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Features of the ontogenetic structure of the coenopopulations of *Medicago sativa* L. in Uzbekistan

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SUMMARY

The aim of this study was to investigate the phytocoenotic associations, age composition, and ontogenetic structure of *Medicago sativa* L. coenopopulations in Uzbekistan. Research was conducted in the Eastern Cliff of Ustyurt (Karakuduk, Kassarma, Akbulak), in the Pamir – Alay mountain system, including the southwestern and northern spurs of the Gissar Range, the Kukhitangtau Mountains, the Sangardak River basin, Zhindarya, the Baysuntau Mountains (Upper Machai), and the Nuratau Mountains (Hayatsay), as well as in the Tien-Shan mountain system, including the Kuramin Range (Kamchik mountain pass) and the Tashkent Alatau (vicinity of the village Nevich). A total of ten coenopopulations were studied under various ecological and phytocoenotic conditions. The results showed that the coenopopulations are generally normal but incomplete. The basic ontogenetic spectrum is centered, corresponding to the generative stage with a predominance of middle generative individuals and, considering the biological characteristics of the species (a taproot system with well-developed lateral roots), corresponds to the characteristic type. Coenopopulations (CP 1, 6, 7, 9) of the left-sided type represent deviations from the characteristic pattern, likely determined by anthropogenic factors, habitat conditions, soil properties, and vegetation cover. Evaluation of age structure (Δ) and population efficiency (ω) indicated that most coenopopulations belong to the maturing type.

INTRODUCTION

Analysis of the demographic and spatial structure of plant populations is important for establishing effective conservation programs based on an understanding of the life strategies of different species, their conservation in different habitats and their interactions with the environment. Population studies provide a scientific background for the conservation and management biodiversity (Mirkin et al., 1985). One of the fundamental concepts in plant population ecology is the concept of the coenotic population of a species as a complex system comprising individuals at different ontogenetic stages in a given plant community. The ontogenetic spectrum of populations reflects the processes of population dynamics, including recruitment, reproduction, dispersal and mortality (Abdushaeva et al., 2005; Zlobin, 2009).

The genus *Medicago* L. belongs to the Fabaceae family and, according to various estimates, comprises 91 to 110 recognised species, which are annual and perennial herbs (POWO, 2024; GBIF, 2024). The original distribution area of the genus *Medicago* is the temperate and subtropical Old World. There are 23 species in Central Asia (Khassanov, 1981), and 8 species in Uzbekistan (Golodkovsky, 1955).

The subject of our study, alfalfa – *Medicago sativa* L., is a crop widely distributed in Uzbekistan in natural, semi-natural and modified habitats in the Western Tien Shan, Western Pamir-Alay, southeastern and southwestern Kyzylkum (including the remnant mountains) Kyzylkum, as well as on the eastern cliff of the Ustyurt Plateau.

Alfalfa is an important forage crop that is grown almost worldwide to provide relatively inexpensive high-quality, protein-rich feed for livestock. It is one of the most ancient and highest-yielding crops native to the Mediterranean, Southwest and Central Asia (Barnes et al., 1995). Currently, alfalfa is one of the most widely cultivated species of the Fabaceae family in the world after soybean and is adapted to a wide range of soil and climatic conditions. It is commonly incorporated into crop rotation systems as a means of enhancing soil fertility through its nitrogen-fixing capacity. This species is also a valuable medicinal plant (Bolton et al., 1972; Radovic et al., 2009).

In Uzbekistan, *Medicago sativa* occurs in various plant communities both as a dominant plant and as a participant. On the eastern cliff of Ustyurt,

for example, it grows in patches along the ravines together with *Agropyron repens*, *Cynoglossum viridiflorum* and *Convolvulus arvensis*, and forms 4 associations – *Medicagetur sativae mixtoherbosum*, *Medicagetur sativae fragile agropyrosum*, *Medicagetur sativae viridiflori cynoglosetum*, *Medicagetur sativae arvensi convolvulosum* (Sarybaev, 1981).

The coenopopulations of several species of the genus *Medicago* have been studied primarily by Russian botanists, and their findings provide valuable insights into the demographic and ontogenetic dynamics of this genus. One of the earliest works was conducted by N.M. Grigorieva (1975), who analyzed the ontogenetic and spatial structure of *Medicago falcata* coenopopulations in the forest, forest-steppe, and steppe zones of European Russia. Her study demonstrated how ecological conditions influence population stability and stage distribution, highlighting the importance of habitat in shaping demographic patterns. However, this research was geographically limited and did not include *M. sativa*, leaving an open question regarding its behavior in other regions.

Later, Z.I. Gladkova (2005) focused on the population structure, as well as the anatomical and morphological characteristics of *M. sativa* and *M. falcata* in the Novosibirsk region. The study revealed significant variability in morphological traits that were closely linked to environmental conditions, illustrating the adaptive potential of these species. For our research, this work is particularly relevant, as it suggests that population structure cannot be considered in isolation but must be analyzed alongside morphological and ecological factors. At the same time, the Novosibirsk context differs significantly from the arid and semi-arid conditions of Central Asia, which underlines the need for regional studies.

The research of V.N. Ilyina (2017) shifted attention to *Medicago cancellata*, a rare species in the flora of the Samara region. Her findings showed that the populations of this species exhibit narrowed age spectra and disrupted ontogenetic structures, reflecting their vulnerability and limited potential for long-term persistence. While this species differs from *M. sativa* in ecological role and abundance, the methodological framework of Ilyina's study is useful for assessing the stability and sustainability of coenopopulations, which is directly applicable to our work.

A more recent study by Z.J. Mammadova (2021) also focused on *M. cancellata*, providing a comprehensive assessment of its populations. The research combined demographic analysis with an evaluation of phytocoenoses and species composition, offering a holistic view of the ecological position of this species within plant communities. Such an integrative perspective is highly valuable for our investigation, as it suggests that the role of *M. sativa* in Central Asian ecosystems should be studied not only at the demographic level but also in connection with community structure and biodiversity.

