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ADAPTIVE STRATEGIES OF THE HALOPHYTE POPULATIONS

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Abstract – Studies of the adaptive strategies of halophytes at different levels of their organization are important not only for assessment of their health condition and prognosticating their future behaviors, but also for testing potential suitability of technogenic edaphotopes for plant growth without making additional analyses. We investigated the population structure and morphological variation of three halophilic *Gypsophyla* L. species which actively spread in different technogenic ecotopes of Ukraine by methods generally accepted in ecology and phytocenology. By the type of strategy populations of species of the genus *Gypsophila* in technogenic edaphotopes can change the primary type of strategy for the secondary, or gain the stress-tolerant type, mainly due to the changes of parameters of seed productivity. The studied populations are stable with predominance of individuals which reached the prereproductive and reproductive stages of their development. At the organism level the species differ by phenotypic plasticity revealing in compensatory development of vegetative and generative organs. This reflects not only in absolute values of parameters of features, but also when calculating the coefficients of divergence, variation, as well as the vitality classes in populations.By the adaptive strategy halophytes are candidates for use in local phytoremediation of disturbed lands.

Keywords: salinity, Gypsophila, population, morphological variability, anthropogenic stress, phytorecultivation

Introduction

The results of human industrial activity, such as, for example, extraction of water, building materials, natural resources are certainly aimed at bringing direct benefit to society, bringing welfare and comfort. On the other hand, one of the indirect negative effects of technogenesis is the increasing number of disturbed lands, i.e. the areas with disturbed or completely destroyed natural components: plant and soil cover, soil, groundwater, local hydrographic network; changed terrain. This problem has now become global (Van Duuren et al., 2007).

In technogenic disturbed areas edaphotopes are characterized by insufficient amount of nutrients, moisture and often excessive salinity. Therefore, salt-tolerant species – halophytes – are the best candidates for phytorecultivation of anthropogenically disturbed areas. For phytoremediation, melioration and desalination of saline substrates in different countries various halophyte species are used (Kramer, 2005; Zare & Keshavarzi, 2007; Song et al., 2009; Wu et al., 2009; Toderich et al., 2010; Elsey-Quirk et al., 2011). Halophyte populations often show wide variation in salinity tolerance that is determined by their different adaptive reactions – from biochemical adaptations to specialized morphological and population ones (Thompson et al., 1991; Hester et al., 1998). At the morphological and populations level the following adaptive strategies are revealed: prolonged germination period, persistent seed bank, decrease in general plant mass, compensatory reproductive mechanisms, for example, an increase in seed weight along with a decrease in the number of seeds and a size of the whole plant (Ungar, 1998) or increase in seed production with simultaneous decrease in the number of flowers and seed weight (Van Zandt et al., 2003). There is an increase in variation of the number of leaves of some salt plant species, however, variation of the leaf size is reducing in response to increased salinity level

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and decreased water and organic substance levels (Richards et al., 2005). At present, the spread of halophytes on newly developing salt marsh are actively studied (Akhani, 2004; Igegnoli & Giglio, 2004; Davy et al., 2011), both at their different successional stages (Dormann et al., 2000) and across a salt marsh tidal gradient (Rand, 2000), and also in coastal ecotones (Traut, 2005). As noted, halophyte plant zonation in salt marsh is related both to biotic factors (competition with other plant species, biological features of these plants, their phenotypical flexibility) and to abiotic ones (edaphotope characteristics, tidal regime, elevation, atmospheric nitrogen input, etc.) (Castillo et al., 2000; Huckle et al., 2000; Costa et al., 2003; Pennings et al., 2005; Minchinton et al., 2006; Engels et al., 2011). However, there are practically no complex studies of the halophyte adaptive strategies under stress conditions of technogenic edaphotopes until now.

The aim of our research is to determine the features of structural and functional organization of populations and morphological variability of halophilic plant species to establish mechanisms of their adaptation in technogenic ecotopes.

Materials and methods

To perform this work we selected three herbaceous halophilic species of the genus *Gypsophila* L. – *Gypsophila paulii* Klokov, *Gypsophila perfoliata* L. and *Gypsophila scorzonerifolia* Ser.

We analyzed information on their spread in technogenic ecotopes and generalized it according to our long-term (1970 – 2011 years) observations including the data of Herbarium of the Donetsk Botanical Gardens (DNZ) and literature data.

Technogenic ecotopes can be characterized as sites, formed in the process of the human industrial activities, causing irreversible or radical changes to vegetation cover.

Detailed study of population structure and morphological variability of these species was carried out in ecotopes of coal mine dumps, industrial sites and slag dumps of metallurgical works and coke plants.

