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Research Article

The Yozyovon Sand Massif as a proposed Important Plant Area in the Fergana Valley: floristic value, habitat loss, and threats

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Abstract

Lowland sand ecosystems are among the most vulnerable and least represented habitat types in area-based conservation frameworks, particularly in the arid landscapes of Central Asia. Despite their high ecological specialization and endemism, these ecosystems remain poorly integrated into national and regional conservation planning. In this study, the applicability of the Important Plant Area (IPA) framework to arid lowland sands was assessed, and the Yozyovon Sand Massif in the Central Fergana Valley (FV), Uzbekistan, was evaluated as a proposed IPA. Floristic surveys conducted between 2023 and 2025, supplemented by herbarium and documentary records, yielded an integrated inventory of 296 vascular plant taxa belonging to 175 genera and 44 families; historical but unconfirmed records were flagged separately and excluded from the IPA trigger-species assessment. The application of 14 Criterion A trigger taxa of high conservation importance, whereas the habitat-based assessment under Criterion C revealed greater spatial discontinuity and a marked reduction in the extent of continuous sandy habitats. Anthropogenic pressures were evaluated using an IUCN-aligned threat assessment approach, which identified irrigated agriculture, hydrological modification, and substrate disturbance as the dominant drivers of ecosystem degradation. To quantify long-term habitat dynamics, Random Forest classifications were applied to Landsat imagery for 1991, 2000, 2015, and 2025 and evaluated using held-out, spatially separated reference data. Within the fixed 416.24 km² study extent, the mapped Sand area declined from 125.95 km² in 1991 to 54.79 km² in 2025, corresponding to an overall reduction of 56.50%. The integration of floristic evidence, standardized threat assessment, and validated land-cover classifications provided a more comprehensive basis for applying the IPA framework in data-poor arid lowland environments. The results support the proposal of the Yozyovon Sand Massif as an IPA. If formally recognized, the site would represent the fourth IPA in the FV and would address a major gap in the regional IPA network. More broadly, this study highlights the need to explicitly incorporate desert sand ecosystems into biodiversity conservation strategies and provides an evidence-based approach for conservation prioritization in arid regions.



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Key words: Conservation prioritization, Fergana Valley, Important Plant Area, IUCN-aligned threat assessment, land-cover change, psammophytic flora, sand ecosystem degradation

Introduction

Global biodiversity loss has intensified calls for area-based conservation as a central strategy for safeguarding ecosystems and their services. This approach was formally reinforced by the Kunming-Montreal Global Biodiversity Framework (GBF), adopted under the Convention on Biological Diversity, which sets an ambitious target to effectively conserve at least 30% of the world's terrestrial and marine areas by 2030 (CBD 2022). Achieving this target requires spatially explicit and scientifically robust prioritization tools capable of identifying sites of exceptional biological value under increasing anthropogenic pressure.

Among these tools, the IPA program represents a rigorous and plant-focused global framework for prioritizing biodiversity. Developed in the mid-1990s and refined through revised global guidelines (Darbyshire et al. 2017), the IPA framework identifies sites of international and national importance for plant and fungal diversity based on the presence of threatened species, outstanding botanical richness, and threatened or distinctive habitats. While the Key Biodiversity Areas (KBAs) standard provides a unifying framework for multi-taxon conservation planning, IPAs remain a complementary and independent mechanism specifically tailored to the exceptional taxonomic, ecological, and biogeographical diversity of plants (Kor and Diazgranados 2023; Kor et al. 2024). This flexibility is particularly critical in regions where botanical knowledge is uneven, and ecosystems are undergoing rapid transformation.

Central Asia is located at the heart of the Irano-Turanian floristic region, one of the world's major centers of plant diversity and endemism (Takhtajan 1986; Manafzadeh et al. 2017; Li et al. 2020; Nowak et al. 2022). However, it remains one of the least comprehensively assessed regions in the global IPA network (Tojibaev et al. 2022b, 2023, 2025; Ondo et al. 2024). Central Asia supports a complex mosaic of deserts, foothills, and mountain systems shaped by long-term geological and climatic processes. However, these ecosystems are increasingly threatened by agricultural expansion, water abstraction, land-use intensification, and demographic growth, leading to accelerated habitat degradation and biodiversity loss (Volis 2024). This underscores the urgent need for systematic site-based conservation assessments using standardized and transparent methodologies.

Within this regional context, the FV is one of the most distinctive and densely populated biogeographical units in Central Asia. Enclosed between the Tian Shan and Pamir-Alay mountain systems, the valley is characterized by pronounced climatic gradients and long-term ecological isolation, which have contributed to high levels of plant endemism and habitat specialization (Tojibaev et al. 2018; Nazarov et al. 2023). Recent studies have identified three IPAs within the valley: the Chust-Pop Badlands, Bozbu-Too-Ungortepa Massif, and Shorsuv Massif, each highlighting different facets of floristic uniqueness and conservation concerns (Tojibaev et al. 2022b, 2023, 2025). Nevertheless, the arid sand

ecosystems of the valley remain critically understudied, despite mounting evidence that they are among the most rapidly declining habitats in the region.

Globally, sand ecosystems are among the most vulnerable habitats to anthropogenic disturbances (Xu et al. 2024). Agricultural conversion, groundwater extraction, grazing pressure, and landscape modification have resulted in the widespread contraction, fragmentation, and severe degradation of sandy habitats, with particularly severe consequences for psammophytic and endemic plant species (Wilson et al. 2021; Volis and Beshko 2023). In Central Asia, long-term satellite-based analyses have revealed substantial reductions in sandy landscapes in recent decades, indicating a trajectory of progressive ecosystem degradation. The Yozyovon Sand Massif, a major sandy formation within the Central FV, exemplifies this pattern. Preliminary field surveys and herbarium records indicate that this massif supports several nationally and globally threatened species. However, it has not been evaluated under the IPA framework, which represents a significant gap in regional conservation planning.

Given the continuing degradation and contraction of sand ecosystems and their importance to regional plant diversity, a comprehensive IPA assessment of the Yozyovon Sand Massif (Central Fergana Sands) is both timely and necessary.

Specifically, this study aims to: (1) identify plant species that support IPA designation under Criterion A; (2) assess the extent and severity of sand-ecosystem degradation under Criterion C; (3) quantify long-term changes in sandy habitats using land-cover analysis; (4) delineate the proposed Yozyovon Sand Massif IPA and assess its contribution to the regional IPA network; and (5) provide evidence-based recommendations for biodiversity conservation and planning.

By integrating floristic data, threat assessment, and long-term remote sensing analysis, this study identifies the Yozyovon Sand Massif as a plant-diversity hotspot undergoing severe ecological degradation and provides a scientific basis for proposing the Yozyovon Sand Massif as an IPA.

Materials and methods

Study area

This study was conducted within the Yozyovon Sand Massif, located in the central part of the FV in eastern Uzbekistan (Fig. 1). This massif represents a major sandy landscape unit of the Central Fergana Depression and forms part of a broader aeolian sand system within the Irano-Turanian floristic region. The Yozyovon Sand Massif comprises a heterogeneous mosaic of stabilized and semi-stabilized dunes, sandy plains, and interdunal depressions that collectively create a wide range of microhabitats supporting highly specialized psammophytic vegetation.

The Central Fergana Sands have long been recognized for their distinctive floristic composition and high biodiversity value (Arifkhanova 1967). The region also contains numerous microendemic species exhibiting extremely narrow distribution ranges (Korovin 1961). Together, these features make the region one of the principal centers of psammophytic plant diversity in Central Asia and underscore its importance for plant conservation.

The boundary of the proposed IPA was delineated based on geomorphological features, vegetation continuity, the distribution of Criterion A trigger taxa, and current

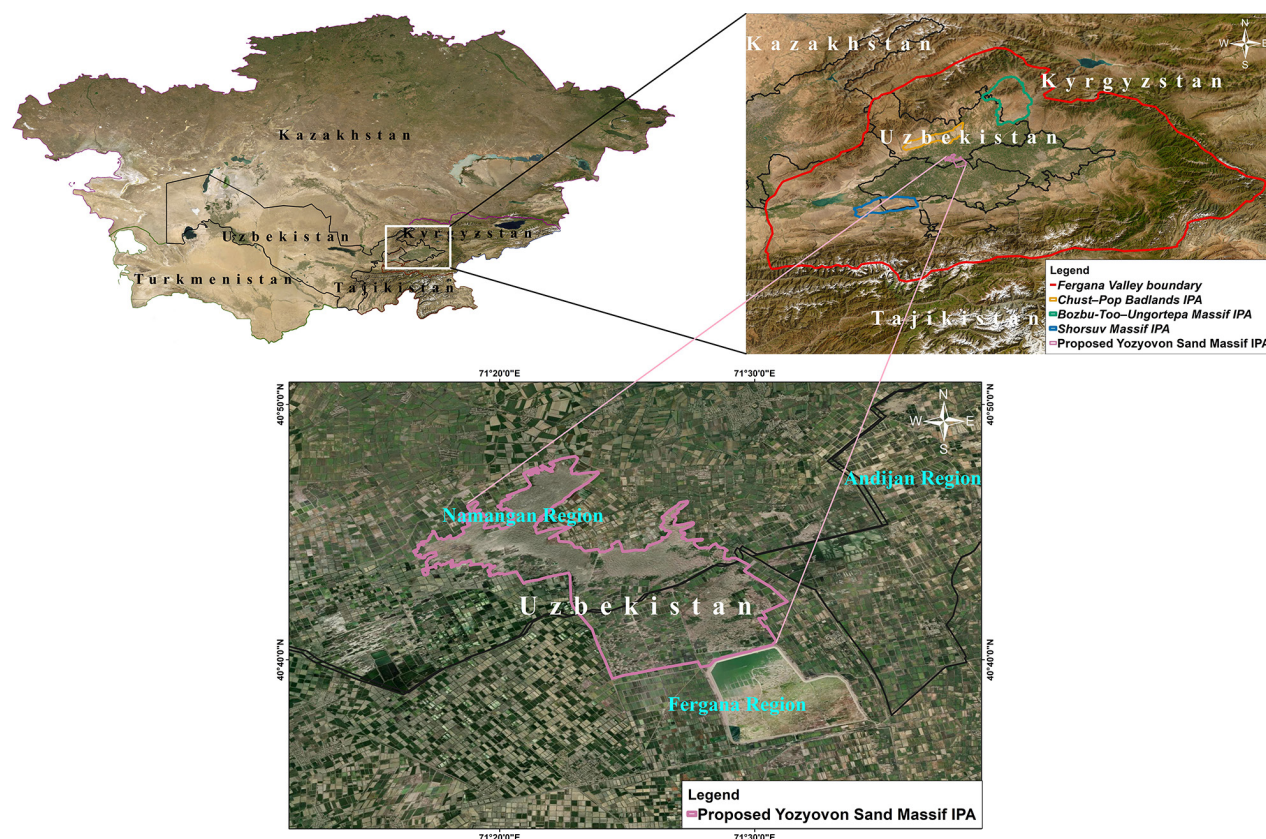


Figure 1. Geographic setting of the proposed Yozyovon Sand Massif IPA in the FV, showing its spatial relationship to the three previously identified IPAs and to the administrative boundaries of the Namangan, Andijan, and Fergana regions.

land-use patterns. The proposed Yozyovon Sand Massif IPA covers 54.79 km² and is bounded approximately by 40.668995–40.792003°N and 71.306224–71.654225°E in the WGS 84 geographic coordinate system (EPSG:4326) (Fig. 1). Its boundary encompasses the principal remaining sandy-habitat patches while excluding adjacent intensively cultivated and heavily transformed areas. The Yazavan Natural Monument forms a small protected component within the broader proposed IPA boundary. The climatic conditions in the study area are strongly continental and arid, characterized by low annual precipitation, pronounced seasonal variability, and high summer temperatures. Consequently, plant communities are subject to severe edaphic and hydrological constraints.

These environmental conditions have led to the development of distinct sandy desert ecosystems with a high degree of ecological specialization and limited resilience to disturbances. Representative habitat and disturbance conditions within the proposed IPA, including stabilized sands, semi-stabilized dunes, a moist interdunal depression affected by livestock grazing, and a sandy sector disturbed by sand extraction, are shown in Fig. 2.

Field surveys and floristic data collection

Extensive floristic surveys were conducted during spring, summer, and autumn over three consecutive years (2023–2025). The field component was designed as a comprehensive floristic inventory rather than as a quantitative geobotanical survey; consequently, no fixed transects or vegetation plots were established.

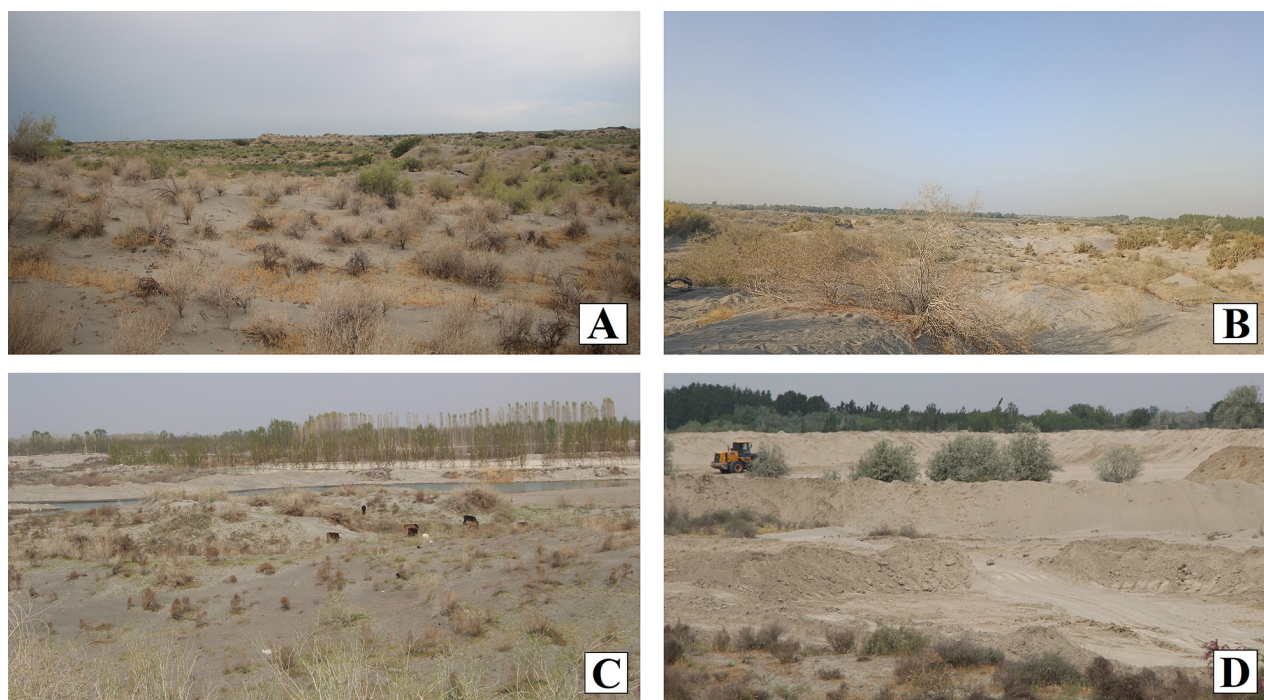


Figure 2. Representative habitats and disturbances in the proposed Yozyovon Sand Massif IPA. **A.** Stabilized sands; **B.** Semi-stabilized dunes; **C.** A moist interdunal depression with livestock grazing; **D.** A sand-extraction site.

The full extent of the proposed IPA was examined through repeated route-based surveys covering the principal habitat types, including stabilized and semi-stabilized sands, interdunal depressions, saline microsites, and anthropogenically disturbed sectors. The principal survey routes were revisited in different seasons to account for phenological turnover and to document taxa with differing flowering and fruiting periods. Sampling effort was therefore coverage-based and phenology-driven rather than standardized by transect length, plot area, or equal sampling quotas among habitat types. During each survey, vascular plant taxa encountered along the routes were recorded in field notebooks, and voucher specimens were collected where taxonomic verification was required.

Relatively intact and visibly disturbed sectors were not selected as paired experimental plots. Instead, both habitat conditions were incorporated into the continuous floristic survey routes to ensure representative coverage of the habitat mosaic across the proposed IPA. Relatively intact sectors were recognized by preserved sandy landforms, comparatively continuous natural psammophytic vegetation, and limited visible evidence of direct anthropogenic alteration. Disturbed sectors were identified by visible evidence of agricultural conversion, intensive grazing, roads or settlement influence, substrate disturbance, hydrological alteration, or fragmentation of the natural vegetation cover. These habitat conditions were documented descriptively in the field and were subsequently considered together with spatial habitat and threat data.

Field coordinates were recorded as waypoints using the MAPS.ME mobile application on GPS-enabled smartphones operating offline. Coordinates were referenced to WGS 84 (EPSG:4326) and stored in decimal degrees to six decimal places. Waypoints were placed adaptively at route starting points, plant localities, and habitat transitions, commonly at intervals of approximately 10–50 m. Device-reported horizontal accuracy was checked during recording and

varied according to field conditions; coordinate reliability was subsequently verified using field notes, locality descriptions, route continuity, and GIS-based spatial-consistency checks.

Field-notebook records and collecting localities were subsequently entered into a unified georeferenced occurrence database. Field surveys conducted during 2023–2025 generated 10,950 georeferenced occurrence records from direct observations. These data were complemented by 118 historical herbarium specimens deposited in major botanical collections, including the National Herbarium of Uzbekistan (TASH), the Moscow State University Herbarium (MW), the Komarov Botanical Institute Herbarium in St. Petersburg (LE), and other Central Asian herbaria, including AA, FRU, and TAD (Thiers 2026). To enhance spatial coverage and historical depth, additional distributional records were obtained from verified online databases, including Plantarium (www.plantarium.ru) and the Global Biodiversity Information Facility (GBIF; www.gbif.org). All digital occurrence records were carefully screened, and those with uncertain identification, imprecise locality data, or doubtful taxonomic attribution were excluded from spatial analyses and IPA qualification. Separately, taxa reported in authoritative national floristic or conservation sources but lacking verifiable recent occurrence records were retained in the integrated floristic checklist as historical and unconfirmed records. Such records were not used for distribution mapping, extent of occurrence (EOO) or area of occupancy (AOO) calculations, or the Criterion A trigger-species assessment.

During the study period, 8,500 herbarium specimens were collected. Following taxonomic verification, nomenclatural harmonization, and integration of field, herbarium, online, and documentary records, the integrated floristic inventory comprised 296 vascular plant taxa belonging to 175 genera and 44 families. Historical but currently unconfirmed taxa were flagged separately and retained only for documentary and floristic completeness. The annual species-richness values represent the number of species recorded during each individual survey year and are therefore non-additive because many taxa were documented in more than one year. For each field-recorded taxon, documentation included precise geographic coordinates, habitat characteristics, qualitative abundance estimates, and notes on population structure and ecological preferences. Particular attention was paid to psammophytic species, regional endemics, and taxa of conservation concern. The resulting integrated dataset provided the empirical basis for subsequent spatial analyses, application of the IPA criteria, and assessment of anthropogenic threats.

Herbarium and taxonomic verification

All newly collected specimens were deposited in the National Herbarium of Uzbekistan (TASH), where they were processed, mounted, catalogued, and incorporated into the institutional database in accordance with standard herbarium protocols. Herbarium preparation followed established practices to ensure long-term preservation and traceability of the voucher material.

Taxonomic identification and verification were conducted through direct comparison with authoritatively identified reference specimens housed at the National Herbarium of Uzbekistan (TASH) and other major regional herbaria, including the Moscow State University Herbarium (MW) and the Komarov

Botanical Institute Herbarium in St. Petersburg (LE). Herbarium acronyms follow Index Herbariorum (Thiers 2026). High-resolution digital images were examined where physical access to specimens was restricted. This multi-source approach supported the consistent application of taxonomic concepts and reduced the risk of misidentification.

Taxonomic determinations were based on critical evaluation of authoritative regional floristic treatments, including Flora of Uzbekistan (Kudryashev 1941; Vvedensky 1953, 1962), Conspectus Florae Asiae Mediae (Kovalevskaya 1968, 1971; Bondarenko and Nabiev 1972; Pachomova 1974, 1976; Kamelin 1981; Adylov 1983, 1987; Adylov and Zuckerwanik 1993; Khassanov 2015), and recently published volumes of the Flora of Uzbekistan (Sennikov 2017, 2018, 2019, 2022, 2023a, 2023b). Classical and contemporary regional taxonomic literature, including the foundational work of Arifkhanova (1967) and subsequent syntheses (Pratov 1970), was also critically reviewed to ensure continuity and accuracy in interpreting species concepts.