In summary, previous studies of *Medicago* coenopopulations have made an important contribution to understanding the demographic and ontogenetic structure of the genus. Nevertheless, most of this research has focused on *M. falcata* and *M. cancellata*, or on specific regions of Russia, while the ontogenetic structure of *M. sativa*

coenopopulations in Central Asia remains unexplored. Our study seeks to fill this gap by examining the demographic and ontogenetic patterns of *M. sativa* in this region, thereby contributing new data to both theoretical population ecology and the applied management of this economically important species.

MATERIALS AND METHODS

Study area

The research was carried out in northwestern, central, and southern Uzbekistan, on the eastern cliff of the Ustyurt Plateau, on the northern and southern slopes of the Hissar Range and in the ranges Kughitang and Nuratau (Fig. 1). It should be noted that the map presented in Figure 1 illustrates the locations of the sampled sites included in the present study and does not represent the full distribution range of *Medicago sativa*.

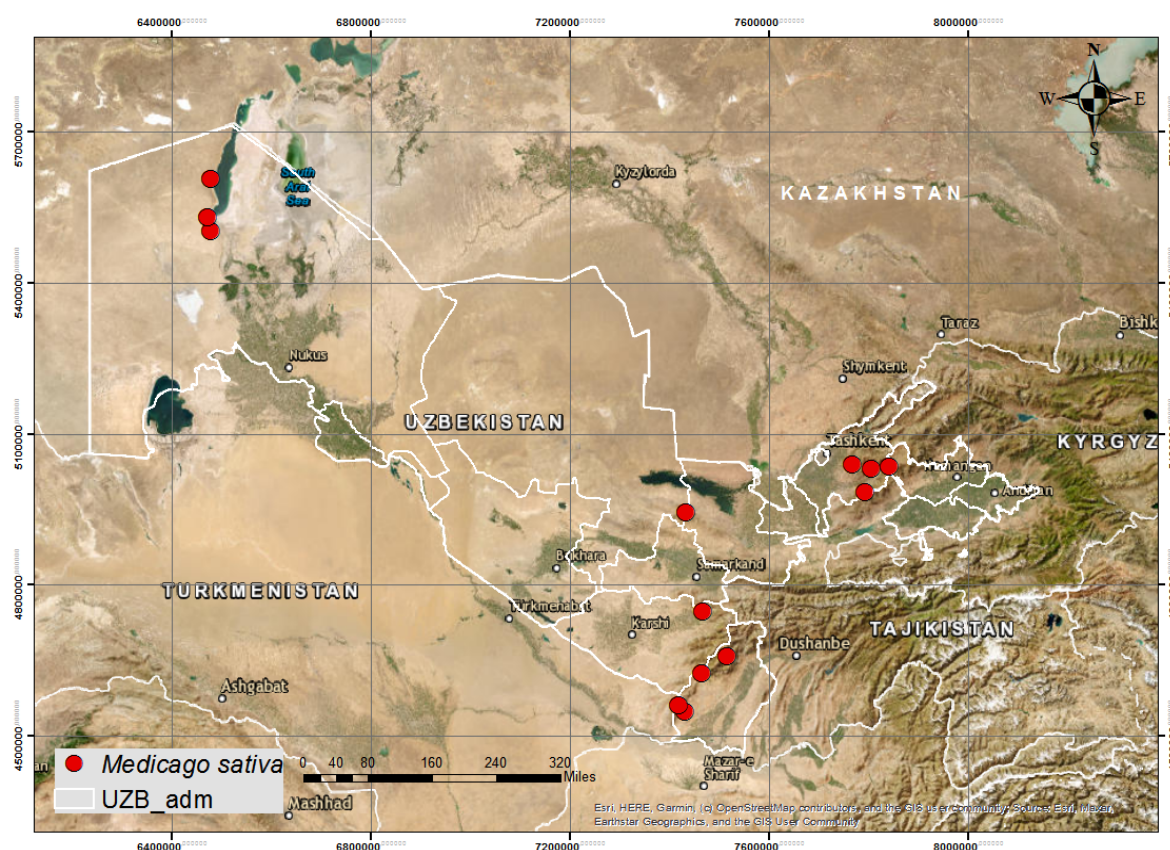


Figure 1. Sampling sites of *M. sativa* in Uzbekistan. The red dots show the distribution of sample plots in the study area.

The Ustyurt Plateau is a cross-border area, the northern and western parts of plateau belong to Kazakhstan, the southern parts – to Turkmenistan and the eastern and central part to Uzbekistan (Republic of Karakalpakstan). It is an elevated desert plain located in the central part of the Turan Lowland and in the northern part of the Aralo-Caspian watershed, bordered by steep and high cliffs in the west, south and east (Rachkovskaya et al., 2003). The main landscape type of Ustyurt is gypsum desert. The eastern cliff of Ustyurt is a very specific type of landscape, the former western shore of the Aral Sea. It is a limestone cliff up to 350 m high, strongly dissected by deep ravines and terraces (Sarybaev, 1981). The following soil types are distinguished in Ustyurt: gray – brown, taky, loamy, desert sandy soils and saline soils (solonchak). They are characterized by a low humus content and salt content (Kleimenova, 2010). According to the Köppen climate classification (Kottek & al., 2006), this region belongs to the zone of cold arid desert climate (BWk).

Our field survey was carried out in the central part of the eastern cliff of Ustyurt in surroundings of the dry well Karakuduk, the Kassarma descent and the Akbulak spring. According to the data from the nearest Aktumsuk weather station, the absolute maximum temperature in July is +45.5°C, the minimum temperature in January is -37 °C and the average annual precipitation is 120 mm. The precipitation occurs mainly in March-April, and the dry period is June-July.

The Hissar Range is one of the main ranges of the Pamir – Alay mountain system, located in its western part and extending for more than 300 km in the sub-latitudinal direction across the territory of Tajikistan and Uzbekistan; its westernmost spurs are situated in Turkmenistan. This is the highest mountain range in Uzbekistan (4,668 m above sea level) with highly rugged terrain and outstanding diversity of habitats and environmental conditions, widely varying depending to the geographic position, elevation and slope aspect (Tojibaev et al., 2017).

