Ontogenetic structure of Coenopopulations of *Centaurea jacea* L.

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**Abstract.** The study of the structure of coenopopulations (CP) is one of the directions in phytocoenology. Analysis of the morphological characteristics of individuals, ontogenetic structure, vitality, effective density allows predicting the dynamics of population development, which is important for the rational use of both plant resources and territories occupied by different populations. We chose *Centaurea jacea* L. (meadow cornflower) as the object of our study. It is a perennial short-rhizome herb of the family *Asteraceae* Dumort., Hemicyrptophyte, xeromesophyte, and a frequent component of meadow communities. Using the ecological scales of D.N. Tsyganov, a phytcoindication assessment of the habitat conditions of *Centaurea jacea* L. is given. The values of the realized ecological valence fit into all ranges of the scales given by D N Tsyganov for this species. This indicates a fairly wide range of tolerance of *C. jacea*. Coenopopulations of *C. jacea* are normal. Ontogenetic spectra are single-vertex: in CP 1 - centered, in CP 2, 5 - right-sided, in CP 3 - left-sided. In CP 4 of *C. jacea*, the spectrum of ontogenetic states is bimodal. According to the "delta-omega" classification by L A Zhivotovsky CPs 1 and 2 of *C. jacea*, according to the values of efficiency and age indices, are characterized as mature, CPs 3 and 4 are transitional, and CP 5 is aging. The ontogenetic structure and type of spectrum depend on the growth rate of individuals, seed productivity, ecological conditions (soil turf, economic activity and mode of use).

1. **Introduction**

Today, due to increasing anthropogenic impact on ecosystems, there is a need for research to recognize and conserve biological diversity. Such a research, first of all, requires a comprehensive study of the species population biology.

Knowing the biology of the species and the structure of coenopopulations (CP), it is possible to predict the course of their growth and the reaction to the adverse effects of the environment [1, 2, 3, 4, 5, 6, 7].

We chose *Centaurea jacea* L. (meadow cornflower) as the object of our study. It is a perennial short-rhizome herb of the family *Asteraceae* Dumort., Hemicyrptophyte, xeromesophyte, and a frequent component of meadow communities.

The genus *Centaurea* has more than 500 species, mainly found in the Mediterranean region. There are 6 species of this genus in the Republic of Mari El: *Centaurea pseudomaculosa* Dobrocz.,...
C. pseudophrygia C.A. Mey., C. jacea L., C. Cyanus L., C. sumensis Kalen., C. phrygia L., C. scabiosa L. [8].

C. jacea grows in meadows, steppes, forest edges, clearings, roadsides, clearings, field edges, on slopes [9]. In the Republic of Mari El, C. jacea is found throughout the territory - it often infests fields, creating some difficulties for agriculture [8].

C. jacea is a medicinal plant. The entire aerial part of the plant with flowers is used as a medicinal raw material. It contains tannins, centaurin (xanthoglycoside). In folk medicine, it is used for heart disease, headache, stomach ailments, dropsy, diathesis and rheumatism. The plant has a diuretic, choleric, anti-inflammatory, analgesic effect [10, 11]. C. jacea is a forage and honey plant. Sugar productivity of one flower is 0.2 mg, honey productivity is from 130 to 220 kg / ha. In the European part of Russia, the sugar productivity of the flower is 0.08 mg, the honey productivity is 100-150 kg / ha [12].

2. Materials and Methods
We conducted research on the territory of the Republic of Mari El in the Orshansky and Morkinsky administrative regions (figure 1). Orshansky administrative district occupies the northwestern agroclimatic region. It is located on an elevated hilly plain. Soils are light loamy, sod-weak and medium-podzolic loamy. The relief is flat, formed by marls, clays and sandstones of the Tatar stage, overlapped by mantle loams of varying thickness. The depth of erosion is approximately 25-75 m.

Figure 1. Administrative map of the Republic of Mari El. [13]
Districts: 1 - Volzhsky, 2 - Gornomariysky, 3 - Zvenigovsky, 4 - Kilemarsky, 5 - Kuzhenersky, 6 - Mari-Tureksky, 7 - Medvedevsky, 8 - Morkinsky, 9 - Novotoryalsky, 10 - Orshansky, 11 - Paranginsky, 12 - Sernursky, 13 - Sovetsky, 14 - Yurinsky.

