Rhododendron conservation in Sikkim Himalaya

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A review on the rhododendron conservation effort in the Sikkim and other parts of Indian Himalaya is presented here, with particular emphasis on ecology, baseline assessment, uses, growth studies, *ex situ* and *in situ* conservation initiatives. Identification of major gaps and constraints of forestry policy and plans and current practices of rhododendron conservation and management have been made. The impact of land use and management on the conservation of diversity is analysed and discussed. Species richness and diversity are significantly lower in heavily utilized forest. This study emphasizes that the forest rhododendrons in the habitats are severely threatened. Deforestation is the consequence of the tourist pressure for fuelwood along with other reasons in Himalaya. The degradation of rhododendrons in Himalaya is also due to lack of appropriate policy to guide the legal, institutional and operational development for the conservation. There is a need to implement the conservation obligations by transforming them into regulations in order to make them legally binding.

Keywords: Assessment, conservation, *Rhododendron*, Sikkim Himalaya.

THE genus *Rhododendron* (Greek Rhodon = Rose and dendron = tree) belongs to the family Ericaceae and was for the first time described by Carl Linnaeus in 1837 in *Genera Plantarum*. Joseph Hooker's journey to the Sikkim Himalaya between 1848 and 1850 opened the doors to the rhododendrons of this area. Within the brief span that he travelled in Sikkim, he gathered and described 34 new species and details of the 43 species including varieties from the Indian region in his monographs entitled *Rhododendron of Sikkim Himalaya*[1]. Rhododendrons are the denizens of high altitude, comprising about 1000 species mainly inhabiting a vast section of Southeastern Asia stretching from Northwestern Himalaya through Nepal, Northeastern India, Eastern Tibet, Northern Burma and Western & Central China; more than 90% of the world population of rhododendrons are from this region[2,3]. The genus *Rhododendron*, having about 85 taxa in India, is mainly distributed in the Himalayan region (one species *R. nilagiricum* in South India). Out of this, a total of 36 species with 45 different forms including subspecies and varieties occur in Sikkim alone[3–5]. Survey of various threatened plants in the Sikkim Himalaya and the search of various species were also carried out[6,7]. Recently Pradhan and Lachungpa[2] have explored the whole area and found 36 species. However, some taxa such as the five varieties of *R. cinnabarinum* and *R. lepidotum* may require more work.

Sikkim Himalaya, which extends between 27°03′41″ to 28°7′34″ North and 88°3′40″ to 88°57′19″ East, is defined by the great drainage region of the river Tista that constitutes the hill of Sikkim (7096 km^2) and the Darjeeling Gorkha Hill Council area of West Bengal (3149 km^2), range altitudinally from 100 m above mean sea level (amsl) (foot hill) through 4000 m amsl (timberline) up to 8548 m amsl (Mt Khangchendzonga). The area thus covers several ecological zones, viz. subtropical, temperate, subalpine and alpine. In such a small area climatic variations in different ecological zones have promoted a rich diversity and variations in rhododendron species. Sikkim is rich in cultural and biological diversity. Lepachas, Bhutias, Limbus and Nepalese are the main ethnic groups of Sikkim and they differ from each other in their food habits and lifestyle, which also play a major role in survival and conservation of Sikkim Himalayan rhododendrons.

Rhododendrons have a characteristic slow growth rate. Ranging in size from tiny mat-like growths in alpine region (*R. pumilum*, *R. setosum*) having a few centimetres fall individuals to giants having 25 m (*R. arboreum*) is another characteristic feature of the genus. The existing records indicate that about 98% of the Indian species are found in the Himalayan region, out of which 72% are found in Sikkim Himalaya. The genus forms a very important dominant combination of forest types in cool temperate and subalpine region, and also on the alpine meadows of the Sikkim Himalaya. It supports a wide range of biodiversity, which, if disturbed, can degrade habitats that threaten associated biodiversity. In the subalpine to alpine transition zone that includes timberline in the most fragile ecosystem in the Sikkim Himalaya, rhododendrons is the only group of plants that has continuum in the aforesaid ecotone and maintains the biological sustenance in this fragile zone.

