Changes in plant CSR strategies under new anthropogenic transformations

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Abstract. The indicator plant species (*Diplotaxis muralis* (L.) DC., *Senecio vulgaris* L., *Tripleurospermum inodorum* (L.) Sch. Bip., *Echium vulgare* L., *Atriplex mircantha* C.A.Mey., *Ceratodon purpureus* (Hedw.) Brid, *Bryum caespiticium* Hedw., and others) were analyzed on the territory of Donbass, which under conditions of geochemical contrast and physical transformation develop different strategies for their survival and population preservation. The methods of calculating CSR strategies by the global calculator for biomes (vegetative method) and approaches in assessing reproductive potential and generative success were used. It was found that indicator species significantly rearrange themselves to preserve their own life and the population as a whole when ecological conditions of growth change. It is proved that the way of taking into account atypical plant morphogenesis also has a different diagnostic vector from typical C-strategy to forced R- (35 %) or S-strategies (48 %) of survival at the level of model cenopopulations *Cichorium intybus* L., *Capsella bursa-pastoris* (L.) Medik., *Berteroa incana* (L.) DC., *Tanacetum vulgare* L., *Reseda lutea* L., *Nigella arvensis* L., *Centaurea diffusa* Lam.

1 Introduction

The territory of modern Central Donbass occupies a large area of steppe areas of Eastern Europe. The peculiarity of this area is deep anthropogenic transformation of landscapes and natural ecosystems. The reasons for this condition are the high level of industrial production (mining and processing of minerals, chemical technologies and agrarian sector), urbanization and the events related to the militarization of the region over the last 10 years.

In the conditions of anthropogenic transformations [1, 2], it is necessary to use technologies for restoration of disturbed ecosystems [3, 4]. Therefore, there is a need to develop effective methods to optimize the environment: landscaping [5], detoxification [6], restoration of soil fertility [4, 7], reduction of erosion [8], all forms of weathering and destruction of the natural framework of the terrain [9, 10]. Such ways of improving landscapes are possible with the right approach in the use of adapted plant species to the factors of technogenesis [11]. Plants are the primary productive medium for restoration of ecosystems [12] by natural and evolutionarily justified methods [13, 14].

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The aim of the work is to expand the existing ecological phytomonitoring procedures in Donbass [14, 15] based on the results of CSR calculation using existing vegetative methods and adapted methods of analyzing the generative sphere of plants.

2 Materials and methods

Groups of plant samples of species typical in phytoindication of the Northern Azov region were used. The material was collected in the nodes of the monitoring network and data were selected in the following categories of ecotopes: 1) areas of reserves – reference, 2) technogenic zones by chemical pollution, 3) ruderal zones by mechanical disturbance, 4) areas of post-war conflicts after explosions and placement of military equipment.

The unified calculation [16, 17] is performed within the framework of the methodologies used in the global assessment of biomes [18, 19]. At the same time, the usual procedure is to collect information on leaf plates of plants [20, 21], which is the principle of vegetative sphere assessment [18, 22]. The generative sphere in ecotope diagnostics was also used as an indicator of ecotope transformation specificity [23, 24]. The quality of seed material by the level of polymorphism is studied by standard methods [25]. We proposed to use the index of reproductive success in sum with the index of teratogenesis of seeds and fruits of plants. The criteria for vegetative and generative way of interpretation of the results were compared in visual schemes of the universal Grime-Ramensky triangle [17, 26]. The distance value was estimated at the displacement of characteristics in the information field of the CSR strategy triangle [16, 21]. Among the flowering plants studied: *Cichorium intybus* L. (occurrence in ecotopes – 48 %), *Capsella bursa-pastoris* (L.) Medik. (43 %), *Atriplex mircantha* C.A.Mey. (43 %), *Tripleurospermum inodorum* (L.) Sch. Bip. (40 %), *Centaurea diffusa* Lam. (38 %), *Berteroa incana* (L.) DC. (38 %), *Diplotaxis muralis* (L.) DC. (37 %), *Tanacetum vulgare* L. (35 %), *Sagina procumbens* L. (35 %), *Alsine media* L. (31 %), *Glaucium corniculatum* (L.) Rudolph (24 %), *Plantago major* L. (24 %), *Echium vulgare* L. (24 %), *Reseda lutea* L. (24 %), *Tragopogon major* Jacq. (20 %), *Nigella arvensis* L. (19 %), *Gipsophila paniculata* L. (19 %), *Stellaria subulata* Boeber ex Schlecht. (18 %), *Dianthus campestris* M. Bieb (17 %), *Reseda lutea* L. (17 %), *Moehringia trinervia* (L.) Clairv. (15 %), *Senecio vulgaris* L. (14 %), *Fumaria schleicheri* Soy.-Willem (14 %), *Portulaca oleracea* L. (10 %).