The Hissar Range occupies a huge area in the Kashkadarya and Surkhandarya regions of Uzbekistan. Our expeditions were carried out in the Kitab District of Kashkadarya Region and Baysun and Sariosiyo Districts of Surkhandarya Region, in basins of three rivers: Jindidarya – a left tributary of Kashkadarya, which divides Hissar and Zeravshan

Ranges; Machaydarya – the upper part of the river Sherobod in the southwestern spurs of the Hissar Range, Baysuntau Mountains; Sangardak – a right tributary of the Surkhandarya and one of the major rivers flowing down the southern slope of the Hissar Range. According to data from meteorological stations of Sherabad and Termez, the long-term average temperature is between 17.3 and 17.8 °C, the monthly average temperature during the growing season is 26.1-26.2 °C. The absolute minimum air temperature in June is 31.2 to 31.9 °C, the absolute maximum temperature is 48 °C, precipitation is 130-160 mm per year.

The Kughitang Range is a large southwestern branch of the Hissar Range stretched on about 100 km in the sub-longitudinal direction. The highest elevation is 3,139 m a.s.l. The southeastern slope of Kughitang belongs to Uzbekistan and its northwestern slope is situated in Turkmenistan. The southeastern slope of this range has strongly rugged terrain with deep canyons, steep slopes and rocky cliffs; the foothills are represented with arid badlands composed by outcrops of variegated gypsaceous beds (Tojibaev et al., 2017).

Our field survey was performed in Sherobod District of Surkhandarya Region, in the central part of the southeastern slope of Kughitang Range, in basin of the river Maydan, a right tributary of the river Sherobod, in surroundings of Surkhan Nature Reserve.

The Nuratau Range is located in the transition zone between the Pamir-Alay and Tien-Shan Mountain systems and the desert plains of Turan, in one of the most peculiar and botanically interesting regions of Central Asia. Orographically, Nuratau is a northwestern branch of the Turkestan Range, one of the major ranges of the Pamir-Alay system. This is a medium-altitude ridge (2,169 m above sea level) of a sublatitudinal direction with a length of about 200 km. In the west, it is wedged deeply into the Kyzylkum desert (Tojibaev et al., 2017). The terrain of the Nuratau Range is generally less rugged than Hissar and Kughitang. According to the Köppen climate classification (Kottek & al., 2006), the climate of the eastern piedmonts of Nuratau Mountains is hot-summer Mediterranean (Csa), the climate of the western piedmonts is cold semi-arid (Bsk), whereas the climate of montane zone is hot humid continental (Dsa). According to the data of weather station Farish (WMO code 38574), the mean temperature of January is -0.1°C, the mean

temperature of July is 29.4 °C, a mean annual temperature is 14.4°C, and a mean annual precipitation is 344 mm in the montane zone. The rainfall occurs mainly in the winter and spring (the maximum precipitation falls in March–April), and the dry period is June–September.

Our field survey was performed in Farish District of Jizzakh Region, in the central part of the northern slope of Nuratau Range, in the valley Hayatsay, in surroundings of Nuratau Nature Reserve.

The Tien Shan is one of the largest mountain systems of Central Asia, and its climate is highly heterogeneous due to the wide elevation range, complex relief, and remoteness from oceans. The region is characterized by pronounced continentality and vertical zonation: mean annual temperatures range from +6 to +10 °C in the foothills, while in the highlands they drop below zero (Aliiev, 1984; Bazhenova, 2008). Precipitation is distributed very unevenly, from 200–300 mm in intermontane depressions to 800–1200 mm in the mid- and high-mountain zones. Windward slopes receive substantially more precipitation than leeward slopes; snow cover persists for 6–8 months, and in glaciated areas it remains year-round (Murzayev, 1974; Li et al., 2015; Guo & Wang, 2014). Recent studies highlight the intensification of climate change in the region, including glacier retreat, upward shifts of the snowline, and altered precipitation regimes (Aizen et al., 2006; Chen et al., 2010; Sorg et al., 2012). In the Chinese part of the Tien Shan, elevation-dependent warming has been detected (Gao et al., 2021), which directly affects regional water resources and the stability of mountain ecosystems.

Our field survey was conducted in two mountainous regions of Uzbekistan: the Kuramin Range, in the area of the Kamchik mountain pass, which is part of the western Tian Shan system, and the Tashkent Alatau, in the vicinity of the village of Nevich, characterized by mid-mountain landscapes with diverse vegetation.

The field methods

The field surveys were carried out in growing season of 2022–2024, by traditional methods of geobotanical research commonly used for sampling of native non-forest vegetation, recognition of floristic composition and spatial patterns of plant communities (Field Geobotany, 1964). Transects of 10 m in length were established and subdivided into

plots of 1 m². In each coenopopulation, from 10 to 30 plots of 1 m² were laid out. The ontogenetic structure of coenopopulations was determined as the ratio of individuals at different ontogenetic stages within the population, with the individual taken as the accounting unit. The characterization of population structure was based on the concept of the characteristic ontogenetic spectrum (Zaugolnova, 1994). According to the distribution of ontogenetic groups, four types of spectra are distinguished: left-sided, centered, right-sided, and bimodal. A total of nine phytocoenoses were studied, for which species lists were compiled; for each species, abundance and cover were assessed using the Braun-Blanquet scale. The accepted scientific names of the plant species are given in accordance with the global taxonomic database Plants of the World Online POWO (<https://powo.science.kew.org>). The following ontogenetic stages of *Medicago sativa* were identified according to the standard criteria (Rabotnov, 1950; Uranov, 1969): juvenile (j), immature (im), virginile (v), young generative (g1), medium generative (g2), old generative (g3), senile (s). The structure of the coenopopulations of *Medicago sativa* was studied by the generally accepted methods of Uranov (1975) and Smirnova et al. (1976). The assessment of the state of the coenopopulation was carried out according to the classification "delta-omega" by Zhivotovsky (2001). Population density was determined based on the number of individuals per unit area. The following parameters were also determined for each coenopopulation: the average density (the number of individuals per unit of the total sampling area (30 m²)) and the ecological density (the number of individuals per unit of the sampling area of suitable habitat that can actually be occupied by the studied species) (Odum, 1986). The method of N. V. Glotov (1998) was used to determine the aging and recovery indexes. The reproductive effort of plants was evaluated as the proportion of biomass invested in generative structures (flowers and fruits) relative to the total biomass of an individual. This indicator, calculated following the approach of Markov and Pleshchinskaya (1987), reflects the allocation of resources to reproduction and is widely used as a measure of reproductive strategy in plants. To compare the studied coenopopulations as demographic units, a set of population and ontogenetic indicators was calculated for each coenopopulation using Excel (Version 16.0). These included population densities (total, average, and

ecological density), the proportion of individuals at different ontogenetic stages, the type of ontogenetic spectrum, the values of the delta (Δ) and omega (ω) indices, aging and recovery indices, as well as reproductive effort. The distribution map of the studied coenopopulations was compiled using ArcGIS Pro (Version 3.0) software.

