bengal, Calcutta.
6. Pradhan, U.C. and S.T. Lachungpa, 1990. Sikkim Himalayan Rhododendrons, Primulaceae Books, Kalimpong, West Bengal.
7. Bhattacharyya, D. and M. Sanjappa, 2008. *Rhododendron* habitats in India. J. American Rhododendron Soc., 2: 14-18.
8. Philipson, W.R. and M.L. Philipson, 1975. A Revision of Rhododendron 1. Section *Lapponicum*, Notes from the Royal Botanic Garden Edinburgh, 34: 1-72.
9. Cullen, J., 1980 A Revision of Rhododendron 1. Subgenus Rhododendron Sections Rhododendron and Proganathum. Notes from the Royal Botanic Garden Edinburgh, Vol. 39, No. 1.
10. Hooker, I.D., 1949-51. The Rhododendron of the Sikkim Himalaya; being an account, botanical and geographical of the rhododendron recently discovered in the mountains of eastern Himalaya, Reeve, London.
11. Parton, M.R., 1986. Sikkim Rhododendrons in Scotland. Himalayan Plant J., 4: 78-80.
12. Singh, K.K., S. Kumar, L.K. Rai and A.P. Krishna, 2003. Rhododendron Conservation in Sikkim Himalaya, Current Science, 85(5): 602-606.
13. Paul, A., M.L. Khan, A. Arunachalam and K. Arunachalam, 2005. Biodiversity and conservation of rhododendrons in Arunachal Pradesh in the Indo-Burma biodiversity hot spot, Current Science, 89: 623-634.
14. Tiwari, O.N. and U.N. Chauhan, 2006. Rhododendron Conservation in Sikkim Himalaya. Current Sci., 90(4): 532-541.
15. Pradhan, U.C., 1985. A preliminary enumeration of rhododendrons of the region. Part I. Himalayan Plant J., 3 (8): 123.
16. Pradhan, U.C., 1986. A preliminary enumeration of rhododendrons of the region. Part II, Himalayan Plant J., 4: 73- 76.
17. Lave and R.S. Smoerum, 2001. Sikkim 2000: The Denish Rhododendron Adventure. J. American Rhododndron Soci., 55(4): 193-194.

18. Justice, C., 2000. Sikkim 2000: The Ascent to Yumthang and the search for *R. wightii.* J. American Rhododendron Soc., 54(3): 162-170.
19. Maiti, A. and A.S. Chauhan, 2000. Threatened plants in the Sikkim Himalaya, Hima-Paryavaran, pp: 113-120.
20. Hooker, J.D., 1849. Notes, chiefly botanical, made during an excursion from Darjeeling to Tonglu. J. Asia. Soc. Beng, 18: 419-446.
21. Clarke, C.B. and J.D. Hooker, 1875. Flora of British India, 3: 462-475.
22. Rai, T.D. and L.K. Rai, 1993. Trees of the Sikkim Himalaya, Indus Book Publishing Co., New Delhi.
23. Singh, P. and A.S. Chauhan, 1998. An overview of plant diversity of Sikkim, in *Sikkim:* Perspective for Planning and Development, S.C. Rai, R.C. Sundriyal and E. Sharma (Eds.). Bishen Singh and Mahendra Pal Singh, Dehra Dun.
24. Korner, C.H. and W. Larcher, 1988. Plant life in cold climates, in Plants and Temperature, S.P. Long and Woodward, (Eds.). The Company of Biologists Limited, Cambridge, U.K., pp: 25-57.
25. Kumar, S., K.K. Singh, S. Chhetri, and L.K. Rai, 2003. Studies on pollen tetrads morphology of Sikkim Himalayan Rhododendrons. Journal of Hill Research, 16: (2)70-73.
26. Cullen, J. and D.F. Chamberlain, 1978. A Preliminary synopsis of the genus rhododendron. Notes Roy. Bot. Garden, Edinburgh, 36: 105-126.
27. Kumar, S., L.K. Rai, K.K. Singh and U. Bajpai, 2005. Spermoderm Pattern in Seeds of Rhododendron in Sikkim Himalaya, India-1. SEM Studies, Phytomorphology, 55: 01-08.
28. Kumar, V., 1993. Biological diversity in eastern Himalaya: A status report. University of Delhi and WWF-India, New Delhi.
