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RESEARCH ARTICLE

Assessment of populations of *Lagochilus vvedenskyi* (Lamiaceae) in the Kyzyl-Kum desert of Uzbekistan under drying climate

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Abstract

The desert ecosystems of Central Asia, particularly Uzbekistan, feature rich biodiversity and distinctive plant communities. Global warming and drought have led to habitat destruction in Central Asia, resulting in increase in the number of endangered species. Intense human activity and prolonged droughts driven by climate change have resulted in habitat destruction and a corresponding vegetation cover crisis in these regions. This study aimed to assess the current five populations of *L. vvedenskyi*, which are primarily distributed in the Kyzyl-Kum desert of Uzbekistan. This species has been affected by climatic changes and human pressure in Uzbekistan. *Lagochilus vvedenskyi* populations show strong ecological sensitivity to increasing drought conditions in arid regions. The present study describes five populations of *L. vvedenskyi* in Uzbekistan. The populations were estimated, measured and the population spectrum was determined for all five groups. The plant communities comprise 42 species, including one species of semi-shrub, two species of dwarf-shrubs, seven species of shrubs, 26 species of perennial herbs and six species of annual herbs. The ontogenetic structure of these communities is incomplete, meaning that not all age groups are represented due to biological characteristics and the dry climate. Across all sites, the population density is low, with most populations classified as mature ontogenetic structures. Significant changes in $\delta^{13}C$ indicate that the response to reduced precipitation is linked to drought stress. Given the expected drier and hotter climate in Uzbekistan in the upcoming decades, these findings enhance our understanding of the current state of *L. vvedenskyi*, suggesting that this species may soon face extinction in the wild. Consequently, establishing conservation and protection areas for this species is essential.

Keywords: arid; climate change; desert; endemic; *Lagochilus vvedenskyi*; population structure

Introduction

Climate extremes such as droughts are expected to increase in frequency and intensity due to global changes (1). Rising global temperatures and extended droughts are projected to make drylands increasingly arid and saline (2). Climate change-driven drought stress has led to numerous large-scale mortality events in woody species in recent decades (3). Climatic scenarios are projected to become increasingly extreme, with changes in precipitation characterized by more intense rainfall and prolonged dry periods. Global warming is expected to cause biodiversity loss by changing vegetation cover, particularly affecting desert C3 plants (5, 6). Climate change and increasing human pressures on ecosystems negatively impact rare biodiversity worldwide (7). The impact of human activity on the Earth's climate is becoming increasingly evident. Climate observations demonstrate a trend of global warming: the global average temperature has increased by 0.8 °C since 1900 (8).

In Central Asia, climate change is marked by rising average temperatures, altered precipitation patterns and fluctuations in extreme weather events. The temperature in the region has been increasing unevenly. Analysis of observational datasets shows that a temperature rises of 1.2 °C has led to a 20 % reduction in snow depth in Central Asia over the past 70 years, especially in mountainous areas. In recent decades, the lengthening of summers and a decrease in icing days-by more than 20 days each year-have put unprecedented stress on the components of Central Asia's climate system (9). Central Asia is among the world's most ecologically diverse and climatically vulnerable regions (10).

Central Asia is a region that includes the glacierized mountain systems of the Tien Shan and Pamir, as well as desert and semi-desert areas. Studies consider it a hotspot (11-13). The mountains of Central Asia provide crucial environmental functions and ecosystem services, which are increasingly impacted by climate change. Efforts for climate change adaptation (CCA) are ongoing (14). "In terms of biodiversity, the mountain ecosystems of Central Asia belong to the most valuable areas in the world, called hotspots. These ecosystems embrace unique plant communities and many endemic species" (15). In response to ecological changes, species can adapt through phenological plasticity and genetic evolution or shift their distribution ranges to locate more favorable conditions (16).

Recent studies investigating the effects of climate change on biodiversity have employed the IUCN Red List Criteria to assess extinction rates based on anticipated shifts in species ranges (17). The combined effects of climate change and other factors have transformed Uzbekistan's flora, leading to an increase in the number of endangered species in the last 30 years, from 163 in 1984 to 324 in 2009 (18).

