THREAT STATUS OF THREE IMPORTANT MEDICINAL HIMALAYAN PLANT SPECIES AND CONSERVATION IMPLICATIONS

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A lack of precise information about the threat status of species hampers their effective conservation. The Target 2 of the Convention on Biological Diversity calls for evaluation of threat status at global, national and regional levels to identify plant species of urgent conservation concern. Here we have empirically assessed the threat status of three valuable medicinal plant species (*Trillium govanianum*, *Rheum tibeticum*, and *Arnebia euchroma*) through extensive field studies and herbarium consultations in Kashmir Himalaya and cold desert region of Trans-Himalayan Ladakh. In accordance with the IUCN Red List categories and criteria, each of the three target species turned out to be Near Threatened (NT). According to the NatureServe Conservation Status Assessment, each of these species faces the overall threat impact of «High» to «Very high». We found that the anthropogenic threats emanating from unplanned economic development, road construction and other infrastructure related projects contribute to a fast decline in natural populations of these three species. Keeping in view the value of these species, on the one hand, and growing threats to their survival in the wild, on the other one, we call for urgent conservation strategies in the vulnerable Himalayan habitats for regional socio-economic development.

Key words: *Arnebia euchroma*, Kashmir Himalaya, Near Threatened, overall threat impact, *Rheum tibeticum*, threat assessment, Trans-Himalaya, *Trillium govanianum*

Introduction

Extinction of species is a natural phenomenon that is fundamental to evolutionary change since the origin of life on Earth (Turvey & Crees, 2019). However, in the present era of Anthropocene, the dominant role of humans in global ecosystems has led to a steep rise in the rate of extinctions in comparison to the background levels (Johnson et al., 2017). As a result, there has been a loss of rich biodiversity at an unprecedented rate (Meng et al., 2021). Recent studies have shown that extinction forces operate differently in various ecoregions worldwide based on regional socio-economic, geographical and political factors; though rapid global change triggers new extinction drivers with time (Le Roux et al., 2019). Nevertheless, it is anticipated that main drivers of plant extinctions in hotspots will be anthropogenic including habitat destruction, land-use changes, hydrological disturbance and urbanisation (Le Roux et al., 2019; Bowler et al., 2020). Subtle ecological interactions among species are compromised with the loss of even a single species, which may cascade and cause deterioration of ecosystems and underlying ecological processes thereof (Johnson et al., 2017).

Of the 34 global biodiversity hotspots (Myers et al., 2000), India houses sizeable proportion of four biodiversity hotspots including the Western Ghats, the Himalayas, Indo-Burma and Sundaland (Chitale et al., 2015). The Indian Himalayan Region (IHR) contains nearly 30% of India's total 11 058 endemic flowering plants (Mehta et al., 2020). Despite supporting such a rich biodiversity, the IHR is under tremendous anthropogenic pressure due to over exploitation, urbanisation, invasion of alien species, illegal trade of medicinal and valuable plants, deforestation, developmental activities like roads, dams and environmental pollution. On top of that, the threats of climate change and land-use land-cover changes have significantly exacerbated the biodiversity loss (Roy et al., 2015; Ganie et al., 2019; Mehta et al., 2020).

Medicinal plants are essential forest resources, which are extracted from their natural habitats for ethno-medicinal and pharmaceutical values for local use and trade rather ruthlessly (Tali et al., 2015, 2018). In India, about 90% of medicinally valuable plants are directly collected from natural habitats thereby declining their natural populations (Dawa et al., 2018). These valuable plants are a means of revenue generation for Himalayan dwellers (Olsen & Larson, 2003; Singh et al., 2019) and a source of raw medicine for local healers (Samant et al., 1998; Badola & Aitken, 2003). Overharvesting of these species increases their risk of extinction, as overexploitation and habitat loss make 21% of medicinal plant species to be endangered globally (Schippmann et al., 2006; Chen et al., 2016). Despite several international initiatives such as the «Convention on Biological Diversity» and «Aichi Biodiversity targets» to reduce the biodiversity loss, conservation progress is hampered by huge information gaps about most taxa (Butchart et al., 2010; Shepherd et al., 2016; Johnson et al., 2017).

To conserve the biodiversity, especially of various threatened taxa, a collective effort spanning various dimensions, such as scientific technology, socio-economic aspects, organisational capacity and level of engagement and of course the political will is required both at global and national levels (Heywood, 2017). In this regard, proper knowledge about distribution and threat status of taxa (Sequeira et al., 2018) is the first and foremost requirement. A lack of credible scientific data about the impact of various threats on the plant species distribution constrains the proper conservation of these plants. Prioritisation of taxa for conservation in tandem with extinction risk needs credible knowledge of the specific conservation status of each taxon (Tali et al., 2018). The International Union for Conservation of Nature (IUCN) Red List Categories and Criteria have been developed and modified (IUCN, 2001, 2012b, 2019) to achieve objectivity and transparency in conservation status assessment practice and as such classify species at high extinction risk. Based on that, conservation strategies have been developed (Collen et al., 2016) that help in taking proper decisions and steps for conservation of species in particular, and biodiversity in general (Maron et al., 2012).

Despite the increasing population and a growing demand on natural resources, India has shown a strong interest and care for the safeguarding of its biodiversity. For the conservation of various facets of biodiversity, a number of measures from constitutional, policy and administrative side including Wildlife (Protection) Act, 1972, Indian Forest Act, 1927 and Forest (conservation) Act, 1980, Biological Diversity Act, 2002, The National Green Tribunal Act, 2010 etc. are in place (Rao, 2019). India is also party to different international programmes and conventions like CITES, Man and Biosphere (MAB) of UNESCO, CBD and a global goal of Bonn challenge (Rawal et al., 2021). Being aware of the importance of Himalaya for ecological security of the country, the Government of India places great focus on the Himalayan ecosystems, which are unique but exceedingly fragile. The National Mission on Himalayan Studies (NMHS), a Grant-in-Aid Central Sector (CS) Scheme, aims to focus via holistic understanding of the components of the system and their connections, to solve the primary conservation and sustainable natural resource management challenges in order to increase the quality of life and preserve the regional ecosystems' health in the region (https://nmhsportal.org).