Scientific names and authorship of taxa at the species, genus, and family levels were generally standardized according to the International Plant Names Index (IPNI 2025) and Plants of the World Online (POWO 2025). An explicitly documented exception was made for *Calligonum elegans*, which was treated as a distinct species following the regional taxonomic concepts of Drobow (1953) and Soskov (2011), supported by direct examination of newly collected voucher specimens and diagnostic fruit morphology. The identification of the three recent voucher collections was independently confirmed by Prof. X. Shomurodov of the Institute of Botany, Academy of Sciences of Uzbekistan, on 10 June 2026. For taxa of conservation concern, historical herbarium records were examined to assess their long-term persistence, distributional limits, and potential shifts in occurrence patterns within the study area.

Data analysis and mapping

Spatial data processing was conducted using ArcGIS 10.6.1 and QGIS 3.34. ArcGIS was used to manage occurrence records and assign validated points to the indexed cells of the floristic grid, whereas QGIS was used for spatial data management, overlay operations, analytical processing, and cartographic visualization.

A pre-existing nationwide 5 × 5 km floristic grid covering the territory of Uzbekistan was used as the spatial reference framework (Tojibaev et al. 2022a). No separate site-specific grid was generated for the present study. Following coordinate validation, each occurrence point from the Yozyovon Sand Massif was assigned in ArcGIS 10.6.1 to the indexed grid cell containing its geographic coordinates. Two complementary grid-level metrics were calculated: species richness and occurrence-record density. Species richness was defined as the number of unique vascular plant taxa recorded within each grid cell; therefore, repeated records of the same taxon within the same cell, including records from different seasons or survey years, contributed only one taxon presence to the richness value. Occurrence-record density was defined as the total number of independent validated occurrence records assigned to each grid cell. Consequently, records of the same taxon obtained during different survey visits, seasons, or years were retained and counted separately in the record-density

analysis, whereas exact database duplicates were removed. Each grid cell was treated as an independent analytical unit, allowing the spatial comparison of floristic richness, survey and collection intensity, and the distributions of endemic, threatened, and habitat-specialist taxa across the study area.

Occurrence records derived from field surveys, herbarium specimens, published sources, and verified online databases were integrated into a unified spatial database. Before spatial analysis, all records were checked for taxonomic identity, source traceability, coordinate completeness, and consistency between the geographic coordinates and the stated locality. Exact database duplicates representing the same taxon, coordinates, date, and record or voucher identifier were removed. Independent observations or collections made during different survey visits, seasons, or years were retained because they contributed to the occurrence-record-density analysis. For species-richness calculations, however, multiple records of the same taxon within a single grid cell were reduced analytically to one taxon–grid-cell presence. Coordinates inconsistent with the locality information were checked against field notebooks, herbarium labels, or the original data source and were corrected only when the available evidence permitted an unambiguous correction; otherwise, the record was excluded from spatial analysis.

Spatial uncertainty was evaluated according to coordinate availability, the precision of the locality description, and whether a record could be assigned unambiguously to a single 5 × 5 km grid cell. Records lacking original coordinates were retained for grid-based analysis only when the locality description permitted reliable georeferencing and confident assignment to one grid cell. Records with contradictory locality information, unresolved coordinate errors, or locality descriptions too imprecise for unambiguous grid-cell assignment were excluded from grid-based analyses. Historical or documentary records retained for floristic completeness but lacking verifiable spatial evidence were not used in species-richness or occurrence-record-density mapping, EOO or AOO calculations, or the Criterion A trigger-taxon assessment.

Species were classified according to their ecological affiliation (e.g., psammophytic, halophytic, xerophytic), and conservation status was assigned according to the IUCN Red List categories (IUCN 2025) and the Red Data Book of the Republic of Uzbekistan (2019).

Life forms were assigned at the species level according to Raunkiaer's classification (Raunkiaer 1934), with regional interpretation following Sanjerehei (2019), using plant longevity, growth form, and the position of perennating buds. Each of the 296 vascular plant species was assigned to one of five principal life-form categories: therophytes, hemicryptophytes, cryptophytes, chamaephytes, or phanerophytes. For analytical consistency, nanophanerophytes were included within the broader phanerophyte category.

Spatial analyses were performed to identify the floristic and habitat patterns relevant to IPA designation. Specifically, mapping outputs were generated for visualization of (i) spatial patterns of vascular plant species richness across the Central Fergana Sands; (ii) grid cells containing endemic and threatened taxa qualifying under IPA Criterion A; (iii) the distribution, continuity, and condition of psammophytic habitats relevant to Criterion C; and (iv) the spatial relationship between the proposed IPA boundary and existing protected areas.

The resulting spatial analyses enabled the identification of biodiversity hotspots and areas of elevated conservation concern, thereby providing an objective and spatially explicit basis for delineating the proposed IPA. These outputs also form a baseline for future ecological monitoring, land-use planning, and adaptive management within the Yozyovon Sand Massif.

Assessment under IPA Criteria A and C

The assessment of the Yozyovon Sand Massif as a proposed IPA followed the revised global IPA guidelines, with primary emphasis on Criterion A, concerning threatened species, and Criterion C, concerning threatened or ecologically distinctive habitats (Anderson 2002; Blasi et al. 2009, 2011; Darbyshire et al. 2017). These criteria were selected as the most appropriate for evaluating biodiversity value in arid lowland sand ecosystems characterized by high ecological specialization and increasing anthropogenic pressure.

Criterion B was considered during preliminary screening but was not applied as a formal qualifying criterion. A robust assessment under this criterion would require standardized comparisons with ecologically equivalent sandy habitats at the national or regional scale, and such comparative data were not available for the present study. Accordingly, the formal IPA assessment was restricted to Criteria A and C.

Criterion A (threatened species)

The application of Criterion A followed the IPA framework of Anderson (2002) and the revised global guidelines of Darbyshire et al. (2017), using the regional operational interpretation previously applied in IPA assessments of the FV (Tojibaev et al. 2022b, 2023, 2025). Under this interpretation, subcriterion A(i) includes globally threatened taxa; A(ii) includes nationally or regionally threatened taxa recognized in national conservation lists; A(iii) includes national endemics and subendemic taxa restricted to the transboundary FV; and A(iv) includes range-restricted endemic taxa associated with the Afghan–Turkistan Province. National endemics were defined as taxa restricted to an individual country whose territory includes part of the FV, whereas subendemics were defined as taxa restricted to the FV as a geographical unit extending across political boundaries.

For all 14 Criterion A trigger taxa, verified occurrence records available across their known global native ranges were compiled from field observations, herbarium specimens, published sources, and reliable georeferenced databases. EOO and AOO were calculated or recalculated in GeoCAT, with AOO estimated using a 2 × 2 km grid-cell size (Bachman et al. 2011). The assessment of *Calligonum elegans* also incorporated the newly verified occurrence records documented in the present study. To retain methodological comparability with previous IPA assessments in the FV, study-derived global EOO/AOO range classes were reported using the same combined notation applied in those studies (Tojibaev et al. 2022b, 2023, 2025). Calculated EOO and AOO values were compared separately with the standard IUCN geographic-range thresholds for threatened categories: EOO < 100 km² for CR, < 5,000 km² for EN, and < 20,000 km² for VU;

and AOO < 10 km² for CR, < 500 km² for EN, and < 2,000 km² for VU. For values exceeding the VU thresholds, NT was assigned where the available distributional and threat evidence indicated that the taxon was close to qualifying for VU; otherwise, LC was assigned. Because the IUCN framework does not prescribe a single numerical boundary between NT and LC, these two classes were interpreted using the overall range evidence and expert judgment.

The resulting global EOO/AOO range classes were reported in combined notation, with the first component representing the EOO-based class and the second representing the AOO-based class; for example, VU+EN indicates VU based on EOO and EN based on AOO. Where both spatial metrics yielded the same class, a single code was reported. These study-derived global range classes are reported separately from conservation categories formally published on the IUCN Red List and from national categories in the Red Data Book of Uzbekistan (2019). The use of EOO and AOO in this section supports species-level spatial assessment under IPA Criterion A and is unrelated to IPA Criterion B, which was not applied as a qualifying criterion in the present study. In Table 5, NE denotes Not Evaluated in the published global IUCN Red List, whereas NL denotes Not Listed in the Red Data Book of Uzbekistan (2019).

Taxa were accepted as Criterion A triggers only when their occurrence within the proposed IPA was supported by a traceable voucher specimen, a reliable recent field observation, or a sufficiently precise and verifiable occurrence record. Historical reports lacking both a verifiable voucher and confirmed occurrence within the proposed IPA were retained in the integrated floristic inventory for documentary completeness but excluded from distribution mapping, EOO and AOO calculations, and the Criterion A trigger-taxon assessment.

Criterion C (threatened habitats)

The sandy desert ecosystem of the Yozyovon Sand Massif was assessed for its conservation importance under IPA Criterion C on the basis of its restricted distribution, ecological distinctiveness, substantial long-term contraction, and continuing degradation. Habitat condition was evaluated using field evidence of vegetation structure and anthropogenic disturbance together with remote-sensing evidence of reduced habitat extent and greater spatial discontinuity. Habitat assessment under Criterion C integrates spatial evidence from remote-sensing analyses and threat-based evaluation, enabling combined consideration of structural habitat degradation and the intensity of anthropogenic pressures affecting the sand ecosystem.

IUCN-aligned threat classification and adapted impact assessment

Direct threats affecting the Yozyovon Sand Massif were identified and coded according to the IUCN Threats Classification Scheme (Version 3.3). The IUCN scheme was used to standardize threat names and hierarchical codes, whereas the relative importance of threats at the site level was evaluated using an adapted semi-quantitative index developed for this study (IUCN 2022).

The assessment considered three descriptors used in IUCN threat documentation: timing, scope, and severity. Timing indicated whether a threat was ongoing, expected to occur in the future, or had occurred in the past; scope

was defined as the proportion of the Yozyovon sandy habitat affected by the threat; and severity represented the magnitude of habitat loss, degradation, or ecological alteration within the affected area. Because the assessment unit was a habitat complex rather than an individual taxon population, the IUCN population-based definitions of scope and severity were operationally adapted to habitat area and habitat condition (IUCN 2022; BirdLife DataZone 2025).

Category assignments were based on field observations, mapped evidence of land-use transformation, multitemporal remote-sensing outputs, and expert evaluation of habitat condition. Each descriptor was assigned an ordinal score ranging from 0 to 3 according to the operational definitions summarized in Table 1.

Table 1. Adapted scoring framework used to prioritize threats affecting the Yozyovon Sand Massif.

Dimension	Category	Definition (IUCN-based)	Score
Scope	Whole	Threat affects nearly the entire habitat area (>90%)	3
	Majority	Threat affects most of the habitat area (50–90%)	2
	Minority	Threat affects a smaller portion of the habitat area (<50%)	1
	Unknown/negligible	Extent cannot be established or is negligible	0
Severity	Very rapid degradation	Causes or is likely to cause >30% habitat loss or degradation	3
	Rapid degradation	Causes or is likely to cause 20–30% habitat loss or degradation	2
	Slow but significant degradation	Causes measurable degradation of <20%	1
	Negligible/no measurable degradation	No measurable or only negligible degradation	0
Timing	Ongoing	Threat is currently active and continuing	3
	Future/imminent	Threat is expected to become active in the near future	2
	Past, likely to recur	Threat occurred previously and may recur	1
	Past, unlikely to recur	Threat is no longer active and unlikely to recur	0

For comparative site-level prioritization, an adapted total impact score was calculated as follows: Total impact score = Scope score + Severity score + Timing score.

Total scores of 8–9 were classified as High impact, scores of 6–7 as Medium impact, scores of 3–5 as Low impact, and scores of 0–2 as Negligible or No impact.

The resulting scores were used solely to rank the relative importance of pressures affecting sandy habitats and psammophytic flora and to support the interpretation of habitat conditions under IPA Criterion C (Darbyshire et al. 2017). The numerical summation and impact classes represent an author-defined site-level adaptation and should not be interpreted as formal IUCN Red List threat-impact scores.

Remote sensing and land cover change analysis

Long-term changes in mapped sandy-habitat extent were quantified using supervised Random Forest classification of multitemporal Landsat imagery. Random forest is an ensemble-learning algorithm based on randomized classification trees (Breiman 2001). The analysis was conducted for four reference epochs—1991, 2000, 2015, and 2025—within a fixed Yozyovon study extent of 416.24 km². A consistent binary classification system comprising Sand and

Non-sand surfaces was applied across all epochs. Raster processing and area calculations were performed at a spatial resolution of 30 × 30 m in the WGS 84 / UTM zone 42N projected coordinate reference system (EPSG:32642).

Landsat Collection 2 Tier 1 Level-2 surface-reflectance products were used because they provide atmospherically corrected observations suitable for consistent multitemporal land-surface analysis (U.S. Geological Survey 2021). The 1991 classification was based on one Landsat 5 TM scene acquired on 14 July 1991. The 2000, 2015, and 2025 composites were generated from 4 Landsat 7 ETM+, 14 Landsat 8 OLI, and 30 Landsat 8 OLI and Landsat 9 OLI-2 scenes, respectively. The retained observations covered WRS path/row combinations 152/032, 153/031, and 153/032, depending on the epoch. Complete acquisition dates, product identifiers, path/row values, sensor information, cloud cover, and valid-data coverage are provided in the Suppl. material 1.

Image selection was restricted to June–August to reduce seasonal and phenological variability. Scenes with metadata cloud cover of 30% or more were excluded. Clouds, cloud shadows, snow, fill pixels, and other contaminated observations were masked using QA_PIXEL, while radiometrically saturated pixels were removed using QA_RADSAT. A single quality-masked image was used for 1991, whereas median composites were generated for 2000, 2015, and 2025 from the retained quality-masked observations. Surface-reflectance digital values were converted to physical reflectance using $\rho = \text{DN} \times 0.0000275 - 0.2$, where ρ is scaled surface reflectance and DN is the original digital number.

Sensor-specific bands were harmonized into six common spectral variables: blue, green, red, near-infrared, shortwave infrared 1, and shortwave infrared 2. Eight derived predictors were also calculated: the Normalized Difference Vegetation Index, Normalized Difference Water Index, Modified Normalized Difference Water Index, Normalized Difference Built-up Index, Bare Soil Index, Normalized Burn Ratio, normalized SWIR difference, and spectral brightness. The same set of 14 predictors was used for all epochs. Sensor-specific band assignments, predictor equations, and their methodological references are provided in the Suppl. material 1.

Reference polygons representing confidently identifiable Sand and Non-sand surfaces were delineated separately for each epoch using false-color Landsat composites, GIS-based visual interpretation, and field knowledge. Sand included bare, mobile, semi-stabilized, and sparsely vegetated sandy surfaces that could be confidently assigned to sandy habitat. The aggregated Non-sand class included cultivated land, densely vegetated surfaces, saline areas not confidently identified as sand, water bodies, settlements, roads, and other transformed land-cover types. The binary scheme was designed to quantify mapped sandy-habitat extent rather than to identify individual transition classes within the Non-sand category.

Reference polygons were divided into separate calibration and held-out validation subsets before point extraction. For each epoch, 80 calibration points—40 Sand and 40 Non-sand—and 120 held-out validation points—60 Sand and 60 Non-sand—were generated. Calibration and validation points were sampled from different reference polygons and unique 30 × 30 m raster cells to avoid duplicated cells and reduce spatial dependence between the datasets.

Random Forest probability classification was implemented in R using the ranger package (Wright and Ziegler 2017). Each model comprised 1,000 trees, used the Gini split rule, a minimum terminal node size of 1, and $mtry = 3$. Classification thresholds were selected separately for each epoch using out-of-bag Sand probabilities from the calibration data. Candidate thresholds from 0.05 to 0.95 were tested at increments of 0.01, and the threshold maximizing balanced accuracy was retained; in the event of a tie, the value closest to 0.50 was selected. Held-out validation observations were not used for model fitting or threshold selection. The selected thresholds are reported in Table 7 and the Suppl. material 1.

Classification performance was evaluated separately for each epoch using the held-out validation data and standard confusion-matrix-based measures, including overall accuracy and its 95% confidence interval, Cohen's kappa, producer's and user's accuracies, F1 score, and balanced accuracy (Olofsson et al. 2014). Probability-based classification ambiguity was expressed as $U = 2 \times \min(P_{\text{SAND}}, 1 - P_{\text{SAND}})$, where values approaching 1 indicate increasingly ambiguous class assignment. Complete accuracy statistics, confusion matrices, out-of-bag Brier scores, and ambiguity summaries are provided in the Suppl. material 1. Sand and Non-sand areas were calculated using fractional pixel coverage along the fixed study boundary. Changes were summarized for 1991–2000, 2000–2015, 2015–2025, and 1991–2025 using absolute, relative, and annualized rates. Because the analysis comprises four selected reference epochs rather than a continuous annual time series, it was not interpreted as evidence of a continuously accelerating or decelerating trend. The resulting maps and area estimates were evaluated together with floristic, field, and threat-assessment evidence to support habitat assessment under IPA Criterion C.

Spatial analysis and boundary delineation

Spatial analyses were conducted in a GIS environment to integrate floristic occurrence data, habitat distribution patterns, threat intensity layers, and land-cover change outputs. All spatial datasets were harmonized to a common coordinate reference system and analyzed using ArcGIS and QGIS. Species occurrence points, habitat polygons, and spatial representations of anthropogenic pressures were overlaid to identify areas of elevated conservation significance and examine spatial congruence between biodiversity values and threat patterns.

The delineation of the proposed IPA boundary was guided by multiple complementary criteria. Primary emphasis was placed on the spatial concentration of threatened, endemic, and habitat-specialist species qualifying under IPA Criterion A, as well as on the extent, continuity, and condition of sandy habitats relevant to Criterion C. Areas exhibiting high floristic values combined with relatively intact or restorable habitat structures were prioritized in the boundary design.

Ecological connectivity among sandy habitat patches was explicitly considered to minimize fragmentation and ensure the functional coherence of the proposed IPA. Where appropriate, buffer zones were incorporated to enhance ecological integrity, reduce edge effects, and improve the feasibility of future management interventions. The fixed 416.24 km² Yozyovon study extent was

used solely as a consistent analytical domain for multitemporal Random Forest classification. The 2025 mapped Sand class provided the primary spatial basis for delineating the proposed IPA boundary, which was subsequently verified against field observations, confirmed localities of Criterion A trigger taxa, habitat continuity, and the boundary of the existing Yazyavan Natural Monument. Intensively cultivated and heavily transformed areas were excluded. The resulting proposed IPA encompasses 54.79 km² of mapped sandy habitat.

This spatially explicit, multicriteria approach ensured that the proposed IPA boundary reflected both current biodiversity patterns and underlying ecological processes, thereby providing a robust basis for future conservation planning, monitoring, and adaptive management within the Central Fergana sand ecosystems.

Results

Boundary and spatial extent of the proposed IPA

The proposed Yozyovon Sand Massif IPA encompasses 54.79 km² of sandy habitat mapped in 2025 and is bounded approximately by 40.668995–40.792003°N and 71.306224–71.654225°E (WGS 84; EPSG:4326). The delineated boundary includes the principal remaining sandy-habitat patches and the verified localities of the Criterion A trigger taxa recorded within the proposed site (Fig. 1). The Yazyavan Natural Monument forms a small protected component within the broader proposed IPA boundary. The fixed 416.24 km² extent used for the Random Forest analysis represents a broader analytical domain and should not be interpreted as the area of the proposed IPA.

Floristic composition and species richness

The cumulative floristic inventory of the Yozyovon Sand Massif comprised 296 unique vascular plant species belonging to 175 genera and 44 families (Table 2). Annual surveys recorded 244 species in 2023, 232 species in 2024, and 168 species in 2025. These annual richness values are non-additive because many taxa were documented repeatedly across the three survey years. Despite harsh edaphic conditions and increasing anthropogenic pressure, the lowland sandy ecosystems of Central Fergana supported considerable vascular plant diversity.

Table 2. Summary of field surveys, occurrence records, specimens, and integrated floristic richness in the study area.

Year	Survey period	Number of field surveys	Occurrence records	Herbarium specimens collected	Total species recorded
2023	March–June	20	4,420	3,560	244
2024	March–June	16	3,650	2,840	232
2025	March–June	12	2,880	2,100	168
Total		48	10,950	8,500	296

Note: Annual species-richness values refer to taxa recorded during each field-survey year and are non-additive because many species were documented in more than one year. The cumulative total of 296 represents the integrated floristic inventory combining consolidated field and herbarium records with separately flagged historical documentary records. Historical but unconfirmed taxa were retained for floristic completeness but excluded from spatial analyses and the IPA trigger-species assessment.

