BIODIVERSITAS
Volume 26, Number 5, May 2025
Pages: 2051-2064

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260504

Implications of population size, structure, and soil parameters for the conservation of *Allochrusa gypsophiloides* in Kazakhstan

ASEM TASTANBEKOVA[1], KANAT KULYMBET[1,2,♥], MERUYERT KURMANBAYEVA[1], MARIA HÖHN[3], MOLDIR ZHUMAGUL[1,4,5], OZODBEK ABDURAIMOV[6], GANI I. ISSAYEV[7], ORYNBASSAR ALSHYNBAYEV[8], MURAT TOKTAR[2], ZHASSULAN SMANOV[9]

[1]Department of Biodiversity and Bioresources, Al-Farabi Kazakh National University. Al-Farabi Ave 71, Almaty 050040, Kazakhstan
[2]Department of Soil Ecology, U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry. Al-Farabi Ave 75B, Almaty 050040, Kazakhstan. Tel./fax.: +7-778-3858788, ♥email: qulymbet.qanat@gmail.com
[3]Department of Botany, Hungarian University of Agriculture and Life Sciences. Pater Karoly Str. 1, Godollo 2100, Hungary
[4]Astana International University. Kabanbay Batyr 8, Astana 020000, Kazakhstan
[5]Astana Botanical Garden. Orynbor Str. 16, Astana 010000, Kazakhstan
[6]Institute of Botany, Academy Sciences Republic of Uzbekistan. Durmon yuli Str. 32, Tashkent 100047, Uzbekistan
[7]Khoja Akhmet Yassawi International Kazakh-Turkish University. Bekzat Sattarhanov Str. 29, Turkestan 161200, Kazakhstan
[8]Mukhtar Auezov South Kazakhstan Research University. Tauke khan Ave 5, Shymkent 160012, Kazakhstan
[9]Space Technologies and Remote Sensing Center, Al-Farabi Kazakh National University. Al-Farabi Ave 71, Almaty 050040, Kazakhstan

Manuscript received: 12 February 2025. Revision accepted: 27 April 2025.

Abstract. *Tastanbekova A, Kulymbet K, Kurmanbayeva M, Höhn M, Zhumagul M, Abduraimov O, Issayev GI, Alshynbayev O, Toktar M, Smanov Z. 2025. Implications of population size, structure, and soil parameters for the conservation of* Allochrusa gypsophiloides *in Kazakhstan. Biodiversitas 26: 2051-2064.* The study examines the distribution, population size, and ecological conditions of *Allochrusa gypsophiloides* in the Karatau Mountain Range, Kazakhstan. This rare species, listed in the Red Data Book, was found in four populations (P1-P4): Sayasu Gorge (P1), Kuyuk Pass (P2), and The Vicinity of Birlik (P3) and Kenestobe Villages (P4). Geobotanical research assessed species composition, plant communities, and ontogenetic structure using Uranov's classification. Soil properties, including humus content, nutrient levels, and pH, were analyzed. The total number of *A. gypsophiloides* individuals across all sites was 91, with low population densities (0.15-0.29 individuals/m²). Age structure analysis revealed no senile individuals, with generative individuals predominating in two populations. Generative (g1) individuals accounted for 20.0% in P1 and 18.52%, 24.14%, and 33.34% in P2-P4, respectively. Post-generative (sub-senile) individuals were rare (0-13.34%). Despite a relatively stable age composition, low population density remains a concern. Soils across populations shared similar characteristics: low humus and nutrient content, moderately to strongly alkaline pH, and sandy loam to medium loam textures. The species' restricted distribution, low density, and specific soil requirements make it highly vulnerable to environmental changes and human activities. Conservation efforts of *A. gypsophiloides* should be aimed at protecting key habitats (Sayasu Gorge, Kuyuk Pass, and The Vicinity of Birlik and Kenestobe) with limited economic activity, introducing a system for long-term monitoring of the number and age structure of populations using standardized techniques, as well as assessing opportunities for reintroduction of the species to suitable sites. Further research on reproductive biology and ecological interactions is essential for ensuring the species' long-term survival in the Syrdarya Karatau Mountain Range.

Keywords: Caryophyllaceae, conservation, endemic species, Karatau, population ecology

INTRODUCTION

Allochrusa is a genus belonging to the family Caryophyllaceae. This family includes 81 genera and 2625 species (Gemejiyeva and Grudzinskaya 2018), where 215 species from 30 genera are found in Kazakhstan (Mursaliyeva et al. 2023a). Previously, species of the genus *Allochrusa* were included in the genus *Acanthophyllum*; which consisted of nine species. Currently, The Plant List (2024) includes eight recognized species into *Allochrusa*, namely *A. bungei*, *A. paniculata*, *A. gypsophiloides*, *A. persica*, *A. tadshikistanica*, *A. takhtajanii*, *A. transhyrcana*, *A. versicolor*, while according to the POWO (2025), there are 11 species belong to this genus with the addition of *A. lutea*, *A. pulchella*, *A. ferganensis*.

Allochrusa gypsophiloides (syn. *Acanthophyllum gypsophiloides*) is an endemic Central Asian species (Mursaliyeva et al. 2023b). This plant grows in desert loess steppes and on gravelly foothill slopes. It is a mesoxerophyte species with flowering period is May-July (Ghaffari 2021). *Allochrusa gypsophiloides* is found in the mountains of Central Asia from the foothills to the mid-mountain belt. The eastern border runs along the Western Tien Shan. In Kazakhstan, it is found in the Syrdarya Karatau, Talas Alatau, Kazygurt, and Kyrgyz Alatau Ranges (Aidarbayeva et al. 2022; Berdikulov et al. 2023). The species has a long lifespan sustaining with a strong rhizome and highly branched above-ground part. Plant height is 50-90 cm, with a strongly developed tap root. Stems are numerous, straight, whitish-colored; leaves are up to 2 cm long and 3 mm wide, linear-awl-shaped. Flowers are the shoot tips with narrowly white-edged teeth branches in loose dichasias (Mamadalieva et al. 2023).

In terms of phytochemical composition, *Allochrusa* is rich in biologically active compounds, including saponins, amino acids, essential oils, inulin, as well as carbohydrates, flavonoids, and vitamins. *Allochrusa*'s root is a rich source of saponin, a natural biosurfactant with high potential for food applications. In addition, saponin has hemolytic activity, anti-inflammatory, antifungal and adjuvant properties (Tuleuov et al. 2018; Tileshova et al. 2024). *Allochrusa gypsophiloides* is characterized by an increased level of triterpene saponins of the oleanolic series in the roots. The saponins *Allochrusa* B, C and D- derivatives of gypsogenin and quilic acid - were extracted from them (Khatuntseva et al. 2012). For many years, *A. gypsophiloides* was exported as a valuable source of plant saponins with annual planned volumes of dry roots collection reached 700-800 tons (Mamadalieva et al. 2024). The raw materials of *A. gypsophiloides* are used in food, pharmaceutical, construction, fur, textile, dyeing and perfume industries (Jakimiuk et al. 2022; Temirgaziev et al. 2019). In the 50-80s, technical saponin *A. gypsophiloides* was used in the manufacture of foam concrete to improve the technological qualities of concrete, heat-insulating properties, and durability of concrete structures of irrigation systems. Industrial harvesting of soap root took place in Central Asian and Kazakhstan, nevertheless since the 1950s, due to the depletion of natural thickets in Central Asian countries, Kazakhstan has remained the sole supplier of *A. gypsophiloides* (Mursaliyeva et al. 2023c).

Allochrusa gypsophiloides is included in the Red Data Books of Kazakhstan (1978; 1981; 1984, 2014) (Red Data Book of Kazakhstan 2014). Unregulated root harvesting has caused a sharp decline in population size and a significant reduction in the species' range. Currently, only a small portion of the population is protected within the Aksu-Zhabagaly and Karatau Reserves (Mursalıyeva et al. 2020). Previously, the species was one of the most widespread plants in its range. Currently, this species has a relatively limited territory, and it is found in the foothills of some mountain ranges of the Western Tien Shan (Mursalıyeva and Imanbayeva 2020).

Biodiversity conservation is a global priority, as essential bioresources are limited and face the risk of decline or extinction. Its significance is recognized across all ecosystem levels, with international programs dedicated to assessing, monitoring, and preserving biodiversity (Gafforov et al. 2024; He et al. 2024; Myrzagaliyeva et al. 2024). In Central Asia, significant research has been conducted in this field (Abduraimov et al. 2022, 2023; Saribaeva et al. 2022; Khojimatov et al. 2023), highlighting the need for continued efforts to protect and sustain biodiversity.

The aim of this study was to investigate and assess the distribution and population abundance of *A. gypsophiloides* and to characterize soil properties of their populations in natural habitats, including the ontogenetic structure of their populations. The following hypotheses have been put forward in the framework of the study: (i) populations of *A. gypsophiloides* have low density and limited distribution due to specific soil conditions and environmental factors; (ii) generative individuals dominate populations, which may indicate the stability of the species in the short term, but the low density and absence of senile individuals indicates potential risks for long-term survival; (iii) soil characteristics such as humus level, nutrient content and pH play a key role in creating optimal conditions for the growth of the species. The obtained results can serve as a scientific basis for developing measures for the conservation and sustainable use of *A. gypsophiloides*, including recommendations for regulating anthropogenic load and selecting priority areas for monitoring and restoring populations.

MATERIALS AND METHODS

Study area and period

The object of the study is *A. gypsophiloides* population, distributed in Syrdarya Karatau, Kazakhstan. The research work was carried out in the period 2022-2024. Geographical zoning and names of mountain ranges are indicated according to the Physical Map of Kazakhstan (2023). During the study, four populations of *A. gypsophiloides* were identified, the first population (P1) in Sayasu Gorge, the second population (P1) in Kuyuk Pass, the third population (P3) Vicinity Birlik Village, and the fourth population (P4) Vicinity Kenestobe Village (Figure 1) (Pop 1 - E 70°43'12.00" N 42°53'60.00"; Pop 2 - E 70°58'40.00" N 42°45'33.00"; Pop 3 - E 69°29'33.36" N 42°58'49.44"; Pop 4 - E 69°37'18.16" N 43° 2'7.69").

