ABS ACTA BIOLOGICA SIBIRICA
A journal on the biodiversity of Siberia and the adjacent lands

Acta Biologica Sibirica 12: 1207–1222 (2026)
doi: 10.5281/zenodo.22822900
http://journal.asu.ru

RESEARCH ARTICLE

Status and ontogenetic structure of *Codonopsis bactriana* (Campanulaceae) in southwestern Uzbekistan

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Academic editor: R. Yakovlev | Received 3 August 2026 | Accepted 2 September 2026 | Published 20 September 2026

http://zoobank.org/E4D3194C-48E9-48E2-B9E7-E406DBC25B2F

Citation: Mavlanov BJ, Sirojidinov BA, Maxmudov V, Murodov SA, Maxmudov AV, Abduraimov OS (2026) Status and ontogenetic structure of *Codonopsis bactriana* (Campanulaceae) in southwestern Uzbekistan. Acta Biologica Sibirica 12: 1207–1222. https://doi.org/10.5281/zenodo.22822900

Abstract

Codonopsis bactriana F.O. Khass., U. Kodyrov & A. Myrz. is a rare endemic medicinal species distributed in the mountainous regions of southwestern Uzbekistan. The present study aimed to assess the current status and ontogenetic structure of natural populations of *C. bactriana* under different ecological and phytocoenotic conditions. Field investigations were conducted during 2023–2025 in the Surkhandarya and Kashkadarya regions, where eight cenopopulations were identified and analyzed. The ontogenetic structure was studied according to discrete ontogenetic stages, and population dynamics were evaluated using demographic indices and the Δ–ω classification. The results revealed four types of ontogenetic spectra: left-skewed (CP3, CP7), centered (CP1, CP5, CP8), bimodal (CP6), and right-skewed (CP2, CP4). Most cenopopulations exhibited unimodal, centered spectra with a peak at middle-aged generative individuals, indicating relatively stable population dynamics. Population density ranged from 0.8 to 2.7 individuals/m², while ecological density varied from 0.94 to 3.17 individuals/m². Recovery index values exceeding unity in most cenopopulations suggest effective seed regeneration, whereas relatively high aging indices in several populations indicate increasing aging trends. According to the Δ–ω classification, the studied cenopopulations were categorized as young (CP3, CP6, CP7), transitional (CP8), mature (CP5), maturing (CP1), and old (CP2, CP4). The main factors influencing population structure included unsystematic harvesting by local populations, grazing pressure, and geological exploration activities. These findings provide important insights into the population status, regeneration potential, and conservation requirements of *Codonopsis bactriana* in southwestern Uzbekistan.

Keywords
Codonopsis bactriana, endemic species, medicinal plant, cenopopulation, ontogenetic structure, population dynamics, southwestern Uzbekistan

Introduction

Medicinal plants constitute an essential component of global biodiversity and play a significant role in modern pharmacology, traditional medicine, and the sustainable use of biological resources (Shomurodov et al. 2024). In recent decades, the growing demand for medicinal plants, combined with large-scale ecosystem transformation and climate change, has led to a substantial decline in natural populations of many species. It has been estimated that anthropogenic activities have caused the degradation or complete loss of natural habitats for nearly 40% of plant species worldwide, resulting in significant population reductions (Newbold 2015; Maxmudov et al. 2025). Under these conditions, assessing the current state of medicinal plant populations, particularly through the analysis of their ontogenetic structure, is of considerable scientific importance for evaluating population stability and developing strategies for sustainable resource use (Moran 2016).

Protected areas are widely recognized as one of the most effective tools for conserving medicinal plant diversity. These territories ensure relatively stable ecological conditions for rare, endemic, and economically valuable species while reducing anthropogenic pressure on natural populations (Dudley 2008; McNeely 2020). However, ongoing climate change has resulted in shifts in species distribution ranges, causing some medicinal plant populations to occur outside protected areas. Consequently, such populations become more vulnerable to anthropogenic disturbances and environmental stressors, which negatively affects their long-term stability (Jenkins 2013; Du 2023).

Central Asia, particularly the Pamir-Alai mountain system, represents one of the most important centers of medicinal plant diversity. The complex relief, altitudinal zonation, and heterogeneous climatic conditions of this region have promoted the formation of numerous endemic and narrow-range medicinal plant species. Therefore, the mountains of Central Asia have been recognized as one of the global biodiversity hotspots (Mittermeier 2005) and identified as a priority region for biodiversity conservation and further scientific investigation (Giam et al. 2010; Nowak and Nobis 2010).