RESULTS AND DISCUSSION

Distribution and characteristics of plant communities with the participation of *Medicago sativa*

The structure of ten coenopopulations (CP) of *Medicago sativa* in northwestern, central and southern regions of Uzbekistan was studied. Their geographical location and the characteristics of the plant communities are described below.

CP1 was found in the Eastern cliff of Ustyurt, in the vicinity of the dry well Karakuduk (44.4224° N, 58.1359° E (WGS84), 217 m a.s.l.). The soil is gypsiferous gray-brown desert soil, rich in humus. The influence of anthropogenic factors and overgrazing by livestock are occurred. In this area (3 ha), *M. sativa* is a dominant of *Atraphaxis spinosa* – *Medicago sativa* community, and *A. spinosa* is the subdominant. The vegetation cover was 60 %. The floristic composition of the community includes 14 species.

CP2 was found in the south-eastern part of the Ustyurt cliff, on the descent, near the Kassarma hill (44.4645° N, 58.1264° E, 232 m a.s.l.). The studied species occurs here as participant of the community dominated by *Artemisia diffusa*. The total area of this coenopopulation does not exceed 3-4 ha. The road infrastructure is being developed on the territory. The soil is gypsiferous and coarse-grained gray-brown desert soil. The total vegetation cover is 40%. The floristic composition of the community includes 15 species.

CP3 was found in the eastern cliff of Ustyurt, in the vicinity of the Akbulak spring as part of the *Agropyron fragile* + *Medicago sativa* community (44.9069° N, 58.1905° E). The floristic composition of this community includes 15 species. The total vegetation cover of the herbage is 80%, the share of *M. sativa* is 50 %, *A. fragile* is 30 %. This coenopopulation grows on the foamed shallow gray-brown desert soil at the outcrops of the bedrock. There are gas pipeline lines.

CP4 was described in the Jindidarya River basin on the northern slope of the Hissar Range (39.1772° N, 67.0776° E; 891 m a.s.l.), among tall grass community dominated by *Hordeum bulbosum* and *Poa bulbosa*. *M. sativa* is a participant in this community, its cover is 10 %. The total vegetation cover of the herbage does not exceed 50%. The soil is loamy gray. The floristic composition of this community includes only 10 species of vascular plants. Nearby there are settlements and overgrazing of livestock.

CP5 population grows in the central part of southeastern slope of Kughitang Range, in vicinity of the village of Zarabag, 500 m from the cemetery, on stony-loamy soil (37.7687° N; 66.7498° E; 1005 m a.s.l.), as well as in the Abjaysay, whose headwaters are located on the northern slope of the Kuramin Range, Akhangaran District (40.8050° N; 69.9935° E; 1291 m a.s.l.). There are 14 species of vascular plants in the forb- *Medicago sativa* + *Hordeum bulbosum* community, where this coenopopulation is registered. The dominant species is *H. bulbosum*, the subdominant is *M. sativa*. The total vegetation cover of the herbage is 50 %, of which about 35% is made by for by the dominant species. The projective cover of the studied species in this community does not exceed 15%. The vegetation cover is mainly composed of perennial and annual herbaceous plants.

CP6 was found in the vicinity of Sangardak village, Sariasiy District (spurs of the Gissar Mountains) (38.5555° N; 67.4997° E; 1392 m a.s.l.), also was described in the central part of Kughitang, in surroundings of the village Sholkon in the Sherabad district, near the summer children's camp. Power lines and gas pipelines have been installed, as well as tourism. There is a strong anthropogenic pressure and occupies about 3-4 ha. It is part of the *Medicago sativa* + *Poa bulbosa* community (37.8624° N; 66.6341° E; 1758 m a.s.l.). The soil is fine-grained and gray – brown. The total vegetation cover of the herbage is 60%. The floristic composition consists of 18 species.

CP7 is registered in Baysuntau Mountains (southwestern branch of Hissar Range), in the Machaydarya River basin, near the village Upper Machay at an altitude of 1298 m above sea level (38.3148° N; 67.0429° E), as well as on the southeastern slope of the Chatkal Range, in Yangiabad, in the vicinity of the Dukentsay (41.1272° N, 70.1098° E; 1364 m a.s.l.) in the *Trifolium pratense* + *Medicago sativa* community.

Livestock grazing is developed, and there is an average anthropogenic load and occupies about 2-3 ha. The floristic composition of this community includes 16 species. The soil is loamy brown. The vegetation is rather sparse, the vegetation cover is 45 %. The vegetation is dominated by *M. sativa*, *T. pratense* (Table 1).

CP8 grows in the vicinity of the field station of the Nuratau Nature Reserve, in the valley of the stream Hayatsay, in central part of the Nuratau Range (40.5275° N; 66.7749° E), among a bulbous barley-forb-walnut community at an altitude of 959 m above sea level. This coenopopulation grows in a semi-natural habitat, in a fenced area that is used for haymaking, and occupies about 3-4 ha. The soil is loamy meadow soil. The projective cover is 80 %. In this community dominated by *Juglans regia*, the subdominants are the perennial herbs *M. sativa*, *T. pratense* and *H. bulbosum*, 25 species were recorded.

CP9 was recorded near the Kamchik mountain pass on the ridge of the Kuramin Range (41.1514° N; 70.4430° E). The species inhabits a forb *Crataegus turkestanica* phytocoenosis at an elevation of 1267 m a.s.l. The soil is classified as stony loam. The total projective cover is about 70%, while the share of the studied species does not exceed 15%. The community comprises 12 plant species. The main dominant is *Crataegus turkestanica*, whereas the subdominants are perennial herbs, including *Sisymbrium loeselii*, *Trifolium repens*, *Medicago sativa*, and *Melilotus officinalis*.

