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## Original article

## Ecology, distribution mapping and conservation implications of four critically endangered endemic plants of Kashmir Himalaya



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## ABSTRACT

During the last few decades, human-driven activities have led to indiscriminate habitat destruction and exploitation of many plant species in Kashmir Himalaya. As a result, many species have become threatened and are struggling for survival. Of particular concern are the endemic and critically endangered species which have the highest risk of the extinction, hence warranting immediate conservation actions. Therefore the current study was carried out to understand the distribution, ecology and conservation implications of the four critically endangered endemic plants of Kashmir Himalaya. Habitat distribution modelling showed that the suitable potential areas for the species occurred from subalpine to alpine meadowlands with an elevational range of 1500–4600 m asl. The output of the MaxEnt model and field surveys have revealed that their highest potential distribution is in Panchari, Khrew, Ramnagar, Pahalgam, Gurez, Sonamarg, Gulmarg and Kishtwar forest ranges. Based on the field explorations and herbarium records, *Saussurea costus* (Falc.) Lipsch have 27 distribution areas, *Gentiana kurroo* Royle 18, *Lilium polyphyllum* D. Don 12 and *Aconitum chasmanthum* Stapf have 15. Precipitation of the driest month and annual mean temperature played an important role in the distribution of the studied species. The species started their lifecycle with the onset of the spring season, flowered in summer, fruit in autumn and senesce in the winter season. Under natural conditions, the number of days required for germination ranged from 180 to 210 where cold stratification played a pivotal role. Since last few decades, the populations of these species have been shrinking in their natural habitats due to over-exploitation for medicinal purposes and habitat destruction through amplified humanoid interferences like the expansion of agricultural land, road building, grazing and urbanization. Thus there is an urgent need to come up with positive strategies to save whatever is left and plan long term rescue measures not only to protect these species from extinction but also to reintroduce them along with framing the plans to supply sustained raw materials for medicine.

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## 1. Introduction

Worldwide, biodiversity is under high risk due to changes in land use, climate and socio-economic components (Keenan et al. 2015). The intense developmental activities over the last few decades have left behind forests that are highly fragmented and noncontiguous, which interferes with the plant dispersal patterns, induces a genetic drift, modifies microclimatic settings of the area and favours inva-

sion of the alien species (Laurance et al. 1998). All these factors ultimately lead to the extinction of the plant species (Tilman et al. 1994). Many studies have confirmed that human-induced changes have accelerated the rate of habitat loss (Kardol and Wardle, 2010), altered the distribution of plant species (Dawson et al. 2011) and have triggered the sixth major extinction episode in life history (Vetaas et al. 2012). According to the World Conservation and Monitoring Centre (WCMC), more than 10,000 plant species are endangered in the world (IUCN, 2003). Globally, conservation biologists have estimated that 36.5% (435,000) of plant species are extremely rare (Enquist et al. 2019) and around 25% of them may go extinct during the next few decades (IUCN, 2003).

On conservation priority scale, endemic and critically endangered species are of particular interest as they are first in the list to go extinct (Myers et al. 2000). These species colonizes niches with specific environmental requirements and are often characterized by low abundance, small population size, poor genetic variability,

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restricted geographic distribution, low reproductive potential, low capacity of competition and dependence on dispersal ability (Markham, 2014; Silva et al. 2017). These characters are likely to render such species more vulnerable to human disturbance and a host of other kinds of threats (IPCC, 2014). Thus, there is an urgent need to take effective conservation actions in terms of recovering these species before many of them are completely lost.

Of particular concern are the places with special biological features that encompass higher levels of diversity, conservation value and endemism (Mir et al. 2019). Such areas have become the concern of conservation scientists, practitioners and planners (Margules et al., 2002; Myers et al. 2000). Indian Himalaya is one of the well-known such regions with a great range of plant diversity and high conservation value (Sahni, 1982; Hajra and Rao, 1990; Dar et al. 2012). Out of 47,513 plant species found in India, Indian Himalaya supports about 18,440 species alone (Singh and Dash, 2014). The Kashmir Himalaya which is a part of North-Western Himalaya represents a unique bio-region owing to its varied habitat heterogeneity and topography. Phytogeographically located at the intersection of Paleotropical and Holarctic floristic realms, the region is endowed with heaving treasure of 2312 plant species, of which 153 are endemic (Dar et al. 2012). The region once encumbered with green landscapes has now come into the ways of anthropocentric pressures. Habitat loss, fragmentation, agricultural expansion, uncontrolled grazing and over-exploitation have rendered 355 plant species threatened in the region (Dar and Naqshi, 2002). There has been a growing concern about the increasing number of plant species of the region that are listed in IUCN and are now declared as globally threatened. This includes 04 Critically Endangered (*Gentiana kurroo* Royle, *Lilium polyphyllum* D. Don, *Saussurea costus* (Falc.) Lipsch and *Aconitum chasmanthum* Stapf), 04 Endangered (*Cypripedium himalaicum* Rolfe, *Angelica glauca* Edgew., *Aconitum heterophyllum* wall., and *Dalbergia congesta* Wight & Arn.), 04 Vulnerable (*Aconitum violaceum* Jacq. ex Stapf., *Ulmus wallichiana* Planch, *Rhynchosia heynei* Wight & Arn., and *Eleiotis rottleri* Wight & Arn.) and 05 Near Threatened (*Allium roylei* Stearn, *Abies spectabilis* (D. Don) Mirb., *Pinus gerardiana* Wallich ex D. Don, *Cajanus cajanifolius* (Haines) Maesen and *Carex kashmirensis* C.B. Clarke).

