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RESEARCH ARTICLE

Spatial patterns of species richness and endemism of *Acantholimon* (Plumbaginaceae) in Uzbekistan: implications for conservation in Central Asian Mountain flora

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Abstract

The mountains harbour considerable diversity of *Acantholimon* Boiss., but broad-scale patterns of documented richness, endemism, elevation, and range restriction remain poorly quantified. We analysed 269 georeferenced records of 28 species (1870–2016; two records undated) using a 20 × 20 km grid, fixed 200 m elevation classes, and GeoCAT. Records occurred in 95 out of 1,262 cells, with one to five species per occupied cell; the highest documented cell richness occurred in northern Nuratau (AC46). Ten national endemics (35.7%) occupied 17 cells. AC46 and Hissar cell AM49 each contained three national endemics, but together represented only six of the 10 species. Raw elevation frequencies placed 150 records (55.8%) between 1,600 and 2,800 m, with the highest 200 m class at 2,000–2,200 m (n = 30). The exact species–coordinate deduplication retained 260 records and the same modal class, although the frequencies were not standardised by available land area or collecting effort. Preliminary GeoCAT screening according to IUCN criterion B2 identified four endemics below the AOO threshold (< 10 km²) and six below the EN level threshold (≥ 10 and < 500 km²). The minimum convex poly-

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gon EOO could not be calculated for three taxa represented by fewer than three occurrence points. These grid- and record-dependent results identify priorities for standardised field reassessment, not definitive biological hotspots, representative conservation networks, or formal IUCN categories.

Keywords
Area of occupancy, criterion B2, elevational distribution, GeoCAT, grid mapping, range size screening

Introduction

Acantholimon Boiss. (Plumbaginaceae) comprises approximately 200 Irano-Turanian xerophytic species, most of which have a cushion-forming growth habit. Phylogenetic and biogeographical evidence links diversification of the genus with morphological innovation and the expansion of mountain habitats after the uplift of the Irano-Turanian region during the Mio-Pliocene (Moharrek et al. 2019). However, the broad-scale spatial and elevational structure of its diversity and the geographical restriction of endemic species in Uzbekistan remain poorly quantified.

Tien Shan and Pamir-Alay are the main centres of temperate plant diversity in Central Asia. Their steep environmental gradients and fragmented landscapes provide an important biogeographical setting for the persistence and differentiation of specialised mountain lineages (Kamelin 1973). Botanical studies have further refined knowledge of the regional flora through taxonomic revision (Tojibaev et al. 2020), re-examination of type material (Ovchinnikova et al. 2020), updated vascular plant records (Levichev et al. 2023; Tajetdinova et al. 2025) and spatial analysis of endemic plant diversity (Tojibaev et al. 2022).

Current treatments recognise 28 species of *Acantholimon* in Uzbekistan, occurring mainly in the Western Tien Shan and Pamir-Alay (Beshko 2015; Sennikov 2019; Li and Tojibaev 2025; Turginov 2025). Ten of these species are endemic to Uzbekistan. The 2019 Red Data Book of Uzbekistan included five species of *Acantholimon*, whereas the recent national reassessment for the sixth edition recognises six species, with *A. zakirovii* added to the protected list (Khasanov 2019; Shomurodov et al. 2026). Despite floristic and conservation studies in the Nuratau Mountains and neighbouring regions (Rakhimova et al. 2021; Beshko et al. 2025), spatial variation in *Acantholimon* richness and endemism across the principal mountain systems remains incompletely resolved. Grid-based mapping provides a reproducible framework for documenting such patterns and has previously been applied to mountain plant distributions in southern Uzbekistan (Tajetdinova et al. 2024).

Against this background, the present study aimed to document broad-scale, grid-dependent spatial and elevational patterns of *Acantholimon* species richness and endemism in Uzbekistan and to screen the range sizes of national endemics. We additionally evaluated sensitivity to exact coordinate duplicates and record age, while treating richness values as documented, rather than sampling-corrected estimates.

Materials and methods

Occurrence data and taxonomic verification

A spatial database of *Acantholimon* Boiss. occurrences in Uzbekistan were compiled from specimens deposited at the National Herbarium of Uzbekistan (TASH), the Herbarium of Moscow State University (MW), the Herbarium of the Institute of Botany and Phytointroduction, Almaty (AA), the Komarov Botanical Institute (LE), and the Herbarium of the Nuratau State Nature Reserve. Herbarium data were supplemented with published floristic accounts, taxonomic revisions, regional checklists, and field observations (Beshko 2015; Sennikov 2019; Turginov 2025).

