Біологічний вісник МДПУ імені Богдана Хмельницького 6 (3), стор. 295–302, 2016
Biological Bulletin of Bogdan Chmelnitskiy Melitopol State Pedagogical University, 6 (3), pp. 295–302, 2016

ARTICLE ***UDC 574.38***

THE DEVELOPMENT OF THE CONCEPT OF PLANT FUNCTIONAL TYPES WITH REGARD TO RARE SPECIES

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Plant functional type (PFT) is a description of the main functional and structural characteristics of plant species, which ensure its vitality and adaptive capabilities. In practice, researchers choose a subset of these characteristics, based on a specific scientific task. We assessed the level of biological and ecological individuality and diversity of the whole community of the protected plant species towards plant functional types in Sumy region (Ukraine). At present, there are 150 species of protected vascular plants in Sumy region. The selection of key parameters to evaluate PFT of the protected and rare plant species has a significant limitation. The phytosozological literature contains no data which are usually taken into consideration for the widespread plant species. The biological and morphological parameters included life-form (4 levels), age (3 levels), root system (3 levels), presence and type of underground metamorphoses of the vegetative organs (5 levels), type of reproduction (5 levels). The analysis has shown that Euclidean distances are not equal to zero for a couple or a group of plant species. Each plant species has its own functional type which is characteristic only for it. Some six pairs or groups of species with the closest Euclidean distances in the range from .10 to .15 were revealed from a number of 150 examined plant species. Overall, only 13 species were considered as the similar by their functional type. The remaining 137 species have significantly large differences in their structure, biology, and ecology parameters. This result is consistent with the principle of structural and functional individuality of each of the taxonomic plant species. Based on this fact, the system of rare plant species protection in Sumy region should be individualised in accordance with the functional type of the specific protected plant species and its requirements for the ecological-coenotic environment.
Key words: *biodiversity, rare plants, plant functional types, Sumy Region.*

Citation:
Klimenko, A.A. (2016). The development of the concept of plant functional types with regard to rare species. *Biological Bulletin of Bogdan Chmelnitskiy Melitopol State Pedagogical University, 6* (3), 295–302.
Поступило в редакцию / Submitted: 14.10.2016
Принято к публикации / Accepted: 26.11.2016
crossref **http://dx.doi.org/10.15421/201698**

INTRODUCTION

The Biodiversity Program (1991) and Convention on Biological Diversity (1992) were adopted at the international level in connection with a reduction in ecosystem biodiversity. These documents, as well as a number of international and regional regulations, have resulted in compiling the lists of plant species to be protected, publication of the Red Data Books and regional lists of the protected plants. The main criteria for the decision on granting a plant species with the protected status are its rarity and the associated threat of extinction. The features of life form, biology, ecology, and other properties of rare plant species are considered only in some special publications that covered particular plant species. The integrated assessment of the plant species was not related to administrative units or physiographic regions (Andrienko, 2008; Didyck, 2008; Logvinenko, 2014).

At present, 150 species of vascular plants are protected in Sumy region (Ofitsiyni pereliky, 2012). The analysis of their individual biological and ecological properties has not been carried out. In this regard, our task was to assess the level of biological and ecological individuality and diversity of the whole community of the plant species with protected status in Sumy region regards plant functional types.

During the first quarter of the last century, L.H. Ramensky (1924) formulated a fundamentally new perspective on plan arrangement according to: (a) biological and ecological individuality of each plant species and b) continuum. The second statement was confirmed by many scientists, and is currently being considered as an axiom, whereas the first statement has not been originally disputed. But it has not received a comprehensive development. This time the main ideas was to find the ways to group the plants according to similarities in their characteristics. The classifications uniting plant species by morphological and biological characteristics by Raunkiaer, Golubeva, Serebryakova and others, have become apparent, and the doctrine of ecological and coenotic plant strategies by J. Grime has experienced a rapid development (Golubev, 1972; Grime, 1979; Raunkiaer, 1934; Serebryakov, 1964).

At present we use the concept of plant functional type (PFT). Overview of the current state of the doctrine of plant functional type was made in the works of Zlobin (2012a, 2012b) and Mirkin (2012), Sandra Lavorel et al. (2007). Accordingly, the concept 'plant functional type' was used in the pioneering works as 'a *separate plant type* or a group of species that react to the habitat conditions in the same manner' (Shugart, 1997, p. 20).