The most important species of mosses *Bryum argenteum* Hedw., *Dicranella cerviculata* (Hedw.) Schimp., *Aulacomnium palustre* (Hedw.) Schwägr., *Ceratodon purpureus* (Hedw.) Brid, *Didymodon fallax* (Hedwig) R. H. Zander, *Brachythecium salebrosum* (F.Weber & D.Mohr) Bruch et al., *Bryum caespiticium* Hedw., *Brachythecium campestre* (Müll.Hal.) Bruch et al., *Syntrichia ruralis* (Hedw.) F. Weber & Mohr, *Dicranum polysetum* Sw., *Tortula mucronifolia* Schwaegr., *Bryum capillare* Hedw.

Seed material and plants of each species were initially taken in a single generative set and placed for growth and development at different points in the monitoring network, active monitoring method and mathematical statistics. The data of sample collections from 1996 to 2024 were used in the work, special attention for visualization of the strategy was paid to the collections from 2014 to 2024 for the period of military events on the territory of Donbass.

3 Results

For the accomplishment of tasks on detection of functional differences between experimental and control plant specimens, herbaceous species with a wide ecological amplitude are the most suitable.

The theoretically expected and practically obtained results of the strategy triangles differ to some extent (fig. 1).

In the figures 1 and 2, green color indicates results for ecotopes of natural vegetation, yellow – ruderal, red – anthropogenic, and blue – transformation zones as a result of military events. Each plant species has a unique specificity of response to factors of habitat change. More conservative species (*F. schleicheri*, *P. oleracea*, *S. procumbens*, *B. salebrosum*, *B. caespiticium*, *B. campestre*, *S. ruralis*, *D. polysetum*, *T. mucronifolia*, *B. capillare*, *N. arvensis*, *G. paniculata*, *S. subulata*, *D. campestris*, *R. lutea*, *A. media*, *G. corniculatum*) and the most variable ones (*C. intybus*, *C. bursa-pastoris*, *A. mircantha*, *T. inodorum*, *C. diffusa*, *B. incana*, *D. muralis*, *T. vulgare*, *P. major*, *E. vulgare*, *T. major*, *M. trinervia*, *S. vulgaris*, *B. argenteum*, *D. cerviculata*, *A. palustre*, *C. purpureus*, *D. fallax*) as a result of the sharp impact of new factors that are not characteristic of the natural growing environment have been established.

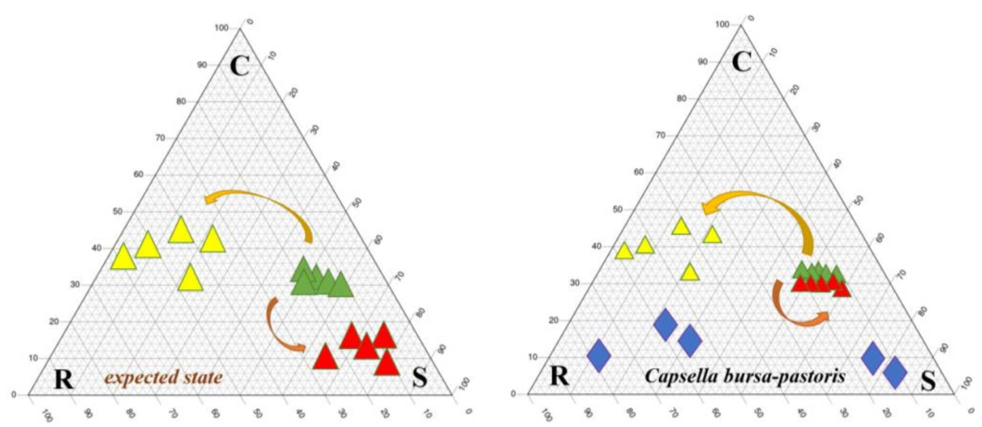

Fig. 1. Differences in theoretically expected indicators and those identified in practice for the *Capsella bursa-pastoris* (L.) Medik.

