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ASSESSMENT OF THE CURRENT CONDITION OF POPULATIONS OF THE RED LIST SPECIES *Salvia submutica* BOTSCH. & VVED. (LAMIACEAE LINDL.) IN NURATAU MOUNTAIN RIDGE, UZBEKISTAN

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Abstract

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The high-mountain ecosystems of Central Asia consist of very rich biodiversity with unique plant communities and many endemic species. High human pressure and long drought periods due to global warming have caused habitat destruction in these areas and a parallel increase in the number of endangered species. In Uzbekistan, the number of red listed plant species has risen in the last 30 years, from 163 in 1984 to 324 in 2009. Among those red-listed species are 23 species in the Lamiaceae family. The aim of this study was to estimate the current populations of red-listed species *Salvia submutica*. This species is endemic to the Nuratau ridge, and it is growing under climatic changes and human pressure. We found two populations of this species in the Nuratau ridge. For each population, we measured the plant density and determined the population spectrum. We also describe the plant community where each population grew. At all sites, the population density was low, with most populations being classified as mature with centered ontogenetic structure. These results indicated this species might, in the near future, become extinct in the wild.

Key words: climate change, human pressure, population, *Salvia.*

Introduction

Ineffective use of plant resources for human welfare has resulted in the loss of plant biodiversity worldwide (World Conservation and Monitoring Centre, 1992; IPCC, 2001). In terms of biodiversity, the highest mountain ecosystems of Central Asia link to the most utility areas in the world called hotspots (Mittermeier et al., 2004). A high level of endemism in mountains is linked to environmental conditions such as geological structure, high mountain ranges, and climatic conditions. Threats to the biodiversity of Central Asia have been recognized since the middle of the 20th century (Zakirov, 1955). Global warming is likely to drive loss of vegetation cover (Ehleringer et al., 1997). Scenarios' climate change is expected to become more extreme and with longer drought periods (Connor, Hawkes, 2018). "The Millennium Ecosystem Assessment estimates a global reduction of vascular plant biodiversity of between 13 and 19%, between 1970 and 2050, and a reduction of between 7 and 9%, from 2000 to 2050 has also been predicted" (Alkemade et al., 2009).

According to the International Union for Conservation of Nature IUCN Red List update in 2008, over 900 species have gone extinct since 1500 (http://www.iucnredlist.org) including many vertebrates, invertebrates, and plants. In parallel, the number of endangered species has increased. In combination with global warming-related changes in climatic conditions, these developments have also affected the flora of Uzbekistan, with the number of Red List plant species having almost doubled in the last 30 years: from 163 in 1984 to 324 in 2009. Indeed, these ecosystems are exposed to intense human pressure, such as roads being used by shepherds and hunters, in geological test for mining, and also used by intensively developed oil and gas industry, which has caused habitat destruction (Shomurodov et al., 2014, 2015). Currently, global climatic change is reducing the vegetation cover of many subregions, for example, the Tian Shan mountains (Dimeyeva et al., 2015). Long-term drought periods cause higher risk to endangered species (Akhmedov et al., 2021).

Lamiaceae, a family with a cosmopolitan distribution, has 236 genera with 6900–7200 species (Harley et al., 2004). Lamiaceae comprises 201 species in 41 genera in the flora of Uzbekistan (Vvedensky, 1961). Mint family (Lamiaceae) has some economic value. For example, *Lagochilus leiacanthus* is a folk medicine

Table 1. Site characteristics of *Salvia submutica*.

Population number	MAP (mm yr^{-1})	MAT (°C)	Soil	Landscape	Latitude/N	Longitude/E	Elevation (m a.s.l.)
1	203	15.1	Gray-brown, sandy, and brown	Mountain	40°32´12.2˝	66°33´14.3˝	1480
2	206	13.3	Stony-gravelly, gray-brown	Mountain	40°50´43.4˝	66°96´017˝	1835

Notes: MAP – mean annual precipitation; MAT – mean annual temperature.

