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FLORISTIC AND BIOECOLOGICAL ANALYSIS OF *Saxifraga* L. SPECIES GROWING IN THE TERRITORY OF THE NAKHCHIVAN AUTONOMOUS REPUBLIC

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ФЛОРИСТИЧЕСКИЙ, БИОЭКОЛОГИЧЕСКИЙ АНАЛИЗ ВИДОВ *Saxifraga* L., ПРОИЗРАСТАЮЩИХ НА ТЕРРИТОРИИ НАХЧЫВАНСКОЙ АВТОНОМНОЙ РЕСПУБЛИКИ

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Abstract. The present study examines the floristic composition, ecological characteristics, geographical distribution, phenology, and potential utilization of species of the genus *Saxifraga* L. (Saxifragaceae) occurring in the Nakhchivan Autonomous Republic. The work is based on floristic literature, taxonomic sources, field observations conducted during 2024–2026, and comparison with updated nomenclatural information. Nine of the fourteen *Saxifraga* species reported for Azerbaijan were identified as occurring in Nakhchivan. The species are concentrated mainly in rocky habitats, crevices, stony slopes, subalpine meadows, and alpine belts. Ecological analysis classified five species as xerophytes, two as mesophytes, and two as xeromesophytes. The taxa were assigned to five areal classes, with Caucasian, European mountain, and Front Asian mountain elements predominating. The expanded interpretation emphasizes the relationship between species distribution, altitude, substrate lithology, slope exposure, and microclimatic variability. The study also outlines scientifically justified prospects for rock-garden design, ecological restoration, phytomelioration, ex situ conservation, and bioindicator research. The proposed scientific novelty lies in integrating floristic, ecological, chorological, and applied-conservation perspectives into a single regional framework, while identifying priorities for future population-genetic, molecular-taxonomic, and climate-resilience investigations.

Аннотация. Рассматриваются флористический состав, экологические характеристики, географическое распространение, фенология и возможности использования видов рода *Saxifraga* L. (сем. Saxifragaceae), произрастающих на территории Нахичеванской Автономной Республики. Работа базируется на анализе флористической литературы и таксономических источников, результатах полевых наблюдений, проведенных в 2024–2026 гг., а также на сопоставлении с актуальными номенклатурными данными. Установлено, что из 14 видов *Saxifraga*, отмеченных для Азербайджана, в Нахичевани произрастают девять. Эти виды приурочены преимущественно к скальным местообитаниям, расщелинам, каменистым склонам, субальпийским лугам и альпийскому поясу. Экологический анализ позволил классифицировать пять видов как ксерофиты, два — как мезофиты и два — как ксеромезофиты. Выявленные таксоны отнесены к пяти типам ареалов; при этом преобладают кавказские, европейские горные и переднеазиатские горные элементы. В работе

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подчеркивается взаимосвязь между распространением видов, высотой над уровнем моря, литологией субстрата, экспозицией склонов и микроклиматическими условиями. Также обоснованы перспективы использования данных видов в создании альпинариев, экологической реставрации, фитомелиорации, сохранении биоразнообразия ex situ и биоиндикационных исследованиях. Научная новизна работы заключается в комплексном подходе, объединяющем флористические, экологические, хорологические и прикладные природоохранные аспекты в рамках единого регионального исследования, а также в определении приоритетных направлений для будущих популяционно-генетических, молекулярно-таксономических исследований и изучения устойчивости видов к климатическим изменениям.

Keywords: flora, mountain plants, phytocenoses, ecological features, chorological features.

Ключевые слова: флора, горные растения, фитоценозы, экологические особенности, хорологические особенности.

The flora of the Nakhchivan Autonomous Republic is characterized by considerable ecological and geographical heterogeneity resulting from its complex relief, continental climatic conditions, uneven precipitation, and broad vertical zonation. Mountain slopes, rocky outcrops, screes, ravines, alpine, and subalpine meadows create a mosaic of habitats in which plants with different ecological strategies coexist. Within this floristic context, the family Saxifragaceae and the genus Saxifraga L. represent an important component of mountain vegetation.

Species of Saxifraga are commonly associated with rocky substrates, rock fissures, stony slopes, and high-elevation habitats. Their occurrence in environments with limited soil depth, fluctuating temperatures, seasonal water availability, and strong solar radiation makes them relevant objects for studying plant adaptation and ecological resilience. Their compact growth forms, basal rosettes, cushion-like structures, and ability to occupy microhabitats contribute to vegetation establishment on substrates where larger plants may have limited competitive advantage.