The Syrdarya Karatau ridge extends 420 km northwest from the western end of the Kyrgyz Alatau and the northern slopes of the western Talas Alatau, reaching into the arid landscapes of the Syrdarya's right bank. Its average absolute elevation ranges from 1,000 to 1,500 meter above sea level (m asl), while relative heights from the foothills are just a few hundred meters. The ridge is composed of shales, sandstones, conglomerates, and limestones. Its peaks are relatively flat, while the slopes are steep and rugged (Imanbayeva et al. 2024; Kenesbay et al. 2024).

In Syrdarya Karatau, the average temperature in January is -10°C. However, the difference between the average January temperatures on the northeastern and southwestern slopes ranges from 4-6°C, due to the warming influence of air masses on the southwestern slopes. Annual precipitation varies depending on elevation: the foothill slopes receive 200-400 mm, while the higher areas receive 400-600 mm. The distribution of vegetation in this climate is primarily influenced by three key factors: terrain, soil composition, and moisture availability (Terekhov et al. 2021).

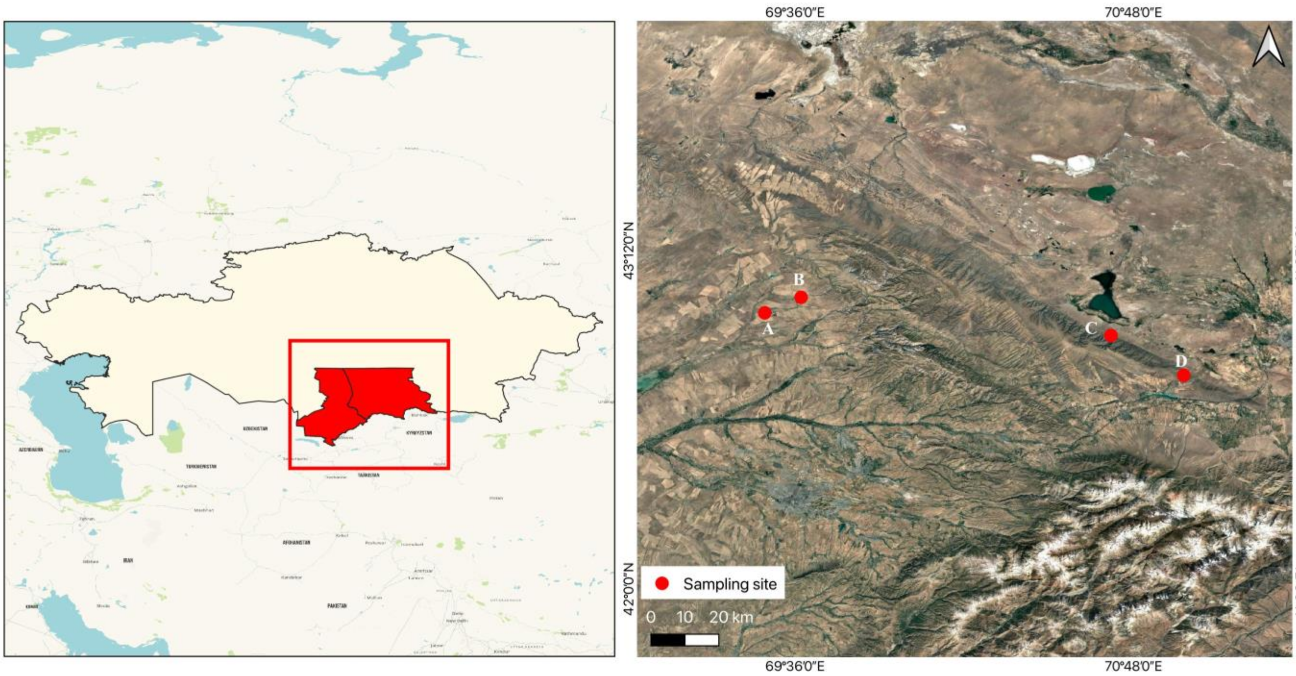


Figure 1. Map of the four studied populations of *Allochrusa gypsophiloides*: Sayasu Gorge (P1), Kuyuk Pass (P2), Vicinity Birlik Village (P3), Vicinity Kenestobe Village (P4)

At the foot of the Karatau Range, to the northwest, the plains are covered with grey-brown desert soils and light northern serozem soils, which gradually transition into southern serozem soils further south. In the mountains, light and ordinary serozem soils are predominant (Pachikin et al. 2022). On the steep and sloping slopes of both Northern and Southern Karatau, saline mountain serozem soils are widespread, while lower foothill areas are characterized by serozem soils (Kakabayev et al. 2024).

Geobotanical analysis

The study was carried out in accordance with generally accepted methods in population studies. The coordinates of all populations were determined using a GPS unit. Field geobotanical studies were carried out to identify phytocenotic features of *A. gypsophiloides* populations. The species composition and vegetation cover of plant communities were determined (Kubentayev et al. 2021; 2023; Tynybekov et al. 2024). The age of the population was determined using the Uranov's classification (Ydyrys et al. 2024).

Populations were characterized using botanical description forms. Accordingly, in each population, 15 plots with size of 100 m^2 per plot were allocated using a common methodology, resulting a total of 60 observation plots. Population density was determined by the number of individuals per unit area. Special attention was given to mean density, i.e. the number of individuals per unit of total space or ecological density, i.e. the number of individuals per unit of inhabited space that could actually be occupied by the population. This was followed by the following main steps: determination of the vegetation type based on dominant species; floristic composition of the community, and morphological features of the 15 replicates. *Allochrusa gypsophiloides* distribution maps and schematic maps were prepared using ArcGIS GIS software (ArcGIS Desktop 10.4 2024).

Soil analysis

During the field studies, morphological methods were applied to ensure the accuracy and reliability of soil diagnostics, as well as to characterize their morphological properties (Korolyuk 2012). In total, 12 soil profiles were laid in the areas where populations were found. For chemical soil analysis, 48 samples were collected, each analyzed in four replicates. Soil samples were analyzed in the analytical laboratory of U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry, Kazakhstan. Soil organic matter content was determined by Tyurin method. Total nitrogen was analyzed by titration (Kjeldahl method). Total phosphorus and potassium were measured using a spectrophotometer (Specord 210 Plus, Germany). Soil pH was determined using a pH-meter (I-160MI, 2007, Russia). CO_2 content-using a calcimeter. Granulometric composition was determined by Kachinsky method. Total salt content in soil was analyzed using a flame photometer (Flapho4, Germany).

Statistical analysis

Correlation analysis was calculated using the R-studio statistical platform to analyze morphological parameters between populations (R-Studio Team 2020). The Pearson correlation coefficient was used as a measure of the relationship between variables and the level of statistical significance was set at $P<0.05$.

RESULTS AND DISCUSSIONS

Distribution of *Allochrusa gypsophiloides*

Allochrusa gypsophiloides is distributed in the Syrdarya Karatau, Talas Alatau, Kazygurt, Kyrgyz Alatau in South Kazakhstan and in the Chatkal and foothills of the Ugam Range (Uzbekistan). Herewith the herbarium specimens studied to obtain the geographical distribution of *A. gypsophiloides*: Syrdarya Karatau, Boztorgai Gorge, 19.VII.1974, Pimenova ME and Sdobnina LI (MW); South Kazakhstan, Beltau Mountain (Alymtau), 21.V.1989, Klyuikov EV (MW); Uzbekistan, Tashkent Region, Galva-sai (Gazalkent), 8.VII.1969, Dyukhananov (MW); Uzbekistan, Tashkent Region, western spurs of Chatkal ridge, slope above Chatkal river opposite Obirahmat tract, 9.VI.2015, Gaziev A (TASH); South Kazakhstan, Talas Alatau, Aksu-Zhabagly reserve, Aksu canyon, 14.VII.1961, Barabanov E (MW); Ugam River Gorge, stony slope, 19.VII.1958, Medvedeva L (LE); South Kazakhstan, Bostandyk, Ugam Ridge, headwaters Sidzhak-sai Gorge, stony slope, 22.VII.1953, Pavlov V (MW); Karatau Mountains, Bir-Isak River, 3.VI. 1952, Parfentova N (MW); Zhambul Region, Karatau Mountains, foothill steppe under Mingelke, 28.VI.1940, Pavlov N (MW); Western Tien-Shan, Karatau Mountains, northern foothills, rubbly slope, near Suleyman-say Mine, 19.VI.1936, Chilikina L (MW); South Kazakhstan, Arys District, 15.2 km west of Montaitas Village, 28.VI.2015, Gemedzhieva N (AA); South Kazakhstan, Kazygurt District, 4.2 km south-west of Rabat settlement, 1.VII.2015, Gemedzhieva N (AA); South Kazakhstan, Saryagash District, 19.3 km north-west of Shymyrbai settlement, 3.VII.2015, Gemedzhieva N (AA); South Kazakhstan, Tolebi District, 4 km west of Abai settlement, 6.VII.2015, Gemedzhieva N (AA); Zhambyl Region, eastern slope of Syrdarya Karatau, Sayasu Gorge, gorge slope, 12.VI.2022, Kulymbet K and Tastanbekova A (AA); Zhambyl Region, Syrdarya Karatau, Kuyuk Pass, rubbly slope, 14.VI.2022, Kulymbet K and Tastanbekova A (AA); Turkestan Region, Vicinity Birlik Village, 16.VI.2022, Kulymbet K and Tastanbekova A (AA); Turkestan Region, Vicinity Kenestobe Village, 16.VI.2022, Kulymbet K and Tastanbekova A (AA). The distribution map is presented in Figure 2.