used for treatment of inflammation and ulcer in Xinjiang, China. In Japan, this species has been studied for two new flavanones (Furukawa et al., 2011), *L. setulosus* contains sugar and some chemical compounds (Akramov et al., 2021) and the genus *Salvia* is economically the most important from Lamiaceae family. The genus is an economically important of the Lamiaceae family. For instance, *Salvia miltiorrhiza,* endemic to China, is a traditional Chinese medicine that is widely used to treat cardiovascular and cerebrovascular diseases and hyperlipidemia (Wang, 2010). The genus *Salvia* comprises approximately 1000 species worldwide (Alziar, 1988; Walker et al., 2004; Wei et al., 2015; Drew et al., 2017; Will, Classen-Bockhoff, 2017). In the flora of Uzbekistan, the genus *Salvia* is represented by 16 species (Vvedensky, 1961). *S. submutica* and another five *Salvia* species are included in the Red Book of the Republic of Uzbekistan (2009). *S. submutica* grows in Nuratau Mountain only. Populations studies are so important for the estimation and conservation of rare species (Rakhimova et al., 2021, Saribaeva et al., 2022).

The aim of this study is to estimate the current conditions of populations of this focal species.

Material and methods

Study site and climate

The research was conducted in the Nuratau ridge. The Nuratau ridge is located at the north-western edge of the Pamir-Alai mountain range. The genus *Salvia* L. is distributed widely, and *S. submutica* grows in the Nuratau Mountain only (Fig. 1). The climate of this site is Mediterranean, the mean annual temperature is 13.3 °C, and the mean annual rainfall exceeds 206 mm (Figs 2, 3; Table 1). Soil is gray-brown, sandy, and brown (Zakirov, 1971). The Nuratau ridge includes several mountains (Nuratau, Koytash, Gubdintau, Karachatau, Aktau, and Karatau) and is located at the north-western edge of the Pamir-Alai mountain range. The highest point in Nuratau reaches 2169 m above the sea level (a.s.l.). Long-term meteorological data are not available in Uzbekistan. Thus, the mean monthly precipitation and temperature data were obtained from the Climatic Research Unit (CRU) TS3.10 datasets (Harris et al., 2014) for each site.

Study species

This study focuses on the red list species *S. submutica.* This species is endemic to the Nuratau. *S. submutica* is a polycarpic perennial of height 15–20 cm (Fig. 4). It blooms in June, fruiting in July and August. This species mainly reproduces by seeds, but has a low germination rate, rapid transition to flowering, and slow development of individuals (Vvedensky, 1961).

Fig. 1. Location of populations with taxonomy of this focal species.

The geobotanical description of selected plant communities within populations of *S. submutica* was made according to conventional geobotanical methods. We described the plant community and then inventoried all plant species occurring in one randomly selected 25×25 m plot. Unidentified plant species were collected for identification. Total vegetation cover was estimated in each plot using the method developed by Braun-Blanquet (1965), where each species cover was assessed based on cover classes (0–5, 5–25, 25–50, 50–75, and 95–100%). Plant taxonomy and the life form of plants were described as trees, shrubs, semi-shrubs, dwarf-shrubs, and herbs (perennial, biennial, and annual) according to the plants of the world online (POWO) datasets (www.plantsoftheworldonline.org). For each site, we estimated the following environmental variables: aspect, slope, distance to water, annual precipitation, and anthropogenic factors. Aspect was measured using Global Positioning System (GPS; Garmin 62; Garmin Ltd., Olathe, KA, USA) and slope was visually estimated.

Population structure measurements

Assessment of population structure was carried out using population traits (Zaugolnova, 1994). At each of the sites, we set out three transects, starting from a common random point. From this point, one transect was established to the north, one to the south, and one to the east. Each transect was 1 m wide and 10 m long and was subdivided into 10 squares of 1 m^2. In each of the squares, the number of individuals in each ontogenetic stage was counted (s – seedlings, j – juvenile, im – immature, v – virginile, g1 – young generative, g2 – mature generative, g3 – old generative, ss – subsenile, s – senile) (Rabotnov, 1950; Uranov, 1975; Coenopopulations, 1976). The ontogenetic spectrum of the population was then determined according to the standard meth-

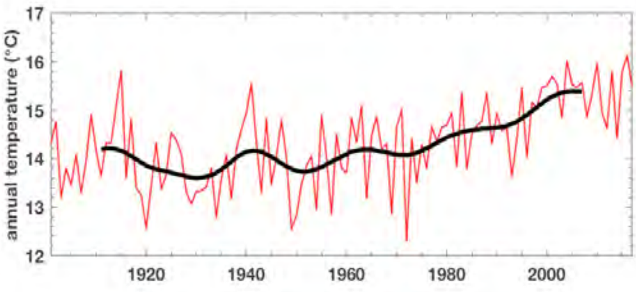

Fig. 2. Annual temperature (°C) of the site.