29. Shenga, N.C., 1994. Status paper on biodiversity in Sikkim, Panda, Vol., pp: 5-10.
30. Myers, N., 1990. The biodiversity challenge: expanded hotspots an analysis. The Environmentalist, 10(4): 243-256.
31. World Conservation and Monitoring Centre, 1992. Global Biodiversity: State of the World's Living Resources, Chapman and Hall, London.
32. Swank, W.T. and Jr. D.A. Crossley, 1988. Forest Hydrology and Ecology of Coweeta, Springer Verlag, New York.
33. McGraw, J.B., 1989. Effect of age and size on life his*tories* and population growth of *R. maximum shoots*. American J. Bot., 76: 113-123.
34. Prakash, D., G. Upadhyay, B.N. Singh, R. Dhakarey, S. Kumar and K.K. Singh, 2007. Antioxidant and free radical scavenging activities of Himalayan Rhododendrons. Current Sci., 92 (4): 526-532.
35. Alper, H.C. and I.D. Rotherham, 2006. A review of the forest vegetation of turkey: Its status past and present and its future conservation, Biology and Environment Proceeding of the royal Iris Academy, 106B, pp: 343-354.
36. Hsia, C.N. and S.S. Korban, 1977. The influence of cytokinins and ionic strength of Anderson's medium on shoot establishment and proliferation of evergreen azalea, Euphytica, 93: 11-17.
37. Karlsson, P.S., 1992. Effect of reproductive status, leaf age and nutrient status on photosynthetic capacity of *Rhododendron lapponicum* leaves, Functional Ecol., 6: 171-175.
38. Moore, R.P., 1973. Tetrazolium staining for assessing seed quality, 1973. In: Seed Ecology, W. Heydecker, (Eds.). Butterworth, London, pp: 347-366.
39. Kigel, J., M. Ofir and D. Kolle, 1977. Control of germination responses of *Amaranthus retroflexus* L seeds by their parental photothermal environment. J. Exp. Bot., 28: 1125-1136.
40. Singh, K.K., S. Kumar and A. Pandey, 2008. Soil Treatments for Improving Seed Germination of Rare and Endangered Sikkim Himalayan Rhododendrons, World J. Agril. Sci., 4(2): 288-296.
41. Durgapal, A., A. Pandey and L.M.S. Palni, 2002. The use of rhizosphere soil for improved establishment of conifers at nursery stage for application in plantation programmes. J. Sustainable Forest., 15(3): 57-73.
42. Pandey, A., M. Nadeem and L.M.S. Palni, 2002. Improvement in seed germination of Himalayan Yew through simple soil treatments. Indian J. Forester, 25(2): 109-113.
43. Pandey, A. and L.M.S. Palni, 2004. Tea Rhizosphere: Microbial Diversity and Characteristic features and comments on microbial communication in rhizosphere. Intl. J. Tea Sci., 3: 285-290.
44. Chaurasia, B., A. Pandey and L.M.S. Palni, 2005. Distribution, colonization and diversity of arbuscular mycorrhizal fungi associated with central Himalayan rhododendrons. Forest Ecol. Manage., 207: 315-324.
45. Hortung, W., B. Ohl and V. Kummer, 1980. Abscisic acid and the rooting of runner bean cutting. J. Pjlanzen Physiol., 98: 95-103.
46. Tamata, S., V.K. Purohit, S.K. Nandi and L.M.S. Palni, 2000. Chemical induction of root formation in *Quercus leucotrichophora* L. stem cutting. Indian J. Forestry, 23: 135-138.

47. Singh, K.K., S. Kumar and R. Shanti, 2008. Raising planting materials of Sikkim Himalayan Rhododendron through Vegetative propagation using 'Air-wet technique'. J. American Rhododendron Soc., 62 (4): 136-138.
48. Kumar, S., K.K. Singh and. L.K. Rai, 2004. *In vitro* Propagation of an Endangered Sikkim Himalayan Rhododendron (*R. maddeni*) from Cotyledonary Nodal Segments. J. American Rhododendron Soc., 58 (2): 101-105.
49. Singh, K.K., 2008. *In vitro* plant regeneration of an endangered Sikkim Himalayan rhododendron (*R. maddeni* Hook. f.) from alginate-encapsulated shoot tips. Biotechnology, 7(1): 144-148.
50. Murashige, T. and F. Skoog, 1962. A revised medium for rapid growth and bioassays with tobacco tissue culture. Physiol. Plant, 15: 473-497.
