UDC 575.17 (582.542.11)

N. Miryuta [1], **J. Smykla** [2, 3], **I. Parnikoza** [1, 4, *] https://orcid.org/0000-0002-0490-8134, O-2781-2019

[1] State Institution National Antarctic Scientific Center, Ministry of Education and Science of Ukraine, 16 Taras Shevchenko Blv., 16, Kyiv, 01601, Ukraine

[2] Institute of Nature Conservation Polish Academy of Sciences, Mickiewicza, 33, 31—120, Kraków, Poland

[3] University of North Carolina Wilmington, 601 S. College Rd., Wilmington, NC 28403-5915, USA

[4] Institute of Molecular Biology and Genetics, National Academy of Sciences of Ukraine, 150 Akad. Zabolotnogo Str., Kyiv, 03143, Ukraine

Corresponding author: ivan.parnikoza@uac.gov.ua

ALGORITHM FOR THE UNITED QUALITY LATENT INDEX OF THE PLANT ADAPTABILITY AND ITS APPLICATION FIELD IN MONITORING OF *DESCHAMPSIA ANTARCTICA* È. DESV. POPULATIONS

ABSTRACT. **Main objective** of the research was to develop an algorithm for the United Quality Latent Index of Adaptability (UQLI, I^q) and to demonstrate its application on the study of *Deschampsia antarctica* È. Desv. at the monitoring site of Galindez Island, Argentine Islands, maritime Antarctic in natural setups. **Methods**. Cover area of eleven populations of *D. antarctica* as well as measurements of their morphometric parameters were obtained for use in the analysis including: leaf length, inflorescence length, flower length (by lower glume), and flower count in an inflorescence. Protein densitometry profiles of seeds from eleven *D. antarctica* populations were also added to the dataset. Extreme grouping method was used to calculate the United Quality Latent Index of Adaptability (UQLI). The estimation of United Latent Quality Index of Adaptability (UQLI, I^q) was performed by pairwise comparisons of sets of spatial pair differences indices. **Results**. We described the use of the algorithm for UQLI estimation for eleven populations of *D. antarctica* from Galindez Island in the 2017/18 season. As an example of practical application, we presented the six-year UQLI trends for six experimental *D. antarctica* populations from Galindez Island. **Conclusions**. The developed algorithm for the UQLI calculation was applied to evaluate the complex adaptability in the six-year monitoring dynamics for six *D. antarctica* experimental populations from Galindez Island. Trends of the UQLI were obtained for all sampled population. The researched populations can be categorized by trends in the proposed adaptation index into three separate groups as follows: passing through maximum, passing through minimum or experiencing oscillations. It is suggested that such categorization is related to individual micro-habitat conditions. Further addition of the observation data will improve the explanation of the oscillating UQLI trends and will allow to study its relationship with other climatic indices. The UQLI index is proposed for reduction of dimensionality of source data at different organization levels that characterize sample populations. The UQLI can be used to compare a sets of populations sample of the same species growing under different conditions, especially during monitoring studies.

Keywords: *Deschampsia antarctica* È. Desv., population dynamic, United Quality Latent Index of Adaptability, Argentine Islands, maritime Antarctic.

INTRODUCTION

In biological systems, stress acclimation as well as development of stress tolerance features are facilitated by a convoluted coordination (or say, orchestration) of biochemical and physiological mechanisms of response to multiple abiotic (and biotic) stress factors, such as cold, drought, salinity, main organic elements content in soils, that in the end influence the plant development. In plants such self-defence mechanisms have been extensively studied on molecular, cellular and physiological levels, e.g. by correlating the effect of the abiotic factor with the synthesis of stress-response proteins (Lee et al., 2012). As well, previous

Cite: Miryuta N., Smykla J., Parnikoza I. Algorithm for the united quality latent index of the plant adaptability and its application field in monitoring of *Deschampsia antarctica* È. Desv. populations. *Ukrainian Antarctic Journal*, 2019. № 1(18), 152—168.

research suggested that the stress response in plants can be inferred through increased synthesis of antioxidants and accumulation of compatible dissolved substances. Multiple research studies have described such specific mechanisms for tolerance maintenance to various abiotic stressors in *Deschampsia antarctica* È. Desv. (Lee et al., 2012).

Monitoring studies of plant populations and their responses to environmental effects require a method that provides for assessment of complex adaptive outcomes across range indices that result from existing under certain natural conditions (such as adaptability to cold, drought, salinity, macroelement content in soils, etc.), which often remain not measured (latent). In addition, it is often unrealistic to measure all values that characterize the environment, causing a set of changes in the plant characteristics available for measurement. This method should be suitable for long-term research of plants' complex adaptability allowing insights into feature dynamics. This especially actual for case of Antarctic vascular plants: *Deschampsia antarctica* È. Desv. and *Colobanthus quitensis* (Kunth.) Bartl. population of that very sensitive to general ecological conditions (Barcikowski et al., 2001; Barcikowski et al, 2003). This actuality starts to be more important in context of current warming in the region (Fowbert Smith, 1994; Day et al., 2008).

Therefore, we have used the type of analysis called the expert-statistical method for constructing an united efficiency index of an object (Ayvazyan et al., 1989) — in our case, set of plant populations could be described by their adaptability to the microenvironment specifics and season meteorological conditions. The ultimate goal of this analysis was to construct a target model. This model is optimizing the system functioning by changing the different individual factors. In considered case, the problem has been the opposite one: we have tried to study what is the ways that population use to adapt to a changing environment at different levels of the organization by changing the united population functioning efficiency index.

The aim of our research was to develop an algorithm that would employ the expert-statistical method for the purpose of the United Quality Latent Index of Adaptability (UQLI) modelling the *D. antarctica* plants populations under various parameters of their corresponding micro-habitats.

MATERIALS AND METHODS

General characteristics and examples of *Deschampsia antarctica* plants source data sets under nature conditions have been presented below.

The following data sets were used in our work.

The plant population cover (S_i) was estimated visually as the percentage cover of the vertically projected area of the above-ground plant parts for n = 11 populations, whereas the *i*-th value corresponds to the number of studied population: D_1 (D1), D_2 (D2), ... D_7 (D7), D_8 (D9), ... D_{n-1} (Dn), D_n (D(n + 1)). In this data series due to the absence of population data with a fixed number on the map, the next population was assigned a regular number with the constant number in brackets, for example, D_8 (D9). S_i sets data used in our work have been received by methods described in article Parnikoza et al. (2015).

Ph_{ij} were morphometric parameters, where j = 1, 2, 3, 4 corresponded to the parameters, respectively: leaf length (dl), inflorescence length (dm), flower length (lower flower glume lenght, dk), number of flowers in the inflorescence (dn). Ph_{ij} sets data used in our work have been received by methods described in articles (Parnikoza et al., 2015, Miryuta et al., 2015, 2017).

Pr_{ik} were the relative content of protective and reserve proteins in the seeds, where k = 1, 2, ... 5 (6) (number of the fraction that corespond to: globulins with molecular mass more than 150, glutenins with "molecular mass" from 94 to 145, sulfur-poor prolamins — from 45 to 80; sulfur-rich prolamins — from 20 to 40; part of sulfur-rich prolamins and probably IRIP protein — 27—31; not full formed prolamins and low molecular weight dehydrins — less than 20 kDa). Pr_{ik} sets data used in our work have been received by methods set described in articles Miryuta et al. (2015, 2017).

An example for the season 2017/2018 is shown in Table 1 and Fig. 1—3.