Phytocenotic structure of *Allochrusa gypsophiloides*

During the field studies, four populations of *A. gypsophiloides* were characterized: P1 in Syrdarya Karatau: Sayasu Gorge, P2 in Kuyuk Pass, P3 in Karatau Foothill Plain, Vicinity of Birlik Village, and P4 in Karatau Foothill Plain, Vicinity of Kenestobe Village. The species inhabits gravelly foothill slopes and stony hills (Figure 2).

Allochrusa gypsophiloides starts its vegetative growth from late April and lasts to early June. The flowering period typically spans from early June to August, followed by fruiting in August. The overall vegetation period lasts about five months. The seasonal development of this species is influenced by the altitude of its habitat, with higher elevations potentially extending the vegetative period. The plants produce a limited number of seeds, which also have relatively low germination rates. In its natural habitat, *A. gypsophiloides* reproduces exclusively through seeds, while vegetative reproduction was not observed. The species is highly dependent on seed-based reproduction and is particularly vulnerable to anthropogenic pressures, such as plowing and overgrazing, which can severely impact its growth and survival.

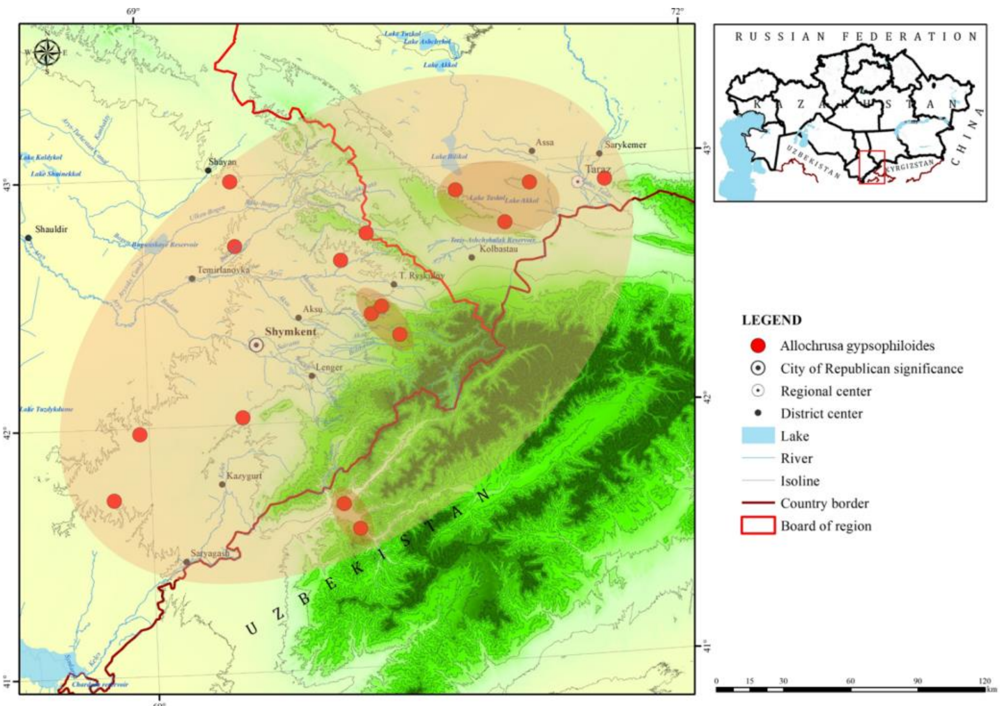


Figure 2. Distribution sites of *Allochrusa gypsophiloides* based on herbarium specimens

P1. Syrdarya Karatau, Sayasu Gorge. Exposure: eastern, located on slope 25^0. Dominant species in a community included *A. gypsophiloides, Rosa persica, Cerasus erythrocarpa, Lappula occultata.* Total vegetation cover: 70%. Associated species were *Pseudosophora alopecuroides, Ziziphora clinopodioides, Lagochilus platycalyx, Centaurea pseudosquarrosa, Astragalus globiceps, Artemisia leucodes, Eremurus tianschanicus, Achillea biebersteinii, Halimodendron halodendron, Lappula sinaica, Taeniatherum crinitum. Ferula karatavica, Poa bulbosa, Cousinia affinis, Couisinia syrdariensis, Aegilops cylindrica, Phlomis salicifolia*. Stony-gravelly, 60% large stones.

P2. Syrdarya Karatau, Kuyuk Pass. Exposure: north-western, located on the slope 17^0. Dominant species in a community included *A. gypsophiloides, R. persica, A. cylindrica, A. leucodes.* Total vegetation cover: 80%. Associated species were *C. erythrocarpa, C. pseudosquarrosa, Rhaphidophyton regelii, R. persica, Cousinia karatavica, Cousinia alberti, Capparis herbacea, Atraphaxis pyrifolia, Rosa hissarica, Z. clinopodioides, P. bulbosa, Galium verum, F. karatavica, P. salicifolia, A. globiceps, Alcea nudiflora*. Stony-gravelly, stony 30-40%.

P3. Karatau plain, vicinity Birlik village. The relief is an undulating plain. Dominant species in a community included *A. gypsophiloides, Achillea millefolium, R. persica, A. leucodes.* Total vegetation cover: 70%. Associated species were *Phragmites australis, P. alopecuroides, T. crinitum, Haplophyllum perforatum, Haplophyllum latifolium, Hulthemia berberifolia, Artemisia diffusa, Ceratocarpus utriculosus, Psoralea drupacea, Acroptilon repens, Plantago lanceolata, Alhagi pseudoaihagi, Ferula foetida, Pseudohandelia umbelifera*.

P4. Karatau plain, vicinity Kenestobe village. The relief is an undulating plain (Figure 3). Dominant species in a community included *A. gypsophiloides, A. millefolium, A. leucodes, A. diffusa.* Total vegetation cover: 80%; Associated species were *T. crinitum, C. utriculosus, Polygonum patulum, H. perforatum, H. latifolium, Malva neglecta, P. alopecuroides, Glycyrrhiza glabra, P. lanceolata, M. neglecta, R. persica, Artemisia cina, Phlomoides sewerzovii, Handelia trichophylla, P. umbelifera, P. drupacea*.

In nature, there is a noticeable trend of sharp population declines for the studied species. Across all populations, the total number of *A. gypsophiloides* individuals was 91. The average population density ranged from 0.15 to 0.29 individuals per square meter across four different populations. The morphometric and quantitative indicators of *A. gypsophiloides* in the studied populations are presented in Table 1.

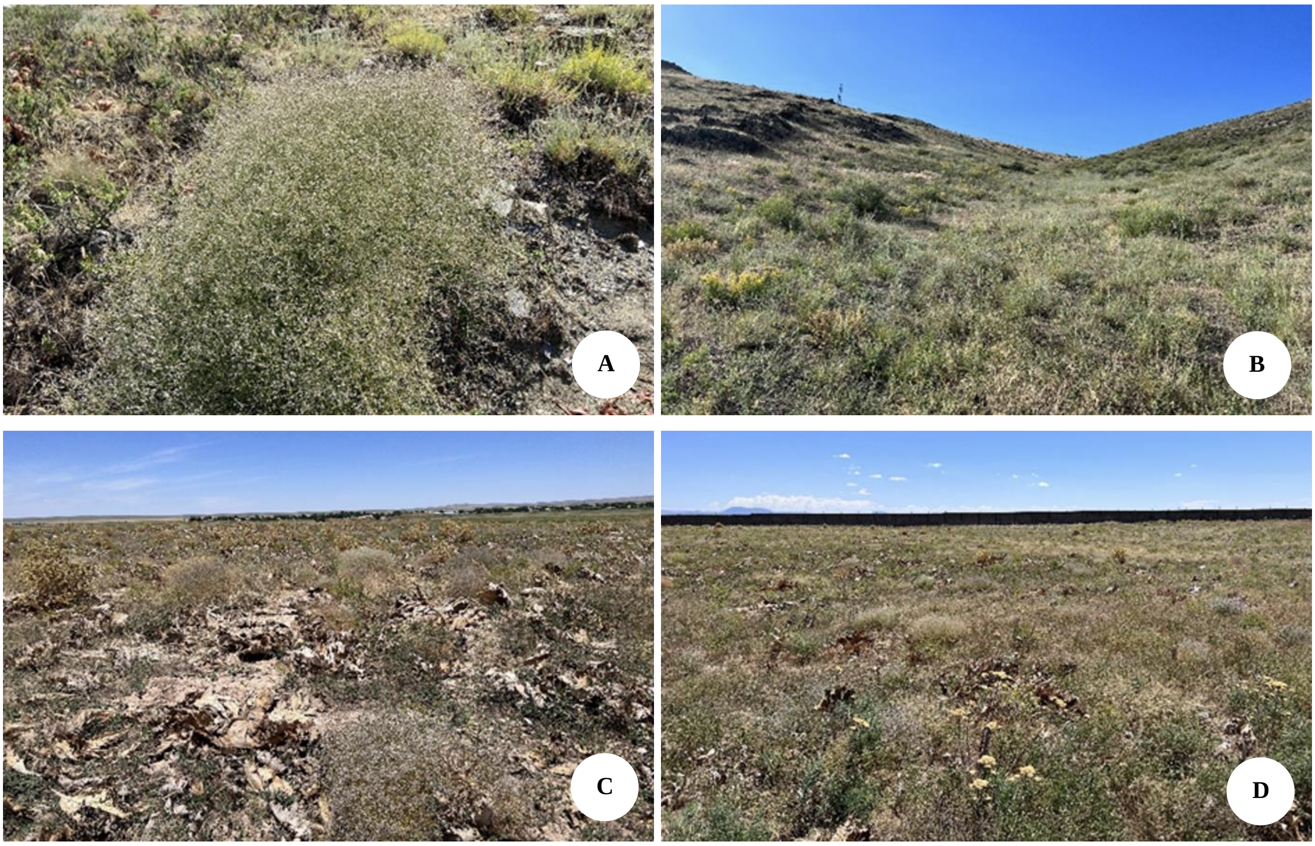


Figure 3. Ecological conditions of *Allochrusa gypsophiloides* habitats in different populations in Kazakhstan: A. Rocky-gravelly slope in Sayasu Gorge (population 1); B. Northwestern slope in Kuyuk Pass (population 2); C. Undulating plain in Vicinity Birlik Village (population 3); D. Undulating plain in vicinity Kenestobe Village (population 4)