Despite many floristic studies available in the Kashmir Himalaya region in India (Dar and Naqshi, 2002, Khuroo et al. 2007, Dar et al. 2012, Jabeen et al. 2013), meager information is available on the distribution and conservation ecology of critically endangered endemic plant species. Though attempts have been done with respect to diversity (Jabeen et al. 2013), micro-propagation (Kour et al. 2016) seed germination (Dar et al. 2009; Bano et al. 2018), phytochemical screening (Wani, 2013; Qayoom, 2015) and reproductive biology (Gujree, 2007), the lack of detailed information across landscapes in a major gap. The studies done so far are either site-specific or species-specific, used hypothetical doctrines of conservation which are often ineffectually tested in the field and have limitations of being relevant in the bigger spatial context. Therefore, the current study was carried out to study the distribution, ecology and conservation implications of critically endangered endemic plant species (*Gentiana kurroo*, *Lilium polyphyllum*, *Saussurea costus* and *Aconitum chasmanthum*) of Kashmir Himalaya. The study will help to locate the hotspots of distribution, ecology and provide a baseline for developing effective strategies for conservation.

## 2. Materials and methods

### 2.1. Study area

In the present study, the Kashmir Himalaya represents the Indian Union territories of Jammu & Kashmir and Ladakh falling

in the biogeographic zone of the North-Western Himalaya (Rodgers and Panwar, 1988). Topographically, the whole region is mountainous with four main ranges viz. Karakoram, Zaskar, Ladakh and Pir Panjal. The valley of Kashmir is surrounded by high mountain ranges, Jammu is mostly hilly, while Ladakh represents the cold desert. The region shows a significant altitudinal, topographical and climatic variation resulting in great habitat diversity. Phytogeographically located at the intersection of Holarctic and Paleotropical floristic realms, the region supports a rich diversity of tropical, subtropical, temperate and alpine flora (Dar et al. 2012). It has 23,611 sq km of forests which represents 10.63% of the total geographic area of the region (Indian State of Forest Report, 2019). It has three different climatic regions viz., cold desert of Ladakh, temperate Kashmir and subtropical Jammu (IMD, 2014). It is marked by four seasons including winter (December to February), spring (March to May), summer (June to August) and autumn (September to November). The average annual rainfall varies from about 600 mm to 800 mm and the average annual temperature ranges from subzero to 40 °C (IMD, 2014).

### 2.2. Study species

During the present study, the species were selected based on the latest IUCN 2019 red list (IUCN, 2020). The species which are found only in the Himalayas as described by published literature (Dhar and Kachroo, 1983; Dar et al. 2012) were considered as endemic. Based on the above criteria, only four species viz., *L. polyphyllum*, *A. chasmanthum*, *G. kurroo* and *S. costus* (Fig. 1) were found to be endemic and critically endangered in the region.

All the species are heavily exploited for their high medicinal value which results in their fast heading towards local extinction in the Kashmir Himalaya (Ved et al. 2003; Jabeen et al. 2013). *S. costus* is used in dysentery, rheumatism, skin disorder, stomachache, cold, cholera, bronchitis, fever, oedema, jaundice, leprosy, phlegm, toothache, earache, ulcer, bruises and cuts. *G. kurroo* is used to treat stomach aches, fever, bronchial infections, urinary disorders and for improving appetite. *L. polyphyllum* is used to cure fever, bronchitis, seminal weakness, burning sensation, kidney problems and redness of eyes. *A. chasmanthum* is used for the treatment of rheumatism, fever, asthma, snake bites and as an ointment to cure abscess and boils. The species have been included in 'Negative List of Exports' based on CITES. *S. costus* has been listed in appendix I of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and specified plants in the Schedule VI of the Wildlife (Protection) Act, 1972 (Kuniyal et al. 2005).

### 2.3. Data collection and analysis

In order to conduct the current study, exploratory field surveys were conducted to different areas of the Kashmir Himalaya. The point distributional records of the selected species along with the coordinates of occurrence points were recorded with a global positioning system (GPS). Along with field data, the supplementary distributional records available on the Global Biodiversity Information Facility (GBIF) were also extracted. To get the detailed information about the history of species distribution and collections in the study area, various herbaria including University of Kashmir Herbarium (KASH), Janaki Ammal Herbarium Jammu (RRLH), University of Jammu Herbarium, Dehradun Herbarium (DD) and Botanical Survey of India Northern Circle (BSD) were consulted. From the herbaria specimen, information such as locality, date of collection and the geographic position was recorded.

To study the potential zones of the species distributions, geographical coordinates were subjected to modelling. The model was developed using Maximum Entropy Modelling (MaxEnt) aided

