

Article

Floristic Diversity, Vegetation Structure, and Ontogenetic Composition of *Sibiraea altaiensis* (Rosaceae) Populations in the Kazakhstan Altai

Anar Myrzagaliyeva , Aidyn Orazov , Talant Samarkhanov , Serik Irsaliyev , Zhanylkan Alemseitova 
and Shynar Tustubayeva 

Laboratory "NatureLab", Astana International University, Astana 010000, Kazakhstan;
an.myrzagaliyeva@gmail.com (A.M.); orazov1994aidyn@gmail.com (A.O.); sirsaliyev@gmail.com (S.I.);
zhanylkan_72@mail.ru (Z.A.)

* Correspondence: talant.68@mail.ru (T.S.); tustubaeva.shynar@gmail.com (S.T.);
Tel.: +7-705-101-1968 (T.S.); +7-777-426-0319 (S.T.)

Abstract

The taxonomic status of the Altai populations traditionally identified as *Sibiraea altaiensis* remains unresolved, with international databases generally treating the name as a synonym of *S. laevigata*. At the same time, regional sources retain it for conservation and floristic purposes. Using *S. altaiensis* as an operational regional name, we established a comparative ecological baseline for six natural populations distributed across the Southern and Western Kazakhstan Altai at 814–2130 m a.s.l. Vegetation was surveyed in July 2024 and July 2025 in ten 10 m × 10 m plots per population using complete vascular plant inventories, Braun–Blanquet abundance–dominance estimates, descriptions of vertical structure, and field assessment of shrub ontogenetic states. Observed vascular plant richness ranged from approximately 35 species at Tautekeli to 78 at Lineinsky; Shubartoc and Ridder contained 76 and 72 species, respectively. Mesophytes constituted 56.3–77.0% of the population floras, demonstrating a predominantly mesic community affinity across contrasting subalpine slopes, river terraces, floodplains, and sparse conifer forest. *Sibiraea altaiensis* was dominant or structure-forming at every locality, although associated species composition and vegetation architecture varied substantially among habitats. Juvenile plants were not detected at five populations, whereas their occurrence at Lineinsky was insufficiently documented for comparison; this pattern is interpreted cautiously because dense midsummer vegetation and litter may reduce seedling detectability. Floristic richness did not conform to a simple Southern-versus-Western Altai division, indicating that local habitat heterogeneity and vegetation context may be more informative than regional position alone. The study provides a verified descriptive baseline and identifies permanent plot monitoring, early-season recruitment surveys, direct environmental measurements, and integrated molecular taxonomic analyses as priorities for conservation assessment.



Academic Editor: Mario A. Pagnotta

Received: 27 April 2026

Revised: 2 July 2026

Accepted: 8 July 2026

Published: 16 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

Keywords: *Sibiraea altaiensis*; floristic richness; vegetation structure; ontogenetic composition; Braun–Blanquet method; mountain shrub communities; Kazakhstan Altai; conservation monitoring

1. Introduction

Mountain ecosystems encompass pronounced climatic, edaphic, hydrological, and topographic gradients over relatively short geographic distances. Changes in elevation,

slope exposure, substrate properties, moisture availability, snow-cover duration, and local disturbance regimes create highly heterogeneous environmental conditions and a complex mosaic of habitats. This heterogeneity promotes high species turnover, local endemism, ecological specialisation, and the persistence of geographically isolated populations. Mountain landscapes may also serve as long-term refugia for plant taxa that have disappeared from surrounding lowlands due to historical climatic changes, habitat transformation, or competition with more widespread species. Consequently, the ecological characteristics of mountain plant populations often reflect both present-day environmental conditions and the legacy of past biogeographic processes [1–6].

The ecological complexity of mountain regions is particularly pronounced in Central Asia, where major mountain systems form important centres of plant diversity and endemism. These territories are characterised by strong continentality, considerable variation in precipitation and temperature, marked altitudinal zonation, and a high diversity of geological and soil conditions. Local plant communities may change substantially over short distances, even where populations are geographically close to one another. In addition, contemporary environmental heterogeneity is superimposed on a complex Quaternary history involving repeated climatic oscillations, shifts in vegetation belts, population contractions, and the subsequent recolonisation of suitable habitats [7,8]. Such historical processes may have promoted the fragmentation and long-term isolation of plant populations, resulting in differences in their ecological structure, demographic composition, and associated vegetation.

At present, mountain ecosystems in Central Asia are increasingly affected by climate change, grazing pressure, recreational use, infrastructure development, fires, and other forms of habitat disturbance. Even where direct anthropogenic pressure remains moderate, changes in temperature and precipitation may alter snow accumulation, soil moisture, competitive relationships, and the timing of plant development. These effects may be especially important for geographically isolated populations with narrow ecological requirements and limited opportunities for migration. Establishing reliable population-level ecological baselines is therefore essential for detecting temporal changes, identifying vulnerable populations, assessing habitat quality, and developing evidence-based conservation measures [7,8]. Such baselines should include not only the geographic location and population size of a target species but also the structure of the surrounding vegetation, floristic richness, habitat conditions, ecological composition of associated species, and the representation of different ontogenetic stages.

The genus *Sibiraea* Laxm. belongs to the tribe Spiraeae within the family Rosaceae [9]. Representatives of the genus are perennial deciduous shrubs, mainly associated with temperate and mountain environments of Eurasia. Their modern distribution is geographically fragmented, and several populations occur as isolated or regionally restricted components of mountain vegetation. This disjunct distribution has attracted interest from taxonomic, phylogenetic, biogeographic, and conservation perspectives. However, the delimitation and nomenclatural treatment of the taxa included in *Sibiraea* remain controversial, particularly with respect to populations occurring in the Altai region.

Plants of the World Online and the World Checklist of Vascular Plants generally treat *Sibiraea altaiensis* (Laxm.) C.K.Schneid. as a synonym of *S. laevigata* (L.) Maxim., whereas regional floras, herbarium collections, field inventories, and conservation documents in Kazakhstan continue to recognise the Altai populations as *S. altaiensis* [10,11]. This discrepancy reflects differences between global taxonomic databases and regional botanical practice. Global databases tend to follow broad species concepts based on consolidated taxonomic treatments. At the same time, regional sources may retain names

that are historically established, geographically informative, and widely used in national conservation documentation.