However, in recent times, the natural richness of medicinal flora in the Indian Himalayan region has been facing severe threats from several anthropogenic factors, high dependency of local communities and enhanced climate change (Ganie et al., 2019; Sharma & Sharma, 2019; Rawal et al., 2021). This has triggered extinction of various species and brought a huge figure of medicinal plant species with small natural populations under the threatened category (Tali et al., 2015; Ganie et al., 2019). A total of 456 taxa of the Indian Himalayan region are categorised as threatened under the various threat categories of IUCN (Mehta et al., 2020). The three species selected for the present study (*Trillium govanianum* Wall. ex D.Don, *Rheum tibeticum* Maxim. ex Hook.f., *Arnebia euchroma* (Royle ex Benth.) I.M.Johnst.) have exceptional medicinal and other use-values. But they are yet facing a tremendous pressure of illicit trade together with other natural and anthropogenic threats in the study area. Despite facing a plethora of threats, the conservation status of the target species in this Himalayan region has not been evaluated so far.

The formulation of effective conservation measures requires understanding of the threatened nature of species. In this backdrop, the present study envisaged evaluating the conservation status and overall threat impact (OTI) of these three plant species. The purpose of this study was to investigate two specific questions vis-à-vis these target species including (i) what are the major anthropogenic threats faced and OTI of the target plant species in the study area?; (ii) to which specific IUCN threat category do these target species belong?

Material and Methods

Study area

The Indian Himalayan region stretches to 10 states of India and ranges between 21.7° N and 36.9° N latitude and 72.7° E and 97.5° E longitude. Kashmir Himalaya is a part of the western Himalayan range, covering an area of about 222 235 km^2 (Hussain, 2002). It comprises two union territories of India with three climatic regions: Jammu, Kashmir valley and Ladakh (Romshoo et al., 2020). Kashmir valley is surrounded by lofty mountains of Pir-Panjal in the south and Great Himalayas in the north and east. It is a profound elliptic bowl-shaped valley having an area of 15 948 km^2. Ladakh, surrounded by Karakorum range and Great Himalayas in the north and south, is mostly a Trans-Himalayan land surface with an area of 59 147 km^2. (Fig. 1).

A part of Kashmir Himalaya, including Kashmir valley and Ladakh, which represent the range of the target species, was selected for field surveys. The information about the distribution of the selected plant species and threats associated with each species on the respective localities was collected during the field surveys. Prior to this, the data on taxonomy, distribution and occurrence of the target species were gathered from herbarium specimens at the Herbarium of University of Kashmir (KASH), supplemented with information from e-floras (http://www.efloras.org) and on-line databases such as POWO (https://powo.science.kew.org) and Global Biodiversity Information Facility (GBIF) (https://www.gbif.org). This preliminary information was used for the planning and scheduling the field survey in the study area. Field surveys over 2018–2019 were carried out on a number of occurrence sites in various seasons and with intervals to record the data on selected plant species and evaluate their threat status.

Species evaluated

Three medicinal plant species, *Trillium govanianum*, *Rheum tibeticum*, *Arnebia euchroma* (Fig. 2), were evaluated for the threat assessment. These species are perennial herbs belonging to three plant families, namely Trilliaceae, Polygonaceae and Boraginaceae respectively. The underground part of *T. govanianum* is an important source of trillarin, which upon hydrolysis yields diosgenin (Rathore et al., 2020). It is also traditionally used for the treatment of various ailments including reproductive disorders, cancer, inflammation, hypertension, sepsis, arthritis, giddiness and neurasthenia in the study region and in adjoining areas of the Himalaya (Chauhan et al., 2018). Similarly, *A. euchroma* roots are a rich source of shikonin and its derivatives (Zhang et al., 2018). In addition, it is traditionally used as an antiseptic, antipyretic, anti-inflammatory, cough syrup, to improve hair growth, to treat wound burns, skin disorders, used hair dye, and others (Kumar et al., 2009; Hosseini et al., 2018). The underground part of *R. tibeticum* is used to treat wounds, boils and other skin diseases, as an expectorant and appetizer. The leaves of this species are cooked and used to treat rheumatism, also as a laxative. The distribution and geographical co-ordinates of the sampling sites in the surveyed area are depicted in Fig. 1 and Table 1S, respectively. These three species were assessed in accordance with IUCN Red List Categories and Criteria version 14 (IUCN, 2019) and IUCN Red List criteria on regional level version 4.0 (IUCN, 2012a).

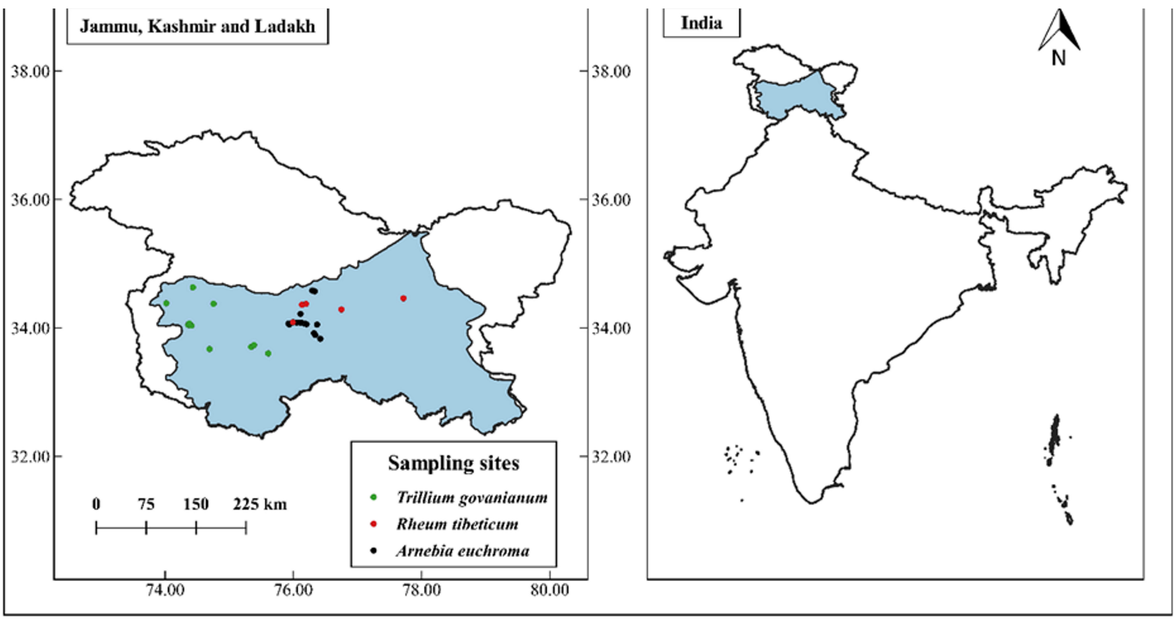

Fig. 1. Map of study area (Kashmir valley and Ladakh region of Western Himalaya) depicting sites of the occurrence of the three target species, namely *Trillium govanianum*, *Rheum tibeticum* and *Arnebia euchroma*.