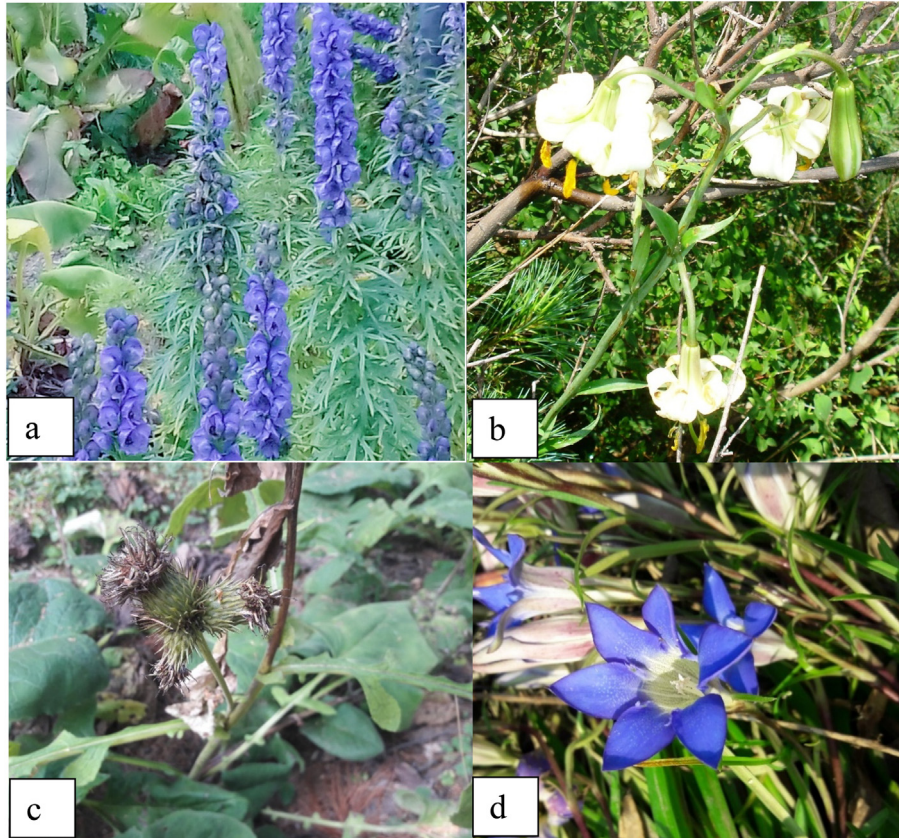


Fig. 1. Photos showing a) *A. chasmanthum* b) *L. polyphyllum* c) *S. costus* and d) *G. kurroo*.

by DIVA-GIS and ARC-GIS software (Phillips et al. 2006). After removing the duplicate presence records of the species, 15, 21, 16 and 32 presence records were used for *L. polyphyllum*, *A. chasmanthum*, *G. kurroo* and *S. costus* respectively. Of the presence data for each species, 70% of the data was used for model training and 30% for testing. Since species distribution is influenced by environmental factors, therefore, 19 bioclimatic variables and elevation datasets with 30 s spatial resolution from WorldClim and United States Geological Survey (USGS) datasets were used. These datasets are derived from measurements of altitude, temperature and rainfall from weather stations across the globe (Khanum et al. 2013) and are frequently used in modelling species distribution (Adhikari et al. 2012). A subset of the study area was clipped in ARC GIS and the continuous data was extracted and resampled to 30 s spatial resolution and converted to ASCII grid for use in MaxEnt. To avoid cross-correlation within the 19 environmental variables tests for correlation were done using ENM tools and highly correlated variables ( $r > 0.8$ ) were eliminated.

According to the probability of distribution and habitat preferences, the potential distributional zones were divided into five categories based on the set threshold as very low (0.0–0.2), low (0.2–0.4), medium (0.4–0.6), high (0.6–0.8) and very high (0.8–1). To validate the model robustness, 05 replicated model runs for each species with a threshold of 10 percentile training presence was executed by cross-validation technique. The models were parameterized using 10,000 background points, 500 iterations, and a convergence threshold of 0.00001 (Phillips and Dudik, 2008). Percent variable contributions and Jackknife procedures were used to estimate the relative influence of unlike variables. Receiver operating characteristics (ROC) investigation was used for examining the performance of a model by a single number called the area under the curve (AUC). The model quality was classified based on AUC

values following Thuiller et al. (2005) as ‘poor’ if AUC < 0.8, ‘good’ if AUC is 0.8–0.9, ‘fair good’ if AUC is 0.9–0.95 and ‘very good’ if AUC is 0.95–1.0.

Field surveys were conducted to different parts of Kashmir Himalaya to study the habitat characteristics and ecology of the species. For each species, the characteristics like habitat, habit, breeding system, flower colour, fruit type, modes of dispersal and reproduction were recorded. During the field surveys, threats operating including extraction of the species for medicine, encroachment for agriculture, road construction, grazing and tourism-related activities were also noted. The information on germination and growth is based on published literature (Raina et al. 2003; Butola and Samant, 2006; Gujree, 2007; Tomar et al. 2012; Dhyani, 2012; Sourabh et al. 2015; Bano et al. 2018; Dhyani et al. 2013, 2018). To record the phenological behaviour of the species, individuals of each species were tagged and monitored for sprouting, fruiting, flowering and senescence for a calendar year.

### 3. Results and discussion

#### 3.1. Habitat characteristics and ecology

All the species are perennial herbs with the generation length of one year. *G. kurroo* has a tufted stem with stout and thick rootstock penetrating deep into the soil. *S. costus* and *A. chasmanthum* have tuberous roots, while *L. polyphyllum* is a bulbous herb. All the species are monoecious except *A. chasmanthum* which is a dioecious species. The species produced three types of fruits and showed three modes of dispersal (Table 1). *S. costus* produces achenes, *A. chasmanthum* pods, whereas *G. kurroo* and *L. polyphyllum* produced capsules. *S. costus* and *G. kurroo* disperses by anemochory,



**Table 1**  
Ecological characteristics of the studied species.

Species	Family	Habit	Breeding System	Flower colour	Fruit Type	Seed colour	Mode of Dispersal	Mode of reproduction
<i>S. costus</i>	Asteraceae	H	Monoecious	Blackish purple	Ac	Black	A	Sexual (seeds)/Asexual (rhizome)
<i>G. kurroo</i>	Gentianaceae	H	Monoecious	Blue	C	Black	A	Sexual (seeds)/Asexual (rhizome)
<i>L. polyphyllum</i>	Liliaceae	H	Monoecious	White–creamy with purple spots	C	Brown	Au	Sexual (seeds)/Asexual (bulbs)
<i>A. chasmanthum</i>	Ranunculaceae	H	Dioecious	Pale blue	P	Black	A/Z	Sexual (seeds)/Asexual (tubers)

**Legend:** H = herb, Ac = achene, C = capsule, P = pod, A = anemochory, Au = autochory, Z = zoochory.

*A. chasmanthum* by both anemochory and zoochory, whereas *L. polyphyllum* disperses by autochory (Table 1).