Among the medicinal plant groups occurring in the Pamir-Alai region, the genus *Codonopsis* Wall. (Campanulaceae Juss.) is of particular interest. This genus is mainly distributed across Central, East, and South Asia and currently includes approximately 42–49 species (Jing-Yu He et al. 2015; Dong et al. 2023; Plants of the World Online). Phytochemical studies have revealed that Codonopsis species contain a wide range of biologically active compounds, including alkaloids, flavonoids, saponins, triterpenoids, and polyacetylenes, which determine their high pharmacological potential (He et al. 2004; Yuan and Liang 2006). Consequently, representatives of the genus are widely used in traditional Asian medicine. In particular, *Codonopsis pilosula* is widely utilized under the name "Codonopsis radix" and is included in more than 110 medicinal formulations, serving as an important pharmaceutical raw material in China, Korea, and Japan (Gao et al. 2018; Yang et al. 2019).

In the flora of Uzbekistan, the genus *Codonopsis* is represented mainly by two species, *C. clematidea* and *C. bactriana*, which occur in the Tien Shan and Pamir-Alai mountain systems. *Codonopsis clematidea* is widely used in traditional medicine, particularly for the treatment of hepatitis, malaria, and digestive disorders (Khojimatov 2023; Ahmad et al. 2006; Sher et al. 2016). In contrast, *Codonopsis bactriana* was relatively recently described as an independent species, and its medicinal potential, population structure, and ecological characteristics remain poorly studied (Khassanov et al. 2018; Sennikov 2017). The endemic and narrow distribution of *C. bactriana*, along with its potential medicinal value, necessitates a comprehensive investigation of its natural populations. In particular, the analysis of ontogenetic structure provides important insights into population stability and resource potential.

Therefore, the aim of this study is to assess the current state of populations of the endemic species *C. bactriana* distributed in southern Uzbekistan by analyzing their ontogenetic structure.

Materials and methods

The research objects

C. bactriana – roots tuber-shaped, 10-30 cm long, 10-30 cm wide. Stems single or numerous, erect or ascending, slightly procumbent, 50-100 cm high; branches slender, erect or slightly spreading, mostly at lower part but those at the upper pat usually fertile, when young. Leaves on main stems smaller and alternate, those on branches opposite; petiole up to 2.5 cm long, sparsely hispidulous, blade ovate, oblong, broadly lanceolate, or lanceolate, 1-3.5 (-5.2) x 0.8-2(-3.2) cm, abaxially densely hispidulous, adaxially sparsely or densely hispidulous, base slightly cordate or rounded, margin entire or occasionally crenulate or sinuate, apex acute. Flowers solitary, terminal on main stems and branches, long pedicellate; pedicels sparsely white hispidulous. Calyx tube adnate to ovary up to middle, hemispheric, glabrous or rarely sparsely white downy, ovate, elliptic, or lanceolate, 10-15 x 6-8 mm, glabrous or apex sparsely puberulent, margin entire, apex acute. Corolla pale blue with dark blue veins and purple spots inside, broadly campanulate, 1.7-2.6 cm long., glabrous. Stamens glabrous; filaments slightly dilated at base, 5-6 mm long; anthers oblong, 5-6 mm long. Capsule semiglobose below, conical above, rostrum acute, 15-20 x 12-15 mm in total; persistent calyx lobes much enlarged, revolute. Seeds numerous, pale brown-yellow to brown, narrowly ellipsoid or oblong, terete, smooth. It is a species of *C. clematidea* is considered very close to (Khasanov et al. 2018).

Study area and species description

Field studies were conducted in southwestern Uzbekistan, covering the Surkhandarya and Kashkadarya regions. During the research, 8 cenopopulations were identified (Fig. 1). The identified cenopopulations exhibit distinct differences based on a range of ecological and geographical parameters. Specifically, they vary in administrative location, elevation above sea level, plant community composition, soil characteristics, and vegetation cover within the study area.