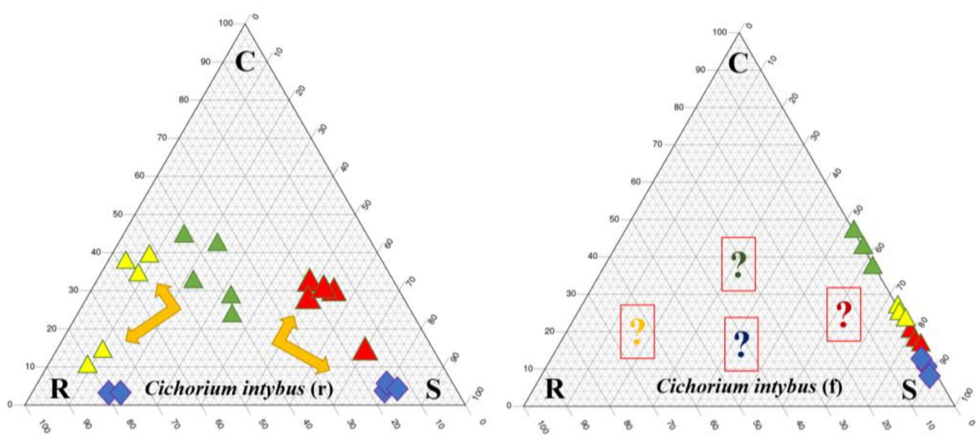

Fig. 2. Features of the revealed patterns of transformation of strategies for the *Cichorium intybus* L., leaves of the basal rosette (r) or in the structure of the inflorescence (f).

To analyze the samples of plant material of *C. intybus*, metric data on the average formation of leaf plates were used, while the calculation method zeroed out the explerent strategy, which is not correct in the case of phytocenotic analysis. When reusing the method, we operated with data on leaf plates of the rosette formation of the indicator species.

In experimental modeling of transformation of *C. bursa-pastoris* strategies, the expected trends were partially confirmed, but conservatism in the transition to patient morphotypes and a wide range of values in the case of ruderalization of the ecotope were noted. It seems that it is reasonable to carry out conditional indication by metric characteristics required in the global calculator method also for the steppe zone of Eastern Europe.

The greatest variation of CSR strategy values was noted in the analysis of military conflict areas, indicating different nature of chemical pollution and physical destruction of land cover. Ingredient analysis of such ecosystem data is presented in previous publications [15].

Regional data obtained on the assessment of reproductive potential and implementation of the success of the program of seed material (quality of the germinal apparatus, structure of seed shells, carpological elements, seed integrity, germination energy, heterocarpy, matrical schizocotyly, syncotyly) formation of indicator species from representatives of the weed-ruderal fraction of the natural flora of Donbass: *Cichorium intybus*, *Diplotaxis muralis*, *Echium vulgare* L., *Reseda lutea*, *Capsella bursa-pastoris*, *Atriplex mircantha*, *Centaurea diffusa*, *Berteroa incana*, and so on, as well as new plant species *Carex divulsa* Stokes, *Carex pilosa* Scop., *Eriophorum latifolium* Hoppe, *Sparganium erectum* L., *Juncus conglomeratus* L., and *Typha angustifolia* L. Different scenarios of teratogenesis (according to the abnormal structure of various organs, dystopia, accretion, oligomerization, dwarfism, gigantism, discoloration and pigmentation, fasciation, changes in habit, tortuosity) manifestation of seeds and fruits of plants indicate gravitation to R (35 %) or S (48 %) strategy of species survival. At the same time, the embryonic apparatus is both a conservative trait (*N. arvensis*, *R. lutea*, *A. media*, *G. corniculatum*) in species identification and a plastic characteristic (*C. intybus*, *C. bursa-pastoris*, *A. mircantha*, *T. inodorum*, *C. diffusa*, *B. incana*, *E. vulgare*, *T. major*) in ecological research of phytoindication purpose.

4 Discussion

A long-term experimental monitoring (1996-2024) of the condition of indicator plants has been implemented in the territory of Central Donbass. The assessment of the degree of disturbance of ecotopes is based on the level of structural plasticity of plants and the results of ingredient analytical control in the indicator tissues of plant organisms. If a landscape profile is ranked according to the level of industrial and (or) toxicogenic impact, the indicator plant [27] traits by their significance coefficients also correspond to the established ranked series. This condition is met in the gradient of territorial accordance [2, 7, 11] as long as the mono-vector does not intersect with other stress vectors; in this case the impact fields overlap. It is proved that the structural plasticity of plants used in field diagnostics for most of the described examples is phenotypic, which makes it possible to realize long-term monitoring observations under dynamically changing environmental characteristics. In the search for indicator traits, systematicity is an important criterion in identification of similar plant responses in closely related taxa. The associated functional-physiological process directly or indirectly has signs of transformations on the whole chain of involved structures available for analysis for monitoring purposes.