Climate projections for Uzbekistan indicate a 5-10 % decline in mean annual precipitation (MAP) and a 3.5 °C rise in mean temperature by the end of this century (19, 20). In the coming decades, prolonged drought and rising temperatures in Uzbekistan should be a top priority for the conservation of rare and endangered species (21).

Uzbekistan has +arid and semi-arid landscapes that sustain a unique flora characterized by high endemism and numerous medicinally valuable species (22). Within this biodiversity hotspot, Lamiaceae (the mint family) represents one of the dominant plant families. Lamiaceae is one of the most diversified and economically important families among angiosperms, renowned for its variety of spices, medicinal herbs, vegetables and ornamental plants (23).

One of the key genera is *Lagochilus* Bunge ex Benth. consists of endangered and endemic species in Central Asia. The genus *Lagochilus* Bunge ex Benth., with 45 accepted species (powo.science.kew.org2025), is a significant component of this regional flora. There are 18 species of the genus *Lagochilus* found in Uzbekistan, according to the National Herbarium of Uzbekistan (TASH). Among these, four species-*Lagochilus wedenskyi, Lagochilus olgae, Lagochilus proskorjakovii* and *Lagochilus inebrians*-are listed in the Red Book of the Republic of Uzbekistan (8). *Lagochilus* possesses economic value due to its leaves, which contain alcohols, lagochilin (0.6–2 %), essential oils (0.03 %) and vitamin K. Additionally, most species within this genus contain narcotic, haemostatic and various other compounds. Many *Lagochilus* species are locally used to treat skin disorders, manage blood loss, address nervous disorders and treat prostate cancer (24-28).

Desertification poses a significant sustainability threat to global drylands, with the health of natural rangelands deteriorating due to the increasing impact of various anthropogenic activities (29, 30). It is one of the most severe environmental disasters that affects the overall condition of the environment (31). Populations of *Lagochilus* species are under pressure due to desertification (32). In assessing the current status of rare and endangered species populations, the most effective approach is to analyze population and organismic characters using a population based method (33-41). Population studies play a crucial role in evaluating and conserving rare species. A geo-botanical approach was integrated with climatic and stable carbon isotope analyses to investigate the long-term effects of climate change on *L. vvedenskyi* in Uzbekistan. Five populations of *L. vvedenskyi* from the Kyzyl-Kum desert were studied from 2022 to 2024. *L. vvedenskyi* is native to the Kyzyl-Kum desert in Uzbekistan.

Materials and Methods

The study was carried out in the Kyzyl-Kum desert, Uzbekistan, with field surveys conducted from 2022 to 2024. The Kyzyl-Kum desert is quite extensive, covering an area of approximately 300000 km^2. Within the Kyzyl-Kum, there are over 20 remaining mountains of various sizes, most of which belong to several distinct mountain systems. Notably, Kukchatau, Kuljuktau, Auminzatau, Muruntau, Tamdytau, Aktau, Bukantau and Sultanuvastau hold significant importance in terms of their location and the area they cover (42). In this study, we examined five populations of *L. vvedenskyi* found in the KyzylKum Desert (Fig. 1 & 2).

Long-term meteorological data is not available in Uzbekistan; therefore, mean monthly precipitation and temperature data were obtained from the Climatic Research Unit (CRU) TS3.10 datasets for each site (43). The mean annual temperature (MAT) is 15.2 °C and the mean annual rainfall exceeds 100 mm in the study sites. The soil types consist of grey-brown and rocky-stony textures (Table 1) (44).

Study species

L. vvedenskyi is a red-listed species and it is included as status 2 (rare endemic species of the Kyzyl-Kum) in the Red Book of Uzbekistan (18). This is a semi-shrub up to 20–50 cm high. The leaves are opposite and broadly ovate with prominent veins and a pubescent underside covered in simple, transparent hairs. Stems are white, pubescent and simple. Flowers are arranged in groups of 2-4 at the top of the stem and flowering in May (Fig. 3).

