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ASSESSMENT OF THE ECOLOGICAL STATE OF THE POPULATION OF THE SPECIES *SCHMALHAUSENIA NIDULANS* (REGEL) PETR. OF THE FLORA OF THE NORTHERN TIEN SHAN

This article presents the results of a comprehensive assessment of the ecological status of populations of the rare endemic species *Schmalhausenia nidulans* native to the high-mountain regions of the Northern Tien Shan. The aim of the study was to investigate the current state of the species populations by analyzing their numbers, ontogenetic structure, morphometric parameters, and anatomical features. Two natural populations of the species were examined: the first population, located on the Uzynkara Ridge at an altitude of 3003 m above sea level, and the second population, growing on the Ile-Alatau Ridge at an altitude of 3260 m above sea level. During the field research, the population size, age structure, and morphological traits of individuals at the juvenile, immature, virginal, and generative stages of development were studied, and an anatomical analysis of the stem structure was also conducted. Both populations were found to be characterized by a complete ontogenetic spectrum, indicating their resilience and capacity for natural self-sustainment. The Ile-Alatau population is characterized by higher abundance and better plant morphometric parameters, which is associated with more favorable environmental conditions in the habitat. The Uzynkara Ridge population is characterized by smaller individuals but maintains a stable age structure and high viability. An anatomical study revealed a radial secondary stem structure with well-developed conductive and mechanical tissues, ensuring the species' adaptation to the extreme conditions of the high-altitude environment. The scientific novelty of this study lies in the comparative population-ontogenetic, morphometric, and anatomical analysis of high-altitude *Schmalhausenia nidulans* populations, which provided new information on the environmental resilience and adaptive mechanisms of this rare endemic species. The obtained results can be used to develop measures for monitoring, conservation, and protection of this plant.

Keywords: *Schmalhausenia nidulans*, population, ontogenetic structure, morphological features, Uzynkara, Ile Alatau.

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Солтүстік Тянь-Шань флорасының *Schmalhausenia nidulans* (Regel) Petr. түрінің популяциясының экологиялық жағдайын бағалау

Бұл мақалада Солтүстік Тянь-Шаньның биік таулы аймақтарында мекендейтін сирек кездесетін эндемикалық *Schmalhausenia nidulans* түрінің популяцияларының экологиялық жағдайын кешенді бағалау нәтижелері ұсынылған. Зерттеудің мақсаты түр популяцияларының санын, онтогенетикалық құрылымын, морфометриялық параметрлерін және анатомиялық ерекшеліктерін талдау арқылы олардың қазіргі жағдайын зерттеу болды. Түрдің екі табиғи популяциясы зерттелді: бірінші популяция Ұзынқара жотасында теңіз деңгейінен 3003 м биіктікте орналасқан және екінші популяция Іле-Алатау жотасында теңіз деңгейінен 3260 м биіктікте өседі. Далалық зерттеу барысында популяция мөлшері, жас құрылымы және дамудың жасөспірім, жетілмеген, тың және генеративті сатыларындағы даралардың морфологиялық ерекшеліктері зерттелді, сондай-ақ сабақ құрылымының анатомиялық талдауы жүргізілді. Екі популяция да толық онтогенетикалық спектрмен сипатталатыны анықталды, бұл олардың төзімділігі мен табиғи өзін-өзі қамтамасыз ету қабілетін көрсетеді. Іле-Алатау популяциясы өсімдіктердің көптігімен және жақсы морфометриялық параметрлерімен сипатталады, бұл тіршілік ету ортасындағы қолайлы қоршаған орта жағдайларымен байланысты. Ұзынқара жотасы популяциясы кішірек даралармен сипатталады, бірақ тұрақты жас құрылымын және жоғары тіршілік ету қабілетін сақтайды. Анатомиялық зерттеу түрдің биік таулы ортаның экстремалды жағдайларына бейімделуін қамтамасыз ететін жақсы дамыған өткізгіш және механикалық тіндері бар радиалды екінші реттік сабақ құрылымын анықтады. Бұл зерттеудің ғылыми жаңалығы биік таулы *Schmalhausenia nidulans* популяцияларының салыстырмалы популяциялық-онтогенетикалық, морфометриялық және анатомиялық талдауында жатыр, бұл сирек кездесетін эндемикалық түрдің қоршаған ортаға төзімділігі мен бейімделу механизмдері туралы жаңа ақпарат берді. Алынған нәтижелерді осы өсімдікті бақылау, сақтау және қорғау шараларын әзірлеу үшін пайдалануға болады.

Түйін сөздер: *Schmalhausenia nidulans*, популяция, онтогенетикалық құрылым, морфологиялық ерекшеліктер, Ұзынқара, Іле Алатауы.