Taxonomic structure

The taxonomic structure of the flora was markedly uneven, with pronounced dominance by a limited number of families (Fig. 3). The most species-rich family was Asteraceae (47 species), followed by Amaranthaceae (43 species), Poaceae (35 species), and Brassicaceae (30 species). Together, these four families accounted for a substantial share of the total species richness in the study area. These lineages were dominant in arid and semi-arid sandy environments and were characterized by traits such as drought tolerance, short life cycles, and effective dispersal (Kamelin 1973, 1990). Other relatively species-rich families included Polygonaceae (17 species), Boraginaceae (16 species), and Fabaceae (14 species). These families contributed to floristic heterogeneity and included both widespread desert taxa and regionally specialized psammophytic species. In contrast, the remaining families were represented by a few species that collectively formed a diverse assemblage of taxonomically and ecologically distinct elements.

At the genus level, species richness was also unevenly distributed. *Calligonum* (nine species) and *Astragalus* (seven species) were the most diverse, followed by *Bromus*, *Heliotropium*, *Lepidium*, *Strigosella*, *Tamarix*, and *Zygophyllum*, each represented by six to seven species. The observed pattern included a high representation of psammophytic and drought-adapted lineages typical of Central Asian sandy deserts.

Life forms

According to Raunkiaer's life-form classification, the flora of the Yozyovon Sand Massif was dominated by therophytes, comprising 172 species (58.11%), followed by hemicryptophytes with 75 species (25.34%), chamaephytes with 24 species (8.11%), phanerophytes with 22 species (7.43%), and cryptophytes with three species (1.01%) (Table 3).

Ecological groups

From an ecological perspective, the flora of the Yozyovon Sand Massif was strongly dominated by psammophytic species, comprising 132 species (44.6%) of the total vascular flora (Table 4). This high proportion of sand-adapted taxa indicates pronounced ecological specialization of the study area and confirms its role as a core sandy ecosystem within the Central Fergana region.

Mesophytic species comprised 84 taxa (28.4%) and were primarily confined to interdunal depressions and microsites influenced by local moisture accumulation. These habitats function as ecological refugia within the otherwise arid sand matrix, contributing to the overall habitat heterogeneity. Halophytic species accounted for 46 taxa (15.5%), reflecting saline soils, solonchak patches, and groundwater-influenced substrates, whereas xerophytic species comprised 34 species (11.5%), occupying the driest and most exposed dune crests and sandy plains.

Overall, the floristic composition of the Yozyovon Sand Massif reflects a highly specialized plant assemblage shaped by arid climatic conditions, sandy substrates, and long-term ecological isolation. The combined patterns of

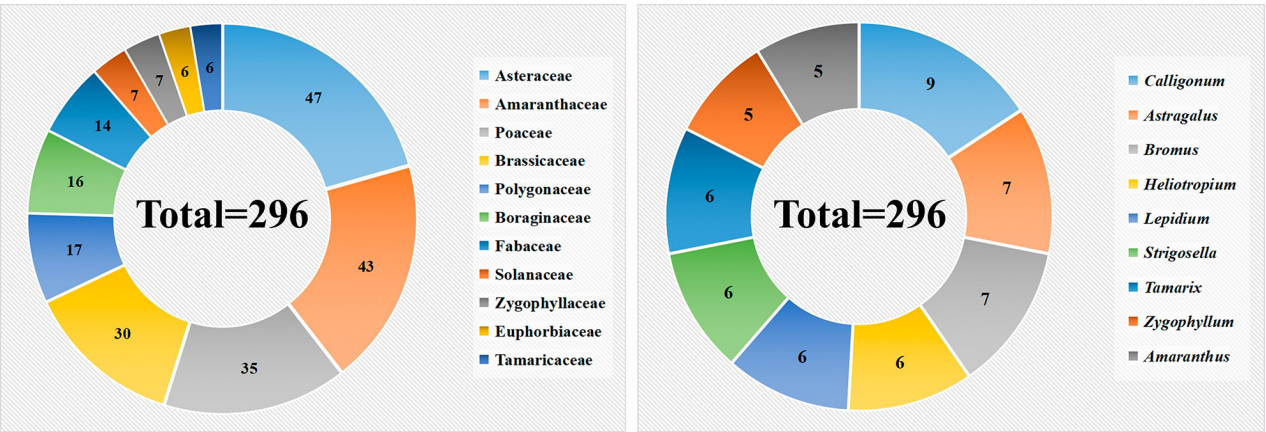


Figure 3. The top families (A) and genera (B) of vascular plants in the study area based on species richness.

Table 3. Life-form spectrum of the flora of the Yozyovon Sand Massif.

Life forms	Number of species	Percentage (%)	Ecological significance
Therophytes	172	58.11	Annual life cycle; persistence through seeds under seasonal aridity and disturbance
Hemicryptophytes	75	25.34	Perennial herbs with renewal buds at soil level; tolerance to seasonal climatic stress
Chamaephytes	24	8.11	Low shrubs and subshrubs with renewal buds close to the soil surface
Phanerophytes	22	7.43	Trees and taller shrubs contributing to vegetation structure, dune stabilization, and habitat formation
Cryptophytes	3	1.01	Below-ground renewal organs; persistence during unfavorable seasons
Total	296	100.00	

Overall, therophytes constituted the dominant component of the life-form spectrum, whereas cryptophytes represented only a minor component of the flora.

Table 4. Ecological group composition of the Yozyovon Sand Massif flora.

Ecological groups	Number of species	Percentage (%)	Dominant habitat/ecological role
Psammophytes	132	44.6	Mobile and semi-stabilized sands; core sand ecosystem specialists
Mesophytes	84	28.4	Interdunal depressions; moisture refugia
Halophytes	46	15.5	Saline soils, solonchaks, and groundwater-influenced sites
Xerophytes	34	11.5	Exposed dune crests and arid sandy plains
Total	296	100.0	

high species richness, taxonomic concentration in arid-adapted lineages, and dominance of psammophytic ecological strategies underscore the ecological distinctiveness of the area and provide a scientific basis for its consideration as a proposed IPA.

IPA Criterion A (threatened species)

The results of the IPA assessment demonstrate the importance of the Yozyovon Sand Massif for the conservation of threatened and regionally restricted plant species characteristic of the Southern Turan sub-province. The study area is located within the lowland plains of Central Asia and belongs to the phytogeographic

Turanian Province of the Ancient Mediterranean Region (Takhtajan 1986; Kamelin 1965, 1973, 1990; Tojibaev et al. 2016), forming part of the broader Irano-Turanian floristic region (Manafzadeh et al. 2017). This biogeographical context strongly influences both the floristic composition of the area and the application of IPA Criterion A in Central Asia, where regionally restricted and habitat-specialized taxa play a key role in qualifying sites under this criterion.

Based on comprehensive field surveys, verified herbarium and occurrence records, and conservation status assessments, 14 vascular plant taxa qualified as trigger species under IPA Criterion A for the proposed Yozyovon Sand Massif IPA (Table 5). Of these, one taxon qualified under A(i), one under A(ii), three under A(iii), and nine under A(iv). These taxa are of global, national, or regional conservation concern and include species characterized by restricted distributions, habitat specialization, or populations exposed to ongoing habitat degradation.

All 14 Criterion A trigger taxa were evaluated in the present study at the global-range level using verified occurrence records compiled from across their known native distributions. Table 5 separates the resulting study-derived global EOO/AOO range classes from published global IUCN Red List status and national status in the Red Data Book of Uzbekistan (2019). The updated analysis of *Calligonum elegans*, incorporating newly verified occurrence records, again yielded EN, consistent with its published global and national status. *Astragalus rubellus* also yielded EN in the present analysis and is nationally listed as Endangered, although it has no published global IUCN assessment. The remaining 12 trigger taxa were likewise evaluated in the present study but currently have neither published global IUCN assessments nor national Red Data Book listings.

The trigger taxa were assigned to the relevant Criterion A subcriteria in accordance with the revised IPA guidelines (Darbyshire et al. 2017). Subcriterion A(i) was represented by the globally Endangered *Calligonum elegans*, for which two recent voucher-backed records confirmed occurrence within the proposed IPA. Subcriterion A(ii) was represented solely by *Astragalus rubellus* (EN). Three FV endemics—*Asparagus ferganensis*, *Haplophyllum ferganicum*, and *Limonium ferganense*—qualified under A(iii), while nine regionally significant taxa qualified under A(iv).

The largest group of Criterion A trigger taxa was assigned to subcriterion A(iv) and comprised nine taxa: *Arnebia obovata*, *Artemisia ferganensis*, *Asparagus turkestanicus*, *Astragalus chodshenticus*, *Astragalus cognatus*, *Astragalus ammodendron*, *Calligonum × dubianskyi*, *Limonium drepanostachyum*, and *Xylosalsola paletziana*. All nine taxa were evaluated in the present study using verified occurrence records compiled from across their known global native ranges. Their study-derived global EOO/AOO range classes comprised seven LC+EN and two VU+EN combinations. None of these nine taxa currently has a conservation assessment formally published on the global IUCN Red List or is listed in the Red Data Book of Uzbekistan (2019). Their inclusion under A(iv) is supported by the newly derived spatial range classes together with their regional restriction, association with the Afghan–Turkistan Province, habitat specialization, and vulnerability within the rapidly degrading low-land landscapes of Central Fergana.

Table 5. Criterion A trigger taxa recorded within the proposed Yozyovon Sand Massif IPA.

Nº	Accepted taxon	IPA subcriterion	EOO (km ²)	AOO (km ²)	Study-derived global EOO/AOO range class	Published IUCN status	Red Data Book of Uzbekistan (2019)	Voucher herbaria
1	<i>Calligonum elegans</i> Drobow.	A(i)	3,062.527	40	EN	EN	EN	TASH
2	<i>Astragalus rubellus</i> Gontsch.	A(ii)	1,308.327	48	EN	NE	EN	TASH, MW
3	<i>Asparagus ferganensis</i> Vved.	A(iii)	17,690.212	80	VU+EN	NE	NL	TASH, FRU, MW, TAD
4	<i>Haplophyllum ferganicum</i> Vved.	A(iii)	13,871.311	76	VU+EN	NE	NL	TASH, MW
5	<i>Limonium ferganense</i> Ikonn.-Gal.	A(iii)	36,507.104	68	NT+EN	NE	NL	TASH, FRU, MW, TAD
6	<i>Arnebia obovata</i> Bunge.	A(iv)	387,211.939	320	LC+EN	NE	NL	TASH, FRU, AA, MW, TAD
7	<i>Artemisia ferganensis</i> Krasch. ex Poljakov.	A(iv)	1,550,017.854	252	LC+EN	NE	NL	TASH, FRU, MW
8	<i>Asparagus turkestanicus</i> Popov.	A(iv)	3,069,628.067	52	LC+EN	NE	NL	TASH, FRU, MW
9	<i>Astragalus chodshenticus</i> B.Fedtsch.	A(iv)	9,314.422	36	VU+EN	NE	NL	TASH, FRU, MW
10	<i>Astragalus cognatus</i> C.A.Mey.	A(iv)	962,167.739	60	LC+EN	NE	NL	TASH, FRU, MW
11	<i>Astragalus ammodendron</i> Bunge.	A(iv)	1,892,167.189	148	LC+EN	NE	NL	TASH, FRU, AA, MW
12	<i>Calligonum × dubianskyi</i> Litv.	A(iv)	628,844.271	28	LC+EN	NE	NL	TASH, FRU, MW
13	<i>Limonium drepanostachyum</i> Ikonn.-Gal.	A(iv)	6,789.546	28	VU+EN	NE	NL	TASH, FRU, MW
14	<i>Xylosalsola paletziana</i> (Litv.) Akhani & Roalson.	A(iv)	215,114.752	52	LC+EN	NE	NL	TASH, FRU, MW

Category A(i)

Subcriterion A(i) was represented by *Calligonum elegans* Drobow. The species is listed as Endangered in both the published global IUCN Red List and the Red Data Book of Uzbekistan. Its global EOO and AOO were recalculated in the present study using an expanded dataset that incorporated newly verified occurrence records. The updated global-range analysis again yielded EN, thereby independently supporting the previously published conservation status while refining the known distribution of the species.

***Calligonum elegans* Drobow in Bot. Mater. Gerb. Bot. Inst. Uzbekistansk. Fil. Akad. Nauk S.S.S.R. 3: 23 (1941).**

Figs 4, 5, 8A

Calligonum elegans is treated here as a distinct species following the regional taxonomic concepts of Drobow (1953) and Soskov (2011), supported by examination of newly collected voucher specimens. It differs from *C. leuclidum* subsp. *leuclidum* by its oval to slightly globose fruit, brown, delicate, oval, and finely toothed wings, gray bark on older branches, a fruiting perianth

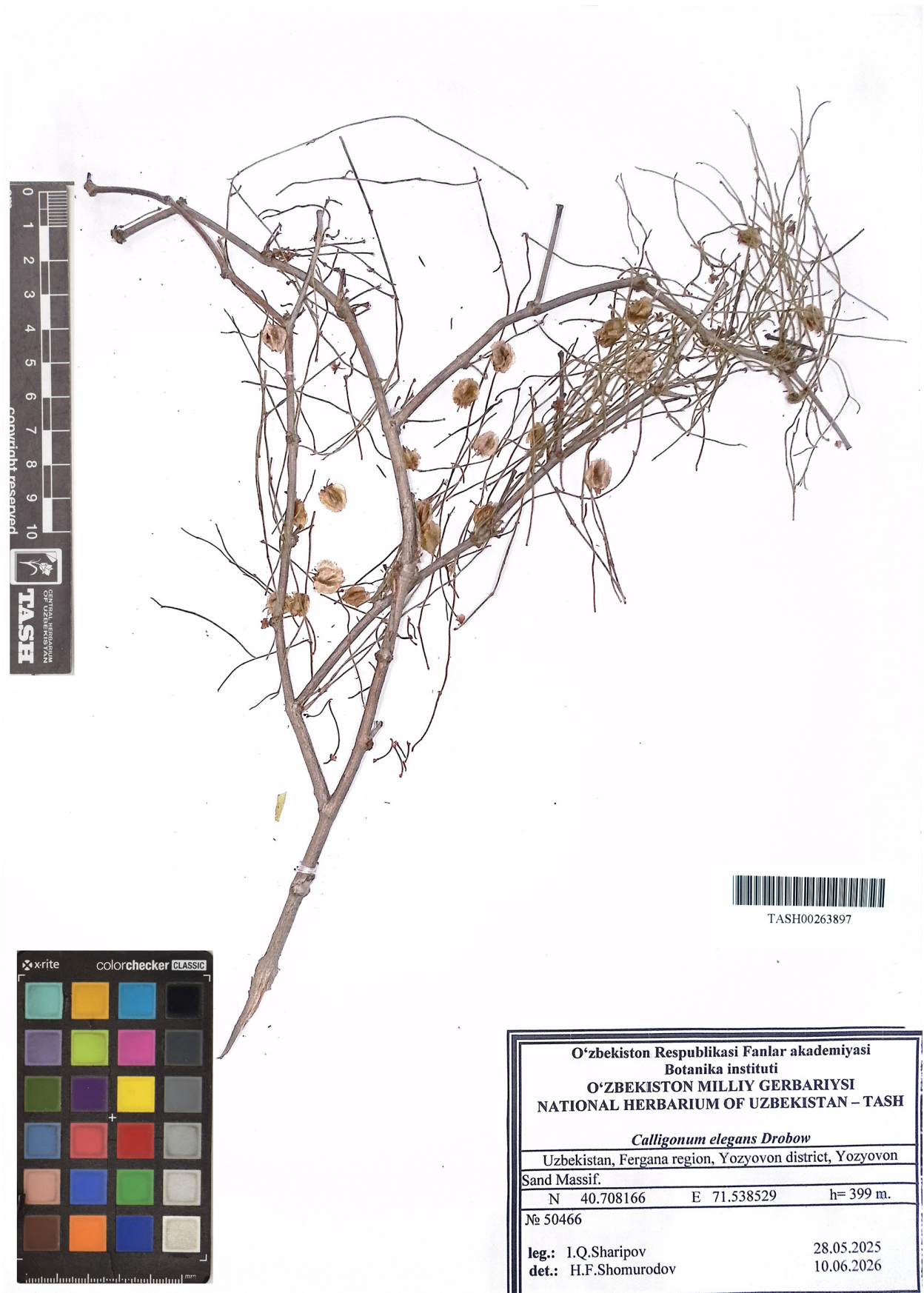


Figure 4. Voucher specimen of *Calligonum elegans* Drobow from the proposed Yozyovon Sand Massif IPA, Fergana Region, Uzbekistan (40.708166°N, 71.538529°E; 399 m a.s.l.; TASH00263897).



Figure 5. *Calligonum elegans* Drobow. Photo by Ilyosbek K. Sharipov.

compressed between the wings, and a nutlet rotated by approximately 90°. In *C. leucocladum* subsp. *leucocladum*, the fruit is oval to oblong-oval, the wings are yellowish, oblong-ovate, and entire or unevenly blunt-toothed, the bark of older branches is pale, the fruiting perianth lobes are reflexed, and the nutlet is straight (Drobow 1953; Soskov 2011).

Regional identification literature reports *C. elegans* from exposures of variegated geological formations and from sands where the underlying bedrock lies close to the surface (Kovalevskaya 1971). Its habitat is therefore not restricted to gypseous outcrops but also includes sandy substrates with shallow underlying bedrock.

The 2007 IUCN assessment classified *C. elegans* as Endangered under criterion B2ab(iii,v) and described its range as restricted to the Sokh River basin in southern Fergana (Participants of the FFI/IUCN SSC Central Asian Regional Tree Red Listing Workshop 2007). The newly verified records reported here extend the confirmed contemporary distribution of the species beyond the range documented in that assessment and demonstrate its occurrence in the sandy lowlands of Central Fergana.

Three recent voucher-backed localities were documented: sandy habitats near Haydarobod village, Ulugnor District, Andijan Region (40.806542°N, 71.644275°E; 402 m a.s.l.; 28 April 2024; I.Q. Sharipov; TASH00263898); Gumxona, Shodaqoziq village, Beshariq District, Fergana Region (40.472315°N, 70.387151°E; 354 m a.s.l.; 22 April 2025; I.Q. Sharipov; TASH00263896); and the Yozyovon sands, Yozyovon District, Fergana Region (40.708166°N, 71.538529°E; 399 m a.s.l.; 28 May 2025; I.Q. Sharipov; TASH00263897) (Fig. 4). All three voucher specimens were independently confirmed as *C. elegans* by Prof. X. Shomurodov on 10 June 2026.

The Yozyovon locality lies within the proposed IPA boundary and provides direct voucher-based evidence of the occurrence of *C. elegans* within the proposed site. The Haydarobod locality lies close to, but outside, the northern boundary of the proposed IPA, whereas the Gumxona locality is situated approximately 60–70 km outside the proposed site. The Haydarobod and Gumxona records were used to clarify the broader distribution of the species and to inform the GeoCAT analysis; neither was treated as evidence of occurrence within the proposed IPA.

The updated GeoCAT analysis, based on verified occurrence records and a 2×2 km grid, yielded an EOO of 3,062.527 km² and an AOO of 40 km² (Bachman et al. 2011). Both values fall within the numerical range thresholds for the Endangered category under criterion B (IUCN 2012). However, these values are presented as study-derived spatial metrics and do not constitute a formal IUCN Red List reassessment.

Limiting factors. Conversion and fragmentation of sandy habitats, livestock grazing, and cutting of shrubs.

Measures of protection. Listed in the Red Data Book of Uzbekistan; the proposed IPA currently has no formal protected status.

Existing conservation threats. Continuing loss, degradation, and fragmentation of lowland sandy habitats.

General distribution. Uzbekistan; currently documented from the Uzbek part of the FV.

Distribution in the FV. The Sokh foothill zone and the sandy lowlands of Central Fergana.

Category A(ii)

One species, *Astragalus rubellus*, qualified under subcriterion A(ii). The species is listed as Endangered in the Red Data Book of Uzbekistan and has a restricted distribution in the Central Fergana lowlands. Its inclusion is consistent with the formulation of Darbyshire et al. (2017), under which a site may qualify when it supports a species included in an IUCN Regional Red List or another regionally approved and peer-reviewed threat list.