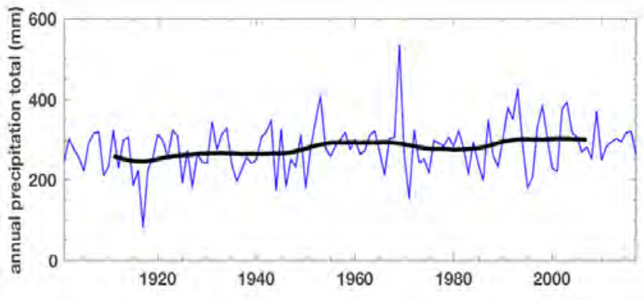

Fig. 3. Annual precipitation (mm) of the site.

Fig. 4. *Salvia submutica*: (left) general view, (right) flower detail (June 2019, Photo: A. Akhmedov).

Table 2. Types of ontogenetic spectra.

No.	Ontogenetic spectrum	Ontogenetic stages	Dominated by
1.	Left sided	j, im, v, and g1	Regenerative and generative stages
2.	Bimodal	j, im with g2 or g3	Regenerative, generative, or post-generative
3.	Centered	g2	Generative
4.	Right sided	g3, ss, and s	Generative and post-generative

od by Uranov and Smirnova (1969). Four types of ontogenetic spectra can be distinguished (Zaugolnova, 1994) depending on the proportion of individuals in the pre-generative states (s, j, im, v), generative states (g1, g2, g3), and post-generative states (ss, s). The four population structure scenarios are as follows: 1. Left-sided spectrum: This consists of prevalent individuals in the pre-generative state or in one of the generative states. This type of spectrum is very dynamic, and members of the groups in specific populations are quite diverse. 2. Centered spectrum: Individuals of the average age generative ontogenetic state prevail. 3. Bimodal spectrum: For this type of spectrum, two maximums are characteristic, one in the regenerative part and the other one in older (less often mature) generative plants. 4. Right-sided spectrum. In this spectrum, old individuals are dominant and there is lack of the young ontogenetic stages (Table 2).

Results

Description of the vascular plant communities with Salvia submutica

In this study, we focus on the two populations of *S. submutica*. The sites were surveyed in Nuratau Mountain area in 2015–2021. Due to the limited distribution of *S. submutica*, only two populations have been described in the wild.

The first population (pop1) of *S. submutica* was in the south-east of the Nuratau ridge, in the border located between Kushrabad and Nuratau districts, at an altitude of 1480 m a.s.l., and the coordinates were 40°32´122˝ 66˚33´143˝. The vegetation was wastage, and the total vegetation cover was 40%. The total

Table 3. List of species with life forms of population-1.

№	Species	Total vegetation cover (%)						Life form
		2015	2016	2017	2018	2019	2021	
1.	*Cotoneaster lindleyi* Steud.	10	10	10	9	9	7	Shrub
2.	*Prunus spinossisima* (Bunge) Franch).	10	10	10	8	8	7	Shrub
3.	*Prunus bucharica* (Korsh.) Hand.-Mazz.	1	1	1	1	+	+	Shrub
4	*Ephedra intermedia* Schrenk & C.A. Mey.	1	1	1	1	1	1	Shrub
5.	*Artemisia tenuisecta* Nevski	2	2	2	1	1	1	Semi-shrub
6.	*Lagochilus olgae* Kamelin	1	1	1	1	1	1	Semi-shrub
7.	*Artemisia juncea* Kar. & Kir.	+	1	1	1	+	+	Semi-shrub
8.	*Ferula ovina* Boiss.	1	1	1	1	1	1	Perennial
9.	*Centaurea squarrosa* Willd.	+	+	+	+	+	+	Perennial
10.	*Thalictrum isopyroides* C.A. Mey.	1	1	1	+	+	+	Perennial
11.	*Poa bulbosa* L.	1	1	1	+	1	+	Perennial
12.	*Phlomoides eriocalyx* (Regel) Adylov, Kamelin & Makhm.	1	1	1	+	+	+	Perennial
13.	*Onosma dichroantha Boiss.*	+	+	+	+	+	+	Perennial
14.	*Salvia submutica* Botsch. & Vved.	+	+	+	+	+	+	Perennial
15.	*Acantholimon subavenaceum* Lincz.	+	+	+	+	+	+	Perennial
16.	*Astragalus leptostachys* Pall.	1	1	1	+	1	+	Perennial
17.	*Vulpia persica* (Boiss. & Buhse) Krecz. & Bobrov	+	+	+	+	+	+	Annual
18.	*Ziziphora tenuior* L.	+	+	+	+	+	+	Annual
19.	*Filago arvensis* L.	+	+	+	+	+	+	Annual
20.	*Alyssum desertorum* Stapf	+	+	+	+	+	+	Annual
21.	*Bromus tectorum* L.	+	+	+	+	+	+	Annual
22.	*Taeniatherum crinitum* (Schreb.) Nevski	10	10	8	6	9	5	Annual