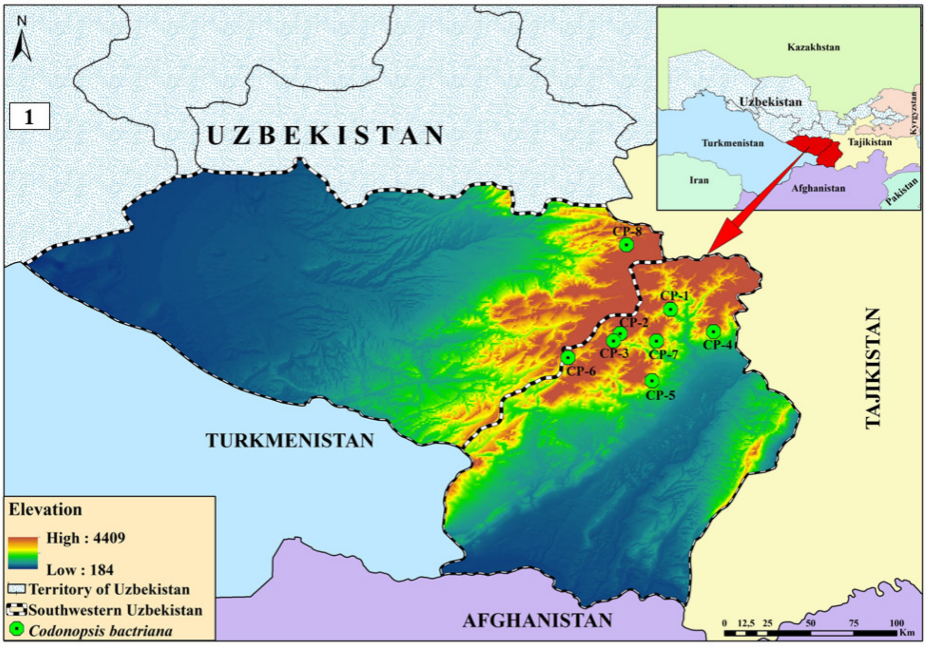


Figure 1. Map of the distribution of *C. bactriana* in Uzbekistan.

This area is bounded by the Hissar Mountain Range to the north, the Amu Darya Valley to the south, the Babatag and Baysuntau ranges to the east, and the Karshi Desert to the west. The region is characterized by a complex topography that includes plains, foothills, and mountainous landscapes, with elevations ranging from 270 to 4,409 m above sea level. The climate is continental and arid, with annual precipitation varying significantly depending on elevation. Precipitation ranges from 100–200 mm in lowland areas to 600–800 mm in high mountain zones. Under these arid climatic conditions, seasonal snow accumulation in mountainous areas plays a crucial role in maintaining regional water resources and ecosystem stability (Kuzmina 2016).

A number of studies have been conducted in Uzbekistan focusing on the populations of rare (Shomurodov et al. 2021; Abduraimov et al. 2022; Maxmudov et al. 2024) and endemic (Khamraeva et al. 2023; Abduraimov et al. 2025) plant species and the assessment of their current status. These investigations have addressed key aspects such as species distribution range, population structure, ontogenetic composition, and the influence of environmental factors. However, despite these efforts, information on the current status of cenopopulations of the genus *Codonopsis* remains limited. In particular, data on population structure, stability, and dynamics of *Codonopsis* species are insufficient. Furthermore, ontogenetic spectra, demographic parameters, and adaptive responses of natural populations to environmental conditions have not been adequately studied. This lack of comprehensive data highlights the necessity for detailed population-based research aimed at assessing the current state of *Codonopsis* species and developing effective conservation strategies.

The study focused on natural populations of *Codonopsis bactriana* Khassanov & Sennikov occurring within the Western Hissar mountain system at elevations between 1,500 and 3,000 m above sea level (Khassanov 2018). The mountain ecosystems of this region are characterized by high biodiversity, pronounced altitudinal gradients, and heterogeneous ecological conditions, which significantly influence plant population structure and dynamics (Abduraimov et al. 2026).

Sampling and ontogenetic structure analysis

The ontogenetic structure of cenopopulations of was studied using a commonly accepted method (Uranov 1975). The ontogenetic structure of the cenopopulations was examined across 8 age stages (j, im, v, g1, g2, g3, ss, s). The area occupied by each population was determined using GPS. The ontogenetic structure of cenopopulations is defined as the average ratio of individuals at different ontogenetic stages within a population. The individual organism was taken as the counting unit. When characterizing population structure, the concept of a characteristic ontogenetic spectrum was used. Based on the distribution pattern of ontogenetic groups, four types of ontogenetic spectra are distinguished: left-skewed, centered, right-skewed, and bimodal, according to the classification of Zaugolnova (1976). The characteristic spectrum depends on the biological features of the species. Cenopopulations were described according to the determined by A.A. Uranov and O.V. Smirnova (1969). The type of cenopopulation was determined following the "delta-omega" (Δ-ω) classification by L.A. Zhivotovsky (2001). Population density was determined as the number of individuals per unit area (1 m^2). Both average densities, i.e., the number of individuals per unit of the total surveyed area, and ecological density, i.e., the number of individuals per unit of the area actually occupied by the population, were calculated (Odum 1986). The values of the aging index and recovery index were determined using the methodology of N.V. Glotov (1998) and A.R. Ishbirdin (2004). For species identification of plants, the "Determinant of plants of Central Asia" key (1968-2015) was used. Accepted Latin names of the studied species are given according to the international database Plants of the World Online (POWO 2024). Geobotanical descriptions of plant communities were carried out using a standard method on 100 m² plots (Field Geobotany 1964). All plant species were recorded, along with their abundance, height, vitality, and phenophase, as well as the total projective cover of the herb layer (TPC) and the projective cover of each species (PCS). The condition of the vegetation cover, the anthropogenic factors affecting it, and the degree of their impact were also noted (Table 1).

To determine the species' spatial distribution and map the locations of coenopopulations, ArcGIS 10.8.2 software was employed. Geographic coordinates and elevation data of the coenopopulations were processed using the WGS84 coordinate system. Terrain characteristics of the study area were analyzed using SRTM digital elevation model (DEM) data with a spatial resolution of 30 m.