In the present study, we retain *S. altaiensis* as an operational regional name to maintain consistency with field records, herbarium documentation, published regional literature, and conservation practice in Kazakhstan. This approach facilitates comparison with earlier surveys and allows the investigated populations to be discussed within the terminology currently used by local botanists and conservation institutions. At the same time, this pragmatic usage should not be interpreted as a formal taxonomic conclusion or as evidence against the synonymy accepted by international taxonomic databases. A definitive resolution of the taxonomic status of the Altai populations would require an integrative analysis combining detailed morphology and anatomy, population-level molecular data, phylogenetic reconstruction, and comparisons with material from other parts of the distribution range.

Previous research has addressed the disjunct distribution, phylogenetic relationships, genetic differentiation, biogeographic history, and conservation significance of *Sibiraea* populations across Eurasia [12,13]. These studies have contributed to understanding the historical isolation of populations and the broader evolutionary context of the genus. Research conducted in eastern Kazakhstan has primarily documented known localities, herbarium records, and the regional occurrence of the taxon [14,15]. Such information is essential because it defines the species' geographic range and provides evidence of its persistence in specific mountain systems. Serafimovich and Efimova [16] also summarised the potential uses of the taxon and discussed possible approaches to its conservation.

Although these contributions established an important taxonomic, biogeographic, and geographical foundation, standardised population-level ecological comparisons remain limited. Existing descriptions often focus on the presence of the target species at individual localities without providing comparable quantitative information on the associated vegetation. Consequently, it remains difficult to determine whether differences observed among populations are related primarily to altitude, habitat moisture, vegetation type, disturbance intensity, or local topographic conditions. Information is also limited on whether isolated populations occupy a relatively narrow ecological niche or persist across a broader range of environmental settings.

In particular, no integrated field assessment has systematically compared vegetation structure, associated floristic richness, ecological group composition, habitat characteristics, and field-observed ontogenetic spectra across multiple populations in the Kazakhstan Altai. These variables describe complementary aspects of population ecology. Floristic richness reflects the number of species occurring in the habitat and provides a general indication of community diversity. Vegetation structure characterises the development and spatial organisation of the plant cover, including the relative contribution of tree, shrub, and herbaceous layers. Ecological group composition provides information on the moisture, habitat, and life-form affinities of associated species and can therefore help interpret environmental differences among localities. Ontogenetic observations, although strongly dependent on sampling season and detectability, provide preliminary evidence regarding population regeneration and the representation of earlier developmental stages.

Comparative information from several localities is required to distinguish population-specific features from broader ecological tendencies. A characteristic observed in a single population may reflect a temporary disturbance, local soil conditions, slope exposure, or sampling effects rather than a general ecological property of the taxon. In contrast, patterns repeated across several populations may indicate consistent habitat preferences or common limitations affecting population structure. Multisite comparisons are therefore essential for

identifying the range of environmental conditions under which populations persist and for recognising localities that may require special conservation attention.

The Kazakhstan Altai provides an appropriate setting for such a comparison because populations occur in environmentally contrasting habitats. Differences in elevation, slope position, moisture availability, canopy cover, and proximity to rivers create distinct ecological conditions within the regional distribution range. Open subalpine slopes are generally exposed to greater fluctuations in temperature, wind, and solar radiation. In contrast, river terraces and floodplains may provide more stable moisture conditions and deeper or more developed soils. Sparse coniferous forests may reduce temperature extremes and create structurally complex vegetation, but they may also increase competition for light, water, and nutrients. Evaluating populations across these habitats can therefore provide insight into the ecological amplitude of *S. altaiensis* and the extent to which its associated communities vary across local environmental gradients.

Moisture availability may be especially important in determining vegetation richness and structure. Floodplain and forest habitats frequently support more ecological niches than exposed slopes because they contain vertical vegetation layers, variable light conditions, and microsites that differ in moisture and substrate properties. However, greater habitat complexity does not necessarily result in better conditions for the target species. Dense herbaceous vegetation, closed shrub cover, or increasing tree-canopy development may reduce the availability of suitable microsites for seedling establishment. Conversely, open habitats may contain fewer associated species but provide reduced competition and greater availability of exposed soil surfaces. A comparative analysis is therefore needed to assess whether apparently favourable community-level conditions correspond to the occurrence of younger individuals and potential population renewal.

Population regeneration is a particularly important conservation issue for long-lived shrubs. Adult individuals may persist for many years even when successful seedling establishment has become infrequent, so the continued presence of mature or generative plants does not necessarily demonstrate long-term population stability. The regeneration niche may be constrained by seed availability, microsite suitability, litter accumulation, competition, and the timing of disturbance [17,18]. The detection of juvenile and immature individuals can provide evidence of recent recruitment, but stage-specific detectability may vary substantially when small plants are obscured by dense vegetation or litter [19]. For this reason, ontogenetic observations collected during a single midsummer survey should be interpreted cautiously and regarded as an initial field assessment rather than a complete demographic or population-viability analysis [20].

This study, therefore, combines community- and population-level observations to provide an ecological baseline for *S. altaiensis* in eastern Kazakhstan. The emphasis is placed on standardised comparison rather than on formal causal inference because altitude, habitat type, moisture regime, canopy structure, and disturbance are not independent under natural field conditions. Nevertheless, the inclusion of six populations representing several habitat types allows identification of consistent contrasts and the formulation of hypotheses for subsequent long-term studies. The resulting dataset can also support the selection of representative monitoring sites and the development of repeatable field indicators.

Accordingly, we compared six populations occurring in open subalpine slopes, river terraces, floodplain environments, and sparse conifer forests. We evaluated three exploratory hypotheses: (H1) floristic richness and vegetation structure differ among populations along the combined altitudinal and habitat gradient; (H2) relatively moist forest and floodplain habitats support greater associated species richness and structural complexity than exposed open habitats; and (H3) adult vegetative and generative shrubs are detected more frequently than juvenile individuals during midsummer surveys. The objectives were

to characterise habitat and vegetation structure, compare observed floristic richness and ecological group composition, summarise field-observed ontogenetic states, and define priorities and repeatable indicators for population-based conservation monitoring of *S. altaiensis* in eastern Kazakhstan. Because altitude, moisture, canopy structure, and disturbance covary under natural field conditions, these hypotheses are evaluated descriptively rather than as causal tests.