RESULTS AND DISCUSSION

The method of model object efficiency united index constructing was used in the current research to com-

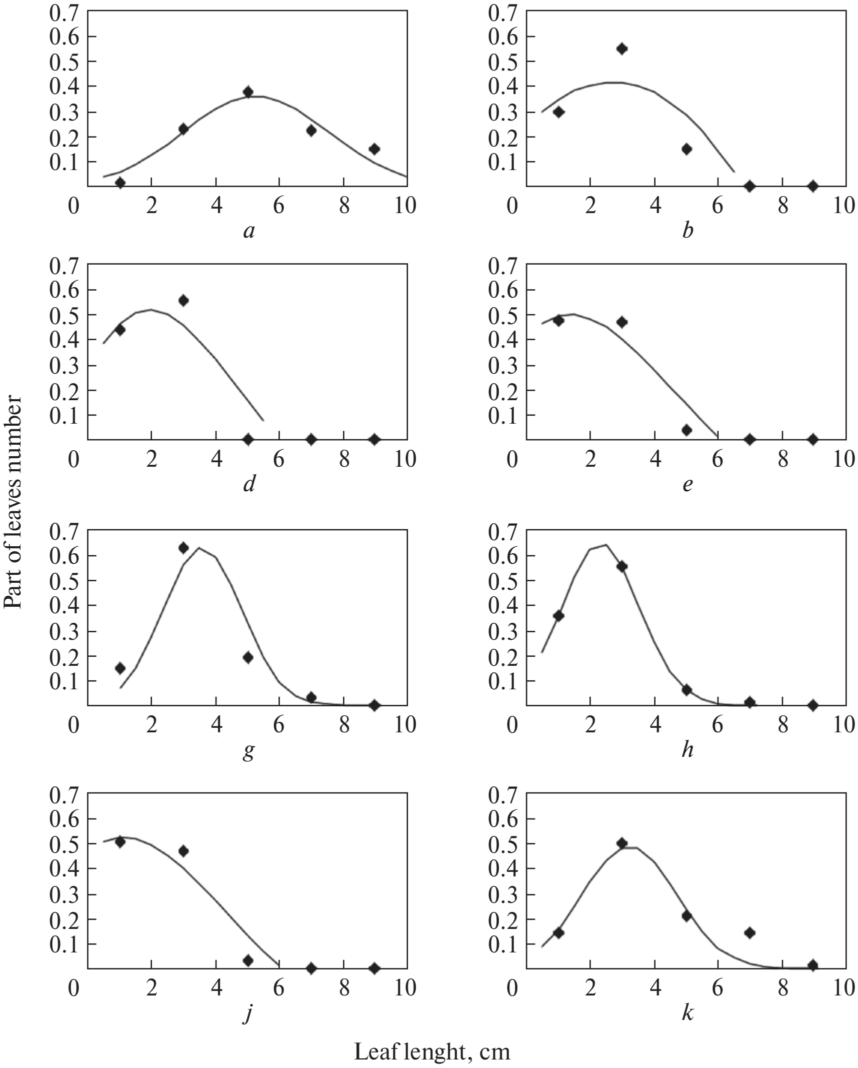

Fig. 1. Density functions of a leaf length of *D. antarctica* plants from populations: *a* — D1, *c* — D3, *g* — D7, *h* — D9, *i* — D10, *k* — D12 (Gaussian model) and *b* — D2, *d* — D4, *e* — D5, *f* — D6, *j* — D11 (Polinomial Fit) in the season 2017/2018

pare and organize objects – plant populations' set by latent property – adaptability, which has reflections set under changing conditions according to the concepts used in Ayvazyan et al. (1989). Methods set combined by this name have been used usually to compare the functioning of organizations set with a similar profile of activity. The constructed target functions for organizations were not unchanged, but rather, it was needed to optimize the system functioning. This research has been an attempt to use this type of analysis to determine the complex adaptability of plants populations set at different hierarchical levels under the micro-environment and meteorological conditions of the season. It should be noted that the aim of building a population functioning united index was the opposite the one for the organization. We have aimed to understand how ways the studied plant in concrete population used to adapt at different organization levels under changing environment by functioning united index efficiency.

Thus, the biological meaning of the UQLI (I^q) of population adaptability among the region population samples has been named the quantitative characteristic of the population's integrated response to the microenvironment influence, what was embodied in the general adaptation trend under dynamic research conditions for each sampled population.

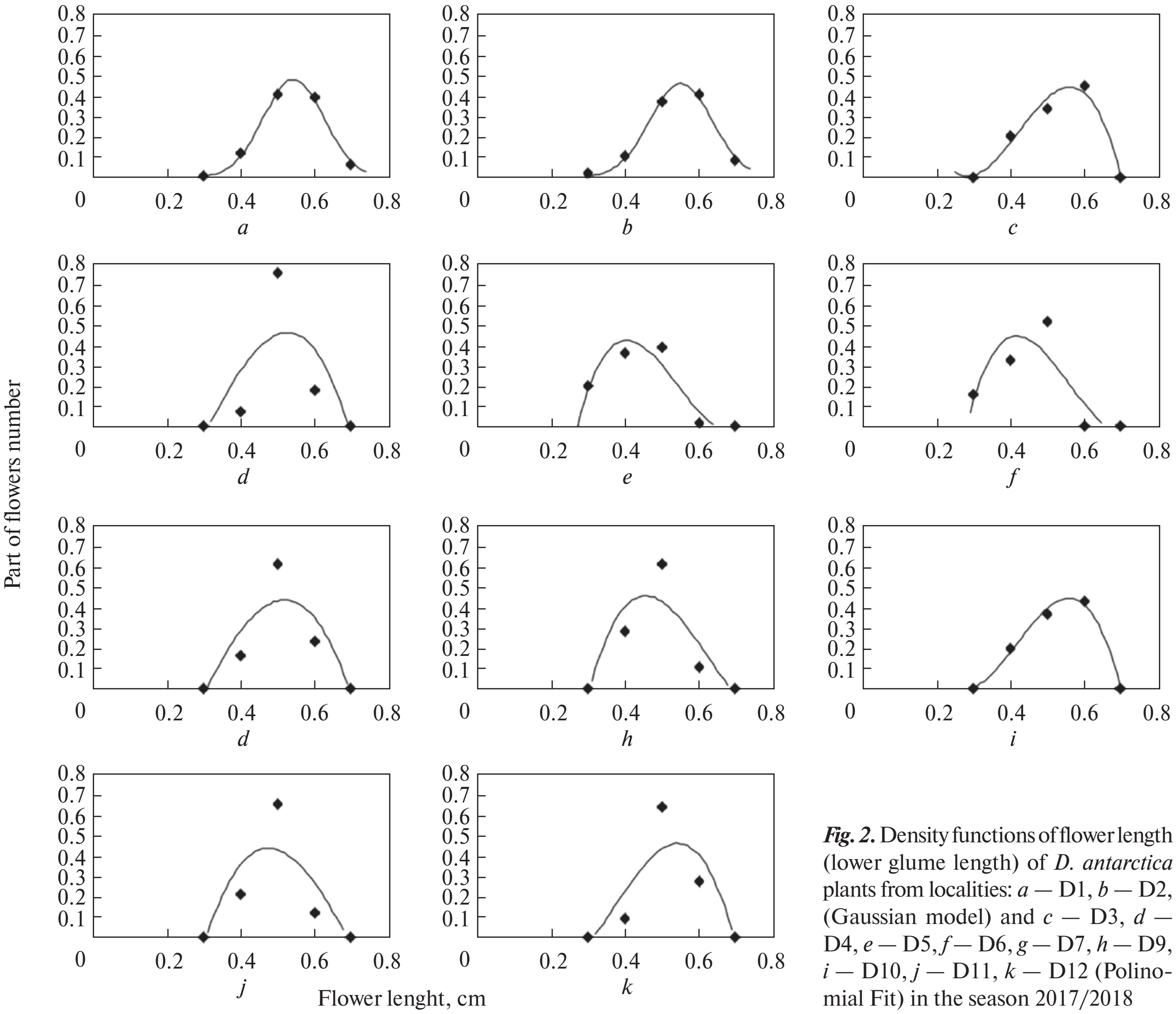

Fig. 2. Density functions of flower length (lower glume length) of *D. antarctica* plants from localities: *a* — D1, *b* — D2, (Gaussian model) and *c* — D3, *d* — D4, *e* — D5, *f* — D6, *g* — D7, *h* — D9, *i* — D10, *j* — D11, *k* — D12 (Polinomial Fit) in the season 2017/2018

An algorithm for the UQLI (I^q) estimation in *D. antarctica* plants populations under natural conditions based on the experimental material was previously published in the series of articles (Parnikoza et al., 2015, Miryuta et al., 2015, 2017). An example of the algorithm for three indices is shown in Fig. 4. The group of 11 populations was selected for the study, the list and coordinates presented in Table 1.

We would consider the scheme shown in Fig. 4 step by step.

