Ontogenetic and spatial structure of *Ptilostemon echinocephalus* (Willd.) Greuter (*Lamyra echinocephala* (Willd.) Tamamsch.) coenopopulations in the Crimean Mountains

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**Abstract.** The article analyzes the state of *Ptilostemon echinocephalus* (Willd.) Greuter (*Lamyra echinocephala* (Willd.) Tamamsch.) coenopopulations, a relict species included in the Red Data Book of the Republic of Crimea. Studies of *Ptilostemon echinocephalus* coenopopulations were conducted in 2018-2021 on the territory of the Crimean Peninsula in 10 associations. The analysis of the ontogenetic and spatial structure of *Ptilostemon echinocephalus* was conducted. The characteristics of coenopopulations are given according to the age index \(\Delta\), the efficiency index \(\omega\), according to the classification of L.A. Zhukova. The spatial structure score is determined using the Clark-Evans nearest neighbor index (R). The characteristics of ontogenetic and spatial structures reflect the adaptive properties of the studied plants and populations as a whole: in the phrygana communities, apparently, *Ptilostemon echinocephalus* does not experience significant competitive pressure, which allows its seeds and ramets to settle next to the maternal individuals, then forming groups. The seeds of *Ptilostemon echinocephalus* can grow mainly in the intervals between other plant species due to high competition, thus forming a random spatial distribution in petrophytic steppes with a varied species composition.

**1. Introduction**

One of the global problems of modern civilization, quite clearly manifested by the end of the 20th century, was the problem of deep synanthropization of the plant cover, which led to the loss of alpha and beta diversity by ecosystems. Most of the progressive countries, realizing the catastrophic nature of this phenomenon for natural ecosystems, have developed a series of actions to neutralize the negative human impact on biodiversity – the Convention on Biodiversity [1]. Seminars held in territories with valuable biodiversity were a positive consequence of this decision. One of them was held in Crimea – Biodiversity Support Program [2]. The developed programs formed the basis for the creation and specification of data for the Red Data Books of the Republic of Crimea and the city of Sevastopol [3, 4]. At present, there is no doubt that the stability of the complex system of man and nature is provided only through the stability and ability to self-renewal of natural ecosystems, which, first of all, depends on their biological diversity [5, 6].
For the Crimean Peninsula, as one of the centers of European biodiversity [2], it remains relevant to obtain the missing data on the state of populations of rare and protected plant species. This also applies to the object of this study, *Ptilostemon echinocephalus* (Willd.) Greuter (*Lamya echinocephala* (Willd.) Tamamsch.), a relict species included in the Red Data Book of the Republic of Crimea with the conservation status “rare” [3], with numerous gaps in information about the state of its populations. In the composition of Crimean plant communities, the phytocoenotic role of *P. echinocephalus* can vary markedly, showing the importance of a plant ecology dominant or subdominant, or correspond to the rank of a minor, single component [7-9].

This adaptive strategy is determined by a complex of phytocoenosis and ecotope conditions. *P. echinocephalus* forms coenopopulations of various ontogenetic and spatial structures in accordance with these conditions. The study and analysis of the spatial and ontogenetic structure of *P. echinocephalus* populations in various ecological and coenotical conditions is the purpose of this study.

### 2. Materials and methods

Studies of *P. echinocephalus* coenopopulations in Mountain Crimea during grow seasons 2018-2021 in 6 associations of petrophytic steppes were conducted: Festucetum thymosum (Zelenogorsko B, Belogorsk district); Stipetum ptilostemosum (Mountain Dolgorukovskaya yaila); Festucetum helianthemosum (Levadky, Simferopol district); Stipetum helianthemosum (Nauchnyi, Bakhchysarai district); Festucetum helianthemosum (Manhup-Kale); Festucetum thymosum (Chufut-Kale) and in 4 associations of phrygana communities (xerophytic formations): Ptilostemetum teucriosum (Zelenogorsko A, Belogorsk district); Ptilostemetum thymosum (Mountain Chatyr-Dag); Ptilostemetum saturejosum (Kuybyshevo, Bakhchysarai district); Ptilostemetum cephalariosum (Mountain Bairakly, Simferopol district) (Figure 1).