2. Materials and Methods

2.1. Study Area

Field investigations were conducted during the principal flowering and fruiting period in July 2024 and July 2025 in the Kazakhstan Altai and East Kazakhstan, including protected landscapes associated with Katon-Karagay and the West Altai. The region is characterised by a strongly continental mountain climate, marked elevational zonation, and pronounced spatial variation in precipitation, snow persistence, vegetation belts, and soil development [21,22].

Six accessible populations known from previous regional surveys were selected purposively to represent the principal habitat types and a broad elevational interval within the taxon’s distribution in Kazakhstan. Four populations were located in the Southern Altai and two in the Western Altai. The design covered 814–2130 m a.s.l. and included open sub-alpine shrub–forb communities, river-valley terraces, shrub–meadow floodplain vegetation, and sparse dark-conifer forest. The population was treated as the primary comparative unit, whereas the ten plots within each population served as standardised subsamples for documenting local floristic and structural variation. The localities, therefore, constitute a stratified comparative set rather than a random sample of all known occurrences. This design supports controlled descriptive comparison among the surveyed populations and habitat contexts, but it does not justify statistical generalisation to all populations in the Kazakhstan Altai.

2.2. Studied Populations

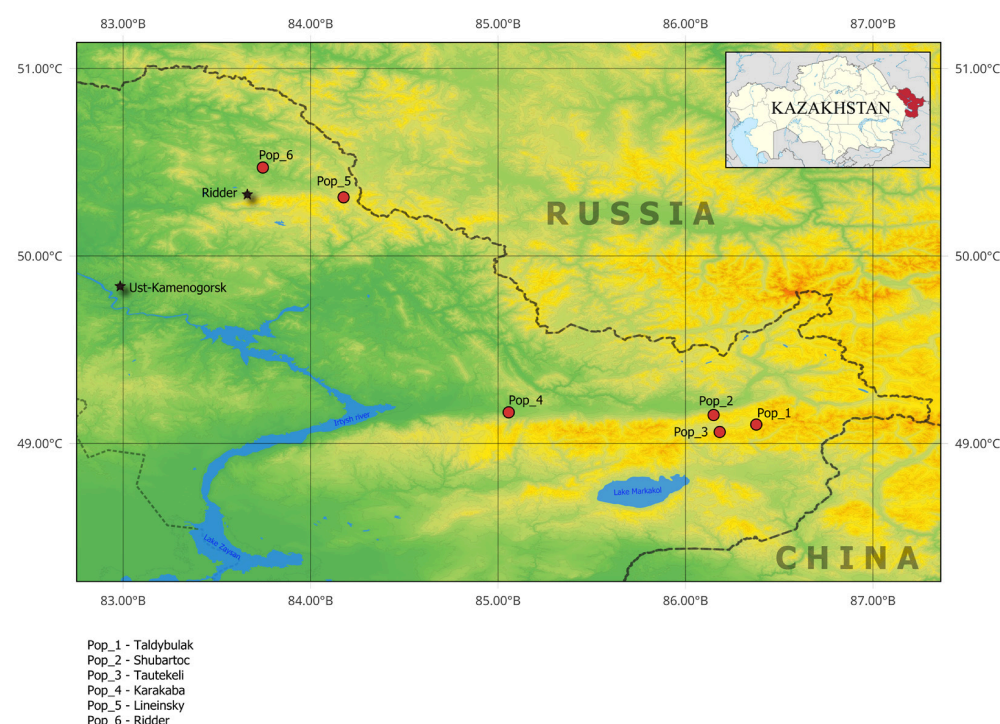
Geographic coordinates, elevation, landform, substrate, qualitative moisture regime, light environment, and vegetation type are summarised in Table 1. Coordinates were recorded in the WGS84 geographic reference system using a handheld GPS receiver. Taldybulak, Shubartoc, Tautekeli, and Karakaba represented the Southern Altai, whereas Lineinsky and Ridder represented the Western Altai (Figure 1).

Table 1. Description of natural populations of *Sibiraea altaiensis*.

Population	Coordinates	Elevation (m)	Landform/Location	Regional Climate Context	Soil/Substrate	Qualitative Moisture Regime	Canopy/Light Environment	Vegetation Type
Pop_1 Taldybulak	49°06.355' N, 86°07.890' E	1816	Open right-bank valley of the Taldybulak River; southeastern slope of Mt. Shubartoc	Cool continental mountain climate	Alluvial, stony-loamy, well-drained	Moderate; precipitation and seasonal snowmelt	High; open site	Mountain-meadow shrub and subalpine shrub–forb vegetation
Pop_2 Shubartoc	49°06.102' N, 86°08.051' E	2102–2130	Southern and southeastern slopes of Mt. Shubartoc; Burkit Uya peak	Cool continental mountain climate	Alluvial, stony-loamy, well-drained	Moderate; snowmelt supported	High; open site	Subalpine shrub–forb vegetation
Pop_3 Tautekeli	49°03.103' N, 85°58.764' E	1726	Open the left-bank valley of the Tautekeli River	Cool continental mountain climate	Dark mountain chernozem	Moderate; abundant snow and local water retention	High; open site	Mountain shrub–forb vegetation

Table 1. Cont.

Population	Coordinates	Elevation (m)	Landform/Location	Regional Climate Context	Soil/Substrate	Qualitative Moisture Regime	Canopy/Light Environment	Vegetation Type
Pop_4 Karakaba	49°03.436' N, 86°00.176' E	1607–1693	Kara-Kaba River terrace, approximately 500 m from the channel	Cool continental mountain climate	Meadow- chernozem and alluvial- meadow soils	Moderate to variable	High; open site	Shrub–meadow floodplain and terrace vegetation
Pop_5 Lineinsky	50°24.309' N, 84°09.807' E	1430–1435	Southern macroslope of the Lineinsky Ridge	Strongly continental; cool summer	Mountain-forest brown soils	Relatively high	Partial canopy; southern exposure	Sparse dark-conifer forest with shrub understory
Pop_6 Ridder	50°17.723' N, 83°29.900' E	814–956	Gromatukha River floodplain near Ridder	Strongly continental; cool summer	Alluvial soils with high humus content	Elevated	Generally high	Shrub–meadow floodplain vegetation

Figure 1. Map of the locations of the studied populations of *S. altaiensis* in Eastern Kazakhstan.