Species names and taxonomic circumscriptions were checked against World Flora Online (WFO 2026), Plants of the World Online (POWO 2026), and recent regional treatments. Historical localities without coordinates were georeferenced in ArcGIS v10.8 (ESRI, Redlands, CA, USA) using locality descriptions, topographic maps, gazetteers, and satellite imagery. Records with uncertain identifications, unresolvable localities, missing coordinates, or documented spatial uncertainty greater than 1 km were excluded. Repeated occurrence records that shared coordinates were retained in the occurrence database, but each species was counted only once within a grid cell. The final database comprised 269 georeferenced records representing 28 species (Fig. 1).

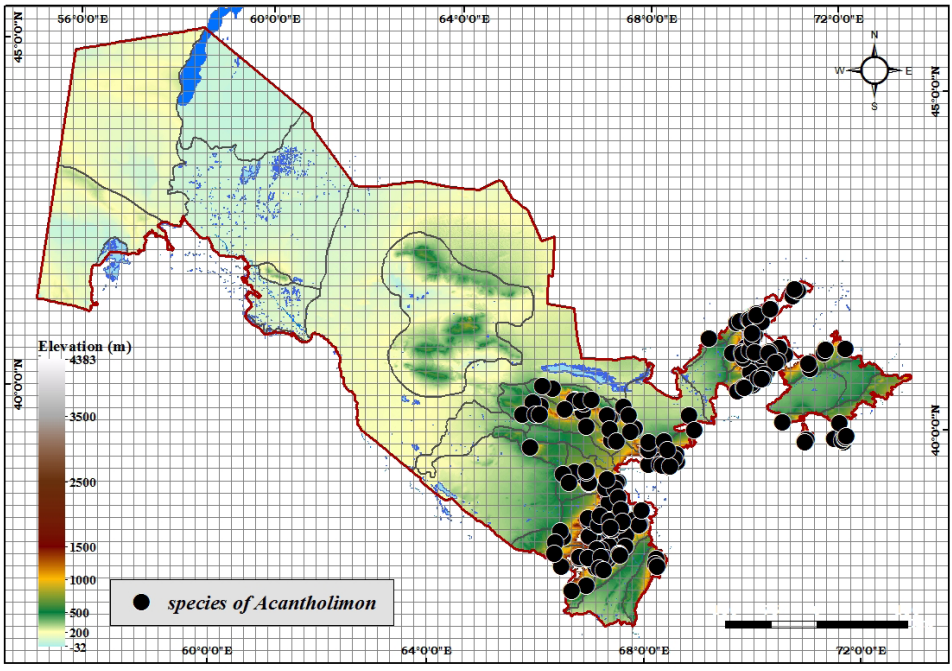


Figure 1. Study area and *Acantholimon* occurrence records in Uzbekistan.

Temporal provenance and sensitivity screening

Collection years were transcribed from the sample labels or source records and verified against the documentary text. A year was resolved for 267 of 269 records, spanning 1870-2016; two records remained undated. For sensitivity screening, records before 2000 were operationally classified as historical and those from 2000-2016 as recent. This cutoff point was used only to examine the influence of record age and is not an IUCN rule. Primary grid, elevation, and GeoCAT analyses retained all validated records, including historical occurrences. For national endemics, AOO was also recalculated from post-1999 records. Taxa lacking post-1999 records were reported to be inestimable on the recent-only screen, not as AOO = 0 or extinct.

Spatial framework and richness mapping

A regular 20 × 20 km grid was generated in ArcGIS v10.8 and overlayed on the national boundary of Uzbekistan. It comprised 1,262 cells and occurrence records were assigned to cells using a spatial join. Richness was calculated as the number of unique species recorded in each cell. Endemic species richness was calculated separately for the national endemics of Uzbekistan, the Tien Shan endemics, and Pamir-Alay endemics, with each species counted once per cell. The endemism assignments followed the regional distributions compiled from the taxonomic and floristic sources cited above.

