

Research Article

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Floristic diversity, geobotanical structure and ecological significance of plant communities of *Tanacetum vulgare* L. in the foothill ecosystems of Southeast Kazakhstan

The article presents the results of a comprehensive study of the floristic diversity, geobotanical structure, and ecological significance of plant communities of *Tanacetum vulgare* L. growing in the foothill ecosystems of southeastern Kazakhstan. The relevance of the study is determined by the multifunctional significance of common tansy, a multipurpose plant used for food, fodder, technical, and ornamental purposes, as well as in traditional and conventional medicine. In the context of increasing anthropogenic pressure and the transformation of natural ecosystems, studying the ecological and coenotic role of this species is of particular scientific and practical importance. It was established that *Tanacetum vulgare* L. plant communities are characterized by high floristic diversity and a predominance of mesophytic and mesoxerophytic species. The studied species occurs as a constant or subdominant component of the herbaceous layer, demonstrating high ecological plasticity and resistance to changing environmental conditions. The obtained results expand our understanding of the structure and functioning of foothill phytocenoses and may be used for biodiversity monitoring, ecosystem status assessment, and the rational and sustainable use of plant resources in southeastern Kazakhstan.

Keywords: *Tanacetum vulgare* L., floristic diversity, geobotanical structure, phytocenosis, ecological significance, foothill ecosystems, phytopreparation Southeast Kazakhstan.

Introduction

Accelerated landscape modification driven by expanding land use and increasing climatic variability has intensified the need to investigate vegetation processes in ecotonal territories [1]. Foothill ecosystems represent transitional zones that connect steppe plains with mountain systems and function as dynamic interfaces where species exchange, environmental gradients, and structural heterogeneity converge. Owing to their complex topography and microclimatic variability, these landscapes are particularly sensitive to both natural fluctuations and anthropogenic disturbances [2–5].

The functional integrity of plant communities is closely linked to their taxonomic diversity and spatial organization. Ecosystems with high species richness typically demonstrate greater resistance to environmental stress through niche differentiation and functional complementarity. In contrast, reduced floristic complexity often results in diminished soil stabilization capacity, altered hydrological regulation, and lower primary productivity. In foothill belts, where environmental gradients overlap with human activity, evaluating vegetation structure and species composition is essential for forecasting successional shifts and ecosystem transformation [6–8]. Within this ecological framework, plant communities incorporating *Tanacetum vulgare* L. offer a valuable model for integrated geobotanical analysis. The species exhibits wide ecological amplitude and occurs across meadow, meadow-steppe, forest-steppe, and riparian habitats from lowland areas to middle mountain elevations. Its morphological and physiological adaptations—including a well-developed perennial root system, high regenerative ability, prolonged vegetative phase, and tolerance to moderate grazing and trampling—enable long-term persistence under semi-natural and moderately disturbed

conditions. Depending on habitat characteristics, *T. vulgare* may function as a constant community component or achieve subdominant status, influencing interspecific competition and vegetation structure [9].

Beyond its ecological adaptability, *T. vulgare* possesses considerable medicinal and biochemical significance. The aerial parts of the plant contain 0.1–0.3 % essential oil, rich in monoterpenes and oxygenated compounds. The principal constituents of the essential oil include β -thujone (up to 60–70 % of the oil fraction depending on population), camphor (10–20 %), borneol (5–10 %), and pinene derivatives [10, 11]. In addition to volatile compounds, the plant accumulates sesquiterpene lactones (including tanacetin), flavonoids such as luteolin and quercetin (total flavonoid content typically exceeding 2–2.5 % in dry matter), hydroxycinnamic acids, alkaloids (~0.04 %), and tannins. These secondary metabolites are responsible for documented anti-inflammatory, antimicrobial, antiparasitic, choleric, and antioxidant properties, which explain the long-standing application of the species in traditional medicine and its current use in phytopharmaceutical and cosmetic industries. Extracts of *T. vulgare* are also utilized in the production of botanical insecticides and repellents due to their bioactive terpene composition. However, the relatively high concentration of thujone—a neurotoxic monoterpene ketone—necessitates controlled dosage and scientifically grounded application standards [12].

Therefore, understanding the ecological distribution and population structure of this species is important not only for vegetation science but also for sustainable management of medicinal plant resources. At the same time, increased anthropogenic disturbance may alter community equilibrium by enhancing the competitive advantage of *T. vulgare*, potentially leading to reduced floristic evenness. Such structural shifts may influence overall ecosystem functioning, particularly in transitional foothill landscapes where species interactions are strongly modulated by environmental gradients [13, 14]. Despite its wide Eurasian distribution and recognized pharmacological relevance, the structural role and coenotic contribution of *T. vulgare* in the foothill ecosystems of Southeast Kazakhstan remain insufficiently characterized. The scarcity of comprehensive regional geobotanical assessments limits objective evaluation of vegetation dynamics, species interactions, and successional development under changing environmental conditions [15].

Accordingly, the present study aims to analyze the floristic diversity, spatial structure, and ecological significance of plant communities containing *T. vulgare* L. in the foothill zone of Southeast Kazakhstan, and to identify the environmental drivers that determine its distribution patterns and functional role within phytocenoses.

Experimental

Field investigations were carried out in the foothill ecosystems of the Kapchagay (Konayev) region, Southeast Kazakhstan, within the northern slope of the Ile Alatau mountain system. The study area is located within the geographic range of 43.70°–43.95° N and 76.90°–77.30° E (WGS84, EPSG:4326). Vegetation cover is represented by meadow, meadow-steppe, and typical foothill plant communities. The spatial distribution of the sampling sites is shown in Figure 1. The absolute elevation of the surveyed sites ranged from 600 to 1,200 m above sea level (a.s.l.), corresponding to the lower and middle foothill belt. Elevation values were recorded using a handheld GPS device and subsequently verified using the SRTM-based Digital Elevation Model (DEM) available in Google Earth Pro (Fig. 1).