Morkinsky administrative district is located in the southern part of the Mari-Vyatka uval [14]. The area is composed of limestone-dolomite strata of the Kazan stage and clay-marly deposits of the Tatar stage. Soils are sod-podzolic, brown and gray forest, different in strength of podzolization and texture. Both districts are similar in terms of climate [15].

We studied the ontogenetic structure of C. jacea coenopopulations: 2 coenopopulations in the vicinity of the village of Otary (Orshansky district), and 3 coenopopulations in the vicinity of the
village of Korkatovo and in the Maly Karman-Kuryk natural monument (Morkinsky district) (table 1). In each habitat, 20 plots of 0.25 m² were established. The total sample size was 100 sites.

In order to assess the environmental conditions of the studied habitats of *C. jacea*, we carried out geobotanical descriptions, indicating the abundance of species in points on the Brown-Blanquet scale [16]. Floristic lists were processed using the EcoScaleWin program [17] by the method of the weighted average midpoint of the interval using 10 amplitude scales by Tsyganov [18]: Tm - thermoclimatic, Kn - continental climate, Om - ombroclimatic aridity-humidity, Cr - cryoclimatic, Hd - soil moisture, Tr - soil salt regime, Nt - soil nitrogen richness, Rc - soil acidity, fH - variability humidification, Lc - illumination-shading.

### Table 1. Characteristics of the habitats of *Centaurea jacea*

| № CP | Habitat | Association |
|------|---------|-------------|
| 1    | Surroundings of the village Korkatovo, hillside. Hay mowed. | *Dactylis glomerata* L. + *Centaurea jacea* L. + *Pimpinella saxífraga* L. |
| 2    | Small Karman-Kuryk. Meadow for hay and pasture use. | *Festuca pratensis* L. + *Medicago sativa* L. + *Fragaria viridis* Duch. |
| 3    | Surroundings of the village Korkatovo, a former stone quarry. | *Dactylis glomerata* L. + *Trifolium hybridum* L. + *Leontodon autumnalis* L. |
| 4    | Surroundings of the village Otary. Lowland meadow. | *Deschampsia caespitosa* L. + *Geranium pratense* L. + *Centaurea jacea* L. |
| 5    | Surroundings of the village Otary. Dry meadow. | *Poa pratensis* L. + *Potentilla anserina* L. + *Fragaria vesca* L. |

We determined the potential (PEV) and realized (REV) ecological valences, the tolerance index (Iₜ), and using the environmental efficiency ratio (Kₑₑₑₑ₊ₑ) we estimated the efficiency of ecological space development by specific coenopopulations of *C. jacea* for each factor [19].

We used the following demographic indicators as integral characteristics of the structure of *C. jacea* coenopopulations: age index (Δ) [2] and efficiency index (ω) [20]:

To determine the type of coenopopulation, the classification "delta-omega" was used, based on the estimates of Δ and ω obtained from the data of the entire age distribution [20].

### 3. Results and Discussion

Any species has a certain range of factors within which it can exist.

Table 2 shows the results of processing geobotanical descriptions of *C. jacea* coenoses according to ecological scales by D.N. Tsyganov [18]. According to these results, all coenopopulations of *C. jacea* are found in subboreal and subboreal / nemoral climates (scores from 7-8); according to the ombroclimatic factor - from sub-humid to subarid-sub-humid (8-9).

On the scale of moisture, the habitats of this species are characterized as dry-meadow (wet-meadow). According to the factor of salt regime, *C. jacea* grows on soils from poor / poor to fairly rich soils. According to the scale of soil nitrogen richness, the habitat CP 3 has the richest soils, and the habitat CP 1 is the poorest.

The variability of moisture varies from slightly variable to moderately variable. On the scale of acidity, the most acidic soils are CP 4, neutral - CP 5 soils, and weakly acidic - all others. According to the illumination scale, the most open habitats are CP 1 and 2, half-open - CP 3, the border position is occupied by the habitats of CP 4 and 5 coenopopulations. The values we obtained (table 2) fit into the ranges given by D N Tsyganov [18] for *C. jacea*. 