Elevational distribution

Elevation values for the 269 occurrence records were extracted at the recorded point coordinates from the Shuttle Radar Topography Mission digital elevation model at approximately 30 m spatial resolution (Farr et al. 2007). Values were grouped into fixed 200 m classes with lower bounds included and upper bounds excluded. A sensitivity data set retained one record per exact species-latitude-longitude combination, reducing the histogram data set from 269 to 260 records. Elevation frequencies were not standardised by the land area available within each elevation band or by collecting effort. Furthermore, historical georeferencing was accepted up to 1 km and no elevation buffer uncertainty analysis was performed. Therefore, the histogram describes documented record frequencies, not population abundance, elevation-specific species richness, or habitat preference.

GeoCAT range-size screening

Extent of Occurrence (EOO) and Area of Occupancy (AOO) were screened for the 10 national endemics using the GeoCAT Web tool (Bachman et al. 2011). AOO was estimated using the standardised 2 × 2 km grid. The minimum convex polygon (MCP) EOO was calculated only for taxa represented by at least three non-collinear

occurrence points. Therefore, EOO was reported as not calculable for *A. annae*, *A. taschkurganicum*, and *A. vvedenskyi*, each represented by fewer than three points. For *A. subavenaceum*, the calculable EOO was smaller than AOO and was set equal to AOO following the IUCN guidelines (IUCN Standards and Petitions Committee 2024).

Species with AOO < 10 km² were described as meeting the CR-level numerical threshold under Criterion B2, and those with AOO ≥ 10 and < 500 km² as meeting the EN-level numerical threshold. These classes were used only for the preliminary range-size screening. Formal IUCN categories were not assigned because Criterion B requires additional evidence and Subcriteria B (a-c) were not evaluated (IUCN Standards and Petitions Committee 2024).

Results

Taxonomic composition, endemism, and spatial-elevational distribution

The final data set comprised 269 georeferenced occurrence records representing 28 species of *Acantholimon*, of which 10 (35.7%) were endemic to Uzbekistan. National endemics were documented mainly in the Nuratau, Kurama, Hissar, Baysun, and Chulbair ranges. Several species were represented by few records: *A. annae* by one record, *A. taschkurganicum* and *A. vvedenskyi* by two records each, and *A. subavenaceum* by three records. The collection year was resolved for 267 of 269 records: 239 were historical (before 2000), 28 were recent (2000–2016), and two were undated. All 46 national endemic records were dated; 34 were historical and 12 were recent. Post-1999 records represented *A. butkovii* (n = 2), *A. nuratavicum* (n = 4), *A. subavenaceum* (n = 2), and *A. zakirovii* (n = 4).

Occurrences were recorded in 95 of the 1,262 grid cells (7.5%). The documented species richness ranged from one to five species per occupied cell, with larger record concentrations in the Pamir-Alay and Western Tien Shan. Under the selected 20 × 20 km grid, the highest documented richness of five species occurred in cell AC46 in the northern Nuratau Range (Fig. 2).

The elevations ranged from 276 to 3,571 m above sea level. In the unstandardised histogram of the 269 records, 150 (55.8%) occurred between 1,600 and 2,800 m, and the highest frequency was in the class of 2,000-2,200 m (n = 30). Records below 1,000 m numbered 41 (15.2%), including 21 in the 800-1000 m class. The exact species-coordinate deduplication retained 260 records; the modal class of 2,000 to 2,200 m remained unchanged (n = 30), 145 records (55.8%) occurred between 1,600 and 2,800 m, and 40 (15.4%) occurred below 1,000 m (Fig. 3).