Isotopic analysis of δ^{13}C in *L. vvedenskyi*

Isotopic analyses of carbon-13 were performed at the Geobotany Department, Trier University, Germany using cavity ring down spectroscopy (CRDS) method, IRMS Delta V™ isotope ratio mass spectrometer (Thermo Scientific, Bremen, Germany). An amount of 1 mg was mounted onto a combustion module equipped with an auto-sampler (ECS 4010, Costech Analytical, Valencia, CA, USA) was placed in a combustion module equipped with an autosampler (plate number 1, Costech Analytical, Valencia, CA, USA). The resulting CO^2 gas was analyzed using a carbon-^{13} analyzer (Picarro G2131i, Picarro, Santa Clara, CA, USA), which was directly connected to the combustion module. The results were expressed as parts per thousand ‰) deviations from the international carbon isotope standard, Vienna Pee Dee Belemnite (VPDB). The global δ^{13}C values were obtained from previously published data (21, 44).

Population structure measurements

Population structure was assessed using specific population traits (45). At each site, three transects were established, starting from a common random point. From this point, the transect was directed to the north, one to the south and one to the east. Each transect was 1 m wide and 10 m long, subdivided into 10 squares, each measuring 1 sq m. Within each square, the number of individuals in each ontogenetic stage was counted. The stages included: s - seedlings, j - juvenile, im - immature, v - virginile, g1 - young generative, g2 - mature generative, g3 - old generative, ss - subsenile and se - senile (46-48). The ontogenetic