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Table 2. Ecological characteristics of *C. jacea* coenopopulations according to ecological scales by D.N. Tsyganov [18]

| Scales * | CP 1 | CP 2 | CP 3 | CP 4 | CP 5 |
|----------|------|------|------|------|------|
| Tm       | 7.00 | 7.00 | 7.00 | 8.00 | 7.00 |
| Om       | 9.00 | 8.50 | 8.50 | 8.00 | 9.00 |
| Kn       | 9.00 | 9.00 | 9.00 | 8.00 | 9.00 |
| Cr       | 8.00 | 8.00 | 8.00 | 7.50 | 8.00 |
| Hd       | 12.00| 12.00| 12.00| 12.00| 12.00|
| Tr       | 6.00 | 7.00 | 7.00 | 7.00 | 4.50 |
| Nt       | 4.50 | 5.50 | 6.00 | 5.50 | 5.00 |
| Rc       | 7.00 | 7.50 | 7.00 | 6.00 | 9.00 |
| Lc       | 2.00 | 2.00 | 3.00 | 2.50 | 2.50 |
| fH       | 6.50 | 6.50 | 6.00 | 5.50 | 6.00 |

* Tm – thermoclimatic scale, Om - ombroclimatic aridity-humidity scale, Kn - continental climate scale, Cr – cryoclimatic scale, Hd - soil moisture scale, Tr - soil salt regime scale, Nt - soil nitrogen richness scale, Rc - soil acidity scale, Lc - illumination-shading scale, fH - variability humidification scale.

The efficiency of the space development of the studied coenopopulations of *C. jacea* was assessed using the potential and realized ecological valences as well as environmental efficiency ratio [19] (table 3). Analyzing the potential ecological valence of *C. jacea*, it can be concluded that *C. jacea* is a mesovalent species according to the factors of thermoclimatic, ombroclimatic and cryoclimatic scales and the scale of illumination-shading; hemi-eurevalent species according to the factors of the salt regime of soils; euryvalent species according to the factors of climate continentality scales, soil nitrogen richness, soil acidity, illumination-shading, and according to the factor of the scale of moisture and variability of soil moisture - a hemistenovalent species.

Table 3. Ecological valence and environmental efficiency ratio of *Centaurea jacea* coenopopulations

| Ecological scales | Ecological position of the species | Realized ecological position of species | Potential ecological valence (PEV), in shares | Realized ecological valence (REV), | Environmental efficiency ratio (K_{eff}), % |
|-------------------|----------------------------------|----------------------------------------|---------------------------------------------|-----------------------------------|------------------------------------------|
| Tm (1-17)         | 4-12                             | 7.0-8.0                                | 0.53 MV a                                   | 0.06                              | 11.3                                     |
| Kn (1-15)         | 3-12                             | 8.0-9.0                                | 0.67 EV                                     | 0.07                              | 10.4                                     |
| Om (1-15)         | 5-11                             | 8.0-9.0                                | 0.47 MV                                     | 0.07                              | 14.9                                     |
| Cr (1-15)         | 6-12                             | 7.5-8.0                                | 0.47 MV                                     | 0.03                              | 6.4                                      |
| Hd (1-23)         | 9-17                             | 12.0                                   | 0.39 HSV                                    | –                                 | –                                        |
| Tr (1-19)         | 3-13                             | 4.5-7.0                                | 0.58 HEV                                    | 0.13                              | 22.4                                     |
| Nt (1-11)         | 1-9                              | 4.5-6.0                                | 0.82 EV                                     | 0.14                              | 17.1                                     |
| Rc (1-13)         | 1-13                             | 6.0-9.0                                | 1.00 EV                                     | 0.23                              | 23.0                                     |
| Lc (1-9)          | 1-5                              | 2.0-3.0                                | 0.56 MV                                     | 0.11                              | 19.6                                     |
| fH (1-23)         | 1-8                              | 5.0-6.50                               | 0.35 HSV                                    | 0.04                              | 11.4                                     |

a abbreviations: MV - mesovalent, EV - eurevalent, HSV - hemistenovalent, HEV - hemieurevalent

Analysis of ecological scales characterizing climatic factors (Tm, Kn, Om, Cr) showed that *C. jacea* reacts to these factors as a mesobiont; the tolerance index is 0.54. For soil scales (Hd, Tr, Nt, Kn, Om).
Re (pH), the tolerance index for this species is 0.63. This indicates that *C. jacea* reacts to the influence of these factors as a hemi-eurybiont. Consequently, the studied species has a fairly wide range of tolerance.