Table 1. Characteristics of the studied cenopopulations

CP No	Location	Geographical coordinates	h, m	CP area, ha	Dominant species	GPGC, %	PCS, %
1	Sariasiya dist., Khondiza	N 38°34′26.00″ E 67°38′57.83″	2909	3	*Platanus orientalis+ Vitis vinifera+ Codonopsis bactriana*	45	3
2	Sariasiya dist., Bogcha (Kishtansoy)	N 38°35′37.14″ E 67°27′2.33″	1869	1	*Rosa canina+ Mentha longifolia* var. *asiatica+ Achillea filipendulina*	40–50	1
3	Sariasiya dist., Boghcha	N 38°35′0.21″ E 67°26′14.99″	1650	2	*Salix alba+ Sorbus persica+ Origanum tyttanthum*	45	2
4	Sariasiya dist., Sharghun	N 38°37′22.02″ E 67°56′52.64″	1697	1	*Juniperus seravschanica+ Mentha longifolia* var. *asiatica+ Origanum tyttanthum*	30–35	1
5	Denau dist., Sina	N 38°22′1.15″ E 67°37′33.82″	1866	2	*Aquilegia vicarial+ Hordeum bulbosum+ Rheum maximowiczii*	40	2
6	Baysun dist., Kentala	N 38°29’14.98" E 67°11’16.66"	1833	3	*Salix alba+ Mentha longifolia* var. *asiatica+ Codonopsis bactriana*	50–60	5
7	Sariasiya dist., Duoba	N 38°44′24.79″ E 67°43′24.49″	1852	2	*Acer semenovii+ Lonicera nummulariifolia+ Mentha longifolia* var. *asiatica*	45	3
8	Shakhrisabz dist., Ghilon	N 39°4′35.03″ E 67°29′35.85″	2520	3	*Lonicera microphylla+ Cotoneaster nummularius+ Codonopsis bactriana*	60	5

Note: CP – cenopopulations; h - Height above sea level, m; GPGC - General projective grass cover, %; PCS - projective cover species.

Results and discussion

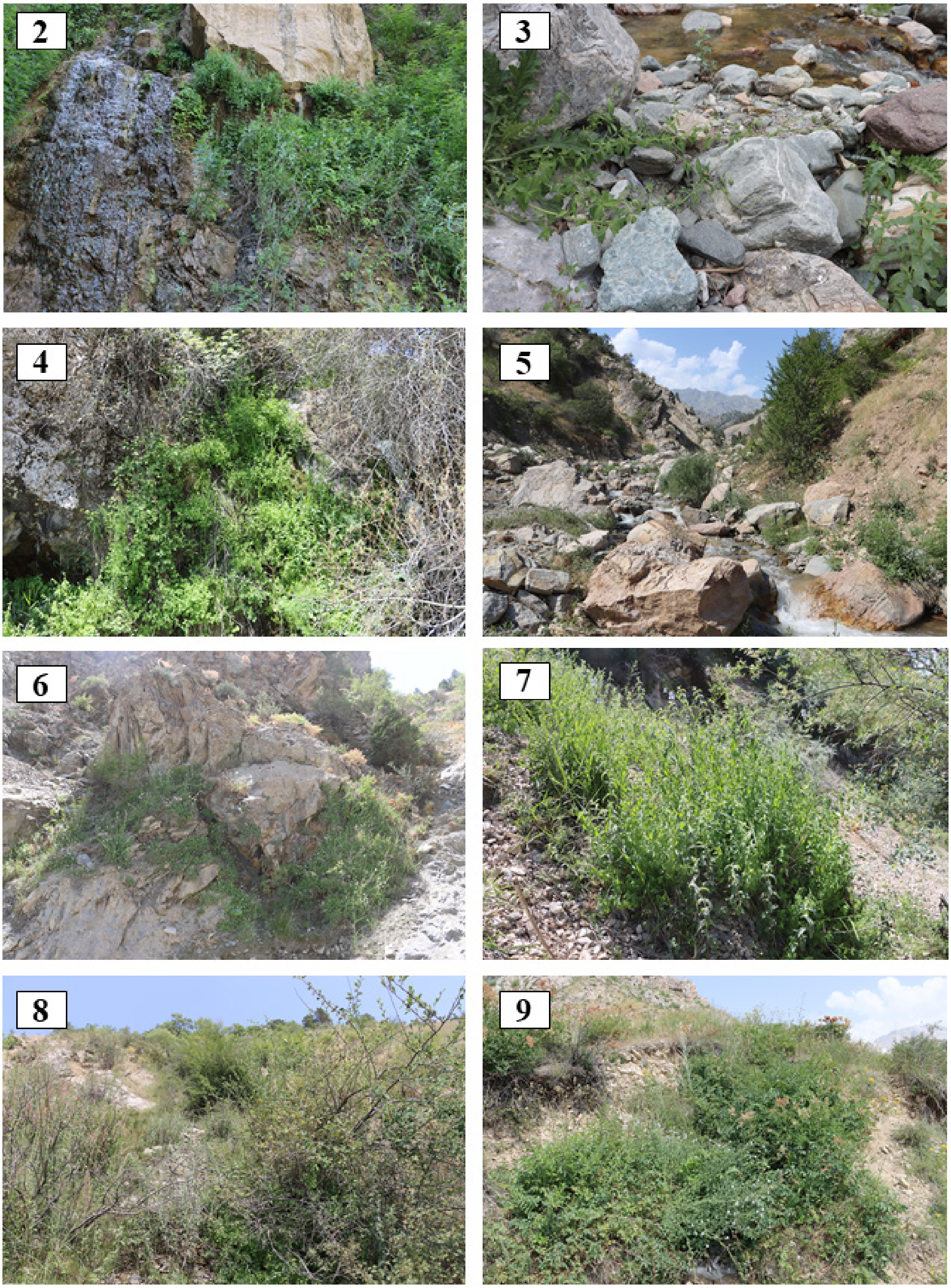
Codonopsis bactriana is a perennial herbaceous species characterized by a well-developed taproot system and a caudex-based growth form. The species exhibits slow individual development, an extended life cycle, and a polycarpic reproductive strategy. These biological features influence the structure and dynamics of natural coenopopulations in mountain ecosystems of Uzbekistan and reflect adaptation to environmentally heterogeneous habitats. The ontogenetic development of *C. bactriana* was analyzed according to the concept of discrete ontogenetic stages proposed by T. Rabotnov (1950) and further elaborated by A. Uranov (1975). According to this framework, three main ontogenetic periods are distinguished: pregenerative, generative, and postgenerative.