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Оценка экологического состояния популяции вида *Schmalhausenia nidulans* (Regel) Petr. флоры Северного Тянь-Шаня

В статье представлены результаты комплексной оценки экологического состояния популяций редкого эндемичного вида *Schmalhausenia nidulans* произрастающего в высокогорных районах Северного Тянь-Шаня. Целью исследования являлось изучение современного состояния популяций вида на основе анализа их численности, онтогенетической структуры, морфометрических показателей и анатомических особенностей. Были исследованы две природные популяции вида: первая популяция, расположенная на хребте Узынқара на высоте 3003 м над уровнем моря, и вторая популяция, произрастающая на хребте Иле-Алатау на высоте 3260 м над уровнем моря. В

ходе полевых исследований изучались численность популяций, возрастная структура и морфологические признаки особей на ювенильной, имматурной, виргинильной и генеративной стадиях развития, а также проведён анатомический анализ строения стебля. Установлено, что обе популяции характеризуются полночленным онтогенетическим спектром, что свидетельствует об их устойчивости и способности к естественному самоподдержанию. Популяция Иле-Алатау отличается более высокой численностью и лучшими морфометрическими показателями растений, что связано с более благоприятными экологическими условиями местообитания. Популяция хребта Узынкара характеризуется меньшими размерами особей, однако сохраняет стабильную возрастную структуру и высокую жизнеспособность. Анатомическое исследование выявило радиальное вторичное строение стебля с хорошо развитыми проводящими и механическими тканями, обеспечивающими адаптацию вида к экстремальным условиям высокогорной среды. Научная новизна работы заключается в проведении сравнительного популяционно-онтогенетического, морфометрического и анатомического анализа высокогорных популяций *Schmalhausenia nidulans*, что позволило получить новые сведения об экологической устойчивости и адаптационных механизмах редкого эндемичного вида. Полученные результаты могут быть использованы для разработки мероприятий по мониторингу, сохранению и охране данного растения.

Ключевые слова: *Schmalhausenia nidulans*, популяция, онтогенетическая структура, морфологические признаки, Узынкара, Иле Алатау.

Introduction

Conservation of biological diversity in mountain ecosystems is one of the priority tasks of modern ecology and botany. Mountain regions are characterized by a high degree of endemism and vulnerability of natural complexes to both natural and anthropogenic impacts. In this context, the study of rare and relict plant species, whose population status serves as an indicator of ecological stability in natural mountain ecosystems, gains particular significance. Many rare and endangered endemics adapted to extreme conditions—low temperatures, strong winds, a short growing season, and poor soils—are concentrated in mountain natural ecosystems. Endemic species play a key role in maintaining ecological balance, contributing to soil stabilization, water runoff regulation, and preservation of genetic diversity. However, anthropogenic factors such as recreational pressure, livestock grazing, and climate change threaten their existence (D’Antraccoli et al., 2023; Edwards & Wyse, 2019; Iasnović et al., 2024; Salles et al., 2023; Slezák & Douda, 2022; Maunder et al., 2022; Slezák et al., 2022; Peruzzi et al., 2021; Adamo et al., 2021; Peruzzi et al., 2022; Gestri et al., 2023; Tiburtini et al., 2022). For several decades, the biodiversity of the mountain ecosystem of the Northern Tien Shan, including the Uzynkara and Ile-Alatau ranges, has been under intense pressure from human economic activity (Lemenkova, 2014). The Northern Tien Shan is a unique mountain region in Central Asia, characterized by high levels of biodiversity and a significant number of endemic plant and animal species. Rare endemic species, such as *S. nidulans* a representative of a monotypic genus in the *Asteraceae* family, deserve special atten-

tion in the context of the biodiversity of the Northern Tien Shan. The populations of this species are characterized by the dominance of mature vegetative and generative individuals, indicating stability but also vulnerability to external impacts. Studying such species allows for a deeper understanding of the processes by which plants adapt to high-altitude conditions and the evolutionary aspects of the Tien Shan. *S. nidulans* is a rare endemic representative of the flora of the Northern Tien Shan, confined to specific ecological-coenotic conditions of mountain slopes and rocky habitats of the Ile Alatau. The species is distinguished by a narrow ecological amplitude, a limited distribution range, and sensitivity to changes in environmental conditions flora (Syedina et al., 2024).

Despite the scientific and conservation value of *S. nidulans* information on the current status of its populations in the Ile Alatau remains fragmentary. The abundance, age structure, ecological condition, and resilience of the populations in the context of increasing anthropogenic impacts, including recreational pressure, changes in soil cover, and climatic fluctuations, have not been sufficiently studied. The relevance of studying rare and endangered endemic species of the Northern Tien Shan, including *S. nidulans* is determined by several key factors. First, the region faces intense anthropogenic pressure: recreational tourism in the Ile-Alatau National Park, agricultural activities, and urbanization lead to the degradation of natural habitats. *S. nidulans* as a rare species of category II, is included in the Red Book of the Republic of Kazakhstan and is at risk from livestock overgrazing, soil erosion, and population fragmentation. Second, climate change—such as warming and shifts in snow cover boundaries—