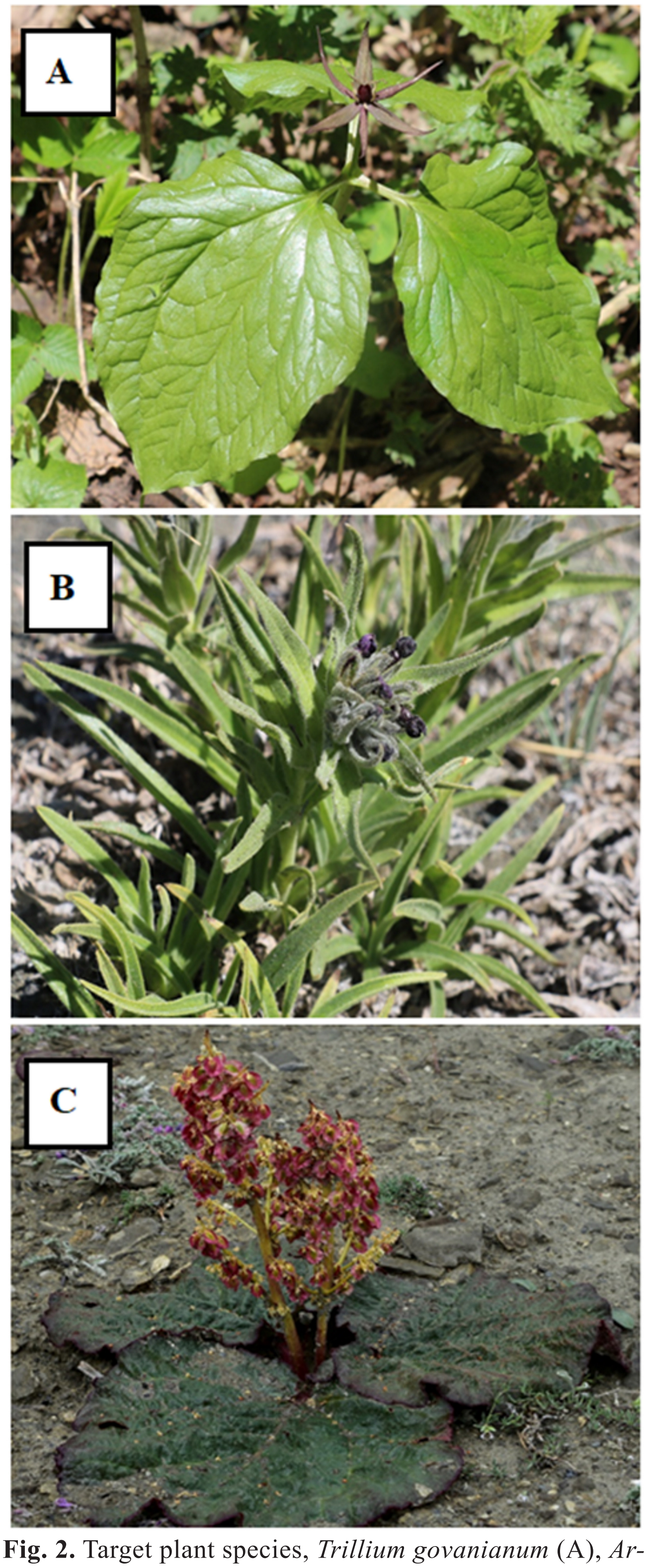

Fig. 2. Target plant species, *Trillium govanianum* (A), *Arnebia euchroma* (B), and *Rheum tibeticum* (C), in their natural habitats in Kashmir and Ladakh regions of the Western Himalaya.

Criteria used for assigning a threat

For threat assessment, data obtained during the field surveys and other sources were prepared in view of the IUCN Red List Categories and Criteria version 14 (IUCN, 2019) and following the regional IUCN guidelines version 4.0 (IUCN, 2012a). For assignment of the threat status to any taxon of the world, the IUCN has defined five criteria (A–E); however, only one criterion A, B, C, D or E should be followed. Only one criterion needs to be met to assign a threatened category (although data should be gathered for as many criteria as possible) and when little or no observed data are available, assessors are encouraged to make use of an estimation, inference, projection and suspicion (IUCN, 2001, 2012b). The five criteria (A–E) of the IUCN extinction risk assessment are based on three parameters: diminution (criteria A and E), geographic range (criterion B) and abundance (criteria C and D) (Le Breton et al., 2019). The present analysis of risk assessment was carried out by following criteria B, i.e. geographic range of IUCN Red List Categories and Criteria. According to criterion B, a geographic range should be in the form of either B1 (Extent of Occurrence; hereinafter – EOO) or B2 (Area of Occupancy; hereinafter – AOO) and a taxon should also follow two of the three (a, b and c) conditions (Table 1).

A decline in the number of mature individuals was recorded during the field survey in two consecutive years (2018–2019) on most of the study sites. Besides field surveys, research papers and other reports were used to record the population status of the species. For example, Chauhan et al. (2018) reported the overexploitation and grazing of *Trillium govanianum* from some areas of Himachal Pradesh and Uttarakhand resulting in a decline and disappearance of some of its populations. Similarly, Singh et al. (2012) reported ruthless extraction of *Arnebia euchroma* roots by local residents from the Western Himalaya for various purposes resulting in habitat degradation and a decline in the population density of the plant.