Plant functional type (PFT) is a description of the main functional and structural parameters of a separate plant species, which ensure its vitality and adaptive capabilities. In practice, researchers choose a subset of these key parameters, based on a specific scientific task. An important advantage of the PFT concept was its flexibility. It can be used not only to establish the individuality of each type separately (PFT), but also to identify plant groups with similar properties, i.e. plant functional groups (PFG).

On the first stage of development of PFT under the influence of the interests prevailing during this period in geobotany, the researchers used a methodology to identify plant functional groups (PFG) rather than plant functional types. So, Diaz and Cabido (1997, p. 463) have identified 'plant functional type as a group of species that show similar response to the habitat and have similar impact on the processes prevailing in the ecosystem'. Later, V.E. Smirnov (2007, p. 1) determined plant functional group (PFG) as a 'group of plant species similar in some set of functional properties and in relation to certain environmental factors, without taking into account phylogenetic relationships between these species'.

Justifying this approach, Liao and Wang wrote: 'The analysis of plant functional groups allows researchers to focus on a small set of functional parameters that are common to many plant species, instead of studying each plant species in its great details' (Liao & Wang, 2010, p. 9208). In fact, in many studies the allocation of plant functional groups was carried out only on the basis of several qualitative characteristics, which led to the allocation of plant functional groups rather than plant functional types, e.g. tropical trees, deciduous trees, shrubs, etc. (Box, 1996). Later, this approach was used in a different form by many researchers mainly to analyse plants in the large botanical and geographical zones with a slightly increased number of parameteres, included not only the features of vegetative organs but also reproductive structures (Wang & Chen, 2013).

In fact, the allocation of PFG that based on a small number of subjectively selected parameters reduced the concept of plant functional types to the usual classification of plant species according to the types of life form, the peculiarities of the morphological structure or signs of adaptation to the habitat. The only difference is the term. The term 'plant functional groups' (Hanin et al., 2015) is used instead of the terms 'life form', 'growth form' or 'ecologo-cenotic strategy'.

In contrast to the PFG allocation method, the quantitative parameteres of plants which are the most important to ensure the viability of plant species and their adaptation to the phytocenotic environment are mainly used for establishing the PFT. A set of key plant parameters could be large enough so that it is essential to use the methods of multivariate statistics such as cluster analysis for the final estimation of PFG. As an incentive for the development of this direction, some researchers (Cornelissen et al., 2003, Pérez-Harguindeguy et al., 2013) had developed and independently published the standard procedures for registration and measurement of the plant parameters which give a fairly complete description of its functional type. This is essential for the assessment of the plant species by morphological structure, branching of shoots, plant height, morphology and anatomy of leaves, quantitative parameters of growth, type of reproduction, method of pollination, evaluation of the selected biochemical and physiological parameters and some others.

The main disadvantage of this method is the disregard of ecological properties of the species, i.e. its ecological optimum and width of ecological amplitudes towards main habitat factors. From our point of view, such ecological data should be an essential component in assessing the viability and sustainability of any plant species in phytocenoses and considered in the selection of the functional types of the protected plant species.

MATERIAL AND METHODS

Some 12 key parameters (five bio-morphological and 7 ecological) were used in our work to assess the biological and ecological characteristics of 150 protected rare plant species in Sumy region (Ofitsiyni pereliky, 2012). Sumy region is in the north-east of Ukraine. Its area is 23834 square kilometers. The population of the region is 1,113,300 people (2016).

The biological and morphological parameters included life-form (4 levels), age (3 levels), root system (3 levels), presence and type of underground metamorphoses of the vegetative organs (5 levels), type of reproduction (5 levels). All characters were determined from the analysis of geobotanical descriptions, field descriptions of species, herbarium specimens and mainly from literature data: The Red Data Book of Ukraine (2009), the Red Data Book of the Azov region (2012), special reference books and numerous publications devoted to the biology and ecology of plants. All abovementioned parameters and habitat (7 levels) were used as the structural and functional characters of 150 studied rare plant species of Sumy region.