Pregenerative period (3–5 years). The pregenerative period includes latent (se), seedling (p), juvenile (j), immature (im), and virginal (v) stages. **Latent stage (se)**. Seeds narrowly ellipsoid, 1.5–2.5 mm long, smooth, pale brown; germination rate low under natural conditions. **Seedling stage (p)**. Plants 1–2 cm high; primary taproot 1–2 cm long; cotyledons present; first true leaves 0.3–0.5 cm long. **Juvenile stage (j)**. Plants 3–5 cm high; taproot 3–5 cm deep; 1–2 pairs of juvenile leaves 0.5–0.8 cm long; caudex primordium weakly expressed. **Immature stage (im)**. Plants 7–12 cm high; root depth 8–10 cm; 5–8 leaves measuring 1.0–1.5 × 0.8–1.3 cm; lateral roots and initial caudex formation observed; 1–2 lateral shoots. **Virginal stage (v)**. Plants 12–18 (–25) cm high; branched root system penetrating 12–20 cm; 10–12 leaves up to 2.0 × 1.8 cm; 2–4 stems; reproductive organs absent.

Generative period (5–12 years). The generative period includes young generative (g_1), mature generative (g_2), and old generative (g_3) stages. **Young generative stage (g1)**. Plants 30–60 cm high; 2–5 stems; tuberiform root 15–25 cm long; 1–5 flowers per individual; corolla 1.7–2.3 cm long; moderate seed production. **Mature generative stage (g2)**. Plants 80–100 (–120) cm high; 5–15 stems; root system 25–40 cm deep; leaves up to 3.5 (–5.2) cm long; 10–30 flowers; capsules 15–20 mm; maximum reproductive output. **Old generative stage (g3)**. Plants 50–80 cm high; 3–8 stems; root system 20–35 cm deep; 3–10 flowers; reduced reproductive activity; enlarged caudex with remnants of previous shoots.

Postgenerative period (2–4 years). The postgenerative period includes subsenile (ss) and senile (s) stages. **Subsenile stage (ss)**. Plants 20–50 cm high; 1–3 weakened shoots; caudex 5–10 cm in diameter; flowering rare or absent; structural degradation increases. **Senile stage (s)**. Plants 5–20 cm high; shoots absent or solitary; caudex strongly deformed; regenerative capacity nearly absent; progressive mortality observed.

The total life span of *Codonopsis bactriana* ranges from 12 to 27 years. The species is characterized by slow ontogenetic development, caudex-forming growth form, and a conservative life-history strategy typical of mountain representatives of the genus *Codonopsis* (Figs 2–9).



Figures 2–9. Habitats of cenopopulations of *C. bactriana*.

The ontogenetic structure of the studied *C. bactriana* cenopopulations includes four types of spectra: left-skewed (CP-3, 7), centered (CP-1, 5, 8), right-skewed (CP-2, 4), and bimodal (CP-6).