1. Source data sets. Examples of data sets are partially shown in Table 1 (S_i) and in Fig. 1—3 (Ph_{ij} and Pr_{ik}).

2. Spatial pairwise comparison of the source data sets (by i). The comparison was carried out as follows. We have found pairwise spatial differences in the modulus for S_i and Pr_{ik} data sets. The test value for pairwise comparison of distributions for the data set Ph_{ij} has been found by the Mood median test. This non-parametric test is a variation of the χ^2 test, which allows estimating intra-group differences for two populations without assessing the normal distribution of population indices. The Table 2 included the non-zero values of criterion statistics (which are proportional to the distance between the medians), which exceeded the table value

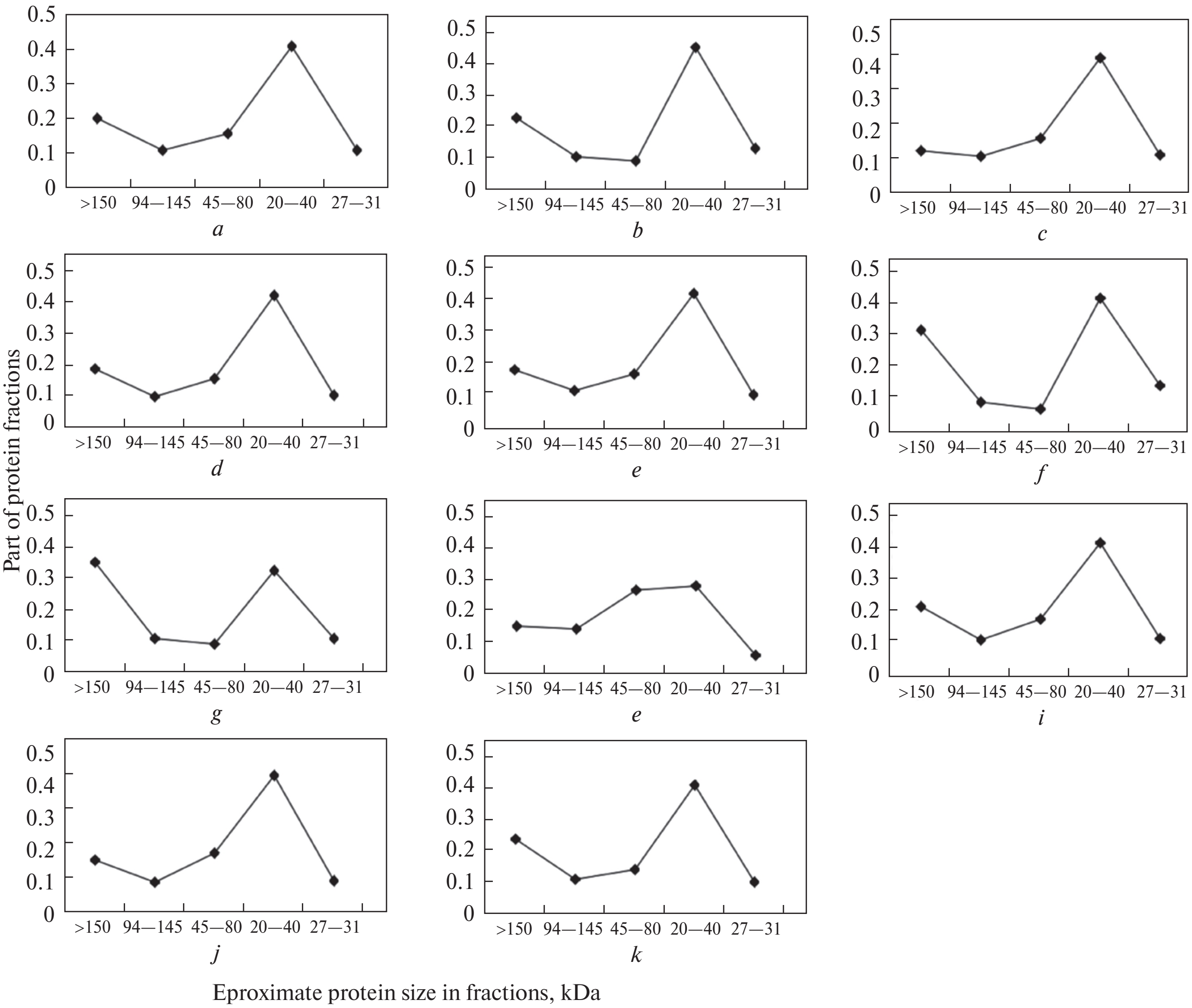

Fig. 3. The values of the different protein fractions parts in *D. antarctica* seeds under natural conditions from populations: *a* — D1, *b* — D2, *c* — D3, *d* — D4, *e* — D5, *f* — D6, *g* — D7, *h* — D9, *i* — D10, *j* — D11, *k* — D12 in the season 2017/2018. Fractions of protective and reserve proteins that corresponds to: globulins with molecular mass more than 150, glutenins with molecular mass from 94 to 145, sulfur-poor prolamins — from 45 to 80; sulfur-rich prolamins — from 20 to 40; part of sulfur-rich prolamins and probably IRIP protein — 27—31; not full formed prolamins and low molecular weight dehydrins — less than 20 kDa

of 5% limit $\chi_{n-1}^2 = 3.84$ (n = 2) and zero if test value didn't exceed 3.84 by χ^2 test (Pollard, 1982; Corder, Foreman 2014). The resulting sets of pairwise spatial comparisons were denoted by ΔS_i, ΔPh_{ij}, ΔPr_{ik}. Examples of such comparisons are presented in Table 2, 3.

3. Extreme grouping of point in pairwise spatial differences indices sets pairs. We have used the method of extreme grouping of point in pairwise spatial differences indices sets pairs to reduce the dimension of the studied space signs in the research of populations sample described by several indices (Ayvazyan et al., 1989, Bauman et al., 2008). The obtained adaptability indices have reflected the researched populations properties by an indirect way. That's why obtaining results was not easy to interpret. So, sets of pairwise comparisons of all studied populations were grouped

Table 1. **Localization and cover (S_i) of *D. antarctica* studied populations, Galindez Island, Argentine Islands in the season 2017/2018 (local names according to Parnikoza et al., 2018)**

i	D_i	Localization of the population	S_i,%
1	D_1(D1)	Meteo Point, coastal rocks of Marina Point near the meteorological station, S 65.244780°, W 64.255800°	1
2	D_2(D2)	near main station building (Coronation House), Marina Point, S 65.245700°, W 64.256400°	30
3	D_3(D3)	Leopard Tower, Penguin Point, S 65.247500°, W 64.241200°	3
4	D_4(D4)	Ship Rock, Penguin Point, S 65.248600°, W64.238230°	3
5	D_5(D5)	the upper terrace of the Govorukha dome under the Anna Hill, S 65.248260°; W 64.245240°	1
6	D_6(D6)	near the Antarctic pearlwort (*Colobanthus quitensis* (Kunth) Bartl.) point on the Roztochia Ridge, S 65.247990°, W 64.242720°	3
7	D_7(D7)	on the Krapla Rock, S 65.247017°, W 64.243167°	5
8	D_8(D9)	on the rocky shore of the Neck Ridge behind the large magnetic pavilion, S 65.245467°, W 64.249867°	15
9	D_9(D10)	on Magnit Cape, S 65.245008°, W 64.253205°	5
10	D_{10}(D11)	on the Cemetry Ridge near the pavilion of Very Low Frequencies (VLF), S 65.246170°, W 64.248250°	1
11	D_{11}(D12)	on the Gull Tower slopes on Stella Point, S 65.247450°, W 64.252740°	10

by three sets pairs of adaptability indices: ΔPh_{ij} — $|\Delta S_i|$, $|\Delta Pr_{ik}|$ — $|\Delta S_i|$, $|\Delta Pr_{ik}|$ — ΔPh_{ij}. Extreme grouping was carried out by pairwise linear regression technique. The choice of this technique is based on the fact that it is probably the only possible way to interpret these results. Due to the latency of specific environmental factors that determine a particular value of the adaptation index, factor analysis cannot be applied. The closest Mantel test only finds cases when the analyzed parameters are in synchrony (with positive correlations). In this context, we compared the differences between populations in the measured indices sample series by quantitative changes phase or antiphase (that from biological point of view correspond to synchrony or asynchrony of following adaptation mechanisms, see Parnikoza et al., 2015) in pairwise comparable indices sets. Example of extremal grouping of pairwise spatial differences for indices pairs $|\Delta Pr_{i1}|$ versus ΔPh_{i1} and $|\Delta Pr_{i5}|$ versus ΔPh_{i1} were shown in Fig. 5.

Extreme grouping refers to heuristic methods of statistical analysis, those cannot be performed according to a given machine algorithm, but needs to solve special problems with researcher participation. Extreme grouping is as follows: one spatial differences set are applied on the x-axis and another one on the y-axis for all pairs of experimental populations. The regression line and the coefficient R^2 indicate that there is no correlation. Next, the researcher, based on points location, determines the possible configuration of the passage of the regression lines, which are likely to have positive and negative correlations. Separate point manipulations allow you to divide the points of the spatial differences values into two groups for optimal R^2 of regression values. Note that, after isolation of groups with significant correlations, the manipulation of each individual doubtful orientated difference only slightly changes the overall picture of the grouping.