The Southern Altai localities were situated mainly in open river valleys and on southern or southeastern slopes at 1607–2130 m a.s.l. In contrast, the Western Altai localities occupied a lower-elevation forest macroslope and a river floodplain at 814–1435 m a.s.l. The sampling set consequently encompassed broad contrasts in elevation, canopy context, substrate, snowmelt influence, and qualitative moisture availability.

2.3. Vegetation Survey and Floristic Data

Ten 10 m × 10 m plots were surveyed in each population (60 plots in total). Candidate plot positions were identified throughout the area occupied by *S. altaiensis*. From the available positions, ten plots were selected purposively to provide broad spatial coverage of the population while remaining within the same visually homogeneous vegetation type. Where several positions met these criteria, preference was given to locations that increased spatial separation from previously selected plots and improved coverage of the population area. Plot placement was independent of local species richness and the abundance of particular associated species. If a candidate position coincided with an abrupt ecotone, a path, an eroded area, or another clearly disturbed microsite, the plot was shifted by the minimum necessary distance to the nearest representative patch of the same vegetation type. Thus,

the plots represented spatially distributed purposive subsamples of each population habitat rather than the only available homogeneous locations. For each plot, all vascular plant taxa were recorded, together with total projective cover, vertical vegetation structure, and species abundance–dominance, following standard phytosociological procedures [23–26]. Abundance–dominance was estimated using the Braun–Blanquet scale: r, solitary individuals with negligible cover; +, few individuals with <1% cover; 1, numerous individuals but <5% cover; 2, 5–25%; 3, 25–50%; 4, 50–75%; and 5, 75–100% [25,26]. The original ordinal classes were retained and were not converted to percentage midpoints. The same plot size and field protocol were applied at all six populations. The population, rather than each plot, was treated as the independent comparative unit; plot observations were consolidated to characterise within-population floristic and structural variation. Taxonomic nomenclature was checked against Plants of the World Online, except that the regional operational name *S. altaiensis* was retained as described above [10]. The complete species-by-population phytosociological summary is provided in Supplementary Table S1.

2.4. Population-Structure and Ontogenetic Observations

For population-structure observations, the field sampling unit was a spatially discrete shrub clump that could be consistently recognised above ground. Because underground connections were not excavated and genetic identity was not assessed, these units are described as sampled shrubs rather than confirmed genets; individual shoots within a clump may represent ramets. Recorded attributes included general plant condition, spatial arrangement, reproductive status, and the presence of operational ontogenetic states. Population-level morphometric means were excluded from comparative interpretation when their population-specific origin could not be independently verified.

Ontogenetic states were assigned using field-observable morphological criteria. Juvenile plants were defined as seedlings or very small single-shoot individuals with simple architecture; immature plants as small non-reproductive individuals with several vegetative shoots; virginal plants as developed multi-shoot individuals without reproductive shoots; young generative plants as relatively small flowering shrubs with incompletely developed crowns; middle-aged generative plants as fully developed flowering or fruiting shrubs; subsenile plants as individuals with reduced flowering and visible shoot dieback; and senile plants as strongly degraded individuals lacking functional reproductive shoots. Because dense midsummer herbaceous cover and litter can obscure small seedlings, the category “juveniles not recorded” denotes a field observation rather than demonstrated recruitment failure.

2.5. Data Processing and Analytical Scope

Population-level synthesis was restricted to descriptors that could be verified directly from the consolidated field records: observed numbers of vascular plant species, genera, and families; proportional representation of ecological groups; total projective cover; dominant and subordinate species; vertical vegetation structure; and reported ontogenetic states. Ecological affinity was assigned from published indicator and habitat literature and summarised as the proportions of mesophytes, xeromesophytes, mesoxerophytes, hygrophytes, and related groups [27]. Life-form spectra were interpreted within the Raunkiaer framework [28].

Moisture, soil trophicity, and light were treated as ordinal habitat descriptors based on topographic position, canopy openness, visible substrate characteristics, snowmelt influence, and regional environmental literature. They were not derived from instrumental measurements and were therefore used only to contextualise floristic and structural differences. Observed richness represents the pooled number of taxa recorded under nominally

equal sampling effort at each population; it is not an asymptotic richness estimator and was not rarefied.

Because only six population-level units were available and the complete plot-by-species abundance matrix could not be independently audited, statistical inference was intentionally conservative. The originally reported entropy indices, accumulation curves, and constrained ordination were not retained. Comparisons are descriptive and hypothesis-guided rather than confirmatory. Once plot-level abundance data and metadata are curated and archived, Hill numbers, coverage-based rarefaction, accumulation analyses, and multi-variate community models would provide an appropriate inferential framework [29–31].

3. Results

3.1. Habitat and Community Structure

The six populations occupied four major ecological settings: open subalpine shrub-forb slopes (Taldybulak, Shubartoc, and Tautekeli), a river-terrace shrub-meadow habitat (Karakaba), a sparse conifer-forest understory (Lineinsky), and a moist floodplain shrub-meadow habitat (Ridder). *Sibiraea altaiensis* was dominant or structure-forming in all settings, but the identity of associated species, canopy context, and vertical organisation of the vegetation differed markedly among localities.

The open Southern Altai communities generally comprised two or three recognisable vegetation layers, and total projective cover approached 95% where recorded. At Taldybulak and Tautekeli, *S. altaiensis* contributed more than 70% of the shrub-layer cover. At Karakaba, the species occurred as comparatively sparse clumps above a species-rich herb layer. At Shubartoc, the highest-elevation locality, turnover in shrub-layer dominants was observed toward the upper part of the surveyed slope, indicating fine-scale structural variation within the population (Figure 2).