In the course of coal mining there were formed many huge cone-shaped waste dumps composed of rock, coal particles and slag. Most dumps are burning releasing high concentrations of hydrogen sulfide, carbon and sulphur dioxides into the environment. A special microclimate is formed in the dumps due to their irregular surface, steep (up to 40°) slopes, height of 40 to 120 m above the level of surrounding area. Wind speed is 4 to 6 times higher on the dump top than in the city streets. Difference of surface temperature on the dump of northern and southern exposition can be as high as 20°C. Only rainfall is watering the rock. When the draught sets in, the rock loses all water available for plants to a depth of 20 – 30 cm. In addition, the rock of the "newly" formed dumps is plant toxic due to its low pH (3 to 4), high salinity, heterogeneity of the mechanical fractions and nutrient deficiency.

Population studies were carried out in the "old" waste dump of № 6-14 mine and the "new" dump of "Hanzovka" mine (Makeyevka, Donetsk region). Newly-formed coal mine dumps over dozens of years are biologically sterile as they contain toxic concentrations of water-soluble mineral acids and salts. As the dump is "aging" certain acid compounds are neutralized and soluble salts are washed away of the substrate, that is the favorable factor for plant growth. "6-14" mine dump is a transformed waste heap with a flattened top. It was formed in 1915. "Hanzovka" mine dump was formed in 1955. The process of burning has not stopped yet, and erosions, landslides etc. occur constantly due to its conic shape. Registration plots were laid on dumps' tops and slopes, as well as on the northern and southern expositions.

Metallurgical enterprises present one of the major threats to the environment in the study region. Their emissions are characterized by a complex chemical composition. The most plant toxic component of them is sulphur dioxide. Plants were studied in the industrial sites exposed to conditional high gas concentrations.

Slag dumps are confined to the areas of metalworks. Their substrates are nitrogen and phosphorus deficient, characterized by an alkaline reaction, high salinity, rough mechanical composition, and water deficiency of surface layers. To carry out population research, we chose 10 fixed sites (1 m x 1 m) along transect.

Structure

When studying population structure of the species we used methods generally accepted in ecology and phytocenology (Elzinga et al., 1998). For each cenopopulation we chose on the average 15 – 20 registration plots of 1 m^2. Population density was determined as a number of specimens per square unit.

To study occurrence rate of the species, we chose 100 haphazard registration plots on the surface of technogenic land, where we registered the presence or absence of the species. To carry out population research, we laid out 10 fixed plots (1m x 1m) in each type of technogenic land along transect. When laying out the plots in mine dumps, we took into account the exposition (south, north) and height (top, slope).

Investigation of structure and dynamics of populations was carried out in the framework of ecological and demographic approach with the determination of age differentiation of specimens. Age groups were determined and selected by a set of morphological (qualitative and quantitative) characteristics. We selected germs (g), juvenile (j), immature (im), virgin (v), young generative (g_1), mature generative (g_2), old generative (g_3), subsenile (ss), senile plants (s). For each species we measured 14 parameters of morphological characteristics.

Vitality

To determine vitality structure we used the univariate approach based on vitality assessment of each specific specimen by one characteristic. Such a characteristic, adequately integrating vitality, is one of the morphometric parameters (Zlobyn, 1989). To analyze vitality we chose: monomer length, the number of monomers, leaf surface index, the number of seeds in a capsule.

As a basis for construction of population spectra we took the division of a series into three gradation classes – lower (poorly developed), average (moderately developed) and higher (well-developed), indicated on the axis of abscissas. On the axis of ordinates relative frequencies are indicated, calculated according to the formula:

$$W = \frac{n_i}{N}, \quad (1)$$

where n_i – variant of a series, N – sampling size.

Further on, it is necessary to calculate index of the population quality according to the formula:

$$Q = \tfrac{1}{2}\,(a + b), \quad (2)$$

where a – a lower gradation class, b – an average gradation class.

Based on the calculated index of cenopopulation quality it is possible to single out three major structural cenopopulation types: prosperous – $Q > c$; balanced – $Q = c$; depressive – $Q < c$, where c – the highest gradation class.

For every parameter of all populations we calculated indicators of central tendency of a parameter and divergence coefficient of parameters (DC) (Schmidt, 1984). DC is based on a study of the measure of deviation of parameters of the objects compared. One of the samples is taken as a standard. To determine the divergence value it is important to know the variation size of these deviations, expressed in a uniform scale (not the absolute difference between arithmetical means of parameters of the standard and samples of the other). This is achieved by referring deviations to the sigma standard, i.e. their normalization:

$$\delta = \frac{(M_i - M_{st})}{\sigma_{st}}, \quad (3)$$

where δ – normalized deviation; M_i – sample average; M_{st} and σ_{st} – arithmetical average and standard deviation of a standard. Normalized deviations of each parameter of all samples compared are calculated by formula (3). Plotting them on a graph (profile) gives a visual representation of a divergence rate of characteristics of the objects studied. To obtain the divergence coefficient one needs to calculate the sum of squared deviations of parameters from the standard ($\Sigma\delta^2$) for every series, then calculate standard deviation which characterize the value of DC:

$$DC = \sqrt{\frac{\sum \delta^2}{(n-1)}}, \quad (4)$$

where n – the number of parameters.