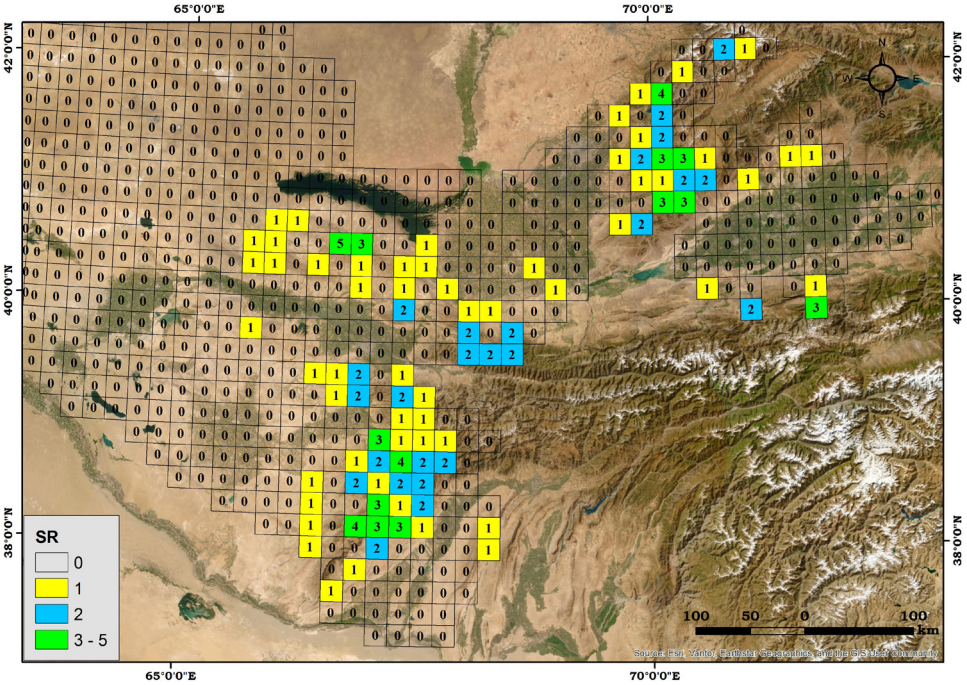


Figure 2. Grid-cell documented species richness of *Acantholimon* in Uzbekistan. The colours indicate the number of species recorded in each 20 × 20 km cell. Cell-specific values are conditional on this grid resolution and origin.

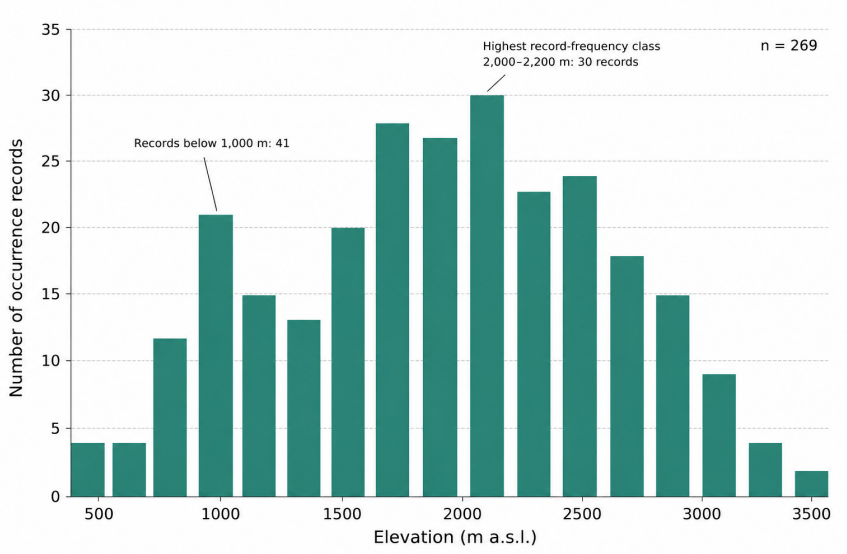


Figure 3. Elevational distribution of 269 georeferenced *Acantholimon* occurrence records in Uzbekistan. The bars show unstandardised record counts within fixed 200-m elevation classes. Frequencies were not standardised by available land area or collection effort and should not be interpreted as habitat preference.

Spatial patterns of endemism

The spatial distribution of the endemic species of *Acantholimon* differed among the three groups of endemism mapped at a resolution of 20 × 20 km (Fig. 4). The 10 national endemics (35.7% of the 28 species; 46 records) occupied 17 grid cells in the Nuratau, Kurama, Hissar, Baysun and Chulbair ranges (Fig. 4A). Eleven cells contained one national endemic, four contained two, and two contained three. The highest documented richness of three species occurred in cell AC46 in the northern Nuratau Range, containing *A. nuratavicum*, *A. subavenaceum* and *A. zakirovii*, and in cell AM49 in the Hissar Range, containing *A. hissaricum*, *A. taschkurganicum*, and *A. vvedenskyi*.