***Astragalus rubellus* Gontsch. in Bot. Mater. Gerb. Bot. Inst. Komarova Akad. Nauk S.S.S.R. 9(1): 94 (1941).**

Figs 6, 8B

Astragalus rubellus is a rare endemic of Uzbekistan known from sandy and slightly saline habitats in Central Fergana, including the vicinity of Kokand, Kara-Kalpak, and the Yozyovon sands. The TASH collection contains five historical specimens collected between 1928 and 1952, while recent field and photographic records confirm its continued occurrence in the region. Its restricted distribution, limited historical collections, and dependence on declining sandy habitats support its inclusion under subcriterion A(ii).

Measures of protection. Protected in the Yazyavan Natural Monument.

Existing conservation threats. Loss and fragmentation of sandy habitats.

General distribution. Uzbekistan.

Distribution in the FV. Endemic to Central Fergana.



Figure 6. *Astragalus rubellus* Gontsch. Photo by Ilyosbek K. Sharipov.

Historical record excluded from the Criterion A assessment

Oenanthe fedtschenkoana Koso-Pol. was retained in the integrated floristic inventory as a historical but currently unconfirmed record. The Red Data Book of Uzbekistan (2019) treats the species as an extremely rare endemic of the FV known only from a single historical collection reportedly made near Kokand. The type specimen was previously reported to be deposited at MW; however, subsequent searches at MW and MHA (Thiers 2026) failed to locate it, and no duplicate or later collections are known from Central Asian herbaria. Repeated botanical surveys around Kokand, including recent field investigations, also failed to relocate the species. Much of the historical locality has since been urbanized or converted to irrigated agricultural land, and suitable habitat may therefore have been lost. No verified occurrence is known from the Yozyovon Sand Massif. Accordingly, the taxon was retained solely for documentary completeness and was excluded from distribution mapping, EOO and AOO calculations, and the Criterion A trigger-species assessment.

Category A(iii)

Category A(iii) is represented by three Fergana Valley endemic species: *Asparagus ferganensis*, *Haplophyllum ferganicum*, and *Limonium ferganense*. Each has a restricted regional distribution and was assessed according to the regional operational interpretation of IPA subcriterion A(iii) applied in previous Fergana Valley studies (Darbyshire et al. 2017; Tojibaev et al. 2023).

***Asparagus ferganensis* Vved. in Fl. Uzbekistan. 1: 544 (1941).**

Figs 7A, 8C

Asparagus ferganensis is a desert endemic of the FV occurring in lowland and foothill habitats. It is morphologically similar to the more widespread *A. persica* but can be distinguished by its markedly shorter peduncles (2–3 cm vs. 10–20 cm) and interrupted, flexuous branches, whereas those of *A. persica* are uninterrupted and flexuous. The two taxa also occupy distinct ecological niches and exhibit different habitat preferences. The restricted regional distribution of *A. ferganensis*, together with the continuing loss and fragmentation of its natural habitats, supports its inclusion under IPA subcriterion A(iii).

Measures of protection. Not protected.

Existing conservation threats. Reduction of natural landscapes and fragmentation.

General distribution. Kyrgyzstan, Tajikistan, Uzbekistan.

Distribution in the FV. Endemic to the foothills and lowlands of the FV.

***Haplophyllum ferganicum* Vved. in Bot. Mater. Gerb. Inst. Bot. Zool. Akad. Nauk Uzbeksk. S.S.R. 10: 3 (1948)**

Figs 7B, 8D

Haplophyllum A.Juss. is a species-rich but taxonomically insufficiently resolved genus of Rutaceae, comprising approximately 68–71 species, with its principal center of diversity in the Irano-Turanian region (Townsend 1986; Salvo et al. 2011). More than 20 species occur in Central Asia, over half of which are regional endemics (Adylov 1983; Khassanov 2015).

Haplophyllum ferganicum is a narrow endemic restricted to the plains and foothills of the FV (Adylov 1983). It is characterized by basally connate filaments and pale-yellow petals that are usually dorsally pubescent. The species is distinguished from the closely related *H. versicolor* by its sparse, short pubescence or nearly glabrous surfaces, less densely pubescent inflorescence, and smaller capsules, approximately 3 mm wide rather than approximately 4 mm. Much of its known habitat is situated near intensively cultivated land and human settlements, where continuing agricultural expansion, habitat conversion, and fragmentation increase its conservation vulnerability. Its narrow regional distribution, diagnostic distinctiveness, and exposure to ongoing habitat loss support its inclusion under IPA subcriterion A(iii).

Measures of protection. Not protected.

Existing conservation threats. Reduction of natural landscapes and fragmentation.

General distribution. Kyrgyzstan, Tajikistan, Uzbekistan.

Distribution in the FV. Endemic to the plains and foothills of the FV.

***Limonium ferganense* Ikonn.-Gal. in Trudy Bot. Inst. Akad. Nauk S.S.S.R., Ser. 1, Fl. Sist. Vyssh. Rast. 2: 262 (1936)**

Figs 7C, 8E

= *Limonium komarovii* Ikonn-Gal. ex Lincz. & Czukav. in Novosti Sist. Vyssh. Rast. 21: 131 (1984).

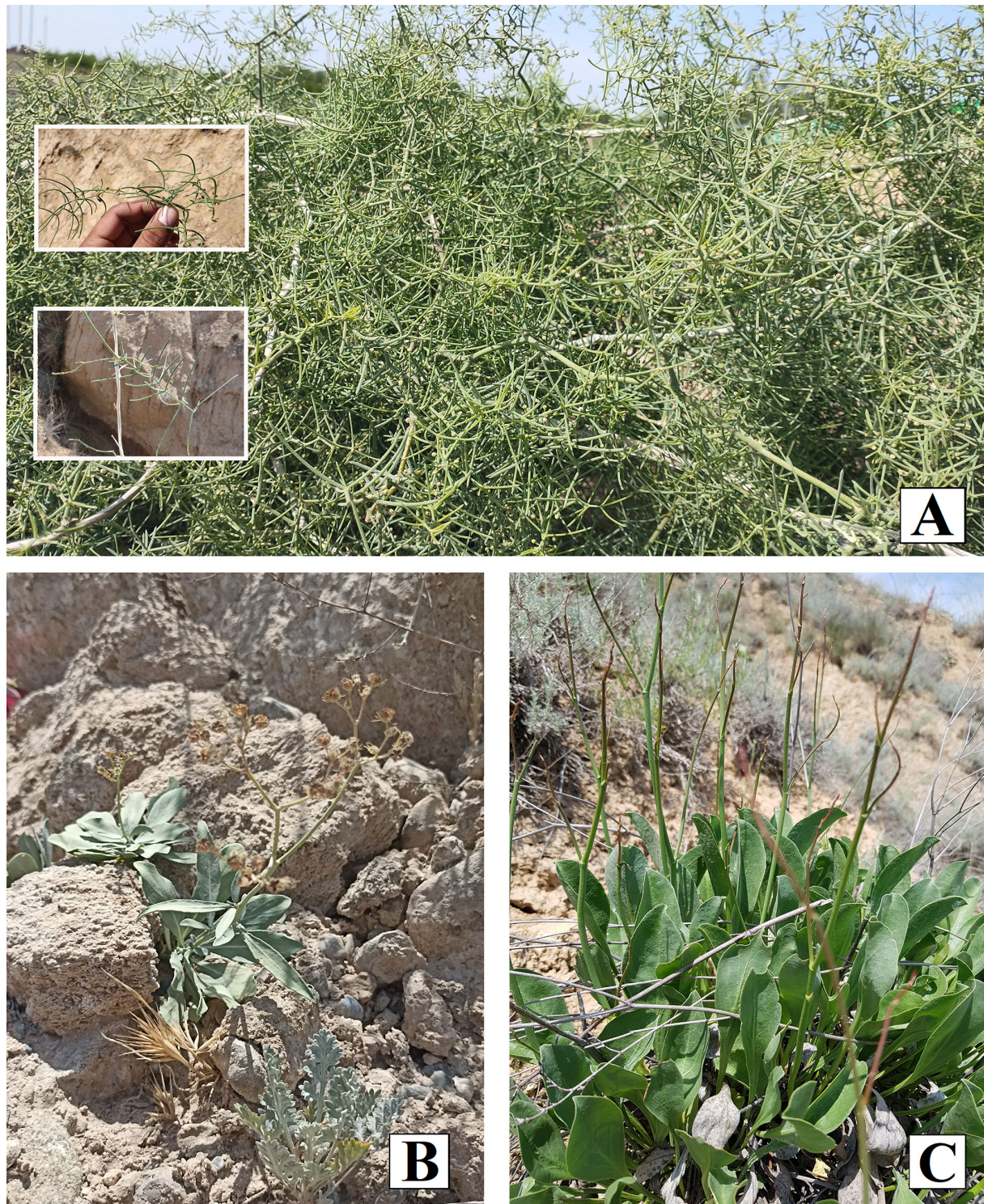


Figure 7. Natural populations of three FV endemic species qualifying under IPA subcriterion A(iii). **A.** *Asparagus ferganensis*; **B.** *Haplophyllum ferganicum*; **C.** *Limonium ferganense*. Photographs: **A** and **C** by Hushbaht R. Hoshimov; **B** by Ilyosbek K. Sharipov.

Limonium Mill. is the largest genus of Plumbaginaceae, comprising more than 600 species distributed mainly in coastal and inland saline habitats worldwide, with its principal center of diversity in the Mediterranean region (Lledó et al. 2011; POWO 2025). At least 26 species occur in Central Asia, approximately half of which are narrow-range endemics, confirming the regional importance of the genus.

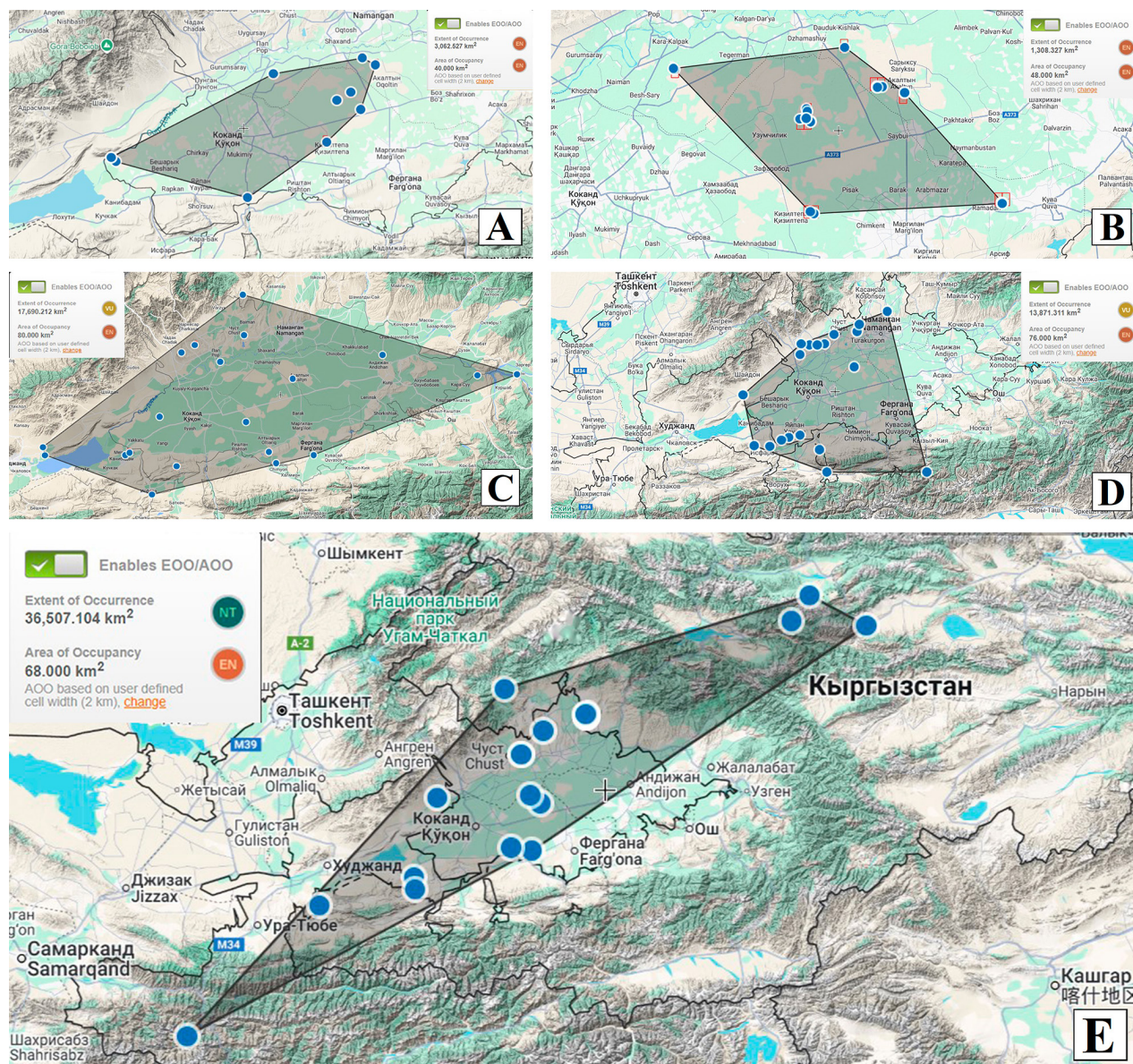


Figure 8. Distribution maps of five species qualifying under IPA Criterion A based on GeoCAT analyses. **A.** *Calligonum elegans*, subcriterion A(i); **B.** *Astragalus rubellus*, subcriterion A(ii); and **C.** *Asparagus ferganensis*, **D.** *Haplophyllum ferganicum*, and **E.** *Limonium ferganense*, subcriterion A(iii).

Limonium ferganense is endemic to the FV and occurs mainly in foothill and saline habitats. In the present geographic-range screening, its calculated EOO of 36,507.104 km² exceeded the numerical threshold for VU. Nevertheless, an EOO-based NT class was retained on the basis of its fragmented distribution and the continuing loss and degradation of its habitats through agricultural transformation and grazing. Its regional endemism, restricted distribution, association with specialized foothill and saline habitats, and exposure to ongoing habitat degradation support its inclusion under IPA subcriterion A(iii).

Measures of protection. Not protected.

Existing conservation threats. Reduction of natural landscapes and fragmentation.

General distribution. Kyrgyzstan and Uzbekistan.

Distribution in the FV. Endemic; foothills of the FV.

Category A(iv)

Nine species were included under subcriterion A(iv). Unlike subcriteria A(i)–A(iii), which rely primarily on formal global or national threat categories, A(iv) was applied to taxa whose conservation importance is expressed at the regional level through restricted occurrence, habitat specialization, or vulnerable populations within the FV. Several of the included taxa are classified as Least Concern globally, or their global assessments do not adequately reflect their regional exposure to habitat loss and fragmentation in Central Asia (Darbyshire et al. 2017; Wilson et al. 2021).

***Arnebia obovata* Bunge in Beitr. Fl. Russl.: 231 (1852)**

Figs 9A, 10A

Arnebia Forssk. comprises approximately 36 species distributed from the eastern Mediterranean and northern Africa to Central and East Asia, including at least 12 species recorded in Central Asia (POWO 2025; Li and Tojibaev 2024, 2025).

Arnebia obovata is a perennial desert species occurring in arid and sandy habitats across Central Asia, including the plains and foothills of the FV. It is morphologically distinctive within the genus because of its perennial stems and violet flowers, whereas most regional congeners are annual and predominantly yellow-flowered. The species differs from the morphologically related perennial taxa *A. guttata* and *A. tibetana* in corolla color and leaf morphology. Within the FV, its populations occur in increasingly fragmented natural landscapes affected by agricultural conversion and other forms of habitat disturbance. Its regional occurrence, diagnostic distinctiveness, and exposure to continuing habitat degradation support its inclusion under IPA subcriterion A(iv).

Measures of protection. Not protected.

Existing conservation threats. Reduction of natural landscapes and fragmentation.

General distribution. Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan.

Distribution in the FV. Plains and foothills of the FV.

***Artemisia ferganensis* Krasch. ex Poljakov in Bot. Mater. Gerb. Bot. Inst. Komarova Akad. Nauk S.S.S.R. 16: 409 (1954)**

Fig. 9B

Artemisia ferganensis was included under IPA subcriterion A(iv) because Central Asia, particularly the FV, represents the principal core of its distribution, although its range extends eastward into Xinjiang, China. It is an important forage species in the desert ecosystems of the FV and occurs mainly in relatively moist habitats within otherwise arid landscapes. The species is distinguished from related members of subgen. *Seriphidium* by its comparatively broad terminal lobes of the lower leaves, which are up to 1.5 mm wide and may bear two or three apical teeth, and by its characteristically light green foliage (Jin et al. 2023). Within the study region, its populations occur in landscapes increasingly affected by agricultural expansion, settlement development, and habitat fragmentation. Its regional concentration, diagnostic distinctiveness, ecological

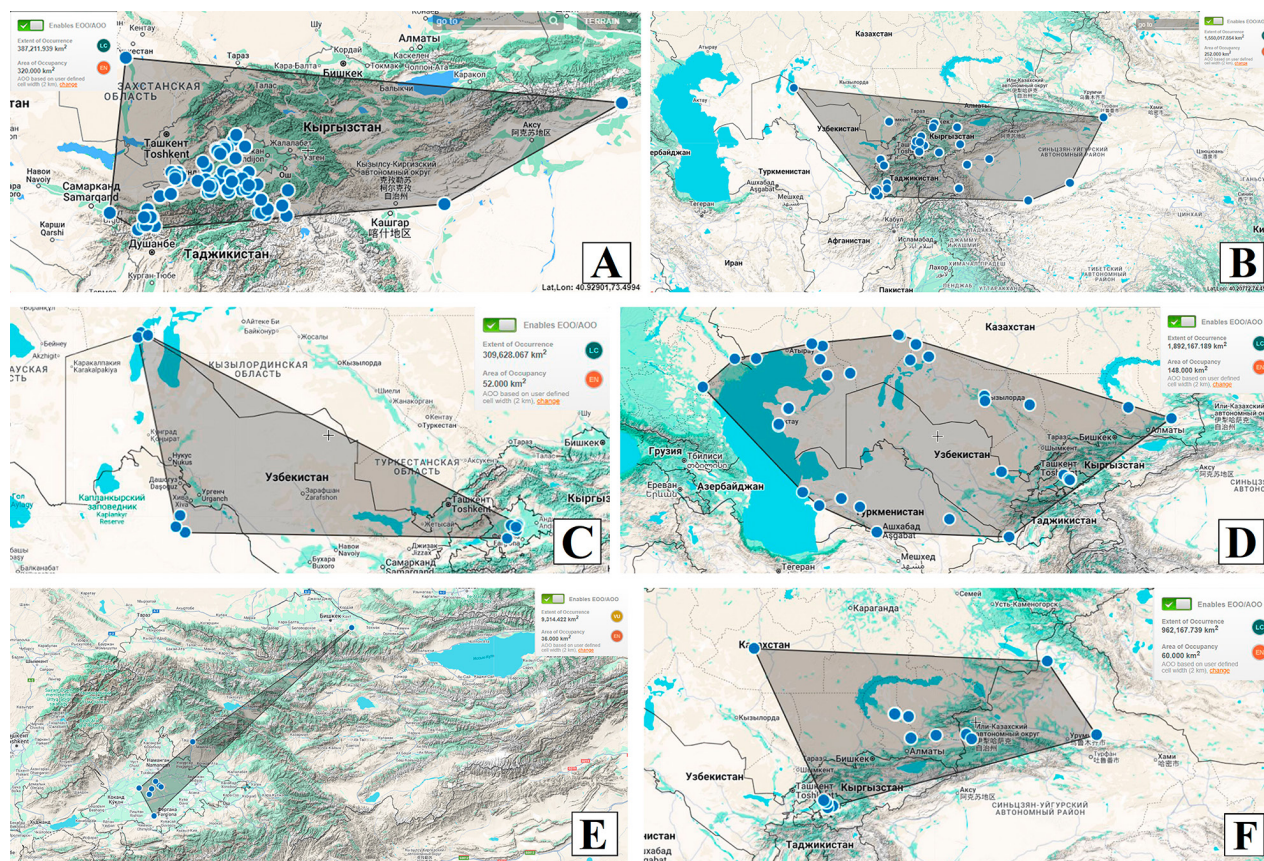


Figure 9. Distribution map of six species qualifying under IPA subcriterion A(iv) based on GeoCAT analyses. **A.** *Arnebia obovata*; **B.** *Artemisia ferganensis*; **C.** *Asparagus turkestanicus*; **D.** *Astragalus ammodendron*; **E.** *Astragalus chodshenticus*; **F.** *Astragalus cognatus*.

importance, and exposure to continuing habitat loss support its inclusion under IPA subcriterion A(iv).