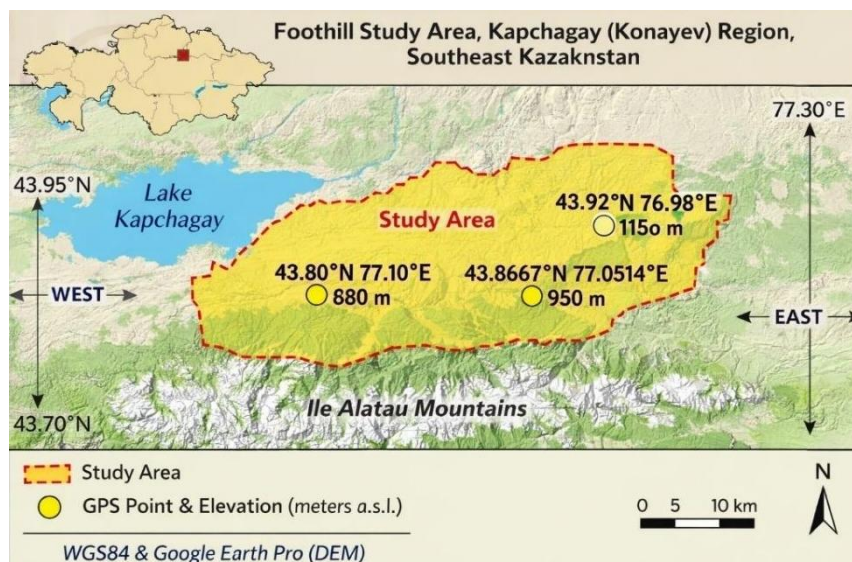


Figure 1. Geographic location and spatial arrangement of the studied cenopopulations of *Tanacetum vulgare* in the foothill coastal zone of South-East Kazakhstan (Kapchagay area)

The soil cover of the foothill coastal zone of the Kapchagay region is predominantly composed of chestnut-type gray-brown soils and soddy-meadow soils formed under a temperate continental climate with pronounced seasonal variability in precipitation and temperature. Gray-brown soils are mainly distributed on well-drained northern and northeastern slopes. They are characterized by light to medium loamy texture, moderate humus content in the upper horizons, carbonate accumulation in subsurface layers, and a neutral to slightly alkaline soil reaction (pH 7.0-8.2). Their relatively low water-holding capacity is typical of semi-arid steppe environments and supports meadow-steppe phytocenoses dominated by xeromesophytic species [16].

Soddy-meadow soils occur within the coastal belt of the Kapchagay Reservoir and in moisture-accumulating depressions. These soils exhibit higher organic matter content in surface horizons, improved structural aggregation, and increased moisture availability, creating favorable edaphic conditions for mesophytic perennial grasses. The soil moisture regime varies along the topographic gradient, remaining moderate on elevated slopes and increasing in areas adjacent to the reservoir due to capillary water rise and local microclimatic effects. Anthropogenic pressure is assessed as low to moderate and is associated with seasonal recreational use, localized livestock grazing, and partial agricultural transformation. These factors contribute to localized soil compaction and enhanced spatial heterogeneity of vegetation cover [16]. The existing soil conditions represent a transitional edaphic environment between meadow and meadow-steppe ecosystems, providing favorable ecological conditions for the stable persistence of *T. vulgare* populations. Climatically, the region belongs to a temperate continental semi-arid zone, characterized by warm summers and relatively mild winters.

Fieldwork was conducted during the active growing season, specifically in May and June 2025, corresponding to the flowering and seed formation stages of most plant species. This period ensured accurate taxonomic identification based on morphological characteristics. The research program included route surveys, establishment of transects and sampling plots, and detailed geobotanical descriptions of plant communities. Route surveys were conducted to identify vegetation diversity, locate areas where *T. vulgare* occurs, and preliminarily assess its growth conditions in different ecotypes [17].

The study focused on one population of *T. vulgare*, within which three cenopopulations were distinguished according to habitat conditions. Within each cenopopulation, three transects were established. Each transect corresponded to a permanent 10 × 10 m (100 m²) sampling plot. The total number of transects was nine (3 cenopopulations × 3 transects). Transects were located within three vegetation types: meadow communities, meadow-steppe communities, and typical foothill communities [18]. Sampling plots were selected within homogeneous vegetation patches to minimize edge effects. In the geobotanical and floristic survey, a complete inventory of higher vascular plants was conducted within each 100 m² plot [19]. For each species, the following parameters were recorded: presence, abundance, projective cover (%), and spatial distribution pattern within the community. Species identification was performed during flowering and fruiting stages

based on morphological characteristics of vegetative and generative organs using regional floras and identification manuals [20]. Plant specimens collected in the study area were identified using Flora of Kazakhstan (Volumes I–IX) and the Illustrated Guide to Plants of Kazakhstan [20, 21]. Species abundance was assessed using the Braun–Blanquet cover-abundance scale and the Hult–Drude scale, allowing comparability with classical geobotanical studies. Projective cover (%) was visually estimated within each 100 m² plot. Spatial distribution patterns were classified as uniform, grouped (clustered), or patchy [22]. The vertical and horizontal structure of phytocenoses was analyzed, including stratification, density of the herb layer, and the position of dominant and subdominant species.

For *T. vulgare* additional parameters were evaluated, including frequency of occurrence, cenotic position within the community (dominant, subdominant, or accompanying species), and its contribution to total projective cover. In biodiversity assessment and statistical analysis, species richness (S) was calculated as the total number of higher vascular plant species per 100 m² plot. Floristic diversity was evaluated using the Shannon–Weaver index (H') [23] and Simpson index (D) [24].

Results and Discussion

During the study, the population of *T. vulgare* was investigated in the foothill zone of the Kapchagay (Konaev) region on the northern slope of the Ile Alatau mountain system, within the coordinate range of 43.70°–43.95° N and 76.90°–77.30° E (WGS84, EPSG:4326). Phytocenotic Structure and Ecological Characteristics of Cenopopulation I (430–500 m above sea level, near the reservoir belt). Cenopopulation I, examined within the foothill ecosystems of Southeastern Kazakhstan, occupies humid meadow-forest sites situated at elevations of 430–500 m above sea level in close proximity to the reservoir. Due to the specific features of microrelief, this territory is relatively well moistened; its soils belong to the soddy-meadow type and it is characterized by favorable light conditions associated with open habitats. Such environmental conditions allow the formation of a plant community distinguished by high density and stable structural organization. The floristic composition of the community developed in a mesophytic direction. Perennial grasses occupy a leading position in the species structure. The principal dominants and subdominants include *Poa pratensis*, *Festuca pratensis*, *Dactylis glomerata*, and *Phleum pratense*. These species are characterized by high frequency values and considerable projective cover. Their well-developed root systems stabilize soil structure and contribute to moisture retention.