Cenopopulations with a left-skewed ontogenetic spectrum. Cenopopulations characterized by a left-skewed ontogenetic spectrum showed a high proportion of virginal (35%) and juvenile (33.33%) individuals. Such a spectrum is typically formed due to the high potential seed productivity of the species and rapid development rates of young individuals. However, under stony-gravelly soil conditions, seed germination is not always successful, which negatively affects seed-based population regeneration. At the same time, this phenomenon is not permanent but rather temporary and is expressed by a relatively low transition rate of young individuals to the immature stage.

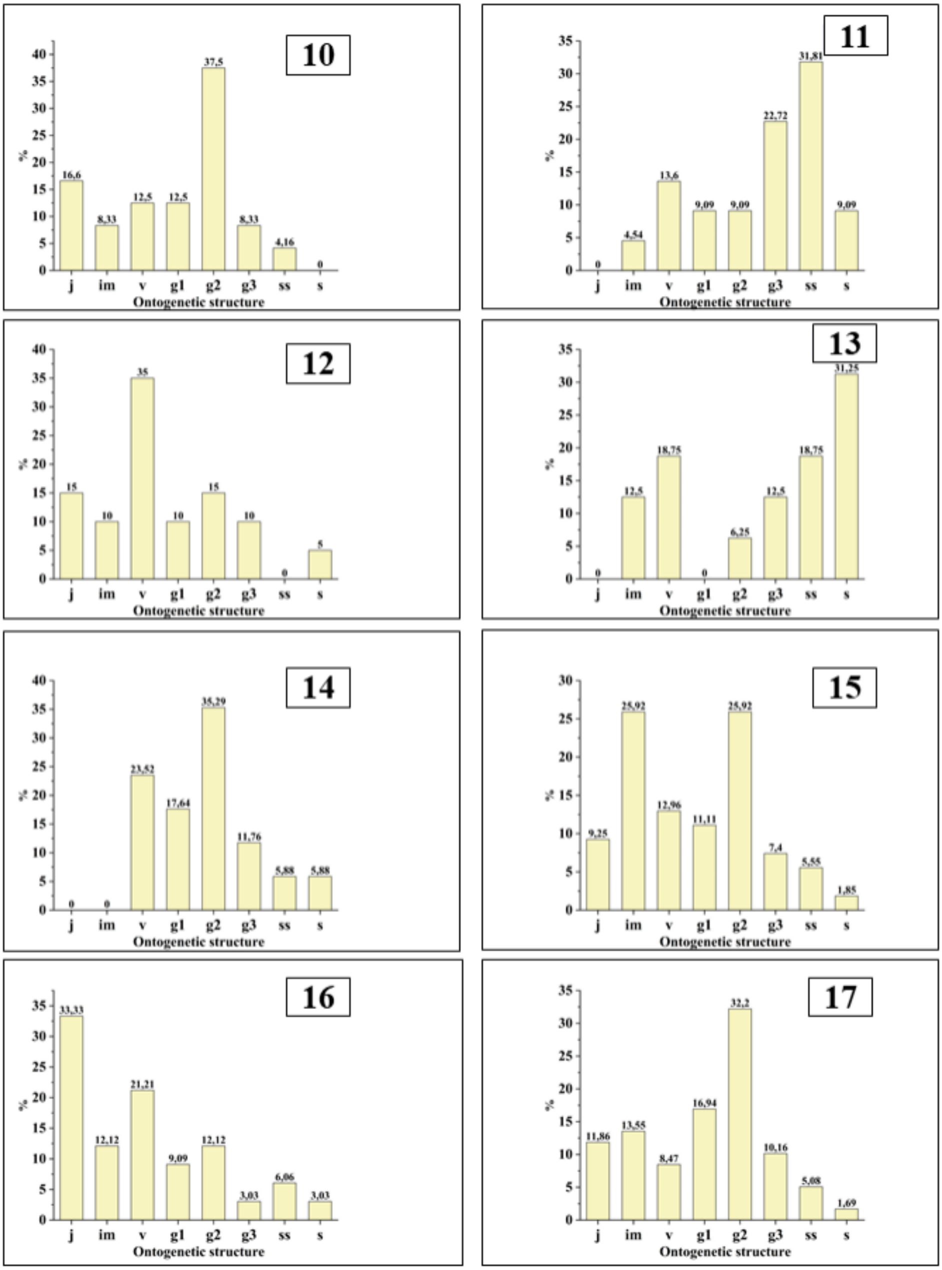
The accumulation of individuals in the virginal (v) stage within the cenopopulation is mainly explained by the relatively long duration of this ontogenetic phase. In particular, under insufficiently favorable ecological conditions, virginal individuals may persist for several years, continuing vegetative growth and delaying the transition to the generative stage. Cenopopulations of this type are generally characterized as complete. Only in the third cenopopulation was the absence of individuals belonging to the subsenile stage recorded (Figs 10–17).