Measures of protection. Not protected.

Existing conservation threats. Agricultural expansion, settlement development, and habitat fragmentation.

General distribution. Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, and Xinjiang, China.

Distribution in the FV. Plains and foothills of the FV.

***Asparagus turkestanicus* Popov in B. A. Fedtschenko & al., Fl. Turkmen. 1: 312 (1932)**

Fig. 9C

Asparagus turkestanicus is readily distinguished from other Central Asian congeners by the complete absence of cladodes. Its broader distribution extends from the Balkhash and Aral regions through the Karakum Desert to the mountainous areas of Turkmenistan. In Uzbekistan, the species has also been recorded in the Kyzylkum Desert, the Sultanuizdag Mountains, and the FV. The FV populations occur near the southern limit of its known range and are therefore biogeographically important peripheral populations. Within the region, the species occupies sandy and foothill habitats affected by continuing habitat reduction and fragmentation. Its diagnostic distinctiveness, periph-

eral regional occurrence, and habitat vulnerability support its inclusion under IPA subcriterion A(iv).

Measures of protection. Not protected.

Existing conservation threats. Reduction and fragmentation of sandy habitats.

General distribution. Kazakhstan, Turkmenistan, and Uzbekistan.

Distribution in the FV. Sandy plains and foothills of the FV.

***Astragalus ammodendron* Bunge in Arbeiten Naturf. Vereins Riga 1: 233 (1847)**
Figs 9D, 10B

= *Astragalus ammodendron* subsp. *transcaspicus* (Freyn & Bornm.) Basil. in Trudy Prikl. Bot. 18: 547 (1928).

Astragalus sect. *Ammodendron* Bunge comprises approximately 26 species in Central Asia, most of which are associated with sandy environments and include important components of desert vegetation.

Astragalus ammodendron is a characteristic psammophytic species of Central Asian sandy deserts. It is morphologically distinguished by its narrow, linear leaves and densely pubescent, prominently protruding pods. Within the FV, it occurs in sandy habitats and contributes to the structure and stabilization of desert vegetation. Its dependence on sandy substrates, together with the continuing reduction and fragmentation of these habitats, supports its regional conservation relevance and inclusion under IPA subcriterion A(iv).

Measures of protection. Not protected.

Existing conservation threats. Reduction and fragmentation of sandy habitats.

General distribution. Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan.

Distribution in the FV. Sandy plains and foothills of the FV.

***Astragalus chodshenticus* B.Fedtsch. in Trudy Tadzhiksk. Bazy 2: 152 (1936)**
Figs 9E, 10C

= *Astragalus thaumatococcus* Vved. in Bot. Mater. Gerb. Inst. Bot. Akad. Nauk Uzbeksk. S.S.R. 13: 22 (1952).

Astragalus chodshenticus is distinguished within sect. *Ammodendron* by its oval, oblong-oval, lanceolate, or elliptical leaflets, usually 13–15 mm long; leaves typically bearing two pairs of leaflets; and persistent, lignified petioles that become arcuately recurved and subspinescent on older branches. The TASH collection contains 10 specimens collected between 1915 and 1974, most originating from Central Fergana. Recent photographic records published through Plantarium provide additional evidence of its regional occurrence. Its restricted regional distribution and continuing exposure to the loss and fragmentation of sandy habitats support its inclusion under IPA subcriterion A(iv).

Measures of protection. Not protected.

Existing conservation threats. Reduction of sandy dunes and fragmentation.

General distribution. Kyrgyzstan, Tajikistan, Uzbekistan.

Distribution in the FV. Foothills of the FV.

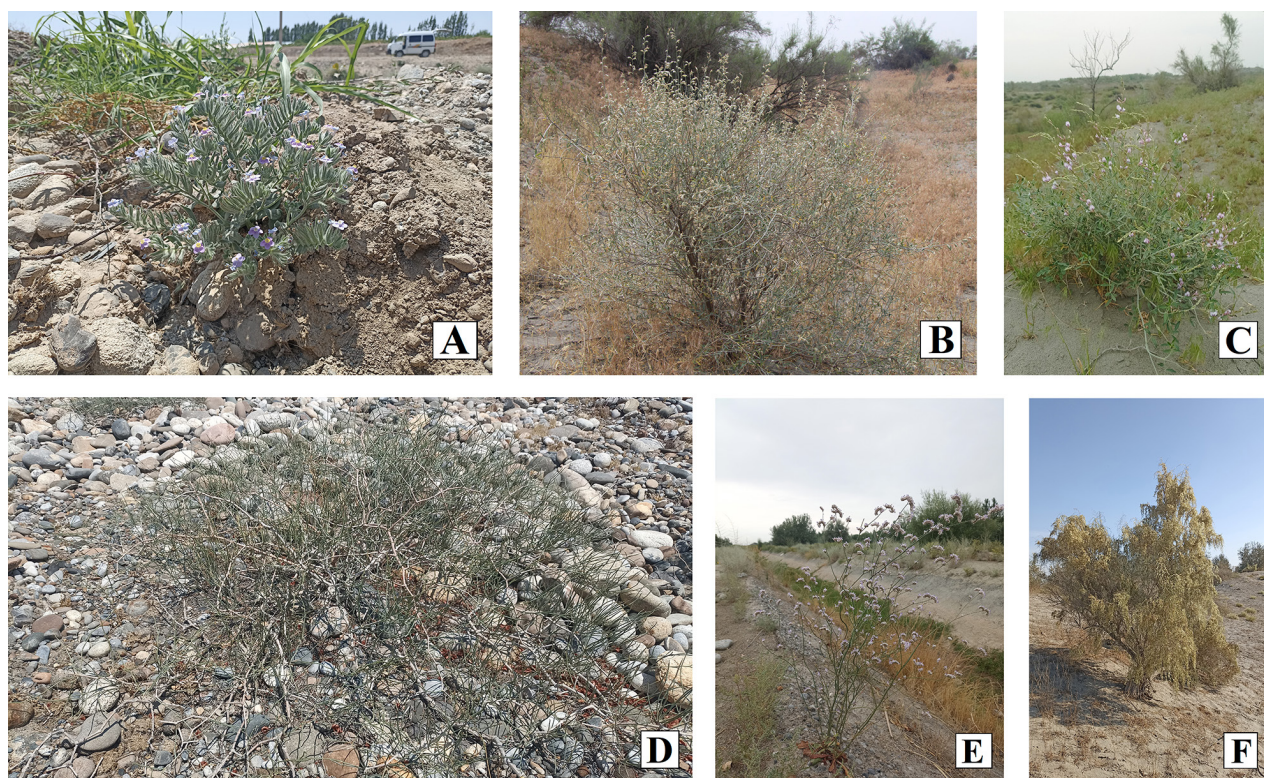


Figure 10. Natural populations of six species qualifying under IPA subcriterion A(iv). **A.** *Arnebia obovata*; **B.** *Astragalus ammodendron*; **C.** *Astragalus chodshenticus*; **D.** *Calligonum* × *dubianskyi*; **E.** *Limonium drepanostachyum*; **F.** *Xylosalsola paletzkiana*. Photographs by Ilyosbek K. Sharipov.

***Astragalus cognatus* C.A.Mey. in F. E. L. von Fischer & C. A. von Meyer, Enum. Pl. Nov.: 81 (1841)**

Fig. 9F

Astragalus cognatus is frequently recorded in sandy habitats of the study area. Within sect. *Ammodendron*, it is characterized by leaves bearing three to five leaflets and by inflated, ovoid to oblong-ovoid pods. Its continued occurrence in fragmented sandy habitats exposed to dune loss and other forms of habitat degradation supports its regional conservation relevance and inclusion under IPA subcriterion A(iv).

Measures of protection. Not protected.

Existing conservation threats. Reduction of sandy dunes and fragmentation.

General distribution. Kyrgyzstan and Uzbekistan.

Distribution in the FV. Sands of the FV.

***Calligonum* × *dubianskyi* Litv. in Trudy Bot. Muz. Imp. Akad. Nauk 11: 57 (1913)**
Figs 10D, 11A

Calligonum L. is a predominantly desert genus distributed from the eastern Mediterranean and North Africa through western and Central Asia to western Siberia, Mongolia, and Xinjiang, with Central Asia representing a major center of its diversity (Soskov 2011; Khassanov 2015). *Calligonum* × *dubianskyi* is treated here as a taxonomically complex hybrid taxon associated with the sandy flora of the FV. The hybrid sign is retained consistently throughout the manuscript,

while the parentage of the taxon is not evaluated in the present study. POWO (2025) lists more than 12 heterotypic synonyms associated with the taxon, reflecting its complex nomenclatural history. Its occurrence in fragmented sandy habitats and dependence on declining dune systems support its inclusion under IPA subcriterion A(iv).

Measures of protection. Not protected.

Existing conservation threats. Reduction of sandy dunes and fragmentation.

General distribution. Kazakhstan, Tajikistan, Turkmenistan, and Uzbekistan.

Distribution in the FV. Sands of Central Fergana.

***Limonium drepanostachyum* Ikonn.-Gal. in Trudy Bot. Inst. Akad. Nauk S.S.S.R., Ser. 1, Fl. Sist. Vyssh. Rast. 2: 267 (1936)**

Figs 10E, 11B

= *Eremolimon drepanostachyum* (Ikonn.-Gal.) Lincz. in Novosti Sist. Vyssh. Rast. 22: 203 (1985).

Limonium drepanostachyum is a Central Asian species associated with saline and sandy habitats, including the Central Fergana Sands. It belongs to a group characterized by compact spikes, borne singly or in groups of up to three at the tips of the scape branches, and by a tubular calyx with a weakly developed, slightly recurved to erect limb. The species is distinguished from its closest relative, *L. fajzievii*, by its obtuse outer bracts, measuring 2.5–3.5 mm long, rather than more or less pointed bracts, and by simple hairs on the bracts and calyx rather than fine glandular pubescence. Its restricted occurrence within fragmented sandy habitats supports its inclusion under IPA subcriterion A(iv).

Measures of protection. Not protected.

Existing conservation threats. Continuing loss and fragmentation of sandy habitats.

General distribution. Kazakhstan, Tajikistan, Turkmenistan, Uzbekistan.

Distribution in the FV. Sands of Central Fergana.

***Xylosalsola paletzkiana* (Litv.) Akhani & Roalson in Int. J. Pl. Sci. 168: 947 (2007)**

Figs 10F, 11C

≡ *Salsola paletzkiana* Litv. in Spisok Rast. Gerb. Russk. Fl. Bot. Muz. Rossiisk. Akad. Nauk 8: 91 (1922).

Xylosalsola paletzkiana, formerly treated as *Salsola paletzkiana*, is a large shrub or small tree native to the sandy deserts of the southern Turan region. Its placement in *Xylosalsola* follows the molecularly informed subdivision of the formerly broad concept of *Salsola* (Akhani et al. 2007), while subsequent taxonomic work confirmed that *Xylosalsola* comprises several distinct species (Sukhorukov 2015). The genus currently includes four accepted species (POWO 2025). *Xylosalsola paletzkiana* is characterized by pale-gray bark and a densely branched habit and is taxonomically close to the more widely distributed *X. richteri*. In Central Fergana, it occurs on sandy soils and forms part of the structural shrub vegetation of the desert ecosystem. Continuing dune loss and habitat fragmentation support its inclusion under IPA subcriterion A(iv).

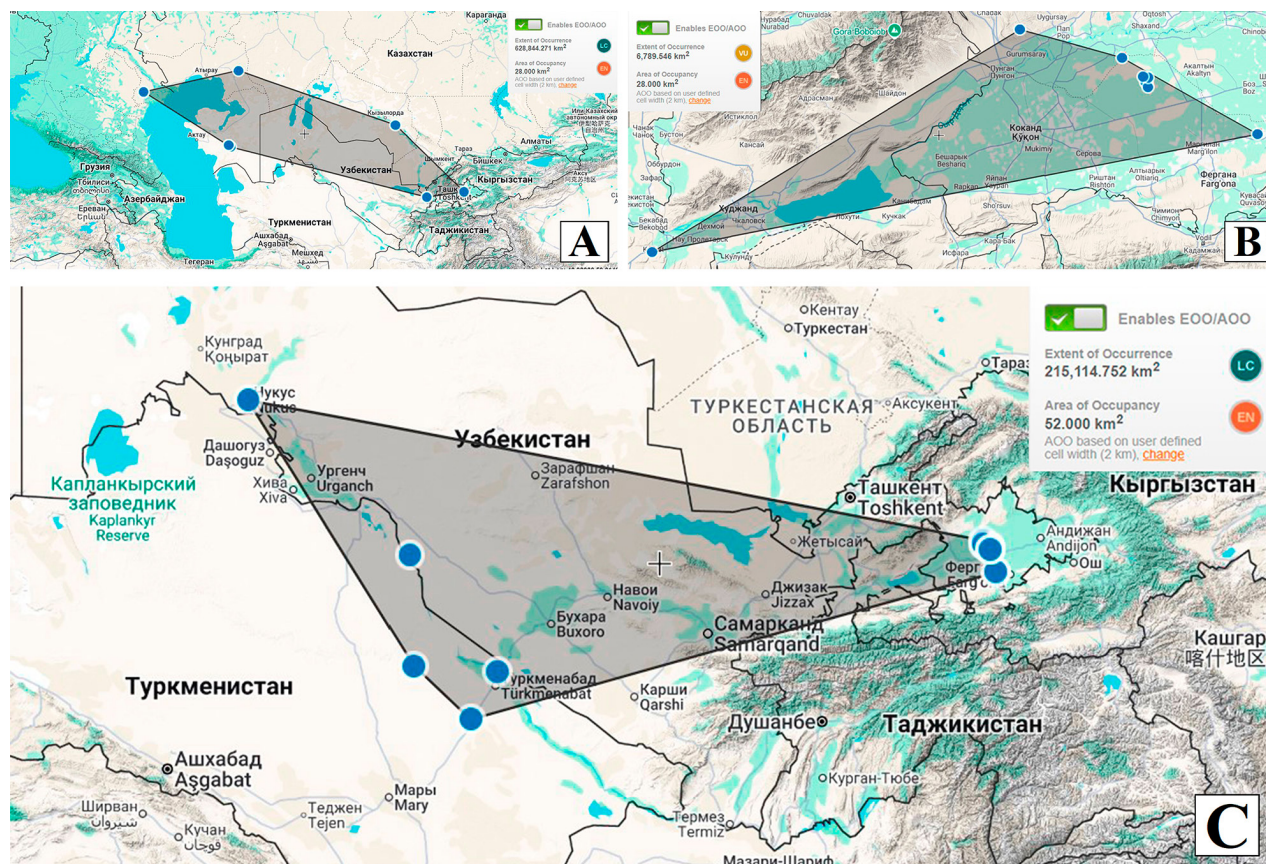


Figure 11. Distribution map of three species qualifying under IPA subcriterion A(iv) based on GeoCAT analyses. **A.** *Calligonum x dubianskyi*; **B.** *Limonium drepanostachyum*; **C.** *Xylosalsola paletzkiana*.

Measures of protection. Not protected.

Existing conservation threats. Continuing loss and fragmentation of sandy habitats.

General distribution. Kazakhstan, Turkmenistan, and Uzbekistan.

Distribution in the FV. Sands of Central Fergana.

Overall, all 14 Criterion A trigger taxa were evaluated in the present study using verified occurrence records from across their known global native ranges. One taxon, *Calligonum elegans*, has a published global IUCN assessment and was again assigned an EN range class using the updated dataset. Two taxa, *Calligonum elegans* and *Astragalus rubellus*, are listed as Endangered in the Red Data Book of Uzbekistan, whereas the remaining 12 taxa are not nationally listed. The study-derived global EOO/AOO range classes, together with published conservation status, endemism, biogeographical restriction, habitat specialization, and occurrence within threatened sandy habitats, provide strong evidence that the proposed Yozyovon Sand Massif IPA meets Criterion A under the regional operational interpretation applied in the FV.

Woody vegetation and habitat structure

The woody component of the flora comprised 22 phanerophytes, represented mainly by species of *Populus*, *Salix*, *Tamarix*, *Haloxylon*, *Calligonum*, and other arid-adapted genera (Table 3, Fig. 12). These species occurred as discrete

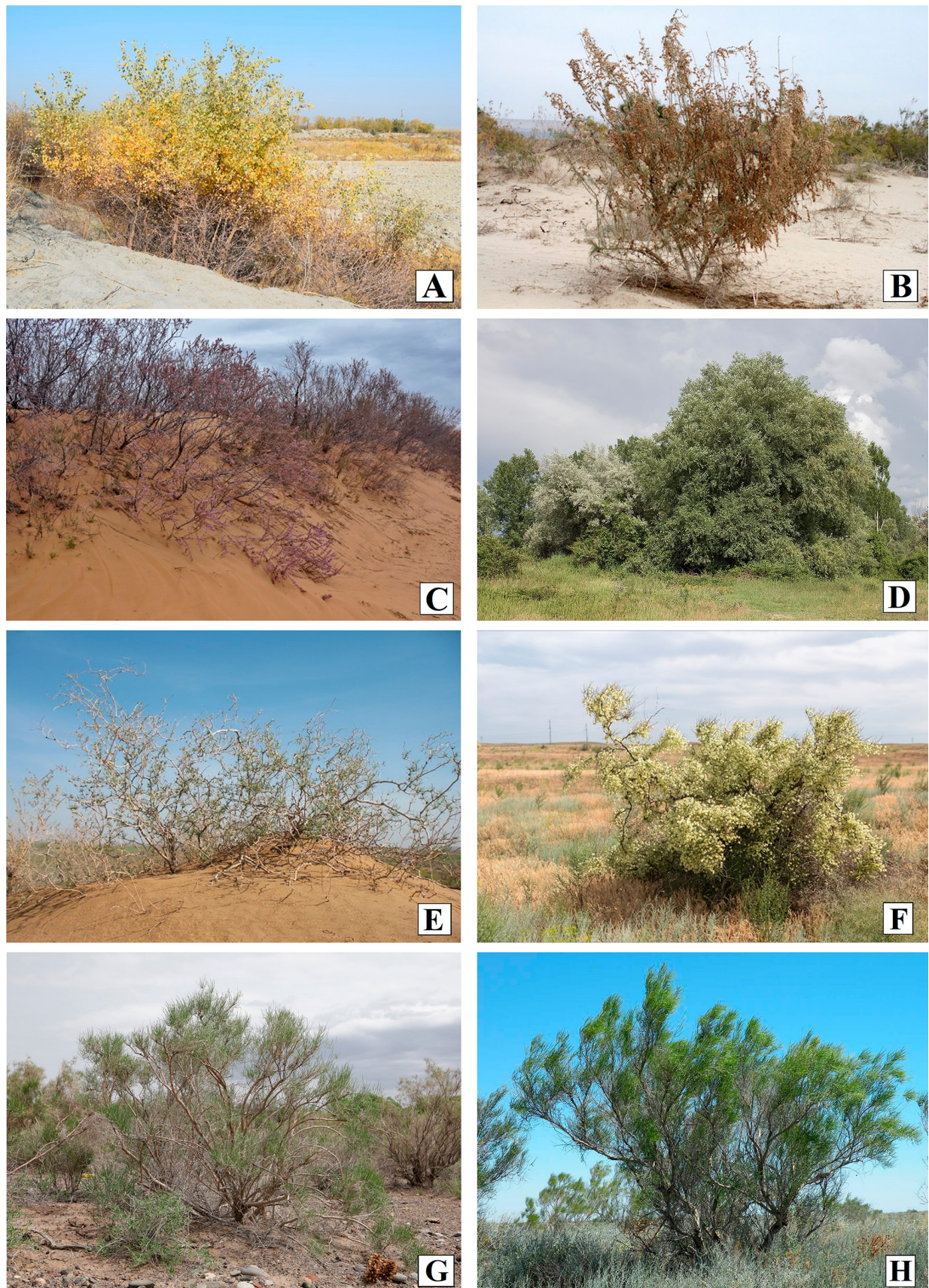


Figure 12. Representative tree and shrub species recorded within the proposed Yozyovon Sand Massif IPA. **A.** *Populus pruinosa*; **B.** *Xylosalsola richteri*; **C.** *Tamarix laxa*; **D.** *Salix alba*; **E.** *Calligonum caput-medusae*; **F.** *Calligonum aphyllum*; **G.** *Haloxylon persicum*; **H.** *Haloxylon aphyllum*.

stands, small patches, or scattered individuals across sandy and saline habitats. Field observations indicated greater fragmentation of woody vegetation in areas exposed to grazing, fuelwood collection, and land-use transformation (Table 6). These patterns provide additional site-level evidence of habitat disturbance and form part of the ecological context for the subsequent assessment under Criterion C.