To assess the level of interdependence in the system of morphometric parameters indicating vitality of specimens, we calculated the index of morphological integrity (as a ratio of statistically significant associations ($P < 0{,}05$ %) in the correlation matrix to their total number) that enables to assess the integrity of specimens by ecological and cenotic gradients (Mirkin et al., 1989).

For every morphological parameter of all individuals in the cenopopulations we calculated standard statistical indicators – arithmetic mean value and standard error (SE) of mean. SE of mean is the standard deviation of the sample-mean's estimate of a population mean, it is estimated by the sample estimate of the population standard deviation (sample standard deviation) divided by the square root of the sample size (assuming statistical independence of the values in the sample).

Strategy

Seed production was studied by counting the main diagnostic indicators: the number of fruits per plant, the number of seeds in a fruit, length and width of a fruit, weight of 1000 seeds, germination energy and capacity. In addition, we estimated reproductive ability of specimens in populations by the relation of variation coefficient of seed productivity to its arithmetical average; this value is the reproduction ability coefficient (RAC). To determine the laboratory germination capacity and germination energy, seeds were germinated in Petri dishes on filter paper moistened with distilled water, over 30 days, at room temperature and light. Over this period we made a calculation of germinated seeds.

We consider the use of the Ramensky-Grime classification of three primary types of strategies (Ramensky, 1938; Grime, 1979) to be the most reasonable with respect to the populations of plants in technogenic ecosystems: 1) stress-tolerant (S-type) type of strategy according to

J. Grime, patient phytocenotype according to L. Ramensky, the plants are characterized by slow growth and low productivity, they are able to exist for a long time in uninhabitable places with strong stress and slight disorders, tolerant species distinguished by their resistance to extreme growth conditions; 2) ruderal (R-type) type of strategy, explerent phytocenotype: due to intensive growth and significant production of diasporas the plants easily acclimate to highly disturbed but favorable habitats, i.e. they exist in conditions of a slight stress and strong disorders; 3) competitive (C-type) type of strategy, violent phytocenotype, respectively, such species are able to withstand competition and have optimal productivity in optimal for their existence undisturbed conditions (i.e. slight stress and slight disorders). We also singled out the «secondary» types of strategy: ecotopic (S_L) patients – species which can withstand abiotic stress, have physiological and biochemical adaptations for using low environmental resources; phytocenotic (S_K) patients – species that are subjected to cenotic stress from competitors and have adapted to it; intermediate secondary strategies which combine features of the C–R, C–S, S–R, S–C, C–S–R types. This is especially important for ecotopes of technogenic ecosystems since in changeable conditions of anthropogenically transformed environment aggravated by air, soil, water pollution intermediate types of strategies often occur, or secondary types of strategies appear.

RESULTS

We have revealed the general features of morphological structure and strategies of three halophilic species of the genus *Gypsophila* L., allowing them to exist even in phytotoxic conditions of technogenic ecotopes.

Halophilic species of the genus *Gypsophila* are typical ecotopic obligate patients in natural habitats. In technogenic ecotopes with phytotoxic environmental factors (increased insolation, amorphy, poor substrate, moisture deficit, etc.) these species quite quickly form stable viable populations due to their high capacity for cenosis formation, thus, they reveal C–R strategy. Individuals in the population of this type of strategy are usually characterized by lower average values of indicators of seed productivity (the number of seeds in capsule, the number of capsules per plant, absolute seed weight), lower coefficients of variation and reproductive capacity, compared to natural habitats. At the same time, the increase in these parameters of plants in secondary ecotopes of technogenic areas (railway embankments, industrial sites) indicate that the populations gain secondary S–C-type of strategy (Fig. 1).

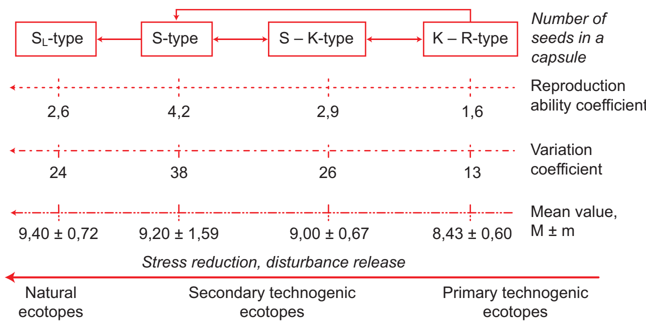

Fig. 1. Some indicators of seed productivity of *Gypsophila paulii* Klokov depending on a strategy type of populations.