The scales of Didukh (2011) such as moisture content, nutrient status of the soil, temperature and light were used to assess the ecological optimum of rare plant species. The assessment of wide ecological amplitudes of the protected plant species was conducted for two major environmental regimes: climatic conditions and nutrient soil status by method Zhukov (2010), according to which the potential ecological amplitude (in his terminology 'valence') is:

$$PEV = (A_{max} – A_{min} +1)/n,$$

where A_{max} and A_{min} are the maximum and minimum values of the factor at the ecological scale, n - number of stages in the ecological scale calculated for each plant species.

Then, on the basis of the obtained values of PEV, the tolerance index of this species to the relevant environmental regime was calculated according to the following formula:

$$It = \Sigma\ PEV / \Sigma\ Sc,$$

where Sc is the number of scales included in this ecological regime.

By tolerance index all the plant species were divided into five groups from stenobionts (< .34) to evribionts (> .67) by two groups of factors separately – climate and soil.

The computer database with 12 characters and properties for each species was formed at first phase of work for 150 plant species with protected status in Sumy region.

Data processing was carried out using the cluster method and the method of discriminant analysis (Durand et al., 1977; Computer Biometrics, 1990; Barseghyan et al., 2009). The use of cluster analysis requires standardization of initial data, otherwise we could mainly have the greatest absolute values (Kaufman, Rousseeuw, 2009). Such standardization was performed for the ecological indicators dividing the optimal value by a number of graduation levels in this ecological scale. Therefore, they were in the range from 0 to 1 for each factor. The same coding was undertaken for the quality characters of plants.

RESULTS AND DISCUSSION

Based on the results of the cluster analysis, the matrix of Euclidean distances of 150x150 and a dendrogram (Fig. 1) were obtained for 150 studied rare plant species.