Assessment against IPA Criterion C: habitat condition and threatened ecosystems

The revised Random Forest analysis, evaluated using held-out, spatially separated reference data, provided a single internally consistent estimate of sandy-habitat change within the fixed 416.24 km² Yozyovon study extent. Mapped Sand area declined from 125.95 km², representing 30.26% of the study extent, in 1991 to 54.79 km², or 13.16%, in 2025. This corresponds to an absolute reduction of 71.16 km² and a relative reduction of 56.50%. Sand extent declined during each analyzed interval, while the classified maps indicated greater spatial discontinuity of the remaining sandy surfaces.

Field surveys confirmed that the remaining sandy habitats continue to support specialized psammophytic plant assemblages and ecologically distinctive habitat features, including the occurrence of *Populus pruinosa* on dune substrates. The substantial reduction in mapped Sand extent, together with the increasing spatial discontinuity visible in the classified maps and the continuing anthropogenic pressures documented through field observations and the threat assessment, supports recognition of the site's conservation importance under IPA Criterion C.

Results of the adapted threat-prioritization assessment

The adapted site-level threat-prioritization assessment identified 18 direct threats affecting the Yozyovon Sand Massif (Table 6). Three threats were classified as High impact, 10 as Medium impact, and five as Low impact. None of the assessed threats fell within the Negligible or No impact class.

The resulting pattern was dominated by pressures associated with agricultural land conversion, hydrological modification, resource extraction, and direct physical alteration of sandy habitats. The highest scores were assigned to threats characterized by broad spatial scope, rapid habitat degradation, and ongoing activity. Representative field examples of irrigated agriculture, sand extraction, and infrastructure-related substrate disturbance are shown in Fig. 13.

Priority threats

The High-impact class comprised three threats, each with a total score of 8: shifting agriculture (2.1.1), agro-industrial farming (2.1.3), and other ecosystem modifications (7.3). Their high scores resulted from the combined effects of broad spatial scope, rapid habitat degradation, and ongoing activity. Together, these pressures represent the principal drivers of habitat loss, fragmentation, and structural transformation within the Yozyovon Sand Massif.

Ten threats were classified as Medium impact. Four threats attained a total score of 7: smallholder farming (2.1.2), mining and quarrying (3.2), work and

Table 6. Prioritization of direct threats affecting the Yozyovon Sand Massif using the adapted site-level scoring framework.

IUCN threat code	Direct threat	Scope category (score)	Severity category (score)	Timing category (score)	Total score	Impact class
2.1.1	Shifting agriculture	Whole (3)	Rapid degradation (2)	Ongoing (3)	8	High
2.1.3	Agro-industrial farming	Whole (3)	Rapid degradation (2)	Ongoing (3)	8	High
7.3	Other ecosystem modifications	Whole (3)	Rapid degradation (2)	Ongoing (3)	8	High
2.1.2	Smallholder farming	Majority (2)	Rapid degradation (2)	Ongoing (3)	7	Medium
3.2	Mining and quarrying	Majority (2)	Rapid degradation (2)	Ongoing (3)	7	Medium
6.3	Work and other activities	Majority (2)	Rapid degradation (2)	Ongoing (3)	7	Medium
7.2.3	Abstraction of surface water for agriculture	Majority (2)	Rapid degradation (2)	Ongoing (3)	7	Medium
5.3	Logging and wood harvesting	Majority (2)	Slow but significant degradation (1)	Ongoing (3)	6	Medium
5.4.2	Intentional use, large scale	Majority (2)	Slow but significant degradation (1)	Ongoing (3)	6	Medium
7.2.10	Large dams	Majority (2)	Slow but significant degradation (1)	Ongoing (3)	6	Medium
8.1	Invasive and other problematic species and diseases	Majority (2)	Slow but significant degradation (1)	Ongoing (3)	6	Medium
9.1	Domestic and urban wastewater	Majority (2)	Slow but significant degradation (1)	Ongoing (3)	6	Medium
11.1	Habitat shifting and alteration	Majority (2)	Slow but significant degradation (1)	Ongoing (3)	6	Medium
1.1	Housing and urban areas	Minority (1)	Slow but significant degradation (1)	Ongoing (3)	5	Low
2.3	Livestock farming and ranching	Minority (1)	Slow but significant degradation (1)	Ongoing (3)	5	Low
5.2.2	Unintentional effects	Minority (1)	Slow but significant degradation (1)	Ongoing (3)	5	Low
9.3	Agricultural and forestry effluents	Minority (1)	Slow but significant degradation (1)	Ongoing (3)	5	Low
11.2	Droughts	Minority (1)	Slow but significant degradation (1)	Ongoing (3)	5	Low

Note: Threat codes and names follow the IUCN Threats Classification Scheme, Version 3.3 (IUCN 2022). The total impact score was calculated as the sum of the scope, severity, and timing scores. Impact classes were defined as High (8–9), Medium (6–7), Low (3–5), and Negligible or No impact (0–2). The numerical scores represent an adapted site-level prioritization index and should not be interpreted as formal IUCN Red List threat-impact scores.

other activities (6.3), and abstraction of surface water for agriculture (7.2.3). Six additional threats attained a score of 6: logging and wood harvesting (5.3), intentional use at a large scale (5.4.2), large dams (7.2.10), invasive and other problematic species and diseases (8.1), domestic and urban wastewater (9.1), and habitat shifting and alteration (11.1). These pressures act through land-use expansion, resource extraction, hydrological modification, biological disturbance, pollution, and habitat transformation. Although individually less influential than the High-impact threats, their cumulative and interacting effects may further reduce habitat integrity and ecological resilience.

Five threats attained a total score of 5 and were classified as Low impact: housing and urban areas (1.1), livestock farming and ranching (2.3), unintentional effects (5.2.2), agricultural and forestry effluents (9.3), and droughts (11.2). Their lower ranking reflects their comparatively limited spatial scope



Figure 13. Representative anthropogenic pressures affecting the Yozyovon Sand Massif: irrigated rice cultivation, intensive sand extraction, and road construction and associated substrate disturbance.

and lower estimated severity at the study-site scale. Nevertheless, these pressures may intensify ecosystem degradation when superimposed on habitats already affected by High- and Medium-impact drivers.

Overall, the adapted prioritization index identified agricultural conversion, hydrological modification, and direct physical modification of sandy substrates as the dominant pressures affecting the Yozyovon Sand Massif. The ranked threat pattern provides a transparent basis for interpreting habitat condition under IPA Criterion C and for directing conservation and management measures toward the most influential site-level pressures (Fig. 14).

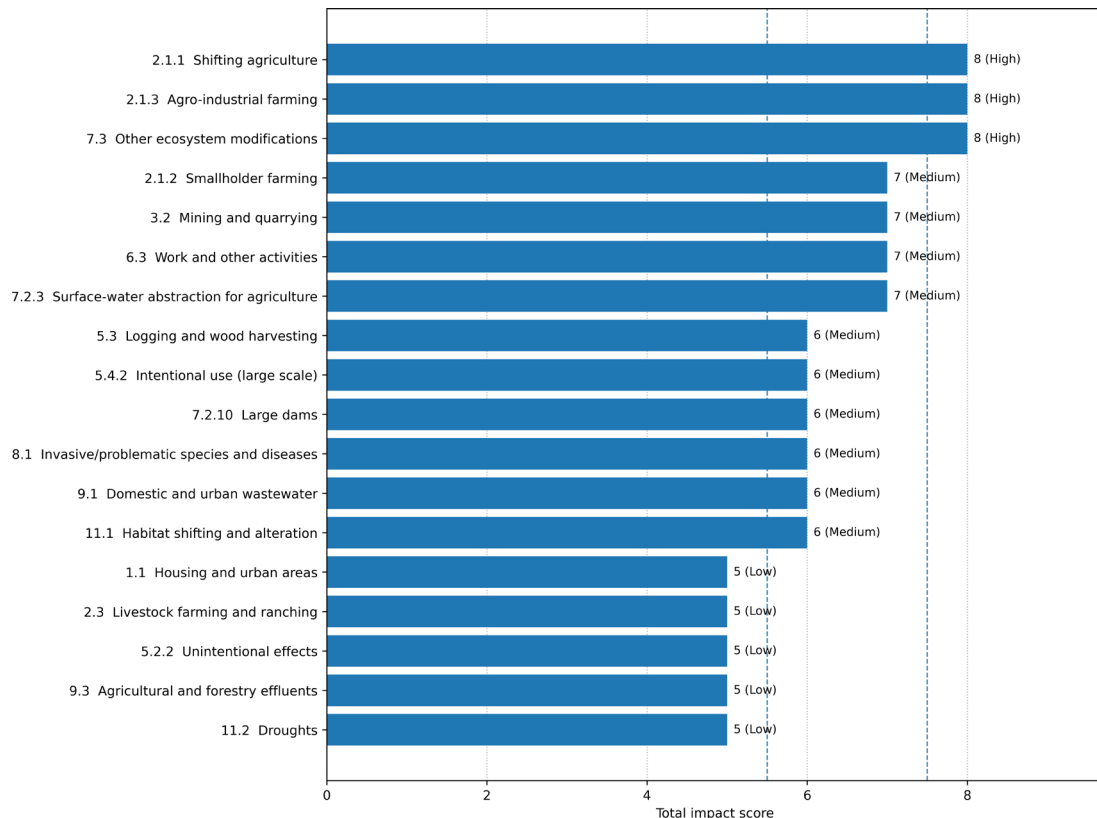


Figure 14. Ranked direct threats affecting the Yozyovon Sand Massif based on the adapted site-level threat-prioritization index. Total impact scores were calculated as the sum of scope, severity, and timing scores. Impact classes were defined as High (8–9), Medium (6–7), Low (3–5), and Negligible or No impact (0–2). Dashed vertical lines indicate the boundaries between the Low, Medium, and High impact classes.

Land-cover change results

Random Forest classification performance

The Random Forest models showed consistently high predictive performance across the four reference epochs. The selected Sand probability thresholds were 0.50 for 1991, 2000, and 2015 and 0.54 for 2025. Overall accuracy was 0.925 for 1991, 0.950 for 2000, 0.983 for 2015, and 0.975 for 2025, with corresponding Cohen's kappa values of 0.850, 0.900, 0.967, and 0.950. The 95% confidence intervals for overall accuracy were 0.862–0.965, 0.894–0.981, 0.941–0.998, and 0.929–0.995, respectively. Balanced accuracy ranged from 0.925 to 0.983, while out-of-bag Brier scores ranged from 0.0098 to 0.0747. Probability-based classification ambiguity was concentrated mainly along class boundaries and spectrally mixed surfaces. Complete confusion matrices, class-specific accuracy statistics, and year-specific ambiguity summaries are provided in the Suppl. material 1.

Long-term change in mapped sandy-habitat extent

The classifications revealed a pronounced long-term contraction of mapped sandy habitat. The Sand class covered 125.95 km², or 30.26% of the fixed study extent, in 1991; 109.61 km², or 26.33%, in 2000; 71.73 km², or 17.23%,

in 2015; and 54.79 km², or 13.16%, in 2025. Across the full 1991–2025 period, mapped Sand area decreased by 71.16 km², equivalent to a 56.50% reduction relative to its 1991 extent, while the aggregated Non-sand class increased from 290.30 to 361.46 km² (Table 7). The mapped Sand extent in 2025 provided the primary spatial basis for delineating the proposed 54.79 km² Yozyovon Sand Massif IPA.

Interval-specific changes are summarized in Table 7. Between 1991 and 2000, Sand area declined by 16.34 km², or 12.97%, corresponding to an annualized rate of $-1.82 \text{ km}^2 \text{ yr}^{-1}$. The largest absolute and annualized reduction occurred between 2000 and 2015, when Sand area decreased by 37.88 km², or 34.56%, at an annualized rate of $-2.53 \text{ km}^2 \text{ yr}^{-1}$. Between 2015 and 2025, a further reduction of 16.94 km², or 23.62%, was recorded, corresponding to $-1.69 \text{ km}^2 \text{ yr}^{-1}$. Sand extent therefore declined during every analyzed interval, although the magnitude and annualized rate of reduction varied through time. The four reference epochs do not support an interpretation of monotonically accelerating or decelerating decline.

Spatial pattern of sandy-habitat contraction

In 1991, mapped Sand surfaces occupied substantial but spatially discontinuous portions of the fixed study extent. By 2000, these surfaces had contracted further, while the 2015 and 2025 classifications showed progressively reduced extent and greater spatial discontinuity of the remaining sandy patches. By 2025, mapped Sand surfaces were largely restricted to smaller and more discontinuous remnants, whereas the aggregated Non-sand class dominated most of the study extent (Fig. 15).

Table 7. Mapped Sand and Non-sand areas and interval-specific changes within the fixed Yozyovon study extent based on Random Forest classification.

A. Mapped area and classification performance by reference epoch.						
Reference epoch	Sand area (km ²)	Sand (%)	Non-sand area (km ²)	Non-sand (%)	Classification threshold	Overall accuracy
1991	125.95	30.26	290.30	69.74	0.50	0.925
2000	109.61	26.33	306.64	73.67	0.50	0.950
2015	71.73	17.23	344.52	82.77	0.50	0.983
2025	54.79	13.16	361.46	86.84	0.54	0.975
B. Interval-specific change in mapped Sand area.						
Period	Absolute change (km ²)	Relative change (%)	Annualized change (km ² yr ⁻¹)			
1991–2000	–16.34	–12.97	–1.82			
2000–2015	–37.88	–34.56	–2.53			
2015–2025	–16.94	–23.62	–1.69			
1991–2025	–71.16	–56.50	–2.09			

Note: All area estimates refer to the same fixed 416.24 km² Yozyovon study extent. Areas were calculated using fractional pixel coverage along the study-extent boundary. Overall accuracy was calculated using held-out validation data. The mapped areas are direct map estimates and were not adjusted using a design-based area estimator. Complete confusion matrices, class-specific accuracy statistics, probability-based classification ambiguity summaries, and Landsat scene metadata are provided in the Suppl. material 1.

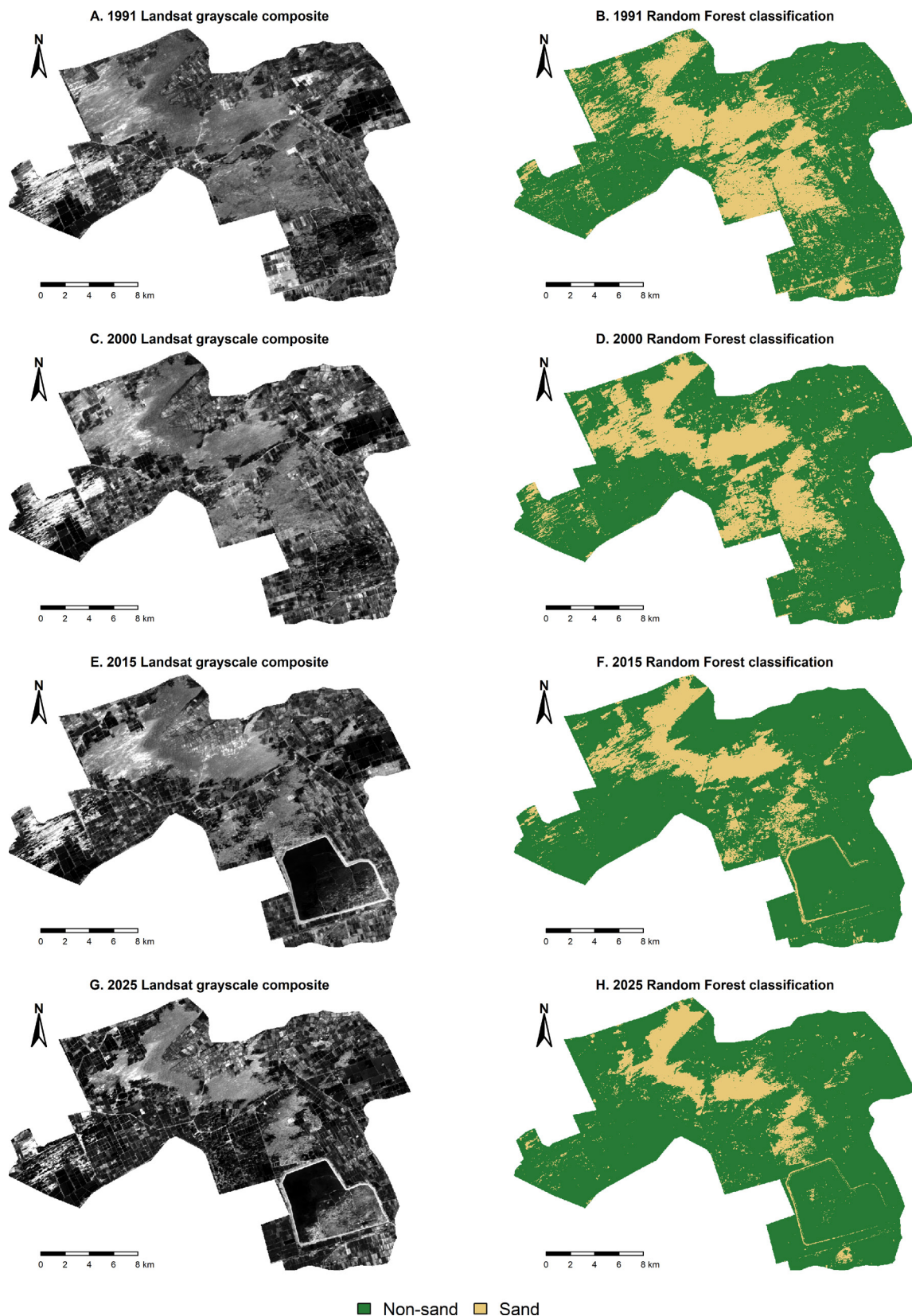


Figure 15. Landsat source imagery and corresponding Random Forest classifications of Sand and Non-sand surfaces within the fixed 416.24 km² Yozyovon study extent. **A, B.** 1991; **C, D.** 2000; **E, F.** 2015; and **G, H.** 2025. Left-hand panels show grayscale source imagery for visual reference, whereas right-hand panels show the corresponding 30-m binary classifications generated from the 14 predictors described in the Methods and evaluated using held-out, spatially separated reference samples.

The binary classification documents contraction of the Sand class and expansion of the aggregated Non-sand class but does not independently distinguish whether individual converted pixels became cultivated land, saline surfaces, settlements, roads, infrastructure, or another specific land-cover type. Interpretation of the drivers of sandy-habitat contraction therefore relies on convergence between the classified maps, field observations, and the separately conducted threat assessment rather than on direct multiclass transition attribution. Together, the magnitude of mapped Sand loss and the greater spatial discontinuity of the remaining sandy surfaces provide quantitative support for evaluating habitat condition under IPA Criterion C.

Discussion

Floristic and biogeographical significance of the Yozyovon sands

The Yozyovon sands represent one of the last remaining lowland psammophytic ecosystems in the FV and occupy a distinct biogeographical position within the Turanian Province of the Ancient Mediterranean Region and the broader Irano-Turanian floristic region (Kamelin 1973, 1990; Takhtajan 1986; Manafzadeh et al. 2017). In contrast to the majority of IPAs identified in Central Asia, which are predominantly associated with mountain systems and foothill belts, the Yozyovon sands are situated entirely within a lowland desert system. This setting confers exceptional scientific value, as it preserves floristic elements and ecological processes that are poorly represented in existing protected area networks and IPA portfolios across the region.

A comparative analysis of the three previously identified IPAs in the FV highlighted the complementary and non-redundant conservation value of the proposed Yozyovon Sand Massif IPA within the regional IPA framework. The Shorsuv Massif IPA, although sometimes broadly referred to as a “massif,” is phytogeographically confined to the adyr (foothill) zone and is characterized by variegated outcrops developed on Cretaceous and Paleogene sedimentary substrates. Its floristic distinctiveness is driven primarily by oreogypsophilous and lithophytic assemblages, a high proportion of microendemics, and relict taxa associated with ancient geological formations rather than by lowland desert processes (Tojibaev et al. 2025).

Similarly, the Ungor-Tepa–Bozbuto IPA represents a transboundary foothill system at the interface between the FV and the western Tian Shan, where the floristic composition is shaped by altitudinal climatic gradients, heterogeneous substrates, and transitional vegetation belts (Tojibaev et al. 2023). The Northern Fergana foothills and badland IPA are dominated by xerophytic and lithophytic communities adapted to eroded loess, clay, and rocky substrates under strong continental climatic conditions, supporting assemblages of drought-tolerant and disturbance-adapted taxa (Tojibaev et al. 2022b).