The comparison of populations of three species of the genus *Gypsophila* by age structure in conditions of a slag dump revealed that, according to the stages of formation and development, the populations of these species are normal with incomplete representation of members, i.e. not dependent on the entry of germs from the outside and able of self-maintaining (Fig. 2). They are characterized with the incomplete representation of members and predominance of the young part of the spectrum due to the formation of a

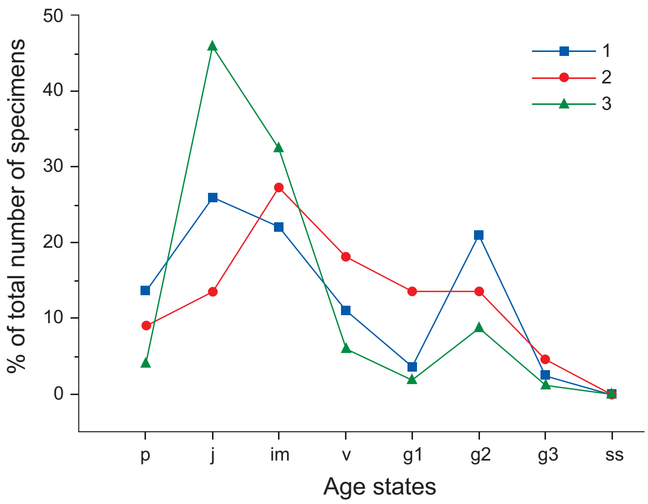

Fig. 2. Age structure of populations of halophilic species of the genus *Gypsophila* L. in conditions of a slag dump: 1 – *Gypsophila scorzonerifolia* Ser., 2 – *Gypsophila perfoliata* L., 3 – *Gypsophila paulii* Klokov.

large number of seedlings. This predominance is the most noticeable in *G. perfoliata* and *G. paulii.* In *G. scorzonerifolia* the number of specimens of g_2 and j age states is almost equal and *G. paulii* has the largest number of juvenile specimens. Despite incomplete representation of members in populations, a large number of seedlings provides addition of the young part of the spectrum. According to the increased lifetime of cenopopulations in technogenic ecotopes the species studied are ranked as follows: *G. paulii* → *G. perfoliata* → *G. scorzonerifolia*.

Comparative analysis of the age structure of *G. scorzonerifolia* populations in different technogenic ecotopes is presented in Figure 3. By the age structure, i.e. relation between age and number of individuals, all of these populations belong to the stable (or stationary) populations. Population which is represented by all or almost all age groups is referred to as stable. Such population is independent and capable of self-management. The temporary absence of individuals of any age states caused by unfavorable environmental conditions do not have any negative effect on population viability, often due to a high seed production of the species individuals.

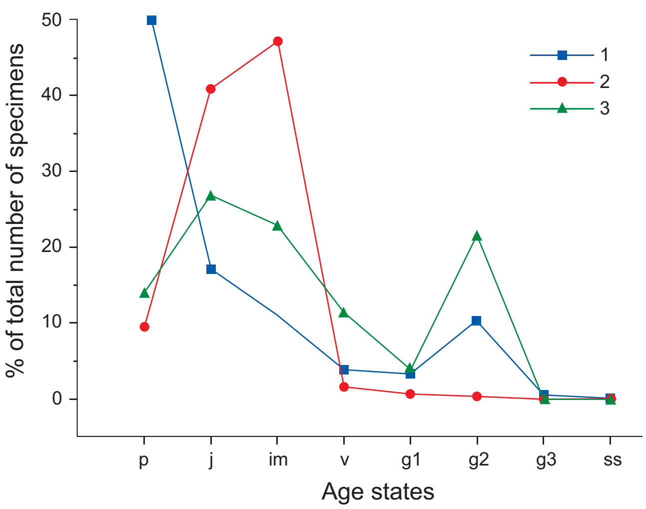

Fig. 3. Age structure of *Gypsophila scorzonerifolia* Ser. populations in ecotopes of different technogenic areas: 1 – coal mine dump, 2 – metalworks industrial site, 3 – metalworks slag dump.

There is a large number of germs in the population from ecotopes of the coal mine dump. Then they pass into the next age states. At the metalworks industrial site and slag dump there is a predominance of the young part of the spectrum (juvenile and immature specimens) in the age structure of populations, however, the percentage of generative specimens is larger in the second case. The absence of specimens at the senile stage is caused by inappropriate conditions for senile particulation in these ecotopes. We detected the highest density of specimens in the *G. scorzonerifolia* populations in the ecotopes of the metallurgical works area (31,4 ± 6,0 units) and in the coal mine dump whereas in the ecotopes of the slag dump the density was low and averaged 5,3 specimens per 1 m^2. However, the total spread area of this species in such conditions is quite large and constitutes about 100 m^2. *G. scorzonerifolia* plants have distributed throughout the area and grow even in the conditions (steep slopes, strong stoniness of the substrate), under which no other plant grows. The area where the population is distributed in conditions of the industrial site is small (about 10 m^2) and, judging by the age spectrum, this population is the youngest one due to the big amount of seeds formed. This allows more young specimens of the spectrum to consolidate and over time the spread area of this population may increase, provided there is an absence of extremely unfavorable factors. *G. scorzonerifolia* population is the most prosperous in ecotopes of the coal mine dump. The conditions of ecotopes of the dump are the most favorable compared to the other technogenic sites studied. This dump is «old», agrochemical parameters of substrate are favorable for planting and plant growth, the stage of mass planting is replaced with the next stage of the increase in species composition and approximation to semi-natural vegetation. *G. scorzonerifolia* populations are distributed both at the top and on slopes of the dump, the occurrence rate is uniformly high (Table 1).