Among Fabaceae, *Trifolium pratense*, *Medicago falcata*, and *Melilotus officinalis* are widely distributed. Through nitrogen fixation processes, they enhance soil fertility and participate in maintaining the trophic balance of the community. Among Asteraceae, *Achillea millefolium*, *Taraxacum officinale*, and *T. vulgare* perform an important phytocenotic role. In Cenopopulation I, *T. vulgare* was recorded at the subdominant level. Its projective cover averaged 8–12 %, reaching up to 15 % in certain microsites. The sufficient number of generative shoots indicates a stable population state. Within the community, *Tanacetum vulgare* is relatively evenly distributed and, together with the dominant grasses, contributes to maintaining the structural integrity of the phytocenosis. The overall vegetation cover density reached 95–100 %. Such a high projective cover confirms the high productivity of the phytocenosis and sufficient moisture availability. The soil surface is almost entirely covered by herbaceous vegetation, and bare patches are practically absent. The community is characterized by a distinct four-layered structure.

The uppermost layer (1.5–3.0 m) consists of sparsely distributed woody and shrub species, including *Salix alba*, *Salix triandra*, *Rosa iliensis*, and *Elaeagnus oxycarpa*. This layer regulates the light regime, reduces wind speed, and creates specific microclimatic conditions. The second layer (60–110 cm) is composed of tall perennial herbaceous species. In this layer, *D. glomerata*, *T. vulgare*, and *A. millefolium* predominate. This layer forms the main vertical profile of the phytocenosis.

Cenopopulation I, studied within the foothill ecosystems of Southeastern Kazakhstan, occupies humid meadow-forest sites situated at elevations between 430 and 500 m above sea level in close proximity to the reservoir. Owing to specific microrelief features, this area is relatively well moistened; its soils belong to the soddy-meadow type and are characterized by favorable light conditions associated with open habitats. Such environmental settings enable the formation of a plant community distinguished by high density and stable structural organization. The floristic composition of the community has developed predominantly in a mesophytic direction. Perennial grasses occupy a leading position in the species structure. The principal dominants and subdominants include *P. pratensis*, *F. pratensis*, *D. glomerata*, and *P. pratense*. These species are characterized by high frequency values and considerable projective cover. Their well-developed root systems stabilize soil structure and contribute to moisture retention.

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The third layer (30–60 cm) was composed of dominant grasses and formed the main bulk of community biomass. Within this layer, *P. pratensis*, *F. pratensis*, *D. glomerata*, and in some sites *Bromus inermis* predominated. These species were distinguished by high projective cover and well-developed vegetative reproduction capacity. Their dense turf-forming root systems stabilize soil structure and contribute to maintaining its aggregate composition. This particular layer ensures the overall density of vegetation cover, shades the soil surface, and reduces the intensity of moisture evaporation. In addition, it moderates seasonal temperature fluctuations and creates favorable microclimatic conditions for plants of the lower layers. The stable development of the third layer serves as a key indicator of phytocoenosis productivity and ecological stability.

The fourth layer (5–30 cm) consisted of low-growing mesophytic and eurytopic species. This layer included *Plantago major*, *V. chamaedrys*, *Potentilla anserina*, *T. officinale*, and other low herbaceous plants. These species form a dense ground cover that prevents erosion processes. The lower-layer plants participate in the accumulation of organic residues and humus formation, thereby playing an important role in increasing soil fertility. Furthermore, this layer facilitates regeneration processes and ensures rapid recovery of vacant microsites. The ecological plasticity of species within the lower layer enhances the adaptive capacity of the community to changing environmental conditions.

Thus, the third and fourth layers maintain the structural integrity of the phytocoenosis and ensure its functional stability. While the third layer forms the primary biomass component, the fourth layer performs soil-protective and regenerative functions. The interaction between these layers allows the community to maintain ecological balance.

Structurally, Cenopopulation I represents a stable, uniform, and ecologically balanced system. According to both Hult–Drude and Braun–Blanquet scales, the high proportion of dominant categories indicates strong biomass concentration and dense vegetation cover. The relatively low proportion of rare species reflects a high level of structural stability.

From an ecological perspective, this cenopopulation develops in a hydromesophytic direction and is dependent on the moisture regime. The combination of elevation and microclimatic conditions supports high phytocoenosis productivity and stable vertical organization. Under these conditions, *T. vulgare* maintains a stable subdominant position and functions as an integral structural component of the community. Cenopopulation I belongs to the humid meadow-forest type and represents a structurally well-developed and ecologically stable phytocoenosis. Its high vegetation cover density, clearly expressed stratification, and predominance of mesophytic species indicate that this system is developing under relatively favorable ecological conditions.

As a result of the study, 50 species of higher vascular plants were recorded within the territory of Cenopopulation I. Due to its proximity to the reservoir, the community was characterized as hydromesophytic. According to the Frequency (%) structure, species were grouped as follows: — High frequency (≥ 60 %) — 8 species (16 %) (*P. pratensis*, *F. pratensis*, *D. glomerata*, *Artemisia vulgaris*, etc.); Medium frequency (30–59 %) — 22 species (44 %); — Low frequency (< 30 %) — 20 species (40 %).

According to the Hult–Drude cover-abundance scale, the distribution of species within Cenopopulation I was as follows: Cop3–Cop2 (dominants and subdominants) — 14 species (28 %); Cop1 (moderate abundance) — 18 species (36 %); Sp (rare) — 12 species (24 %); Sol (solitary individuals) — 6 species (12 %). The proportion of 14 species belonging to the Cop2 — Cop3 categories indicates the for-

mation of an ecologically significant structural core within the community. This group primarily includes perennial grasses and stable mesophytic elements that determine the vertical structure of the phytocoenosis, vegetation density, and the main portion of biomass accumulation. The relatively high proportion of the Cop1 category (36 %) enhances the structural diversity of the community and provides additional ecological stability to the dominant core. Species within this group form secondary structural components of the phytocoenosis and contribute to spatial mosaicity. The combined proportion of Sp and Sol categories (36 %) demonstrates the considerable presence of species occurring as rare or solitary individuals. Such species are often adapted to specific ecological niches or may represent temporary succession elements. The relatively high share of Cop2–Cop3 categories (28 %), together with the predominance of Cop1 species, confirms that the phytocoenosis is dense, well-developed, and structurally stable. This pattern is directly associated with the hydromesophytic character of Cenopopulation I and the favorable moisture regime. Overall, the data obtained according to the Hult–Drude scale indicate that Cenopopulation I represents an ecologically balanced meadow community with a clearly expressed dominant structure and relative resistance to anthropogenic impact.