cover of *S. submutica* was less than 1%. Species richness showed 22 vascular plants in the community (Table 3), of which four were shrubs, three were semi-shrubs, nine were perennials, and six were annual plants.

The second population (pop2) of *S. submutica* was in the central part of the Nuratau ridge, 10‒12 km to the north of Nuratau (Hayotsoy village), at an altitude of 1835 m a.s.l., and the coordinates were 40°50´ 434˝ 66°96´017˝. This population was on the northwestern slope of this mountain, the steepness of which was 50°–60°. The soil was stony and gravelly. The vegetation was wastage, and the total vegetation cover was 20%. The total cover of *S. submutica* was less than 1%. We found 30 species of vascular plants in the community (Table 4), of which two were shrubs, eight were semi-shrubs, and 20 were perennials. This vegetation cover changes due to climate and human pressure.

Population structure of Salvia submutica

The population structure of the studied species has not been studied before. The population structure was determined according to the standard method by Uranov and Smirnova (1969). In this mountain region, growth of montane vegetation is limited by both temperature and aridity. For example, *Lagochilus olgae* semi-shrubs growing at 1850 m in the Nuratau Mountains of Uzbekistan showed loss of regeneration in drought years (Akhmedov et al., 2021; Islamov et al., 2022). *Salvia submutica* grows in this region only. *S. submutica* was represented only by generative individuals (there were no young generative individuals in pop1 and pop2). As it forms the majority of species of the genus, *S. submutica* is also characterized by the seed of self-maintenance of populations, a short regenerative period, a long stay in the middle-aged generative state, and rapid aging of individuals and their mortality. These biological features allow us to assume that the characteristic spectrum of populations of this species will be centered. In all studied populations, the ontogenetic spectrum is incomplete, unimodal, and centered.

The peak found in the spectra of the studied populations belonged to a group of middle generative plants. In pop1, the percentage ratio of these age groups was 90.47%, in pop2 it was 72.72%. The absence of a young fraction in the populations and the peak in the middle generative plant range were probably connected with the biology of the species, as it has low seed germination, rapid transition to flowering, and slow development of individuals in the mature generative state. The absence of pre-generative individuals in both populations is associated with the flushing of young immature individuals during spring mudflows, trampling of small ruminants, and the irregularity of seed renewal. The absence of individuals of the senile age state is probably one of the biological features of the species, that is, death of individuals after the old generative state.

The decrease in the young generative stage (g1) in this population in 2018–2019‒2021 was due to the irregularity of seed renewal. This was caused, on the one hand, by dry climate and high temperature, and on the other, by a constant wind blowing the plant seeds beyond the boundaries of the population. The percentage of old generative stages was 10%, which increased to 20% in 2021, that is, without any young plants. We investigated and found that the peak in the spectrum of the studied popula-

Table 4. List of species with life forms of population-2.