In the zoochoric mode of dispersal, the agents involved were rodents and birds, whereas the autochoric dispersal occurred by forcefully eviction of seeds by dehiscence and bursting. Insects (bees, butterflies, wasps etc.) were found to be the main agents of pollination during the study. The species have variedly coloured flowers which indicates their potential to be used for ornamental purposes. All the species propagates both by sexual (seeds) as well as asexual (tubers, bulbs, rhizome) means but *S. costus* and *L. polyphyllum* prefers to reproduce through asexual means. Vegetative propagation is simply a means of perpetuation to ensure re-sprouting in the succeeding season and works as a strategy for these species to persist year after year (Dhyani et al. 2014). These species are found growing in association with the communities of the shrub (e.g. *Berberis lyceum*, *Cotoneaster affinis*, *Rosa webbiana*, *Rubus niveus*, *Viburnum grandiflorum*), herb (e.g. *Aconitum heterophyllum*, *Atropa acuminata*, *Bergenia ciliate*, *Fragaria nubicola*, *Geranium wallichianum*, *Lavatera cashemiriana*, *Phytolacca acinosa*, *Viola odorata*) and occasionally with tree (e.g. *Abies pindrow*, *Acer caesium*, *Betula utilis*, *Cedrus deodara*, *Pinus wallichiana*) species of the temperate nature.

The preferable habitats of the species varied from subalpine to alpine meadowlands and grow in the higher altitudes with an elevational range of 1500–4600 m asl (Table 2). *S. costus* and *A. chasmanthum* grows in subalpine and alpine meadows and occasionally in rocky slopes and moist ravines in temperate forests from 2100 to 4600 m elevation. *L. polyphyllum* prefers shady moist places from an elevational range of 2200–3200 m asl, where it thrives well in humus-rich soil with a good composition of sand, silt and humus (Dhyani, 2017). On the other hand, *G. kurroo* prefers to grow on open slopes of mid and higher mountain ridges from 1500 to 3500 m asl. Such sites are attributed by high insolation, frequent winds and low temperature where it remains overshadowed by scrubs and tall grasses. The neighboring land use of the

sites of occurrence of these species include roads, coniferous forests, agricultural and horticultural fields, human settlements, rivers, meadows, glaciers, etc.

### 3.2. Distribution

All the species have restricted geographic range and are found in the Himalayan region only. Globally, the species are distributed in Himalayan regions of India, Pakistan, Nepal, Afghanistan and China (Table 2).

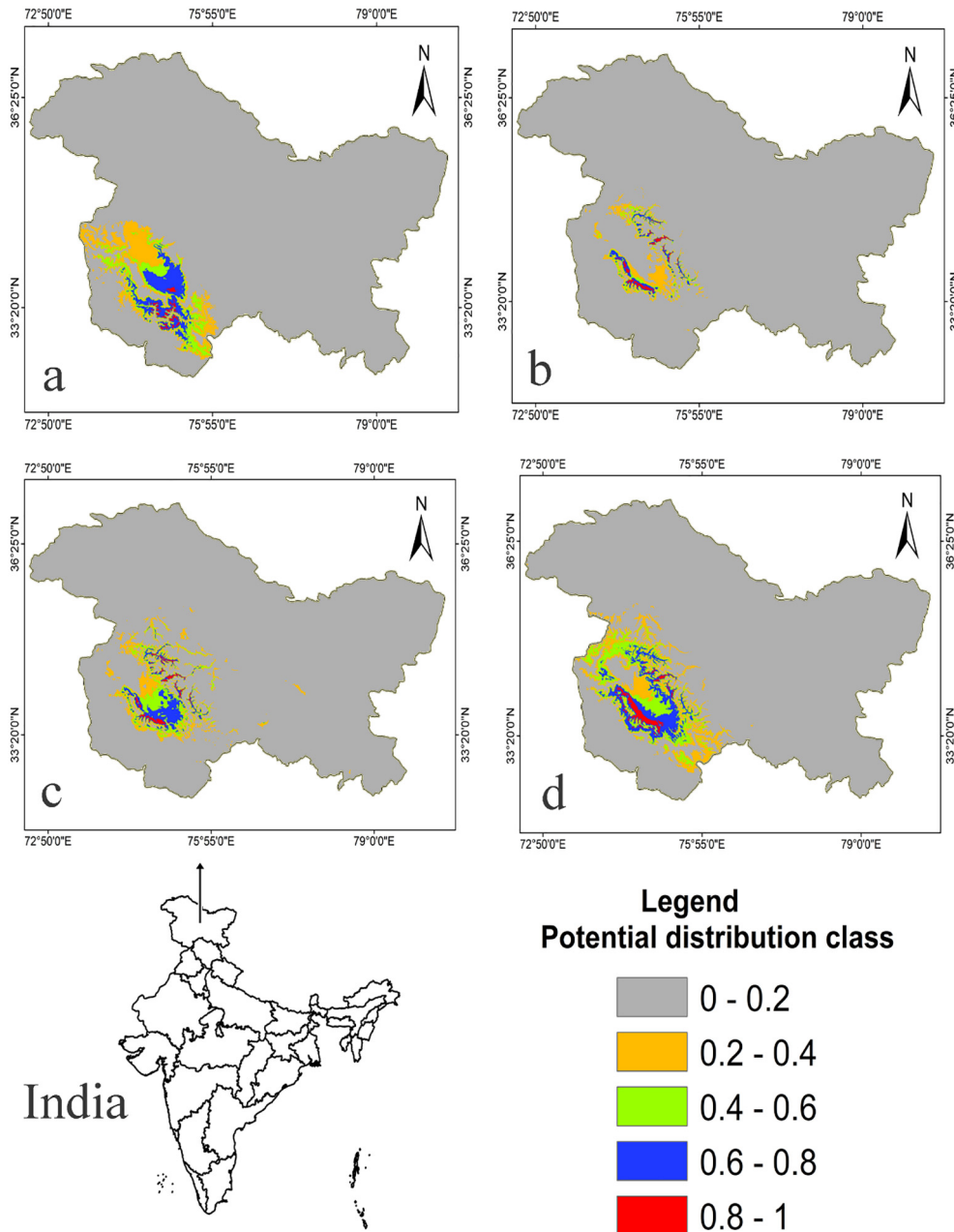
The output of the MaxEnt model showed that most suitable habitats for the studied species varied (Fig. 2). The highest potential distribution zones for *G. kurroo* are located in Pir Panchal Mountains from Banihal to Panchari forest range in Udhampur district and Khrew area of Kashmir region. The species also showed distribution zones in Banjal and Kardoh in Kathua district and Ramnagar forest division in Udhampur district (Fig. 2a). Pahalgam, Gurez, Sonamarg, Gulmarg and Kishtwar forest ranges have higher potential distributional zones for *S. costus*, while Machil, Minimarg, Banihal and Baderwah forest ranges fall in medium probable distributional zones (Fig. 2b). Scattered zones of distribution were shown by *L. polyphyllum* with the highest distribution in Sonamarg, Baltal, Gurez, Aru and Aharbal forest ranges. The lower threshold for distribution was found in Kishwar, Panikhar, Drass etc. (Fig. 2c).