To assess species abundance and vegetation cover levels in Cenopopulation I, both the Hult–Drude and Braun–Blanquet scales were applied. The results of the two scales were mutually consistent and confirmed the structural stability of the community. According to the Hult–Drude scale: Cop3–Cop2(dominant/subdominant) — 28 % of species; Cop1 — 36 %; Sp + Sol — 36 %. These indicators demonstrate the presence of a clearly formed dominant core within the phytocoenosis, while secondary and rare elements ensure structural diversity.

According to the Braun–Blanquet scale: Classes III–IV (moderate to high cover) — 36 %; Class II — 40 %; Class I + — 24 %. Thus, the predominance of classes III–II confirms the high overall vegetation density (80–90 %). Cop2–Cop3 categories largely correspond to Braun–Blanquet classes III–IV, indicating that dominant and subdominant species are widely distributed and possess high projective cover. Cop1 species mainly correspond to Braun–Blanquet class II, meaning these species are stable structural components but not absolutely dominant. Sp and Sol categories correspond to Braun–Blanquet classes I and +, reflecting species that occur rarely or at the periphery of the community. In the ecological interpretation of the community structure, dominant species were mainly represented by perennial grasses. Subdominants consisted of mesophytic and mesoxerophytic perennials, whereas rare species were primarily ruderal or successional elements. Such a structural organization ensures high biomass production, well-developed stratification, stable microclimate formation, and relative resilience to anthropogenic disturbance (Tab. 1).

Table 1

**Floristic diversity and ecological structure of Cenopopulation I (430–500 m a.s.l.)
of *Tanacetum vulgare* in the Kapchagay foothills (South-East Kazakhstan)**

No	Species	Frequency, %	Hult–Drude	Braun–Blanquet	Ecological group
1	<i>Equisetum arvense</i>	25	2	II	Mesophyte
2	<i>Phragmites australis</i>	30	3	III	Hygrophyte
3	<i>Typha angustifolia</i>	15	2	II	Hygrophyte
4	<i>Poa pratensis</i>	40	3	III	Mesophyte
5	<i>Festuca pratensis</i>	35	3	III	Mesophyte
6	<i>Dactylis glomerata</i>	45	3	III	Mesophyte
7	<i>Bromopsis inermis</i>	45	3	III	Xeromesophyte
8	<i>Agrostis stolonifera</i>	30	3	III	Hygromesophyte
9	<i>Phleum pratense</i>	30	3	III	Mesophyte
10	<i>Stipa capillata</i>	40	3	III	Xerophyte
11	<i>Allium decipiens</i>	15	2	II	Xerophyte
12	<i>Carex colchica</i>	25	2	II	Hygromesophyte
13	<i>Juncus compressus</i>	20	2	II	Hygrophyte
14	<i>Trifolium pratense</i>	35	3	III	Mesophyte
15	<i>Trifolium repens</i>	30	3	III	Mesophyte
16	<i>Medicago falcata</i>	40	3	III	Mesophyte
17	<i>Melilotus officinalis</i>	30	3	III	Xeromesophyte
18	<i>Vicia cracca</i>	25	2	II	Mesophyte
19	<i>Achillea millefolium</i>	45	3	III	Mesophyte

Continuation of Table 1

No	Species	Frequency, %	Hult–Drude	Braun–Blanquet	Ecological group
20	<i>Taraxacum officinale</i>	30	3	III	Mesophyte
21	<i>Tanacetum vulgare</i>	25	2	II	Xeromesophyte
22	<i>Artemisia austriaca</i>	20	2	II	Xerophyte
23	<i>Artemisia vulgaris</i>	50	4	IV	Xeromesophyte
24	<i>Xanthium spinosum</i>	20	2	II	Mesophyte
25	<i>Onopordon acanthium</i>	15	2	II	Xerophyte
26	<i>Conyza canadensis</i>	20	2	II	Mesophyte
27	<i>Dodartia orientalis</i>	20	2	II	Xerophyte
28	<i>Verbascum songoricum</i>	15	2	II	Xeromesophyte
29	<i>Galium verum</i>	25	2	II	Xeromesophyte
30	<i>Plantago major</i>	25	2	II	Mesophyte
31	<i>Plantago lanceolata</i>	30	3	III	Xeromesophyte
32	<i>Convolvulus arvensis</i>	20	2	II	Mesophyte
33	<i>Thlaspi arvense</i>	20	2	II	Mesophyte
34	<i>Descurainia sophia</i>	20	2	II	Mesophyte
35	<i>Berteroa incana</i>	15	2	II	Xeromesophyte
36	<i>Rosa iliensis</i>	10	1	I	Xeromesophyte
37	<i>Polygonum aviculare</i>	30	3	III	Mesophyte
38	<i>Salix alba</i>	20	2	II	Hygromesophyte
39	<i>Salvia stepposa</i>	35	3	III	Xeromesophyte
40	<i>Papaver rhoeas</i>	40	3	III	Xeromesophyte
41	<i>Urtica dioica</i>	20	2	II	Hygrophyte
42	<i>Euphorbia palustris</i>	35	3	III	Hygrophyte
43	<i>Elymus repens</i>	40	3	III	Mesophyte
44	<i>Capsella bursa-pastoris</i>	20	2	II	Mesophyte
45	<i>Rumex acetosa</i>	25	2	II	Mesophyte
46	<i>Rumex crispus</i>	20	2	II	Mesophyte
47	<i>Chenopodium album</i>	15	2	II	Xeromesophyte
48	<i>Atriplex patula</i>	15	2	II	Xeromesophyte
49	<i>Thymus marschallianus</i>	20	2	II	Xerophyte
50	<i>Campanula patula</i>	15	2	II	Mesophyte
51	<i>Stellaria graminea</i>	20	2	II	Mesophyte

Cenopopulation II (500–570 m above sea level). Cenopopulation II is located in the upper part of the altitudinal gradient and represents a transitional meadow-steppe type. As a result of the study, 45 species of higher vascular plants were identified within this cenopopulation. The taxonomic structure was classified into two divisions, three classes, and 17 families. The majority of the flora is represented by angiosperms (Magnoliophyta), whereas the division Equisetophyta is represented by only a single species. Among the classes, dicotyledons (Magnoliopsida) occupy the leading position, indicating an increasing contribution of steppe elements within the community. At the same time, the monocotyledonous class (Liliopsida) also plays a significant role in the taxonomic structure of the community. A total of 14 species belonging to the class Liliopsida were identified, the majority of which are representatives of the family Poaceae. Grasses form the dominant and subdominant structure of the community and constitute the main component of phytocoenotic biomass. Species such as *P. pratensis*, *F. pratensis*, *Stipa capillata*, *Aegilops cylindrica*, and *Bromopsis inermis* were distinguished by high frequency and cover values. These species form the principal part of the second vertical layer (II layer) within the phytocoenosis and ensure the overall density of vegetation cover.