If a trait in the structure of a plant organism fits into the range of structural variability according to discrete data, a stable prerequisite for the formation of a scale of structural plasticity of the trait with subsequent empirical rechecking to establish interval values for the corresponding numerical index is created.

The method of strategy selection is important for ecological research in determining the resilience potential of a species and its ability to change under extreme conditions [17, 19, 24]. In fundamental plant knowledge [16, 20, 23], it also indicates the evolutionary youthfulness and mobility of a species in realizing its life potential. Some moss species under such conditions are considered both evolutionarily progressive (*Aulacomnium palustre*

(Hedw.) Schwägr., *Brachythecium salebrosum* (F.Weber & D.Mohr) Bruch et al., *Pleurozium schreberi* (Willd. ex Brid.) Mitt) and without possibility for further evolution (*Orthotrichum diaphanum* Brid., *Dicranella cerviculata* (Hedw.) Schimp., *Homalothecium lutescens* (Hedw.) H. Robins., *Pleuridium acuminatum* Lindb.) due to apparently exhausted genetic resource. The stability of a plant organism can be determined by both conservativity and plasticity of structures; in each particular case, this pattern is taxon-specific and corresponds to individual trends of evolutionary morphogenetic transformations.

Functional botany [24, 26] is accomplished in the analysis of different levels of structural organization of plants (diagnostics at the level of tissues, individual microstructures of surfaces and conformation) in conjunction with ecological conditions. In field practice, as well as for targeted diagnostics of ecotope conditions and unification of data obtained on plants on a global scale, a general method of calculation is used, while modeling survival processes at the cenopopulation level (synphytoindication) as a variant of outfitoindication. Strategy-specific valuation approaches have been used in a variety of fields, including economics and financial analysis [28]. Often there are questions in adapting the methodology to obtaining primary and interpreting calculated data.

Plant systems in Donbass experience several levels of stress, which is also reflected in the specificity of the orientation of adaptive mechanisms: hyperaccumulation, teratogenesis, physiological tolerance, compensatory mechanisms of survival, a resource of stability due to biochemical reserves.

The greatest effect of transformation is determined for species with high morphological plasticity, which has phenotypic character of manifestation (during active environmental monitoring).

5 Conclusions

The established regularities of changes in the place of species in the distribution system of the CSR strategy triangle reflect microevolutionary processes at the individual level in the development of photosystems. Such microevolutionary processes make it possible to state the realization of adaptation processes and ensuring the stability of species under sharply changing environmental conditions (technogenesis, wars, local catastrophes of anthropogenic origin, etc.).

The structural plasticity of plants that have shown indicator properties increases under conditions of increased geochemical heterogeneity of the landscape. Specific plant neoplasms may occur under the formation of local toxic conditions, the indicator role of which is a signal for field diagnostics in the realized expertise of the ecotope state. Indicator features of plants are also summarized in most cases during the summation effects of ecosystem transformation.

The following species of flowering plants are the most promising for the restoration of ecosystems damaged by hostilities: *Tortula muralis, Bryum argenteum*, *Pleurozium schreberi*, *Leskea polycarpa*, *Ceratodon purpureus*, *Bryum caespiticium*, *Brachythecium campestre*, *Bryum capillare* (mossy at the first stage of succession), and *Phleum pratense* L., *Elytrigia stipifolia* (Czern.) Nevski, *Astragalus cicer* L., *Trifolium campestre* Schreb., *Trifolium pratense* L., *Carex pilosa* Scop., *Sparganium erectum* L., *Oenothera biennis* f. stenopetala (E.P. Bicknell) B.Boivin, *Cirsium vulgare* (Savi) Ten., *Setaria verticillata* (L.) P.Beauv. at the stages of restoration of the vegetation cover.

Ecological valence of species is a property of living matter to reflect changing environmental conditions, which is proved for contrasting characteristics of anthropogenic transformation of ecotopes; this approach is also true for examples of analysis of cenopopulation structures of plants. Wildlife does not tolerate emptiness. All ecological niches tend to be filled, first by elements of dissemination, and then by stable populations with preserved genetic potential for further struggle for existence.

The task has been completed within the framework of the youth laboratory "Diagnostics and mechanisms of adaptation of natural and anthropogenically transformed ecosystems of Donbass" (№ 1023110700153-4-1.6.19;1.6.11;1.6.12; № 124051400023-4).

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