With the shrinking of green cover almost everywhere, the rhododendrons also are experiencing the impact of

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disturbed ecological system. This is clearly visible in the Sikkim Himalaya where the ecological system and land physiography are fragile and disturbed. The rise in population caused demand on land for farming, increased number of animals, construction of roadways, hydel power stations and allied works, army personnels garrisoned at alpine locations, tourist influx over the natural trails and lately the climatic conditions have resulted in dwindling population of the rhododendron species[8].

The rhododendron flowers have an enormous range of colour, shapes and size in their wild forms. The horticultural values are internationally known. Horticulturists in the Western countries have further worked to produce quite a range of beautiful hybrids. The rhododendrons are conducive to inter- and intra-generic crosses and therefore open to hybridization. Revolution on horticultural and biotechnological aspects of the genus is needed to fully convert the aesthetic of rhododendrons into commercial advantage. Their commercial value can be judged by the fact that in USA, the Briggs Nursery alone grows and sells 400,000 azaleas (a subgenus of rhododendron) each year and average sales price is US$ 1.25 per plant. Apart from their aesthetic use worldwide, several species of Sikkim Himalayan rhododendrons have ethnic uses from times immemorial and their survival in the wild is threatened. 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 are found with varying degrees of threat within their habitat (Table 1)[2,7–9].

Taxonomy

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. Variation in size of pollen tetrads and morphology is found to be remarkable in rhododendrons. This categorization may help to identify the plant at species level. Seed morphological characters of different species of rhododendrons, especially the features of testa topography also help in identification of the species. Seeds of rhododendrons are clearly distinguished by their morphological variability at species level[10]. The plants generally prefer acidic soil[5,11]. Various workers have described the keys that help in identification of Sikkim Himalayan rhododendron[2,4,11].

Ecology

The best observation on the ecological requirements of Sikkim rhododendron was made by Sir Joseph Hooker[1] for quite a number of species. However some ecological studies have been carried out for other than Sikkim Himalayan rhododendron. Age structure and dynamics of *R. ferrugineum* populations in the Northwestern French Alps were studied and it was found that biotic and abiotic factors might be responsible for the speciation and survival of species[12]. Taking note of the present development pattern of a population, further development can be predicted based on the knowledge of age structure, vegetation cover and population establishment[13]. The determination of nutrient status of plants is important for understanding the development of population or ecosystem[14]. Until now, the availability of nutrient in the soil and the total amount of elementary nutrients in the plant organs (e.g. leaves) were used as indicators of the nutrient status of plant. By applying this strategy it is assumed that the bioelement level in a plant might be a response to the nutrient availability in the soil[15]. Growth rate and nutrient status of an open and closed population of *R. ferrugineum* has indicated that the nitrogen availability could be largely responsible for the variations observed between populations, as phosphorus analyses showed that the population did not suffer significant phosphorus deficiencies. Differences in the vitality of *R. ferrugineum* may be explained by the fact that in an open population it is the sole species to exploit a specific pool of nutrient[16]. As carbon is the primary photosynthetic product which can be used both as storage and build-up substance as well as in energy metabolism, its allocation pattern profile could tell us a great deal about the responses of the plant to environmental factors[17]. Subcanopy evergreen rhododendron can inhibit canopy tree recruitment for nutrient competition. For example the invasive species *R. ponticum* inhibits regeneration of canopy tree in the United States[18]. Nutrient and water fluxes between the associated species are filtered and possibly impacted by this genera[19]. 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 has on the forests[20]. It has been hypothesized that the dominant species under natural conditions should have less discrepancy between its realized and potential climate niche. This was confirmed in the most dominant species of Himalaya (*R. arboreum*). The splitting into subspecies[5], which grow in different temperature ranges, indicates a high level of genetic variation[21]. This probably has contributed to rhododendron dominance in the Sikkim Himalaya. Although rhododendrons are very competitive, the lack of particular species beyond the realized altitudinal range[8] could also be attributed to a lack of suitable soil condition in different climates, which Lenihan[22] indicated for American tree species. This applies to all rhododendrons as they

Table 1. Rarity status of Sikkim Himalayan rhododendrons[2,7–9]