№	Species	Total vegetation cover (%)						Life form
		2015	2016	2017	2018	2019	2021	
1.	*Rosa maracandica* Bunge	+	+	+	+	+	+	Shrub
2.	*Atraphaxis virgata* (Regel) Krasn.	+	+	+	+	+	+	Shrub
3.	*Artemisia juncea* Kar. & Kir.	4	4	3	2	2	2	Semi-shrub
4.	*Jurinea kokanica* IIjin	+	+	+	+	+	+	Semi-shrub
5.	*Ziziphora clinopodioides* Lam.	1	1	1	+	1	+	Semi-shrub
6.	*Perovskia scrophulariifolia* Bunge	2	2	2	2	2	2	Semi-shrub
7.	*Scutellaria ramosissima* Popov	+	+	+	+	+	+	Semi-shrub
8.	*Astragalus bactrianus* Fisch.	+	+	+	+	+	+	Semi-shrub
9.	*Phlomis nubilans* Zakirov	2	2	1	+	1	+	Semi-shrub
10.	*Lagochilus proskorjakovii* Ikramov	+	+	+	+	+	+	Semi-shrub
11.	*Centaurea squarrosa* Willd.	+	+	+	+	+	+	Perennial
12.	*Bupleurum exaltatum* M. Bieb	+	+	+	+	+	+	Perennial
13.	*Salvia submutica* Botsch. & Vved.	+	+	+	+	+	+	Perennial
14.	*Echinops nuratavicus* A.D.Li	+	+	+	+	+	+	Perennial
15.	*Dianthus helenae* Vved.	+	+	+	+	+	+	Perennial
16.	*Phlomoides anisochila* (Pazij & Vved.) Salmaki.	+	+	+	+	+	+	Perennial
17.	*Poa versicolor* Besser	2	2	2	1	1	+	Perennial
18.	*Eremurus soogdianus* (Regel) Benth. & Hook.f.	+	+	+	+	+	+	Perennial
19.	*Parrya olgae* (Regel & Schmalh.) D.A.German & Al-Shehbaz	+	+	+	+	+	+	Perennial
20.	*Hypericum scabrum* L.	1	1	1	+	+	+	Perennial
21.	*Tulipa turkestanica* (Regel) Regel	2	2	1	+	1	+	Perennial
22.	*Bromus scoparius* L.	2	2	2	1	1	+	Perennial
23.	*Ferula ovina* Boiss.	2	2	1	1	1	1	Perennial
24.	*Acanthophyllum gypsophiloides* Regel	+	+	+	+	+	+	Perennial
25.	*Silene guntensis* (B.Fedtsch.) B.Fedtsch. ex Schischk.	+	+	+	+	+	+	Perennial
26.	*Piptathorum sp.*	+	+	+	+	+	+	Perennial
27.	*Stipa hohenackeriana* Trin. & Rupr.	2	2	2	1	1	1	Perennial
28.	*Stipa lipskyi* Roshev.	1	1	1	1	1	1	Perennial
29.	*Oxytropis tachtensis* Franch.	2	2	2	1	1	1	Perennial
30.	*Thalictrum isopyroides* C.A. Mey.	+	+	+	+	+	+	Perennial

tions corresponded to a group of middle generative plants. The percentage ratio of these age groups was 59.6%–90.47% (Fig. 5). It was probably connected with the biology of the species, that is, low seed germination, dry climate, harvesting for its medicinal uses, and grazing.

Discussion

The current study describes the climate sensitivity and population dynamics of *S. submutica* in Uzbekistan. Results presented here confirm the hypotheses populations of *S. submutica* is under increasing risk, and decrease in young generation with lower precipitation amounts in recent years. Impacts of climate change pose very high risk to Central Asia, and this area is highly vulnerable to climatic change (Vakulchuk et al., 2022).

Plant populations under a changing climate

Past studies have shown that precipitation may affect seed germination and seedling growth and being. Biodiversity investigations have shown that such changes and extreme rainfall and drought stress may be mitigated by plant species abundance. Plant species richness changes by climatic extremes within the growing season. Semi-arid landscapes have highly inadequate water and are characteristically quite responsive to changes in the amount of precipitation and event size. Ecosystems of semi-arid and arid landscapes change by dry climate (Padilla et al., 2019).

Certainly, studies on desert and mountain shrub communities appear to be correlated to our observations on *S. submutica.* Nevertheless, the stages of this population show that the survival of mature individuals is the only process that maintains the population, as no new individuals are being listed. In our case, the mature stages of *S. submutica* are relatively tolerant to drought.

Implications for conservation

Changing precipitation regimes can deeply affect plant growth in land ecosystems, particularly in arid and semi-arid regions.