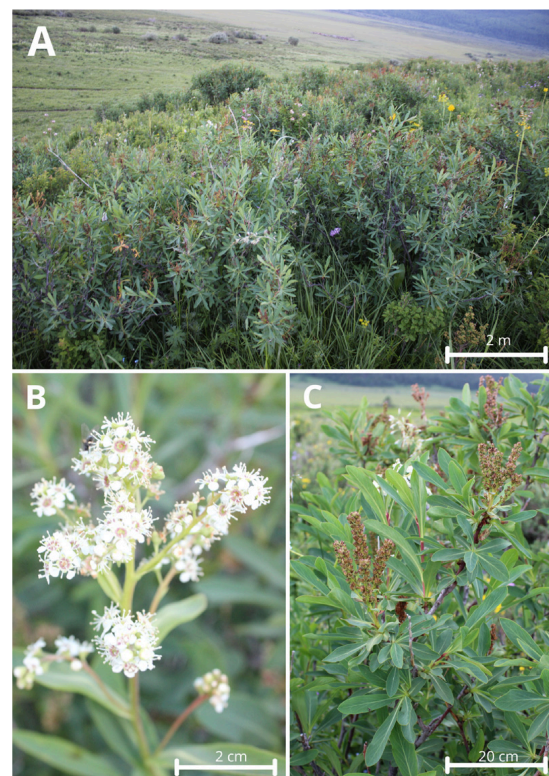


Figure 2. Habitat and morphological features of the studied species: (A) general view of the plant community; (B) inflorescence; (C) vegetative shoots (leaves and fruits).

The Lineinsky population occurred beneath a discontinuous conifer canopy comprising *Larix sibirica*, *Abies sibirica*, *Pinus sibirica*, and *Picea obovata*. Its understory exhibited greater vertical and taxonomic complexity than that of the open sites and included several additional rosaceous shrubs, including *S. altaiensis*.

The Ridder population occupied a topographically heterogeneous floodplain characterised by hummocks and shallow gullies. Total vegetation cover ranged from 90% to 97%, and the community displayed a well-developed three-layered structure. Source descriptions indicated that *S. altaiensis* contributed more than 60% of the shrub-layer cover.

Across the six populations, *S. altaiensis* co-occurred repeatedly with meadow, forest-edge, and subalpine taxa, including *Dasiphora fruticosa*, *Carex pediformis* var. *macroura*, *Iris ruthenica*, *Calamagrostis epigejos*, *Rosa* spp., and *Spiraea media*. Nevertheless, the combination and relative abundance of dominant and subordinate species differed among populations, providing descriptive support for H1.

Detailed phytosociological records and Braun–Blanquet abundance–dominance classes are presented in Supplementary Table S1. The main text, therefore, focuses on cross-population contrasts rather than on reproducing complete species lists for each locality.

3.2. Floristic Richness and Ecological Composition

Observed vascular plant richness varied more than twofold, from approximately 35 species at Tautekeli to 78 at Lineinsky (Table 2; Figure 3). Shubartoc, the highest-elevation locality, supported 76 species, and Ridder supported 72 species. Thus, richness did not follow a monotonic elevational pattern and did not separate consistently between the Southern and Western Altai populations.

Table 2. Comparative descriptive summary of floristic richness, vegetation structure, and juvenile detection in the six surveyed populations.

Juveniles	Principal Habitat	Role of <i>S. altaiensis</i>	Cover (%)	Mesophytes (%)	Taxa (S/G/F)	Population
Not recorded	Open subalpine valley	Dominant; >70% shrub cover	≈95	75.5	53/37/23	Taldybulak
Not recorded	High-elevation open slope	Dominant; locally >70%	≈95	68.4	76/61/30	Shubartoc
Not recorded	Open river valley	Dominant; >70% shrub cover	≈95	71.4	≈35/30/19	Tautekeli
Not recorded	River terrace	Structure-forming; sparse clumps	Not available consistently	56.3	48/39/21	Karakaba
Not reported consistently	Sparse conifer forest	Dominant; 45–50%, locally 70%	90–95	77.0	78/68/31	Lineinsky
Not recorded	Moist floodplain	Dominant; >60% shrub cover	90–97	73.6	72/69/25	Ridder

Note: S/G/F = species/genus/family. “Not recorded” means that juveniles were not observed during the survey and does not demonstrate their true absence.

Mesophytes constituted the largest ecological group at every locality, ranging from 56.3% at Karakaba to 77.0% at Lineinsky. Their consistent predominance indicates a broadly mesic affinity of the associated vegetation. At the same time, variation in xeromesophytes, mesoxerophytes, hygrophytes, and other transitional groups reflected local differences in exposure, substrate, canopy, and water availability.

Perennial herbs dominated the life-form spectra throughout the study, whereas shrubs contributed most strongly in the forest-understory and selected subalpine communities. High richness at both Shubartoc and Lineinsky, despite their contrasting elevation and canopy conditions, suggests that local habitat heterogeneity and vegetation-belt turnover may be as influential as elevation or regional position considered independently.

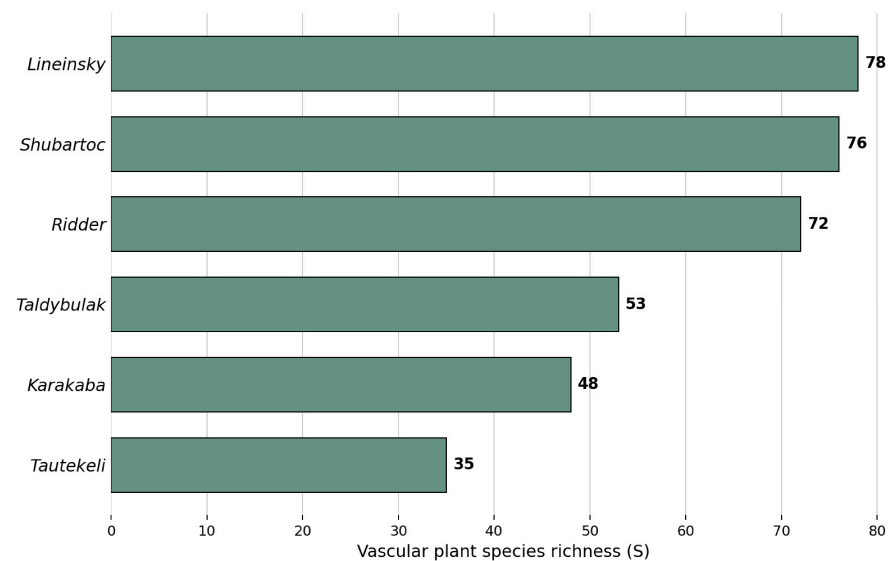


Figure 3. Observed vascular plant richness in the six surveyed populations. Values are pooled population-level totals recorded under nominally equal sampling effort (ten 10×10 m plots per population); they are not rarefied richness estimates. A uniform colour is used because all populations represent comparable sampling units.