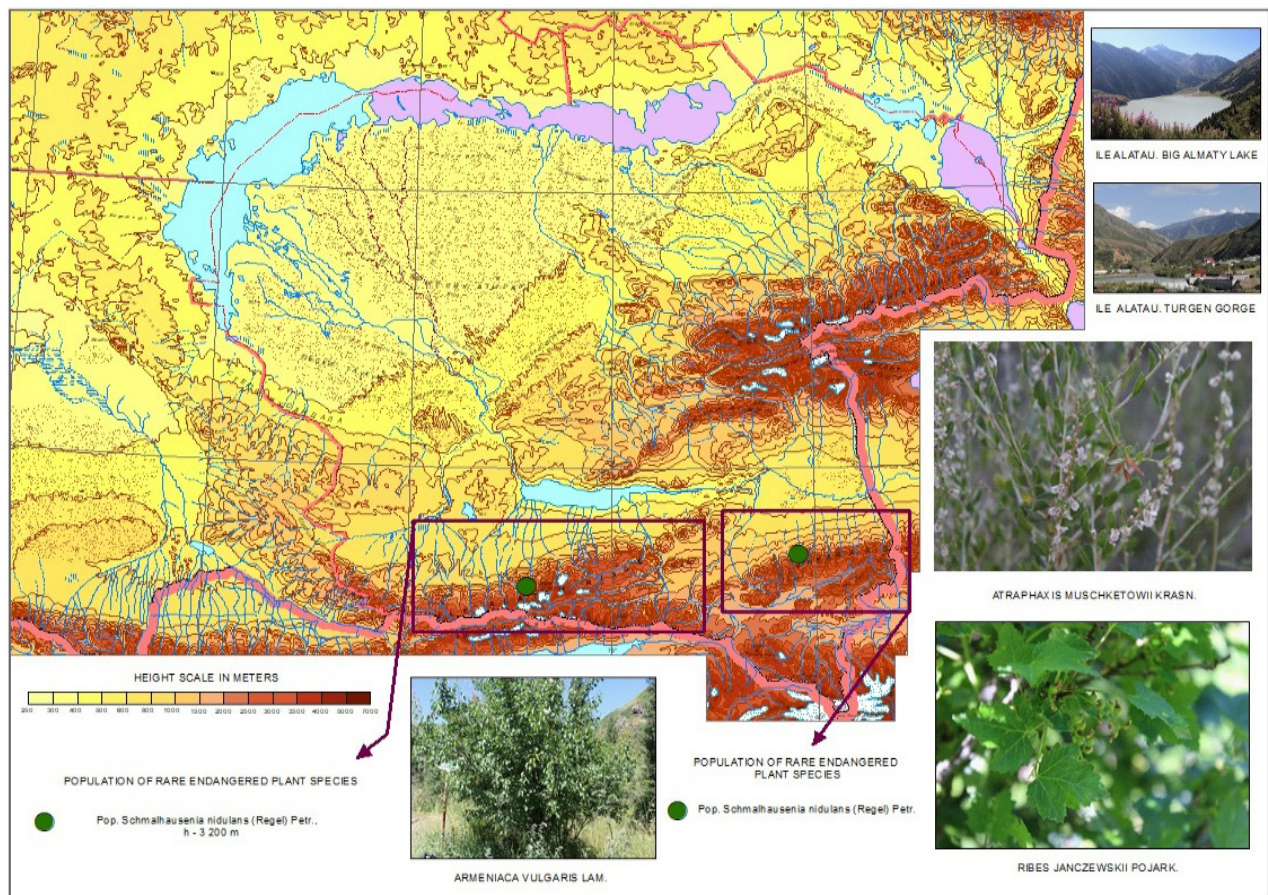
threatens the high-altitude ecosystems where this species resides, potentially leading to a reduction in its range (Baitenov, 1981). In a global context, conserving such species contributes to meeting international commitments under the Convention on Biological Diversity (1992), highlighting the role of the Northern Tien Shan as a center of endemism in Central Asia. The conducted research expands the understanding of the ecological and biological features of the rare endemic species *S. nidulans* which grows in the high-altitude ecosystems of the Northern Tien Shan. New data have been obtained on the current ecological status, population size, ontogenetic structure, and morphological characteristics of its populations within the Uzynkara Ridge and the Ile Alatau, complementing theoretical principles of population ecology and serving as a basis for further monitoring studies.

The aim of this study was to investigate the current population status of the rare species *Schmalhausenia nidulans*.

Materials and methods

The subject of this study was the natural populations of the rare species *Schmalhausenia nidulans* which belongs to the family *Asteraceae* and the genus *Schmalhausenia*. The subject of this study were natural populations of the rare species *Schmalhausenia nidulans*, a member of the *Asteraceae* family and the genus *Schmalhausenia*. Between 2024 and 2025, we studied *Schmalhausenia nidulans* populations in the Ile Alatau Mountains in the Bolshoye Almatinskoye Gorge at an altitude of 3,260 m and in the Uzynkara Kalzhat Gorge at an altitude of 3,003 m (Figure 1).