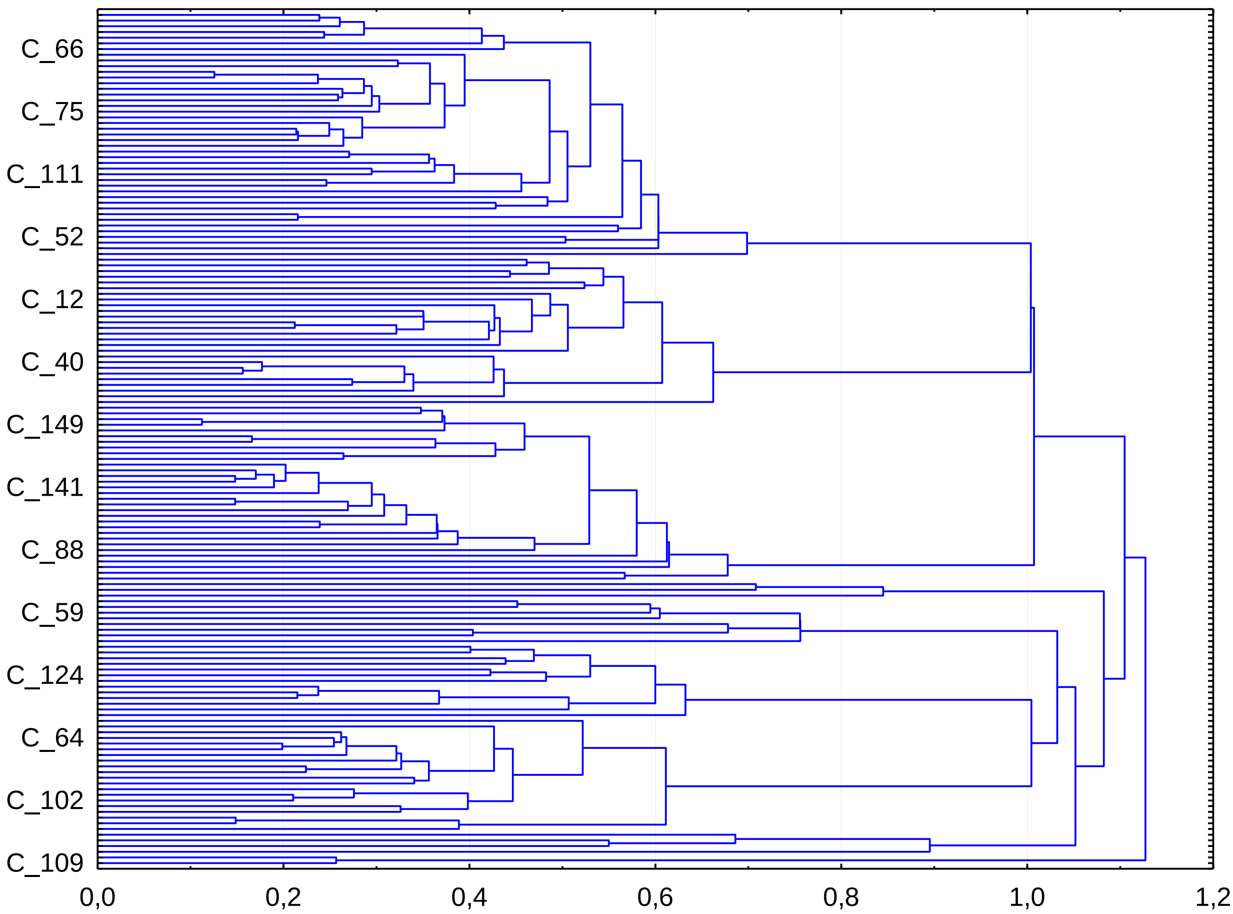

Fig. 1. Dendrogram of Euclidean distances for 150 rare plant species in Sumy region.

Only six pairs or groups of 150 species with the closest Euclidean distances were in the range from .10 to .15. They are:

1. *Astagalus dasyanthus* Pall. and *Stipa capillata* L. – with different morphological structure and systematic position; these two species are combined into in a single cluster by the similarity of requirements for the habitat: both species are subxerophytes, heliophytes, and mesotherms according to Didukh classification and have the same way of reproduction.

2. *Linum flavum* L. and *Jurinea calcarea* Klokov being the calciphile plants that grow on the steppe, in limestone slopes have the similar functional type. They are hemistenobionts with narrow ecological amplitudes of edaphic factors. They propagate by seeds only.

3. Another cluster consists of two typical meadow species: *Gentiana cruciata* L. and *Inula helenium* L. They are the perennial herbs of caudex type characterized by seed reproduction only. They have the similar requirements for basic ecological factors of the habitat, but the first species is hemistenobiont in relation to edaphic factors, and the second one is mesobiont.

4. The fourth cluster contains three closely similar PFT – *Cypripedium calceolus* L., *Epipactis helleborine* (L.) Crantz and *Listera ovata* (L.) R.Br. All three-plant species are perennial forest herbs of the rhizomatous type. In this case, the Euclidean distance between *Cypripedium calceolus* and *Epipactis helleborine* is minimal (.10) for the complete matrix of 150 species. The main difference between these species caused by the more arrower ecological amplitude of *Epipactis helleborine* in relation to the nutrient soil status and factors of climatic complex. *Listera ovata* (Euclidean distance .14) with similar structural and functional characters is also included in this cluster. All three plant species of this cluster are the hemisciophytes.

5. The fifth cluster includes *Prunella grandiflora* (L.) Scholler and *Veratrum nigrum* L., which are the perennial forest herbs with similar requirements for habitat conditions. They are the submesophytes, semieutrophic plants, mesotherms. The only difference was that *Veratrum nigrum* has a wider ecological amplitude of climatic and soil factors.

6. The sixth cluster contained closely similar PFT (Euclidean distance .11) consisted of two meadow species, representatives of Orchid family: *Dactylorhiza majalis* (Rchb.) Hunt and *Malaxis monophyllos* (L.) Sw. They are the perennial herbs with similar structure of underground organs. However, the first of these species, according to soil properties is hemistenobiont and the second one is mesobiont that is able to grow on wider range of soil properties. In addition, *Dactylorhiza majalis* belongs to the group of submicrotherms, and *Malaxis monophyllos* is submesotherm.

Overall, only 13 species, which are rather similar, but not identical, were selected from 150 protected plant species by their functional type. The remaining 137 species have significantly larger differences in their structure, biology, and ecology.

Some four plant species of functional type that was significantly different from the bulk of species were revealed. Their Euclidean distance were in the range of .80–1.12. They are:

1. *Crataegus ucrainica* Pojark. – a tree or a large shrub included in the European list of the IUCN protected plants. In Sumy region, they are occasionally found on the edges of deciduous forests.