The eight Tien Shan endemics, represented by 126 records, occupied 57 grid cells and had the broadest spatial coverage among the three groups (Fig. 4B). Forty-six cells contained one species, seven contained two, three contained three, and one contained four. The maximum richness of four species was recorded in cell V61, which encompassed localities in the Ugam and Pskem ranges.

The 10 Pamir-Alay endemics, represented by 97 records, occupied 43 grid cells (Fig. 4C). Thirty-one cells contained one species, 11 contained two, and one contained three. Their distribution extended across the Alay, Turkestan, Zeravshan, Hissar, Baysun, and adjacent mountain ranges. The maximum richness of three species was recorded in cell AF68 in the eastern Alay Range near Shakhimardan.

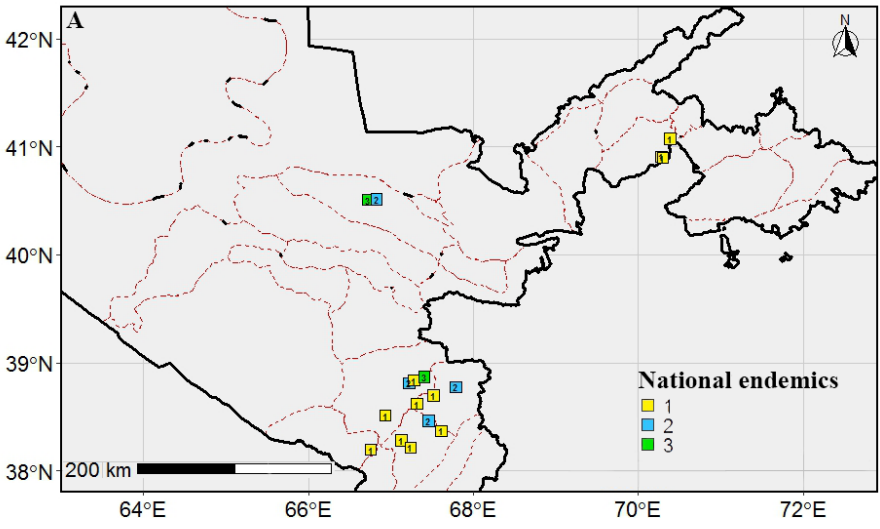


Figure 4. Grid-cell endemic *Acantholimon* richness in Uzbekistan (20 × 20 km grid). A – National endemics of Uzbekistan (continued on next page).