Against this background, the Yozyovon sands occupy a fundamentally different ecological and biogeographical niche, representing the last extensive remnant of lowland psammophytic ecosystems in Central Fergana. Unlike adyr-based variegated outcrops or rocky and loess-derived foothill systems, the Yozyovon sands are defined by mobile and semi-stabilized aeolian substrates that support highly specialized sand-dependent plant communities.

This distinctiveness underscores the need to incorporate psammophytic habitats into the regional IPA network to ensure comprehensive representation of FV floristic and ecological diversity.

The sandy geomorphology of the Yozyovon sands has facilitated the development of specialized psammophytic flora composed of narrowly adapted taxa, many of which exhibit limited dispersal capacity, patchy spatial distribution, and strong dependence on dune stability and groundwater dynamics. Consequently, the floristic assemblage of the Yozyovon sands includes numerous species that are absent or only marginally represented in mountain and foothill IPAs, reinforcing the site's distinct contribution to the regional conservation framework.

This ecological specialization is also reflected in the life-form spectrum of the flora. The pronounced dominance of therophytes reflects adaptation to seasonal aridity, unstable sandy substrates, and recurrent disturbance, which favor short-lived species capable of completing their life cycles during brief periods of favorable moisture availability (Sanjerehei 2019). Hemicryptophytes constitute the principal perennial herbaceous component of the flora. Chamaephytes and phanerophytes represent the low-shrub, shrub, and tree components of the vegetation and contribute to habitat structure and surface stabilization. In contrast, the very low proportion of cryptophytes may reflect the limited representation of species relying on below-ground renewal organs under the strongly arid edaphic conditions of the study area.

From a biogeographical perspective, the Yozyovon sands function as a relict lowland analog of desert-riverine landscapes that once occupied larger portions of the Fergana Depression following the retreat and reconfiguration of the Syr Darya. The persistence of psammophytic vegetation elements alongside species typically associated with tugai ecosystems reflects the long-term continuity of ecological conditions and is now increasingly rare in Central Asia. This unique combination of desert and riparian floristic elements within a sandy matrix highlights the biogeographical significance and ecological uniqueness of the site.

In the context of IPA Criterion A, the floristic importance of the Yozyovon sands was further enhanced by the concentration of threatened and regionally rare taxa characteristic of the Southern Turan subprovince. Mountain IPAs often derive their conservation value from high levels of narrow endemism linked to altitudinal isolation. The Yozyovon sands contribute a different but equally critical dimension: the preservation of lowland desert specialists that are disproportionately vulnerable to land-use change, irrigation expansion, and hydrological modification. This distinction is particularly relevant in Central Asia, where conservation priorities have historically focused on mountainous areas, resulting in a systematic underrepresentation of lowland desert ecosystems.

The dominance of psammophytic taxa provides strong ecological evidence for recognizing the Yozyovon Sand Massif as a habitat of high conservation value under IPA Criterion C. Simultaneously, the presence of numerous ecologically specialized and geographically restricted taxa established a critical foundation for conservation assessment under Criterion A.

Taken together, these comparisons demonstrate that the Yozyovon Sand Massif does not duplicate the conservation values of the three previously identified IPAs in the FV but instead fills a major ecological and biogeographical gap. Its proposed inclusion in the IPA network would enhance regional

representativeness by integrating lowland psammophytic ecosystems with mountain and foothill systems, thereby strengthening the coherence and completeness of regional plant-conservation strategies.

IPA Criteria A and C: methodological and regional reflection

The application of IPA Criteria A and C to the Yozyovon sands highlights both the flexibility and regional specificity required for effective plant conservation prioritization in Central Asian lowland ecosystems. While the IPA framework was originally developed with broad global applicability, its operationalization in arid continental landscapes demands careful consideration of the biogeographical context, data availability, and ecological characteristics of target habitats (Darbyshire et al. 2017; Kor and Diazgranados 2023).

Criterion A: significance of threatened and range-restricted taxa

Criterion A proved to be a robust and informative tool for identifying conservation values in the Yozyovon sands. The concentration of threatened and regionally rare taxa typical of the Southern Turan subprovince underscores the suitability of this criterion for lowland desert systems, where narrow endemism and habitat specialization are often driven by substrate specificity rather than altitudinal isolation. In contrast to mountain IPAs, where Criterion A frequently captures taxa restricted to high elevations or isolated ridges, the Yozyovon sands demonstrated that lowland psammophytic habitats can support equally irreplaceable plant assemblages that are highly sensitive to land-use change and hydrological modification.

While subcriteria A(i) and A(ii) rely primarily on formal global or national threat assessments, the application of subcriterion A(iv) requires explicit species-level justification because it captures regional conservation values that may not be adequately represented by global Red List categories. Many psammophytic taxa remain without published global IUCN assessments, while broad EOO values may obscure substantially smaller and fragmented areas of occupancy. The separate consideration of EOO and AOO is therefore particularly informative in arid landscapes where suitable sandy habitats are spatially discontinuous and rapidly declining.

Methodologically, the effectiveness of Criterion A was enhanced by integrating intensive field surveys, comprehensive herbarium verification, and grid-based spatial analyses. This approach reduced common biases associated with uneven sampling effort and taxonomic underrepresentation, which have been widely reported in IPA assessments that rely primarily on historical records or opportunistic data sources (Kor et al. 2024). Therefore, the identification of trigger species under Criterion A reflects not only their conservation status but also their ecological dependence on intact sandy habitats.

The case of *Calligonum elegans* illustrates the importance of reassessing historical range statements through contemporary field and herbarium evidence. The 2007 IUCN assessment described the species as restricted to the Sokh River basin, whereas three recent voucher collections document its contemporary occurrence in the sandy lowlands of Central Fergana. Of the three voucher-backed localities, Yozyovon lies within the proposed IPA and provides direct evidence

of the species' occurrence within the site. Haydarobod lies close to, but outside, the northern boundary of the proposed IPA, whereas *Gumxona* occurs farther outside the site; both records were used only to refine the broader range assessment. The occurrence of the species in sandy lowland habitats is consistent with regional identification literature, which records it both on exposures of variegated geological formations and on sands with shallow underlying bedrock. These data reconcile the earlier Sokh-based range interpretation with the use of *C. elegans* as an A(i) trigger species for the proposed Yozyovon Sand Massif IPA.

The role of Criterion A(iv) in arid and sandy ecosystems

In Central Asia, where arid and desert landscapes occupy extensive areas, the application of IPA Criterion A(iv) is particularly important for identifying conservation priorities that are insufficiently reflected in global Red List assessments. Although the sandy deserts of the Kyzylkum and Karakum and the Ustyurt Plateau are generally characterized by comparatively low overall species richness, they support a high degree of taxonomic differentiation, including numerous regionally restricted and habitat-specialized taxa.

For seven A(iv) taxa, the global EOO-based class was LC, whereas the substantially smaller AOO-based class was EN. This LC+EN pattern indicates that a geographically broad extent of occurrence may coexist with highly restricted and fragmented occupancy, particularly where suitable sandy habitats occur as isolated remnants. These study-derived global EOO/AOO range classes represent spatial conservation screening results and should not be interpreted as conservation categories formally published on the IUCN Red List. This pattern is especially pronounced in genera such as *Astragalus*, *Calligonum*, and *Limonium*, as well as within the family Amaranthaceae (Chenopodiaceae), which represents some of the most taxonomically prominent lineages in the contemporary flora of Central Asian deserts. However, global threat assessments often fail to capture the regional-scale vulnerabilities associated with habitat specificity and ongoing landscape transformation.

Central Asian deserts are increasingly affected by large-scale irrigation, infrastructure development, resource extraction, and climate-related aridification. Under such conditions, extinction risk is driven primarily by habitat degradation and fragmentation rather than by immediate, detectable population decline.

This pattern is well illustrated by several taxa recorded within the Yozyovon Sand Massif (Central Fergana Sands), including *Arnebia obovata*, *Artemisia ferganensis*, *Astragalus chodshenticus*, and *Calligonum × dubianskyi*. These species are ecologically confined to sandy substrates and exhibit restricted regional distributions within the Southern Turan subprovince. Despite their relatively broad global distributions, their populations are highly sensitive to sand stabilization, irrigation expansion, and land-use conversion, which disproportionately affect lowland sandy ecosystems.

Similarly, habitat-specialist taxa, such as *Astragalus ammodendron* and *Asparagus turkestanicus*, exemplify species for which regional extinction risk may increase substantially, even in the absence of a documented global population decline. Therefore, the inclusion of such taxa under IPA Criterion A(iv) provides an ecologically meaningful mechanism for recognizing conservation values linked to habitat specificity, regional rarity, and ecosystem-level vulnerability.

By incorporating species whose conservation significance emerges primarily at the regional and ecosystem scales, Criterion A(iv) ensures that IPA designation in arid landscapes reflects not only global threat categories but also the disproportionate sensitivity of sand-dependent flora to ongoing environmental change. This approach is particularly relevant for lowland desert systems where biodiversity loss is often gradual, spatially heterogeneous, and poorly captured by global-scale indicators.

Criterion C: threatened habitats and ecosystem integrity

Criterion C played a complementary role by capturing the conservation importance of the Yozyovon sands at the ecosystem level. Random forest classifications evaluated using held-out, spatially separated reference data showed that mapped Sand area within the fixed 416.24 km² study extent declined from 125.95 km² in 1991 to 54.79 km² in 2025, representing a 56.50% reduction. Sand extent declined during every analyzed interval, with the largest absolute and annualized reduction occurring between 2000 and 2015. Together with the greater spatial discontinuity visible in the classified maps, these results demonstrate a substantial loss of sandy-habitat extent and reduced spatial continuity, while field observations and threat-assessment results indicate continuing deterioration in habitat condition.

Methodologically, integrating validated land-cover classifications with floristic evidence and the adapted site-level threat-prioritization assessment extends the application of Criterion C beyond qualitative habitat description. Separate calibration and held-out validation samples, explicit accuracy assessment, probability-based classification thresholds, and classification ambiguity summaries provide a transparent basis for connecting mapped habitat contraction with plant conservation significance. The Yozyovon case therefore illustrates how Criterion C can reveal the conservation importance of declining lowland ecosystems that may be insufficiently represented when prioritization relies predominantly on species richness (Darbyshire et al. 2017; Kor and Diazgranados 2023).

Criterion B was considered during preliminary screening but was not used as a formal qualifying criterion. A robust application of this criterion would require standardized comparisons with ecologically equivalent sandy habitats at the national or regional scale (Darbyshire et al. 2017), and such comparative data were not available for the present assessment. Accordingly, this study makes no formal claim regarding qualification or non-qualification under Criterion B; the proposed IPA is supported through Criteria A and C. This emphasis is consistent with the ecological structure and biogeographical context of lowland sandy ecosystems in Central Asia, where conservation significance may be expressed primarily through habitat vulnerability, ecological distinctiveness, and the occurrence of regionally restricted species rather than through exceptional species richness alone.

Implications for IPA methodology in Central Asia

Taken together, the application of Criteria A and C to the Yozyovon Sand Massif underscores the importance of context-sensitive IPA assessments in Central Asia. Lowland desert and psammophytic ecosystems require assessment approaches that appropriately account for habitat specificity, threat sensitivity,

and ecological function alongside species-level conservation evidence. This case study demonstrates that IPA proposals in arid lowland landscapes can be supported by systematic field data, spatial analyses, and explicit consideration of regional biogeographical patterns.

Drivers of sand-ecosystem degradation

The degradation of the Yozyovon sand ecosystem is associated with an interconnected set of land-use and hydrological pressures, as indicated by convergence among the validated land-cover classifications, field observations, and the adapted site-level threat-prioritization assessment. The remote-sensing analysis demonstrates a substantial contraction of mapped Sand surfaces and a corresponding expansion of the aggregated Non-sand class. Because the classification is binary, however, it does not determine whether individual converted pixels became cultivated land, saline surfaces, settlements, roads, infrastructure, or another specific land-cover type. Interpretation of the drivers of mapped change therefore relies on convergence among complementary lines of evidence rather than on direct multiclass transition attribution.

The largest absolute and annualized reduction in mapped Sand area occurred between 2000 and 2015. This temporal pattern is consistent with agricultural and hydrological pressures documented during field surveys and ranked in the threat assessment, although it does not demonstrate that every converted pixel resulted directly from agricultural expansion. Irrigated agriculture, water abstraction and redistribution, secondary salinization, infrastructure development, sand extraction, road construction, and land leveling represent plausible and mutually reinforcing mechanisms contributing to sandy-habitat contraction and degradation (CEPF 2017; Volis and Beshko 2023; Volis 2024).

The threat-prioritization results indicate that agricultural conversion, hydrological modification, and direct physical alteration of sandy substrates are the principal site-level pressures. Agricultural expansion increases demand for irrigation water, while altered hydrological conditions may facilitate soil degradation and salinization. Sand extraction, construction, and land leveling further modify substrate structure and reduce the extent of suitable habitat. These pressures may also amplify the effects of lower-ranked drivers, including grazing, wood harvesting, wastewater, and drought.

Overall, integrating validated land-cover classifications with the adapted site-level threat-prioritization assessment provides a coherent interpretation of the observed decline in the Yozyovon sand ecosystem. The evidence supports continued contraction of mapped Sand surfaces during all analyzed intervals, with temporally variable rates and the highest annualized reduction during 2000–2015. It does not support a monotonically accelerating or decelerating trend.

Socioeconomic context and challenges for biodiversity conservation in Central Fergana

Biodiversity conservation in the Central Fergana lowlands is shaped by a complex socioeconomic context that constrains the effectiveness of conventional protection approaches. The FV represents one of the most densely populated

and intensively cultivated regions in Central Asia, where long-standing dependence on irrigated agriculture and the limited availability of undeveloped land generate persistent tensions between conservation objectives and local livelihoods (UN DESA 2015; CEPF 2017; Volis 2024). Within this setting, lowland sandy ecosystems are particularly vulnerable, as they are frequently perceived as marginal or underutilized landscapes suitable for agricultural conversion.

A central challenge arises from the dominance of irrigated agriculture as the primary economic driver. Large-scale irrigation schemes, originally developed to maximize agricultural output, continue to expand and intensify, exerting sustained pressure on remnant natural habitats (Volis and Beshko 2023; Volis 2024). Sandy areas are often targeted for land reclamation, crop production, and aquaculture because of their flat topography and proximity to irrigation infrastructure, thereby intensifying the High-impact pressures identified through the adapted site-level threat-prioritization analysis.

Water governance is an additional structural constraint on biodiversity conservation. Competition for surface and groundwater resources is particularly acute during the growing season, and water allocation policies consistently prioritize agricultural demand over ecosystem maintenance (CEPF 2017). In sandy landscapes, altered hydrological regimes accelerate soil salinization, destabilize the dune system, and reduce the resilience of psammophytic vegetation. These processes are rarely incorporated into regional land-use planning or environmental impact assessments, further amplifying ecosystem vulnerability.

Institutional- and policy-related challenges exacerbate these pressures. Existing protected area networks in the FV are predominantly oriented toward mountainous and foothill environments, reflecting historical conservation priorities and administrative feasibility rather than ecosystem representativeness (Tojibaev et al. 2022b, 2023, 2025; Kor and Diazgranados 2023). Consequently, lowland desert and sandy ecosystems remain largely outside formal protection frameworks and lack both legal recognition and dedicated management capacity.

Socioeconomic pressures are further compounded by limited awareness among local stakeholders regarding the ecological and evolutionary significance of psammophytic ecosystems. Sandy habitats are frequently regarded as degraded or transitional land rather than as repositories of specialized biodiversity and ecosystem functions, undermining public and institutional support for conservation initiatives (Darbyshire et al. 2017). Simultaneously, the strong economic dependence on agriculture limits the feasibility of strict protection models, underscoring the need for flexible, context-sensitive conservation strategies.

In this context, the IPA framework provides a pragmatic mechanism for reconciling scientific evidence with socioeconomic realities. By identifying sites of high plant conservation value without imposing immediate legal restrictions, IPA designation can support integrative conservation planning and facilitate dialogue among conservation practitioners, land managers, and policymakers (Darbyshire et al. 2017; Kor and Diazgranados 2023). Regarding the Yozyovon sands, this approach offers a realistic pathway for embedding biodiversity considerations within broader development and water management strategies rather than positioning conservation in direct opposition to local socioeconomic priorities.

Implications for the regional IPA network

The identification of the Yozyovon Sand Massif as a proposed IPA has important implications for the representativeness and coherence of the regional IPA network in the FV and, more broadly, across Central Asia. To date, IPA identification in the region has been concentrated mainly in foothill and mountainous landscapes, reflecting both the historical focus of botanical research and the prominence of narrow endemism associated with orographic isolation. The proposed inclusion of the Yozyovon Sand Massif would address a major representational gap by incorporating lowland psammophytic ecosystems into the regional conservation framework, thereby improving the ecological completeness and balance of the IPA network (Darbyshire et al. 2017; Kor and Diazgranados 2023).

From a network perspective, the Yozyovon sands contribute a distinct functional and biogeographical component that complements existing IPAs such as the Shorsuv, Ungor-tepa–Bozbuto, and the Northern Fergana foothills and badlands. Whereas these sites primarily capture floristic diversity shaped by adyr belts, heterogeneous lithological substrates, and altitudinal gradients, the Yozyovon sands represent a fundamentally different system governed by aeolian processes, groundwater dynamics, and substrate specialization. This ecological complementarity reduces redundancy within the regional IPA network and enhances its resilience by ensuring that conservation priorities are not disproportionately biased toward a single environmental zone.

The regional importance of the Yozyovon sands was further amplified by the rapid loss and fragmentation of sandy habitats across the Central Fergana lowlands. As lowland psammophytic systems become increasingly spatially discontinuous and degraded, the function of IPAs extends beyond identifying sites with high plant diversity to safeguarding ecological processes and habitat continuity at the landscape scale. In this context, the Yozyovon Sand Massif represents a strategic focal area within the lowland sand mosaic and, if formally recognized, could support coordinated conservation action, long-term monitoring, and restoration planning.

Crucially, the proposal of the Yozyovon Sand Massif as an IPA illustrates the applicability of the IPA framework beyond formally protected areas. In regions where strict protection is constrained by socioeconomic, demographic, or political factors, IPAs offer a flexible, evidence-based mechanism for integrating plant conservation priorities into land-use planning, water management, and agricultural policy without imposing immediate legal restrictions (Darbyshire et al. 2017; Kor and Diazgranados 2023). This function is particularly relevant in Central Asia, where competing land-use demands and limited institutional capacities often restrict the expansion of conventional protected area networks.

On a broader spatial scale, the proposed inclusion of the Yozyovon Sand Massif in the regional IPA network underscores the importance of adopting a landscape-oriented, transboundary perspective in IPA development. The FV spans multiple national jurisdictions, yet its ecological systems operate as an integrated whole. Incorporating lowland IPAs into regional conservation strategies creates opportunities for cross-border dialogue, harmonized monitoring approaches, and coordinated prioritization of threatened habitats, while also aligning plant conservation objectives with complementary frameworks such as KBAs and national biodiversity strategies.

Overall, the proposed inclusion of the Yozyovon Sand Massif in the regional IPA network would elevate the conservation profile of lowland sand ecosystems and provide a methodological precedent for future IPA assessments in arid, densely populated, and highly transformed landscapes. By broadening the ecological scope of IPA networks and aligning them more closely with regional conservation challenges, this case study contributes to the continuing development of IPA practices in Central Asia.

Limitations and future research directions

Several limitations should be considered when interpreting the results. First, although the floristic inventory was based on repeated multi-year surveys and extensive herbarium verification, the detectability of short-lived and ephemeral species remains sensitive to interannual precipitation and phenological variation. Some taxa may therefore have been under-recorded during climatically unfavorable seasons. Continued multi-season monitoring under a broader range of climatic conditions would improve estimates of species persistence, population dynamics, and temporal turnover.

Second, the habitat-change assessment relied on 30-m Landsat imagery and four selected reference epochs rather than a continuous annual time series. This design supports consistent multidecadal comparison but may overlook short-term fluctuations and fine-scale changes in dune morphology, vegetation structure, and soil condition. Temporal replication was also lower for 1991, which was represented by a single quality-masked Landsat 5 TM scene, than for 2000, 2015, and 2025, which were represented by median composites. The binary Sand/Non-sand classification was selected to maximize class separability and validation reliability, but it does not distinguish individual Non-sand transitions such as cultivation, salinization, settlement, road construction, or other infrastructure development.