According to the source material, fourteen species of Saxifraga are recorded for Azerbaijan, nine of which occur in the Nakhchivan Autonomous Republic. This proportion indicates the regional importance of Nakhchivan for the conservation and study of the genus. However, the presence of a taxon in a floristic list alone does not sufficiently explain its ecological amplitude, population structure, reproductive performance, vulnerability, or practical potential. Therefore, a broader synthesis of distribution, ecological groups, phenology, substrate relations, and possible applications is needed.

The objective of this study is to provide an integrated floristic and bioecological assessment of Saxifraga species occurring in Nakhchivan and to identify scientifically grounded directions for conservation, ecological restoration, botanical introduction, and landscape use. Particular attention is given to the relationship between ecological characteristics and habitat conditions, as well as to the research priorities that can be developed from the existing regional evidence.

Research Material and Methodology

The research was conducted in different botanical-geographical regions of the Nakhchivan Autonomous Republic during 2024–2026. The main research objects were *Saxifraga* species occurring in rocky, stony and mountainous habitats, including subalpine and alpine belts. The study combined analysis of floristic literature, taxonomic comparison, ecological interpretation and field observations.

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Taxonomic names and systematic affiliation were checked using A. Askerov's Flora of Azerbaijan [1], Flora of Azerbaijan [4] and other fundamental floristic sources. Nomenclatural status was compared with updated information available through the World Flora Online database [6]. Ecological groups were determined according to habitat characteristics and moisture relations reported for the studied taxa. Areal classes were interpreted on the basis of the geographical distribution of the species.

The assessment included the following parameters: species identity, ecological group, altitude belt, substrate and habitat type, areal class, flowering and fruiting period, decorative and ecological value, and potential application. The present study should be regarded as an integrated floristic-ecological synthesis. Quantitative population estimates, molecular analyses, controlled cultivation experiments and pharmacological assays were not conducted and therefore are proposed as directions for subsequent research rather than presented as completed results.

Floristic and Systematic Composition

The genus *Saxifraga* L. is represented in the studied regional flora by nine species: S. *cartilaginea* Willd., *S. exarata* Vill., *S. juniperifolia* Adams, *S. cymbalaria* L., *S. kolenatiana* Regel, *S. sibirica* L., *S. moschata* Wulf, *S. pontica* Albov and *S. adenophora* C. Koch. These taxa differ in habitat preference, ecological group, altitudinal range, flowering period and geographical affiliation.

The distribution pattern demonstrates that the genus is not restricted to a single habitat type. Some species are strongly associated with exposed alpine rocks and cliffs, whereas others occupy moist rocky areas near streams and springs or occur in meadows and middle-mountain habitats. This ecological differentiation is important because it suggests that the regional *Saxifraga* assemblage is structured by several interacting environmental factors rather than by altitude alone (Table).

Table

TAXONOMIC COMPOSITION OF SPECIES BELONGING TO THE GENUS *Saxifraga* L.

Species	*Ecological group*	*Main habitat*	*Altitudinal belt*	*Areal class*	*Phenology*
Saxifraga cartilaginea Willd. ex Sternb.	Xerophyte	Rocks and cliffs	Subalpine–alpine	Caucasus	VI–VIII
S. exarata Vill.	Xerophyte	Rocky cliffs	Alpine	European mountain	VII
S. juniperifolia Adams	Xerophyte	Rocky habitats	Alpine	Caucasus	VI–VII
S. cymbalaria L.	Mesophyte	Middle and high mountains	Middle–high mountain	Ancient Eastern Mediterranean	VI–VIII
S. kolenatiana Regel	Xerophyte	Rocks and cliffs	Subalpine–alpine	Caucasus	VI–VIII
S. sibirica L.	Mesophyte	Moist rocks near streams	Middle–subalpine	Front Asian mountain	V–VIII
S. moschata Wulfen	Xeromesophyte	Meadows and rocks	Subalpine–alpine	European mountain	VI–VIII
S. pontica Albov	Xerophyte	Alpine rocks	Alpine	Caucasus mountain	VII
S. adenophora K. Koch	Xeromesophyte	Subalpine and alpine habitats	Subalpine–alpine	Front Asian mountain	VII

The ecological analysis showed that five species are xerophytes, two are mesophytes and two are xeromesophytes. Thus, xerophytes constitute the dominant ecological group. This structure

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corresponds to the prevalence of dry rocky habitats and continental climatic conditions in many mountainous parts of Nakhchivan.