4. Determination of the matching probability into positive or negative group for each population by number i.

The number of indices pairs, indicated by the lower index *l* in the algorithm shown in Fig. 4, where the indices pairs ΔPh_{ij} versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ ver-

Table 2. **Spatial differences (by value *i*) of cover (ΔS_i) and morphometric indices ($\Delta Ph_{ij,}$ where j = 1 for leaf length (dl), 2 — inflorescence length (dm), 3 — flower length (flower lower glume lenght, dk), 4 — number of flowers in the inflorescence) for *D. antarctica* populations, Galindez Island, Argentine Islands in the season 2017/2018**

ΔD_i	ΔS_i	ΔPh_{i1} (dl)	ΔPh_{i2} (dm)	ΔPh_{i3} (dk)	ΔPh_{i4} (dn)
D1 — D2	29	53.64	14.49	0	16.59
D1 — D3	2	11.01	10.84	0	0
D1 — D4	2	95.07	0	7.92	0
D1 — D5	0	78.89	7.04	43.85	0
D1 — D6	2	90.05	10.39	73.15	12.98
D1 — D7	4	53.31	0	30.51	16.49
D1 — D9	14	88.48	0	60.36	27.86
D1 — D10	4	52.39	0	0	4.98
D1 — D11	0	110.68	4.88	59.81	35.06
D1 — D12	9	14.03	0	16.48	12.42
D2 — D3	27	16.58	10.88	0	7.44
D2 — D4	27	11.12	0	6.96	0
D2 — D5	29	3.89	3.86	38.86	0
D2 — D6	27	5.16	0	65.77	0
D2 — D7	25	9.22	22.27	18.33	5.02
D2 — D9	15	0	7.48	45.34	0
D2 — D10	25	0	18.05	0	14.76
D2 — D11	29	5.78	0	42.79	0
D2 — D12	20	6.12	16.7	10.29	0
D3 — D4	0	83.77	0	7.64	0
D3 — D5	2	34.47	17.33	43.9	0
D3 — D6	0	75.67	20.34	73.52	0
D3 — D7	2	12.9	0	32.44	0
D3 — D9	12	37.12	10.16	62.23	4.79
D3 — D10	2	12.93	0	0	0
D3 — D11	2	81.51	13.05	62.25	7.63
D3 — D12	7	0	0	16.94	0
D4 — D5	2	0	6.28	9.26	0
D4 — D6	0	0	0	21.52	0
D4 — D7	2	40.89	0	0	0
D4 — D9	12	7.89	0	0	0
D4 — D10	2	26.08	0	6.63	0
D4 — D11	2	0	0	0	0
D4 — D12	7	33.53	0	0	0
D5 — D6	2	0	6.11	0	0
D5 — D7	4	25.71	0	0	0
D5 — D9	14	0	0	5.56	0
D5 — D10	4	14.09	9.31	41.08	4.17
D5 — D11	0	0	8.21	7.11	3.97
D5 — D12	9	19.98	8.42	21.33	0

End of Table 2

ΔD_i	ΔS_i	ΔPh_{i1} (dl)	ΔPh_{i2} (dm)	ΔPh_{i3} (dk)	ΔPh_{i4} (dn)
D6—D7	2	32.56	18	32.76	0
D6 — D9	12	0	0	12.95	0
D6— D10	2	18.17	13.56	69.49	7.22
D6— D11	2	0	0	15.6	4.22
D6 — D12	7	25.31	12.46	39.09	0
D7 — D9	10	17.8	7.76	14.91	0
D7— D10	0	0	0	28.26	5.86
D7— D11	4	35.83	10.67	12.35	9.35
D7 — D12	5	0	0	0	0
D9 — D10	10	7.41	4.81	57.67	13.64
D9 — D11	14	0	0	0	3.88
D9 — D12	5	12.6	3.88	21.26	0
D10— D11	4	20.15	7.48	57.48	21.61
D10 — D12	5	3.94	0	13.94	5
D11 — D12	9	27.81	6.51	18.78	3.89

Table 3. **Spatial differences (by value i) of protective and reserve protein fractions parts (ΔPh_{ij}) for *D. antarctica* populations, Galindez Island, Argentine Islands in the season 2017/2018**

ΔD_i	ΔPr_{ik}, KDa				
	>150 (k = 1)	94—145 (k = 2)	45—80 (k = 3)	20—40 (k = 4)	27—31 (k = 5)
D1 — D2	0.055	0.001	0.067	0.043	0.018
D1 — D3	0.069	0.004	0.018	0.021	0.008
D1 — D4	0.017	0.014	0.001	0.01	0.008
D1 — D5	0.03	0.006	0.005	0.006	0.018
D1 — D6	0.131	0.008	0.08	0.023	0.047
D1 — D7	0.167	0.014	0.048	0.069	0.014
D1 — D9	0.047	0.036	0.116	0.129	0.046
D1 — D10	0.013	0.008	0.014	0.003	0.0
D1 — D11	0.028	0.014	0.035	0.031	0.007
D1 — D12	0.049	0.006	0.015	0.002	0.005
D2 — D3	0.124	0.005	0.085	0.022	0.01
D2 — D4	0.072	0.013	0.066	0.033	0.026
D2 — D5	0.085	0.005	0.072	0.037	0.036
D2 — D6	0.076	0.007	0.013	0.02	0.029
D2 — D7	0.144	0.015	0.019	0.112	0.004
D2 — D9	0.102	0.037	0.183	0.172	0.064
D2 — D10	0.042	0.007	0.081	0.04	0.018
D2 — D11	0.083	0.013	0.102	0.012	0.025

End of Table 3

ΔD$_i$	ΔPr$_{ik}$, KDa				
	>150 (k = 1)	94—145 (k = 2)	45—80 (k = 3)	20—40 (k = 4)	27—31 (k = 5)
D2 — D12	0.006	0.007	0.052	0.041	0.023
D3 — D4	0.052	0.018	0.019	0.011	0.016
D3 — D5	0.039	0.01	0.013	0.015	0.026
D3 — D6	0.2	0.012	0.098	0.002	0.039
D3 — D7	0.236	0.01	0.066	0.09	0.006
D3 — D9	0.022	0.032	0.098	0.15	0.054
D3 — D10	0.082	0.012	0.004	0.018	0.008
D3 — D11	0.041	0.018	0.017	0.01	0.015
D3 — D12	0.118	0.002	0.033	0.019	0.013
D4 — D5	0.013	0.008	0.006	0.004	0.01
D4 — D6	0.148	0.006	0.079	0.013	0.055
D4 — D7	0.184	0.028	0.047	0.079	0.022
D4 — D9	0.03	0.05	0.117	0.139	0.038
D4 — D10	0.03	0.006	0.015	0.007	0.008
D4 — D11	0.011	0.0	0.036	0.021	0.001
D4 — D12	0.066	0.02	0.014	0.008	0.003
D5 — D6	0.161	0.002	0.085	0.017	0.065
D5 — D7	0.197	0.02	0.053	0.075	0.032
D5 — D9	0.017	0.042	0.111	0.135	0.028
D5 — D10	0.043	0.002	0.009	0.003	0.018
D5 — D11	0.002	0.008	0.03	0.025	0.011
D5 — D12	0.079	0.012	0.02	0.004	0.013
D6 —D7	0.036	0.022	0.032	0.092	0.033
D6 — D9	0.178	0.044	0.196	0.152	0.093
D6 — D10	0.118	0.0	0.094	0.02	0.047
D6 — D11	0.159	0.006	0.115	0.008	0.054
D6 — D12	0.082	0.014	0.065	0.021	0.052
D7 — D9	0.214	0.022	0.164	0.06	0.06
D7 — D10	0.154	0.022	0.062	0.072	0.014
D7 — D11	0.195	0.028	0.083	0.1	0.021
D7 — D12	0.118	0.008	0.033	0.071	0.019
D9 — D10	0.06	0.044	0.102	0.132	0.046
D9 — D11	0.019	0.05	0.081	0.16	0.039
D9 — D12	0.096	0.03	0.131	0.131	0.041
D10— D11	0.041	0.006	0.021	0.028	0.007
D10 — D12	0.036	0.014	0.029	0.001	0.005
D11 — D12	0.077	0.02	0.05	0.029	0.002