*A. chasmanthum* showed a wider range of distribution with the highest distribution zones in Banihal, Poonch, Pahalgam, Gulmarg and Sonamarg forest divisions. It also showed distribution in Machil, Kishtwar, Padder, Basantgarh and Ramnagar forest ranges (Fig. 2d).

Based on our field explorations and herbarium records, *S. costus* has 27 distribution areas where the collections of the species have been reported, *G. kurroo* has 18, *L. polyphyllum* 12 and *A. chasmanthum* has 15 distributional areas reported until now (Table 2). To develop a suitable conservation agenda, all the areas need to be

**Table 2**  
Habitat, global and local (based on field surveys and herbarium records) distribution of the studied species.

Species	Habitat	Altitudinal range (m)	Distribution	
			Global level	Kashmir Himalaya
<i>S. costus</i>	Subalpine to alpine meadows	3200–4000	India (Himachal Pradesh, Uttrakhand, Jammu and Kashmir) Pakistan, China	Gurez, Tilel in Kishanganga Valley, Suru Valley, Lidder valley, Khand, Kunpathri, Ramban, Kilshai, Badzalkod nullah Batakut, Gulmarg, Agharwat, Kolhoi, Khilanmarg, Sinthan top, Dhara Mahader Mountains Srinagar, Aharbal, Pahalgam, Baltal, Kuthwali Gali, Pathargali, Gagariyan, Seoj, Bhaderwah, Kounsarnag, Dahi Nalla, Sonamarg, Toshmaidan
<i>G. kurroo</i>	Subalpine to alpine meadows	1500–3500	India (Himachal Pradesh, Uttrakhand, Jammu and Kashmir) Pakistan, Nepal	Banihal Ridge, Kiramichi, Ramnagar, Termain, Kardoh, Khajare Bani, Hamusan Rakh, Pal Reasi, Sheshnag, Lapri Dhar, Hathi Matha, Pahalgam, Drass, Dachigam, Verinag, Overa Wildlife Sanctuary, Bhaderwa, Khrew Trikuta Hills, Gurez, Sonamarg, Lidder valley, Patni top, Thanda Pani, Lidderwat, Aharbal, Kishtwar, Chandanwari, Banihal
<i>L. polyphyllum</i>	Shady moist places of alpine meadows	2200–3200	India (Himachal Pradesh, Uttrakhand, Jammu and Kashmir) Afghanistan, Pakistan, Nepal	
<i>A. chasmanthum</i>	Alpine meadowland	2100–4600	India (Himachal Pradesh, Uttrakhand, Jammu and Kashmir) Pakistan, Nepal, China	Bhaderwah, Bandipora, Agharwat, Gulmarg, Tunga, Dison Nala, Gurez, Chorwan, Drass, Bandipora, Mahaganesh Top, Posh Pathri, Lidderwat, Machil, Sinthan top



**Fig. 2.** Distribution areas of a) *G. kurroo*, b) *S. costus*, c) *L. polyphyllum* and d) *A. chasmanthum* in Kashmir Himalaya [Note: The map does not authenticate legal administrative boundaries and is meant for research purpose only]

surveyed thoroughly for the current existence of the species. Especially the areas where the species have been reported before 50 years and could not be recollected from the same locality afterwards.

The MaxEnt model for species performed well with an AUC value of >0.95. Fig. 3 shows the results of the jackknife test for variable importance of the studied species. Precipitation of driest month appears to be the most influencing variable as it decreases the gain the most when it is omitted and thus has the most information as compared to other variables.

The potential distribution of all the four species is largely affected by the precipitation of driest month (Table 3). Annual mean temperature determined the distribution of *A. chasmanthum*, *L. polyphyllum* and *S. costus*. Temperature seasonality also influenced the distribution of *G. kurroo* and *L. polyphyllum*. Though

the elevation had a lesser effect on other species, it was the strongest predictor for the distribution of *A. chasmanthum* (Table 3).

### 3.3. Phenological characteristics

The natural habitat of the studied species is covered with snow from November to February with subzero temperature, hence the species remain underground during the period. During this time, the roots help in the process of nutrient and water absorption along with pulling the bulb/tuber/rhizome deeper into the soil to protect it from frost injury (Dhyani, 2018). With the onset of the spring season when the temperature starts rising and snow melts, the species started life cycle activities by sprouting of vegetative parts. The timing of the shoot emergence varies in different altitudinal zones as the higher reaches remain covered with snow for