**Figure 1.** Localization of the studied *Ptilostemon echinocephalus* coenopopulations on the Crimean Peninsula.

The study of phytocoenoses (identification of the floristic composition and the establishment of dominants and codominants) was conducted using standard geobotanical methods [10]. The individuals were categorized to age states using the identified morphological criteria [9, 11]. The number, density of populations, construction of ontogenetic spectra of *P. echinocephalus* and their analysis were also carried out according to generally accepted population methods [12-16]. The nearest neighbor analysis was used to establish the spatial structure. The data obtained to Clark-Evans index (R, nearest neighbor) were analyzed [17].

### 3. Results and discussion

*P. echinocephalus* coenopopulation in the association of petrophytic steppe (Festucetum thymosum) (Zelenogorsko B, Belogorsk district) is represented by 108 individuals: j – 18 (16.7%); im – 18 (16.7%); v – 29 (26.8%); g – 40 (37.0%); ss – (2.8%).
In the ontogenetic spectrum, there are no seedlings and plants of senile age; therefore, the spectrum is incomplete and monomodal. Generative plants represent the largest share in the spectrum, however, the total participation of pregenerative individuals (65) indicates a sufficient reserve for self-maintenance (Figure 2a).

The *P. echinocephalus* coenopopulation in the association Stipetum ptilostemosum (Dolgorukovskaya yaila) is not numerous and is represented by 37 individuals: p – 10 (27.0%); j – 2 (5.4%); im – 3 (8.1%); v – 3 (8.1%); g – 19 (51.3%). The population is also incomplete: there are no individuals of subsenile and senile ages, and the monomodality of the spectrum is also provided by a noticeable predominance of generative plants. They account for more than half of the total number. In the general structure of the spectrum, seedlings account for almost one third of the total number of individuals (Figure 2b).

The following two coenopopulations have almost the same population size: *P. echinocephalus* in the association Festucetum helianthemosum (Levadky, Simferopol district) grows in 47 individuals: p – 2 (4.2%); j – 4 (8.5%); im – 4 (8.5%); v – 4 (8.5%); g – 30 (63.8%); ss – 1 (2.1%), s – 2 (4.3%), in the Stipetum helianthemosum association (Nauchnyi, Bakhchisarai district), the species is represented by 51 individuals: p – 10 (19.6%); j – 3 (5.9%); im – 7 (13.7%); v – 6 (11.8%); g – 20 (39.2%), ss – 3 (5.9%), s – 2 (3.9%). Both coenopopulations are full-membered and monomodal with distinct peaks in the area of generative individuals (Figure 3a, b). However, more than 60% of generative individuals are in the association Festucetum helianthemosum (Figure 3a), where it, together with senile and subsenile plants, makes the right-side of the spectrum dominant over the left. The spectrum shows that the reserve of pregenerative individuals is small and the coenopopulation can be assessed as mature with a tendency to aging. In the Stipetum helianthemosum association, pregenerative and generative individuals are more evenly distributed: the right-side and left-side parts of the spectrum are almost equal (Figure 3b).
**P. echinocephalus** coenopopulations in the associations Festucetum helianthemosum (Manhup-Kale) and Festucetum thymosum (Chufut-Kale) are also almost the same in numbers: 53 and 49 individuals, respectively. For the first, their distribution by age group looks like this: p – 4 (7.5%); j – 8 (15.1%); im – 5 (9.4%); v – 12 (22.6%); g – 22 (41.5%); ss – 1 (1.9%); s – 1 (1.9%) (Figure 4a); for the second: p – 3 (6.1%); j – 5 (10.2%); im – 4 (8.2%); v – 5 (10.2%); g – 29 (59.2%); ss – 2 (4.1%); s – 1 (2%) (Figure 4b).

Both coenopopulations are full-member, monomodal, and individuals of the generative phase of development predominate in both coenopopulations. However, association Festucetum helianthemosum has a sufficient reserve of young individuals, in the association Festucetum thymosum, the tendencies of the aging coenopopulation prevail (Figure 4a, b).

**Figure 4.** Ontogenetic spectrum of *P. echinocephalus* coenopopulations within the associations of Festucetum helianthemosum (Manhup-Kale) – a; Festucetum thymosum (Chufut-Kale) – b.