Common name (Botanical name)	Space vs availability	Number	Status
NiloPate Chimal (*R. aeruginosum*)	Localized	Few	Threatened
Dupi Gurans (*R. anthopogon*)	Acutely localized	Large	Threatened
Lali Gurans (*R. arboreum*)	Ubiquitous	Large	Vulnerable
Bailey ko Chimal (*R. baileyi*)	Acutely localized	Few	Threatened
Lal Chimal (*R. barbatum*)	Ubiquitous	Few	Out of danger
Chia-phule Guransn (*R. camelliiflorum*)	Localized	Few	Out of danger
Nilo Chimal (*R. campanulatum*)	Localized	Large	Out of danger
Bangophale Gurans (*R. campylocarpum*)	Localized	Large	Out of danger
Junge Chimal (*R. ciliatum*)	Acutely localized	Few	Threatened
Sano Chimal (*R. cinnabarinum*)	Localized	Few	Out of danger
Lahare Chimal (*R. dalhousiae*)	Ubiquitous	Few	Out of danger
Jhukaune Korlinga (*R. decipiens*)	Acutely localized	Few	Threatened
Edgeworth ko Chimal (*R. edgewarthii*)	Ubiquitous	Few	Out of danger
Korlinga (*R. falconeri*)	Ubiquitous	Large	Threatened
Chimal (*R. fulgens*)	Localized	Extremely few	Rare
Takma Chimal (*R. glaucophyllum*)	Localized	Few	Out of danger
Patle Korlinga (*R. grande*)	Ubiquitous	Large	Threatened
Seto Chimal (*R. griffithianum*)	Localized	Few	Out of danger
Gulabi Korlinga (*R. hodgosonii*)	Localized	Large	Out of danger
Bhutle Gurans (*R. lanatum*)	Localized	Few	Out of danger
Bhule Sunpate (*R. lepidotum*)	Localized	Few	Out of danger
Jhinophale Gurans (*R. leptocarpum*)	Acutely localized	Extremely few	Endangered
Sano Lahare Chimal (*R. lindleyi*)	Localized	Few	Out of danger
Madden ko Chimal (*R. maddenii*)	Localized	Extremely few	Rare
Hinu Gurans (*R. nivale*)	Localized	Few	Threatened
Hinu Pate Gurans (*R. niveum*)	Acutely localized	Extremely few	Endangered
Jhundinae Chimal (*R. pendulum*)	Localized	Extremely few	Rare
Purke Gurans (*R. pumilum*)	Localized	Extremely few	Endangered
Tsallu Gurans (*R. setosum*)	Localized	Large	Threatened
Sikkimae Gurans (*R. sikkimense*)	Acutely localized	Extremely few	Endangered
Thomsen ko Gurans (*R. thomsonii*)	Localized	Large	Vulnerable
Pahenle Chimal (*R. triflorum*)	Localized	Few	Threatened
Khianuae pale Gurans (*R. vaccinoides*)	Ubiquitous	Few	Out of danger
Hanginae Gurans (*R. virgatum*)	Localized	Few	Out of danger
Wallich ko Chimal (*R. wallichii*)	Localized	Large	Out of danger
Wight ko Gurans (*R. wightii*)	Localized	Few	Threatened

mostly prefer acidic and humus-rich soil[23], also to Sikkim Himalayan rhododendrons as most of the rhododendron habitats have acidic soil (pH 4.5 to 6.5) and humus rich conditions[9]. *R. campanulatum* provides a biogeographical example of a sub-dominant taxon, which ranges from subalpine to cold temperate zones. *R. lepidotum* is also found in ecologically disturbed sites (personal observation). This may indicate that temperature affects the performance of rhododendrons species in natural condition and prevent their co-existence. Studies in relation to global warming with respect to rhododendrons indicate that rhododendrons may survive global warming *in-situ* because of high temperature tolerance (ref. 21 and references therein), but the long-term effect on their regeneration is uncertain. However, mild winters without frost may be problematic for their survival as the frost is requisite for their seasonal growth rhythm[21]. To establish the true ecological reasons for the potentiality and survival of rhododendrons in Sikkim Himalaya more data are required, so that geographical separation, actual regeneration limit and the limit of realized range could be predicted.