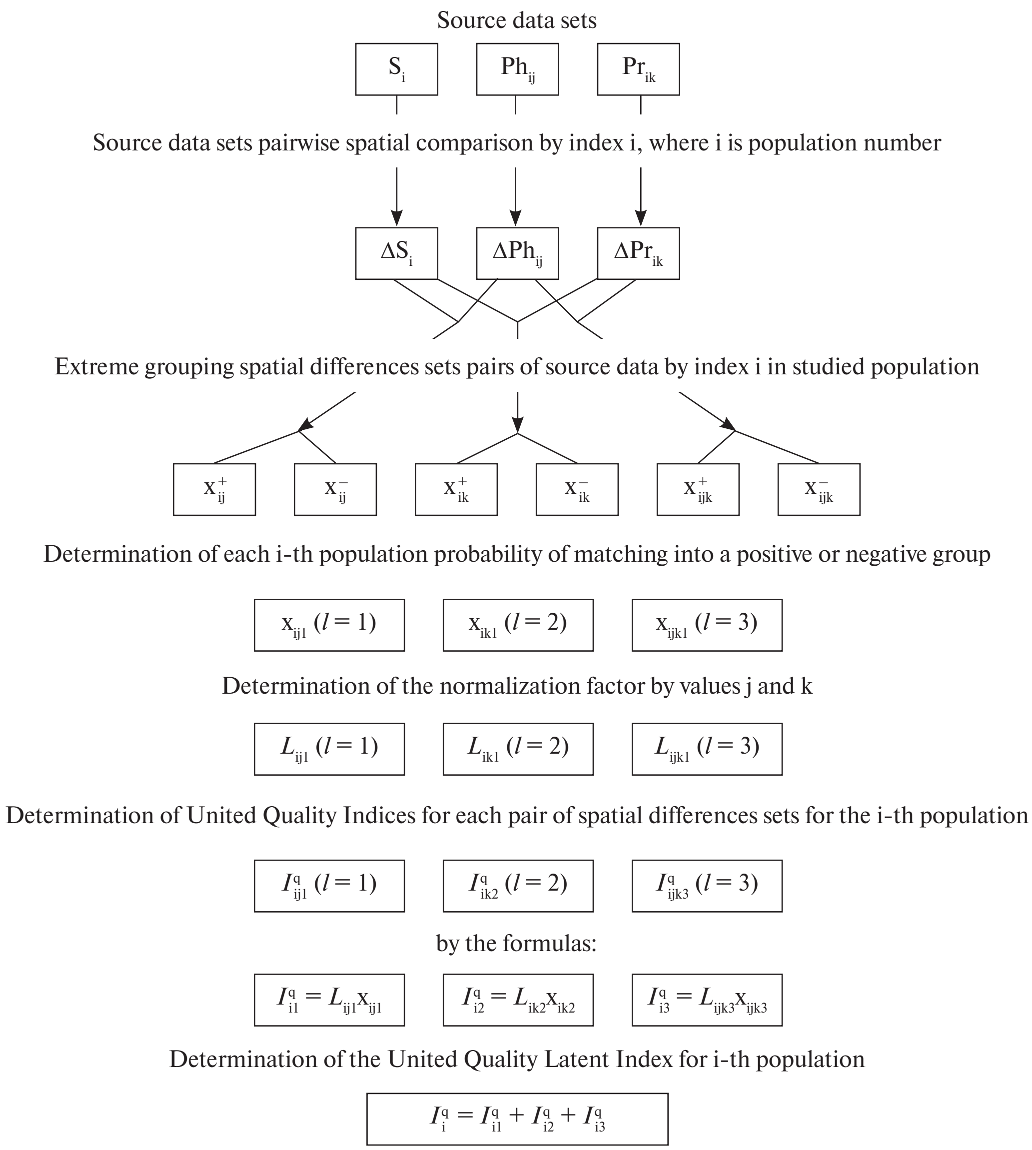

Fig. 4. The algorithm for determination plant populations UQLI (I^q) by three indices under natural conditions

sus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus ΔPh_{ij} assigned value $l = 1, 2, 3$, respectively.

To determine the probability that each population (by number *i*) matched to the positive or negative group in the table obtained for each indices pair in MsGraph was presented in the binary approximation form in the Table 4 as example.

The parts of matches to the positive and negative groups X^+_{ijk} and X^-_{ijk} (j = 1, k = 1, 2 ... 5) have been determined for each value *i*. The example presented in Table 4, the size of the sample population was $i_{max} = n$ (in the considered case n = 11). The maximum number of points is n-1. To determine the total matching probability to X^+_i or X^-_i for indices pairs ΔPh_{ij} versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus ΔPh_{ij} formulas (1)—(3) were applied for each value $l = 1, 2, 3$:

$$X_{i1} = \frac{1}{n-1}\sum_j (X^+_{ij} - X^-_{ij}) \text{ for } l = 1 \quad (1)$$

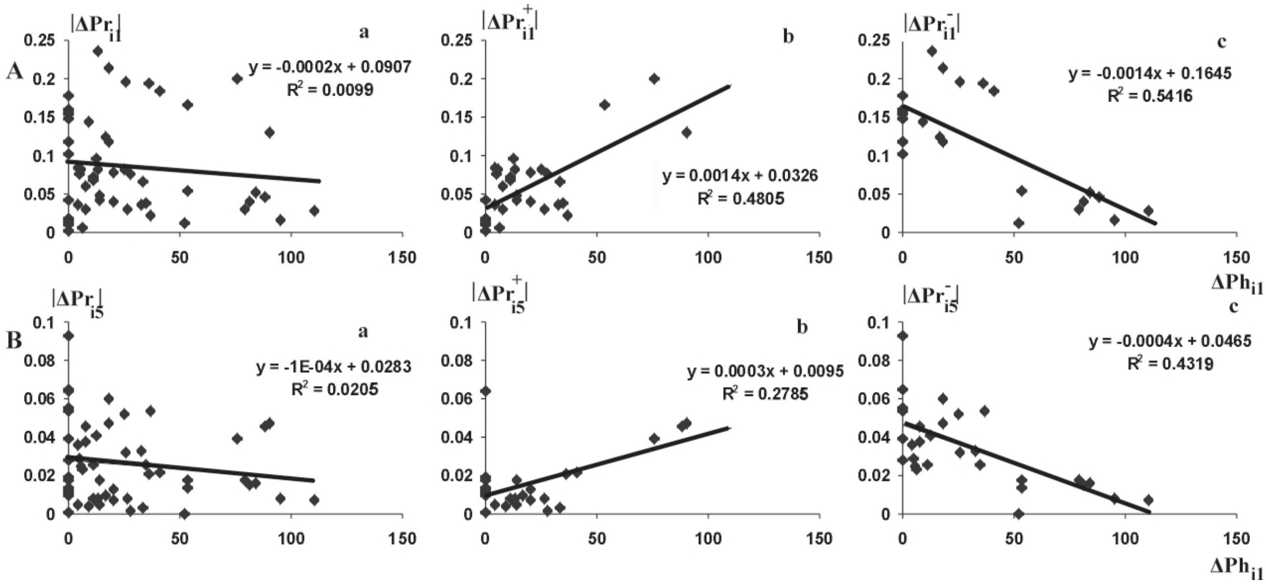

Fig. 5. Dependence of spatial differences sets of *D. antarctica* populations of Galindez Island, Argentine Islands in the season 2017/2018 by the leaf length characteristic (ΔPh_{i1}) and protein content differences: ($|\Delta Pr_{i1}|$, $|\Delta Pr_{i5}|$) for all points located on plane of the plot, $|\Delta Pr^{+}_{i1}|$, $|\Delta Pr^{+}_{i5}|$ - for points located on the plot plane which belong to positive group, $|\Delta Pr^{-}_{i1}|$, $|\Delta Pr^{-}_{i5}|$ — for points located on the plot plane which belong to negative group) for fractions > 150 (*A*) and 27—31 kDa (*B*): *a* – for all researched variables between all populations; *b* – for differences that have a positive correlation $|\Delta Pr^{+}_{i}|$ versus ΔPh_i by the least squares technique; *c* – for differences that have a negative correlation $|\Delta Pr^{-}_{i}|$ versus ΔPh_i. The regression equations by the least squares technique and squares of the corresponding correlation coefficients between values $|\Delta Pr_i|$, $|\Delta Pr^{+}_{i}|$, $|\Delta Pr^{-}_{i}|$ and ΔPh_i are presented on the charts *a,b,c*. The test value of R^2, on the charts: *a* – $F_{1,53}=0.53$ (*A*) and $F_{1,53}=1.11$ (*B*) (do not exceed the value of the upper 5% F-distribution limit for N=55 ($F_{1,43}=4.08$)), *b* – $F_{1,29}=17.55$ and *c* – $F_{1,22}=26.00$ (exceed the value of the upper 5% F-distribution limit for N=31 ($F_{1,29}=4.18$) and N=24 ($F_{1,22}=4.30$)) (*A*), *b* – $F_{1,24}=9.00$ and *c* – $F_{1,27}=20.52$ (exceed the value of the upper 5% F-distribution limit for N=26 ($F_{1,24}=4.26$) and N=29 ($F_{1,27}=4.21$)) (*B*). This fact means the absence of linear dependence in the first case (*a*) and the presence of linear dependence in the second and third cases (*b*, *c*) for both *A* and *B*