CP10 was studied in the vicinity of Nevich village, Parkent District, Tashkent Alatau (41.1864° N; 69.7744° E). The species composition of the phytocoenosis is rich in perennials, forming a *Trifolium pratense* + *Phragmites australis* community. The total projective cover is 70%. The study object, *Medicago sativa*, accounts for 10% of the total cover. The soil is fine-grained with gravel admixture. The community is dominated by *Phragmites australis* and *Trifolium pratense*.

Thus, *M. sativa* demonstrates a wide ecological amplitude, which is reflected in its ability to occur both within the intrazonal vegetation of desert ecosystems (Ustyurt) and within the structure of tall-grass semi-savannas of the mountain regions of Uzbekistan. The diversity of formations in which this species is recorded indicates the high ecological plasticity and adaptive potential of *M. sativa*. Moreover, its dominance in *Atraphaxis spinosa* – *Medicago sativa*, *Agropyron fragile* + *Medicago*

sativa, and *Trifolium pratense* + *Medicago sativa* communities confirms the significant role of the species in the formation of phytocoenoses and the maintenance of their stability. The identified patterns highlight both the ecological and coenotic significance of *M. sativa* and its potential as a promising object for pasture and forage use in various natural zones of Uzbekistan.

Ontogenetic structure of coenopopulations of *Medicago sativa*

As shown by the results of our research, all studied coenopopulations of *Medicago sativa* growing in different natural and semi-natural habitats of northwestern, central and southern Uzbekistan are normal, but incomplete. Taking into account the biological traits of the species, including a robust, deep-penetrating root system with a thick taproot and well-developed lateral roots—features that suggest self-maintenance is possible only through seed reproduction—the coenopopulation spectrum of this species can be characterized as centered.

The ontogenetic structure of CP 1, CP 6, CP 7 and CP 9 belongs to the left-sided type, which does not correspond to the characteristic spectrum. In these coenopopulations, a higher ratio of the young fraction is observed, which may be connected with habitat conditions, as well as the location of CP 6 and CP 7 near settlements where anthropogenic impact is significant, especially haymaking, which contributes to the rejuvenation of coenopopulations. The absolute maximum in the ontogenetic spectrum of CP 1, CP 6 and CP 7 falls on young generative individuals (g1 – 42.8%, 51.3% and 45.2%). The low proportion of the young fraction in CP 1 is associated with the growth conditions (Eastern cliff of Ustyurt), arid climate, lack of moisture, and soil erosion, which negatively affect seed germination and increase the elimination of juvenile individuals. In CP 6 and CP 7, where the climate is relatively humid (Sangardak, Boysun), the proportion of the young fraction reaches 48–50%. CP 9 was found in the Tien Shan Mountains, where the high proportion of young individuals is determined by a combination of natural and anthropogenic factors that promote the renewal of plant communities. Extreme mountain conditions, pronounced microhabitat mosaicism, frequent disturbances (landslides, mudflows), high solar radiation, and a short growing season create

Table 1. Characteristics of species composition, habitats, and vegetation cover of *M. sativa* communities.

№ CP	Geographic locations coenopopulation	Geographical coordinates	Community/ dominant species	Species composition	Total projective cover (%)	The projective cover of <i>Medicago sativa</i> , (%)
1	Eastern Cliff of Ustyurt, Karakuduk	44.4224° N 58.1359° E	<i>Medicago sativa</i> , <i>Atraphaxis spinosa</i>	<i>Ephedra intermedia</i> , <i>Acroptilon repens</i> , <i>Agropyron fragile</i> , <i>Allium caesium</i> , <i>Capparis spinosa</i> , <i>Centaurea apiculata</i> , <i>Echinops meyeri</i> , <i>Galium septentrionale</i>	60	45
2	Eastern Cliff of Ustyurt, Kassarma	44.4645° N 58.1264° E	<i>Artemisia diffusa</i> , <i>Medicago sativa</i>	<i>Glycyrrhiza aspera</i> , <i>Dodartia orientalis</i> , <i>Calamagrostis dubia</i> , <i>Allium caesium</i> , <i>Agropyron fragile</i> , <i>Acroptilon repens</i> , <i>Asperugo procumbens</i> , <i>Atraphaxis spinosa</i> , <i>Artemisia terrae-albae</i> ,	40	10
3	Eastern Cliff of Ustyurt, Akbulak	44.9069° N 58.1905° E	<i>Medicago sativa</i> , <i>Agropyron fragile</i>	<i>Artemisia terrae-albae</i> , <i>Atraphaxis spinosa</i> , <i>Asperugo procumbens</i> , <i>Atriplex moneta</i> , <i>Cardaria pubescens</i> , <i>Chorispora tenella</i> , <i>Dodartia orientalis</i> , <i>Echinops meyeri</i> , <i>Geranium transversale</i> , <i>Poa bulbosa</i> , <i>Rheum tataricum</i> , <i>Rochelia bungei</i> , <i>Tulipa sogdiana</i>	80	50
4	Kitab region, Jindidarya River valley	39.1772° N 67.0776° E	<i>Hordeum bulbosum</i> , <i>Poa bulbosa</i>	<i>Ranunculus arvensis</i> , <i>Sisymbrium altissimum</i> , <i>Centaurea melitensis</i> , <i>Plantago major</i> , <i>Avena fatua</i> , <i>Roemeria refracta</i> , <i>Elymus repens</i> , <i>Medicago sativa</i>	50	10
5	Kughitang, Near the village Zarabag, Kuramin Range, Abjazzsay	37.7687° N 66.7498° E 40.8050° N 69.9935° E	<i>Hordeum bulbosum</i> , <i>Medicago sativa</i> , <i>Poa bulbosa</i>	<i>Koelpinia linearis</i> , <i>Lactuca serriola</i> , <i>Cichorium intybus</i> , <i>Convolvulus arvensis</i> , <i>Avena fatua</i> , <i>Helichrysum arenarium</i> , <i>Melilotus officinalis</i> , <i>Plantago major</i> , <i>Taraxacum officinale</i>	50	15
6	Sangardak, the southern slope of Hissar Range, Kughitang, Sholkon	38.5555° N 67.4997° E 37.8624° N 66.6341° E	<i>Poa bulbosa</i> , <i>Medicago sativa</i> ,	<i>Capsella bursa-pastoris</i> , <i>Geranium pusillum</i> , <i>Holosteum umbellatum</i> , <i>Vicia sativa</i> , <i>Lactuca serriola</i> , <i>Inula grandis</i> , <i>Mentha longifolia</i> , <i>Poa trivialis</i> , <i>Taraxacum officinale</i> , <i>Rosa canina</i> , <i>Hordeum bulbosum</i> , <i>Plantago major</i> , <i>Trifolium pratense</i> , <i>Trifolium repens</i>	60	20
7	Baysuntau mountains, near the village Upper Machay Western Tien Shan, Chatkal	38.3148° N 67.0429° E 41.1272° N 70.1098° E	<i>M. sativa</i> , <i>Trifolium pratense</i> ,	<i>Capsella bursa-pastoris</i> , <i>Geranium pusillum</i> , <i>Koelpinia linearis</i> , <i>Polygonum aviculare</i> , <i>Lactuca serriola</i> , <i>Aeluropus littoralis</i> , <i>Convolvulus arvensis</i> , <i>Plantago major</i> , <i>Taraxacum officinale</i> , <i>Trifolium repens</i>	45	20

