Spatio-temporal variability of soil surface temperature affects adaptation of Antarctic hairgrass populations. 1. Fluctuations of average monthly local temperature near plants influence biometrical, biochemical, and ecological characteristics

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Abstract

A spatial-temporal temperature influence on *Deschampsia antarctica* populations adaptation was studied in the Galindez Island (Argentine Islands, the maritime Anatrctic) during seven consecutive Antarctic summer seasons (2017/19 – 2023/24). The subject of the research is the evaluation of complex adaptability (I^{qk}_i) characteristic for eleven populations of *Deschampsia antarctica.* Another goal was to analyze the temperature variables obtained with the help of microlimate loggers located at eleven sites, and their effects on the measured plant populations adaptability indices and to determine the united indices I^{k}_i of their influence on them. Determination of the I^{k}_i contribution to the complex index I^{qk}_i for eleven populations in the dynamics of seven summer seasons was calculated. Methods of determining the plants number in populations and measuring the morphometric indices of *D. antarctica* plants populations were used. Reserve and protective seed proteins were studied by polyacrylamide gel electrophoresis (PAGE). The spatial variables of these indices extreme grouping method were applied for eleven populations to obtain an I^{qk}_{I} and I^{k}_{i}. Sets of complex indices were compared by regression technique. The populations forming general population (G-population) were found to develop unevenly depending on microconditions. In particular, individual populations with different frequencies matched into an asynchronous group, the populations of which were not matched of the general development trend of the G-population rest. The I^{k}_i contributions to I^{qk}_{i} were shown be not always positive. Negative contributions were observed in the season k=3 (2019/20) and in some individual months of the seasons k=5, 6, 7.

Key words: *Deschampsia antarctica*, I^{qk}_i, I^{k}_i in dynamic, Argentine Islands, the maritime Antarctic

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Introduction

The problem of the global changes influence on the planet ecosystems is one of the most important humanity problems. Such changes are felt most strongly in the polar regions, whose biota are most sensitive to the smallest environmental influences. Studying the response to climate change is one of the priorities of modern Antarctic research (Kennicutt et al. 2014). Previous studies of the climate change response to terrestrial systems components indicator such as vascular plants were carried out on the regular repeated surveys of the same areas basis and the calculation of the plants number and populations size (Fowbert and Smith 1994, Parnikoza et al. 2009, Torres-Mellado et al. 2011). Previously applied methods did not fully allow us to assess the terrestrial ecosystems response to environmental changes. To overcome this limitation, we are developing an approach for annual assessment of the Antarctic environmental factors impact based on an available experimental populations network of the Galindez Island monitoring sites.

We have shown the possibility of using several Antarctic hairgrass populations and individual adaptability indices measured annually which we interpret as adaptability indices in previous studies (Parnikoza et al. 2015, Miryuta et al. 2017). We proposed a complex adaptability assessment for cereal *D. antarctica* populations in nature on the basis of a complex index, the United Quality Latent Index (UQLI, I^{qk}_i) (Parnikoza et al. 2015).

The above-specified approach makes it possible to assess complex adaptability in the dynamics of Antarctic seasons (Miryuta et al. 2015, 2019a). The term 'latent' means that the united quality latent index for a particular season is the result of plants adaptation to the sum of abiotic and biotic conditions which remain not described in detail that is, latent. Attempts to find a direct relation between environmental indices - in particular, meteorological variables and plant adaptability indices are extremely difficult due to the impossibility of practical registration of the latter with a short time range. With this in mind it is necessary to evaluate the contribution of the selected measured environmental indices to the current value of UQLI as the total a specific season result. At the same time it is necessary to apply a discrete spatial approach that is, the use of data obtained for each population separately. In this work the following indices were used: the number of populations, plants morphometric indices, portions of reserve and protective seed proteins fractions to assess each specific population complex adaptability which was reflected in the united quality latent index (UQLI, I^{qk}_i) (Miryuta et al. 2014, 2015, 2017; Parnikoza et al. 2015, Miryuta et al. 2019a). The UQLI value of different populations turned out to be individual and as shown by the comparison of the UQLI dynamics with the dynamics of general meteorological variables most likely, dependent on the dynamics of specific micro-conditions indices of each plant population existence (Parnikoza et al. 2018). The influence of specific meteorological variables (Savenets et al. 2023) such as average monthly temperature measured near plants on specific plant vital activity indices (*e.g.*, the populations plant number, plant morphometric indices, portions of reserve and protective seed protein fractions) were embodied in complex temperatures influence index UTII (I^{tk}_i) on plant populations (Miryuta et al. 2019b).