Data collection

To evaluate the threat status of a species, its population size, threats, geographic range parameters, i.e. EOO and AOO, were calculated according IUCN Red List guidelines (IUCN, 2001). On each site, the whole population was monitored to know the habitat type, operative threats and the decline in the number of mature individuals by following Ali & Qaiser (2010) and Tali et al. (2015), i.e. based on visual/physical observations. Besides, the information about the dynamics of a population or threats faced by the plants in areas, where field surveys could not be conducted (i.e., extent areas of target species outside Ladakh and Kashmir valley), was gathered from the literature surveys, including research papers (Dhyani et al., 2020; Lal et al., 2020).

Table 1. Summary of criterion B of the IUCN Red List Categories and Criteria (IUCN, 2019) used to evaluate if a taxon belongs to any threat category (Critically Endangered, Endangered and Vulnerable)

Geographic range in the form of either B1 (extent of occurrence) and/ or B2 (area of occupancy)			
	Critically Endangered (CR)	Endangered (EN)	Vulnerable (VU)
B1 Extent of Occurrence	< 100 km^2	< 5000 km^2	< 20 000 km^2
B2 Area of Occupancy	< 10 km^2	< 500 km^2	< 2000 km^2
and at least two of the following three (a, b, c) conditions			
(a) severely fragmented or number of locations	= 1	≤ 5	≤ 10
(b) Continuing decline observed, estimated, inferred, or projected in any of (i) EOO; (ii) AOO area; (iii) extent and or quality of habitat; (iv) number of locations or subpopulations (v) number of mature individuals.			
(c) Extreme fluctuations in any of (i) EOO; (ii) AOO; (iii) number of locations or subpopulations; (iv) number of mature individuals.			

Note: EOO – Extent of Occurrence, AOO – Area of Occupancy.

The field survey data were supplemented with records of the target plant species obtained from various sources including the on-line sources GBIF database (http://www.gbif.org), ENVIS (Environmental Information System), Centre on Medicinal Plants (http://envis.frlht.org/frlhtenvis.nic.in) and herbarium records from CAL, BSD, DD and KASH, published research articles including Dhyani et al. (2020), Lal et al. (2020). The occurrence data from all sources were then used to calculate the parameters for an assessment of the threat status of the target plant species.

Calculation of geographic range parameters

The R software package «Con R» (Dauby et al., 2017) was used for calculation of various parameters (EOO, AOO) of criterion B in the IUCN risk assessment for estimating the threat category of the target plants. EOO is a polygon that is drawn to include all the known locations and/or occurrences of a species and AOO is the total occupied area index, computed by summarising areas of standard size (2 × 2 km) grid cells (Bland et al., 2017; IUCN, 2019).

Location and sub-population

The term «location» indicates a distinct geographical or ecological area where a single threatening event has potential to quickly influence all members of the taxon present (IUCN, 2001; Rivers et al., 2010; Dauby et al., 2017). Whereas sub-population is defined as a spatially distinct segment of the global population that experiences low or reproductively unsuccessful migration (of seeds or pollen) from other sub-populations. (IUCN, 2012b; Dauby et al., 2017). A location may comprise single or many sub-populations depending on the area affected by the threatening event (IUCN, 2012b; Dauby et al., 2017).

In «ConR» package, the circular buffer method and a fixed or sliding grid approach are used for estimation of the number of sub-populations and locations respectively. In the circular buffer approach, each site is encircled by a given radius and those circles, which overlap forms a single sub-population (Dauby et al., 2017). The circular buffer method gives as estimation of the subpopulation number (Rivers et al., 2010) and may be higher or lower when the dispersal ability of a species is taken into consideration. In the fixed or sliding grid approach, the cell grid is laid over the whole taxon distribution in a way that gives a minimum count of the estimated locations (Dauby et al., 2017).

During the present study, each unique occurrence was buffered with a circle of 5-km radius and overlaid with a 10-km size of grid cells for the estimation of a sub-population and location respectively. The output results of various calculated and estimated/approximated parameters are then visualised along with the threat assignment and distribution map.

Estimation of overall threat impact

To determine the actual and potential threats to the natural population(s) of the target plant species in the study area, extensive field surveys were conducted. The OTI indicates the degree to which a species is observed, inferred, or suspected to be directly or indirectly threatened in the area of interest (globe, national, regional) (Salafsky et al., 2008). The observed threats are defined as «the proximate (human) activities or processes that have caused, are causing, or may cause the destruction, degradation, and/or impairment of biodiversity and natural processes» (Salafsky et al., 2008). In the present study, the «Impact»/«Magnitude» has been calculated from the «scope» and «severity» according to Master et al. (2012) and Ganie et al. (2019) (Electronic Supplement).

Results

Species distribution

Distribution data of the target species were collected from field surveys conducted in two consecutive years (2018 and 2019), from 36 sites over the geographical range of the Indian Himalaya encompassing the regions of Kashmir Himalaya and Trans-Himalayan Ladakh. The field survey data were augmented with herbarium records and various online data sources to include the presence data for estimation of the EOO and AOO of each species from other regions of Indian Himalaya. During this study, the plant species were investigated in various habitats with varying altitudinal range in the Kashmir and Ladakh regions. We found that *Trillium govanianum* grows in the moist, sub-alpine forests with a good content of humus in the Kashmir Himalaya, at an altitude range from 2264 m a.s.l (Sheikhpora Anantnag) to 2887 m a.s.l. (Doodhpathri). *Arnebia euchroma* grows in the alpine, open, dry, stony, and steeper region with an altitude range from 3214 m a.s.l. (Karpokhar, Kargil) to 4453 m a.s.l. (Drung Drung glacier). *Rheum tibeticum* was found in alpine, rocky, open, dry, and steeper regions with an altitudinal range from 3628 m a.s.l. (Parkachik, Kargil) to 4370 m a.s.l. (Sapi La, Kargil) in the Ladakh region of the Trans-Himalayas (Table 1S).

Operative threats and overall threat impact

During the course of field survey, the major operative threats in the natural habitats for the sampled species include overexploitation, overgrazing, illicit trade, invasion, construction activities, uncontrolled tourism, deforestation, landslides, and others (Table 2). The intensity and the impact of these threats varied on various locations having various levels of scope, severity and impact, affecting target plants and their habitats. For *Trillium govanianum* a total of ten threats were found in its natural habitat of all surveyed areas, though the number of operative threats varies from site to site. A maximum of eight threats were found on the sites «Khilanmarg Gulmarg» and «Drung» and a minimum number (three threats) was found on the site of «Sheikhpora Anantnag» (Table 2). Overgrazing is the major operative threat to *T. govanianum* followed by deforestation, overexploitation and road construction in the Kashmir Himalaya (Table 2). The OTI of *T. govanianum* varied from «High» to «Very high» on various study sites (Table 3, Table 3S). The number of mature individuals was 8270 in 2018 and 7661 in 2019. The decline in the percentage of mature individuals was profound with a decline of 7.4% mature individuals per year.