Table 1. Population density of *Gypsophila scorzonerifolia* Ser. in different technogenic ecotopes

Habitat	**Mean ± error in mean**
«Old» coal mine dump, the southern exposure	27,00 ± 4,73
«Old» coal mine dump, the northern exposure	40,10 ± 4,99
Metalworks' industrial site	31,40 ± 6,00
Metalworks' slag dump	5,30 ± 0,25

When comparing *G. scorzonerifolia* populations studied by the divergence of morphometric characters, we indicated that *G. scorzonerifolia* population in ecotopes of the northern exposition of the coal mine dump most highly differed from the standard (DC = 24,21), that was probably caused by heterogeneity of microconditions forming at the dump (Fig. 4). Normalized deviations of the following characteristics: E (monomer length), F (leaf width), H (location of the widest part of a leaf) were especially exceeding the standard values. Populations from other technogenic ecotopes had a similar structure by divergence coefficient, the D (shoot length) and E characteristics were distinguished by being lower than the standard. The population from the dump top differed least from the control (DC = 3,2). Divergence coefficients of populations from the slag dump and the «new» coal mine dump were 6,6 and 4,1, respectively.

The range of species differentiation by size and elements of their morphological structure reveals the external differences between specimens. Absolute values of morphological characters of plants are important for phytoindication because sizes of specimens characterize the environmental conditions in which they develop and live. Average values and morphological variability of some characteristics of species

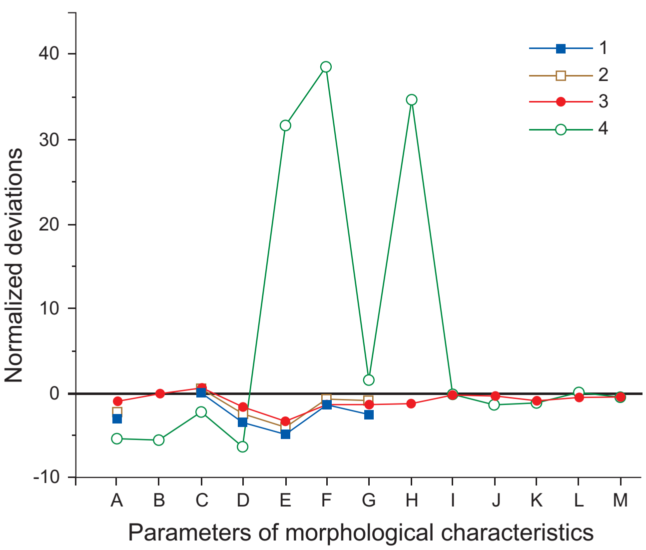

Fig. 4. Normalized deviations of morphological characteristics of *Gypsophila scorzonerifolia* Ser. in technogenic ecotopes in south-east Ukraine: parameters of morphological characteristics on the x-axis: A – inflorescence length (cm); B – the number of leaves per plant (unit); C – the number of monomers on a shoot (unit); D – shoot length (cm); E – monomer length (cm); F – leaf width (cm); G – leaf length (cm); H – location of the widest part of a leaf (cm); I – inflorescence weight (g); K – the number of capsules per plant (unit); J – the number of seeds in a capsule (unit); L – capsule length (mm); M – capsule width (mm). 1 – slag dump; 2 – «new» coal mine dump; 3 – «old» coal mine dump, the top; 4 – «old» coal mine dump, the northern exposure.

of genus *Gypsophila* in technogenic ecotopes are given in Table 2.

A general regularity of morphological variability that is inherent to all three species observed in technogenic ecotopes, compared to control, is a decrease in absolute values of shoot length and monomer length. There is also an increase in the number of shoots, whereas, conversely, their average height is reduced. Moreover, the rate of monomers per plant increases. We also registered the inverse relation of these characteristics in *G. perfoliata* – monomer length increases while the number of monomers decreases. When the plant is growing under conditions of permanent annual prolonged technogenic stress, for example, *G. paulii* is found in edaphotopes of a slag dump, one may detect a general reduction in size of all parts of the plant body (the number of monomers, their length, the length of a shoot and inflorescence).