The main aim of the work is to evaluate the temperature variables effects measured at eleven sites on plant population adaptability indices in order to determine their united index influence I^{tk}_i on plant populations and its contribution to I^{qk}_i.

Material and Methods

The research was conducted in the seven southern seasons 2017/2018 – 2023/2024. Each Antarctic summer is divided between two years, therefore, we will hereafter also use the term Antarctic season to describe each monitoring year, for example the 2017/2018 season.

We chose the Galindez Island that is central in group of Argentine Islands considering previous research on plant communities in this area (Fowbert and Smith 1994, Parnikoza et al. 2009) and data availability for performing research. The plant population distribution included in the general G-population of Galindez Island is presented in the earlier studies (Parnikoza et al. 2018, Yevchun et al. 2021) (Fig. 1).

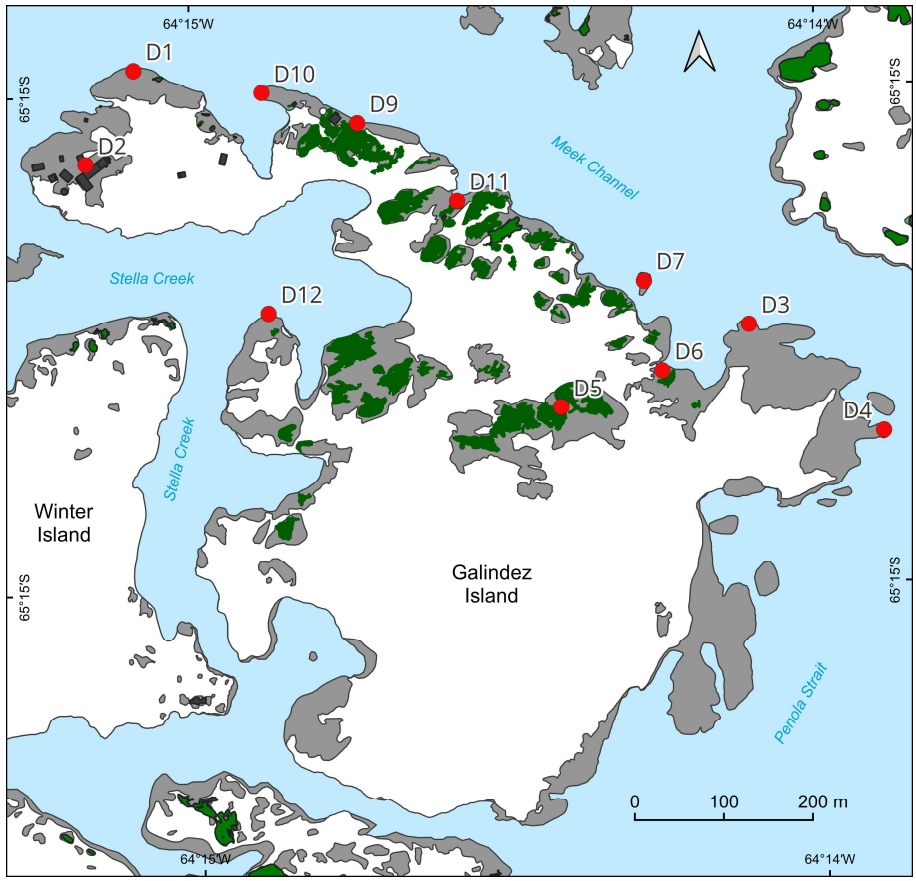

Fig. 1. Map of the location of the researched *D. antarctica* populations on Galindez Island, Argentine Islands.