Range, Yangiabad, Dukentsay						
8	Nuratau Range, Hayatsay valley	40.5275° N 66.7749° E	<i>Juglans regia</i> u <i>Medicago sativa</i> , <i>Trifolium pratense</i> u <i>Hordeum bulbosum</i>	<i>Rubus caesius</i> , <i>Conyza canadensis</i> , <i>Vicia angustifolia</i> , <i>Daucus carota</i> , <i>Echium biebersteinii</i> , <i>Verbascum blattaria</i> , <i>Althaea litwinowii</i> , <i>Allium subtilissimum</i> , <i>Cichorium intybus</i> , <i>Cousinia umbrosa</i> , <i>Elytrigia repens</i> , <i>Elwendia chaerophylloides</i> , <i>Medicago lupulina</i> , <i>Melilotus officinalis</i> , <i>Plantago lanceolata</i> , <i>Poa pratensis</i> , <i>Poterium lasiocarpum</i> , <i>Potentilla pedate</i> , <i>Trifolium repens</i> , <i>Verbena officinalis</i> , <i>Populus afghanica</i>	80	20
9	Kuramin Range, Kamchiksay	41.1514° N 70.4430° E	<i>Crataegus turkestanica</i> , <i>Sisymbrium loeselii</i> , <i>Trifolium repens</i> , <i>Medicago sativa</i>	<i>Melilotus officinalis</i> , <i>Taraxacum officinale</i> , <i>Lepidium draba</i> , <i>Potentilla multifida</i> , <i>Capsella bursa-pastoris</i> , <i>Malva neglecta</i> , <i>Matricaria chamomilla</i> , <i>Echium vulgare</i> .	70	15
10	Tashkent Alatau, Nevich village	41.1864° N 69.7744° E	<i>Phragmites australis</i> , <i>Trifolium pratense</i>	<i>Poa pratensis</i> , <i>Plantago lanceolata</i> , <i>Populus alba</i> , <i>Hordeum murinum</i> , <i>Hypericum perforatum</i> , <i>Daucus carota</i> , <i>Prunus cerasifera</i> , <i>Rumex crispus</i> , <i>Salix tianschanica</i> , <i>Centaurea sp.</i>	70	10

favorable conditions for the germination of early ontogenetic stages, while simultaneously limiting the persistence of mature individuals. As a result, the proportion of g2 is low and accounts for only 19.04% (CP 1), 22.72% (CP 6), and 20% (CP 7), whereas individuals in g3 and s stages were not recorded.

CP 2, CP 3, CP 4, CP 5, CP 8, and CP 10 exhibit a centered spectrum, reflecting the biological characteristics of the species. The proportion of young generative individuals (g1) in these coenopopulations ranges from 16.4% (CP 2) to 34.8% (CP 3). The proportion of middle-aged generative individuals (g2) ranges from 35% (CP 5) to 48.1% (CP 4).

In the age structure of most coenopopulations at the time of the study, juvenile individuals were absent; however, immature individuals were present in 6 out of 10 coenopopulations (CP 1, CP 5, CP 6, CP 7, CP 9, CP 10). Seedlings and other individuals at early

ontogenetic stages require favorable conditions for growth and development. Their absence may depend on soil cover characteristics during arid periods. Another reason for their absence could be the washing away of seeds from the soil surface by spring meltwaters, which was especially observed in CP 2. The total area of this coenopopulation does not exceed 3–4 ha, and all individuals are in generative or postgenerative stages. The high proportion of generative individuals in the populations is one of the adaptive mechanisms to harsh slope and riverside habitats. Middle-aged and old individuals persist due to the well-developed root system penetrating deep into the soil.

In addition, the minimal proportion of the pregenerative fraction in CP 3 and CP 4 is apparently caused by anthropogenic impacts, particularly uncontrolled livestock grazing. Only in CP 3 was a small proportion of individuals (8.7%) in the virginal stage recorded. CP 4 is located near the settlements

of Zhindarya (Kashkadarya region), where regular grazing and trampling of vegetation by hoofed animals were observed.

In CP 5, CP 8, and CP 10, the maximum number of middle-aged generative individuals was recorded (g2 – 35%, 40%, and 43%, respectively). However, CP 10, also located in the Tien Shan Mountains, is characterized by a high proportion of g2 individuals because the site is more favorable, and at the time of the study the population was in the flowering and fruiting phase. Therefore, this coenopopulation is of the centered type.

Senile individuals are not always recorded, which is often due to the merging of subsenile and senile plants into one group because of their indistinct differences, the short duration of the senile stage, the time of field sampling, and different approaches of researchers to distinguishing these two final ontogenetic stages. Senile individuals (s – 2%) were recorded only in CP 2.

The higher proportion of young generative and middle-aged generative individuals in the studied coenopopulations is related to the mortality of young plants due to various anthropogenic factors, site conditions, and soil–vegetation cover features affecting seedling emergence and survival, which subsequently influence the ontogenetic spectrum of the studied species, its low seed renewal, as well as the gradual increase in the number of adult individuals.