H1 was supported at a descriptive level by pronounced among-population differences in observed richness and vegetation organisation. H2 received only partial support: the comparatively moist Lineinsky and Ridder habitats were species-rich, but the exposed, high-elevation Shubartoc population was similarly rich. These statements refer to observed contrasts among six population-level units. They should not be interpreted as formal significance tests or causal estimates, as the populations were selected purposively and environmental variables were not measured quantitatively.

Taldybulak contained 53 species representing 37 genera and 23 families. Asteraceae, Rosaceae, Poaceae, Lamiaceae, and Fabaceae were among the most species-rich families, and mesophytes accounted for 75.5% of the recorded flora.

Tautekeli and Karakaba had lower observed richness, with approximately 35 and 48 species, respectively. Karakaba also had the lowest mesophyte proportion (56.3%) and a greater contribution from transitional moisture groups, consistent with its open terrace setting and spatially variable water supply.

Lineinsky had the highest observed richness (78 species, 68 genera, and 31 families), whereas Ridder contained 72 species, 69 genera, and 25 families. Although both Western Altai populations were mesophyte-dominated, they differed substantially in canopy environment, topographic heterogeneity, and vegetation architecture.

These richness contrasts may reflect species turnover among vegetation belts, fine-scale environmental heterogeneity, and local detectability during the survey period. They should not be interpreted as complete inventories of regional diversity or as direct indicators of demographic condition or population viability.

3.3. Observed Population Structure

The completeness and resolution of population-structure records differed among localities. Across available summaries, *S. altaiensis* was consistently described as a multi-shoot shrub forming grouped, patchy, or nearly continuous stands, but quantitative demographic information was not equally detailed across populations.

At Taldybulak, Shubartoc, and Tautekeli, adult and predominantly generative shrubs were reported, while juvenile plants were not detected. Identical preliminary morphometric

means across these three populations were excluded from the comparative synthesis because their independence as population-specific estimates could not be verified.

At Karakaba, shrubs were sparser and appeared less developed than at the other open sites, although reproductive individuals were present. Juveniles were not recorded. The open river-terrace position and variable moisture regime are plausible contextual factors, but the observational design does not permit causal attribution.

The Lineinsky field summary documented several adult ontogenetic states in the forest understory, but juvenile occurrence was not reported consistently enough for direct comparison. At Ridder, immature, virginal, generative, and subsenile shrubs were recorded, whereas juvenile and senile plants were not detected.

H3 was supported only as an observed detection pattern: adult and reproductive shrubs were conspicuous, whereas juveniles were rarely documented during midsummer surveys. This pattern is not demographic evidence of recruitment failure because seedling emergence may be episodic, spatially clustered, seasonally restricted, or obscured by dense herbaceous cover and litter. Repeated, seasonally stratified censuses are required before population renewal can be assessed.

Population-dynamic classifications such as stable, progressive, regressive, or pulsating require repeated censuses and estimates of stage-specific transition through time. Such categories were therefore not assigned from the present cross-sectional observations.

Table 2 shows that *S. altaiensis* retained a dominant or structure-forming role across all surveyed habitat types despite substantial differences in species richness, canopy setting, and total vegetation cover.

Juveniles were not recorded at five populations and were not reported consistently at Lineinsky. Dense herbaceous cover approaching 95% at several sites may have reduced detectability; however, the pattern may also reflect episodic establishment, litter depth, seed availability, microsite limitation, competition, or interannual variation in germination and early survival.

Because ontogenetic observations were collected during midsummer and were not repeated within seasons or across multiple years, they constitute a baseline for future monitoring rather than a population viability assessment.

Future censuses should establish permanent plots, record counts for each ontogenetic state, revisit populations during early and mid-growing seasons, and distinguish ramets from genetically independent individuals wherever feasible.

The verified dataset is sufficient to document among-population heterogeneity and identify monitoring priorities. Still, it cannot support inference about temporal trajectories, population growth rates, recruitment frequency, or extinction risk.

Collectively, the results emphasise habitat-specific community organisation and the need for standardised, repeatable demographic measurements rather than broad regional generalisation.

4. Discussion

The principal ecological result is the persistence of *S. altaiensis* as a dominant or structure-forming shrub across a broad range of Kazakhstan Altai habitats, accompanied by pronounced variation in associated floristic richness, species composition, and vertical vegetation structure. The use of equal nominal sampling effort across localities strengthens the descriptive comparison, although the purposive population selection limits broader generalisation. This pattern supports H1 and extends previous locality- and herbarium-based studies [14–16] by providing a standardised community-level comparison of six environmentally contrasting populations.

The expectation that moist forest and floodplain habitats would invariably support the greatest richness and structural complexity (H2) was only partly supported. Lineinsky and Ridder were species-rich, yet the exposed high-elevation Shubartoc locality was comparably rich. Elevation is a composite geographic descriptor that covaries with temperature, moisture, radiation, snow duration, substrate, and land use and should not be interpreted as a direct ecological driver without measurements of these components [5]. More broadly, environmental heterogeneity can increase species richness by expanding niche availability and promoting species turnover, although the magnitude and even the direction of this relationship depend on spatial scale and ecological context [6]. In the present study, these mechanisms remain hypothetical because microclimate, soil resources, and disturbance intensity were not directly measured.

The predominance of mesophytes at all localities indicates that *S. altaiensis* is primarily associated with communities receiving adequate seasonal moisture, even where the physiognomy ranges from exposed subalpine shrubland to sparse conifer forest and floodplain meadow. This combination suggests ecological breadth at the community scale but should not be equated with physiological tolerance of individual plants. The ecological group categories are literature-based classifications rather than direct measurements of soil water potential, plant water status, or microclimatic conditions [2,5,27].

The recurrent dominance of *S. altaiensis* indicates an important role in shrub-layer architecture, local cover, and habitat heterogeneity. However, the identity and relative abundance of associated species differed among slopes, terraces, forest understory, and floodplain sites. Such local environmental heterogeneity can support distinct species assemblages even within a limited geographic range [6]. Conservation measures should therefore preserve each population together with its local community and habitat context rather than treating all occurrences as ecologically interchangeable. This community-based perspective is particularly relevant for geographically isolated relict shrubs whose persistence may depend on site-specific snow, moisture, canopy, and disturbance regimes.