2. *Aster amellus* L. It is the only typical representative of salt marsh plants in the region. It is the hemicryptophyte, perennial herb with short rhizome, heliophyte. We determined it as the stenobiont which is characterised by narrow ecological amplitude in relation to the climatic and soil factors.

3. *Salvinia natans* (L.) All. and *Trapa natans* L. They are floating aquatic plants, annuals, and heliophytes. They did not form the common cluster: the first of these species is propagated by seeds, and the second species is propagated by spores, so Euclidean distance between them is considerable (.94). These two different functional types of plants have primarily different development cycle.

Other types of rare plants according to their Euclidean distances of .7–.8 take an intermediate position and form several loose clusters. In this clusters dominated forest (36.0% of total number of the protected plant species in Sumy region), meadow (19.3%), steppe (15.3%) and marsh (14.0%) perennial herbs with the pronounced differences in morphological structure, biology, and habitat requirements.

The possibility of allocating of PFG for 150 rare plant species of Sumy region was based on multi-character approach and tested by discriminant analysis. The following factors were consistently used as grouping variable: a) morpho-structural characters, b) ecological properties of species, c) typical habitat. In the group of morpho-structural characters the highest difference was found for the structure of underground organs (the value of Wilks' lambda was .226, Fisher's F was 5.594, $p<0.000$, Fig. 2). We were able to distinguish the following functional groups of rare plants as tap caudex, bulbous, long- and short-rhizomatous types.

The basis of one clusters was the perennial herb with the caudex tap root system. The other looser cluster were long- and short-rhizomatous plant species. The plants of bulbous type became separated cluster quite distant from other groups. The group of plants with underground organs of bulbotuberiferous type turned out to be the least integral by a complex of structural and functional characters.