Since *Medicago sativa* is highly palatable even at the beginning of flowering and is considered the best forage plant for all livestock species, as well as for rabbits, poultry, sheep, and cattle, the proportion of the young fraction is lower compared to the middle-aged fraction in all examined coenopopulations.

Thus, the analysis of the ontogenetic structure of coenopopulations of the studied species in different ecological and phytocenotic conditions showed that the coenopopulations are normal but incomplete. The basic spectrum of the coenopopulations is centered, unimodal, with a peak at the middle-aged generative individuals (Fig. 1).

The role of ecological conditions in shaping the ontogenetic and spatial structure of coenopopulations was previously demonstrated by N.M. Grigorieva (1975), who analyzed *Medicago falcata* populations across forest, forest-steppe, and steppe zones of European Russia. Her study showed that habitat-specific factors significantly influence

population stability and the distribution of ontogenetic stages. In the present study, comparable patterns were revealed in *Medicago sativa* coenopopulations from the Ustyurt region, where variations in ontogenetic spectra and vitality structure were closely associated with environmental heterogeneity. Although Grigorieva's research was geographically limited and focused on a different *Medicago* species, our findings support and extend her conclusions by demonstrating that similar ecological mechanisms govern population structure in *M. sativa* under arid conditions. This suggests that ecological regulation of coenopopulation structure is a common feature within the genus *Medicago* rather than a phenomenon restricted to particular regions or species.

In this broader ecological context, the ontogenetic and demographic structure of *Medicago sativa* coenopopulations in Central Asia, as reflected in their ontogenetic spectra, provides important insights into the ecological role of the species under arid and semi-arid conditions. A similar integrative approach was applied by Z.J. Mammadova (2021) to *M. cancellata*, where demographic analyses were combined with evaluations of phytocoenoses and species composition. This comparison supports the view that the interpretation of ontogenetic spectra in *M. sativa* should be conducted in connection with community structure and biodiversity to achieve a more comprehensive understanding of the species' ecological position.

The interpretation of the population structure revealed in the present study can be supported by the methodological framework proposed by V.N. Ilyina (2017), who investigated *Medicago cancellata*, a rare species in the flora of the Samara region. Ilyina demonstrated that narrowed age spectra and disrupted ontogenetic structures are indicative of reduced population stability and limited long-term persistence. Although *M. cancellata* differs from *M. sativa* in ecological role and abundance, the diagnostic value of ontogenetic spectra emphasized in Ilyina's study is directly applicable to our data. In this context, the incomplete and, in some cases, left-sided ontogenetic spectra observed in several *M. sativa* coenopopulations may reflect population responses to environmental constraints and anthropogenic pressure rather than intrinsic species-specific characteristics. Thus, Ilyina's results provide a methodological basis for interpreting the ontogenetic structure of *M. sativa* coenopopulations

in terms of their stability and sustainability under arid and semi-arid conditions.

At the population level, the ontogenetic structure of *Medicago sativa* coenopopulations is shaped by local ecological conditions, as reflected in the generally normal but incomplete population spectra observed at several sites. Similar conclusions were reported by Gladkova (2005), who demonstrated that population structure in *M. sativa* and *M. falcata* is closely associated with morphological variability and environmental factors. The significant variability of morphological traits identified in that study supports our interpretation that population structure cannot be analyzed in isolation but should be considered in conjunction with ecological conditions. At the same time, the differences between the humid conditions of the Novosibirsk region and the arid and semi-arid environments of Central Asia emphasize the importance of regional studies, such as the present work, for understanding population dynamics under contrasting ecological settings.

In certain cases, the ontogenetic spectra of specific coenopopulations (CP 1, 6, 7, 9) do not correspond to the theoretically established spectrum. The density of individuals in the examined coenopopulations ranged from 1.8 to 3.9 individuals

per m². The assessment of the age index (Δ —delta) and efficiency index (ω —omega) showed that most coenopopulations belong to the maturing type (CP 1, 5, 8, 10) (Table 1). Young coenopopulations (CP 6 $\Delta=0.12$; $\omega=0.41$; CP 7 $\Delta=0.18$; $\omega=0.55$; and CP 9 $\Delta=0.11$; $\omega=0.38$) occur in more humid climates (Sangardak and Boysun), where vegetation begins later. CP 2, 3, and 4 are mature coenopopulations, studied under drier and warmer conditions for growth and development (Eastern cliff of Ustyurt and Kashkadarya region) (Fig. 2).

A comparison was also made of the regeneration index (I_r), aging index (I_a), and replacement index (I_{rp}), which reflect the dynamic processes of coenopopulations. The regeneration index was close to zero in CP 2 and CP 3 ($I_r = 0.09$ – 0.11), where juvenile and immature individuals were absent, and virginal individuals occurred in small numbers (8.7–10%). In CP 9, the regeneration index reached 3.5, indicating good replenishment with young individuals. In almost all coenopopulations, the aging index was close to zero (0–0.02), which is due to the fact that most individuals die at the old generative stage, and rarely at the senile stage, as a result of various factors such as uncontrolled grazing and trampling by livestock (Table 2).

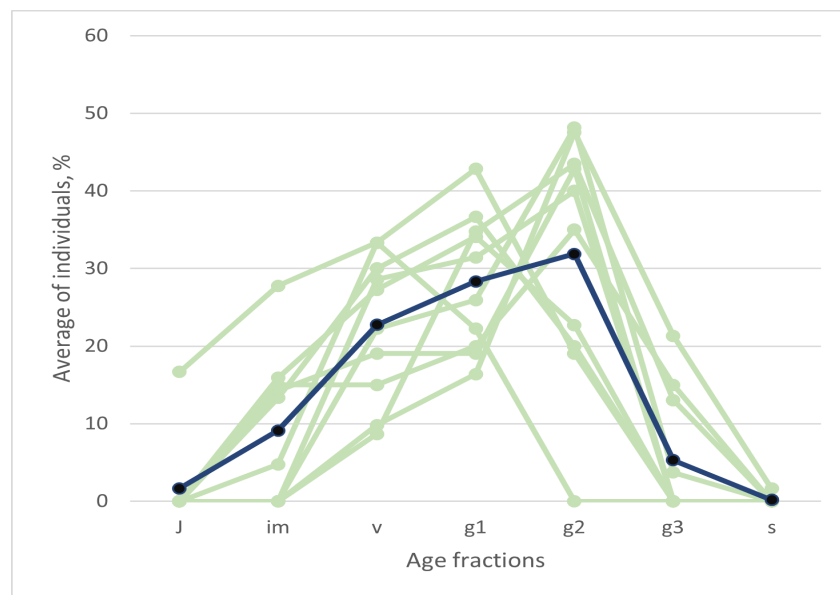


Figure 2. The average value of the age structure of the coenopopulations of *M. sativa*. The proportion of individuals is represented in green, whereas the average value is denoted in black.