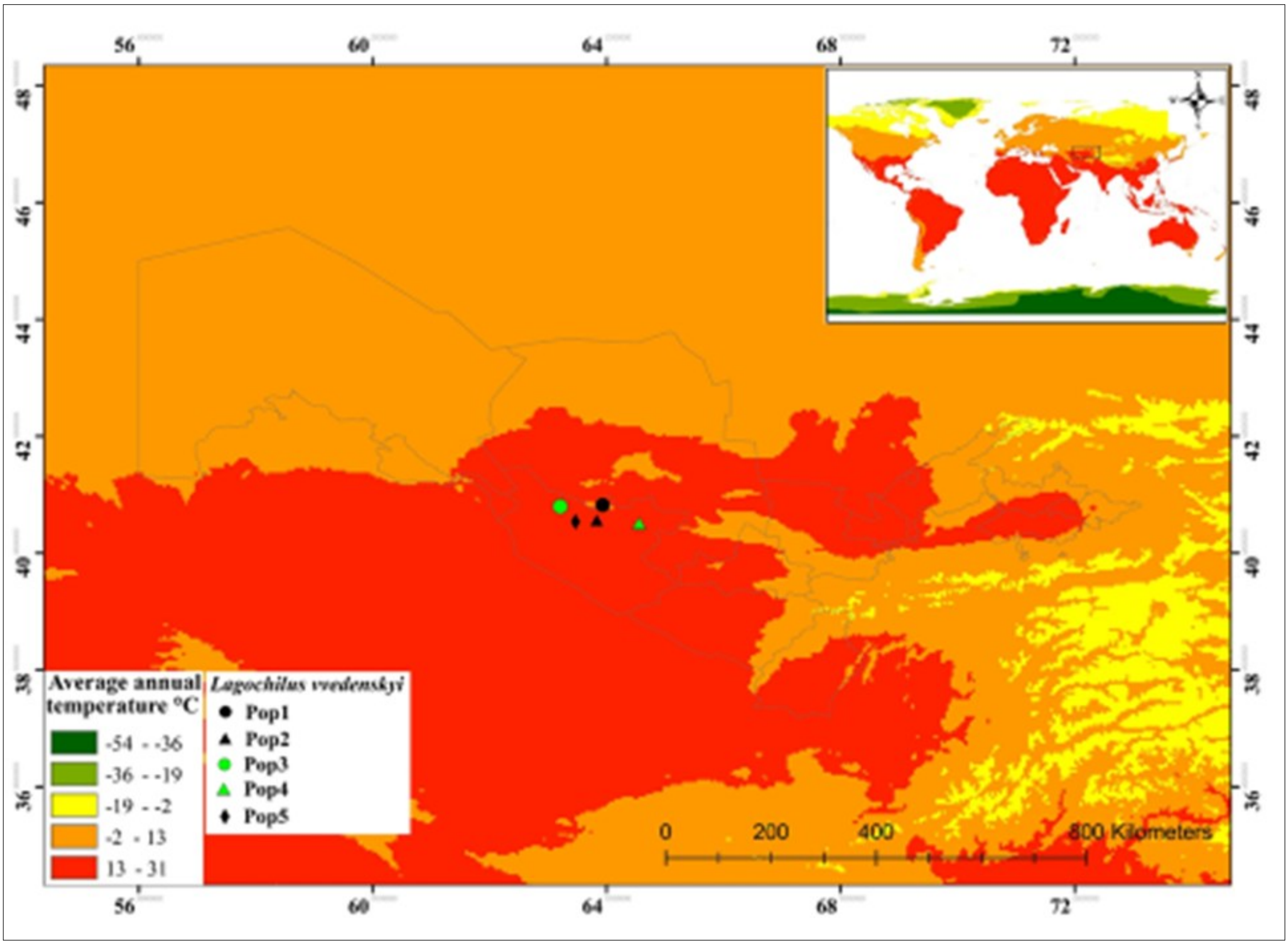

Fig. 1. Regional climates and sampling sites of the investigated *L. vvedenskyi* (retrieved from https://worldclim. org/data/index.html#google_vignette, processed and mapped in Arc-GIS 10.8).