Uses

The rhododendrons have major use in landscaping, accent (area-specific specimens) and woodland planting. Being among the first to colonize wasteland, the plant helps to prevent soil erosion and allows regeneration of vegetation[3]. The leaves of *R. maximum* L. are made into a decoction to treat rheumatism[24], however the leaves of most of the species of this genus contain phenolics compound which has poisonous properties causing slow pulse, lowering of blood pressure, progressive paralysis, and death[25]. Rhododendrons, planted *en masse*, provide more colour than any other flowering shrub/tree. They are ideal for naturalistic forest planting and for massed spring colour effect. *R. arboreum* is the national flower of Nepal. According to common belief, a sip of the juice of the Laliguras (*R. arboreum*) flower dissolves fish bones stuck in the throat. Some people keep this flower at home for such an emergency. The flower is also used in worshipping the Gods and is often worn as an ornamental in the coiffure by mountain women. Apart from their aesthetic use worldwide, several species of Sikkim Himalayan rhododendron have ethnic uses. The leaves of *R. anthopogan* are mixed with those of Juniper to provide an incense that is widely used in Buddhist monasteries (personal observation). Leaves of *R. campanulatum* are exported to the plain, where these are grouped up with tobacco and used as snuff, which is said to be useful in cold and hermicrania[26]. Leaves and pollen of *R. cinnabarinum* and *R. grande* are poisonous to grazing animals. However Sain[27] reports that the corolla is used for making jams by the head Lamas and Tibetan aristocrats. We also noted in Lachung, that the local children eat the corolla of *R. cinnabarinum* and the people also fry the corolla to a tasty delicacy. The trees of *R. fulgens*, *R. falconeri* and *R. hodgsonii* have manifold uses in North Sikkim. The rough leaves are used in packaging apples, lighting fires, its unsplitting wood is used to make cups, spoons and ladles and also Khukri (a local arm used by Lepachas) handles. The thick leaves with glossy surface of these species used for packing apples, yak butter and cheese are packaged in the attractive foliage for presentation and transportation (personal communication). Watt[26] mentions the medicinal properties in *R. lepidotum*. The tiny leaves of *R. nivale* have the fragrance that can be used for aesthetics[10]. *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[2]. The vegetative parts of *R. thomsonii* were found to be highly poisonous. The boiled extract is used as natural insecticides in the Lachung of North Sikkim (personal communication). This may be due to the concentration of the poisonous phenolics compounds. This compound may be toxic to humans, can cause depression of blood pressure, shock and death[28]. *R. maddenii* and *R. niveum* are in demand for community and commercial (tourism) purposes in the trekking corridors of the Sikkim Himalaya[29]. *R. pendulum* is the host for caterpillar of butterflies and among the first to colonize sheltered rock at alpine region of the Sikkim Himalaya, the plants helps to prevent erosion and allow regeneration of vegetation in such places. All the species of Sikkim Himalaya rhododendrons have the potential of commercial value, some of which (*R. maddenii* and *R. dalhousiae*) have also earned awards and merit citation at the Royal Horticultural show.