The predominance of Poaceae reflects the ecological specificity of this transitional ecosystem. With increasing elevation and a relatively reduced moisture regime, the proportion of xerophytic and xeromesophytic grasses increases. According to literature data, these species are characterized by drought tolerance and well-developed root systems, contributing to soil stabilization and the reduction of erosion processes. In addition, monocotyledonous species contribute to maintaining the microclimatic stability of the community. Dense grass cover shades the soil surface, reduces moisture evaporation, and moderates seasonal temperature fluctuations. Such conditions create favorable circumstances for the stable persistence of other mesophytic and xeromesophytic species.

Within the family structure, Poaceae and Asteraceae occupy leading positions, which is characteristic of meadow-steppe phytocenoses. Families such as Fabaceae, Brassicaceae, and Lamiaceae also contribute significantly to the overall floristic composition. Hygrophytic elements decrease in abundance, while the proportion of xerophytic and xeromesophytic species increases.

From an ecological perspective, Cenopopulation II is characterized by the predominance of xeromesophytic and xerophytic species alongside mesophytes. This pattern is directly associated with changes in altitude and the moisture regime. As the distance from the reservoir increases, the direct influence of surface and capillary moisture decreases, leading to a higher proportion of drought-tolerant species. In terms of floristic composition and taxonomic structure, Cenopopulation II corresponds to a transitional meadow-steppe type. Compared to Cenopopulation I, its structure displays a more pronounced xeromesophytic character and a spatially mosaic organization. These features indicate the ecological flexibility of *Tanacetum vulgare* and its capacity to tolerate varying moisture conditions.

Analysis of frequency values among the 45 recorded species revealed three principal groups. Species with high frequency ($\geq 60\%$) comprised 9 taxa (20%), including *P. pratensis*, *F. pratensis*, *A. vulgaris*, *Stipa capillata*, and *Aegilops cylindrica*. Species with moderate frequency (40–59%) accounted for 18 taxa (40%), while low-frequency species ($< 40\%$) also represented 18 taxa (40%).

Most of the high-frequency species belong to xerophytic and xeromesophytic ecological groups. Grasses and wormwood species within this category form the dominant structural framework of the community. Their elevated frequency reflects drought tolerance, well-developed root systems, and effective vegetative reproduction. These adaptive traits confirm that Cenopopulation II has developed under relatively drier environmental conditions associated with increasing elevation.

The group of moderately frequent species (40%) contributes substantially to the ecological diversity of the phytocenosis. This group is largely composed of mesophytic and mesoxerophytic taxa that, together with the dominants, maintain structural integrity and prevent complete xerophytization of the community. Such a configuration is typical of transitional ecosystems, where both meadow and steppe elements coexist.

Low-frequency species (40%) occur sporadically or are confined to localized microhabitats. A considerable portion of these taxa are ruderal or occupy peripheral ecological niches. Their relatively high proportion reflects the mosaic spatial organization and ecological heterogeneity of Cenopopulation II. Structural analysis of frequency data demonstrates a clear predominance of xerophytic and xeromesophytic steppe elements. The dominance of steppe grasses among high-frequency taxa indicates a directional ecological shift toward drier environmental conditions. Simultaneously, the increased share of moderate- and low-frequency species suggests enhanced spatial heterogeneity and structural complexity of the phytocenosis. These transformations are associated with altitudinal gradients and moisture variability, reflecting ecological reorganization of the community. The obtained data further emphasize the high ecological plasticity of *Tanacetum vulgare* and its ability to adapt to diverse moisture and edaphic conditions.

According to the Hult–Drude cover–abundance scale, species distribution within Cenopopulation II was structured as follows: Cop2 (dominants) — 8 species (18%), Cop1 (subdominants) — 17 species (38%), Sp (sparse) — 14 species (31%), and Sol (solitary individuals) — 6 species (13%). These proportions indicate a relatively weaker dominant core and a more spatially heterogeneous organization of the community. The reduced proportion of Cop2 species suggests uneven biomass concentration, while the elevated representation of the Sp category reflects increased ecological niche differentiation and community heterogeneity.

In comparison with Cenopopulation I, the number of dominant species decreased, whereas the proportion of rare taxa increased. This shift confirms structural transformation associated with changes in altitude and moisture availability. Although the dominant layer remains present in Cenopopulation II, it exhibits a distinctly mosaic distribution pattern rather than forming a uniform phytocoenotic core.

According to the Braun–Blanquet cover–abundance assessment, species were distributed as follows: IV class — 5 species, III class — 15 species, II class — 17 species, and I plus (+) — 8 species. The predominance of III–II categories indicates that the phytocenosis has not undergone structural degradation and retains overall stability. However, the reduced number of species in the IV category demonstrates a decline in vegetation density compared to Cenopopulation I, with total projective cover estimated at approximately 75–85%.

The obtained results for Cenopopulation II reflect a noticeable reorganization of community structure. A decrease in cover uniformity suggests that vegetation is no longer spatially continuous but instead exhibits a mosaic pattern. The relative weakening of the dominant layer also affects the vertical organization of the phytocenosis. In contrast to Cenopopulation I, biomass in this case is not evenly concentrated but distributed

heterogeneously across different microsites. This pattern is associated with a reduced proportional cover of dominant species and a simultaneous increase in the spatial contribution of subdominant and sparse taxa. As a result, the structural framework of the community becomes less compact, and the phytocenosis acquires a more dynamic character.

The relative thinning of the lower layer is likewise linked to changes in environmental conditions. With increasing elevation and a less stable moisture regime, the proportion of mesophytic and hygrophytic elements declines. This shift affects both the density and species richness of the lower stratum and may potentially slow regeneration processes. In addition, uneven distribution of light and soil moisture restricts the full development of the ground layer. The observed reduction in cover density and the attenuation of the dominant structure in Cenopopulation II indicate that the community is undergoing ecological adjustment. The phytocenosis appears to be transitioning gradually from a meadow type toward a steppe type. Such structural transformation confirms the ability of *Tanacetum vulgare* populations to persist under varying altitudinal and moisture conditions, demonstrating a high degree of ecological plasticity (Tab. 2).