In the association Ptilostemetum teucriosum (Zelenogorskoe A), *P. echinocephalus* grows in the amount of 114 plants: pl – 3 (2.6%); j – 12 (10.5%); im – 10 (8.8%); v – 22 (19.3%); g – 65 (57.0%); ss – 2 (1.8%) and forms an incomplete monomodal ontogenetic spectrum with a right-sided tendency, but in general, the reserve of the young part of the population is sufficient for self-maintenance (Figure 5a).

The *P. echinocephalus* coenopopulation grows in a small area in the Ptilostemetum thymosum association (Chatyr-Dag), has the smallest abundance and is represented by 21 individuals: p – 3 (14.3%); im – 3 (14.3%); v – 1 (4.7%); g – 11 (52.4%); ss – 2 (9.5%); s – 1 (4.8%) (Figure 5b).

The ontogenetic spectrum is incomplete, monomodal, the peak is focused on generative individuals. The coenopopulation has an insufficient reserve of self-maintenance (33.3%), and with a general low number and the absence of juveniles in the spectrum, such an age structure indicates its clearly depressed state (Figure 5b).

**Figure 5.** Ontogenetic spectrum of *P. echinocephalus* coenopopulations within the associations of Ptilostemetum teucriosum (Zelenogorskoe A, Belogorsk district) – a; Ptilostemetum teucriosum (Chatyr-Dag) – b.
The *P. echinocephalus* coenopopulation in the *Ptilostemon saturejosum* association (Kuybyshevo, Bakhchysarai district) is represented by 99 individuals: p – 9 (9%); j – 8 (8%); im – 20 (20.2%); v – 28 (28.3%); g – 31 (31.3%); ss – 3 (3%). This is the only spectrum in which there is no clearly distinct modality, because virginal individuals are only slightly inferior in number to generative ones, but the predominance remains in generative ones (figure 6a). The spectrum is incomplete, but the absence of senile plants only enhances the left-sided tendency of the trend.

The *P. echinocephalus* coenopopulation in the *Ptilostemon cephalariosum* association (mountain Bairakly, Simferopol district) is the most numerous and is represented by 349 individuals: p – 28 (8%); j – 36 (10%); im – 49 (14%); v – 52 (15%); g – 136 (39%), ss – 48 (14%). The spectrum is incomplete, monomodal, with a peak on generative plants, but in relation to the total of pregenerative plants (47%), it shows the predominance of the left-sided part of spectrum and indicates the normal course of self-maintenance processes of the coenopopulation (Figure 6b).

The ontogenetic structure of *Ptilostemon echinocephalus* coenopopulations was also analyzed using statistical indices $\Delta$ and $\omega$. In the petrophytic steppes, according to the delta-omega classification, three coenopopulations are young, two are mature, and one coenopopulation is of the transitional type. In phrygana communities, there is also a diversity of their ontogenetic structure: two coenopopulations are young, one is transitional and one is maturing (Figure 7).
According to L.A. Zhukova [14] all coenopopulations are normal. In petrophytic steppes, the age index ($\Delta$) varies from 0.25 to 0.39, the efficiency index ($\omega$) from 0.51 to 0.71. For phrygana communities, ($\Delta$) varies from 0.23 to 0.33; $\omega$ from 0.49 to 0.68. Thus, the values of the calculated indices correspond to populations of the normal type.

The distribution of individuals of the coenopopulation over the area of the phytocoenosis shows the type of adaptation of the species to the complex of phytocoenotic and ecotopic conditions. Therefore, the spatial structure was studied for all coenopopulations of *P.echinocephalus*. It has been found that, the distribution of individuals in coenopopulations growing in the phrygana communities corresponds to the contagious (group) type. While in the petrophytic steppes, they are randomly distributed over the area of phytocoenoses (Table 1).