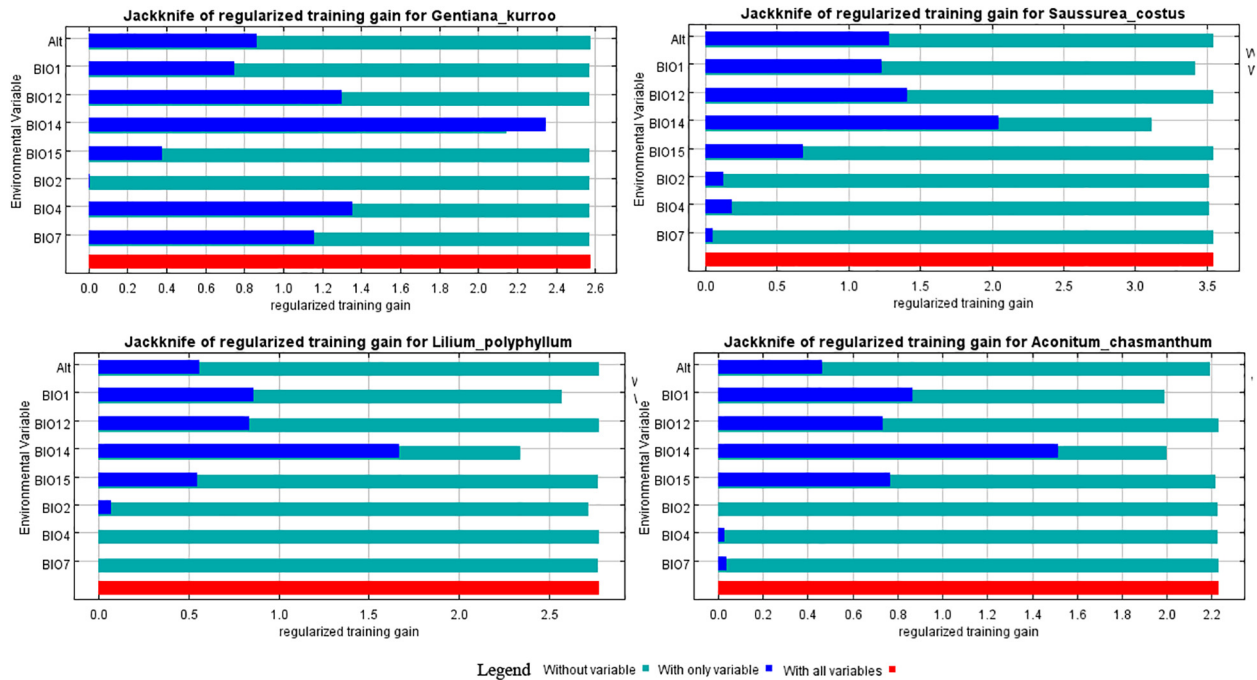


Fig. 3. Jackknife of regularized training gain for the studied species.

Table 3

Analysis of environmental variable contributions showing their respective percent contribution (outside brackets) and permutation importance (inside brackets). Other 12 environmental variables were excluded as they were highly correlated ( $r > 0.8$ ).

Variable	<i>G. kurroo</i>	<i>S. costus</i>	<i>L. polyphyllum</i>	<i>A. chasmanthum</i>
ALT (Elevation)	0.1 (0.0)	0.9 (0.0)	0.0 (0.0)	1.7 (11.7)
BIO 1 (Annual mean temperature)	0.5 (6.4)	10.7 (24.6)	14.2 (23.4)	22 (35.3)
BIO 2 (Mean diurnal temperature range)	0.1 (1.2)	1.3 (1.4)	2.3 (4.5)	0.6 (0.2)
BIO 4 (Temperature seasonality)	6.7 (1.9)	10.4 (1.0)	0 (0.0)	0.5 (0.7)
BIO 7 (Temperature annual range)	2.3 (1.2)	8.6 (0.1)	12.9 (0.4)	1 (0.1)
BIO 12 (Annual precipitation)	0.3 (0.1)	0.7 (0.0)	0 (0.0)	0 (0.1)
BIO 14 (Precipitation of driest month)	89.8 (88.7)	67.2 (72.9)	70.6 (71.7)	73.4 (43.7)
BIO 15 (Precipitation seasonality)	0.2 (0.5)	0.1 (0.0)	0.1 (0.1)	0.8 (8.1)

longer period which delays the sprouting in such areas as compared to plains.

Peak flowering, when most of the species (*S. costus*, *A. chasmanthum* and *L. polyphyllum*) flowered was observed during the summer season, while *G. kurroo* flowered during the autumn season. Mass flowering, a phenomenon where a plant produces a large number of flowers in a short time (1–2 months) was found in *A. chasmanthum* and *G. kurroo*. A long-flowering duration (2–3 months) was observed in *S. costus* and *A. chasmanthum* while *L. polyphyllum* and *G. kurroo* showed shorter flowering period (15 days to 2 months). Peak fruiting was observed during autumn season followed by the summer season (Fig. 4). Flowering and fruiting are determined by the number of environmental factors including photoperiod, humidity and temperature along with the timing of snow-melt at higher altitudes (Kudo and Hirao, 2006). The pattern of phenological events in the studied species coincides with high temperatures and moisture in the summer season which have been found to accelerate the physiological functions related with the maturation of flowers and fruits (Janzen, 1983). The plants started senescence with the drop in temperature during November and remain grounded until February to March during the winter season.

The life cycle of these species is highly vulnerable to anthropogenic disturbances as has been reported for several other threatened species of India (Upadhaya et al. 2018). The timing of a

disturbance event also plays an important role by interacting with delicate phases of plant phenology such as dormancy, pollination, dispersal, seed growth and maturation (Upadhaya et al. 2018). In our case, the disturbances like grazing and tourist flow occur during such critical phases of these species which would have a potential effect on these species. Besides, the timing of the reproductive phenology (flowering and fruiting) could itself be a risk to a particular plant species (Krause, 2013). For example, the availability of the pollinators starts decreasing after the summer season and therefore only those species that flower during spring and summer (*A. chasmanthum*, *S. costus*, *L. polyphyllum*) gets enough pollinators while the species (*G. kurroo*) which flowers during the autumn season face the difficulty in finding pollinating agents, hence would serve as a cause to its rarity (Cortes-Flores et al. 2013). Another important factor is the loss of the ability of plants to disperse to long distances because of fragmented landscapes as a result of road building, deforestation and other related human activities (Ruxton and Schaefer, 2012). Moreover, phenological patterns of these threatened and endemic species localizing to highly specific ecological niches are particularly vulnerable to climatic changes (Manjikola et al. 2005). The confinement of these species to niches with severe climatic conditions would also restrict their dispersal and phenological cycle with changing habitat and climate (Butola and Samant, 2010).