Figure 1
Map of the study areas in the Northern Tien Shan population of *Schmalhausenia nidulans* in the Ile Alatau and Uzynkara ranges



Plant communities featuring *Schmalhausenia nidulans* were described during the summer in two populations located in different geographic locations in the Northern Tien Shan ranges. The first population was described in the Uzynkara mountains; the second, in the Ile Alatau mountains. Population area and coordinates were determined using a Garmin navigator. Geobotanical descriptions of the populations were conducted using route-reconnaissance and semi-permanent methods. Vegetation was described using the generally accepted methodology (Lavrenko & Korchagina, 1964). Collection and processing of herbarium material was carried out using the generally accepted methodology summarized by A.K. Skvortsov (1977). Plant life forms were classified according to the life form systems proposed by K. Raunkier (1934) and I.G. Serebryakov (1962). Species abundance in phytocenoses was estimated using the Drude (1913) abundance scale. The age structure was determined based on the diagnosis of age states of the studied species. The age spectrum was formed based on qualitative and quantitative characteristics of individuals. Comparative analysis of the morphological traits of individuals from different age groups of *Schmalhausenia nidulans* was carried out following generally accepted methodological approaches. Fieldwork was conducted in accordance with methodologies developed by A.A. Uranov (1960), O.V. Smirnova (Smirnova &

Zaugolnova, 1976) and T.A. Rabotnov (1970). Morphological and anatomical studies were conducted on plant material fixed in a mixture of alcohol, glycerol, and water (1:1:1). Anatomical preparations and microtome sections of roots, stems, and leaves were examined using light microscopy, quantitative parameters were determined morphometrically using an ocular micrometer, and the results were documented by means of photomicrography. The preparation and description of anatomical preparations were carried out using standard methods of plant anatomy (Permyakov, 1988; Prozina, 1960; Barykina et al., 2014).

Results and discussion

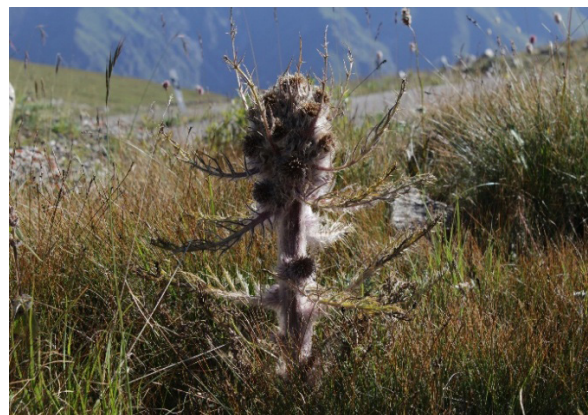
Schmalhausenia nidulans (Regel) Petr. is a very rare endemic species of the monotypic genus (Karmysheva, 1966). This perennial plant reaches 70 cm in height, with an upright, dark-haired stem. The stem is solitary, simple, cobwebby-woolly, with blackish-brown remnants of dead leaves at the base, abundantly foliated. The leaves are oblong-lanceolate, densely gray-woolly on both sides. The inflorescences are large, 4–5 cm in width, densely pubescent. It grows in ancient glacial valleys on gravel-shallow-soil alpine meadows of the Ile-Alatau and Uzynkara ranges (Flora of Kazakhstan, 1966) (Figure 2).

Figure 2

Natural habitats *Schmalhausenia nidulans* (Regel) Petr.



A



B

Natural habitats: A) *Schmalhausenia nidulans* Uzynkara ridge; B) *Schmalhausenia nidulans*, Ile Alatau ridge

On the Ile Alatau ridge, *Schmalhausenia nidulans* is found at an elevation of 3,260 m a.s.l., coordinates: N 43°02'430"; E 076°56'570". The

slope faces southwest. On the Uzynkara ridge, *Schmalhausenia nidulans* occurs at an elevation of 3,003 m a.s.l., coordinates: N 43°05'033"; E

076°59'114". The species is listed in the Red Book of the Kazakh SSR (2014) and the Republic of Kazakhstan (1981). In the spatial structure of the cenopopulations of *S. nidulans* individuals are arranged as sparse solitary specimens. The dominant age spectrum for the cenopopulations of *S. nidulans* consists of middle-aged generative plants, and a significant number of virginile individuals, reflecting the most stable state of the endemic. *S. nidulans* is a rare high-altitude endemic of the Northern Tien Shan, associated with the alpine and subalpine zones of the Ile Alatau. The species is characterized by a compact habit, short shoots, and a well-developed rosette form, which is a typical adaptation to harsh high-altitude conditions. The plant is perennial and herbaceous, with a shortened stem. Leaves are predominantly gathered in a basal rosette, entire, oblong-lanceolate, with a dense leaf

blade. The surface of the leaves is often covered with protective structures (thick cuticle, possible pubescence) that reduce moisture evaporation and protect tissues from ultraviolet radiation and sharp temperature fluctuations. The generative shoots are low-growing, which reduces wind stress and the risk of mechanical damage. The ontogenetic development of the species is accompanied by a gradual increase in leaf blade size and plant height, while maintaining the overall compactness of the habit characteristic of alpine endemics.

Morphological characteristics of populations of Schmalhausenia nidulans.

The analysis of the age structure of *Schmalhausenia nidulans* covers all ontogenetic stages, allowing for the assessment of interpopulation variability in morphometric traits (Table 1).