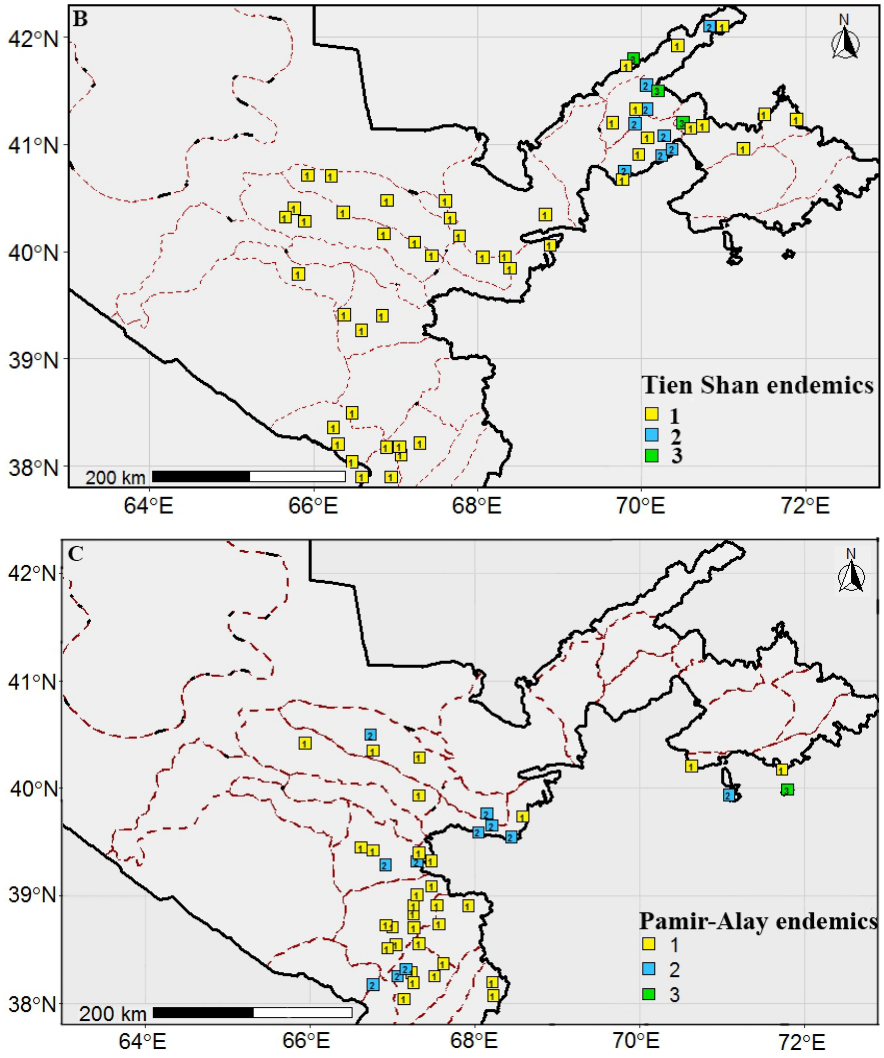


Figure 4. (Continued). B – Tien Shan endemics. C – Pamir-Alay endemics.

GeoCAT range-size screening

Range size estimates varied markedly among the 10 national endemic species (Fig. 5, Table 1). The MCP-based EOO could not be calculated for three taxa represented by fewer than three occurrence points. For the seven taxa with calculable EOO, adjusted values ranged from 8.00 to 1,406.26 km²; AOO ranged from 4 to 36 km² across the 10 taxa.

The smallest AOO was 4 km² for *A. annae*. *A. subavenaceum*, *A. taschkuganicum*, and *A. vvedenskyi* each had an AOO of 8 km². *A. margaritae*, *A. nuratavicum*, and *A. zakirovii* each had an AOO of 16 km².

Four taxa – *A. annae*, *A. subavenaceum*, *A. taschkurganicum* and *A. vvedenskyi* – met the CR-level numerical AOO threshold under Criterion B2 (AOO < 10 km²). The remaining six met the corresponding EN-level threshold (AOO ≥ 10 and < 500 km²). These are preliminary range size indicators rather than formal IUCN Red List categories because subcriteria B(a–c) were not evaluated.

Table 1 reports the full record screening. In the post-1999 sensitivity screen, the recent-only AOO was 8 km² for *A. butkovii*, 8 km² for *A. nuratavicum*, 4 km² for *A. subavenaceum*, and 16 km² for *A. zakirovii*. Recent-only AOO was not estimable for the remaining six taxa because no post-1999 records were available; this absence of recent records should not be interpreted as AOO = 0 or extinction.