Table 4. **The result of extreme grouping for indices pair $|\Delta Pr_{ik}|$ — ΔPh_{ij} (l = 3) in the case of comparison (by value i) of the spatial differences ΔPh_{ij} for leaf length (j = 1) with spatial difference of protective and reserve protein fractions parts (ΔPr_{ik}, k = 1,2, 5), *D. antarctica* populations, Galindez Island, Argentine Islands in the season 2017/2018**

ΔD_i	ΔPh_{ij} (j = 1)	ΔPr_{ik}, KDa									
		>150 (k = 1)		94—145 (k = 2)		45—80 (k = 3)		20—40 (k = 4)		27—31 (k = 5)	
		+	–	+	–	+	–	+	–	+	–
D1 — D2	53.64	0	1	0	1	1	0	0	1	0	1
D1 — D3	11.01	1	0	1	0	1	0	1	0	1	0
D1 — D4	95.07	0	1	1	0	0	1	0	1	0	1
D1 — D5	78.89	0	1	0	1	0	1	0	1	0	1
D1 — D6	90.05	1	0	0	1	1	0	0	1	1	0
D1 — D7	53.31	1	0	1	0	1	0	1	0	0	1
D1 — D9	88.48	0	1	1	0	1	0	1	0	1	0
D1 — D10	52.39	0	1	0	1	0	1	0	1	0	1
D1 — D11	110.7	0	1	1	0	0	1	0	1	0	1
D1 — D12	14.03	1	0	1	0	1	0	1	0	1	0

End of Table 4

ΔD_i	ΔPh_{ij} (j = 1)	ΔPr_{ik}, KDa									
		>150 (k = 1)		94—145 (k = 2)		45—80 (k = 3)		20—40 (k = 4)		27—31 (k = 5)	
		+	–	+	–	+	–	+	–	+	–
D2 — D3	16.58	0	1	1	0	0	1	1	0	1	0
D2 — D4	11.12	1	0	0	1	0	1	1	0	0	1
D2 — D5	3.89	1	0	1	0	0	1	1	0	0	1
D2 — D6	5.16	1	0	1	0	1	0	1	0	0	1
D2 — D7	9.22	0	1	0	1	1	0	0	1	1	0
D2 — D9	0	0	1	0	1	0	1	0	1	1	0
D2 — D10	0	1	0	1	0	0	1	1	0	1	0
D2 — D11	5.78	1	0	0	1	0	1	1	0	0	1
D2 — D12	6.12	1	0	1	0	0	1	1	0	0	1
D3 — D4	83.77	0	1	1	0	0	1	0	1	0	1
D3 — D5	34.47	1	0	1	0	1	0	1	0	0	1
D3 — D6	75.67	1	0	0	1	1	0	0	1	1	0
D3 — D7	12.9	0	1	0	1	0	1	0	1	1	0
D3 — D9	37.12	1	0	0	1	0	1	0	1	0	1
D3 — D10	12.93	1	0	0	1	1	0	1	0	1	0
D3 — D11	81.51	0	1	1	0	1	0	0	1	0	1
D3 — D12	0	0	1	1	0	1	0	1	0	1	0
D4 — D5	0	1	0	1	0	1	0	1	0	1	0
D4 — D6	0	0	1	1	0	0	1	1	0	0	1
D4 — D7	40.89	0	1	0	1	1	0	0	1	1	0
D4 — D9	7.89	1	0	0	1	0	1	0	1	0	1
D4 — D10	26.08	1	0	1	0	1	0	1	0	1	0
D4 — D11	0	1	0	1	0	1	0	1	0	1	0
D4 — D12	33.53	1	0	0	1	1	0	1	0	1	0
D5 — D6	0	0	1	1	0	0	1	1	0	0	1
D5 — D7	25.71	0	1	0	1	0	1	0	1	0	1
D5 — D9	0	1	0	0	1	0	1	0	1	0	1
D5 — D10	14.09	1	0	1	0	1	0	1	0	1	0
D5 — D11	0	1	0	1	0	1	0	1	0	1	0
D5 — D12	19.98	1	0	0	1	1	0	1	0	1	0
D6—D7	32.56	1	0	0	1	1	0	0	1	0	1
D6 — D9	0	0	1	0	1	0	1	0	1	0	1
D6— D10	18.17	0	1	1	0	0	1	1	0	0	1
D6— D11	0	0	1	1	0	0	1	1	0	0	1
D6 — D12	25.31	1	0	0	1	0	1	1	0	0	1
D7 — D9	17.8	0	1	0	1	0	1	0	1	0	1
D7— D10	0	0	1	0	1	0	1	0	1	1	0
D7— D11	35.83	0	1	0	1	0	1	0	1	1	0
D7 — D12	0	0	1	1	0	1	0	0	1	1	0
D9 — D10	7.41	1	0	0	1	0	1	0	1	0	1
D9 — D11	0	1	0	0	1	0	1	0	1	0	1
D9 — D12	12.6	1	0	0	1	0	1	0	1	0	1
D10— D11	20.15	1	0	1	0	1	0	1	0	1	0
D10 — D12	3.94	1	0	0	1	1	0	1	0	1	0
D11 — D12	27.81	1	0	0	1	0	1	1	0	1	0

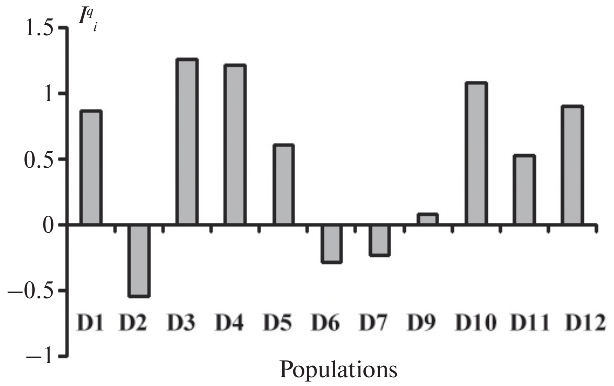

Fig. 6. The United Latent Quality Indices of Adaptability (I^q_i) for eleven *D. antarctica* populations, Galindez Island, Argentine Islands in the summer season 2017/18

$$X_{i2} = \frac{1}{n-1}\sum_{k}(X^{+}_{ik} - X^{-}_{ik}) \text{ for } l = 2 \quad (2)$$

$$X_{i3} = \frac{1}{n-1}\sum_{j,k}(X^{+}_{ijk} - X^{-}_{ijk}) \text{ for } l = 3. \quad (3)$$

5. Determination of the normalization factor for each data set.

In the above example, each indices pair ΔPh_{ij} versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus ΔPh_{ij} has had a different total points number on all charts subjected to extreme grouping, so the normalization was performed for each indices pair separately. The normalization factors were determined as follows. The first indices pair ΔPh_{ij} versus $|\Delta S_i|$ has had charts number j = m (in this case, m = 4):

$$L_{ijl} = 1/m \ (l = 1),\ L_{i41} = 0.25.$$

The second indices pair $|\Delta Pr_{ik}|$ versus $|\Delta S_i|$ k=p (in this case p = 5):

$$L_{ikl} = 1/p \ (l = 2),\ L_{i52} = 0.2.$$

The third indices pair $|\Delta Pr_{ik}|$ versus ΔPh_{ij} j=m, k=p (in this case m = 4, p = 5):

$$L_{ijkl} = 1/mp \ (l = 3),\ L_{i453} = 0.05.$$

6. Determination of United Quality Indices for each pair of spatial differences sets for the i-th population

We denoted United Quality Indices for each pair of spatial differences sets I^q_{i1}, I^q_{i2}, I^q_{i3} for ΔPh_{ij} versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus ΔPh_{ij} respectively. Than we have written down the formulas (4) for the intermediate United Quality Latent Indices:

$$I^q_{i1} = L_{ij1} \times X_{i1} = \frac{1}{m(n-1)}\sum_{j}(X^{+}_{ij} - X^{-}_{ij})$$

$$I^q_{i2} = L_{ik2} \times X_{i2} = \frac{1}{p(n-1)}\sum_{k}(X^{+}_{ik} - X^{-}_{ik}) \quad (4)$$

$$I^q_{i3} = L_{ijk3} \times X_{i3} = \frac{1}{mp(n-1)}\sum_{j,k}(X^{+}_{ijk} - X^{-}_{ijk}),$$

where X^+_{ij}, X^+_{ik}, X^+_{ijk} are the probability of matching into the positive group; X^-_{ij}, X^-_{ik}, X^-_{ijk} are the probability of matching into the negative group; X_{i1}, X_{i2}, X_{i3} are summary probability of matching for each pair of indices ΔPh_{ij} versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus ΔPh_{ij}, respectively for i-th plant population; L_{ij1}, L_{ik21}, L_{ijk31} are the normalization factor for each indices pair ΔPh_{ij} versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus $|\Delta S_i|$, $|\Delta Pr_{ik}|$ versus ΔPh_{ij} respectively.