Table 1. Morphometric and quantitative indicators of *Allochrusa gypsophiloides* in Syrdarya Karatau, Kazakhstan

Morphometric and quantitative indicators		Height of generative individuals at the time of flowering (cm)	Number of adults per 1 m^2 (pcs)	Number of shoots per individual (pcs)	Number of flowers per individual (pcs)
P1	M	67.04	0.15	297.80	958.10
	SD	7.43	0.01	37.43	71.53
P2	M	35.46	0.27	218.10	673.60
	SD	4.12	0.03	33.53	45.58
P3	M	40.22	0.29	226.20	725.20
	SD	4.93	0.03	38.43	68.63
P4	M	44.42	0.21	251.40	832.70
	SD	5.26	0.02	39.47	73.43

Note: M: Mean; SD: Standard Deviation

The study analyzed the types of populations. The longest developmental stage in the ontogeny of *A. gypsophiloides* occurs during the middle-aged generative phase. As a result, the characteristic ontogenetic spectrum for this species is centered around the mature generative individuals, with the highest concentration observed in this age group. Based on these findings, most populations were classified as generative and transitional.

In *A. gypsophiloides*, g_1 individuals (young generative plants) are found in large numbers across the populations. However, senile (s) individuals are absent in all studied populations, and immature (im) individuals are not present in populations P3 and P4. In populations P2, P3, and P4, generative individuals are predominant. In population P1, the proportion of g_1 (young generative) individuals is 20.0%, while in populations P2, P3, and P4, this proportion ranges from 18.52% to 33.34%. The number of post-generative individuals across all populations is minimal, with the proportion of sub-senile (ss) plants varying from 0% to 13.34%.

The overall condition of population P1 is generally satisfactory, though the plants are more spaced out, and their overall abundance is significantly lower compared to the other populations. In P2, post-generative individuals are absent, and the number of pre-generative and generative individuals sufficiently abundant. Specifically, the population consists of 44.44% immature (im), 33.34% vegetative (v), 18.51% young generative (g1), and 3.71% mature generative (g_2) individuals. In terms of age structure, among all the studied populations P2 is the youngest. P3 and P4 exhibit two distinct age classes: the first class (24.14-33.34%) consists of young generative plants (g1), while the second class (28.57-44.83%) includes middle-aged generative individuals (g_2). These age distributions suggest that the natural habitat conditions in these populations are more favorable compared to those of other populations. In P4, generative individuals make up a substantial portion, ranging from 9.52% to 33.4% of the total population. Notably, sub-senile (ss) and senile (s) individuals are absent. The population's size is considered medium, and its overall condition is rated at a medium level. In terms of individual abundance, P4 falls within the normal category. Regarding plant development, the individuals in this population are fully mature, with well-developed leaves and flowers.

The populations of this species are generally considered normal, though most individuals are incompletely mature. The absence of certain age groups on the lower end of the age spectrum can be attributed to irregular seed regeneration, the loss of immature individuals due to various climatic factors, and intensive grazing. A characteristic trait of the species is the low presence of senile individuals in populations, as most do not survive beyond the mature generative stage.

To evaluate the significance of differences between populations, a correlation analysis was conducted using the following parameters: the height of generative individuals at the time of flowering, the number of individuals per square meter (m^2), the number of shoots, and the number of flowers. According to the correlation analysis of the morphological parameters between populations, a weak negative correlation was observed in the height of generative individuals between P1 and P3, as well as between P2 and P4. Regarding the number of individuals, a weak positive correlation was found between P1 and P2, while a weak negative correlation was noted between P1 and both P3 and P4. In terms of the number of flowers, a positive correlation was observed between P1 and P2, as well as between P2 and P4 (Figure 4).

To examine the relationship between trait groups of generative individuals of *A. gypsophiloides*, we conducted a correlation analysis of morphological indicators. Pearson correlation analysis revealed that, during flowering, the average height of individuals in P2, P3, and P4 showed a positive correlation with both the number of shoots and the number of flowers. In all populations, however, the height of individuals during flowering was negatively correlated with the number of individuals. The number of shoots exhibited the strongest positive correlation with the number of flowers (Nf: 0.99). Additionally, in P2 and P4, a positive correlation was observed between the height of generative individuals and the number of shoots (Figure 5).

A strong to moderate positive correlation was observed between the number of shoots and the number of flowers, as well as between the height of generative individuals and the number of flowers. In most populations, the relationships between traits were characterized by moderate correlation coefficients. The lowest correlation values were found in populations inhabiting unfavorable climatic conditions. As environmental conditions deteriorate, the average correlation level may decrease, indicating signs of ecological stress in plants.

Soil analysis of the *Allochrusa gypsophiloides* habitats

Morphological characteristics of soil

The soil profile in the Sayasu Gorge of Syrdarya Karatau (P1) is presented in Table 2. The site has a slope angle of 25^0 (very steep) and soil type of Mountain northern serozem soils. In general, the morphological characteristics of the soil are light gray, sandy loam, compacted, dusty, with a granular structure, having a high content of stones. From a depth of 35 cm (A+B), the profile shows a slight boiling under the influence of acids.

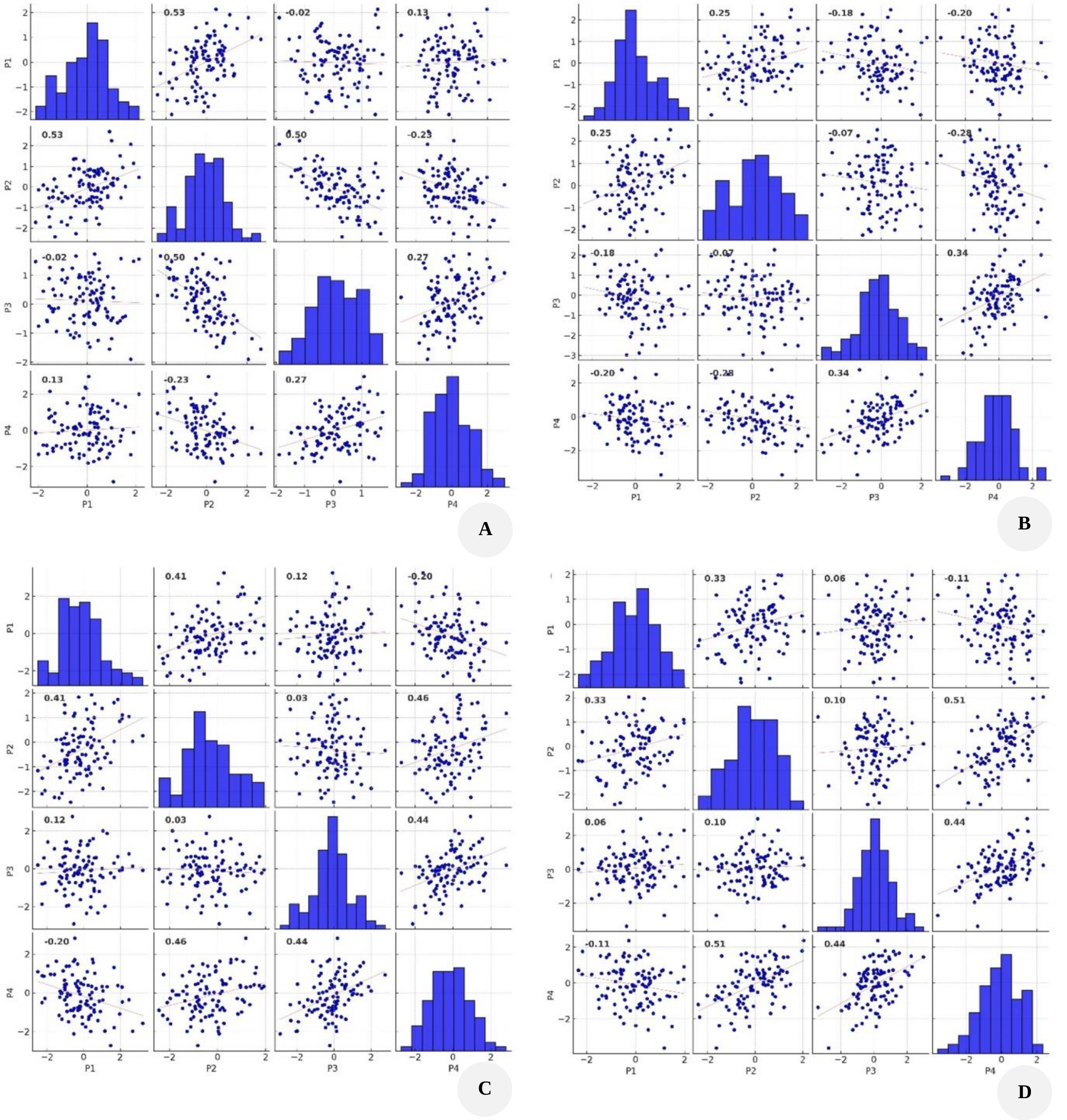


Figure 4. Correlation analysis of morphometric parameters between populations (A-D): A. Height of generative individuals at the time of flowering period (cm); B. Number of adult individuals (pcs); C. Number of shoots per individual (pcs); D. Number of flowers per individual (pcs)