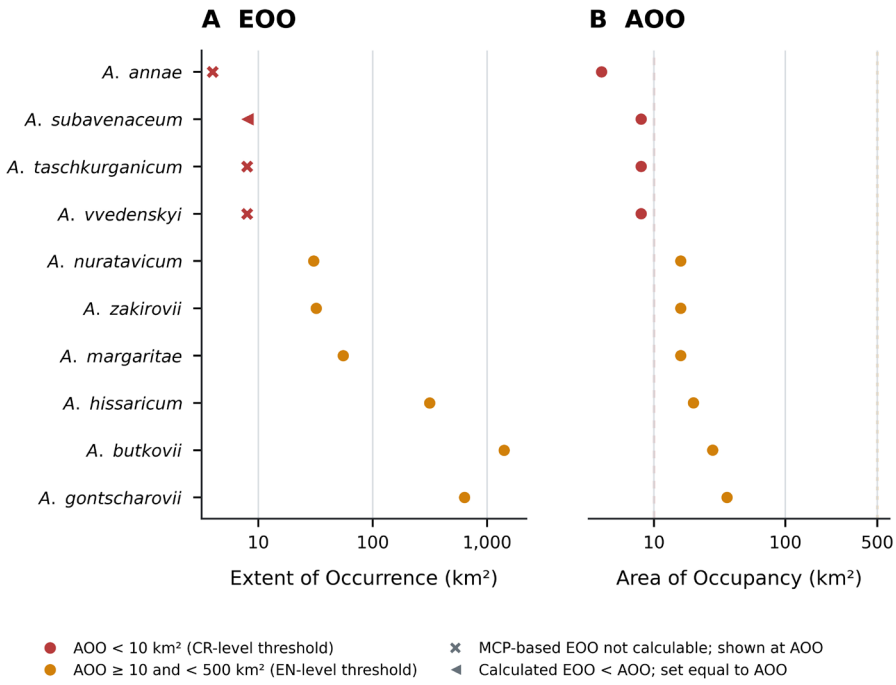


Figure 5. GeoCAT-derived range size screening for the 10 national endemic *Acantholimon* species in Uzbekistan. A – Minimum-convex-polygon Extent of Occurrence (EOO). B – Area of Occupancy (AOO). Colours indicate the numerical AOO threshold class met under IUCN criterion B2. The crosses indicate taxa for which MCP-based EOO could not be calculated from fewer than three occurrence points; they are plotted at the corresponding AOO only to retain the taxa in panel A and are not EOO estimates. The triangle indicates the adjusted EOO of *A. subavenaceum*, set equal to AOO because the calculated EOO was smaller than AOO. The dashed and dotted vertical lines in B mark AOO thresholds of 10 and 500 km², respectively. These classes are preliminary range-size indicators, not formal IUCN Red-List categories.

Table 1. GeoCAT range metrics and preliminary AOO thresholds for national endemic *Acantholimon* species in Uzbekistan

Species	Records (n)	Grid cells (20 × 20 km)	Mountain range(s)	MCP-based EOO (km²)	AOO (km²)	Preliminary B2 AOO threshold
A. annae	1	1	Hissar	Not calculable[a]	4	CR-level
A. butkovii	7	5	Hissar, Baysun, Chulbair	1,406.26	28	EN-level
A. gontscharovii	10	3	Hissar	634.89	36	EN-level
A. hissaricum	7	4	Hissar	314.47	20	EN-level
A. margaritae	4	3	Kurama	55.22	16	EN-level
A. nuratavicum	6	2	Nuratau	30.48	16	EN-level
A. subavenaceum	3	1	Nuratau	8.00[b]	8	CR-level
A. taschkurganicum	2	2	Hissar	Not calculable[a]	8	CR-level
A. vvedenskyi	2	2	Hissar, Chulbair	Not calculable[a]	8	CR-level
A. zakirovii	4	2	Nuratau	32.05	16	EN-level

Notes: [a] MCP-based EOO was not calculated because fewer than three occurrence points do not define a minimum convex polygon; AOO remains independently estimable. [b] For *A. subavenaceum*, the calculated EOO was smaller than AOO and was therefore set equal to AOO following the IUCN guidelines (IUCN Standards and Petitions Committee 2024). CR-level and EN-level denote only the numerical AOO thresholds under Criterion B2; subcriteria B(a–c) were not evaluated.

Discussion

Spatial and elevational structure of *Acantholimon* diversity

The documented occurrence of 28 species, including 10 national endemics, confirms that mountain systems are an important component of the Central Asian distribution of *Acantholimon*. The records were concentrated in Pamir-Alay and Western Tien Shan, consistent with the recognised floristic importance of these regions (Kamelin 1973; Tojibaev et al. 2016; Moharrek et al. 2019). However, the present analysis describes records and does not test the biological processes responsible for this pattern.

The highest observed grid-cell richness occurred in northern Nuratau under the current sampling framework. This record-based concentration should be treated as a priority for standardised field reassessment rather than as a definitive ranking of the underlying biological richness or conservation importance. Five species within the 400 km² cell do not show local sympatry because populations can be separated

between elevations and individual rocky outcrops. Fine-scale surveys are required to resolve this internal structure.

Restricting records to 7.5% of grid cells reflects the fragmented documented distribution of mountain occurrences, not the actual proportion of occupied habitat. A 20 × 20 km cell may combine small rocky refugia with extensive unsuitable terrain, and cell maxima may change with grid size or origin; no alternative grid sensitivity analysis was performed. The collection effort, accessibility, and coverage of the survey were not quantified, so raw cell counts may partly reflect where botanists have collected the most intensively. Consequently, the mapped values are referred to throughout as documented or observed richness.