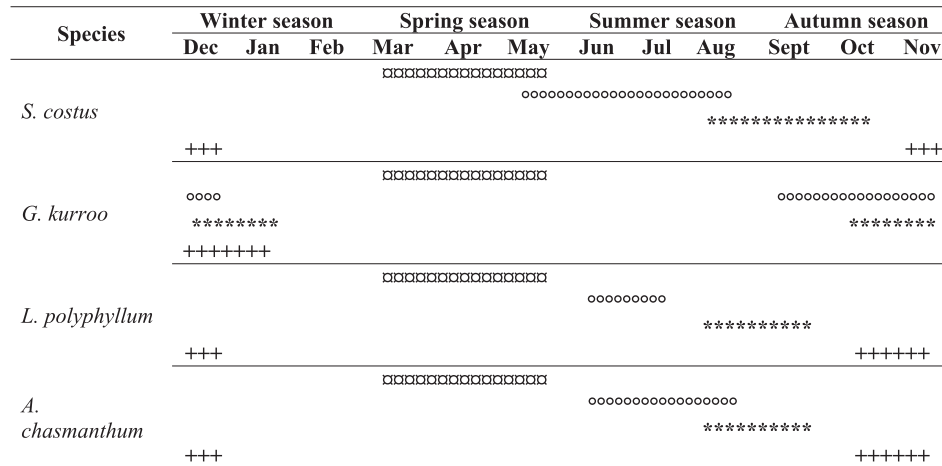


Fig. 4. Phenological calendar of sprouting (□□□□□□□□□□□□), flowering (○○○○○○○○○○○○○○○○○○○○), fruiting (\*\*\*\*\*), and senescence (+++++++), of the studied species.

3.4. Seed germination

In the natural habitats, seed germination and seedling establishment are acute phases in the life cycle of a plant species which have a direct effect on the ecological fitness of a plant species (Baskin and Baskin, 1998, 2014), hence its understanding is important for developing effective conservation strategies. The information not only helps in understanding the seedling establishment requirements but also is required for artificial propagation of the species for effective augmentation, introduction and reintroduction programmes (Shen et al. 2010). Of the studied species, two (*L. polyphyllum* and *A. chasmanthum*) undergo a long (>5 months) period of dormancy, *G. kurroo* undergoes 3–4 months, while laboratory experiments have revealed that the seeds of *S. costus* are non-dormant and lose viability with increasing age (Table 4). The dormancy of seeds in *A. chasmanthum* is attributed to the hard seed coat (Gujree, 2007). The seeds of *L. polyphyllum* have epicotyl morpho-physiological dormancy were the species have underdeveloped embryos at maturity (Dhyani et al. 2013). Under natural conditions, the days required for initiating germination of the studied species ranged from 180 to 210 days, with the longest in *L. polyphyllum*. The seeds of all the species matured during the autumn and winter season indicated chilling (cold stratification) requirement for breaking dormancy (Table 4). The dispersed seeds germinate in the spring season of the following year as soon as temperature improves and reaches to about 15 °C (Dhyani et al. 2017). The dispersal of the seeds during autumn and winter season exposes these species to unfavourable environmental conditions which may hamper their natural regeneration. Since the seeds of

these species pass through winter dormancy, they are vulnerable to seed pests and predators. Besides, the seeds are also susceptible to being washed away by heavy rains and snow from their natural and favourable environment. Germination of the species in the early spring season with a progressive increase in temperature signifies the effect of temperature on germination of these species. However, during this period the seedlings are soon exposed to competition with other associated species which largely affects their abundance and survival. It was observed in field surveys that early snowfall (during November) in Kashmir valley greatly affects the seed maturation and increases abortion in *G. kurroo*. Despite the production of numerous seeds by *G. kurroo*, the seedling establishment is very poor (Raina et al. 2003) which is because of premature anther development (Badola and Pal, 2002). The seeds of *A. chasmanthum* are photoblastic in nature, thus non-availability of light due to burial of seeds underneath litter of the co-existing species and snow for prolonged time affects germination (Gujree, 2007).

Since the germination under natural conditions is not so good, therefore researchers have used different treatments to enhance the germination under laboratory conditions (Table 4). This includes chilling, heat exposure, scarification, and treatments with gibberellic acid (GA<sub>3</sub>), IBA, thiourea, nitric acid (KNO<sub>3</sub>) etc. Scarifying seeds of *L. polyphyllum* with NaOCl and removal of the seed coat mechanically embryo enhanced its germination up to 91% (Dhyani et al. 2013), treatment of *A. chasmanthum* seeds with GA<sub>3</sub> enhanced germination to 70% (Gujree, 2007), culturing seeds of *G. kurroo* at 25 °C enhanced germination up to 68% (Tomar et al. 2012) and treatment of *S. costus* seeds with GA<sub>3</sub> and KNO<sub>3</sub>

Table 4  
Seed germination characteristics of studied species seen under natural and laboratory conditions.

Species	Under natural conditions					Under laboratory conditions			Source
	GT	DT	Seed dispersal	Seed germination	SV	DP	Germination treatments required	GP	
<i>S. costus</i>	H	ND	Sept – Oct	Apr – May	18	Non-dormant	CMS, GA <sub>3</sub> and KNO <sub>3</sub>	9–15	Butola and Samant, 2006; Bano et al. 2018
<i>G. kurroo</i>	H	PD	Nov – Dec	Apr – May	12	120–150	CMS followed by warm treatment (25 °C)	28	Raina et al. 2003; Tomar et al. 2012
<i>L. polyphyllum</i>	H	RMD/PD	Sept – Oct	May – Jun	12	230–530	CMS followed by warm treatment (≥15 °C), GA <sub>3</sub> , IBA and NaOCl	56–75	Dhyani, 2012; Sourabh et al. 2015; Dhyani et al. 2013, 2018
<i>A. chasmanthum</i>	H	PD	Sept – Oct	Apr – May	NA	420	CMS, GA <sub>3</sub> , IBA and NaOCl	13–22	Gujree, 2007

Legend: GT = germination type, DT = dormancy type, SV = seed viability in months, DP = Dormancy period in days, GP = germination period in days, H = Hypogeal, ND = Non dormant, PD = Physiological dormancy, RMD/PD = Epicotyl morphophysiological dormancy and physiological dormancy, CMS = Cold moist stratification.



achieved 100% germination (Butola and Samant, 2006). Studies have found that chilling relieves primary inactiveness and helps to overcome dormancy and enhance the percentage of germination (Dar et al. 2009). Scarification reduces the mechanical opposition to germination and thus allows the embryo to grow and the root to arise (Dhyani et al. 2017).