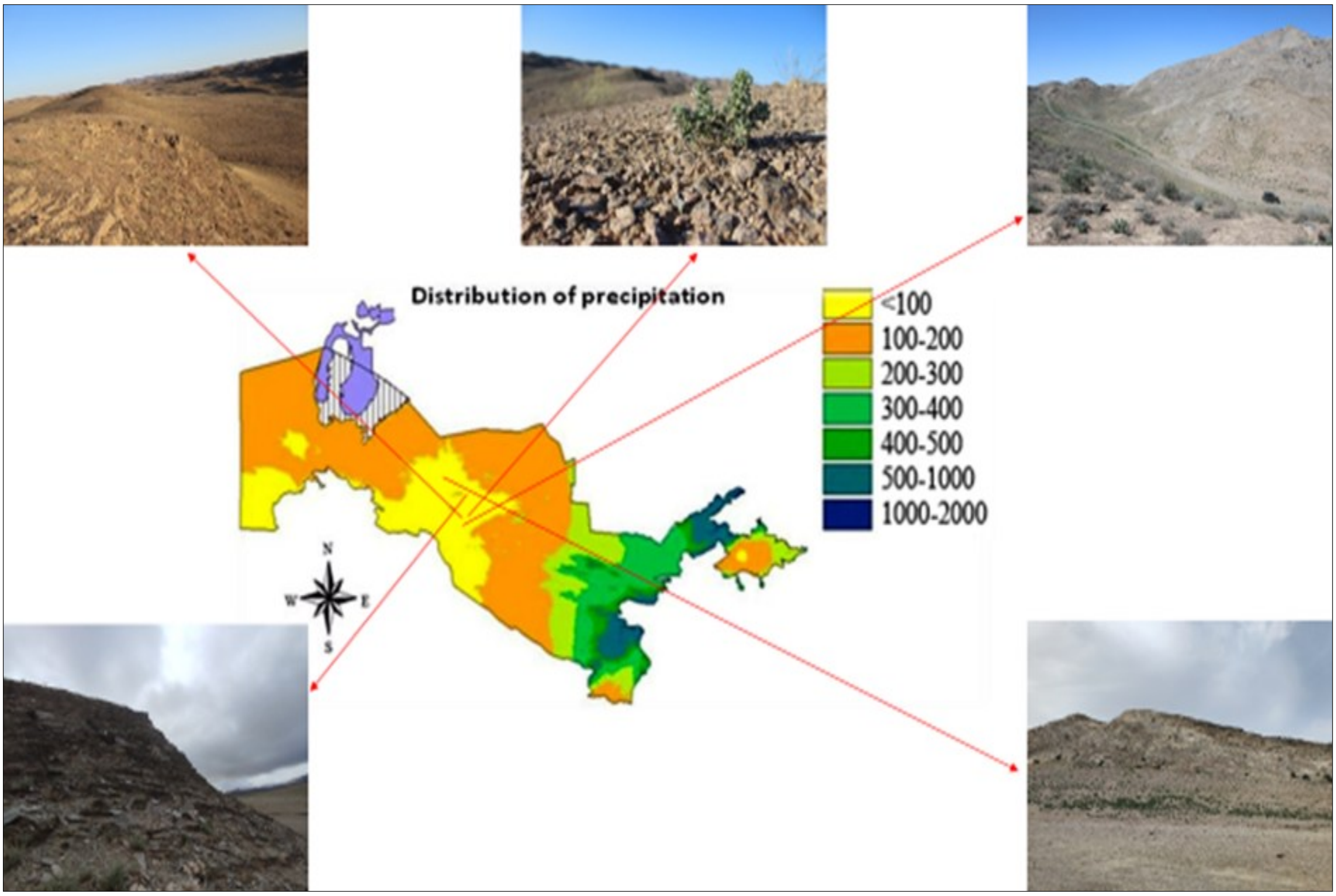

Fig. 2. Distribution map with the location of populations of *L. vvedenskyi* in the Kyzyl-Kum desert, Uzbekistan.

Table 1. Site characteristics of *L. vvedenskyi*

Region	Pop	MAP (mm yr⁻¹)	MAT(°C)	Soil	Landscape	Latitude/N	Longitude/E	Elevation (MASL)
Sultonbibisay	1	70	13	Grey-brown	Desert	40°76′41.8″	63°77`23.5″	436
Aktashlisay	2	65	15.4	Gravelly-pebble	Desert	40°72′38.9″	63°73`76.6″	397
Bashgujimdisay	3	95	15.1	Rocky and gravelly	Desert	40°78′88.9″	63°02`86.6″	608
Tamditau	4	75	16.1	Grey-brown	Desert	40°41′00.8″	64°33`16.7″	417
Bukantau	5	80	13.5	Rocky and stony	Desert	40°54′64.5″	63°35`73.7″	515

Fig. 3. *L. vvedenskyi*: (left) general view; (right) flower details (May 2023, Photo: A. Akhmedov).

spectrum of the population was determined (49).

Results and Discussion

Vascular plant communities and environmental conditions

All five populations of *L. vvedenskyi* are located in the Kyzyl-Kum desert and have been described. The first population (Pop1) occurs 15 km northwest of the Kyzyl-Kum desert station, in the central part of Kuljiktau, specifically in Sultanbibisay. In the plant group where this population was isolated, 21 species were identified. The projective vegetation cover did not exceed 8–10 %. Alongside *L. vvedenskyi*, a few individuals of *Artemisia diffusa*, *Lactuca orientalis and* other species were present (Table 2). The second population was studied in a plant community dominated by *A. diffusa* and *Artimisia turanica*. The total projective cover was 10–12 %. The third population was found in the eastern part of Kuljuktau, known as Bashgudjimdisay. This plant community was not diverse, consisting of only 12 vascular species and the total projective cover reached 10-15 %. The fourth population was described on the southeastern slopes of the Tamditau mountains. The total projective coverage of the community was about 10 %. The dominant species in the vegetation cover were *A. turanica* and *A. diffusa*. The community included 15 species and was dominated by perennial herbs. The fifth population of *L. vvedenskyi* was found in Bukantau (Erlerota), located in the northern part of the Kyzyl-Kum Desert. The area had sparse vegetation, with a total cover of only 10-12 %. The total cover of *L. vvedenskyi* was less than 1 %. The community exhibited a species richness of 12 different vascular plants.

Population structure of *L. vvedenskyi*

The species *L. vvedenskyi* was found to be normal, but its ontogenetic structure was incomplete, as not all life stages of individuals were present. The ontogenetic structure of the studied populations exhibited a single, centered type of spectrum.

The population of *L. vvedenskyi* was represented by the distribution of developmental stages and the revealing of ontogenetic differences. All studied populations exhibited a centered ontogenetic spectrum that generally coincided with the characteristic species spectrum.

The highest proportion occurs among mature generative (g2) individuals, ranging from 55.4 % to 75 %. This pattern is attributed to a gradual increase in life expectancy during the generative phase, along with a reduction in the number of juvenile and immature individuals due to factors such as insufficient soil moisture and grazing pressures in the populations of second, fourth and fifth. During the study, juvenile individuals accounted for 3 % and immature individuals for 9 % in the populations of the first and third, which experienced lower human impact compared to the others. Overall, the spectra were single-peaked and there was a decline in the number of regenerating individuals of this focal species (Fig. 4). This decline was attributed, on one hand, to the arid climate and high temperatures and on the other hand, to the continuous wind that blew plant seeds beyond the population's boundaries. The ontogenetic spectra in all populations reflect the species' biological characteristics and correspond to typical patterns observed in similar species. The peak representation of middle-aged generative individuals is closely linked to the gradual increase in life expectancy during the generative period.