Reproductive traits

Knowledge about the reproductive system and growth pattern of a species can help in understanding the evolution and life history traits of that species caused by the different genetic and ecological consequences of allogamy and autogamy[30]. General life history traits (e.g. life span, resource allocation to reproductive vs vegetative propagation) are correlated with the reproductive system and genetic structure of population[31]. The evolutionary shift between predominant out-crossing and predominant selfing is often associated with several changes in floral morphology and phenology[32]. In several environments, such as subalpine and alpine habits, abiotic factors strongly influence plant production; the timing of flowering of alpine plant is significantly influenced by the timing of snow disappearance[33], and the relatively rapid flowering and fruiting of most alpine species are adaptations to the short growing season[34]. Selfing may be the main means by which entomophilous plants reproduce at low temperatures, as strong winds and short growing period reduce pollinator activity, and thus reduce the opportunity for cross pollination and out breeding[35]. Moreover, natural selection may favour vegetative propagation over sexual reproduction in severe subalpine and alpine environment[36]. *R. aureum* in Japan, lowers sexual reproduction and propagates by layering and producing adventitious roots[33]. *R. ferrugineum* is a subalpine evergreen shrub that dominates numerous communities. It reproduces both vegetatively and sexually[37]. Layering and sexual reproduction in rhododendrons have also been studied by Pornon *et al.*[16]. They found that rhododendrons preferably spread vegetatively in closed and mature population (i.e. when cover 90–100%). When population is scattered, they prefer sexual reproduction. Community level changes (succession, fluctuation, and maturation) are the result of population dispersal and germination of seeds are major processes of plant community development particularly in primary sites[38]. Sexuality, through seed production is a source of genetic variation through recombination and thereby allows evolution of species and population[39]. Rhododendrons have a tremendous reproductive potential as they produce a large quantity of very small seeds. Despite this, the biomass that the plants allocate to seed remains disproportionately limited, as *Rhododendron niveum* produces 9.0 g of seed biomass per m^2 of rhododendron cover and 12.0 g in case of *R. maddenii.* Seed size widely influences seedling fitness and small seeds with very low reserves of nutrients could be potentially disadvantageous to rhododendrons. As a consequence of low nutrient reserves in seeds, the success of seeding establishment is probably strongly determined by its abilities to become autotrophic very rapidly. Furthermore because seedlings grow very slowly (height at the end of the first growing season = 1 to 2 cm), competition with surrounding species, water stress and snow slipping down the slope may be critical selective forces. The production of many small seeds rather than a few large ones could also be an adaptative response to the rareness of favourable sites, increasing the probability that a seed dispersed by wind or by water reaches a safe site. Seed germination requires very high levels of light. Suitable sites for seed germination and seedling survival (e.g. sunny well sheltered small gaps of bare soil) are very rare and the seedling requirement very low. Other selective pressures may have also acted on the number of inflorescence or flowers. A large quantity of inflorescence and flowers may be necessary for pollinator attraction and may confer high fitness at the plant level, as the activity and diversity of pollinators are restricted in subalpine and alpine ecosystems. Finally these sexual reproductive traits may be the result of selective factors no longer in operation or detectable, rendering the search for their current adaptive significance very difficult. A large quantity of small seeds allows the shrub to have both long distance establishment, as seed dispersed may reach new safe sites at the landscape scale, and short distance establishment at the ecotone level[9]. 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. Most of the Himalayan rhododendron species do not show intrinsic dormancy and germination in most of these is better in light than in darkness[40]. Immediately following harvest, the seeds of *R. maddenii* and *R. niveum* show viability and gradually lost viability over time. Since these plants grow at high altitudes and seeds are exposed to subzero temperature and snowfall during the winter, like other alpine species chilling may be essential for germination under natural condition. The dormancy breaking and germination stimulating effects of low temperature could possibly be under control of increased synthesis and sensitivity of seeds to plant growth substances such as gibberellins and cytokinines. Because of this, seeds of *R. maddenii*, *R. niveum* and some other Sikkim Himalayan rhododendrons have shown good germination percentage when treated with gibberellins and cytokines thus advancing the time, synchronizing and stimulating the seed germination. The *in vitro* germination in *R. niveum* and *R. maddenii* favoured by high temperature (20–25°C) and continuous light, proves the adaptive advantage and ensures the establishment of seedling in harsh climatic conditions. The seeds of rhododendrons are sensitive to desiccation; also chilling could not maintain viability over periods[9]. If Sikkim Himalayan rhododendrons are to be conserved, more knowledge about reproductive biology is needed.

Propagation

In horticultural, agricultural and forestry, vegetative propagation is widely used to multiply elite plants obtained in breeding programmes or selected from natural populations[41]. Adventitious root formation is a key step in vegetative propagation. Among auxins, indole-3-butyric acid (IBA), α-napthaleneacetic acid (NAA), indole-3-acetic acid (IAA) are well known to stimulate rooting of stem cutting and air layering[42,43]. In addition, phenolic compounds either alone or in combination with auxins and abscisic acid (ABA) have also been reported to stimulate adventitious root formation in cutting of several plant species[44–46]. 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 to. Propagation in North America is usually done by layering[47]. Layering and air layering 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 great advantage of this is that the root system of the parent plant is not damaged or disturbed (http://www.rhododendron.org). The use of PGS(s) to propagate *R. yakashimanwa* has facilitated the production of roots in cutting[48]. In *R. maddenii* and *R. niveum* auxins were not so effective, however they were given positive response in inducing root formation. The genus also has strong seasonal effect on rooting. The stock plant environment exerts influence on root formation. During monsoon *R. maddenii* and *R. niveum* show best response by vegetative propagation[9], maybe because at this time the plant receives very high humidity and good temperature range, which appears to be essential for proper rooting[49]. Lamoine *et al.*[50] reported up to 60% rooting and 200% growth in rhododendron cuttings inoculated with symbiotic fungus, together with decreased heterogenecity of plant.