For *Arnebia euchroma* the eight major operative threats include land-use change, overgrazing, landslides, overexploitation for local use, constructional activities in natural habitat, underground fibre line transmission for telecommunication, road construction, and unmanaged tourism. The highest number of threats (five) was found on the site of «Zulidok» and the lowest (two) on the sites of «Rungdum», and «Drung Drung glacier». Overgrazing, overexploitation, road construction and landslides were among the major threats followed by constructional activities in natural habitat and unregulated tourism (Table 2). The OTI of this plant species is «High» in all studied habitats except for «Rungdum Gompa» and «Nun Kun glacier» where the OTI for the species was «Low» and «Medium» overall threat rank, respectively (Table 3, Table 3S). For *Arnebia euchroma* 7735 mature individuals were recorded in 2018 and 7508 mature individuals in 2019. A decrease of 2.9% mature individuals was found in all unique occurrences of Ladakh in a period of one year.

For *Rheum tibeticum* the total number of operative threats in the study area was seven threats. They include overgrazing, landslides, overexploitation for local use, illicit trade, road construction, constructional activities and unmanaged tourism. All seven threats were operative in «Parkachi-Kargil» and a minimum of threats (three) in «Khalsar Nubra» (Table 2). Landslides, unmanaged tourism, overgrazing and road constructions were major operative threats for this plant species in the study area (Fig. 3). The OTI of *R. tibeticum* is «Very high» in all studied habitats (Table 3, Table 3S). A total of 4603 mature individuals of *R. tibeticum* were found in 2018 while only 4433 mature individuals were found in 2019. A decrease of 3.7% in mature individuals was found between 2018–2019.

Table 2. Occurrence parameters and operative threats to the selected plant species (*Trillium govanianum*, *Arnebia euchroma*, and *Rheum tibeticum*) in Kashmir valley and Ladakh of Indian Himalayan region

Taxa	Occurrence sites	Population size (number of mature individuals) Year		Threats
		2018	2019	
Trillium govanianum	Ferozpora Tangmarg	477	429	Overgrazing, deforestation, overexploitation for local use, landslides, invasion
	Drung	309	302	Overgrazing, deforestation, overexploitation for local use, landslides, unmanaged tourism, construction activities in natural area, road construction, invasion
	Khilanmarg Gulmarg	1796	1773	Overgrazing, unmanaged tourism, deforestation, overexploitation for local use, construction activities in natural areas, forest fires, invasion, road construction
	Near cantonment	158	138	Overgrazing, unmanaged tourism, illicit trade, landslides, road construction, constructional activities in natural areas
	Alupathri	1043	1012	Unmanaged tourism, deforestation, over exploitation for local use, landslides
	Sheikhpora Anantnag	63	60	Overexploitation for local use, illicit trade, overgrazing
	Patherebal Anantnag	149	111	Overexploitation for local use, illicit trade, overgrazing, deforestation
	Sirinder Bandipora	156	124	Overgrazing, road construction, illicit trade, deforestation, invasion
	Doodhpathri	712	655	Unmanaged tourism, landslides, overgrazing, illicit trade, invasion
	Hirpora shupian	2003	1941	Overgrazing, road construction, invasion, deforestation, over exploitation for local use
	Bungus valley	547	470	Deforestation, road construction, landslides, illicit trade, invasion
	Machil kupawara	271	254	Landslides, overgrazing, road construction, invasion
	Daksum	586	392	Overgrazing, road construction, deforestation, unmanaged tourism, overexploitation for local use, illicit trade
	TOTAL	8270	7661	
Arnebia euchroma	Karpokhar Kargil	202	180	Overgrazing, overexploitation for local use, construction activities in natural areas, landslides
	Sanko Bridge Kargil	153	133	Overgrazing, overexploitation for local use, construction activities in natural areas, landslides
	Parkachi Kargil	167	160	Unmanaged tourism, overgrazing, overexploitation for local use, road construction
	Humbuting La I	246	222	Overgrazing, overexploitation for local use, landslides, road construction, construction activities in natural areas, flash floods
	Himbuting La II	221	217	Overgrazing, overexploitation for local use, landslides, road construction, constructional activities in natural areas
	Lalung La Kargil	578	550	Road construction, overexploitation for local use, landslides, flash floods constructional activities in natural areas, overgrazing
	Changyoul Sapi	1287	1302	Overgrazing, road construction, overexploitation for local use, constructional activities in natural areas, unmanaged tourism
	Tangoli	543	523	Overgrazing, landslides, unmanaged tourism, overexploitation for local use
	Nun Kun glacier	182	174	Road construction, overgrazing, unmanaged tourism, constructional activities
	Suru valley	232	212	Road construction, overgrazing, unmanaged tourism, landslides, overexploitation for local use
	Gulmatungo	578	543	Land use change, overgrazing, overexploitation for local use, road construction
	Zulidok	189	175	Land use change, overgrazing, landslides, overexploitation for local use, constructional activities in natural habitat
	Rungdum	198	205	Road construction, landslides
	Rungdum Gompa	1276	1287	Landslides, overexploitation for local use, transmission of fibre lines
	Panzila	1372	1321	Road construction, overgrazing, landslides, transmission of fibre lines
	Drung Drung glacier	177	174	Road construction, transmission of fibre lines
	Aksho	134	130	Transmission of fibre lines, overgrazing, landslides
	TOTAL	7735	7508	
Rheum tibeticum	Shishithang Kargil	2966	2894	Overgrazing, landslides, unmanaged tourism, road construction
	Sapi La Kargil	876	821	Overgrazing, road construction, unmanaged tourism, landslides, overexploitation for local use
	Changyoul Sapi	58	50	Overgrazing, road construction, unmanaged tourism, landslides, overexploitation for local use
	Parkachi Kargil	52	32	Overgrazing, landslides, overexploitation for local use, illicit trade, road construction, constructional activities, unmanaged tourism
	Lamayuru	634	628	Landslides, overgrazing, unmanaged tourism, road construction, constructional activities
	Khalsar Nubra	17	8	Road construction, unmanaged tourism, landslides
	TOTAL	4603	4433	