We investigated the spectrum of the studied populations and found that the peak corresponds to a group of middle-aged generative plants in the populations of the second, fourth and fifth. However, this peak does not reflect the proportion of young plants. This discrepancy is likely related to the species' biology, which is characterized by low seed germination rates. Additionally, the decline in the population stages of *L. vvedenskyi* can be attributed to dry climate conditions, as well as negative impacts from mining and overgrazing.

Relationships between $\delta^{13}C$ and the MAT of *L. vvedenskyi*

To examine the relationship between leaf $\delta^{13}C$ and temperature, we plotted leaf $\delta^{13}C$ against the temperature during the sampling year (Fig. 5). This analysis demonstrated the expected increase in $\delta^{13}C$ with drought conditions. The highest temperature was in pop4. *L. vvedenskyi* responding as a stronger and more tolerant species.

Table 2. Characteristics of plant communities of *L. vvedenskyi*

Sl No	Species	Total vegetation cover %					Life form
		Pop1	Pop2	Pop3	Pop4	Pop5	
1	*Xylosalsola arbuscula* (Pall.) Tzvelev	+	5	-	-	-	Shrub
2	*Astragalus kuldzhuktauense* F.O.Khass., Shomur. & Esankulov	+	-	1	-	-	Small shrub
3	*Artemisia diffusa* Krasch.ex Poljakov	1	3	2	-	1	Dwarf-shrub
4	*Stipa hohenackeriana* Trin. & Rupr.	1	+	1	-	-	Perennial
5	*Cousinia hamadae* Juz.	+	-	+	+	-	Perennial
6	*Poa bulbosa* L	+					Perennial
7	*Ferula kyzylkumica* Korovin	+	+	-	1	1	Perennial
8	*Dianthus crinitus subsp.* tetralepis (Nevski) Rech.f.	+	+	-	-	-	Perennial
9	*Lepidium subcordatum* Botsch. & Vved.	+	+	-	-	-	Perennial
10	*Tulipa biflora* Pall.	+	+	+	+	-	Perennial
11	*Lactuca orientalis* (Boiss.) Boiss.	1					Perennial
12	*Lagochilus vvedenskyi* Kamelin & Tzukerv.	+	+	+	+	+	Semi-shrub
13	*Pulicaria sp.*	+	-	-	-	-	Perennial
14	*Ziziphora tenuior* L.	+	-	-	1	-	Perennial
15	*Stipa aktauensis* Roshev.	+	-	-	-	-	Perennial
16	*Caroxylon scleranthum* (C.A.Mey.) Akhani & Roalson	+	-	-	-	-	Perennial
17	*Eremopyrum bonaepartis* (Spreng.) Nevski	+	+	-	+	-	Perennial
18	*Lycium ruthenicum* Murray	+	-	-	-	-	Perennial
19	*Meniocus linifolius* (Stephan ex Willd.) DC.	+	-	+	-	-	Annual
20	*Artemisia scoparia* Waldst.& Kit.	1	-	-	-	-	Annual
21	*Astragalus centralis* E. Sheld.	1	1	-	-	+	Small shrub
22	*Atraphaxis pyrifolia* Bunge	-	+	-	-	-	Shrub
23	*Nanophyton erinaceum* (Pall.) Bunge	-	+	-	-	+	Small shrub
24	*Artemisia turanica* Krasch.	-	2	-	4	-	Dwarf-shrub
25	*Lactuca sp.*	-	+	-	-	-	Perennial
26	*Rheum turkestanicum* Janisch.	-	+	-	-	-	Perennial
27	*Takhtajaniantha pusilla (*Pall.) Nazarova	-	+	-	-	-	Perennial
28	*Peganum harmala L.*	-	+			1	Perennial
29	*Silene sp.*	-	-	+	-	-	Perennial
30	*Ixiolirion tataricum* (Pall.) Schult. & Schult.f.	-	-	+	+	-	Perennial
31	*Convolvulus* sp.	-	-	-	2	-	Perennial
32	*Astragalus schrenkianus* Fisch. & C.A.Mey.	-	-	-	+	-	Perennial
33	*Koelpinia leneralis* Pall.	-	-	-	+	-	Annual
34	*Roemeria pavonina* (Schrenk) Banfi, Bartolucci, J.-M.Tison & Galasso	-	-	-	+	-	Annual
35	*Hypecoum littorale* Wulfen	-	+	-	+	-	Annual
36	*Astragalus remanens* Nabiev	-	-	-	+	-	Annual
37	*Acanthophyllum sp.*	-	-	-	-	3	Perennial
38	*Astragalus schrenkianus* Fisch. & C.A.Mey.	-	-	-	-	+	Perennial
39	*Caragana halodendron* (Pall.) Dum.Cours.	-	-	-	-	3	Shrub
40	*Iris songarica* Schrenk ex Fisch. & C.A.Mey.	-	-	-	-	1	Perennial
41	*Leontice incerta* Pall.	-	-	-	-	+	Perennial
42	*Rhamnus erythroxyloides subsp. sintenisii* (Rech.f.) Mabb.	-	-	-	-	1	Shrub