Size, form, and structure of plant leaves have considerable interspecific variation, and many aspects of these variations can be associated with the environmental conditions to which a plant has adapted (Niklas, 1999; Sapir et al., 2000; Vernescu & Ryser, 2009). We have established the fact that the deterioration of growing conditions causes a decrease in size of a leaf blade (its length and width) of *G. perfoliata*, while leaf elongation increases (the ratio of leaf length to width is increased and, simultaneously, location of the widest part of a leaf is changed), whereas the size and elongation of the *G. paulii* leaf is reduced in unfavorable conditions. This could be interpreted as an evolutionary response to stabilize leaf area, and thus carbon gain, as has been observed in many plants. It is believed this is an adaptation to arid conditions (Couso & Fernández, 2012). On the contrary, *G. paulii* exhibits a reduction in both leaf size and leaf relative elongation rate under unfavorable conditions and hence highest sensitivity to the anthropogenic influence as compared with the other two species.

The research showed that the *G. scorzonerifolia* populations studied in the ecotopes of slag dumps and the industrial site had the highest variation of characteristics, while the variations of *G. paulii* and *G. perfoliata* in slag dumps were the lowest. We have found out that among other characteristics there was the highest variation by the number of flowers and leaf width and the lowest – by the number of monomers, stem length and leaf elongation index.

Variability of size characteristics is different in a population (size structure of a population if the only indicator of specimens is considered, or vitality structure – when the complex of parameters is taken into account) and may reflect differences in growing and production processes, efficiency of habitat resource use, resistance to various stress influences, adaptive processes in it. Population analyses require not only the overall assessment of viability, vitality of every specimen, but also the ranking of specimens by the vitality level. We have analyzed the size structure of the studied populations of species of the genus *Gypsophila* by some morphometric characteristics.

The predominance of one or another vitality group of individuals in a population is indicative of its quality. The predominance of individuals of an average vitality group, according to the characteristic of the monomer number in all studied populations (except for No 4), as shown in the Figure 5b, is indicative of these populations being prosperous. It was found that all the populations of the species studied were depressive by monomer length (Fig. 5a). According to the leaf surface index, *G. scorzonerifolia* populations in slag dumps and in the «old» mine dump, as well as *G. paulii* populations in slag dumps and in the industrial site, *G. perfoliata* in slag dumps are depressive, whereas *G. scorzonerifolia* population in the industrial site and in the «new» mine dump, *G. perfoliata* in slag dumps are prosperous. Basing on the characteristic of the number of seeds in a capsule, *G. scorzonerifolia* populations in the «old» mine dump and in the control point are depressive, the populations of all three species of the genus are prosperous in slag dumps.

The difference in size structure of cenopopulations by various morphological characteristics of three species of the genus *Gypsophila* indicates that during the population

Table 2. Morphological variability of some characteristics of populations of halophilic species of the genus *Gypsophila* L. in technogenic ecotopes, with mean and error in mean (above the dash), and variation coefficient, % (under the dash).

Species, habitat	The number of monomers on a shoot, unit	Monomer length, cm	Leaf length, cm	Leaf width, cm	Shoot length, cm	Inflorescence length, cm	The number of flowers per plant, unit
G. scorzonerifolia, slag dump of Donetsk Metallurgical Plant (DMP)	10,50±0,71 / 26	2,48±0,13 / 44	4,73±0.28 / 45	1,02±0,06 / 45	29,23±3,95 / 38	32,19±3,94 / 35	420,00±64,00 / 43
G. paulii, slag dump of DMP	12,91±0,48 / 12	2,25±0,06 / 16	3,24±0,07 / 13	1,27±0,06 / 27	39,33±1,28 / 8	41,83±1,70 / 1	895,00±145,10 / 4
G. perfoliata, slag dump of DMP	61,25±4,87 / 16	1,80±0,18 / 20	5,15±0,06 / 2	1,55±0,16 / 20	26,90±3,85 / 14	37,80±4,62 / 25	794,00±362,17 / 91
G. scorzonerifolia, waste dump of «Hanzovka» mine	11,81±0,23 / 8	3,66±0,23 / 42	7,39±0,42 / 33	1,26±0,07 / 31	41,00±2,00 / 15	41,00±0,69 / 5	439,80±89,10 / 40
G. paulii, DMP	16,54±3,46 / 20	2,57±0,1 / 34	3,23±0,07 / 14	0,99±0,03 / 19	40,00±3,19 / 18	36,60±4,18 / 25	333,20±111,90 / 82
G. scorzonerifolia, DMP	10,00±0,41 / 10	6,13±0,82 / 52	8,15±0,36 / 22	1,80±0,11 / 29	48,90±3,20 / 19	125,00±13,23 / 21	1517,00±312,50 / 62
G. scorzonerifolia, waste dump of «6-14» mine	11,21±0,37 / 17	3,56±0,09 / 47	6,81±0,08 / 28	1,22±0,02 / 38	40,55±1,75 / 23	46,62±2,86 / 32	382,33±12,71 / 13