7. Determination of the United Latent Quality Index for i-th population

Final formula (5) for determining the United Quality Latent Index of Adaptability for *i*-th population:

Table 5. **Results of the United Latent Quality Index (I^q_i) determination for i-th population, *D. antarctica* populations, Galindez Island, Argentine Islands in the season 2017/2018**

D_i	I^q_{i1}	I^q_{i2}	I^q_{i3}	I^q_i
D_1	0.16	0.56	0.15	0.87
D_2	0.05	–0.56	–0.4	–0.55
D_3	0.22	0.64	0.4	1.26
D_4	0.43	0.44	0.35	1.22
D_5	0.03	0.48	0.1	0.61
D_6	–0.29	0	0	–0.29
D_7	–0.2	–0.08	0.05	–0.23
D_8	–0.36	0.44	0	0.08
D_9	0.26	0.52	0.3	1.08
D_{10}	0.05	0.48	0	0.53
D_{11}	0.34	0.36	0.2	0.9

$$I_i^q = \sum_{l=1}^{3} I_{il}^q . \qquad (5)$$

The calculation results for the above example of 11 *D. antarctica* plants populations from Galindez Island in the season 2017/2018 are presented in Table 5 and in Fig. 6.

Example of UQLI (I_i^q) for 11 plant populations sample for one season (2017/2018) was shown in

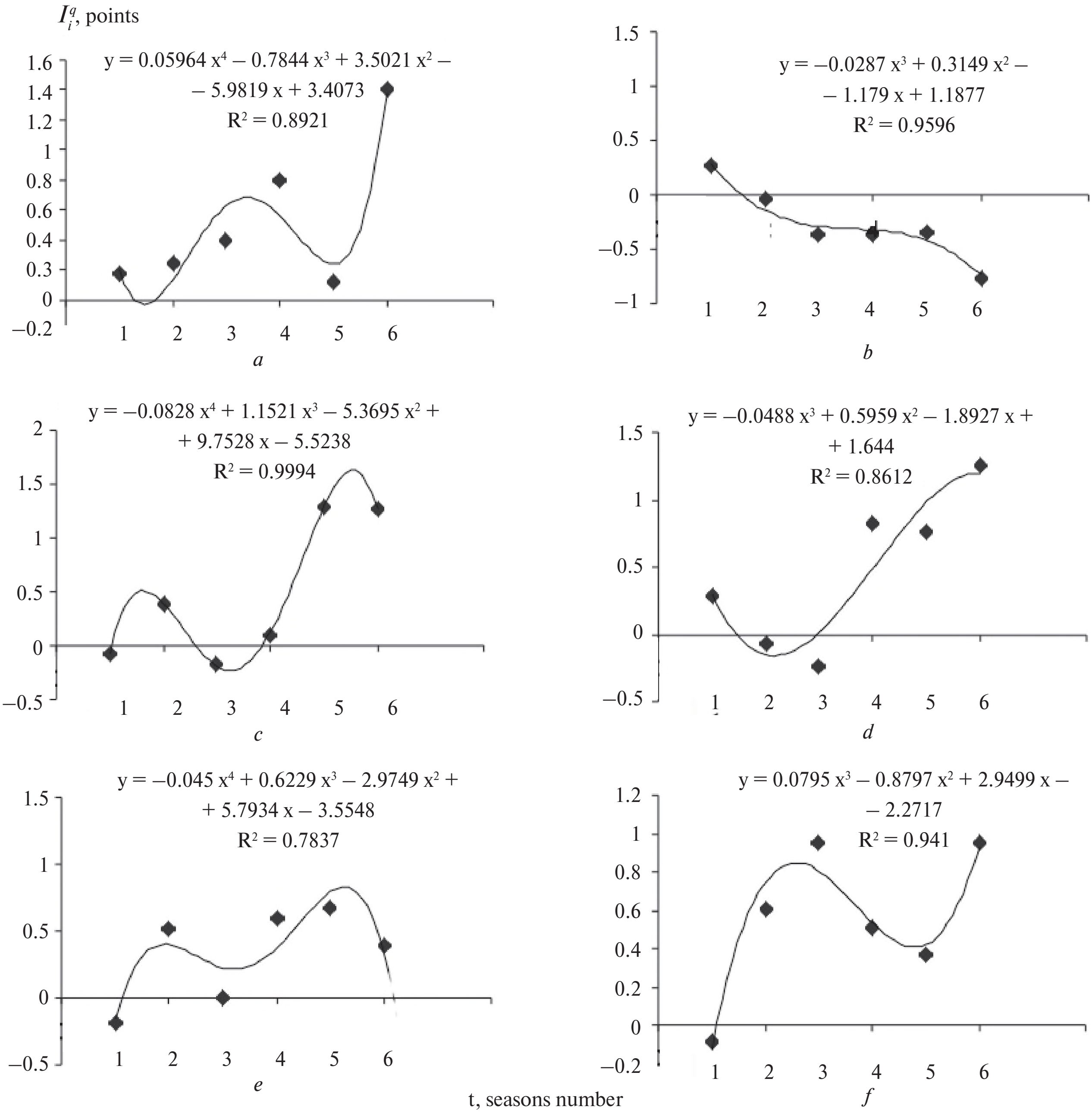

Fig. 7. Dynamics of the United Quality Latent Index of Adaptation (UQLI, I_i^q) for the six studied Galindez Island *D. antarctica* populations: *a* — D1, *b* — D2, *c* — D3, *d* — D4, *e* — D5, *f* — D12, for six seasons (t_1 — 2012/2013, t_2 — 2013/2014, t_3 — 2014/2015, t_4 — 2015/2016, t_5 — 2016/2017, t_6 — 2017/2018)

Fig. 6. It would be interesting to consider its trend for each population under dynamic condition research because of the I^q_i value is not a constant value by definition (Ayvazyan et al., 1989). We supposed that I^q_i trends set for populations sampling would be embodied to general adaptation trends set.

The above-described algorithm allows to increase the abstraction level of population sampling descripted, as well as to characterize the particular plant population state more precisely by its microclimatic conditions. The I^q is particularly important for describing the multilevel population response to the microenvironment variation under growth condition in nature (Miryuta et al., 2017) due to the low *D. antarctica* genetic heterogeneity from the Argentine Islands (Andreev et al., 2010; Volkov et al., 2010).

According to the developed algorithm (Fig. 4), based on the experimental data (Fig. 1 — Fig. 3, Table 1), the value of the I^q (Table 5, Fig. 6) has been calculated for 11 populations for the 2017/2018 season.

Below we show the example of the above algorithm for the estimation of I^q. The I^q was calculated for six plant populations sample during six seasons (t_1 — 2012/2013, t_2 — 2013/2014, t_3 — 2014/2015, t_4 — 2015/2016, t_5 — 2016/2017, t_6 — 2017/2018) by this algorithm. A trends based on the six season dynamics were constructed for each from sample of six plant populations (Fig. 7).

The complex adaptability trend estimated by the UQLI value is established to be individual. This trend is fairly well described by the third degree polynomial fit for D2, D4, and D12 populations, whereas D1, D3, and D5 populations are better described by the fourth degree polynomial fit, that can be seen by comparing the curves correlation coefficients. The populations formed groups by trend form: D1 and D12 (trend passed through maximum and minimum), D3 and D5 (oscillating character of the trend), populations D2 and D4 behave differently: trend D2 had a monotonous decease, in D4 the trend passed through the minimum and passed to the maximum.

Received six-year I^q *D. antarctica* plant population dynamics has confirmed our assumption about this integral index individuality depended not only on the place of growth (Parnikoza et al., 2015), but also on the conditions of a particular season (Miryuta et al., 2017).

CONCLUSIONS

The algorithm for the United Quality Latent Index of Adaptability described in detail on the example of eleven *D. antarctica* populations from Galindez Island is studied in season 2017/18.

The developed algorithm for the I^q calculation was applied to evaluate the complex adaptability in the six-year monitoring dynamics for six experimental populations of *D. antarctica* from Galindez Island. The UQLI trend was obtained for each sample of studied populations.