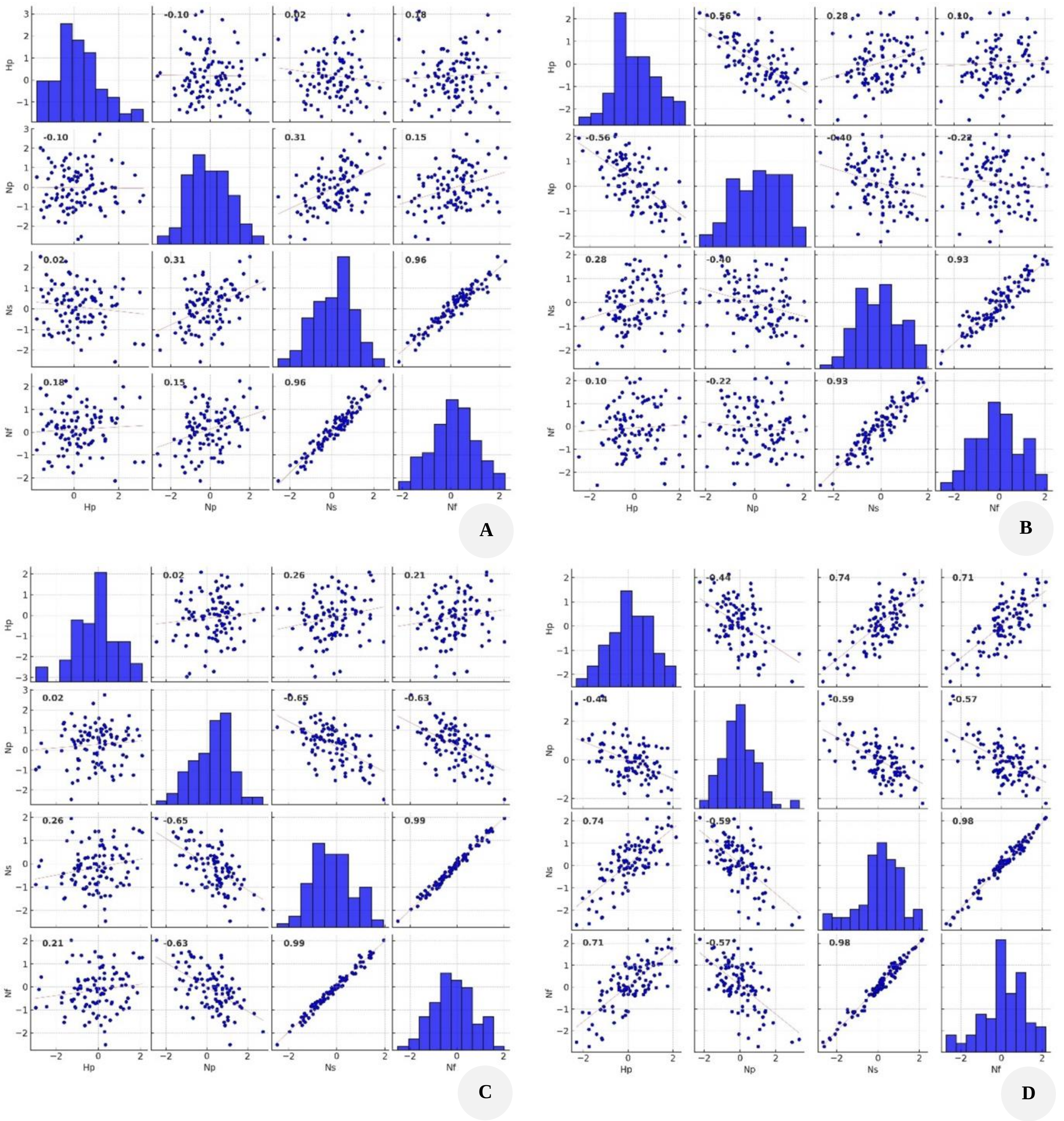


Figure 5. Morphometric parameters and quantitative indicators of individuals in populations P1-P4 (A-D): Hp. Height of generative individuals at the time of flowering period (cm); Np. Number of adult individuals (pcs); Ns. Number of shoots per individual (pcs); Nf. Number of flowers per individual (pcs)

Table 2. Morphological characteristics of soil in Sayasu Gorge of the Syrdarya Karatau (P1), Kazakhstan

Horizon	Depth (cm)	Thickness (cm)	Description
A	0-15	15	Light gray, dry, sandy loam, dust-granular, powdery, friable, finely porous, abundant fine roots and root hairs, no plant residues, rocky inclusions, not boiling, transition clear
B	15-35	20	Dark gray, dry, sandy loam, powdery-granular, dense, close to fused, rich root system, rocky inclusions, not boiling, transition gradual
BC	35-70	35	Brown, slightly moister than the upper horizon, sandy loam, granular, compacted, contains only fine roots, rocky inclusions, slightly boiling

Table 3. Morphological characteristics of soil in Kuyuk Pass of the Syrdarya Karatau (P2), Kazakhstan

Horizon	Depth (cm)	Thickness (cm)	Description
A	0-10	10	Gray-brown, dry, compacted, dusty-granular, low moisture content, abundant fine roots and rocky inclusions, gradual transition to the next horizon, not boiling
B	10-30	20	Light gray-brown, dry, compacted, dust-granular, low moisture content, contains many roots, and has rocky inclusions, slightly boiling, transition gradual
BC	30-70	40	Light brown, compacted, granular, thin roots present, containing gravelly and rocky inclusions, slightly boiling

The soil profile in Kuyuk Pass of the Syrdarya Karatau (P2) is presented in Table 3. The site has a slope angle: 17^0 (moderately steep) with soil type of Mountain gray-brown soils. Mountain gray-brown soils are characterized by a compacted, granular texture, with low moisture retention capabilities. These soils are rich in rocky inclusions, which contribute to their coarse structure, and exhibit a slightly alkaline reaction. Due to their compact nature and limited ability to hold moisture, these soils can present challenges for plant growth, particularly in areas where water availability is a key factor for development.

The soil profile in the Karatau foothill plain of the Syrdarya Karatau (P3 and P4) is presented in Table 4. The site has a slope angle: 3^0 (undulating plain) with soil type of Southern serozem soils. In general, the soil has light gray coloration and is composed of medium loam with a granular texture. It is dense and exhibits a high degree of acidity throughout all soil horizons.

Soil chemistry

The results of laboratory soil analysis of mountain northern serozem soils in Sayasu Gorge (P1) showed that the humus content in the 0-70 cm layer was at a very low level, ranging from 1.52% to 2.62%. The availability of nutrients is also low: nitrogen: 0.140-0.160%; phosphorus: 0.172-0.192%; potassium: 3.125-3.312%. The soil reaction is slightly alkaline, with a pH of 7.72-7.98. The CO_2 content ranged from 0.26 to 0.42 (Figure 4).

The mountain gray-brown soils in Kuyuk Pass (P2), the humus content was low, ranging from 2.62% to 2.96%. Nutrient elements were also present in small amounts: nitrogen: 0.100-0.120%; phosphorus: 0.160-0.172%; potassium: 3.250-3.312%. The soil reaction is slightly alkaline, pH 7.85-7.98. The CO_2 content ranged from 0.26 to 0.51. The mountain southern serozem soils in the Karatau plain (P3 and P4), the humus content was very low, ranging from 0.83% to 0.96%. The availability of nutrients is also low: nitrogen: 0.040-0.050%; phosphorus: 0.144-0.160%; potassium: 2.187-2.312%. The soil reaction was medium alkaline, pH of 8.55-8.69 and CO_2 content of 4.91 to 7.04.

P3 had the lowest humus content, suggesting poor organic matter levels and limited decomposition of plant residues. P2, on the other hand, exhibited a slightly higher humus level compared to the other populations, likely due to more favorable local environmental conditions and microclimate factors. Despite its relatively higher humus content, P2 contains less nitrogen than P1, which may limit plant growth and development. P3 showed significantly higher CO_2 content, which is associated with intensive carbonate decomposition in an alkaline environment, whereas P1 and P2 had low CO_2 levels.

Soil texture

The granulometric composition of the soil profile in Sayasu Gorge (P1), the coarse sand fraction (0.25-1.0 mm) predominated, accounting for 66.58%, followed by the fine sand fraction (13.70%). The sequence of decreasing fraction content in the soil profile (%) was as follows: coarse sand 66.58% < fine sand 13.70% < fine dust 6.62% < dust 4.87% < coarse dust 4.19% < medium dust 4.04%. Based on the content of fractions <0.01 mm, the soil was classified as sandy loam (15.53%).

The granulometric composition of the soil profile in Kuyuk Pass (P2), the coarse sand fraction (0.25-1.0 mm) also predominated, accounting for 56.95%, followed by the fine sand fraction (27.97%). The sequence of decreasing fraction content in the soil profile (%) was as follows: coarse sand 56.95% < fine sand 27.97% < dust 5.11% < coarse dust 3.77% < medium dust 3.37% < fine dust 2.83%. Based on the content of fractions <0.01 mm, the soil was classified as sandy loam (11.30%). The granulometric composition of the soil profile in the Karatau plain (P3 and P4), the coarse dust fraction (0.01-0.05 mm) predominated, accounting for 33.05%, followed by the medium sand fraction (25.35%). The sequence of decreasing fraction content in the soil profile (%) was as follows: coarse dust 33.05% < medium sand 25.35% < fine dust 16.93% < dust 13.00% < medium dust 9.21% < coarse sand 2.46%. Based on the content of fractions <0.01 mm, the soil was classified as medium loam (39.14%) (Figure 6).

P1 and P2 are located in areas with sandy loam soil, which has a high sand fraction, making the soil relatively dry and low in fertility. In contrast, populations 3 and 4 inhabit areas with loamy soil that is rich in fine particles, which helps retain moisture and improves soil fertility.

P3 and P4 are situated in areas with the most fertile and favorable soils for plant growth, providing an optimal environment for their development. In contrast, P1 and P2 are likely to experience limitations in moisture and nutrient availability, which may hinder plant growth and overall population vitality. These differences in soil fertility and resource availability can significantly influence the growth patterns and sustainability of each population.