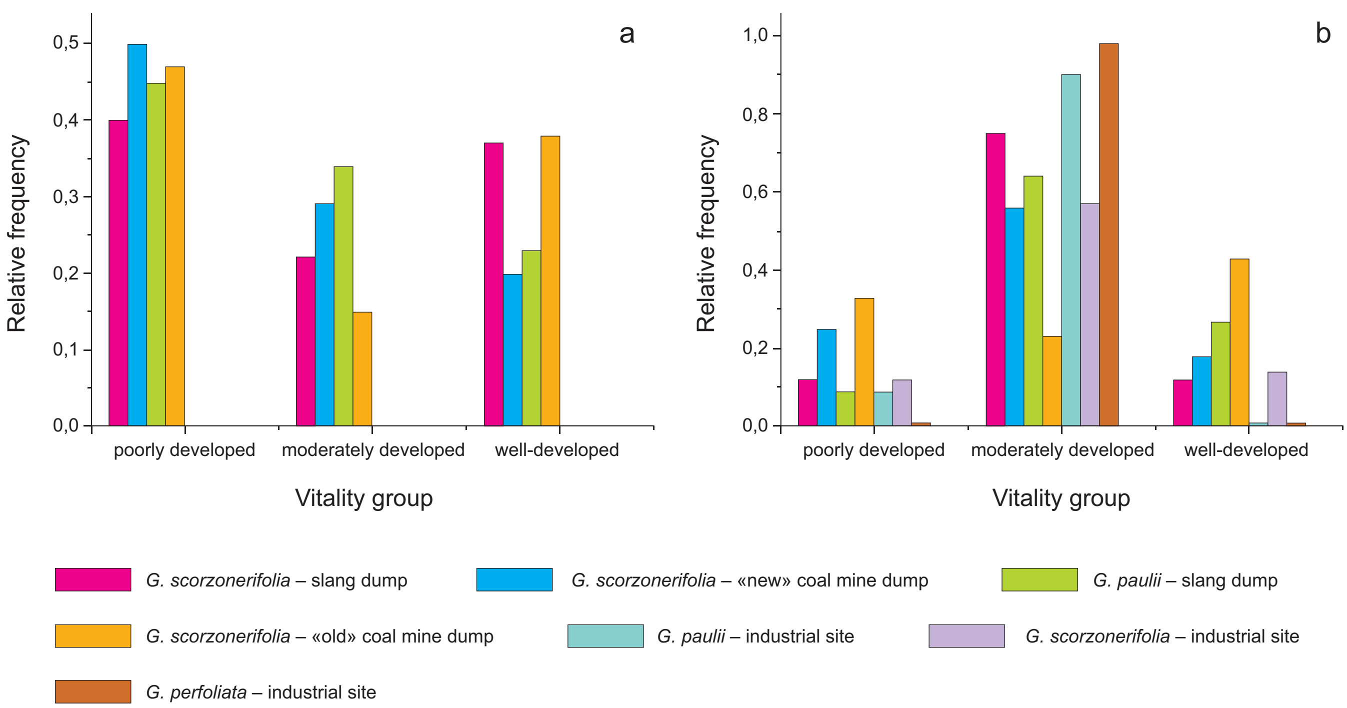

Fig. 5. Size structure of populations of halophilic species of the genus *Gypsophila* by some morphometric characteristics in technogenic ecotopes: a) monomer length; b) the number of monomers.

studies it is necessary to take into account the main principle of vitality concept, i.e. a multidimensional assessment of morphological structure of specimens that is the simultaneous measurement of several parameters of plants reflecting their life condition.

A separate plant body as an integral phytosystem can be represented as a balance of organ masses that have functional differences and deterministic structure: root – stem – leaf – flower/fruit. Between structural elements of plants, which at organism level are represented by the main characteristics of morphological organs, there exist various links leading to the formation of integral system and reflecting vitality of specimens.

A common feature of the studied halophilic species of the genus *Gypsophila* is a low values of morphological integrity of most populations (4 – 5 on average) that indicates their low vitality in technogenic ecotopes in comparison with, for example, some advents (*Iva xanthiifolia* Nutt. – 50; *Conyza canadensis* (L.) Cronq. – 25). The analysis of morphological integrity of *G. paulii* parameters over time (during 2006 – 2010) has showed a significant decrease in this index in populations at the metalworks industrial site (from 3,64 in 2006 to 0 in 2010) and in the slag dump (from 1,82 to 0,48, respectively). By the index of morphological integrity, the vitality of the *G. scorzonerifolia* specimens increases in cenopopulations in ecotopes of the slag dump and the «old» mine dump (1,43) and decreases in populations in ecotopes of the «new» mine dump (0,95). This fact conforms to the obtained data on size structure of plants of the populations of this species.

Discussion

The integrated monitoring of establishment, formation and development of the populations of studied species of the genus *Gypsophila* L. allowed to establish some features of their strategy, structure and morphological variation in technogenic ecotopes.