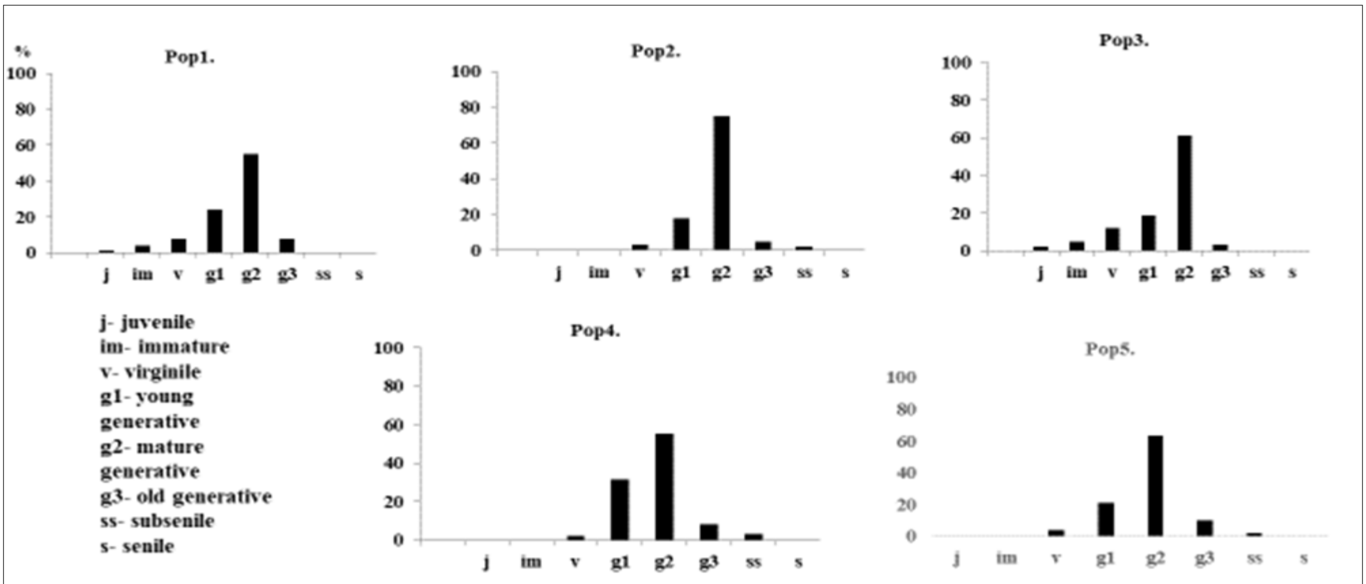

Fig. 4. Population partitioning to developmental stages of *L. vvedenskyi* in the Kyzyl-Kum desert.