Table 3. Overall threat impact for three target plant species (*Trillium govanianum*, *Rheum tibeticum*, *Arnebia euchroma*) in Kashmir Valley and Ladakh region of the Western Himalaya

Taxa	Occurrence sites	Overall threat
Trillium govanianum	Ferozpora Tangmarg	Very high
	Drung	Very high
	Khilanmarg Gulmarg	High
	Near cantonment	High
	Alupathri	High
	Sheikhpora Anantnag	High
	Patherebal Anantnag	High
	Sirinder Bandipora	High
	Doodhpathri	Very high
	Hirpora shupian	High
	Bungus valley	High
	Machil kupawara	High
	Daksum	Very high
Rheum tibeticum	Shishithang Kargil	High
	Sapi La Kargil	Medium
	Changyoul Sapi	Medium
	Parkachi Kargil	High
	Lamayuru	Very high
	Khalsar Nubra	High
Arnebia euchroma	Karpokhar Kargil	High
	Sanko Bridge Kargil	High
	Parkachi Kargil	High
	Humbuting La I	High
	Himbuting La II	High
	Lalung La Kargil	High
	Changyoul Sapi	High
	Tangoli	High
	Nun Kun glacier	Medium
	Suru valley	High
	Gulmatungo	High
	Zulidok	High
	Rungdum	High
	Rungdum Gompa	Low
	Panzila	High
	Drung Drung glacier	High
	Aksho	High

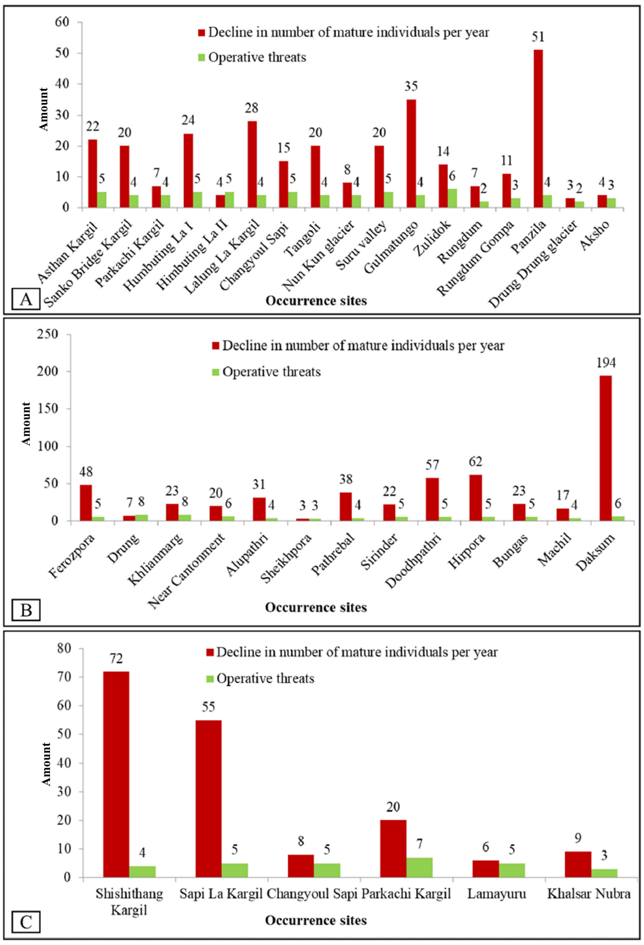

Fig. 3. Number of operative threats and number of mature individuals decline between 2018 and 2019 on various occurrence sites in the number of target plant species in Kashmir Valley and Ladakh of the Western Himalaya. Designations: A – *Arnebia euchroma*, B – *Trillium govanianum*, C – *Rheum tibeticum*.

Threat assessment

During the field survey, a note on potential threats, decline/fluctuation in the number of reproductive/flowering/fruiting individuals were recorded for the target plant species (Table 2). The number of unique occurrences, sub-populations and locations for *Trillium govanianum* turned out to be 72, 47 and 53 respectively, and for *Arnebia euchroma* a total of 200 unique occurrences, 87 sub-populations and 135 locations were calculated. For *Rheum tibeticum* 78 unique occurrences with 40 sub-populations and 55 locations were counted. Based on calculations in the ConR package, the EOO and AOO were respectively 106 338 km^2 and 248 km^2 for *T. govanianum* (Fig. 4A); for *Arnebia euchroma*, the calculated EOO and AOO were respectively 221 329 km^2 and 760 km^2 (Fig. 4B). Finally, the EOO and AOO of *Rheum tibeticum* were respectively 158 429 km^2 and 284 km^2 (Fig. 4C).

For *Trillium govanianum* the number of mature individuals was found to be 8270 in 2018 and 7661 in 2019. The decline in the percentage of mature individuals was profound with a decline of 7.4% mature individuals between 2018 and 2019. For *Arnebia euchroma*, a total of 7735 mature individuals were recorded in 2018 and 7508 in 2019. A total decrease of 2.9% mature individuals was found over one year. A total of 4603 mature individuals of *Rheum tibeticum* were found in 2018 while it was only 4433 individuals in 2019. A decrease of 3.7% mature individuals was found between 2018 and 2019. Based on an analysis using the ConR package and observations made during field study (with a resolution of 10 km^2), a difference in number of locations was noticed.