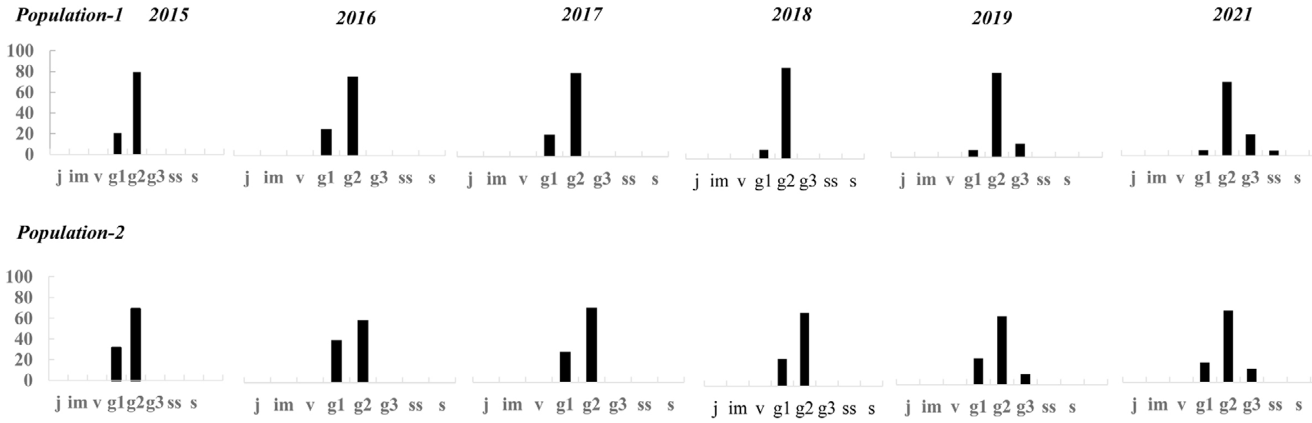

Fig. 5. Dynamics of population partitioning by developmental stages of *Salvia submutica* in Uzbekistan in 2015–2021 (no data in 2020 because of lockdown due to COVID-19).
Notes: x – developmental stage; y – distribution of individuals by developmental stages, %.

However, how changing precipitation, specifically extreme precipitation, effects changes in plant diversity and community is not yet understood. Extreme drought decreases the plant community cover, and they have a higher resistance to drought stress (Zhong et al., 2019). The development of industry and agriculture, as well as the widespread use of natural resources lead to the destruction of the ecological balance and the risk of a decrease in the number of plant species. Rare and endangered species are more vulnerable to any pressure on nature. As practices across the world show, the expansion of specially protected natural areas is a great success in preserving the natural population of vulnerable species. The high climate responsiveness of *S. submutica* studied here is a red alert for the survival of this focal species in its native habitats. To conserve populations of *S. submutica*, the following need to be done: (1) more studies should be conducted on multiple approaches to conservation and in the socioeconomic contexts; (2) promoting conservation of natural populations by removal of societal threats, for example, through outreach activities, and by providing alternatives through cultivation of the most useful species for human use; (3) learning deeply the ecological rules; (4) investigating the gene pool and creating a gene bank; and (5) an important factor is preservation of the population and protected area, as well as to create living collections of this focal species.

Conclusion

The studied populations of *S. submutica* were incomplete due to global warming, drought, and human pressure causing negative effects on the population's structure; therefore, no young generations of this focal species were found. The loss of a young fraction in this population was due to the irregularity of seed renewal. In turn, this was caused, on the one hand, by dry climate and high temperature.

The investigation indicated that the populations were all in all mature, with most plants in the generative state. Populations of this focal species with a centered ontogenetic type are formed in the unfavorable factors of the ecotope (rocky, coarse-grained, rocky-gravelly slopes at rocky outcrops). Mature generative plants dominated in the populations because g2 was tolerant to abiotic and anthropogenic influences.

The first population was close to a settlement; therefore, local people were using it as a traditional medicine herb and made tea with its leaves and flowers; also, trampling by cows, sheep, and goats destroyed the plants. Moreover, this area had been used for agriculture (to create orchards).

Anthropogenic and climate factors pose a threat to the studied populations, such as grazing, overgrazing, extreme ecological conditions of the habitat, global warming, and drought stress.

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