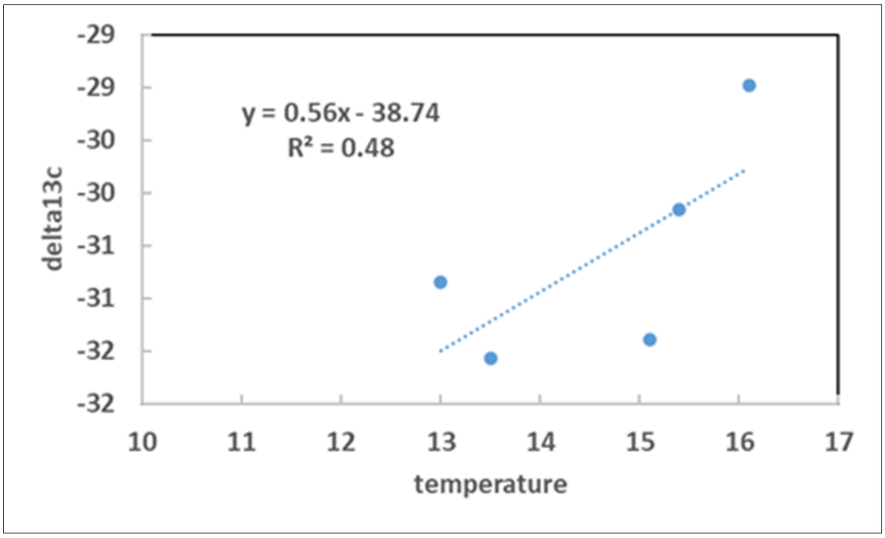

Fig. 5. Relationship between leaf δ^{13}C of *L. vvedenskyi* and annual temperature.

Overall, young plants accounted for a decrease during the dry year.

L. vvedenskyi populations under a drought climate

Ecosystems in arid and semi-arid regions are influenced by dry climates (50). Certain studies on desert shrub communities appear to correlate with our observations of *L. vvedenskyi*. This research examined the climate sensitivity of the population structure of *L. vvedenskyi* in the Kyzyl-Kum desert, Uzbekistan. The results indicate that these populations are at an increasing risk, particularly due to a decline in the younger generation as a result of rising temperatures. The unique sensitivity of Central Asia's arid ecosystems to drought has only recently been studied (51). The loss and fragmentation of natural habitats are causing significant changes to landscapes, which negatively affect plant diversity and raise concerns about how these ecosystems will respond to global changes (52). The impacts of global warming and increasing human activities are threatening the populations of unique and rare species.

Implications for conservation

Human-induced climate change and increased pressure on natural ecosystems negatively impact the populations of endemic and rare biodiversity components (41).

Worldwide experience shows that expanding specially protected natural areas has been an effective strategy for conserving the natural populations of vulnerable species.

Conclusion

In summary, the status of the five populations of *L. vvedenskyi* is unsatisfactory and 42 vascular species have been identified in the Kyzyl-Kum desert, Uzbekistan. The research indicated that the climate is very sensitive to change, impacting the current population status of *L. vvedenskyi*.

The study revealed that all populations were mature based on the biological characteristics and ecological conditions of this target species. The study revealed differences in the successional conditions of *L. vvedenskyi* populations. The populations studied are incomplete due to global warming, instances of drought and the negative impacts of human activity on this focal species.

Given the expectation of a drier and hotter climate in Uzbekistan in the coming decades, prioritizing the conservation of *L. vvedenskyi* populations is essential.

Recommendations

The high climate responsiveness of *L. vvedenskyi*, as studied here, raises a red flag for the survival of this species in its native habitats. To conserve populations of *L. vvedenskyi*, several actions are needed: (1) Conduct more studies using various approaches to conservation and socio-economic contexts, social processes essential for enhancing habitat connectivity to support biodiversity conservation and create resilient landscapes in response to climate change, enhance collaboration between scientists and policymakers for better outcomes; (2) Promote the conservation of natural populations by addressing societal threats, for e.g., through outreach activities and by providing alternatives through the cultivation of the most beneficial species for human use; (3) Gain a deep understanding of ecological principles; (4) Investigate the gene pool and establish a gene bank; (5) Focus on the preservation of populations and protected areas, as well as creating living collections of this focal species; (6) Establish an evidence-based framework for systematic conservation planning that focuses on climate change.

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Authors' contributions

All authors contributed equally to the fieldwork, data collection, analysis and manuscript preparation. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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