### Table 1. Spatial structure of *P.echinocephalus* coenopopulations in the studied associations.

| №  | Associations                              | Density of individuals | Clark-Evans nearest neighbor index (R) | Type of spatial structure of coenopopulation |
|----|------------------------------------------|------------------------|----------------------------------------|---------------------------------------------|
| 1  | Festucetum thymosum (Zelenogorsko B)     | 0.7                    | 0.36                                   | Random                                     |
| 2  | Stipetum ptistemosum (Dolgorukovskaya yaila) | 0.2                    | 0.42                                   | Random                                     |
| 3  | Festucetum helianthemosum (Levadky, Sineropol district) | 0.5                    | 0.47                                   | Random                                     |
|    | Stipetum helianthemosum (Nauchnyi, Bakhchysarai district) | 0.3                    | 0.55                                   | Random                                     |
|    | Festucetum helianthemosum (Manhup-Kale)  | 0.4                    | 0.73                                   | Random                                     |
|    | Festucetum thymosum (Chufut-Kale)        | 0.3                    | 0.43                                   | Random                                     |
| 4  | Ptilostemetum teucriosum (Zelenogorsko A) | 2.1                    | 1.24                                   | Group                                      |
| 5  | Ptilostemetum Teucriosum (Mountain Chatyr-Dag) | 1.9                    | 1.51                                   | Group                                      |
| 6  | Ptilostemetum saturejosum (Kuybyshevo)   | 2.2                    | 1.31                                   | Group                                      |
| 7  | Ptilostemetum cephalariosum (Mountain Bairakly) | 1.9                    | 1.53                                   | Group                                      |

In all phrygana phytocoenoses, the Clarke-Evans coefficient (R) is larger than 1, a high density of individuals of *P.echinocephalus*, especially in the groups formed by them, and *P.echinocephalus* is the dominant and edificator in them. In phytocoenoses of petrophytic steppes, R is less than 1; the phytocenotic role of *P.echinocephalus* has subordinate importance. Only in associations Stipetum ptistemosum (Dolgorukovskaya yayla) *P.echinocephalus* is a part of the subdominants.

### 4. Conclusions

Various approaches used in this article to characterize the ontogenetic spectra of *P.echinocephalus* coenopopulations have shown that the “delta-omega” classification and L.A. Zhukova give a
A generalized description of ontogenetic processes occurring in coenopopulation. They determine the position of coenopopulations in the classifications proposed by the authors in rather optimistic characteristics.

The classical analysis of age spectra made it possible to know subtler processes taking place in the ontogenetic structure. In particular, in all 10 associations of *P.echinocephalus* coenopopulation regardless of their belonging to syntaxa of a higher rank (petrophytic steppes or phrygana phytocoenoses), ontogenetic spectra are formed monomodal with a predominance of generative individuals, mainly with a right-sided tendency. However, in phrygana communities, the spectrum does not show the presence of senile individuals in three of the four studied coenopopulations. In two phytocoenoses of petrophytic steppes (from 6 studied), growing in the most extreme conditions in association Festucetum thymosum (Zelenogorsk B) and Stipetum ptilostemosum (Dolgorukovskaya yazla) (figure 2) there are no senile plants.

Thus, the complex of ecological and coenotic conditions contributes to an incomplete cycle of the ontogenesis of *P.echinocephalus* and death at the stage of subsenile age, when their vegetative live weight decreases so much that individuals can no longer successfully withstand the rigidity of the ecotope conditions and they end their existence.

The type of the coenopopulations spatial structure is also controlled by a complex of ecological and coenotic conditions. It was found that in phrygana communities *P.echinocephalus* does not experience significant competitive pressure, since there are low values of projective cover (up to 25-30%) and a poor species composition. This allows its seeds and ramets to settle next to the original specimen and form groups, within which the distances between individuals vary within 20-25 cm, and between groups they correspond to 85-90 cm. Petrophytic steppes have a projective cover of up to 60-70% and a diverse species composition, therefore, competitive relations play a leading role in determining the spatial structure of species. Here, the seeds of *P. echinocephalus* grow mainly in calvia which have a random distribution over the area of phytocoenoses. That may be the reason for the random distribution of individuals of *P.echinocephalus*.

Thus *P. echinocephalus* forms coenopopulations of a diverse ontogenetic and spatial structure and their diversity at the population level is important to take into account when monitoring existing and organizing new conservation objects to preserve protected species in accordance with the tasks of biodiversity programs.

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