Table 4. Morphological characteristics of soil in the Karatau foothill plain of the Syrdarya Karatau (P3 and P4), Kazakhstan

Horizon	Depth (cm)	Thickness (cm)	Description
A	0-10	10	Light gray, dry, medium loamy, nutty-powdery, slightly compacted, medium porous, contains dead plants, strongly boiling.
B	10-26	16	Brown, dry, medium-loamy, nutty-cubic-granular, compacted, medium porous, contains medium and fine roots, strongly boiling.
BC	26-80	54	Brown, dry, heavy loam, nutty-granular, slightly compacted, medium porous, white veins are found, burrows and insect passages are visible, medium-sized roots are present, strongly boiling.

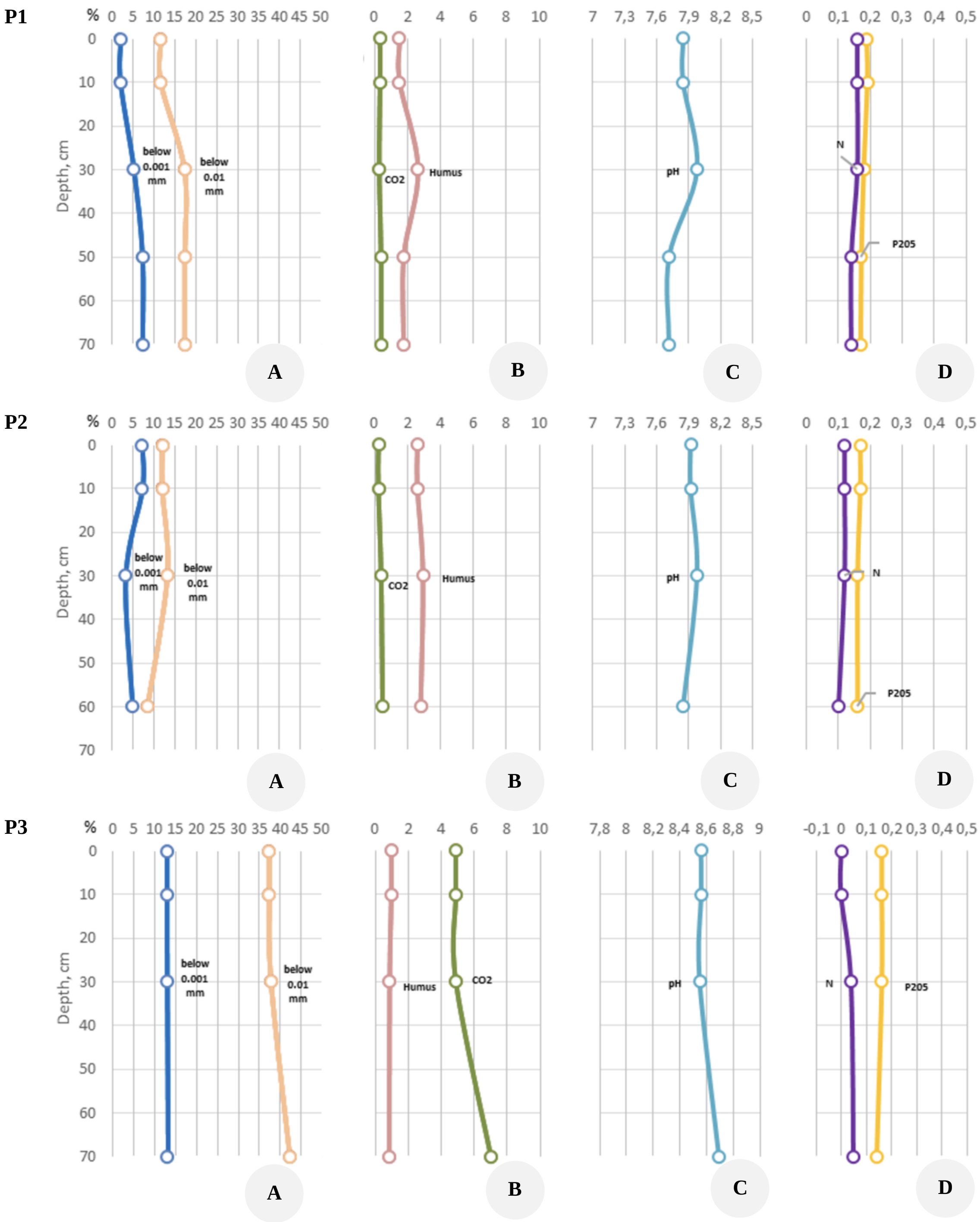


Figure 6. Analytical indicators of the soils in *Allochrusa gypsophiloides* habitats: A. Granulometric composition, fractions (%); B. Humus, CO_2 (%); C. pH; D. Total N (nitrogen), total P_2O_5 (phosphorus) (%)

Soil salinization, the process of accumulation of easily soluble salts in the soil profile, which is not compensated by their removal. As a result of salinization, salt horizons and a salt profile of the soil are formed (Amirov et al. 2023; Osmonali et al. 2024a, b; Balkybek et al. 2025).

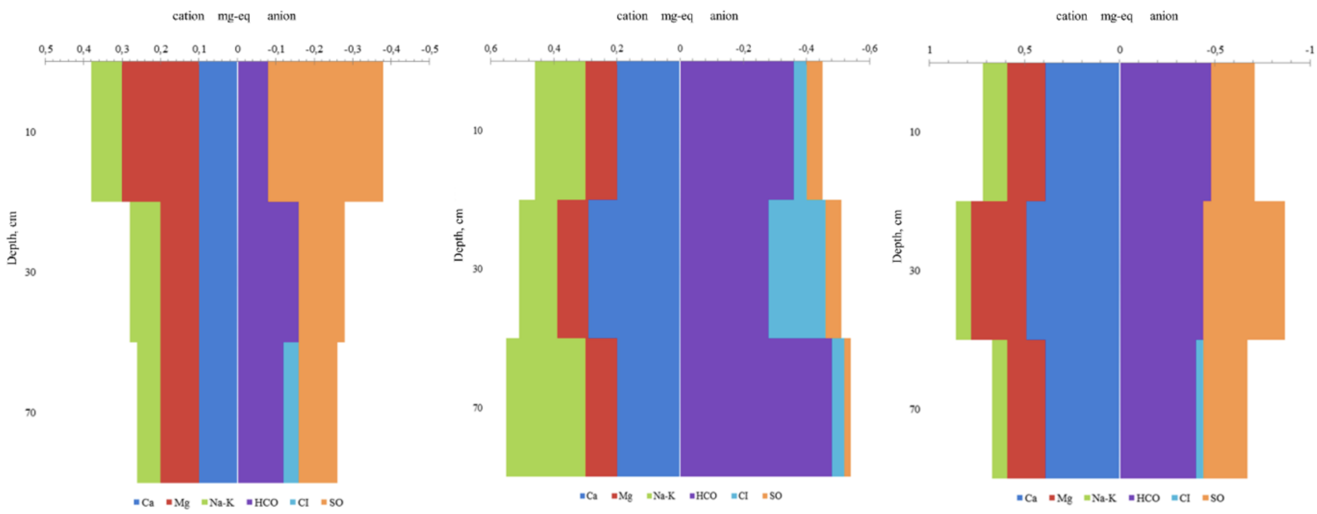
The composition of the soil water extract in P1 was as follows: CO_3^{2-}: not detected; HCO_3^-: 0.08-0.16; Cl^-: 0.04; SO_4^{2-}: 0.10-0.30; Ca^{2+}: 0.10; Mg^{2+}: 0.10-0.20; Na^+: 0.04-0.06; K^+: 0.02. The total salt content ranged from 0.019 to 0.026%. The soil is non-saline, and the salt content decreases with depth. The main salts are chlorides and sulfates, with low alkalinity.

The composition of the soil water extract in P2 was as follows: CO_3^{2-}: not detected; HCO_3^-: 0.28-0.48; Cl^-: 0.04-0.18; SO_4^{2-}: 0.02-0.05; Ca^{2+}: 0.20-0.29; Mg^{2+}: 0.10; Na^+: 0.05-0.18; K^+: 0.07-0.11. The total salt content ranged from 0.017 to 0.029%. The soil is non-saline, but has increased alkalinity, especially in deeper horizons. The levels of chlorides and sulfates are low, but sodium concentration increases with depth, which may indicate the initial stages of alkaline soil transformation.

The composition of the soil water extract in P3 and P4 was as follows: CO_3^{2-}: not detected; HCO_3^-: 0.40-0.48; Cl^-: 0.04; SO_4^{2-}: 0.23-0.43; Ca^{2+}: 0.39-0.49; Mg^{2+}: 0.20-0.29; Na^+: 0.06; K^+: 0.02-0.07. The total salt content ranged from 0.024 to 0.029%. The soil is non-saline, although it has a higher salt content compared to P1 and P2. In the middle horizon (10-26 cm), there is a notable accumulation of chlorides, sulfates, and cations. This accumulation suggests the downward migration of salts within the soil profile. The presence of salts in this specific horizon could be indicative of ongoing soil processes, such as the leaching of salts from the upper layers and their subsequent deposition in the middle horizon. Such patterns of salt distribution might be influenced by environmental factors, such as water movement through the soil or evaporation at the surface (Figure 7).

The soils of mountain northern serozems (P1), mountain gray-brown soils (P2), and southern serozems (P3 and P4) share a similar chemical composition, characterized by low humus content and limited nutrient availability. The soil reaction varies from moderately alkaline to strongly alkaline across these populations. In terms of granulometric composition, these soils are classified as sandy loam and medium loam, which further contribute to their relatively poor fertility and low water retention capacity.