### 3.5. Causes of endangerment

Owing to their unique and high-value medicinal properties, these species have been facing the onslaught of indiscriminate and ruthless exploitation, with the result their natural populations in the Kashmir Himalayan range witness speedy decline. *A. chasmanthum* is harvested for its tubers, *L. polyphyllum* for bulbs and *G. kurroo* for roots and flowers for the use in traditional herbalism and pharmaceutical industry. The species have ample market demand on account of their commercial use as a plant drug and the level of exploitation is high. *S. costus* roots were one of the most valuable herbal exports of Kashmir since the colonial period (Lawrence, 1895). During collection, the whole plant is uprooted resulting in the prevention of flowering and fruiting which hampers the regeneration of the species. Despite the availability of laws on a complete ban on illegal extraction of these species, their strict implementation on the ground is negligible and local scale exploitations are still high.

The population of these species is declining due to over-harvesting and loss of habitat. Habitat loss continues due to construction of high altitude roads, construction of tourist huts, encroachment for agriculture, human settlements and deforestation which has exposed the natural home of these taxa to abiotic and biotic interferences leading to the depletion of their natural populations. At some sites (e.g. Sinthan top, Sonamarg and Panchari), landslides were also observed to cause the death of natural populations. Besides, the proliferation of invasive species such as *Anthemis cotula*, *Xanthium strumarium*, *X. spinosum*, *Galinsoga parviflora*, *Ageratum conyzoides*, *Sambucus wightiana* and *Trifolium repens* in their natural habitats may lead to considerable depletion of their natural populations. Grazing and trampling are other factors which were identified as potential threats to these species. The process reduces the size of the adults, decline the seed production and hampers the life cycle. The combination of all these factors might have resulted in listing these species as Threatened in the Red Data Book of Indian Plants (Nayar and Sastry, 1990) and subsequently as Critically Endangered by the International Union for Conservation of Nature and Natural Resources (IUCN) (IUCN, 2020).

Moreover, the highly specific ecological niches of these species may also hinder their dispersal and range expansion as has been observed in some other threatened species including *Adinandra griffithii* (Adhikari et al. 2018) and *Magnolia rabaniana* (Mir et al. 2017). Since these species are confined to alpine and sub-alpine habitats which experience severe climates like high humidity, sub-zero temperatures and acidic soils which prevents them to acclimatize outside their natural setting (Qu et al. 2018). The earlier snowfall in Kashmir valley was also observed to affect the seed production in *G. kurroo*, therefore affects its population. Such climates have been found to restrict the population size of plant species and affect the sexual cycle (Butola and Samant, 2010). Thus, urgent steps are required to restore the population of these species before they may be irreversibly lost.

### 4. Conservation implications

Despite the large scale cultivation of *G. kurroo*, *S. costus* and *L. polyphyllum* in other states of India, there are no programmes for

the cultivation in Jammu and Kashmir. The conservation efforts have remained confined to small scale *ex-situ* measures and maintenance of individuals of *G. kurroo* and *S. costus* in Forest Department nurseries and botanical gardens of research institutions without any proper multiplication and reintroduction agenda.

One of the basic steps for the conservation is that thorough surveying is needed across the predicted areas of distribution to determine the current status of wild subpopulations and get the appropriate population data. This will also ascertain the areas where the species were reported earlier and are now eradicated. Mass propagation of the species is required followed by reintroduction to suitable habitats so that the viable population of the species can be maintained. For *in-situ* conservation of the species, regular monitoring of the habitats and their complete protection is advised. These species may also be introduced in cultivation by giving facilities and incentives to farmers to provide socio-economic benefits along with the conservation goals. Mass awareness campaign to discourage people for unsustainable collection needs to be launched and conservation capacity building programmes should be started. For long term conservation goals, establishing cooperation between Forest Department, research institutions, non-governmental and other governmental organizations is strongly needed. Moreover, strict implementations of the rules and regulations are also required.

### 5. Conclusion

The study has revealed that the species are restricted to a small geographic range, have generation length of one year, starts life cycle with the onset of the spring season when the temperature rises, reproduce both sexually and asexually and have a long germination period. The restriction of the species to a small geographic range from 1500 to 4600 m asl and their highly specific ecological niche makes them vulnerable to stochastic events and human interferences. The highest influence of precipitation and temperature variables indicates that any changes in climate may affect the distribution and ecology of the species severely. It is also concluded that species distribution models are potential ecological tools for understanding and predicting the distribution of threatened species. The ENM helps in predicting species distribution from smaller sampling units and extrapolates to a larger area by correlating the species existence with its environment. Such kind of approaches supports the development of expressive maps of species potential distribution which can be effectively used for developing conservation strategies for threatened species. The shrinking of natural habitats due to several human interferences has resulted in their speedy decline, hence warrants for immediate conservation actions. Despite many conservation efforts in other parts of the world, there are a few efforts in Kashmir Himalaya. A thorough survey and detailed research is required to get the detailed information about the species. Mass propagation of the species is required followed by reintroduction to suitable habitats along with opening the avenues of cultivation for the species so that the viable population of the species can be maintained.

### Declaration of Competing Interest

None.

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