Traditionally, stem cuttings are used to propagate most rhododendron species. Yet *in-vitro* micropropagation is becoming increasingly important in commercial production[51–54]. Therefore, efforts to establish efficient protocols and optimal media in order to reduce costs of micropropagation are currently ongoing[55]. Although Murashige and Skoog's medium[56] 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[57–59] 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[59–61]. However these are costly and are used at high concentration; moreover, certain cultivars do not respond well to these cytokinins[61]. Thidiazuron (TDZ), a phenyl urea derivative has been effectively used for micropropagation of many recalcitrant woody species[62,63]. Adventitious shoot regeneration of rhododendron species has been induced from various tissues including ovaries[64,65], stamens[66], stem segment[67–70], shoot tips[70] and leaf explants[60–72]. 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[65,69–72]. Direct adventitious shoot regeneration from explants or indirect organogenesis via minimal callus formation can speed the regeneration cycle and avoid the possibility of inducing somaclonal variations. The influence of dark treatment on callus induction has been reported to increase the frequency of shoot regeneration of rhododendrons[64,65]. Change in the spectral quality and level of irradiance has different morphogenic effect on the development of rhododendrons[73,74]. 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 rhododendrons, particularly when explants are taken from mature trees[51]. The level of phenolics content in the stem of *R. niveum* is found very high (110.0 mg/g fresh weight), while this was only 54.5 mg/g in case of *R. maddenii*. This clearly indicates the correlation of phenolics content in culture establishment and shoot proliferation. The level of phenolics content in other plant species, which are easy for *in vitro* culture has been noted very low in comparison to rhododendrons (4.6 mg/g in rice[75], 8.10 mg/g in *Cuscuta platyloba*[76]). On the basis of phenolics content it can be concluded that the low level of phenolics does not as such seem to be harmful to the tissue, but the higher level of phenolics content reduced the capacity of protein synthesis and changes the free amino acid pool and protein pattern in the plant which was reflected as slow growth rate and poor proliferation[77]. *R. maddenii* and *R. niveum* are now under *in vitro* research procedures. Multiplication of shoots in Anderson medium[57] containing 2iP (1.0–15.0 mg/l) along with IAA (0.01–1.0 mg/l) has been found good for cotyledonary nodal parts of *R. maddenii*[8]. Anderson media[59] containing 10 μm 2iP with 0.5 μm NAA have also proved a good combination for *R. maddenii* and in case of *R. niveum* 10 μm 2iP + 5.0 μm zeatin and 0.5 μm NAA showed good results in shoot multiplication for seedling obtained explants[9].

Conservation issue for management

The international rhododendron societies abroad, e.g., the American Rhododendron Society, Rhododendron Species Foundation, Australian Rhododendron Society, International Rhododendron Union, etc. keep records on the development of the genus. However there has been very little assessment in the natural restoration of rhododendron populations in the Sikkim Himalayan context. Now the rhododendrons of the region have reached a stage where many species are found as rare, vulnerable or threatened. G.B. Pant Institute of Himalayan Environment and Development has initiated an assessment of natural population and developmental studies of rhododendrons in Sikkim Himalaya. The Government of Sikkim has also initiated the work for rhododendron conservation. They have extended the protected areas as biosphere reserves, national parks and sanctuaries, keeping in view the conservation of rhododendrons[78]. Improved protected efforts with community participation and *in-situ* and *ex-situ* conservation methodologies need to be developed in order to conserve the rhododendrons[79].