Cenopopulations with a centered ontogenetic spectrum. The centered ontogenetic spectrum represents the most typical and characteristic pattern for the studied species. The high proportion of middle-aged generative individuals observed in all investigated cenopopulations can be explained, on the one hand, by the elimination of younger fractions under various ecological and anthropogenic factors, and on the other hand, by the gradual increase in the lifespan of individuals during the generative period.

In the studied cenopopulations, the proportion of middle generative individuals ranged from 32.2% to 37.5%. The low proportion or absence of individuals in the right part of the spectrum is, in most cases, associated with the harvesting of large generative individuals as medicinal raw materials by local populations. The high proportion of generative individuals creates favorable demographic conditions for the formation of a left-skewed ontogenetic spectrum in subsequent vegetation periods. This indicates positive demographic dynamics, relative population stability, and a high self-renewal potential.

At the same time, in some years incomplete seed maturation or seed loss due to ecological and anthropogenic factors is observed, which may influence the age structure of the population.

Cenopopulation with a bimodal ontogenetic spectrum. The bimodal ontogenetic spectrum is characterized by two peaks, corresponding to the immature and middle generative stages. In the studied cenopopulations, the proportion of individuals belonging to these stages was approximately 25.92%. The high proportion of immature individuals is explained by the high seed productivity of the species. However, despite the abundance of young individuals in some years, a considerable proportion may perish due to unfavorable climatic conditions, insufficient moisture, or anthropogenic pressure. The successful transition of juvenile individuals to the immature stage often leads to the formation of a bimodal ontogenetic spectrum, reflecting the ecological plasticity and adaptive capacity of the population. The studied cenopopulations were also found to be complete, indicating that these populations belong to the normal type.



Figures 10–17. Ontogenetic structure of *C. bactriana* cenopopulations.

Cenopopulations with a right-skewed ontogenetic spectrum. A right-skewed ontogenetic spectrum reflects both the adaptive strategy of the species to environmental conditions and the impact of anthropogenic pressure on population structure. In botanical population studies, a right-skewed spectrum is considered one of the warning indicators of population instability.

The low proportion of pregenerative and generative individuals is regarded as an alarming demographic indicator of population status. Although the studied cenopopulation was classified as complete, demographic parameters contributing to population renewal were relatively low. In particular, the proportion of subsenile and senile individuals ranged from 40.9% (CP-2) to 50% (CP-4), indicating an increasing aging trend within the population.

The scarcity of young individuals in these cenopopulations is associated with irregular seed regeneration, low seed germination success, and erosion of the upper soil layer during spring mudflows. Young, poorly established individuals are often washed away during spring runoff events, whereas middle-aged and older individuals persist due to their well-developed root systems penetrating deeply into the soil.

Thus, a comparison of the ontogenetic structure of cenopopulations of the studied species across different ecological and phytocoenotic habitat conditions revealed that the ontogenetic spectra of all examined cenopopulations were unimodal and centered, with a peak corresponding to middle-aged generative individuals. The ontogenetic spectra of the specific cenopopulations generally correspond to the characteristic pattern typical for the species.

Depending on ecological and phytocoenotic habitat conditions, the population density in the studied communities varied from 0.8 individuals/m^2 (CP4) to 2.7 individuals/m^2 (CP6), while ecological density ranged from 0.94 individuals/m^2 (CP4) to 3.17 individuals/m^2 (CP6).

In addition, indices characterizing the dynamics of cenopopulation processes were analyzed, including the recovery index (I_v), aging index (I_{st}), individual optimum index (I_{io}), and efficiency index (I_{ie}). In most of the studied cenopopulations, the recovery index exceeded unity, indicating relatively effective seed regeneration. The increase in the recovery index is primarily associated with a high proportion of pregenerative individuals in the cenopopulations. Their relative abundance ranged from 0.02 to 2.75. The aging index values in the studied cenopopulations were generally characterized as relatively high, varying from 0.04–0.09 (CP1, CP3, CP6, CP7, CP8) to 0.13–1.0 (CP2, CP4, CP5).

The individual optimum index (I_{io}) was calculated as the ratio of virginal to generative individuals (v/g). The obtained values ranged from 0.5 to 0.95. The efficiency index (I_{ie}) was determined by multiplying the total number of individuals by the efficiency coefficient calculated according to the delta–omega (Δ–ω) classification. According to this parameter, values ranged from 6.24 to 36.58 (Table 2).

Based on the delta–omega (Δ–ω) classification proposed by Zhivotovsky (2001), the studied cenopopulations were categorized as young (CP3, CP6, CP7), transitional (CP8), mature (CP5), maturing (CP1), and old (CP2, CP4). A comparative overview of the studied cenopopulations of the investigated species is presented in Figure 18.