Third, probability-based classification ambiguity summary statistics were calculated for each epoch. However, the class-balanced held-out validation sample was designed primarily for classification-accuracy assessment rather than design-based area estimation. Consequently, the mapped-area values are direct map estimates; they were not adjusted using a design-based estimator, and statistically valid error-adjusted area confidence intervals could not be derived retrospectively from the present sampling design (Olofsson et al. 2014). Future remote-sensing analyses should incorporate denser temporal observations, higher-resolution satellite or UAV imagery, multiclass transition mapping, probability-based area-estimation samples, and statistically adjusted area estimates with confidence intervals.

Finally, the interpretation of degradation drivers was based on field observations, mapped land-use evidence, published information, and the adapted site-level threat-prioritization assessment. The absence of spatially explicit data on land tenure, irrigation intensity, water allocation, and livelihood dependence limits quantitative attribution of mapped habitat change to individual socioeconomic processes. Criterion B was not applied as a formal qualifying criterion because standardized comparative data for ecologically equivalent sandy habitats were unavailable at the national or regional scale (Darbyshire et al. 2017). Future interdisciplinary work should therefore integrate ecological,

hydrological, socioeconomic, and governance data, reassess Criterion B when suitable comparative datasets become available, and examine population genetics, functional traits, and restoration responses of habitat-specialist taxa.

Conclusion

By integrating repeated field surveys, herbarium-based taxonomic verification, assessment under IPA Criterion A, an adapted site-level threat-prioritization framework, and Random Forest classifications evaluated using held-out, spatially separated reference data, this study documented both the species- and ecosystem-level conservation values of the Yozyovon Sand Massif. Fourteen vascular plant taxa were identified as Criterion A trigger species, while the floristic, habitat, and land-cover evidence provided complementary support for the site's conservation importance under Criterion C.

Within the fixed 416.24 km² study extent, mapped Sand area declined from 125.95 km² in 1991 to 54.79 km² in 2025, corresponding to an absolute reduction of 71.16 km² and a relative reduction of 56.50%. The remaining 54.79 km² of mapped sandy habitat formed the primary spatial basis for the proposed IPA boundary. Sand extent declined during every analyzed interval, with the largest absolute and annualized reduction occurring between 2000 and 2015. Convergence among the land-cover classifications, field observations, and threat-prioritization results indicates that irrigated agriculture, hydrological modification, and direct substrate disturbance are the principal pressures associated with the continuing degradation of the remaining psammophytic habitat.

The combined evidence supports proposing the Yozyovon Sand Massif as an IPA under Criteria A and C. If formally recognized, it would represent the fourth IPA identified in the FV and would address an important ecological and biogeographical gap by incorporating a severely degraded and regionally significant lowland sand ecosystem into the regional IPA network. Formal recognition, long-term monitoring, habitat restoration, and the integration of plant-conservation priorities into land-use and water-management planning would provide a practical basis for limiting further habitat loss and ecosystem degradation. Further assessment of adjacent lowland and riverine ecosystems would contribute to the development of a more representative and coherent IPA network across the FV.

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References

- Adylov TA (1983) Conspectus florae Asiae mediae. Vol. 7. Institutum Botanicum Academiae Scientiarum USSR, Tashkent, 414 pp. [In Russian]
- Adylov TA (1987) Conspectus florae Asiae mediae. Vol. 9. Institutum Botanicum Academiae Scientiarum USSR, Tashkent, 24–36. [In Russian]

- Adylov TA, Zuckerwanik TI (1993) *Conspectus florum Asiae mediae*. Vol. 10. Institutum Botanicum Academiae Scientiarum Reipublicae Uzbekistan, Tashkent, 692 pp. [In Russian]
- Akhani H, Edwards G, Roalson EH (2007) Diversification of the Old World *Salsola* s.l. (Chenopodiaceae): Molecular phylogenetic analysis of nuclear and chloroplast data sets and a revised classification. *International Journal of Plant Sciences* 168: 931–956. <https://doi.org/10.1086/518263>
- Anderson S (2002) Identifying Important Plant Areas: A Site Selection Manual for Europe and a basis for developing guidelines for other regions of the world. Plant Life International, London, 52 pp.
- Arifkhanova MM (1967) The vegetation of the Fergana Valley. FAN, Tashkent. [In Russian]
- Bachman S, Moat J, Hill AW, de la Torre J, Scott B (2011) Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool. *ZooKeys* 150: 117–126. <https://doi.org/10.3897/zookeys.150.2109>
- BirdLife DataZone (2025) Threat Definitions and Coding Guidelines. <https://datazone.birdlife.org>
- Blasi C, Marignani M, Copiz R, Fipaldini M (2009) Mapping the important plant areas in Italy. In *Mapping the Important Plant Areas in Italy*. Ministero Dell'ambiente E Della Tutela Del Territorio E Del Mare, 1–32.
- Blasi C, Marignani M, Copiz R, Fipaldini M, Bonacquisti S, Del Vico E, Rosati L, Zavattero L (2011) Important Plant Areas in Italy: from data to mapping. *Biological Conservation* 144: 220–226. <https://doi.org/10.1016/j.biocon.2010.08.019>
- Bondarenko N, Nabiev MM (1972) *Conspectus florum Asiae mediae*. Vol. 3. Institutum Botanicum Academiae Scientiarum Reipublicae Uzbekistan, Tashkent, 264 pp. [In Russian]
- Breiman L (2001) Random Forests. *Machine Learning* 45: 5–32. <https://doi.org/10.1023/A:1010933404324>
- CBD (2022) Kunming-Montreal Global Biodiversity Framework. Convention on Biological Diversity.
- CEPF (2017) Mountains of Central Asia Biodiversity Hotspot. Draft for Submission to the CEPF Donor Council, 184 pp. <https://www.cepfnetwork.org/our-work/biodiversity-hotspots/mountains-central-asia>
- Darbyshire I, Anderson S, Asatryan A, Byfield A, Cheek M, Clubbe C, Ghrabi Z, Harris T, Heatubun CD, Kalema J, Magassouba S (2017) Important Plant Areas: revised selection criteria for a global approach to plant conservation. *Biodiversity and Conservation* 26: 1767–1800. <https://doi.org/10.1007/s10531-017-1336-6>
- Drobow VP (1953) *Calligonum* L. In: Vvedensky AI (Ed.) *Flora of Uzbekistan*. Vol. 2. Academy of Sciences of the Uzbek SSR, Tashkent, 137–143. [In Russian]
- IPNI [International Plant Names Index] (2025) Royal Botanic Gardens, Kew; Harvard University Herbaria; Australian National Herbarium. <http://www.ipni.org>
- IUCN (2012) Guidelines for Using the IUCN Red List Categories and Criteria. Version 3.1. IUCN, Netherlands, and Cambridge. <https://www.iucnredlist.org/resources/categories-and-criteria>
- IUCN (2022) Threat Classification Scheme. Version 3.3. IUCN, Gland. <https://www.iucnredlist.org/resources/threat-classification-scheme>
- IUCN (2025) IUCN Red List of Threatened Species. <https://www.iucnredlist.org/>
- Jin G, Li W, Song F, Yang L, Wen Z, Feng Y (2023) Comparative analysis of complete *Artemisia* subgenus *Seriphidium* chloroplast genomes. *BMC Plant Biology* 23: 136. <https://doi.org/10.1186/s12870-023-04113-1>
- Kamelin RV (1965) Generic endemism of the flora of Middle Asia. *Botanicheskii Zhurnal* 50: 1702–1710.

- Kamelin RV (1973) Florogenetic analysis of the native flora of mountainous Middle Asia. Nauka, Leningrad.
- Kamelin RV (1981) *Astragalus* L. sect. *Xiphidium* Bunge. Conspectus Florae Asiae Mediae, vol. 6. Tashkent, 193–212. [In Russian]
- Kamelin RV (1990) Flora of the Syrdarya Karatau. Science Publishers, Leningrad, 184 pp. [In Russian]
- Khassanov F (2015) Conspectus florae Asiae mediae. Vol. 11. Fan, Tashkent, 222 pp. [In Russian]
- Kor L, Diazgranados M (2023) Identifying Important Plant Areas for useful plant species in Colombia. Biological Conservation. <https://doi.org/10.1016/j.biocon.2023.110187>
- Kor L, Perez F, Inwood K, Darbyshire I, Diazgranados M (2024) An evaluation of Important Plant Areas around the world. Conservation Biology. <https://doi.org/10.1111/cobi.70013>
- Korovin EP (1961) Vegetation of Central Asia and Southern Kazakhstan. Vol. 1. Tashkent: Academy of Sciences, 452 pp. [In Russian]
- Kovalevskaya (1968) Conspectus florae Asiae mediae. Vol. 1. Institutum Botanicum Academiae Scientiarum Reipublicae Uzbekistan, Tashkent, 223 pp. [In Russian]
- Kovalevskaya (1971) Conspectus florae Asiae mediae. Vol. 2. Institutum Botanicum Academiae Scientiarum Reipublicae Uzbekistan, Tashkent, 360 pp. [In Russian]
- Kudryashev SN (1941) Flora of Uzbekistan. Academy of Sciences of the USSR, Tashkent.
- Li W, Tojibaev KS (2024) Checklist of vascular plants in Central Asia. EDP Sciences, Les Ulis. <https://doi.org/10.1051/978-2-7598-3669-7>
- Li W, Tojibaev KS (2025) Checklist of Vascular Plants in Central Asia. Science Press, Beijing, 304 pp. <https://doi.org/10.1051/978-2-7598-3669-7>
- Li W, Tojibaev KS, Hisoriev H, Shomurodov KhF, Luo M, Feng Y, Ma K (2020) Mapping Asia Plants: Current status of floristic information for Central Asian flora. Global Ecology and Conservation 24: e01220. <https://doi.org/10.1016/j.gecco.2020.e01220>
- Lledó MD, Karis PO, Crespo MB, Fay MF, Chase MW (2011) Endemism and evolution in *Limonium*. In: Bramwell D, Caujapé-Castells J (Eds) The Biology of Island Floras. Cambridge University Press, Cambridge, 325–337. <https://doi.org/10.1017/CBO9780511844270.014>
- Manafzadeh S, Staedler YM, Conti E (2017) Visions of the past and dreams of the future in the Irano-Turanian region. Biological Reviews 92: 1365–1388. <https://doi.org/10.1111/brv.12291>
- Nazarov RA, Abduraupov TV, Shepelya EY, Gritsina MA, Melnikov DA, Buehler MD, Lapin JD, Poyarkov NA, Grismer JL (2023) The Fergana Valley is an isolate of biodiversity. Animals 13: 2516. <https://doi.org/10.3390/ani13152516>
- Nowak A, Świercz S, Nowak S, Plášek V, Nobis A, Klichowska E, Nobis M (2022) Diversity and classification of chasmophytic vegetation in Central Asia. Acta Societatis Botanicorum Poloniae.
- Olofsson P, Foody GM, Herold M, Stehman SV, Woodcock CE, Wulder MA (2014) Good practices for estimating area and assessing accuracy of land change. Remote Sensing of Environment 148: 42–57. <https://doi.org/10.1016/j.rse.2014.02.015>
- Ondo I, Dhanjal Adams KL, Pironon S, Silvestro D, Colli Silva M, Deklerck V, Grace OM, Monro AK, Nicolson N, Walker B, Antonelli A (2024) Plant diversity darkspots for global collection priorities. New Phytologist. <https://doi.org/10.1111/nph.20024>
- Pachomova MG (1974) Conspectus Florae Asiae Mediae. Vol. 5. Tashkent, 270 pp. [In Russian]

- Pachomova MG (1976) *Crataegus* L. Conspectus Florae Asiae Mediae. Vol. 5. Tashkent, 149–166. [In Russian]
- Participants of the FFI/IUCN SSC Central Asian Regional Tree Red Listing Workshop (2007) *Calligonum elegans*. The IUCN Red List of Threatened Species 2007: e. T63466A12665527. <https://doi.org/10.2305/IUCN.UK.2007.RLTS.T63466A12665527.en> [Accessed 1 August 2026]
- POWO (2025) Plants of the World Online. Royal Botanic Gardens, Kew. <https://powo.science.kew.org>
- Pratov UP (1970) Chenopodia of the Fergana Valley. FAN, Tashkent.
- Raunkiaer C (1934) The Life Forms of Plants and Statistical Plant Geography. Oxford, 632 pp.
- Red Data Book of the Republic of Uzbekistan (2019) Plants. Chinor ENK, Tashkent, Vol. 1, 356 pp.
- Salvo G, Manafzadeh S, Ghahremaninejad F, Tojibaev KS, Zeltner L, Conti E (2011) Phylogeny, morphology, and biogeography of *Haplophyllum* (Rutaceae), a species-rich genus of the Irano-Turanian floristic region. *Taxon* 60(2): 513–527. <https://doi.org/10.1002/tax.602018>
- Sanjerehei MM (2019) Life forms of plant species and floristic regions in Iran. Tafakkor Talaei, Tehran, 154 pp.
- Sennikov AN [Ed.] (2017) Flora of Uzbekistan. Vol. 1. Navro'z Publishers, Tashkent, xxviii + 173 pp. [In Russian]
- Sennikov AN [Ed.] (2018) Flora of Uzbekistan. Vol. 2. Navro'z Publishers, Tashkent, xii + 200 pp. [In Russian]
- Sennikov AN [Ed.] (2019) Flora of Uzbekistan. Vol. 3. Ma'naviyat Publishers, Tashkent, xii + 201. [In Russian]
- Sennikov AN [Ed.] (2022) Flora of Uzbekistan. Vol. 4. AS RUz "Fan" Publishers, Tashkent, xviii + 238 pp. [In Russian]
- Sennikov AN [Ed.] (2023a) Flora of Uzbekistan. Vol. 5. AS RUz "Fan" Publishers, Tashkent, xiv + 469 pp. [In Russian]
- Sennikov AN [Ed.] (2023b) Flora of Uzbekistan. Vol. 6. Ma'naviyat Publishers, Tashkent, xiv + 209. [In Russian]
- Soskov YD (2011) The Genus *Calligonum* L. Vavilov Institute of Plant Industry, Novosibirsk. [In Russian]
- Sukhorukov AP (2015) Carpology of the Chenopodiaceae family. Doctoral dissertation, Moscow.
- Takhtajan A (1986) Floristic Regions of the World. University of California Press, Berkeley, 522 pp.
- Thiers B (2026) [constantly updated] Index Herbariorum: a global directory of public herbaria and associated staff. <http://sciweb.nybg.org/science2/Indexherbariorum.asp> [Accessed 21 February 2026]
- Tojibaev KS, Karimov FI, Oh BU, Oh SH, Jang CG (2018) Geophytes of the Fergana Valley. *Journal of Asia-Pacific Biodiversity* 11: 431–441. <https://doi.org/10.1016/j.japb.2018.06.003>
- Tojibaev KS, Khassanov FO, Turginov O, Akbarov F, Pulatov S, Turdiboev O (2022a) Endemic plant species richness of Surkhondaryo province, Uzbekistan. *Plant Diversity of Central Asia* 1: 71–84. https://doi.org/10.54981/PDCA/vol1_iss1/a4
- Tojibaev KS, Karimov FI, Hoshimov HR, Jang CG, Na NR, Park MS, Chang KS, Gil HY, Baasanmunkh S, Choi HJ (2022b) Important Plant Areas in the Fergana Valley: badlands

- of the northern foothills. *Nature Conservation* 49: 1–30. <https://doi.org/10.3897/natureconservation.49.84834>
- Tojibaev KS, Karimov FI, Hoshimov HR, Gulomov R, Lazkov GA, Jang CG, Gil HY, Jang JE, Batoshov AR, Iskandarov A, Choi HJ (2023) Important Plant Areas in the Fergana Valley: Bozbu-Too–Ungortepa massif. *Nature Conservation* 51: 13–70. <https://doi.org/10.3897/natureconservation.51.94477>
- Tojibaev KS, Hoshimov HR, Gulomov RR, Sheraliev OK, Karimov FI, Kor L, Batoshov AR, Baasanmunkh S, Jang JE, Jung J, Gil HY, Choi HJ (2025) Conservation priorities in Central Asia: the Shorsuv Massif IPA. *Frontiers in Conservation Science* 6: 1629529. <https://doi.org/10.3389/fcosc.2025.1629529>
- Tojibaev KSh, Beshko NYu, Popov VA (2016) Botanical-geographical regionalization of Uzbekistan. *Botanicheskii Zhurnal* 101(10): 1105–1132. [In Russian]
- Townsend CC (1986) Taxonomic revision of the genus *Haplophyllum* (Rutaceae). In: Hooker's icones plantarum, vol. 40, parts 1–3. Kent, U.K.: Bentham-Moxon Trust.
- UN DESA (2015) World Population Prospects. United Nations Department of Economic and Social Affairs. <https://www.un.org/en/development/desa/news/2015.html>
- U.S. Geological Survey (2021) Landsat Collection 2 Level-2 Science Products. U.S. Geological Survey Fact Sheet 2021–3055, 2 pp. <https://doi.org/10.3133/fs20213055>
- Volis S (2024) Conservation-oriented Restoration in Central Asia. *Plant Diversity of Central Asia* 3: 144–157.
- Volis S, Beshko N (2023) How to preserve narrow endemics in view of climate change? The Nuratau Mountains as the case. *Plant Diversity of Central Asia* 2(2): 82–101. https://doi.org/10.54981/PDCA/vol2_iss2/a3
- Vvedensky AI [Ed.] (1953) Flora of Uzbekistan. Vol. 2. Academy of Sciences of the Uzbek SSR, Tashkent, 549 pp. [In Russian]
- Vvedensky AI [Ed.] (1962) Flora of Uzbekistan. Vol. 6. Academy of Sciences of the Uzbek SSR, Tashkent, 631 pp. [In Russian]
- Wilson B, Dolotbakov A, Burgess BJ, Clubbe C, Lazkov GA, Shalpykov K, Ganybaeva M, Sultangaziev O, Brockington SF (2021) Central Asian wild tulip conservation. *Biodiversity and Conservation* 30: 1705–1730. <https://doi.org/10.1007/s10531-021-02165-z>
- Wright MN, Ziegler A (2017) ranger: A fast implementation of random forests for high dimensional data in C++ and R. *Journal of Statistical Software* 77(1): 1–17. <https://doi.org/10.18637/jss.v077.i01>
- Xu D, Wang Y, Wang J (2024) A review of social-ecological system vulnerability in desertified regions: assessment, simulation, and sustainable management. *Sci. Total Environ* 931: 172604. <https://doi.org/10.1016/j.scitotenv.2024.172604>

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

Field surveys and minimal-impact voucher sampling were conducted in accordance with the national legislation of the Republic of Uzbekistan under Contract No. 4/2023 of 3 July 2023 between the Ministry of Ecology, Environmental Protection and Climate Change and the Institute of Botany, Academy of Sciences of Uzbekistan. For *Calligonum elegans*, only one small branch was collected from each sampled mature shrub for taxonomic verification and deposition at the National Herbarium of Uzbekistan (TASH); no whole individuals were removed or visibly damaged.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.

No AI tools were used in the preparation of this manuscript.

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Author contributions

Komiljon Sh. Tojibaev: Writing—original draft, Investigation, Validation, Data curation, Review and editing. Hushbaht R. Hoshimov: Investigation, Validation, Map preparation, Formal analysis. Ilyosbek K. Sharipov: Investigation, Validation. Feruz I. Akbarov: Methodology, Software, Formal analysis. Shukhrat S. Abdullaev: Investigation, Formal analysis. Avazbek R.

Batoshov: Validation, Data curation, Formal analysis. Farkhod I. Karimov: Formal analysis, Writing—review and editing. Davron B. Dekhkonov: Formal analysis, Review and editing. Laura Kor: Formal analysis, Review and editing. Shukherdorj Baasanmunkh: Formal analysis, Review and editing. Hee-Young Gil: Conceptualization, Review and editing. Ami Oh: Formal analysis, Review and editing. Hyeok Jae Choi: Conceptualization, Supervision, Investigation, Formal analysis.

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Data availability

Floristic occurrence data, species lists, and threat-prioritization matrices supporting the findings of this study are provided in the article and its Supplementary material. The Supplementary material also includes land-cover area summaries, interval-specific change estimates, classification thresholds, validation statistics, confusion matrices, model diagnostics, variable-importance results, and Landsat scene metadata. The herbarium specimens collected during the study were deposited at the National Herbarium of Uzbekistan (TASH). Additional spatial outputs supporting the remote-sensing analysis are available from the corresponding author upon reasonable request.

Supplementary material 1

Additional information

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Data type: xlsx

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