Table 2

**Floristic diversity and ecological structure of Cenopopulation II (500–570 m a.s.l.)
of *Tanacetum vulgare* in the Kapchagay foothills (South-East Kazakhstan)**

No	Species	Frequency, %	Hult–Drude	Braun–Blanquet	Ecological group
1	<i>Poa pratensis</i>	75	Cop2	III	Mesophyte
2	<i>Festuca pratensis</i>	70	Cop2	III	Mesophyte
3	<i>Dactylis glomerata</i>	65	Cop2	III	Mesophyte
4	<i>Stipa capillata</i>	60	Cop2	IV	Xerophyte
5	<i>Bromopsis inermis</i>	55	Cop1	III	Xeromesophyte
6	<i>Elymus repens</i>	50	Cop1	II–III	Mesophyte
7	<i>Anisantha tectorum</i>	50	Cop1	III	Xerophyte
8	<i>Aegilops cylindrica</i>	65	Cop2	IV	Xerophyte
9	<i>Eremopyrum orientale</i>	30	Cop1	II	Xerophyte
10	<i>Taeniatherum crinitum</i>	25	Cop1	II	Xerophyte
11	<i>Artemisia austriaca</i>	60	Cop2	IV	Xerophyte
12	<i>Artemisia frigida</i>	55	Cop1	III	Xerophyte
13	<i>Artemisia vulgaris</i>	70	Cop2	IV	Xeromesophyte
14	<i>Tanacetum vulgare</i>	55	Cop1	II–III	Xeromesophyte
15	<i>Achillea millefolium</i>	60	Cop2	III	Mesophyte
16	<i>Taraxacum officinale</i>	40	Cop1	II	Mesophyte
17	<i>Salvia stepposa</i>	50	Cop1	III	Xeromesophyte
18	<i>Thymus marschallianus</i>	45	Cop1	II	Xerophyte
19	<i>Convolvulus arvensis</i>	40	Cop1	II	Mesoxerophyte
20	<i>Plantago lanceolata</i>	45	Cop1	II	Mesoxerophyte
21	<i>Plantago major</i>	30	Sp	I	Mesophyte
22	<i>Galium verum</i>	50	Cop1	III	Xeromesophyte
23	<i>Medicago falcata</i>	55	Cop1	III	Mesoxerophyte
24	<i>Melilotus officinalis</i>	45	Cop1	II	Xeromesophyte
25	<i>Trifolium pratense</i>	50	Cop1	III	Mesophyte
26	<i>Trifolium repens</i>	35	Sp	II	Mesophyte
27	<i>Vicia cracca</i>	30	Sp	II	Mesophyte
28	<i>Thlaspi arvense</i>	25	Sp	II	Mesophyte
29	<i>Descurainia sophia</i>	25	Sp	II	Mesophyte
30	<i>Berteroa incana</i>	30	Sp	II	Xeromesophyte
31	<i>Polygonum aviculare</i>	35	Sp	II	Mesophyte
32	<i>Papaver rhoeas</i>	45	Cop1	III	Xeromesophyte
33	<i>Rosa iliensis</i>	20	Sol	I	Xeromesophyte
34	<i>Elaeagnus oxycarpa</i>	15	Sol	I	Xeromesophyte
35	<i>Salix alba</i>	15	Sol	I	Hygromesophyte
36	<i>Tamarix ramosissima</i>	20	Sol	I	Haloxerophyte
37	<i>Dodartia orientalis</i>	30	Sp	II	Xerophyte
38	<i>Verbascum songoricum</i>	25	Sp	II	Xeromesophyte

Continuation of Table 2

No	Species	Frequency, %	Hult–Drude	Braun–Blanquet	Ecological group
39	<i>Onopordon acanthium</i>	20	Sol	I	Xerophyte
40	<i>Xanthium spinosum</i>	30	Sp	II	Mesophyte
41	<i>Chenopodium album</i>	25	Sp	II	Xeromesophyte
42	<i>Atriplex patula</i>	25	Sp	II	Xeromesophyte
43	<i>Rumex acetosa</i>	30	Sp	II	Mesophyte
44	<i>Rumex crispus</i>	25	Sp	II	Mesophyte
45	<i>Urtica dioica</i>	20	Sol	I	Hygrophyte

The conducted research demonstrated that plant communities involving *T. vulgare*, although belonging to a single population, exhibit clear structural and ecological differentiation along the altitudinal gradient. Within the elevation range of 430–570 m above sea level, the two cenopopulations differ significantly in floristic composition, dominant structure, vegetation density, and ecological orientation.

Cenopopulation I (430–500 m) is located closer to the reservoir in a relatively well-moistened zone. A total of 50 species of higher vascular plants were recorded here, and the community developed under hydromesophytic conditions. Vegetation cover is dense (80–90 %, reaching up to 95 % in some sites), and the dominant layer is well expressed. According to the Hult–Drude scale, the proportion of Cop2–Cop3 categories reached 28 %, indicating the presence of a stable dominant core within the phytocenosis. The Braun–Blanquet assessment confirmed this pattern: the predominance of species belonging to cover classes III–IV reflects sufficient biomass concentration and uniform vegetation cover. In this community, mesophytic grasses form the structural framework, while *T. vulgare* acts as a stable subdominant species with a relatively even spatial distribution.

Cenopopulation II (500–570 m) is situated at a higher altitudinal level and is characterized by relatively drier ecological conditions. A total of 45 species were identified, indicating a slight decrease in species richness. The floristic composition shows an increased proportion of xeromesophytic and xerophytic elements, corresponding to a transitional meadow-steppe type. According to the Hult–Drude scale, the proportion of Cop2 species decreased to 18 %, while the share of sparse (Sp) species increased to 31 %. This pattern indicates a weakening of the dominant structure and the development of a more mosaic spatial organization. Within the Braun–Blanquet system, the number of species assigned to class IV decreased, whereas classes II–I increased in proportion. Total vegetation cover declined to 75–85 %. These changes suggest reduced uniformity of biomass distribution and a relative weakening of the dominant layer.