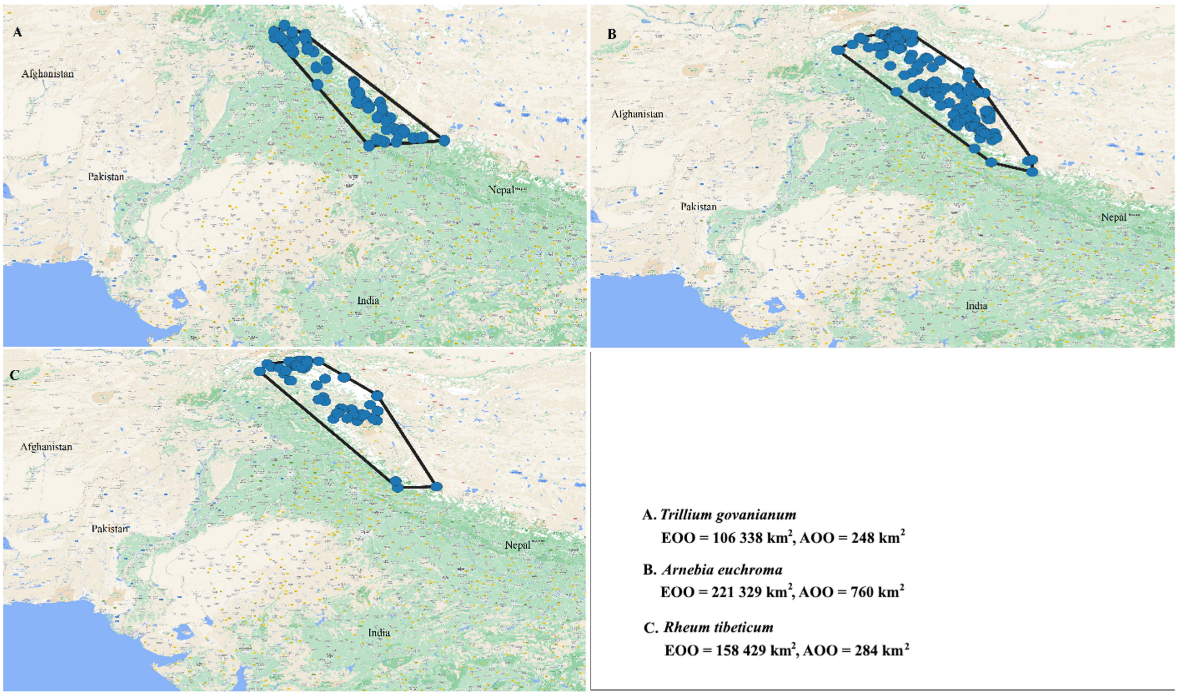

Fig. 4. Occurrence sites of the studied species in the Western Himalaya are shown as blue dots. The convex hull used for calculating the EOO is shown for each species as a black polygon. Designations: A – *Trillium govanianum*, B – *Arnebia euchroma*, C – *Rheum tibeticum*.

Each of the three evaluated species turns out to be ineligible for any threatened category, i.e. «Critically Endangered», «Endangered» or «Vulnerable» as the needful criteria for eligibility in a threatened category do not apply for these species in the current study. However, the three studied species qualify for the IUCN category «Near Threatened» as the taxon meets the area requirements under criterion B for threatened (AOO < 2000 km^2) (Fig. 4), while they are declining, no severe fragmentation of population, and occurring in more than 10 locations with no serious fluctuations (Table 4). This is in agreement with IUCN Red List categories and criteria, i.e. a species should be classified as «Near Threatened» if it is close to be qualified as «threatened» or is likely to qualify for it in the near future (IUCN, 2019). The IUCN (2019) states that a species should be classified as «Near Threatened» if they are close to qualifying as threatened or are likely to qualify for it in the near future.

Discussion

Fair assessment of the species threat status through globally standardised procedures is fundamental for devising the appropriate conservation strategies. One of the key findings of the present study was that the OTI of the target species of plants vary from «High» to «Very high» that underscores the need for their conservation. These important medicinal plant species assume even more special significance for conservation and criteria used for assessing the conservation priorities are receiving an increasing attention globally (Schmeller et al., 2008; Gauthier et al., 2010). In fact, such species are given the highest priority to maximise the benefits of conservation related investment (Ganie et al., 2019).

Table 4. Occurrence sites, population size, EOO, AOO and threat status of the target plant species (*Trillium govanianum*, *Rheum tibeticum*, *Arnebia euchroma*) in the Western Himalaya

Taxa	EOO (km^2)	AOO (km^2)	No. of unique occurrences	No. of sub-populations	Locations	Category Criteria B
Arnebia euchroma	221 329	760	200	87	135	Near Threatened
Rheum tibeticum	158 429	284	78	40	55	Near Threatened
Trillium govanianum	106 338	248	72	47	53	Near Threatened

Note: EOO – Extent of Occurrence, AOO – Area of Occupancy.

The threats emanating from varied anthropogenic pressures, such as land use change, overexploitation for local use, habitat fragmentation and others, if not stopped or reversed, would push the species to the brink of extinction. Whilst the three target species (*Trillium govanianum*, *Rheum tibeticum*, *Arnebia euchroma*) exhibit a relatively wider geographic distribution in terms of EOO, they occupy highly specific habitats comprising a very small AOO. A small geographical range size is one of the strongest clues for predicting the threat of extirpation/extinction of a particular species in its natural habitat (Gaston & Fuller, 2009; Staude et al., 2020). The decrease in population size of species with a small geographical range size makes them more vulnerable to stochastic events (Christiansen & Fenchel, 2012; Robles & Ciudad, 2012). The range size plays a key role in the species categorisation according to their short-term likelihood of extinction, including listing on the IUCN Red List of threatened species. Thus, it contributes significantly to indices of global trends in threat status and to the prioritisation of species for conservation (Baillie et al., 2004). The collection of these medicinally important plant species for local use and overharvesting for trade purposes, besides other threats without any cultivation practice in the surveyed areas, adds to their risk of vulnerability to local extinction to a greater extent. Statements of the local healers to the authors substantiated this during field surveys that today they need far more time and effort to travel the distance for collection of the species as compared to what it would take some years before. A similar sort of observation was made by Chauhan et al. (2018) in case of *T. govanianum* thereby vindicating the existence of this threat a few years before too.

Regardless of the potential of *Arnebia euchroma* to grow over a larger area, it has a small population size because of the high anthropogenic pressure (Singh et al., 2017). In the present study, it was observed that this species is overexploited for local use, particularly in Ladakh region where people collect its roots and use it as a hair dye, besides using it for other medicinal purposes, such as treatment of skin and chest diseases. In addition to sexual reproduction through seeds this plant species mainly reproduces vegetatively by means of stout roots. The clonal reproduction tends to increase with altitude particularly by underground perennating organs like rhizomes and roots. The vegetative organs are safe in extremely hostile habitats such as alpines (Ganie et al., 2017). The overexploitation of roots (perennating organs) for local use has reduced the population size of this plant species in the study area. Harvesting roots also affects the seed set to a large extent as plants are collected in natural populations before seed set (Manjkhola et al., 2005). Overexploitation for local uses is one of the major threats in this Himalayan region (Ganie et al., 2019). Excessive and unchecked exploitation are the main cause of depletion of economically important medicinal plants in Kashmir Himalaya (Tali et al., 2015).