Table 2. Demographic characteristics of *Medicago sativa* coenopopulations.

CP	Demographic indicators								Type of coenopopulation
	I _r	I _a	I _s	Density, individuals /m ²	P _{ecol} , individuals/m ²	Number of individuals	Δ	ω	
1	0.61	0	0.38	2.1	3	21	0.24	0.64	maturing
2	0.11	0.02	0.1	2.95	3.7	59	0.48	0.84	mature
3	0.09	0	0.08	2.3	2.8	23	0.41	0.85	mature
4	0.28	0	0.22	2.7	2.7	27	0.36	0.81	mature
5	0.42	0	0.3	2	2.8	20	0.35	0.69	maturing
6	0.95	0	0.48	3.9	3.9	39	0.12	0.41	maturing
7	1.0	0	0.51	3.1	3.4	31	0.18	0.55	young
8	0.4	0	0.28	3.5	3.5	35	0.32	0.77	young
9	3.5	0	0.77	1.8	1.8	18	0.11	0.38	maturing
10	0.54	0	0.35	2	2	20	0.31	0.71	maturing

Note: (I_r) – regeneration index, (I_a) – aging index, (I_{rp}) – replacement index, (P_{ecol}) – ecological density, (Δ – delta), (ω – omega).

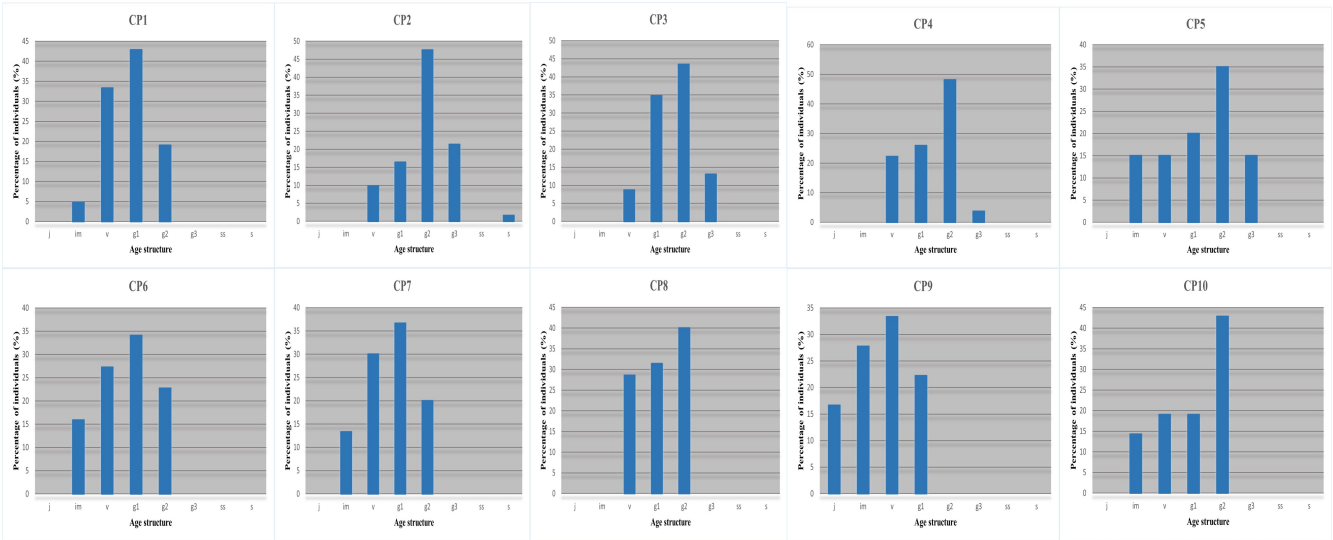


Figure 3. Ontogenetic structure of the coenopopulations of *M. sativa*.

CONCLUSIONS

The analysis of the ontogenetic structure of *Medicago sativa* coenopopulations in various natural and semi-natural habitats of northwestern, central, and southern Uzbekistan demonstrated that, although all populations belong to the normal type, the majority are incomplete. The left-sided spectrum identified in several coenopopulations (CP 1, 6, 7, 9) deviates from the characteristic type, indicating a strong influence of extreme abiotic factors. High solar radiation, pronounced microhabitat mosaicism, frequent exogenous disturbances (landslides, mudflows), and a shortened growing season promote

successful germination at the early ontogenetic stages but simultaneously limit the long-term persistence of mature generative individuals. Thus, abiotic stressors shape an asymmetric ontogenetic spectrum by constraining the processes of age-related regeneration.

In contrast, most coenopopulations (CP 2, 3, 4, 5, 8, 10) exhibit a centered spectrum corresponding to the characteristic type (Fig. 3). This structure reflects a more balanced interaction between external environmental conditions and internal population dynamics, ensuring relative stability through the prevalence of middle-aged

generative individuals. The average age composition is shifted toward the generative stage, with a distinct peak in middle-aged generative plants, which indicates a certain degree of stabilization of population processes under these conditions.

The absence or very low representation of juvenile individuals in most coenopopulations, along with the predominance of middle-aged generative plants, is explained by high mortality at the early stages. This mortality results from the combined effects of anthropogenic pressure, limitations imposed by habitat conditions, and the characteristics of soil–vegetation cover that determine both the likelihood of seed germination and seedling survival. Hence, the early ontogenetic stages appear to be the most dependent on external environmental factors.

Consequently, the ontogenetic spectrum of *Medicago sativa* populations is characterized by reduced seed-based renewal and a gradual increase in the proportion of adult individuals. This pattern highlights that population structure is strongly regulated by the combined effects of abiotic stressors and anthropogenic disturbance, which jointly determine not only the age distribution but also the long-term stability of *M. sativa* coenopopulations.

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