The results obtained from both scales are consistent: the reduction of Cop2 species corresponds to a decrease in the number of class IV species. This confirms structural reorganization of the community and reflects its transition to a more dynamic ecological state. While Cenopopulation I possesses a clearly expressed and stable dominant core, Cenopopulation II demonstrates an increased proportion of subdominant and sparse species, resulting in a comparatively loosened structural configuration.

Altitude and moisture regime exert a direct influence on phytocenotic organization. In the lower belt near the reservoir, mesophytic elements predominate and vegetation cover remains dense and uniform. In contrast, in the higher belt, drought-tolerant species increase in abundance, and the ecological orientation shifts toward steppe conditions. However, this change represents a transitional stage rather than complete transformation.

T. vulgare remains present under both ecological conditions, demonstrating high ecological plasticity. In Cenopopulation I, it occurs as a stable subdominant with relatively even distribution, whereas in Cenopopulation II its cover slightly decreases and distribution becomes less uniform. Nevertheless, the species maintains viability across different moisture and altitudinal regimes. Thus, comparative analysis shows that although both cenopopulations belong to a single population, the altitudinal gradient significantly influences their structural organization, floristic composition, and dominant patterns. Cenopopulation I corresponds to a stable meadow-type community, whereas Cenopopulation II exhibits features of a transitional meadow-steppe system. These findings scientifically substantiate the altitude-dependent structural differentiation of plant communities involving *T. vulgare*.

The high uniformity is primarily due to the developed three-tiered structure of the phytocenoses and the significant proportion of mesophytic rhizomatous grasses (*Poa pratensis*, *F. pratensis*, *D. glomerata*), which form a stable background for the grass stand and prevent the monopolization of space by individual species. Despite the persistent presence of *T. vulgare* as a subdominant, this species does not disrupt the uniform dis-

tribution of floristic elements or suppress associated mesophytic species. The uniform distribution of species within the population contributes to the maintenance of high functional stability of the phytocenoses, including effective microclimate regulation, soil stabilization, and the preservation of an optimal water regime. Thus, the population can be considered a standard (reference) meadow community of the foothill ecosystems of southeastern Kazakhstan, characterized by a highly uniform species distribution, sustainability, and ecological stability.

Application of the Braun-Blanquet scale allowed us to identify a pronounced hierarchical structure of the phytocenoses of population 1 and quantitatively characterize the contribution of individual species to the formation of the herbaceous layer. Category 3 (26–50 %) included the dominant grass species *P. pratensis* L. and *F. pratensis* Huds, which form the main background of the herbage and ensure high community density. Category 2 (6–25 %) included subdominant species: *T. vulgare* L., *D. glomerata* L., *T. pratense* L., *M. falcata* L., *Galium verum* L., and *A. millefolium* L. It was in this group that *T. vulgare* exhibited the greatest cenotic stability. Category 1 (1–5 %) was represented by assectator species: *P. major* L., *V. chamaedrys* L., *Potentilla anserina* L., *T. officinale* F.H. Wigg., *Ranunculus acris* L., *Rumex acetosa* L., which form the regenerative and stabilizing ground layer. Categories r and + (<1 %) included single and rare species: *Capsellabursa-pastoris* L., *Stellaria media* L., *Chenopodium album* L., indicating local anthropogenic influence and micromosaic nature of phytocenoses. The altitudinal gradient in the study area revealed a distinct differentiation in the floristic composition and geobotanical structure of plant communities, accompanied by a consistent change in species frequency. Vertical zonation is due to the complex influence of climatic, edaphic, and orographic factors, primarily changes in air temperature, moisture regime, and slope exposure. The lower part of the altitudinal belt (430–500 m a.s.l.) is characterized by the development of xerophytic-xeromesophytic wormwood-grass communities with the participation of ruderal and halophytic elements. The greatest floristic diversity and maximum occurrence rates are noted here. The dominant species are *Aegilops cylindrica* (90 %, score V), *A. vulgaris* (85 %, scores IV–V), *Stipa capillata*, *Anisantha tectorum*, *Leymus angustus*, and *A. frigida*. These species form a dense turf cover and determine the overall physiognomic appearance of the phytocenosis. The high frequency of ruderal species (*Polygonum aviculare*, *Tanacetum vulgare*, *Xanthium strumarium*, *Descurainia sophia*) indicates significant anthropogenic impact and soil compaction. In the mid-altitude zone, a gradual transition from xerophytic to xeromesophytic-mesophytic meadow-steppe communities is observed. The proportion of mesophytic grasses and legumes increases: *P. pratensis*, *F. pratensis*, *D. glomerata*, *T. pratense*, and *M. officinalis*, accompanied by an increase in the projective cover of the grass stand.

The frequency of xerophytes (*Artemisia frigida*, *Aegilops cylindrica*, and *Taeniatherum crinitum*) decreases slightly, while mesophytic species tend to increase in frequency, which is associated with a more favorable moisture regime and lower thermal stress. In the upper altitude zone, mesophytic meadow-forest communities with tree and shrub forms develop. The frequency of occurrence of mesophytic and hygromesophytic species increases: *Picea schrenkiana*, *Pinus sylvestris*, *Carex colchica*, *Rosa iliensis*, *Schoenoplectus lacustris*. The proportion of ruderal and xerophytic elements significantly decreases, reflecting reduced anthropogenic load and a more stable hydrothermal regime. Thus, a clear zonal change in phytocenoses is observed along the altitudinal gradient: from xerophytic-wormwood-grass communities of the lower belt through xeromesophytic-meadow-steppe communities of the middle belt to mesophytic meadow-forest communities of the upper belt. Changes in species frequency along the altitudinal profile reflect the adaptation of the flora to changing conditions of moisture, temperature, and the degree of anthropogenic impact.

Conclusion

The comprehensive study conducted in the foothill ecosystems of Southeastern Kazakhstan revealed clear structural and floristic differentiation of plant communities involving *Tanacetum vulgare* L. along the altitudinal gradient within 430–570 m above sea level. The identified differences correspond to measurable changes in vegetation cover, dominance structure, and species composition.

Two phytocenotic variants were distinguished within a single population of *Tanacetum vulgare* L. In the lower altitudinal belt (430–500 m a.s.l.), located closer to the reservoir, meadow-type communities were recorded. This cenopopulation included 50 vascular plant species and was characterized by high projective cover (95–100 %) and a well-developed dominant structure. According to the Hult–Drude scale, Cop2–Cop3 categories accounted for 28 %, Cop1 for 36 %, and Sp + Sol for 36 %. The Braun–Blanquet assessment indicated the predominance of classes III–IV, and total vegetation cover ranged between 80–90 %, reaching up

to 95 % in certain plots. These parameters reflect a relatively concentrated biomass distribution and a clearly expressed dominant core.