Table 2. Demographic characteristics of *C. bactriana* cenopopulations

No	I_r	I_a	I_{io}	I_{ie}	The density of individuals, pcs/m^2	P_{ecol}, m^2	ω	Δ	Total number of individuals in the CP, pcs	Type CP
1	0.64	0.04	0.82	15.12	1.2	1.41	0.63	0.34	24	maturing
2	0.02	0.69	0.75	12.1	1.1	1.22	0.55	0.62	22	old
3	1.71	0.05	0.5	9.8	1	1.17	0.49	0.27	20	young
4	1.66	1	0.5	6.24	0.8	0.94	0.39	0.61	16	old
5	0.36	0.13	0.73	12.07	0.85	1	0.71	0.44	17	mature
6	1.08	0.07	0.77	28.62	2.7	3.17	0.53	0.30	54	young
7	2.75	0.09	0.95	12.54	1.65	1.83	0.38	0.22	33	young
8	0.57	0.07	0.87	36.58	2.95	3.5	0.62	0.36	59	transitional

Note: CP – cenopopulation; I_r – index of recovey; I_a – index of aging; I_{io} – index of individual optimum; I_{ie} – index of efficiency; P_{ecol} – ecological density; Δ – index of age; ω – efficiency index according to the delta–omega classification.

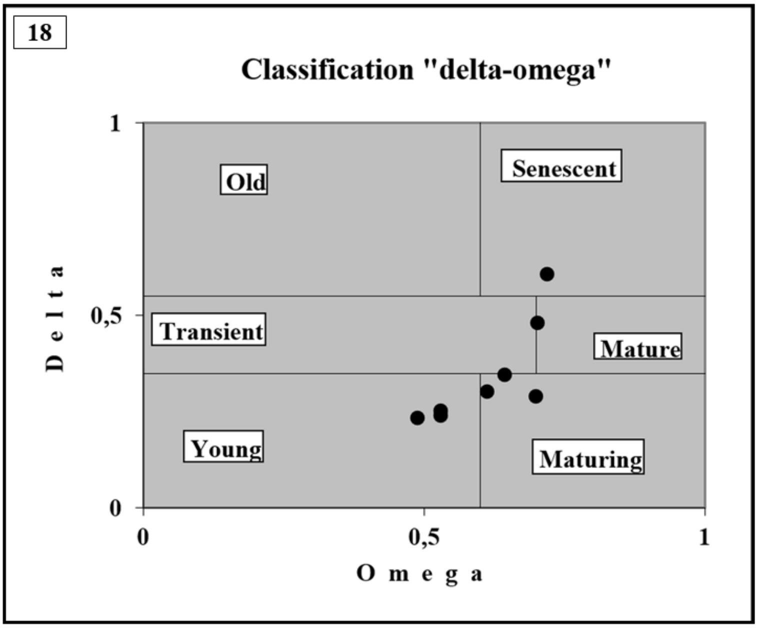


Figure 18. Delta-omega (Δ-ω) classification of cenopopulations.

Conclusions

The present study represents the first comprehensive evaluation of the ontogenetic structure and population status of *Codonopsis bactriana* in southwestern Uzbekistan. The species is characterized by a prolonged life cycle, slow ontogenetic development, and a conservative life-history strategy typical of perennial plants inhabiting mountainous environments. Eight cenopopulations were identified, exhibiting substantial variation in ontogenetic structure depending on ecological and phytocoenotic conditions.

Most cenopopulations displayed centered ontogenetic spectra dominated by middle-aged generative individuals, indicating relatively stable population conditions and sustained reproductive capacity. However, the occurrence of right-skewed spectra in certain populations reflects demographic aging and limited regeneration potential, which may pose risks to long-term population viability. Population density and ecological density showed considerable variation across habitats, emphasizing the role of environmental heterogeneity in shaping population structure.

Demographic indices indicated generally effective seed regeneration in the majority of cenopopulations, although elevated aging indices in some populations suggest emerging demographic imbalances. According to the Δ–ω classification, the studied populations ranged from young to old types, reflecting heterogeneous population dynamics within the study area.

Anthropogenic impacts, including unregulated harvesting, livestock grazing, and geological exploration activities, were identified as the principal factors influencing population structure and regeneration. In addition, natural factors such as climatic variability and soil erosion further affect seedling establishment and population renewal processes.

Overall, populations of *Codonopsis bactriana* in southwestern Uzbekistan remain relatively stable; however, several cenopopulations exhibit signs of demographic aging and reduced regeneration. These findings highlight the need for regular population monitoring, regulation of harvesting practices, and implementation of conservation measures to ensure the sustainable use and long-term preservation of this endemic medicinal species.

Acknowledgements

This research was carried out within the framework of the state Program "Digital Nature" (2025-2029), with support from the Institute of Botany of the Academy of Sciences of the Republic of Uzbekistan, as well as within the fundamental project FL-9024093685, "Biodiversity Centers of the Cross-Border Regions of Uzbekistan and Their Current State", by the Agency for Innovative Development of the Republic of Uzbekistan.

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