The study of *A. gypsophiloides* populations in the Syrdarya Karatau region makes it possible to understand the ecological features of the species, its reproductive limitations and vulnerability to environmental and anthropogenic stresses. The data obtained indicate several key factors affecting the survival and distribution of *A. gypsophiloides*, which are crucial for the conservation efforts of the species. The discovered populations of *A. gypsophiloides* are confined to gravelly foothill slopes and rocky hills, indicating a preference for a well-drained, rocky environment. This specificity of habitats is consistent with previous studies on the flora of steppes and semi-deserts, where plant species show strong adaptation to soil conditions and microclimatic variations (Ozenda 2009). *Allochrusa gypsophiloides* grows at altitudes from 400 to 1300 m asl. In Kyrgyzstan, this species is found on dry river slopes and abandoned arable lands at altitudes of 400-700 m (Mamadalieva et al. 2023), and in Kazakhstan it inhabits the foothills and mountains of South Kazakhstan and Zhambyl region, from foothill plains to the middle mountain belt.



A B C

Figure 7. Salt profile of soils (mg-eq) in *Allochrusa gypsophiloides* habitats

According to our studies, *A. gypsophiloides* grows at altitudes from 451 to 845 m asl. The distribution of this species across altitudes and substrates is determined by the combined influence of edaphic (soil) and climatic factors. Altitudinal confinement indicates the dependence of *A. gypsophiloides* on temperature regime, moisture level and other climatic conditions, while preference for certain substrates emphasizes the importance of soil composition and chemical characteristics of the environment. This makes the species particularly vulnerable to environmental changes, as climate fluctuations or soil disturbance can significantly affect its distribution and abundance (Aqeel et al. 2024).

The reproductive biology of *A. gypsophiloides* is a critical factor determining its conservation status. This species relies solely on sexual reproduction by seed, but it produces few seeds with low germination rates. Similar reproductive restrictions have been observed in other rare or endemic species, where limited seed production and high dependence of germination on the environment reduce the potential for population expansion (Fenner and Thompson 2005). The lack of vegetative reproduction further limits the ability to regenerate and recover after population decline, making it highly susceptible to local extinction (Kulymbet et al. 2023).

The results showed that the correlation coefficient (R) between generative structures of populations was 100%, which is statistically significant ($P<0.05$). This indicates that the development of generative organs largely depends on the intake of nutrients during the development of vegetative structures. Optimal development of vegetative organs plays a crucial role in the successful formation of generative organs of the plant. Our results are consistent with existing literature that emphasizes the critical role of plant nutrient availability for successful reproduction. In other studies, a study conducted on soybean plants showed that reduced nutrient availability resulted in a significant decrease in pod production, indicating that nutrient deficiency during vegetative growth adversely affects reproductive performance (Smith et al. 2022). Similarly, studies on *Epilobium hirsutum* showed that conditions with higher soil moisture and nutrient availability favored both asexual and sexual reproduction, highlighting the importance of normal nutrient supply for reproductive development (Lee et al. 2017).

The expansion of industry and agriculture, along with the extensive exploitation of natural resources, significantly disrupts the ecological balance, posing a serious risk to plant species diversity. As human activities continue to exert pressure on natural ecosystems, rare and endangered species become increasingly vulnerable. These species, in particular, are more susceptible to the negative impacts of habitat destruction, climate change, and resource depletion, which can lead to a decline in their population numbers and even push them toward extinction.

Under natural conditions, the species exhibits a very low rate of self-renewal. A comparison of the ontogenetic structure of populations from different ecological and phytocenotic habitats revealed that the ontogenetic spectrum of all populations is single-peaked, with the peak centered on middle-aged generative individuals. This pattern is consistent across all populations, indicating that the species' ontogenetic spectra align with the characteristic distribution typically observed for this species. The low self-renewal rate, combined with the dominance of middle-aged reproductive individuals in the population structure, highlights the species' reliance on specific ecological conditions for successful reproduction and regeneration.

In conclusion, a detailed study of the reproductive characteristics and condition of populations of rare species is needed to accurately assess their long-term survival prospects and develop effective conservation strategies. In the case of *A. gypsophiloides*, special attention should be paid to the Population 1 located in the Sayasu Gorge, Syrdarya Karatau due to its extremely small population. Although the age composition of *A. gypsophiloides* populations is generally estimated to be relatively stable, their low density may pose a threat to sustainability and reproductive success. Taking these factors into account, it is necessary to implement targeted conservation measures, especially for the small and vulnerable population-1, in order to ensure the conservation of the species in its natural environment. These findings highlight the broader need to develop and implement proactive environmental policies aimed at protecting rare and endangered species from habitat loss and anthropogenic impacts. The integration of the data obtained into global biodiversity conservation programs can contribute to the development of more effective strategies for protecting flora and ensuring environmental sustainability. We recommend that *A. gypsophiloides* be considered for inclusion in the IUCN Red List. Given its limited distribution, ecological specificity, and ongoing anthropogenic pressures, such recognition would contribute to its global conservation visibility and support future protection measures.

REFERENCES

Abduraimov OS, Kovalenko I, Maxmudov AV, Mavlanov BJ. 2023. Floristic diversity and economic importance of wild relatives of cultivated plants in Uzbekistan (Central Asia). Biodiversitas 24 (3): 1668-1675. DOI: 10.13057/biodiv/d240340.

Abduraimov OS, Maxmudov AV, Kovalenko I, Allamurotov AL, Mavlanov BJ. 2022. Ontogenetic structure of cenopopulations of *Allium pskemense* (Amaryllidaceae) in Uzbekistan. Biosyst Divers 30 (1): 88-94. DOI: 10.15421/012209.

Aidarbayeva AK, Amantayeva AA, Taneeva GT. 2022. *Allochruzes* of South Kazakhstan-perspective saponin plants. Bull Kaz Natl Med Univ 1: 571-573. DOI: 10.53065/kaznmu.2022.72.75.086.

Amirov B, Seytmenbetova A, Kulymbet K, Tanirbergenov S. 2023. Modelling of fertilization on the photosynthetic and yield indicators of melon (*Cucumis melo* L.) under the saline soils of southern Kazakhstan. Res Crops 24 (2): 307-315. DOI: 10.31830/2348-7542.2023.ROC-945.

Aqeel M, Khalid N, Noman A, Ran J, Manan A, Hou Q, Deng J. 2024. Interplay between edaphic and climatic factors unravels plant and microbial diversity along an altitudinal gradient. Environ Res 242: 117711. DOI: 10.1016/j.envres.2023.117711.

ArcGIS Desktop 10.4. 2024. https://desktop.arcgis.com/. [Accessed on 26 September 2024]

Balkybek Y, Tynybekov B, Kulymbet K, Kurmanbay U, Umirbayeva Z, Nurakyn, Z, Myltykbayeva A, Ydyrys A, Toktar M. 2025. Study of soil cover of *Veronica spuria* L. populations in Ile Alatau mountains, Kazakhstan. EQA Intl J Environ Qual 66: 99-106. DOI: 10.6092/issn.2281-4485/20806.

Berdikulov BT, Frolov IG, Tashimova AE, Zaripova SKh. 2023. Trends in counts of Columbiformes at Shakpak Pass, Kazakhstan. Biodiversitas 24 (9): 4661-4667. DOI: 10.13057/biodiv/d240906.

Fenner M, Thompson K. 2005. The ecology of seeds. Ann Bot 97 (1): 151-153. DOI: 10.1093/aob/mcj016.

Gafforov Y, Rašeta M, Zafar M, Makhkamov T, Yarasheva M, Chen JJ, Zhumagul M, Wang M, Ghosh S, Abbasi AM, Yuldashev A, Mamarakhimov O, Alosaimi AA, Berdieva D, Rapior S. 2024. Exploring biodiversity and ethnobotanical significance of *Solanum* species in Uzbekistan: Unveiling the cultural wealth and ethnopharmacological uses. Front Pharmacol 14: 1287793. DOI: 10.3389/fphar.2023.1287793.

Gemejiyeva N, Grudzinskaya L. 2018. Current state and prospects for studies on the diversity of medicinal flora in Kazakhstan. In: Egamberdieva D, Öztürk M (eds). Vegetation of Central Asia and Environs. Springer, Cham. DOI: 10.1007/978-3-319-99728-5_9.

Ghaffari SM. 2021. Cytogeography and patterns of distribution of the genus *Acanthophyllum* (Caryophyllaceae). Iran J Bot 27: 164-176. DOI: 10.22092/ijb.2021.355676.1338.

He X, Yin F, Arif M, Zheng J, Chen Y, Geng Q, Ni X, Li C. 2024. Diversity patterns of plant communities along an elevational gradient in arid and semi-arid mountain ecosystems in China. Plants 13 (20): 2858. DOI: 10.3390/plants13202858.

Imanbayeva A, Duisenova N, Orazov A, Sagyndykova M, Belozerov I, Tuyakova A. 2024. Study of the floristic, morphological, and genetic (atpF-atpH, Internal Transcribed Spacer (ITS), matK, psbK-psbI, rbcL, and trnH-psbA) differences in *Crataegus ambigua* populations in Mangistau (Kazakhstan). Plants 13 (12): 1591. DOI: 10.3390/plants13121591.

Jakimiuk K, Wink M, Tomczyk M. 2022. Flavonoids of the Caryophyllaceae. Phytochem Rev 21: 179-218. DOI: 10.1007/s11101-021-09755-3.

Kakabayev AA, Sharipova BU, Baranovskaya NV, Rodrigo-Ilarri J, Rodrigo-Clavero ME, Lo PG, Bazilevskaya EA, Muratbekova S, Nurmukhanbetova N, Durmekbayeva S, Toychibekova GB, Kurmanbayev R, Zhumabayeva A. 2024. Impact of environmental conditions on soil geochemistry in Southern Kazakhstan. Sustainability 16 (15): 6361. DOI: 10.3390/su16156361.

Kenesbay A, Kurmantayeva A, Sitpayeva G. 2024. Assessment of the state of the cenopopulation of *Cousinia mindschelkensis* B. Fedtsch. of Karakuys Gorge in the Karatau Reserve. BIO Web Conf 100: 04044. DOI: 10.1051/bioconf/202410004044.