Table 1

Morphometric parameters of Schmalhausenia nidulans in two populations across ontogenetic stages

Name	Age groups	Juvenile (j)	Immature (i)	Virginal (v)	Generative (g)
Population 1	Leaf length, cm	6.80 ± 2.10	10.33 ± 1.53	16.40 ± 1.60	26.60 ± 3.30
	Plant height, cm	9.20 ± 1.10	19.50 ± 4.80	23.10 ± 5.90	35.72 ± 2.96
Population 2	Leaf length, cm	6.80 ± 2.10	12.67 ± 2.08	17.50 ± 1.10	30.00 ± 3.61
	Plant height, cm	15.73 ± 1.83	22.33 ± 2.53	25.33 ± 2.52	45.67 ± 5.04

The juvenile group includes 35 individuals. The average leaf length is 6.80 ± 2.10 cm, and the average plant height is 9.20 ± 1.10 cm. These values indicate the initial stages of the formation of aboveground plant organs and indicate the average variability of the characteristics characteristic of the early stages of ontogenesis. The relatively small size of juvenile individuals is due to their adaptation to harsh high-altitude conditions and limited environmental resources. The immature group includes 31 individuals. The average leaf length and plant height increase compared to the juvenile period, reaching 10.33 ± 1.53 cm and 19.50 ± 4.80 cm, respectively. Significant growth of vegetative organs and an increase in morphological variability indicate that plants are entering an active period of development and biomass accumulation. Virgin individuals are represented by 54 specimens. The values of leaf length and plant height continue to grow, reaching 16.40 ± 1.60 cm and 23.10 ± 5.90 cm, respectively. This group is characterized by the most intensive vegetative development and the formation of mor-

phological characters necessary for the transition to the subsequent generative stage. The increase in the number of virgin plants indicates favorable conditions for the accumulation of the pregenerative potential of the population. The generative group is the largest, consisting of 89 individuals. The average leaf length and plant height are 26.60 ± 3.30 cm and 35.72 ± 2.96 cm, respectively. A significant increase in plant size at this stage indicates a high level of development of generative organs and the ability of the population to effectively reproduce. The relatively low dispersion of the values indicates the formation and stability of the generative part of the population.

Thus, the first population of *S. nidulans* growing in the Kalzhat gorge on the Uzunkara ridge is characterized by a gradual and systematic increase in leaf length and plant height from the juvenile stage of ontogenesis to the generative stage. The presence of all age groups and the predominance of generative individuals indicate a satisfactory ecological condition of the population and its adaptation to the conditions of high-mountain ecosystems. The morpho-

logical structure of the first population indicates the adaptation of *S. nidulans* to the extreme conditions of the high-mountain zone (approximately 3003 m above sea level), where low temperatures, strong winds, high insolation and soil moisture deficiency prevail. The gradual increase in leaf length and plant height with age indicates normal ontogenetic progress in relatively stable microclimatic conditions. The density of generative individuals suggests a strategy to reduce heat loss and mechanical damage.

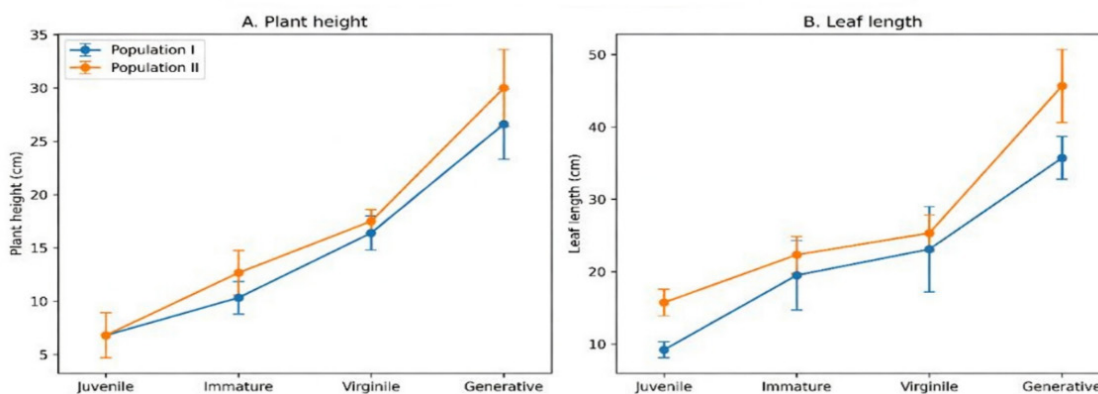
The second population of *S. nidulans* is associated with the high-mountainous conditions of the Great Almaty Gorge and grows at an altitude of 3260 m above sea level. This population is characterized by a large number of individuals and a clearly defined age structure, which indicates favorable conditions for the growth and high survival of the species in this habitat. The juvenile group includes 45 individuals. The average leaf length is 6.80 ± 2.10 cm, and the average plant height is 15.73 ± 1.83 cm. Despite the similarity of the leaf length of the young individuals in the first population, the plant height is significantly greater, which indicates the intensive development of aboveground organs in the early ontogenetic stages. This may be due to the good moisture content of the Great Almaty Gorge and local microenvironmental conditions. The immature group includes 42 individuals. The leaf length and plant height increase compared to the young period, reaching 12.67 ± 2.08 cm and 22.33 ± 2.53 cm, respectively. These values indicate active vegetative growth and the formation of stable morphological characters characteristic of later stages of development. The increase in the number of immature plants indicates the stability of the population renewal processes. Virgin individuals are represented

by 74 specimens. The average leaf length and plant height are 17.50 ± 1.10 cm and 25.33 ± 2.52 cm, respectively. This group is characterized by intensive growth and biomass accumulation necessary for the transition to the generative phase. A significant number of virgin plants indicates a high potential for further reproduction of the population. The generative group consists of the largest, 289 individuals. The average leaf length and plant height reach 30.00 ± 3.61 cm and 45.67 ± 5.04 cm, respectively. A significant increase in the size of generative plants compared to previous ontogenetic periods indicates favorable conditions for the formation of generative organs and a high reproductive capacity of the population. The relatively high variability of these signs indicates the diversity of individual development within the population.