Juvenile plants were generally not detected, whereas adult and generative shrubs were conspicuous, in agreement with H3 as a survey-detection pattern. The regeneration-niche framework predicts that establishment can be limited by propagule supply, the availability of safe microsites, or both [17,18]. In addition, plant demographic surveys may underestimate life stages with low or state-dependent detectability, particularly small vegetative or juvenile individuals concealed by dense vegetation [19]. The present observations, therefore, cannot distinguish among genuine recruitment limitation, episodic establishment, spatially localised seedling emergence, and reduced detectability. Reliable diagnosis requires early-season searches, marked seedlings, permanent plots, and repeated stage-transition censuses; these data are also prerequisites for defensible population-viability assessment [20].

The operational use of *S. altaiensis* in this study should not be interpreted as evidence for species-level taxonomic independence. International databases commonly include the name within *S. laevigata*, whereas regional botanical practice maintains the Altai entity separately [10,11]. Resolving this discrepancy will require an integrative taxonomy that evaluates multiple and complementary lines of evidence, including type-based morphology, population-level genomic data, geographic structure, anatomy, and ecology [12,13,32,33]. The present study contributes habitat and community data to that broader framework but does not test species boundaries.

A practical conservation priority is to maintain the environmental heterogeneity of known population sites and to minimise localised degradation associated with grazing, recreation, fire, infrastructure development, or hydrological alteration. A standardised monitoring protocol should record plot-level abundance, ontogenetic state, flowering and

fruiting, shrub cover, canopy openness, litter depth, soil moisture, and visible disturbance. Early season surveys should specifically target open microsites, turf gaps, and litter discontinuities where seedlings are most likely to be detected. Repeated measurements using consistent sampling units and explicit treatment of observation error are essential for distinguishing real biological change from sampling variation [34].

Several limitations define the scope of inference. The six populations were selected purposively rather than randomly; surveys covered only two field seasons and were concentrated in midsummer; environmental variables were described qualitatively; the complete plot-level abundance matrix was not available for independent reanalysis; and above-ground shrub clumps were not confirmed as genets. These limitations preclude causal and temporal inference, and a single cross-sectional stage distribution cannot establish population viability [20]. Nevertheless, the audited dataset remains valuable as a transparent floristic and structural baseline, provided that future monitoring retains consistent methods and explicitly addresses detection and sampling error [34].

A robust next phase should integrate permanent plot demography with curated species-abundance matrices, direct soil and microclimatic measurements, disturbance indicators, reproductive-output data, and molecular-genetic sampling. Such a design would permit coverage-standardised diversity comparisons, multivariate community modelling, estimation of stage-specific demographic transitions, and evidence-based prioritisation of populations for in situ and ex situ conservation [20,29–31,34].

5. Conclusions

Across six surveyed populations spanning 814–2130 m a.s.l., *Sibiraea altaiensis* consistently formed a dominant or structure-forming component of shrub vegetation in open subalpine slopes, river terraces, sparse conifer forest, and floodplain habitats. H1 was supported descriptively because floristic richness and vegetation organisation differed markedly among localities. H2 received only partial support: moist forest and floodplain sites were species-rich, but the exposed high-elevation Shubartoc population was similarly rich. H3 was supported only as a detection pattern, with adults and generative shrubs recorded more consistently than juveniles; this result does not demonstrate recruitment failure because midsummer vegetation may reduce seedling detectability. Mesophytes predominated at every locality, and the observed richness pattern was more consistent with local habitat heterogeneity and vegetation context than with a simple Southern-versus-Western Altai division. The study establishes a comparative baseline but does not resolve temporal population trends or the taxonomic relationship between *S. altaiensis* and *S. laevigata*. Conservation assessment should prioritise permanent plots, seasonally replicated seedling searches, direct environmental measurements, curated plot-level datasets, and integrated molecular and morphometric evidence.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/d18070428/s1>: Table S1: Species-by-population phytosociological summary, including Braun–Blanquet abundance–dominance classes for vascular plants recorded in the six surveyed populations.