51. Anderson, W.C., 1975. Micropropagation of rhododendrons by tissue culture, part I Development of culture medium for multiplication of shoots. Proc. Intl. Plant Prop. Soc., 25: 129-135.
52. Anderson, W.C., 1978. Rooting of tissue cultured rhododendrons. Proc. Intl. Plant Prop. Soc., 28: 135-43.
53. Anderson, W.C., 1984. A revised tissue culture medium for shoot multiplication of rhododendron. J. Amer. Soc. Hort. Sci., 109: 343-347.
54. Fordham, I. and D.P. Stimart, 1982. Axillary and adventitious shoot proliferation of exbury azaleas *in vitro*. Hort. Sci., 17: 738-739.
55. McCown, B.H. and G.B. Lloyd, 1983. A survey of the response of rhododendron *in vitro* culture. Plant Cell Tissue Org. Cult, 2: 77-85.
56. Almeida, R.S. Gonçalves and A. Romano, 2005. *In vitro* micropropagation of endangered *Rhododendron ponticum* L. subsp. *baeticum* (Boissier and Reuter) Handel-Mazzetti. Biodiversity and Conservation, 14(5): 1059-1069.
57. Meyer, M.M. Jr., 1982. *In vitro* propagation of *Rhododendron catawbiense* from flower buds. Hort. Sci., 17: 891-92.
58. Dai, C., V.N. Lambeth and R. Taven, 1987. Micropropagation of Rhododendron prinophyllum by ovary culture. Hort. Sci., 23: 491-493.
59. Shevade, A. and J.E. Preece, 1993. *In vitro* shoot and floral organogenesis from stamen explants from a rhododendron 'PJM' group clones, Scientia Horticulturae, 56: 163- 170.
60. Hurbage, J.F. and D.P. Stimart, 1987. Adventitious shoot regeneration from *in vitro* subcultured callus of Rhododendron exbury hybrids. Hort. Sci., 22: 1324-1325.
61. Economou, A.S. and P.E. Read, 1988. Azalea regeneration from callus culture. Acta. Hort., 226: 209- 216.
62. Iapichino, G., T.H.H. Chen and L.H. Fuchigami, 1991. Adventitious shoot production from a *vireya* hybrid of rhododendron, Hort. Sci., 26: 594- 596.
63. Iapichino, G., T.H.H. Chen and L.H. Fuchigami, 1991. Plant regeneration from somatic tissue of *Rhododendron lactum aurigerranum*. Plant Cell Tiss. Org. Cult., 27: 37-43.
64. Preece, J.E. and M.R. Imel, 1991. Plant regeneration from leaf explants of rhododendron 'PJM Hybrid', Sci. Hortic., 48: 159-170.
65. Iapichino, G., S. McCulloch and T.H.H. Chen, 1992. Adventitious shoot formation from leaf explants of rhododendron. Plant Cell. Tiss. Org. Cult., 30: 373- 381.
66. Marks, T.R., 1990. Rhododendron cuttings. I. Improved rooting following rejuvenation *in vitro*. J. Hort. Sci., 65: 103-111.
67. Li cy, Lu kc, E.E. Nelson, W.B. Bolen and J.M. Trappe, 1969. Effect of phenolic and other related compounds on growth of *Poria weirri in vitro*. Microbios, 3: 305-311.
68. Bhojwani, S.S. and V. Dhawan, 1989. Acclimatization of tissue culture raised plants for transplantation to the field, in Application of Biotechnology in Forestry and Horticulture, V. Dhawan, (Eds.). Plenum Press, New York, pp: 149-156.
69. Chhetri, S., A.P. Krishna and K.K. Singh, 2002. Ecosystem conservation prospects in the Khangchendzonga Biosphere Reserve, Sikkim, in Compendium of case studies for South Asia Regional Conference on Ecotourism, A.P. Krishna, P.D. Rai and J. Subba, (Eds.). Published by Ecotourism and Conservation Society of Sikkim, Gangtok, India, pp: 41-52.
70. Bhattacharyya, D., 2003. A note on the distribution and rarity of the Sikkim state tree of Sikkim, Envis, 9: 1-2.
71. Magor, E.W.M., 1986. Sikkim Himalayan Rhododendrons in British Gardens. Himal. Plant J., 4: 58-68.