The conservation initiatives of the government are highly commendable, where large areas have been set aside as protected areas in Sikkim Himalaya (Table 2). There is one Biosphere Reserve, two national parks and six wildlife sanctuaries, where 36 species of rhododendrons of the region are found. The Shingba Rhododendron and the Bersey Rhododendron sanctuaries are exclusively declared as protected areas, keeping in view the conservation of rhododendrons. Simple protection from grazing and human interference allows some of the rhododendrons to regenerate naturally. G.B. Pant Institute of Himalayan Environment and Development, Sikkim unit has been evaluating the status of these rhododendron species in nature for the past eight years, and *ex-situ* regeneration work is in progress. Some of the rare and endangered species are now under *in-vitro* research procedures like *R. maddenii*, *R. niveum*, etc. In the whole Himalayan region research and development work on rhododendrons are also being carried out by some other agencies (Table 3).

The Forest Department of Sikkim Government has initiated work on conservation and management along with an awareness drive among local inhabitants, and tourists/trekkers. A policy was also being rationalized by the Sikkim Government. Most of the rhododendrons occur in the restricted areas of the state/central Government and permits are only issued with particular guidelines. This has given a positive sign towards conservation. The Forest Department has also been planting some of the rhododendrons back into natural habitat to see whether sustainable initiative can meet the requirements for traditional use.

Species management

Ecological degradation and its corollary biodiversity loss pose a serious threat to development of rhododendrons in Sikkim Himalaya. In order to bring out sustainable rhododendron conservation and management, it is essential to adopt several different approaches for managing forests and Sikkim Himalaya biodiversity[80].

Further efforts for conservation and management of rhododendrons must drive from a set of clear objectives, mechanism for action, and commitment from all stakeholders. Apart from this, halting process of degradation and species loss requires specialized solutions and an understanding of ecological process. Protecting rhododendron does not merely involve setting aside the areas as national park/sanctuary. Instead, all the ecological processes that have maintained the area's rhododendron population such as pollination, seed dispersal, involving complex interactions between several species of rhododendrons and humans, also need to be ensured[81].

Maintaining viable population of rhododendron species is a crucial factor in conservation and this requires the appropriate conservation methods such as *ex-situ* and *in-situ* conservation approaches. The present study also indicates

Table 2. Protected areas of the Sikkim Himalaya region where rhododendrons are commonly found[8,9]

Place/name	Area (km^2)	Scope
Kanchendzonga Biosphere Reserve	2619.92	Occupies a placed at the apex amongst the high altitude National park in the country (1829 to 8550 m amsl), considered the floral (including rhododendrons), faunal, ecological, geomorphologic importance and wild life potentiality in the area
Barsey Rhododendron Sanctuary	104.00	The Barsey Rhododendron Sanctuary spans over the razor sharp Singalila Range. The climate is wet and cold favouring the spread of the dominant genus Rhododendron with its unique abundance of rhododendron trees and shrub species
Fambonglho Wildlife Sanctuary	51.76	25 km from Gangtok and at an altitude of 1280 to 2652 m amsl. The Sanctuary is the home of Himalayan flora and funna. Black Bear, Red Panda, Civet cat and many varieties of birds and butterflies. The Binturong or Bear-Cat (*Arctictis binturong*) is a rare civet reported from here
Shingba Rhododendron Sanctuary	43.00	Located in North Sikkim in the Lachung Valley, known for its alpine meadow and hot spring. *R. niveum* the state tree of Sikkim occur only in this sanctuary
Maenam Wildlife Sanctuary	35.34	Located in South Sikkim exceedingly rich in *R. griffithianum* and *R. dalhousiae* with some other species
Kyongnpsla Alpine Sanctuary	31.00	Located on the way of Nathula. The sanctuary is rich both in flora and fauna. Rare and endangered ground orchids and rhododendrons are among the important plants present here. The state tree of Sikkim (*R. niveum*) has been introduced here
Singalila National Park	78.60	With other rhododendrons an undergrowth of *R. arboretum*, *R. falconeri*, *R. hodgosonii* and *R. grande* in this dense temperate forest are common
Neora National Park	88.00	Well known for the rhododendron, though most of the rhododendrons are disappearing. The past glory can be visualized through remnants
Sinchel Wildlife Sanctuary	39.45	The sanctuary is rich both in flora and fauna. Rare and endangered ground orchids and rhododendrons are among the important plants present here