Similarly, the population size of *Trillium govanianum* has reduced drastically due to overexploitation as a raw material for pharmaceutical industries (Vidyarthi et al., 2013). The collection of plant species from natural population ruthlessly without following any scientific methods will render most of the medicinal plant species threatened. Chauhan et al. (2018) also reported that *T. govanianum* is at risk of local extinction in the Indian Himalayan region because of unselective, unmanaged and unsustainable collection and and increased market demand for the rhizomes. Ganie et al. (2019) also reported that illicit trade of various medicinal herbs has accelerated recently and is one of the major threats to these plant species. The excessive collection of these species for smuggling has rendered them at the brink of extinction (Tali et al., 2015).

Rheum tibeticum and *Arnebia euchroma* face the anthropogenic threats emanating largely from road construction and laying underground fibre line transmission for telecommunication in Ladakh, in addition to the other natural threats (e.g. landslides and flash floods). We found that these two anthropogenic threats drastically reduce the number of individuals and population size of plant species in the study area. It has been observed that unplanned development and constructional activities pose more serious threats as compared to natural threats. That is why in some areas, where more natural threats are operative, the decline in number of individuals was found to be lesser in comparison to populations/sub-populations where anthropogenic disturbances due to economic development activities were going on. Direct and/or indirect anthropogenic activities threaten around two-thirds of the Italian endemic species

(Orsenigo et al., 2018). Similarly, human activities are reported as main threats to the Mediterranean biome (Underwood et al., 2009) and growing pressure on habitats of the flora of Mozambique (Darbyshire et al., 2019) are mainly emanating from human endeavours. Reid et al. (2019) reported various new and diverse anthropogenic threats mainly affecting freshwater ecosystems in the world. The effect of construction activities like the cable car gondola and road construction in natural habitats have affected the natural populations and habitat of various medicinal plants (Tali et al., 2015). The development of road connectivity to inaccessible areas and recognition of new tourist sites in the Himalayan region has led to the inflow of people, especially tourists, in the natural areas that has influenced the biodiversity of these plants to a great extent (Ganie et al., 2019).

Overall, our data revealed that all the three target plant species are Near Threatened. However, in the study area, these species have a much lower number of populations and sub-populations, which are distributed in the areas beset with various types of threats, both natural and anthropogenic. If these human-driven perilous factors continue to prevail, these species may become threatened in the near future. To focus conservation attention at a regional scale, it becomes necessary to prioritise those species for which the studied region represents its natural distribution range (Butt et al., 2020). Keeping in view the huge operative threats in the study area, the investigation has wide relevance in devising successful conservation strategies for these important medicinal plant species in the vulnerable habitats of the Himalaya.

Conclusions

The practice of labelling species as rare or threatened on rather arbitrary grounds hampers appropriate policy interventions for conservation. This study demonstrates how important the conservation assessment and OTI are in accordance with the latest IUCN Red List regional guidelines and NatureServe Conservation Status Assessments to precisely determine the species status. Following these criteria, using three medicinally important Himalayan plant species, our findings reveal the conservation status of all the three evaluated species to be «Near Threatened». These results also underscore the importance of assessment of the precise threat status and OTI at regional, national and global level to correctly identify plant species that merit immediate conservation and policy intervention. Having identified a myriad of operative threats that contribute to the rareness of these species in the studied Himalayan region, the results clearly indicate that if appropriate conservation strategies are not developed and implemented, not only these prized plant species but also many other similar species may become threatened in the near future and eventually go extinct. We call for the global conservation community to join the IUCN's «reversing the red» campaign to bring such threatened species back from the brink of extirpation and extinction.

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Supporting Information

The description of the studied sites and the guidelines of OTI estimation for *Trillium govanianum*, *Rheum tibeticum*, and *Arnebia euchroma* (Electronic Supplement. Collection sites of target plants with co-ordinates and guidelines for assessment of overall threat impact) may be found in the **Supporting Information**.

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СТАТУС УГРОЗЫ ИСЧЕЗНОВЕНИЯ ТРЕХ ВАЖНЫХ ЛЕКАРСТВЕННЫХ РАСТЕНИЙ ГИМАЛАЕВ И ПРЕДЛОЖЕНИЯ ПО ИХ СОХРАНЕНИЮ

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Отсутствие точной информации о статусе угрозы исчезновения вида препятствует его эффективному сохранению. Задача №2 Конвенции о биологическом разнообразии призывает к оценке статуса угрозы исчезновения на глобальном, национальном и региональном уровнях для выявления видов, представляющих неотложную проблему сохранения. В данной статье мы эмпирически оценили статус угрозы исчезновения трех ценных лекарственных видов растений (*Trillium govanianum*, *Rheum tibeticum* и *Arnebia euchroma*) посредством обширных полевых исследований и анализа гербарного материала в Кашмирских Гималаях и в Ладакхе, холодном пустынном регионе Транс-Гималаев. В соответствии с категориями и критериями Красного списка МСОП все целевые растения были оценены как виды, находящиеся в состоянии близком к угрожаемому (Near Threatened). Согласно оценке природоохранного статуса NatureServe, для каждого из этих видов общее влияние угроз было оценено от «Высокого» до «Очень высокого». Мы обнаружили, что антропогенные угрозы, исходящие от незапланированного экономического развития, строительства дорог и других проектов, связанных с инфраструктурой, способствуют быстрому сокращению естественных популяций этих трех видов. Принимая во внимание ценность этих видов с одной стороны, и растущие угрозы их исчезновению в дикой природе с другой стороны, мы призываем к срочным стратегиям их сохранения в уязвимых местах обитания в Гималаях на пути регионального социально-экономического развития.

Ключевые слова: *Arnebia euchroma*, *Rheum tibeticum*, *Trillium govanianum*, Кашмирские Гималаи, находящийся в состоянии близком к угрожаемому таксон, общее влияние угроз, оценка угрозы исчезновения, Транс-Гималаи