Author Contributions: Conceptualization, methodology, formal analysis, investigation, writing—original draft preparation, writing—review and editing, supervision, A.M.; investigation, data curation, Z.A.; investigation, project administration, T.S.; resources, project administration, funding acquisition, S.I.; software, methodology, writing—review and editing, A.O.; validation, formal analysis, visualization, writing—review and editing, S.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP26198171, “Geoecological and Molecular-Genetic Assessment, Monitoring of the Distribution and Development of Rare Plant Species of the Genera *Prunus*, *Sibiraea*, and *Rosa* (Rosaceae) in Kazakhstan”).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article/Supplementary Materials. Further inquiries can be directed to the corresponding authors.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Rahbek, C.; Borregaard, M.K.; Colwell, R.K.; Dalsgaard, B.; Holt, B.G.; Morueta-Holme, N.; Nogués-Bravo, D.; Whittaker, R.J.; Fjeldså, J. Humboldt’s enigma: What causes global patterns of mountain biodiversity? *Science* **2019**, *365*, 1108–1113. [CrossRef] [PubMed]
2. Körner, C. *Alpine Plant Life: Functional Plant Ecology of High Mountain Ecosystems*, 2nd ed.; Springer: Berlin, Germany, 2003.
3. Pauli, H.; Gottfried, M.; Dullinger, S.; Abdaladze, O.; Akhalkatsi, M.; Alonso, J.L.B.; Coldea, G.; Dick, J.; Erschbamer, B.; Calzado, R.F.; et al. Recent plant diversity changes on Europe’s mountain summits. *Science* **2012**, *336*, 353–355. [CrossRef] [PubMed]
4. Stewart, J.R.; Lister, A.M.; Barnes, I.; Dalén, L. Refugia revisited: Individualistic responses of species in space and time. *Proc. R. Soc. B* **2010**, *277*, 661–671. [CrossRef] [PubMed]
5. Mamyrova, S.; Kupriyanov, A.; Ishmuratova, M.; Ivashchenko, A.; Myrzagaliyeva, A.; Orazov, A.; Kubentayev, S. The current state of *Rhaponticum altaicum* (Asteraceae) populations in northern and central Kazakhstan. *Diversity* **2025**, *17*, 206. [CrossRef]
6. Stein, A.; Gerstner, K.; Kreft, H. Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. *Ecol. Lett.* **2014**, *17*, 866–880. [CrossRef] [PubMed]
7. Eastwood, A.; Lazkov, G.; Newton, A.C. *The Red List of Trees of Central Asia*; Fauna & Flora International: Cambridge, UK, 2009.
8. Sumbembayev, A.A.; Kotukhov, Y.A.; Danilova, A.N.; Aitzhan, M. Endemic and endangered vascular flora of Kazakhstan’s Altai Mountains: A baseline for sustainable biodiversity conservation. *Sustainability* **2025**, *17*, 7283. [CrossRef]
9. Potter, D.; Still, S.M.; Grebenc, T.; Ballian, D.; Božič, G.; Franjić, J.; Kraigher, H. Phylogenetic relationships in tribe *Spiraeae* (Rosaceae) inferred from nucleotide sequence data. *Plant Syst. Evol.* **2007**, *266*, 105–118. [CrossRef]
10. Royal Botanic Gardens, Kew. Plants of the World Online: *Sibiraea altaiensis* (Laxm.) C.K.Schneid. Available online: <https://powo.science.kew.org/> (accessed on 20 June 2026).
11. Govaerts, R.; Nic Lughadha, E.; Black, N.; Turner, R.; Paton, A. The World Checklist of Vascular Plants is a continuously updated resource for exploring global plant diversity. *Sci. Data* **2021**, *8*, 215. [CrossRef] [PubMed]
12. Ballian, D.; Grebenc, T.; Božič, G.; Melnik, V.; Wraber, T.; Kraigher, H. History, genetic differentiation, and conservation strategies for disjunct populations of *Sibiraea* species from Southeastern Europe and Asia. *Conserv. Genet.* **2006**, *7*, 895–907. [CrossRef]
13. Fu, P.C.; Gao, Q.B.; Zhang, F.Q.; Xing, R.; Khan, G.; Wang, J.L.; Liu, H.R.; Chen, S.L. Gene flow results in high genetic similarity between *Sibiraea* (Rosaceae) species in the Qinghai–Tibetan Plateau. *Front. Plant Sci.* **2016**, *7*, 1596. [CrossRef] [PubMed]
14. Baitulin, I.; Myrzagaliyeva, A.; Samarkhanov, T. New localities of endemic and relic species of flora in East Kazakhstan. *News Natl. Acad. Sci. Repub. Kazakhstan Ser. Biol. Med.* **2018**, *1*, 10–14.
15. Orazayeva, M.K. Study of the endemic *Sibiraea altaiensis* in the West Altai State Nature Reserve. *Vestn. Magistr.* **2018**, *5-3*, 13–14.
16. Serafimovich, M.V.; Efimova, M.V. The Altai endemic *Sibiraea altaiensis* (Laxm.) Schneid.: Possible use and methods of conservation. *Plant Biotechnol. Breed.* **2024**, *7*, 35–42. [CrossRef]
17. Orazov, A.; Myrzagaliyeva, A.; Tustubayeva, S.; Irsaliyev, S.; Sailaubekova, A.; Turalin, B. Valuable morphological traits and genetic resources of wild almond relatives in Kazakhstan. *ES Food Agrofor.* **2025**, *20*, 1577.
18. Eriksson, O.; Ehrlén, J. Seed and microsite limitation of recruitment in plant populations. *Oecologia* **1992**, *91*, 360–364. [CrossRef] [PubMed]
19. Kéry, M.; Gregg, K.B. Effects of life-state on detectability in a demographic study of the terrestrial orchid *Cleistes bifaria*. *J. Ecol.* **2003**, *91*, 265–273. [CrossRef]
20. Menges, E.S. Box 1. An annotated glossary of plant PVA terms. *Trends Ecol. Evol.* **2000**, *15*, 51–56. [PubMed]
21. Chlachula, J. Environmental context and adaptations of prehistoric and early historical occupation in the Southern Altai (SW Siberia–East Kazakhstan). *Archaeol. Anthropol. Sci.* **2019**, *11*, 2215–2236. [CrossRef]
22. Chlachula, J. Geoheritage of East Kazakhstan. *Geoheritage* **2020**, *12*, 91. [CrossRef]
23. Mueller-Dombois, D.; Ellenberg, H. *Aims and Methods of Vegetation Ecology*; Wiley: New York, NY, USA, 1974.
24. Kent, M. *Vegetation Description and Data Analysis: A Practical Approach*, 2nd ed.; Wiley-Blackwell: Chichester, UK, 2012.
25. Braun-Blanquet, J. *Plant Sociology: The Study of Plant Communities*; McGraw-Hill: New York, NY, USA, 1932.

26. Westhoff, V.; van der Maarel, E. The Braun-Blanquet approach. In *Classification of Plant Communities*; Whittaker, R.H., Ed.; Springer: Dordrecht, The Netherlands, 1978; pp. 287–399.
27. Ellenberg, H.; Weber, H.E.; Düll, R.; Wirth, V.; Werner, W.; Paulißen, D. Zeigerwerte von Pflanzen in Mitteleuropa. *Scr. Geobot.* **1992**, *18*, 1–258.
28. Raunkiaer, C. *The Life Forms of Plants and Statistical Plant Geography*; Clarendon Press: Oxford, UK, 1934.
29. Magurran, A.E. *Measuring Biological Diversity*; Blackwell Publishing: Oxford, UK, 2004.
30. Jost, L. Entropy and diversity. *Oikos* **2006**, *113*, 363–375. [[CrossRef](#)]
31. Chao, A.; Chiu, C.H.; Jost, L. Unifying species diversity, phylogenetic diversity, functional diversity, and related similarity and differentiation measures through Hill numbers. *Annu. Rev. Ecol. Evol. Syst.* **2014**, *45*, 297–324. [[CrossRef](#)]
32. Dayrat, B. Towards integrative taxonomy. *Biol. J. Linn. Soc.* **2005**, *85*, 407–417. [[CrossRef](#)]
33. Padial, J.M.; Miralles, A.; De la Riva, I.; Vences, M. The integrative future of taxonomy. *Front. Zool.* **2010**, *7*, 16. [[CrossRef](#)] [[PubMed](#)]
34. Salmurzauly, R.; Myrzagaliyeva, A.; Irsaliyev, S.; Samarkhanov, T.; Orazov, A.; Nurtazin, S.; Altynbek, M.; Sagynysh, B. *Fraxinus sogdiana* Bunge forests in Charyn Canyon, Kazakhstan. *Casp. J. Environ. Sci.* **2024**, *22*, 1117–1131.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.