In general, the second population of *S. nidulans* is characterized by a large number of individuals in many ontogenetic groups, a clearly defined age structure, and large values of leaf length and plant height. The presence of a dominant generative fraction and well-developed pregenerative stages indicates a favorable ecological situation of the population and its high adaptation to the conditions of the high-mountain ecosystems of the Ile Alatau.

Morphological differences between *S. nidulans* populations reflect the influence of microrelief, soil conditions, and slopes. The greater leaf length observed in individuals of the second population may be related to the characteristics of the local habitat, while the greater plant height reflects the intensity of vegetative growth. In addition, the low variability of morphometric characters in the first population indicates homogeneous and stable environmental conditions (Figure 3).

Figure 3
Age structure of *Schmalhausenia nidulans* populations



In general, the second population of *S. nidulans* is characterized by a large number of individuals in all ontogenetic states, an increase in leaf length and plant height, and a particularly pronounced development of generative plants. This is probably due to the special ecological and climatic conditions of the Great Almaty Gorge at an altitude of 3260 m above sea level, which contribute to the successful growth, development and reproduction of this species. The first population, despite its low morphometric indicators, retains the full range of ontogenetic groups, which indicates its endurance and long-term stability. Thus, the morphological structure of both populations of *Schmalhausenia nidulans* demonstrates clear ontogenetic differentiation and high ecological plasticity in the extreme conditions of the high mountains of the Northern Tien Shan. Compact habits, medium leaf size and limited vertical growth are the main adaptations that ensure the survival of the species. The identified interpopulation differences highlight the importance of maintaining a diversity of microhabitats for the conservation of the hardiness of this rare endemic species.

Comparative analysis of morphometric characters of two populations of *Schmalhausenia nidulans* revealed both ontogenetic regularities and interpopulation differences. In all age groups of both populations, a significant trend of increasing leaf length and plant height from juvenile to generative individuals is observed, which indicates normal ontogenetic progress. The average values of leaf length in the second population at all ontogenetic states, except for immature individuals, exceed the corresponding values in the first population. This indicates favor-

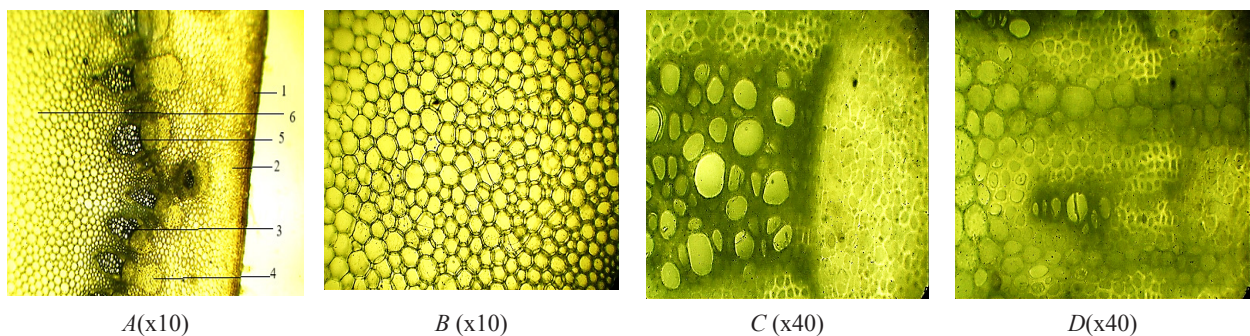
able conditions for the development of the assimilation apparatus in the habitat of the second population. Plant height in the second population is higher than in the first in several age groups (juvenile and generative individuals). This may be due to the characteristics of the microrelief, the depth of snow cover in the winter period, or good soil moisture, which favors vertical growth. Virgin and generative individuals in the first population are characterized by low variability (smaller standard deviation values) in leaf length and plant height, which indicates more stable environmental conditions. In the second population, the increased variability of these morphological characters indicates habitat heterogeneity and the pronounced influence of local environmental factors.

Anatomical structure of the stem of Schmalhausenia nidulans

The anatomical structure of the stem shows that it has a secondary structure typical of the *Asteraceae* family. The outer covering of the stem is covered by the epidermis. The epidermis consists of a collection of oval or round cells filled with loose parenchyma, with a cell thickness of $7.31 \pm 0.51 \mu\text{m}$. The cortex is oval, rectangular, or orbital, with well-developed parenchyma cells filled with distinctly loose parenchyma, forming unicellular or multicellular trichomes. The parenchyma cells of the primary covering are thickened, with a thickness of $5.29 \pm 1.13 \mu\text{m}$. The central cylinder has an increased volume and contains a number of small vascular bundles. Each vascular bundle is filled with upper sclerenchyma. The number of vascular bundles is 8-9, and they are elliptical (Figure 4).