Xerophytic species are adapted to restricted water availability, shallow soils, intense solar radiation and rapid temperature fluctuations. Their ecological performance may be associated with compact growth, dense leaf arrangement, reduced exposed surface, deep or strongly anchored root systems, and the ability to exploit water retained in rock fissures. These adaptations should be examined experimentally in future work, because the precise physiological mechanisms may differ among species.

Mesophytic taxa, including S. cymbalaria and S. sibirica, indicate the presence of more humid microhabitats within the regional mountain landscape. Their occurrence near streams, springs, shaded rocks or sites with greater soil moisture highlights the importance of microscale environmental variation. Xeromesophytes occupy an intermediate ecological position and may demonstrate broader tolerance to changing moisture conditions.

The combination of xerophytic, mesophytic and xeromesophytic species makes *Saxifraga* a useful group for comparative studies of ecological plasticity. A potential scientific innovation for future investigations is the development of a habitat-based monitoring model that relates species occurrence to substrate, slope exposure, soil moisture, elevation and seasonal temperature variation.

The studied species belong to five areal classes. Three species are associated with the Caucasus, two with the European mountain areal class, two with the Front Asian mountain areal class, while the Ancient Eastern Mediterranean and Caucasus mountain classes are represented by one species each. This pattern reflects the transitional biogeographical position of Nakhchivan and the influence of several floristic regions on its mountain flora.

The predominance of Caucasian and mountain areal elements indicates that the genus is closely connected with mountainous evolutionary and ecological environments. At the same time, the presence of European mountain, Front Asian and Ancient Eastern Mediterranean elements demonstrates the floristic complexity of the region. Chorological analysis may therefore contribute to understanding historical migration routes, refugial habitats and the role of mountain systems in maintaining plant diversity. Future studies should combine distribution mapping with geographic information systems, digital elevation models and climate layers. Such an approach could reveal whether populations are concentrated in environmentally stable refugia, whether their ranges are fragmented, and which habi**.** tats may be most sensitive to climate change.

Saxifraga L. - Leaves are alternate, calyx 5-lobed, petals 5, sepals 10, ovary superior or bi-columnar. Fruits are capsules, dehiscent, and many-seeded.

Saxifraga cartilaginea Willd This perennial species is associated mainly with rocky habitats of the subalpine and alpine zones. Its basal rosette and decorative flowers provide potential for rock gardens and alpine plant collections. Its root system and ability to occupy rocky substrates suggest possible relevance to soil-surface stabilization and ecological monitoring.

Saxifraga exarata Vill. The species is a small, decorative mountain plant adapted to rocky environments. Its compact form makes it potentially suitable for alpine gardens and the greening of rocky sites. Its role in vegetation establishment on poorly developed soils warrants further investigation through restoration trials.

Saxifraga juniperifolia Adams. The cushion-like growth form and adaptation to high-mountain conditions make this species relevant to alpine landscaping and ecological restoration. Dense cover may contribute to reducing exposure of the soil surface and limiting erosion on small patches of mountain terrain.

Saxifraga cymbalaria L. This species has a comparatively wider ecological range and occurs in middle- and high-mountain belts. Its flowers and leaf form provide decorative value. Traditional

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medicinal references require pharmacological verification and should not be interpreted as evidence of clinical efficacy without controlled research.

Saxifraga kolenatiana Regel. The species is distinguished by decorative flowers and a dense basal rosette. Its association with rocky habitats suggests potential for naturalistic landscape design, botanical collections and studies of rare mountain plant conservation.

Saxifraga sibirica L. The species is linked to moist rocky areas near streams and springs. It contributes to vegetation cover in mountain meadows and humid rocky microhabitats. Its ecological value includes possible participation in moisture-retaining plant communities and maintenance of local biodiversity.

Saxifraga moschata Wulf. The species forms dense turf and is associated with subalpine and alpine meadows and rocks. Its tolerance of mountain conditions makes it relevant to alpine collections, ecological restoration and research on soil-surface protection.

Saxifraga pontica Albov. As a characteristic element of Caucasian mountain flora, this species has notable scientific and conservation significance. Its restricted high-mountain habitat emphasizes the need for population monitoring, protection of local habitats and ex situ conservation studies.

Saxifraga adenophora C. Koch. This perennial species occurs in subalpine and alpine habitats and may contribute to vegetation formation on rocky and relatively poor soils. Its potential use in rock gardens and erosion-control plantings should be assessed through introduction and survival experiments.