In their natural habitats *Gypsophila* species are found on saline sandy meadows in floodplains of rivers, on the Azov and Black Seas coasts. Structural organization of these species is typically haloxeromorphic: strong root system deeply penetrated into the substrate, fleshy (stretched out or of «brides veil» type of the *G. paulii* and *G. perfoliata* species) overground part, pubescence of all parts of the plant of *G. perfoliata*. These species adapt to the conditions of salinization through salt conservation, i.e. by this characteristic they belong to the ecological and physiological group of salt conservators or hyperhalophytes. These plants grow and develop well only if there is a particular amount of chlorides and sulfates in substrate, which they accumulate in their body. Their tolerance to soil salinity is a result of tissue tolerance strategy consists in the ability of tissue to accumulate salt ions Na^+ and Cl^- (Munns & Tester, 2008). These features of halophytes that evolutionally developed as an adaptation to the life on poor, saline soils enable them to survive as well in anthropogenic transformed lands characterized by agrochemical and physical properties of the substrate, unfavorable for other plants' growth: non-humusness, amorphy, intensive insolation, high temperature, moisture deficit, etc.

In technogenic ecosystems with unstable and unfavorable growing conditions the plants show plasticity at all levels of their organization, which, after all, reflects the life strategy of the species.

By the type of strategy, populations of halophilic species of the genus *Gypsophila* in natural conditions are typical ecotopic obligate patients. But in primary and secondary technogenic neoedaphotopes, owing to the absence of competitors and high vitality and anthropotolerance, they can change the primary type of strategy for the secondary – K–R and S–K-types, or gain the Grime's stress-tolerant S-type (Grime, 1979), mainly due to the changes of parameters of seed productivity.

By the lifetime in technogenic ecotopes populations of halophilic species of the genus *Gypsophila* are stable, they are continuing adaptation processes, which are expressed in the predominance of young specimens in age spectra, low correlation and medium (up to 30%) variability of morphological parameters.

In technogenic ecotopes, by divergence coefficient, the structure of *G. scorzonerifolia* and *G. paulii* populations, which differ from the standard, is similar. *G. paulii* is characterized by the lowest integrity of specimens in populations of technogenic ecotopes by ecological and cenotic gradients.

The study of intrapopulation variability of species is impossible without the measurement of morphological features of a plant individual (Harper, 1977). This issue remains one of central for modern ecology (Sutherland et al., 2013). Therefore the morphological variability of the genus *Gypsophila* populations we studied at the organism level.

Our data partially confirm both the clonal stress hypothesis and with published models of plant reproductive strategies in variable environments, in that salinity and environmental stress stimulated sexual reproduction at the expense of growth (Samson & Werk, 1986; Van Zandt et al., 2003). Actually, in case of the increased environmental stress, at the organism level specimens of all the studied species of the genus *Gypsophila* L. show phenotypic plasticity, expressed in compensatory development of vegetative and generative organs. This fact proves the plasticity-tolerance hypothesis in stress conditions (Couso & Fernández, 2012). So, a lesser shoot height can be compensated by an increased number of monomers and their lesser height; a lesser florescence size is compensated by more numerous flowers; photosynthetic area is compensated by means of a lesser leaf size along with its elongation. However, if the conditions get worse (increased salinity, absence of nutritive elements, high toxicity, stony edaphotopes, dustiness, pollution, dry air etc. – for example on a slag dumps of the metallurgical plants), a general reduction of both linear and quantitative dimensional and reproductive characters is observed. If the plants grow in such marginal environment conditions for a long time, morphological integrity of individuals in halophyte populations reduces significantly and can be as low as zero that indicates the reduced vitality and integrity of the morphological structure of populations.

These adaptive features of morphological and structural organization of the species studied are reflected not only in absolute values of parameters of features, but also when calculating coefficients of divergence, variation and vitality classes in populations.

Thus, all the size morphostructural and age quantitative features of the plant state have a great biological importance, determining the reproduction and development (phytomass formation) ability of plants. Taking this into account, the population level of study of the strategies is not only the easiest for a researcher, but also the most reasonable from the point of considering populations as major specific units. In addition, for an adequate interpretation of results it is necessary to take into account the basic principle of the vitality concept based on the multivariate assessment of morphological structure of specimens, i.e. considering several characteristics of plants which reflect their life condition.

Conclusions

In this paper we study and regard for the first time the adaptive strategies of halophilic plant species in the ecotopes of lands disturbed by industry. This study is based on the generalized research results on these plants population structure, morphologic variability, seed production and the character of their spread.

We have established that under adverse conditions of anthropogenic stress these plants are able to exist, spread and form stable viable populations due to changing their initial patient strategy either to the stress-tolerant one, or to the secondary strategy types (according to Ramensky-Grime). Therefore by the adaptive strategy halophytes are candidates for use in phytorecultivation and local phytoremediation of technogenically disturbed lands.

This morphologic and population approach to studying the plant adaptive strategies, originated by us, is applicable to recultivation and amelioration of the disturbed lands in any other industrial region.

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