Figure 4

Anatomical structure of the stem of Schmalhausenia nidulans (Regel) Petr.



A) 1-epidermis, 2-loose parenchyma, 3-vascular bundle, 4-sclerenchyma, 5-xylem, 6-vascular parenchyma; B) sclerenchyma; C, D) xylem tubes

Anatomical analysis of the stem of *Schmalhausenia nidulans* revealed a secondary structure typical of Asteraceae and indicative of adaptation to the high-altitude conditions of the Northern Tien Shan. Importantly, the anatomical features also show interpopulation differences consistent with ecological variations between habitats. The stem epidermis consists of densely packed oval or round cells with moderately thickened walls ($7.31 \pm 0.51 \mu\text{m}$), which provide protection against mechanical stress, low temperatures, and intense solar radiation. Beneath it lies a well-developed cortex of parenchymatous cells with unicellular and multicellular trichomes that reduce transpiration and increase resistance to wind and UV radiation. These xeromorphic features were more pronounced in the first population, which grew under stressful but relatively stable alpine conditions. The central cylinder contains 8-9 collateral root bundles with well-developed xylem and phloem. The cambial zone of thin-walled cells supports secondary growth, which was more active in the second population and corresponds to plant height and biomass accumulation. Sclerenchyma fibers in the phloem, especially in the first population, are strongly thickened, indicating increased mechanical reinforcement during severe environmental stress.

In general, anatomical differences between populations reflect ecological differentiation of habitats. The first population is characterized by strong defensive and xeromorphic features, which correspond to stressful conditions and low resource availability. The second population shows a tendency to active growth and high transpiration efficiency, which corresponds to favorable moisture conditions and high morphometric values. Ecological and phytocenotic analysis confirms that both populations are found in high-altitude environments, but differ in terms of habitat quality. The first population develops in more stable but resource-limited conditions, while the second experiences relatively good moisture availability and microhabitat heterogeneity, which leads to increased growth intensity and increased morphological variability. Morphological data confirm these patterns: the first population shows large leaf size and low variability, while the second population shows large plant height and high variability, indicating strong ecological plasticity.

In conclusion, *S. nidulans* exhibits a combination of xeromorphic and mechanical defense anatomical features (thickened epidermis, developed cortex, trichomes, sclerenchymatization, and radial stem structure) that enable survival under alpine stress conditions. Variation in these traits among

populations reflects ecological differentiation and is directly related to differences in population status and habitat quality.

Anatomical analysis of the stem of *Schmalhausenia nidulans* revealed the presence of secondary structures typical of members of the Asteraceae family. The stem has well-developed membranous, mechanical and vascular tissues, a pronounced ray structure and collateral vascular bundles with sclerenchyma elements and cambium. The epidermis is formed by densely packed cells with moderately thickened walls, while the cortical parenchyma consists of unicellular and multicellular trichomes. The presence of trichomes, developed sclerenchyma, thickened cell walls and secondary stem thickening increases the resistance of plants to low temperatures, intense solar radiation, strong winds and periodic moisture deficits characteristic of the high-mountainous habitats of the Northern Tien Shan. The anatomical data obtained correspond to the environmental conditions of the studied populations. Both populations of *Schmalhausenia nidulans* are located on high mountain rocky slopes and are exposed to extreme abiotic factors. The identified structural features can be considered as adaptive features that ensure the successful survival of the species in these conditions. The populations of the Ile Alatau and Uzunkara ranges differ in size and ontogenetic structure, but in both cases reproductive individuals predominate, which indicates the preservation of self-sustaining processes. However, the relatively low proportion of pre-regenerative individuals indicates that the natural reproduction of the species is limited. The results obtained confirm the need for further monitoring of the population status and the preservation of their natural habitat.

Conclusion

Thus, the anatomical and morphological features of the vegetative organs of *Schmalhausenia nidulans* (Regel) Petr. indicate a pronounced ecological specialization of the species and its adaptation to the extreme conditions of the high-alpine ecosystems of the Northern Tien Shan. The complex of xeromorphic features, including developed protective structures and features of the sheath and root tissues, indicates a high degree of adaptation to low temperatures, intense insolation, wind loads and moisture deficiency. These features simultaneously limit the ecological range of the species and reduce its ability to quickly recover, which leads to its rarity, fragmented range and small population size. *S. nidu-*

lans populations are characterized by limited natural regeneration and high dependence on the stability of high-altitude habitats. Given the high degree of ecological specialization and vulnerability, the species should be considered a rare endemic, which requires the preservation of natural habitats, limitation of anthropogenic pressure and constant monitoring of the population status.