By the proposed I^q trends of the sampled populations can be categorized as: 1) passing through maximum, 2) passing through minimum or 3) experiencing oscillation. Such individuality probably connected with micro-habitat conditions. Further addition of United Quality Latent Index of Adaptability dynamics would allow to confirm or reject the oscillating nature of the trend and to compare it with some climatic index dynamics. Our next goal is to compare the I^q set values of plant populations with the United Temperatures Influence Indices on plants in places of plant populations locations during the season. The purpose of such a comparison would be to evaluate the contribution of the United Temperatures Influence Indices on plants sets to the I^q value sets.

REFERENCES

1. Ayvazyan, S.A., Buchstaber, V.M., Yenyukov, I.S., Meshalkin, L.D. 1989. *Applied statistics*. Moscow (In Russian).
2. Andreev, I.O., Spiridonova, E.V., Kyryachenko, S.S., Parnikoza, I.Yu., Maidanyuk, D.N., Volkov, R.A., Kozeretska, I.A., Kunakh, V.A. 2010. Population Genetic Analysis of *Deschampsia antarctica* from Two Regions of Maritime Antarctica. *Moscow University Biological Sciences Bulletin*, 65(4), 208–210.
3. Bauman, E.V., Moskalenko, N.E. 2008. Methods of Extremal Grouping of the Fractional Parameters. *Automation and Remote Control*, 69, 1955–1972.
4. Barcikowski, A., Czaplewska, J., Giełwanowska, I., Loro, P., Smykla, J., Zarzycki, K. 2001. *Deschampsia antarctica* (Poaceae)—the only native grass from Antarctica. In: Frey L

(ed). *Studies on grasses in Poland*. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków, 367–377.
5. Barcikowski, A., Czaplewska, J., Loro, P., Łyszkiewicz, A., Smykla, J., Wojciechowska, A. 2003. Ecological variability of *Deschampsia antarctica* in the area of Admiralty Bay (King George Island, maritime Antarctic). In: Frey L (ed). *Problems of grass biology*. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków, 393–407.
6. Corder, G.W., Foreman, D.I. 2014. *Nonparametric Statistics: A Step-by-Step Approach*. Wiley.
7. Day, A.T., Ruhland, C.T., Xiong, F.S. 2008. Warming increases aboveground plant biomass and C stock in vascular-plant-dominated Antarctic tundra. *Glob Change Biol.,* 14, 1827–1843.
8. Fowbert, J.A., Smith, R.L. 1994. Rapid population increases in native vascular plants in the Argentine Islands, Antarctic Peninsula. *Arct Alp Res*., 26, 290–296.
9. Lee, J., Noh, E. K., Choi, H.-S., Shin, S.C., Park, H., Lee, H. 2012. Transcriptome sequencing of the Antarctic vascular plant *Deschampsia antarctica Desv.* under abiotic stress. *Planta*, 237(3), 823—836. doi: 10.1007/s00425-012-1797-5.
10. Miryuta, N.Yu., Parnikoza, I.Yu., Shvydun, P.P., Miryuta, G.Yu., Poronnik, O.O., Kozeretska, I.A., Kunakh, V.A. 2015. Comparative analysys of adaptability united latent quality indicator of *Deschampsia antarctica* population form Galindez island (Argentine Islands, maritime Antarctic) during three seasons. *Ukrainian Antarctic Journal*, 14, 143–157 (In Ukrainian).
11. Miryuta, N.Yu., Parnikoza, I.Yu., Oliinyk, M., Smetana, E., Myryuta, G. Yu., Poronnik, O.O., Kunakh, V.A. 2017. Five seasons dynamic of adaptability united latent quality indicator of *Deschampsia antarctica* population in Galindez Island (Argentine Islands, maritime Antarctic). *Ukrainian Antarctic Journal*, 16, 189–202 (In Ukrainian).
12. Parnikoza, I., Miryuta, N., Ozheredova, I., Kozeretska, I., Smykla, J., Kunakh, V., Convey, P. 2015. Comparative analysis of *Deschampsia antarctica* Desv. population adaptability in the natural environment of the Admiralty Bay region (King George Island, maritime Antarctic). *Polar Biology*, 38, 9. 1401–1411.
13. Parnikoza, I., Berezkina, A., Moiseyenko, Ye., Malanchuk, V., Kunakh, V. 2018. Complex Survey of the Argentine Islands and Galindez Island (Maritime Antarctic) as a Research Area for Studying the Dynamics of Terrestrial Vegetation. *Ukrainian Antarctic Journal*, 1(17), 73—101.
14. Pollard, J.H.P. 1982. *A handbook of numerical and statistical techniques*. Moscow (In Russian).
15. Volkov, R.A., Kozeretska, I.A., Kyryachenko, S.S., Andreev, I.O., Maidanyuk, D.N., Parnikoza, I.Yu., Kunakh, V.A. 2010. Molecular evolution and variability of ITS1-ITS2 in populations of *Deschampsia antarctica* from two regions of the Maritime Antarctic. *Polar Science*, 4, 469–478.

Н. Мірюта[1], *Є. Смикла*[2, 3], *І. Парнікоза*[1, 4, *]

[1] Державна установа Національний антарктичний науковий центр МОН України, бульв. Тараса Шевченка, 16, м. Київ, 01601, Україна
[2] Інститут охорони природи Польської академії наук, алея Міцкевича, 33, 31—120 Краків, Польща
[3] Універистет Північної Кароліни, Вільмінгтон, 601 Ю. Коледж Роуд., NC 28403—5915, США
[4] Інститут молекулярної біології і генетики НАН України, вул. Акад. Заболотного, 150, м. Київ, 03143, Україна

* Автор для кореспонденції: ivan.parnikoza@uac.gov.ua

АЛГОРИТМ РОЗРАХУНКУ ЗВЕДЕНОГО ЛАТЕНТНОГО ПОКАЗНИКА ПРИСТОСОВУВАНОСТІ РОСЛИН ТА ДОСВІД ЙОГО ЗАСТОСУВАННЯ ДЛЯ МОНІТОРИНГУ ПОПУЛЯЦІЙ *DESCHAMPSIA ANTARCTICA* È. DESV.

РЕФЕРАТ. **Мета** дослідження — розробити і детально описати алгоритм розрахунку показника комплексної адаптованості — зведеного латентного показника пристосовуваності (ЗЛПП) та його застосування в оцінці пристосовуваності *Deschampsia antarctica* È. Desv. у природних умовах о. Галіндез, Аргентинські острови, Морська Антарктика. **Методи.** Для оцінки окремих показників пристосовуваності в природі — набору експериментальних даних застосовано методи визначення проективного покриття та вимірювання наступних морфометричних показників одинадцяти популяцій *D. antarctica*: довжина листка, довжина суцвіття, довжина квітки (за довжиною нижньої квіткової луски), кількість квіток у суцвітті. Спектри запасних і захисних білків насіння рослин з цих популяцій досліджено за допомогою електрофорезу в поліакриламідному гелі. Для отримання ЗЛПП застосовано евристичний метод екстремального групування. Розрахунок ЗЛПП проводили за допомогою попарних просторових порівнянь рядів показників.

Результати. Розроблено і детально описано алгоритм розрахунку ЗЛПП на прикладі одинадцяти популяцій *D. antarctica* о. Галіндез в сезоні 2017/18 р. Як приклад практичного застосування наведено отримані шестирічні тренди ЗЛПП для шести дослідних популяцій *D. antarctica* о. Галіндез. **Висновки.** Розроблений алгоритм розрахунку ЗЛПП було успішно використано для оцінки комплексної адаптованості для вибірки шести популяцій в динаміці шестирічного моніторингу *D. antarctica* о. Галіндез. Отримано тренд ЗЛПП для кожної популяції. Досліджені популяції за характером тренда динаміки комплексної пристосовуваності можна, на цьому етапі, об'єднати у три окремі групи, в яких тренд ЗЛПП проходить через максимум, через мінімум або демонструє коливальний процес. Така індивідуальність, ймовірно, пов'язана з мікроумовами зростання. Подальше поповнення ряду динаміки комплексної пристосовуваності дозволить підтвердити чи спростувати коливальний характер тренду ЗЛПП, а також провести порівняння цього ряду з рядами динаміки деяких кліматичних показників. Запропонований інтегральний показник (ЗЛПП) призначено для того, щоб описати велику кількість вихідних даних, що характеризують популяції вибірки на різних рівнях організації, за допомогою зниження розмірності до одного числа. Показник ЗЛПП може бути використаний для порівняння за набором різних показників вибірки популяцій одного й того ж виду, що зростають в різних умовах, особливо — під час моніторингових досліджень.

Ключові слова: *Deschampsia antarctica* È. Desv., динаміка зведеного латентного показника пристосовуваності (ЗЛПП), Аргентинські острови, Морська Антарктика.