Table 3. Indian institutions involved in research and development works on rhododendron[9]

Institution	Location	Activities
High Altitude Plant Physiology Research Centre	H.N.B. Garhwal University, Srinagar, Uttaranchal	Studies on phenology, seed germination, and polysaccharides estimation, etc.
Nainital University	Nainital, Uttaranchal	Effect of fertilizers on flower colour and growth in some species
G.B. Pant Institute of Himalayan Environment and Development (Sikkim Unit)	Tadong, Gangtok, Sikkim	Status, *ex-situ* and *in-situ* conservation efforts
Indian Agricultural Research Institute	New Delhi	Genetic diversity studies
Sikkim Rhododendron Society	Gangtok, Sikkim	Rhododendrons status studies
G.B. Pant Institute of Himalayan Environment and Development (Head Quarter)	Kosi-Katarmal, Almora, Uttaranchal	Microbiological studies
World Wildlife Fund for Nature, India – Sikkim Unit	Gangtok, Sikkim	Baseline assessment
World Wildlife Fund for Nature, India – Arunanchal Unit	Tawang, Arunachal Pradesh	Restoration of rhododendron community forests in partnership with the locals
Forest Department, Govt. of Sikkim	Gangtok, Sikkim	Rhododendron conservation through protected area network program
Tropical Botanical Garden and Research Institute	Palode, Thiruvananthapuram	Genetic variation studies among the population of *R. nilgiricum*
Ashoka Trust for Research in Ecology and the Environment	Bagdogra, Siliguri, West Bengal	Create awareness among local people and visitors of the problems of nature degradation
Botanical Survey of India, Sikkim Himalayan Circle	Gangtok, Sikkim	Botanical survey and herbarium collection

the usefulness of these methods. In a report of Forest Department in which they drew up plans for protected area network to cover the range of rhododendrons in Sikkim Himalaya, they suggested that the rhododendron population under the protected area network was enhanced from 3.8 to 4.6% within the last 10 years. However currently the protected area network does not adequately cover some important rhododendron species of conservation significance (e.g. *R. maddenii*).

Adequate data on species diversity, population, location and extent of habit, major threats to different rhododendron species, and changes in these aspects over time are not available to design a proper strategy for conservation. Given this study, ecological surveys and taxonomic investigations need to be intensified, particularly for rare and endangered species. For conducting ecological studies, species for such studies can be prioritized. The institutions working in the area need to network and coordinate their activities so that priority issues and areas are identified. The Ministry of Environment and Forests (MoEF) through the Botanical Survey of India and Ministry of Science and Technology (Department of Biotechnology) could play a guiding role by preparing a list of priority issues and areas for circulation to relevant institutions based on the countrywide consultation of the experts. Funding for these priority projects could be stepped up to ensure that research focuses on these issues. The MoEF must set up a database for the country rhododendrons as a whole. Owing to habit fragmentation and consequent losses suffered by different population, there is a need for ensuring the safety of the rhododendron growing outside protected areas. Population viability analysis 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 syn. micromeres*). *In situ* conservation approach is a good management scheme. This includes facilitating gene flow through the creation of 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* conservations, *ex-situ* conservation seems to be a good approach. Plant tissue culture and vegetative propagation are the best alternatives towards species management. Although most of the species have been considered as rare and endangered species, large-scale removal still continues at rates well over natural regeneration. Therefore special attention needs to be given for propagation and conservation; systematic propagation would go a long way in achieving conservation. It is desirable to apply simple methods, e.g. seed germination or propagation via air layering/cuttings; these would be easy to perform in the field and cost effective. Local people must be educated on the significance and beauty of the species and their variations in nature. To counteract the possibility of full scale destruction of rhododendron habitats through natural calamities, threatened species like *R. maddenii*, *R. niveum*, *R. pendulum*, *R. leptocarpum* and elite and healthy plants of other species needs *ex-situ* preservation in similar other localities and/or in arboreta. Seeds of such species should be preserved through government research institutions. Forest planners should take into consideration the aesthetic value, tourism importance and economic upliftment of the people while planting rhododendrons.

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