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References

- Adamo, M., Chialva, M., et al. (2021). Plant scientists' research attention is skewed towards colourful, conspicuous and broadly distributed flowers. *Nature Plants*, 7, 574–578. <https://doi.org/10.1038/s41477-021-00912-2>
- Astuti, G., Ciccarelli, D., et al. (2019). Narrow endemic species *Bellevalia webbiana* shows significant intraspecific variation in tertiary CSR strategy. *Plant Biosystems*, 153, 12–18. <https://doi.org/10.1080/11263504.2018.435576>
- Barykina, R., Veselova, T., & Devyatov, A. (2014). *Spravochnik po botanicheskoy mikrotekhnike: Osnovy i metody*. [Handbook of Botanical Microengineering (Fundamentals and Methods)] (pp. 21–79). Moscow State University Press. (In Russian)
- Cherepanov, S. K. (1995). *Sosudistye rasteniya Rossii i sopredelnykh gosudarstv v predelakh byvshego SSSR* [Vascular plants of Russia and neighboring states, within the former USSR] St. Petersburg. [in Russian].
- D'Antraccoli, M., Carta, A., et al. (2023). Comprehensive approach to improving endemic plant species research, conservation, and popularization. *Journal of Zoological and Botanical Gardens*, 4 (2), 490–506. <https://doi.org/10.3390/jzbg4020036>
- Drude, O. (1913). *Die Ökologie der Pflanzen*. Braunschweig.
- Edwards, C., & Wyse, J. (2019). The development of plant conservation in botanic gardens and the current and future role of conservation genetics for enhancing those conservation efforts. *Molecular Frontiers Journal*, 3(3), 44–65. <https://doi.org/10.1142/S2529732519400078>
- Flora Kazakhstana*. (1956–1966). (Vol. 1–9). Alma-Ata. (In Russian)
- Gestri, G., Alessandrini, A., et al. (2023). Identifying bottlenecks in the life cycle of plants living on cliffs and rocky slopes: Lack of knowledge hinders conservation actions. *Biological Conservation*, 286, 110289. <https://doi.org/10.1016/j.biocon.2023.110289>
- Illyustrirovannyyi opredelitel' rastenii Kazakhstana*. (1962–1975). (Vol. 1–2). Alma-Ata. (In Russian)
- Krasnaya kniga Kazakhstana*. (1981). Vol. II: Plants [The Red Data Book of Kazakhstan. vol. II: Plants]. (Vol. 2, pp. 98–99). Nauka. (In Russian)
- Krasnaya kniga Kazakhstana*. (2014). Vol. II: Plants [The Red Data Book of Kazakhstan. vol. II: Plants]. (Vol. 2, pp. 645–647). ArtPrint XXI. (In Russian)
- Maunder, M., Hawkins, J., et al. (2022). Assessing extinction risk across the geographic ranges of plant species in Europe. *Plants People Planet*, 4, 303–311. <https://doi.org/10.1002/ppp3.10251>
- Opredelitel' rastenii Srednei Azii*. (1968–1993). (Vols. 1–10). Tashkent. (In Russian)
- Peruzzi, L., Astuti, G., et al. (2021). Genetic differentiation among populations of the threatened *Bellevalia webbiana* and its consequence on conservation. *Plant Biosystems*, 155, 188–193. <https://doi.org/10.1080/11263504.2020.1857866>
- Peruzzi, L., Dolci, D., et al. (2022). Potential climatic and elevational range shifts in the Italian narrow endemic *Bellevalia webbiana* under climate change scenarios. *Nature Conservation*, 50, 145–157. <https://doi.org/10.3897/natureconservation.50.91265>
- Permyakov, A. I. (1988). *Mikrotekhnika* [Microengineering]. Moscow State University Press. (In Russian)
- Prozina, M. N. (1960). *Botanicheskaya mikrotekhnika* [Botanical Microengineering]. Moscow State University. (In Russian)
- Raunkiaer, C. (1934). *The life forms of plants and statistical plant geography*. Clarendon Press.
- Rabotnov, T. A. (1970). The importance of consortium relationships in determining plant relationships in phytocenoses. *Bulletin of the Moscow Society for Natural History. Biological Section*, 75 (2). Publishing house of Moscow University. (In Russian)
- Salles, D., Carmo, F., et al. (2023). Global hotspots of plant phylogenetic diversity. *New Phytologist*, 240, 1636–1646. <https://doi.org/10.1111/nph.19151>
- Serebryakov, I. G. (1962). *Ekologicheskaya morfologiya rasteniy* [Ecological morphology of plants]. Moscow: Nauka. (In Russian)
- Slezák, M., & Douda, J. (2022). Topographic indices predict the diversity of Red List and non-native plant species in human-alartered riparian ecosystems. *Ecological Indicators*, 139, 108949. <https://doi.org/10.1016/j.ecolind.2022.108949>
- Smirnova, O. V., & Zaugolnova, L. V. (1976) *Kriterii vydeleniya vozrastnykh obshchiny i osobennosti khoda ontogeneza u rasteniy raznykh biomorf // Tsenopopulyatsii rasteniy (osnovnyye ponyatiya i struktura)* [Criteria for identifying age states and

features of the course of ontogenesis in plants of different biormorphs // Cenopopulations of plants (basic concepts and structure)]. (pp. 14–43). Moscow: Nauka. [in Russian]

Tiburtoni, M., Astuti, G., et al. (2022). Integrative taxonomy of *Armeria arenaria* (Plumbaginaceae). *Biology*, 11 (7), 1060. <https://doi.org/10.3390/biology11071060>

Uranov, A. A. (1960). Zhiznennoye sostoyaniye vida v rastitel'nom soobshchestve [The vital state of a species in a plant community]. *Bulletin of the Moscow Society for Natural History. Biological Section*, 65 (3), pp. 77–92. Moscow State University Press. (In Russian)

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