The unstandardised elevation histogram documents many records at 1,600–2,800 m and a smaller set below 1,000 m. The exact species-coordinate deduplication retained the same 200-m modal class, showing that exact duplicate coordinates did not create that mode. However, the frequencies were not divided by land area within each elevation band and were not corrected for collection effort. Additionally, the SRTM values inherit coordinate uncertainty of up to 1 km for historical localities, which may be important on steep slopes. Therefore, the analysis cannot establish two biological elevation zones or an elevation preference. Substrate, lithology, soil, slope, aspect, and habitat type were not analysed; substrate differentiation remains a hypothesis for future field tests, rather than a result of this study.

Mountain centres of endemism

Under the selected grid, cells AC46 and AM49 contained two nonoverlapping three-species assemblages of national endemics: *A. nuratavicum*, *A. subavenaceum* and *A. zakirovii* in AC46, and *A. hissaricum*, *A. taschkurganicum*, and *A. vvedenskyi* in AM49. Together, they represent six of the 10 national endemics. The remaining four – *A. annae*, *A. butkovii*, *A. gontscharovii* and *A. margaritae* – occurred in other cells. Therefore, AC46 and AM49 are complementary field reassessment foci, but this descriptive comparison is not a systematic conservation planning analysis and does not define a representative conservation network.

The Tien Shan endemics occupied 57 cells, compared to 43 for the Pamir-Alay endemics. This difference may reflect range size, habitat continuity, and intensity rather than dispersal alone. Relatively continuous rocky habitats in parts of the Western Tien Shan region may facilitate occupation of neighbouring sites, whereas the deeply dissected Hissar and Baysun ranges contain high-elevation habitats separated by arid valleys. This landscape structure is compatible with the localised distribution of *A. hissaricum* and other stenochoric taxa. However, the present data do not measure habitat connectivity, seed dispersal, or gene flow. Therefore, topographic isolation should be regarded as a biogeographical hypothesis rather than as demonstrated evidence of allopatric speciation.

Range restriction and conservation implications

Documented AOO values of 4 to 36 km^2 indicate restricted recorded ranges between national endemics. Four species – *A. annae*, *A. subavenaceum*, *A. taschkurganicum* and *A. vvedenskyi* – met the numerical CR-level AOO threshold, while the remaining six met the EN-level threshold. These thresholds identify taxa for further investigation, but are not formal IUCN categories because subcriteria B(a–c) were not evaluated (IUCN Standards and Petitions Committee 2024).

Temporal sensitivity further emphasised uncertainty. Post-1999 records were available for only four national endemics, and recent-only AOO was lower than the all-record estimate for *A. butkovii*, *A. nuratavicum*, and *A. subavenaceum*, but unchanged for *A. zakirovii*. The absence of post-1999 records for six taxa does not demonstrate absence or extinction; it indicates that their current occupancy was not estimable from this database. Updated surveys should establish population persistence, size, habitat condition, fragmentation, threat-defined locations, and evidence of continued decline.

The ongoing review of the Uzbekistan's threatened plant list provides a broader conservation context for the present screening. The 2019 Red Data Book of Uzbekistan included five species of *Acantholimon*, while the recent national reassessment for the sixth edition recognises six species, including *A. zakirovii* (Khasanov 2019; Shomurodov et al. 2026). The present GeoCAT results provide a basis for taxon-specific field reassessment of narrowly distributed *Acantholimon* endemics, but they remain a preliminary range-size screen and are not used to assign formal IUCN categories. In particular, the four taxa that meet the CR-level AOO threshold require current field evidence on population status, threats, and Criterion B subcriteria before any formal conservation status decision.

Conclusion

Acantholimon records in Uzbekistan are concentrated in the country's mountain systems. Under the current sampling framework and the selected 20 × 20 km grid, the highest documented cell richness occurred in northern Nuratau. Cells AC46 and AM49 contained non-overlapping endemic assemblages that together represented six of the 10 national endemics; this does not constitute a representative conservation network. GeoCAT screening identified *A. annae*, *A. subavenaceum*, *A. taschkurganicum*, and *A. vvedenskyi* as priorities for field reassessment, not as formally classified threatened species. Standardised surveys, recent confirmation of historical localities, and field-verified evaluation of the IUCN Criterion B subcriteria are required before the biological hotspot rankings or conservation priorities are formalised.

Acknowledgments

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