Saxifraga species participate in the formation of rocky-slope vegetation, alpine and subalpine meadow communities and vegetation in stony debris areas. They occur together with representatives of *Fabaceae, Rosaceae, Lamiaceae, Caryophyllaceae, Asteraceae* and other families [2, 3, 5]. These associations create a complex plant cover that contributes to soil retention, moisture regulation, habitat formation and support of mountain fauna.

The ecological role of *Saxifraga* should not be reduced to direct soil stabilization alone. Small perennial plants occupying rock fissures and shallow soils can contribute to the initial development of organic matter, provide microhabitats for invertebrates and influence local moisture and temperature conditions near the substrate. These functions remain hypotheses requiring quantitative phytocenological and ecosystem measurements in Nakhchivan.

A promising direction for scientific novelty is the assessment of *Saxifraga* as a bioindicator group. Species presence, abundance, flowering time and habitat shifts could be monitored alongside substrate properties and clim atic variables. Such monitoring would help distinguish natural habitat variability from changes potentially associated with warming, drought or disturbance.

The scientific novelty of the expanded study is formulated as a set of research-based interpretations and proposed methodological directions rather than as unsupported claims of newly measured data.

An integrated regional framework is proposed that combines taxonomy, ecological groups, areal classes, altitude, phenology and applied conservation value for nine *Saxifraga* species of Nakhchivan.

The relationship between species distribution and substrate lithology, slope exposure and microclimate is emphasized as a complementary explanation to altitude-based distribution analysis.

The predominance of xerophytic species is interpreted as a basis for investigating drought tolerance and climate resilience in mountain plant communities.

Saxifraga is proposed as a candidate indicator group for monitoring ecological changes in high-mountain habitats, subject to validation through long-term quantitative field studies.

A conservation-oriented application model is suggested, linking in situ habitat protection, ex situ botanical cultivation, rock-garden introduction and restoration of disturbed rocky slopes.

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Future molecular-taxonomic and population-genetic research priorities are identified to clarify taxonomic relationships, genetic differentiation and the conservation status of local populations.

The studied taxa have potential value in decorative gardening, rock gardens, alpine landscape design, botanical collections and ecological restoration. However, any introduction or collection program must be based on the protection of natural populations and the avoidance of uncontrolled removal of plants from their habitats.

In situ conservation should focus on maintaining rocky and alpine habitats, preventing excessive grazing and physical disturbance, and protecting water-dependent microhabitats such as springs and stream margins. Ex situ conservation may include seed collection under approved protocols, living collections in botanical gardens, propagation experiments and documentation of provenance.

Before large-scale use in landscaping or phytomelioration, experiments should evaluate germination, vegetative propagation, substrate requirements, drought tolerance, winter survival and competitive interactions with local vegetation. The use of local genetic material is preferable when the objective is ecological restoration, because it may preserve regional adaptation and reduce risks associated with introducing non-local genotypes.

The current study provides a floristic and ecological synthesis, but several questions remain unresolved. The available material does not include complete population counts, population trends, genetic diversity data, detailed soil analyses, physiological measurements or controlled cultivation experiments. Consequently, conclusions concerning medicinal use, climate resilience and erosion control should be treated as potential research directions rather than definitive applied recommendations.

Future investigations should include: (1) GPS-based mapping of populations; (2) quantitative abundance and density measurements; (3) soil pH, texture, carbonate content and moisture analysis; (4) phenological monitoring across altitudinal gradients; (5) seed germination and propagation experiments; (6) molecular identification and population-genetic analysis; (7) assessment of climate sensitivity; and (8) evaluation of conservation status according to established criteria.

Conclusion

The flora of the Nakhchivan Autonomous Republic contains nine of the fourteen Saxifraga species reported for Azerbaijan, demonstrating the regional significance of the genus.

The studied taxa are mainly associated with rocky, stony, subalpine and alpine habitats and display different ecological strategies.

Five species are xerophytes, two are mesophytes and two are xeromesophytes, indicating a predominance of adaptation to dry mountain environments.

The species are distributed among five areal classes, with Caucasian, European mountain and Front Asian mountain elements forming the principal groups.

Saxifraga species contribute to mountain vegetation structure, soil-surface protection, biodiversity maintenance and the ecological complexity of rocky habitats.

The genus has potential for rock gardens, botanical collections, ecological restoration and conservation, but practical use should be preceded by propagation, ecological compatibility and population-protection studies.

The integrated approach developed here provides a basis for future molecular-taxonomic, population-genetic, phytocenological and climate-change research in Nakhchivan.

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