Khatuntseva E, Men'shov V, Shashkov A, Tsvetkov Y, Stepanenko R, Vlasenko R, Shults E, Nifantiev N. 2012. Triterpenoid saponins from the roots of *Acanthophyllum gypsophiloides* Regel. Beilstein J Org Chem 8: 763-775. DOI: 10.3762/bjoc.8.87.

Khojimatov OK, Gafforov Y, Bussmann RW. 2023. Ethnobiology of Uzbekistan: Ethnomedicinal Knowledge of Mountain Communities. Springer Nature, Basel, Switzerland. DOI: 10.1007/978-3-031-23031-8.

Korolyuk TV. 2012. Soil Interpretation of Space Images in the System of CPC Methods Digital Soil Cartography: Theoretical and Experimental Studies. Moscow, Russia. https://www.esoil.ru/publications_oldadress/. [Accessed on 3 October 2012].

Kubentayev SA, Khapilina ON, Ishmuratova MY, Sarkytbayeva AK, Turzhanova AS, Imanbayeva AA, Alibekov DT, Zhumagul MZ. 2023. Current state of natural populations of *Paeonia anomala* (Paeoniaceae) in East Kazakhstan. Diversity 15 (11): 1127. DOI: 10.3390/d15111127.

Kubentayev SA, Zhumagul MZh, Kurmanbayeva M, Alibekov D, Kotukhov J, Sitpayeva GT, Mukhtubayeva SK, Izbastina KS. 2021. Current state of populations of *Rhodiola rosea* L. (Crassulaceae) in East Kazakhstan. Bot Stud 62 (1): 19. DOI: 10.1186/s40529-021-00327-4.

Kulymbet K, Mukhitdinov N, Kubentayev S, Tynybayeva K, Tastanbekova A, Kurmanbayeva M, Gafforov Y, Kaparbay R, Zhumagul M. 2023. The current state of the cenopopulations of *Adonis tianschanica* (Adolf) Lipsch. (Ranunculaceae) in Southeast Kazakhstan. Biodiversitas 24 (8): 4359-4372. DOI: 10.13057/biodiv/d240817.

Lee EP, Han YS, Lee SI, Cho KT, Park JH, You YH. 2017. Effect of nutrient and moisture on the growth and reproduction of *Epilobium hirsutum* L., an endangered plant. J Ecol Environ 41 (35): 1-9. DOI: 10.1186/s41610-017-0054-z.

Mamadalieva R, Khujaev V, Soral M, Mamadalieva NZ, Wink M. 2023. The genus *Allochrusa*: A comprehensive review of botany, traditional uses, phytochemistry, and biological activities. Diversity 15 (4): 574. DOI: 10.3390/d15040574.

Mamadalieva R, Xujayev V, Sharopov FS, Wink M. 2024. UHPLC-MS characterisation of principal triterpene glycosides and biological activities of different solvent extracts of *Allochrusa gypsophiloides* (Caryophyllaceae). Nat Prod Res 38 (21): 3818-3822. DOI: 10.1080/14786419.2023.2260068.

Mursalıyeva V, Imanbayeva A, Parkhatova R. 2020. Seed germination of *Allochrusa gypsophiloides* (Caryophyllaceae), an endemic species from Central Asia and Kazakhstan. Seed Sci Technol 48 (2): 289-295. DOI: 10.15258/sst.2020.48.2.15.

Mursalıyeva V, Imanbayeva A. 2020. Micropropagation of turkestan soap root *Allochrusa gypsophiloides*-Natural source of saponins. Intl J Second Metab 7 (1): 1-7. DOI: 10.21448/ijsm.627140.

Mursalıyeva VK, Sarsenbek BT, Dzhakibaeva GT, Mukhanov TM, Mammadov R. 2023a. Total content of saponins, phenols and flavonoids and antioxidant and antimicrobial activity of in vitro culture of *Allochrusa gypsophiloides* (Regel) Schischk Compared to Wild Plants. Plants 12 (20): 3521. DOI: 10.3390/plants12203521.

Mursaliyeva V, Algazy A, Satybaldiyeva D, Mukhanov T. 2023b. Obtaining of adventitious roots culture of *Allochrusa gypsophiloides*: saponins-bearing endemic rare species. Plant Biotechnol Rep 17 (3): 421-425. DOI: 10.1007/s11816-023-00836-7.

Mursaliyeva VK, Mukhanov TM, Gemejiyeva NG, Yeskaliyeva BK. 2023c. Chemical analysis and biological activity of Turkestan soaproot *Allochrusa gypsophiloides* (Regel) Schischk growing in the south of Kazakhstan. Khimiya Rastitel'nogo Syr'ya 3: 183-191. DOI: 10.14258/jcprm.20230311993.

Myrzagaliyeva A, Irsaliyev S, Tustubayeva S, Samarkhanov T, Orazov A, Alemseitova Z. 2024. Natural resources of *Rhaponticum carthamoides* in the Tarbagatai State National Nature Park. Diversity 16 (11): 676. DOI: 10.3390/d16110676.

Osmonali BB, Vesselova PV, Kudabayeva G, Duisenbayev S, Taukebayev O, Zulpykhanov K, Ussen S, Abdiildanov DS. 2024a. Salt resistance of species of the Chenopodiaceae family (Amaranthaceae s.l.) in the desert part of the Syrdarya River Valley, Kazakhstan. Biodiversitas 25 (11): 4162-4170. DOI: 10.13057/biodiv/d251115.

Osmonali BB, Tokbergenova A, Taukebayev O, Zulpykharov K, Salmurzauly R, Smanov Z, Ussen S. 2024b. Weed species in plant communities as indicators of degradation of vegetation cover and fertile soil layer in desert regions. Biodiversitas 25 (12): 4930-4938. DOI: 10.13057/biodiv/d251230.

Ozenda P. 2009. On the genesis of the plant population in the Alps: New or critical aspects. Comptes Rendus Biologies 332 (12): 1092-1103. DOI: 10.1016/j.crvi.2009.09.018.

Pachikin KM, Erokhina OG, Songulov EE, Yershibulov AK, Adamin GK, Yakovleva NA. 2022. Soils and soil cover of the foothill plains of the Karatau ridge (Kentau city surroundings). Soil Sci Agrichem 1: 5-15. DOI: 10.51886/1999-740X_2022_1_5. [Russian]

Physical Map of Kazakhstan. 2023. https://fedoroff.net/load/maps/karta/fizicheskaja_karta_kazakhstana/90-1-0-1088?ysclid:m4mbtjjea810758198 (accessed on 25 November 2023).

Plants of the World Online (POWO). 2025. Plants of the World Online. Royal Botanic Gardens, Kew. http://www.plantsoftheworldonline.org/.

Red Data Book of Kazakhstan. 2014. 2rd ed ArtPrintXXI. Astana, Kazakhstan.

R-Studio Team 2020. RStudio: Integrated Development for R. RStudio, PBC, Boston, MA. http://www.rstudio.com/. [Accessed on 26 November 2020]

Saribaeva SU, Abduraimov OS, Allamurotov Al. 2022. Assessment of the population status of *Allium oschaninii* O. Fedtsch. in the mountains of Uzbekistan. Ekológia 41 (2): 147-154. DOI: 10.2478/eko-2022-0015.

Smith MR, Reis HBE, Fuentes D, Merchant A. 2022. Investigating nutrient supply effects on plant growth and seed nutrient content in common bean. Plants 11 (6): 737. DOI: 10.3390/plants11060737.

Temirgaziev BS, Tuleuov BI, Romanova MA, Seidakhmetova RB, Seilkhanov TM, Seilkhanov OT, Salkeeva LK, Adekenov SM. 2019. Supramolecular complexes of 3-Epi-2-deoxyecdysone with cyclodextrins and their anti-inflammatory activity. Russ J Gen Chem 89 (3): 424-428. DOI: 10.1134/S1070363219030095.

Terekhov AG, Abayev NN, Tillakarim TA. 2021 Extremal snowfall on March 13-14, 2021, in the South Kazakhstan. Sovremennye Problemy Distantsionnogo Zondirovaniya Zemli iz Kosmosa 18 (4): 279-284. DOI: 10.21046/2070-7401-2021-18-4-279-284.

The Plant List. 2024. http://www.theplantlist.org/. [Accessed on 12 November 2024].

Tileshova M, Yessimsiitova Z, Alseitova F, Chunetova Z, Pravin N, Tileubayeva Zh, Ryskali T, Yeltay G. 2024. Phytochemical study of milk thistle, *Silybum marianum* (L.) Gaertn. Casp J Environ Sci 22 (5): 1293-1299. DOI: 10.22124/cjes.2024.8345.

Tuleuov BI, Zavarzin IV, Shashkov AS, Chernoburova EI, Adekenov SM. 2018. 3α,14α,22R,25-Tetrahydroxy-5β(H)-cholest-7-en-6-one, a phytoecdysteroid from *Acanthophyllum gypsophiloides* possessing anti-inflammatory and analgesic activities. Russ Chem Bull 67 (4): 663-666. DOI: 10.1007/s11172-018-2120-9.

Tynybekov B, Imanaliyeva M, Kuatbayev A, Satybaldiyeva G, Boribay E, Kulymbet K, Umirbayeva Z, Mamytova N, Bekbossyn N, Kurmanbay U, Sadyrova G, Toktar M, Nazarbekova S, Abdullayeva B, Nurmahanova A. 2024. Adaptation Features of *Gentiana tianschanica* Rupr: Populations to environmental factors in Kazakhstan. ES Energy Environ 26 (1361): 1-26. DOI: 10.30919/esee1361.

Ydyrys A, Mukhitdinov N, Ivashchenko A, Ashirova Z, Massimzhan M, Imanova E, Parmanbekova M, Toktar M, Yeszhanov B, Ilesbek M, Askerbay G, Kaparbay R. 2024. Methodological guide for geobotanical research on rare, endemic, and medicinal plants: A case study of the Ranunculaceae family. ES Food Agrofor 18 (1340): 1-22. DOI: 10.30919/esfaf1340.