In contrast, in the upper altitudinal belt (500–570 m a.s.l.), the community exhibited features of a transitional meadow-steppe type. This cenopopulation contained 45 vascular plant species, and total vegetation cover decreased to 75–85 %. According to the Hult–Drude scale, the proportion of Cop2 species declined to 18 %, while sparse species (Sp) increased to 31 %. The Braun–Blanquet scale showed a reduction in class IV species to five, with classes II–III predominating. These changes indicate a decrease in dominance concentration and a more heterogeneous spatial distribution of vegetation.

Comparative analysis demonstrated that increasing elevation is associated with a reduction in total vegetation cover, a decline in dominance intensity, and an increased proportion of xerophytic and xeromesophytic elements. The concordance between the Hult–Drude and Braun–Blanquet assessments confirms that the decrease in Cop2 abundance corresponds to a reduction in high cover classes, providing consistent quantitative evidence of structural transformation along the altitudinal gradient.

Floristic analysis showed that Poaceae and Asteraceae were the leading families in both cenopopulations, which is typical for foothill meadow and transitional meadow-steppe phytocoenoses. Species richness remained relatively high (50 species in Cenopopulation I and 45 species in Cenopopulation II), reflecting the floristic variability of the study area.

T. vulgare maintained a subdominant position in both ecological conditions. In Cenopopulation I, its projective cover ranged between 8–12 % and its distribution was relatively uniform, whereas in Cenopopulation II, its cover decreased to 5–10 % and spatial distribution became less uniform. Despite these changes, the species remained a consistent structural component of both communities.

Overall, the study provides quantitative evidence of altitude-related structural differentiation of *T. vulgare* communities in the foothill ecosystems of Southeastern Kazakhstan. Cenopopulation I corresponds to a meadow-type phytocoenosis with higher vegetation density and more concentrated dominance, whereas Cenopopulation II represents a transitional meadow-steppe community characterized by reduced cover and increased representation of xeromesophytic species.

Conflict of Interest

The authors declare no conflict of interest.

Author contribution

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript. CRediT: **Smayelova K.A.** — conceptualization, data curation, investigation, visualization, writing — original draft; **Abdukadirova Zh.A.** — project administration, resources, supervision; **Anarbekova G.D., Kozhamzharova A.S.** — writing — review & editing; **Izbastina K.S., Aitzhanova M.O.** — methodology, formal analysis.

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Оңтүстік-Шығыс Қазақстанның тау етегіндегі экожүйелеріндегі *Tanacetum vulgare* L. өсімдіктер қауымдастығының флористикалық әртүрлілігі, геоботаникалық құрылымы және экологиялық маңызы

Мақалада Оңтүстік-Шығыс Қазақстанның тау бөктері экожүйелерінде өсетін *Tanacetum vulgare* L. өсімдіктер бірлестіктерінің флоралық әртүрлілігі, геоботаникалық құрылымы және экологиялық маңызына жүргізілген кешенді зерттеу нәтижелері ұсынылған. Зерттеудің өзектілігі кәдімгі пияздың көпфункционалды маңыздылығымен айқындалады, себебі ол адамзат тарапынан тағамдық, мал азықтық, техникалық және сәндік мақсаттарда, сондай-ақ халықтық және ғылыми медицинада кеңінен қолданылатын әмбебап өсімдік. Антропогендік жүктеменің күшеюі және табиғи экожүйелердің трансформациялануы жағдайында аталған түрдің экологиялық және ценодикалық рөлін зерттеу ерекше ғылыми әрі практикалық мәнге ие. Зерттеу нәтижесінде *Tanacetum vulgare* L. қатысатын өсімдік қауымдастықтары жоғары флоралық әртүрлілікпен және мезофитті әрі мезоксерофитті түрлердің басым болуымен сипатталатыны анықталды. Зерттелген түр шөптесін сатысы тұрақты немесе субдоминант компоненті ретінде көрініс беріп, өзгермелі орта жағдайларына жоғары экологиялық икемділік пен төзімділік танытады. Алынған нәтижелер тау бөктері фитоценоздарының құрылымы мен қызмет ету ерекшеліктері туралы түсінікті кеңейтіп, биоалуантүрлілікті мониторингілеуде, экожүйелердің жай-күйін бағалауда және Оңтүстік-Шығыс Қазақстандағы өсімдік ресурстарын ұтымды пайдалануда қолданылуы мүмкін.

Кілт сөздер: *Tanacetum vulgare* L., флоралық әртүрлілік, геоботаникалық құрылым, фитоценоз, экологиялық маңызы, тау бөктері экожүйелері, фитопрепарат, Оңтүстік-Шығыс Қазақстан.

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Флористическое разнообразие, геоботаническая структура и экологическое значение растительных сообществ *Tanacetum vulgare* L. в предгорных экосистемах Юго-Восточного Казахстана

В статье представлены результаты комплексного исследования флористического разнообразия, геоботанической структуры и экологической значимости растительных сообществ с участием *Tanacetum vulgare* L., произрастающих в предгорных экосистемах Юго-Восточного Казахстана. Актуальность исследования определяется многофункциональной значимостью пижмы обыкновенной, являющейся универсальным растением, используемым человеком в пищевых, кормовых, технических и декоративных целях, а также в народной и научной медицине. В условиях усиления антропогенной нагрузки и трансформации природных экосистем изучение экологической и ценотической роли данного вида приобретает особую научную и практическую значимость. Установлено, что растительные сообщества с участием *Tanacetum vulgare* L. характеризуются высоким флористическим разнообразием и преобладанием мезофитных и мезоксерофитных видов. Исследуемый вид выступает постоянным или субдоминантным компонентом травяного яруса, демонстрируя высокую экологическую пластичность и устойчивость к изменяющимся условиям среды. Полученные результаты расширяют представления о структуре и функционировании предгорных фитоценозов и могут быть использованы при мониторинге биоразнообразия, оценке состояния экосистем и рациональном использовании растительных ресурсов Юго-Восточного Казахстана.

Ключевые слова: *Tanacetum vulgare* L., флористическое разнообразие, геоботаническая структура, фитоценоз, экологическая значимость, предгорные экосистемы, фитопрепарат, Юго-Восточный Казахстан.

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