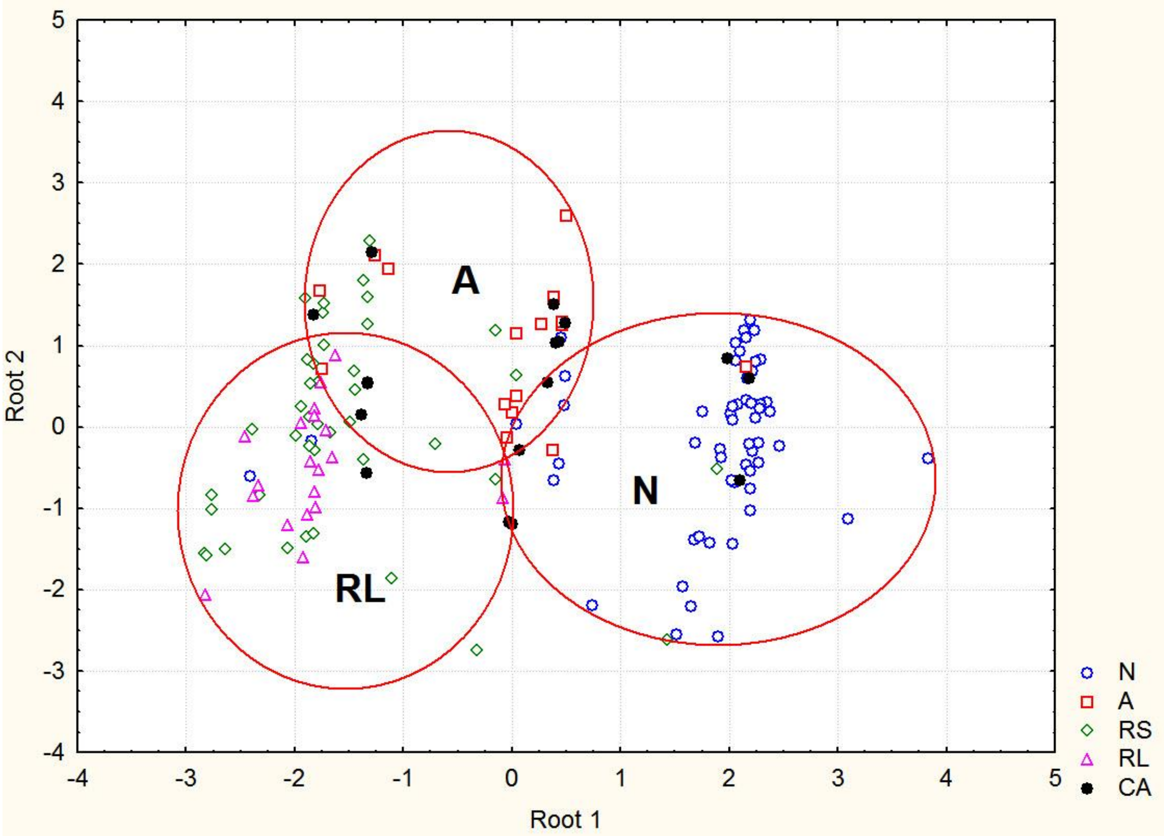

Fig. 2. Discriminant analysis of 150 protected rare plant species in Sumy region by morphological structure. N – tap (caudex) root system, A – bulbous plants, RS – short-rhizomatous plants, RL – long-rhizomatous plants, CA – plants with tubers or bulbous tubers.

The largest cluster of 56 plant species (PFG) were the perennial herbs. Their common feature was root system of tap (caudex) type. The typical representatives of this PFG were:

Astagalus pubiflorus DC – pratant, hemicryptophyte, heliophyte.

Crinitaria linosyris (L.) Less. – stepant, hemicryptophyte, submesophyte, eutroph, mesobiont in relation to climatic factors.

Dentaria quinquefolia M.Bieb. – silvant, mesophyte, submesotherm, sciophyte, stenobiont in relation to the group of climatic factors and hemistenobiont in relation to the soil factors.

Gentiana cruciata L. – hemicryptophyte, mesophyte, pratant, mesobiont in relation to the group of climatic factors and hemistenobiont in relation to the soil factors.

Stipa pennata L. and *Stipa tirsa* Steven. – stepants, subxerophytes, heliophytes, hemieurybionts in relation to the soil and climatic factors.

Overall, this is a fairly loose PFG being combined by the root system type, the seed reproduction only. We observed strong domination of meadow and steppe species with the participation of forest types over there, while plant forest species had low density, because this PFG is characterised by high photophily.

The results of discriminant analysis for other morphological characters were statistically insignificant. Division of rare plant species per functional group in this case is possible only on the basis of one or two characters, but not on all 12 characters as they leveled out the differences between plants of different life forms or different ways of reproduction.

A similar analysis was conducted for the studied plant species with the allocation of one of the ecological characters as the grouping variable. The statistically reliable results were obtained by differentiation of species according to their relation to water regime (Wilks' lambda was .109, Fisher's F-test was 4.369, $p < 0.000$, Fig. 3).

But as the plants with similar moisture requirements belong to the different life forms with different morphological structure, they could hardly be differentiated in the space of the first and second canonical roots. Even a group of the plant species, which are equally valued as subxerophytes by Didukh ecological scales is quite heterogeneous taking into account their characters and properties. It includes the following types which, in general, differ in other features:

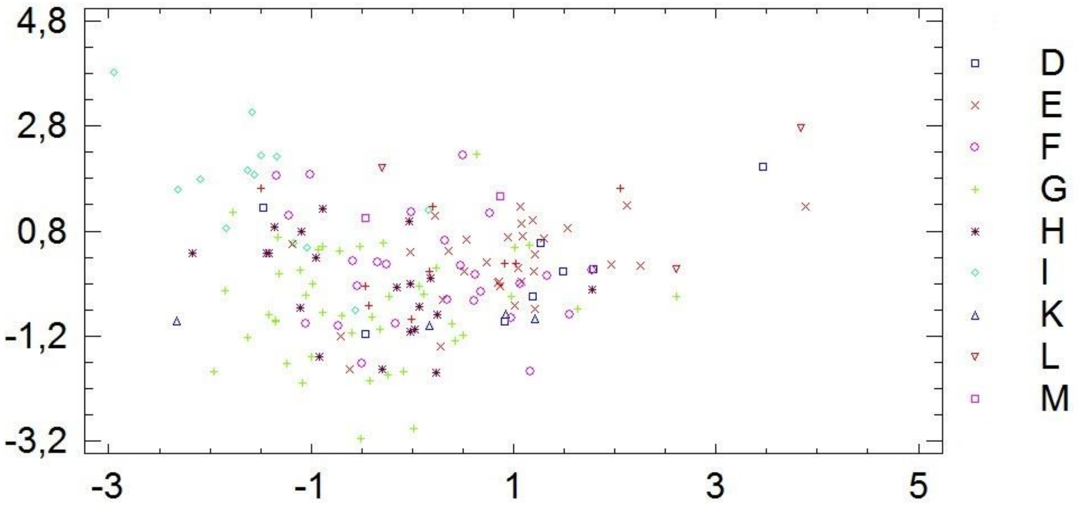

Fig. 3. Results of discriminant analysis of 150 protected rare plant species in Sumy region towards water regime. D – subxerophytes, E – submesophytes, F – mesophytes, G – hygromesophytes, H – hygrophytes, I – perhydrophytes, K – subhydrophytes, L – hydrophytes, M – hyperhydrophytes.

a) *Allium flavescens* Besser is a perennial bulbous plant, the bulbs of which are crowded on the horisontal rhizome, and therefore, it has generative and vegetative reproduction. It is the stenobiont in relation to the climatic and soil factors.

b) *Arctostaphylos uva-ursi* (L.) Spreng. is a perennial evergreen shrub with height up to 30–50 cm, heliophyte. It is mesobiont in respect of the climatic and soil factors.

c) *Hyacinthella leucophaea* (K. Koch) Schur is a perennial herbaceous bulbous plant, stenobiont. It is the entomophilous plant.

d) *Linum austriacum* L. is a perennial plant with woody rhizome, reproducing by seeds. It is mesobiont in respect of the climatic and soil factors.

e) *Stipa capillata* L. is a perennial herbaceous plant from Poaceae, hemicryptophyte, reproducing by seeds. It is mesobiont in respect of the climatic factors, but stenobiont in relation to the edaphic factors. It is the anemophilous plant.

Thus, five considered plant species combined in a single functional group in relation to the water regime actually differ substantially in morphological structure, way of reproduction, and types of pollination. In fact, each of these plant species is a unique functional type.

The discriminant analysis was also conducted on the basis of this grouping variable, a typical habitat for this rare species (Wilks' lambda was .121, Fisher's F-test was 5.249, $p < 0.000$). The position of the plant species concerning the first and second canonical roots is shown in Fig. 4.

In this case, plant species in forest habitats such as silvants, paludants, aquatic plants, and halophytes can be treated as separate functional groups. Functional types of meadow and steppe plants were slightly differentiated from each other by a complex of the estimated parameters.

In general, a set of PFTs in Sumy region was represented by 150 independent functional types, provided that the differences between them has always been not in one character or property, but in several ones. High diversity of PFTs is quite natural as there are 256 natural-protected forest, marsh, and steppe objects in Sumy region (Report..., 2007). Sumy region is located at the junction of the two physiographic zones: Polissya and forest-steppe that predetermines its considerable floristic diversity and, therefore, the diversity of PFTs significantly different from each other. As all 150 plant species that protected in Sumy region are very diverse according to their functional type, their unification in PFG by a set of characters can only be conventional. The boundaries between individual PFG in all the considered cases are amorphous and often overlap because the protected plants of one PFG grow in different protected areas, which sometimes are significantly distant from each other.

It is essential to develop a system of the management measures for the preservation of the protected plants in Sumy region taking into account the high diversity of PFT and connect with each species of plants separately. This approach is consistent with the proposal of Zaveruha and Novosad (1998) to develop the particular sphere of phytosozology – outphytosozology as the protection of plant species. The allocation of territories such as nature reserves and sanctuaries, where rare plant species are registered, is not effective without the target actions for the conservation of these rare species growing on them. It is necessary to carry out regular monitoring of populations of rare species to determine effective methods of protection.

CONCLUSIONs

Based on the analysis of 150 rare plant species protected in the Sumy region, it has been established their identity by functional types PFTs regards 12 characters. It is shown that the accuracy of the functional characteristics of individual types of plants increases, given the importance of environmental optima and ecological amplitude on the main environmental factors. Combining the PFTs in the plant functional groups for structural and morphological characteristics, environmental characteristics, or typical habitats leads to a substantial reduction of their basic features. PFGs advisable to allocate only to solve the most common problems of plants and vegetation analysis. Since all the rare plant species of the Sumy region were characterized by specific features, the development of environmental management of protected plants must take into account the high diversity of PFT for every species.

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