Analysis of the ontogenetic structure of *C. jacea* coenopopulations showed that CP 1-3, 5 are normal incomplete, CP 4 is full-membered. The absent groups in CP 1, 3, 5 were individuals of the ss state, and in CP 2, apart from this group of plants, there were no j, im, and s individuals. In CP 1, the ontogenetic spectrum of *C. jacea* is unimodal, centered with a maximum on individuals in the g₂ state (figure 2). The efficiency ratio is 0.757, the age index is 0.492. The high value of the efficiency ratio can be explained by the dominance of g₂ and g₃ individuals in the coenopopulation of *C. jacea* (34.7 and 26.7%, respectively).

![Figure 2. Ontogenetic spectrum of C. jacea CP 1.](image)

D - share of individuals;
Ontogenetic states: j - juvenile, im - immature, v - virginal, g₁ - young generative, g₂ - middle-aged generative, g₃ - old generative, ss - subsenile, s - senile.

In CP 2, the ontogenetic spectrum is single-peaked (figure 3), right-sided with a maximum on old generative plants (44%). The efficiency ratio is 0.817, the age index is 0.52.

The high values of demographic indicators are not accidental. Coenopopulation 2 of *C. jacea* grows in meadows not only for hay production, but also for pasture use. In this regard, the cutting or biting of the generative shoots occurs, the fruits do not have time to ripen, and as a result, the absence of individuals of the pregenerative period (j and im). Regular grazing of cattle leads to a disturbance of the vegetation cover, and the achenes of *C. jacea* in the soil simply do not have time to germinate.

In CP 3, the ontogenetic spectrum of *C. jacea* is unimodal, left-sided, with a maximum on young generative plants (figure 3). The spectrum is dominated by young generative plants (48.6%); old generative plants account for 15.7% and 23% for individuals of senile state. Therefore, the values of the efficiency and age indices are also high (0.595 and 0.483, respectively). In this coenopopulation, there are very few juvenile and virginal individuals (1.4% each). Community disruption is the reason.
Figure 3. Ontogenetic spectra of *C. jacea* coenopopulations. D - share of individuals; Ontogenetic states: j - juvenile, im - immature, v - virginal, g1 - young generative, g2 - middle-aged generative, g3 - old generative, ss - subsenile, s - senile.

In CP 4 of *C. jacea*, the ontogenetic spectrum is bimodal with a maximum on a group of individuals in the old generative (g3) state (figure 3). The low value of the efficiency ratio (0.39) is associated with the predominance of individuals of the pregenerative period. However, the value of the age index is 0.493 due to the high proportion of individuals in the g3 and s states. In CP 5, the ontogenetic spectrum of *C. jacea* is unimodal, right-sided with a maximum on g3 plants, although the proportion of g2 individuals is also high (figure 3). This is reflected in the values of the efficiency (0.69) and age (0.579) indices.

According to the "delta-omega" classification by L A Zhivotovsky [20] CPs 1 and 2 of *C. jacea*, according to the values of efficiency and age indices, are characterized as mature, CPs 3 and 4 are transitional, and CP 5 is aging.

4. Conclusion
Coenopopulations of *C. jacea* grow in almost similar ecological conditions. The realized ecological niche of the studied coenopopulations of *C. jacea* is within the area of the fundamental ecological niche of this species according to D N Tsyganov [18]. An analysis of the ecological scales characterizing climatic factors showed that *C. jacea* reacts to these factors as a mesobiont (It =
0.54), and to soil factors as a hemi-eurybiont (It = 0.63). Therefore, this indicates a fairly wide range of tolerance of C. jacea

Coenopopulations of C. jacea are normal, all except CP 4 are incomplete. Ontogenetic spectra are single-vertex: in CP 1 - centered, in CP 2, 5 - right-sided, in CP 3 - left-sided. In CP 4 of C. jacea, the spectrum of ontogenetic states is bimodal. The centered type of spectrum is formed as a result of the long presence of a group of middle-aged generative plants in the coenopopulation and irregular seed renewal. Under the influence of anthropogenic load, a right-sided type of spectrum is formed. The formation of the bimodal ontogenetic spectrum is influenced by the irregularity of seed renewal and the rate of development of individuals in the pregenerative period. In addition, intensive grazing, regular haymaking in combination with grazing reduces the lifespan of middle-aged generative plants. They age quickly and pass into the old generative state, therefore, they prevail in CPs 2, 4, 5. These coenopopulations of C. jacea in the delta-omega coordinate system are characterized as mature, transitional, and aging, respectively.

The ontogenetic structure and type of spectrum depend on the growth rate of individuals, seed productivity, ecological conditions (soil turf, economic activity and mode of use).

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