The network of research sites for the regular research of *D. antarctica* populations have been created in 2006 – 2014 on Galindez Island (Miryuta et al. 2015), (Fig. 1). Experimental population locations reflect the variety of Antarctic hairgrass growth conditions and, as we assume, represent different microclimatic conditions of this plant growth on the island.

Biological methods in population research

The research used the plant number counting data in the *D. antarctica* populations on Galindez Island in 2017/18 – 2023/24. The interval between plant number counting in populations and sampling during this period was 1 year (Table 1). We studied the population sizes of eleven experimental sites, biometrical parametres (leaf length, inflorescence length, flower length, number of flowers in the inflorescence) during seven years for eleven populations (Figs. 2, 3) by the methods set described in details in (Miryuta et al. 2015, 2017; Parnikoza et al. 2015, Miryuta et al. 2019a). Within the same period, we studied the reserve and protective seed proteins, seeds were selected from five inflorescences taken from each population. The plant accumulates reserve proteins in seeds. Seeds are located in spikelets since *D. antarctica* is a cereal. Spikelets with seeds are the upper is aboveground part of the plant. Extraction, electrophoretic separation and densitometry were performed according to the methods detailed in (Miryuta et al. 2015). Digital photographs were used for densitometry. The proportions of individual groups of seed proteins which characterize cereal seeds were determined (Sozinov 1985) by measuring the corresponding areas under the densitogram peaks relative to the total protein pool areas using the program ScionImage[1]. Results are presented in Fig. 4. We have analyzed fractions of protective and reserve proteins that coresponds to: globulins with molecular mass more than 150 kDa, glutenins with molecular mass from 94 to145 kDa, sulfur-poor prolamins – from 45 to 80 kDa; sulfur-rich prolamins – from 20 to 40 kDa; part of sulfur-rich prolamins and probably IRIP protein – 27-31 kDa; not full formed prolamins and low molecular weight dehydrins – less than 20 kDa. United Quality Latent Index of adaptability (UQLI, I^{qk}_i) for each plant population was calculated based on these data by the calculation algorithm described in detail in (Miryuta et al. 2019a).

Meteorological methods of population locations research

Onset HOBO UA-002-64 temperature loggers were installed in the 11 plots. The HOBO logger is installed directly on the soil near one of the population`s plants with distance 2 cm from it. The local temperature near native vascular plants was recorded every 30 minutes during seven years (2017/18-2023/24). Average monthly temperatures on the soil surface is presented in Fig. 5 (Savenets et al. 2023).

In order to find out the influence of the local microclimate on the studied populations based on the temperature variables obtained from the loggers the UTII (I^{tk}_i) was calculated based on the average monthly local temperature near plants and biological adaptability indices as described in Miryuta et al. (2019b).

Statistical methods of D. antarctica populations research

A comprehensive fitness index (United Quality Latent Index, UQLI, I^{qk}_i, which is index of plant population adaptability) based on the above indices for eleven populations in the seven seasons dynamics was calculated in the research. The raw data of biological indices (Table 1, Figs. 2, 3, 4) and meteorological variables (Fig. 5) are given in the suplements. The United Quality Latent Index (UQLI, I^{qk}_i) of plant

populations adaptability was determined on the original biological data basis using the algorithm described in detail in (Miryuta et al. 2019a).

The UQLI (I^{qk}_i) describes the populations multi-level response to the micro-environmental conditions variation of all types of their growth in nature on the data available basis measurement characterizing the plant population (Miryuta et al. 2017, 2019a), but does not allow to assess the certain environmental factors influence.

The calculated UTII (I^{tk}_i) values were used for interannual comparison during the last seven seasons with temperature variables of the effect on plants according to the methodology described previously (Parnikoza et al. 2018, Miryuta et al. 2019b). These indices were determined under the assumption that the spatial temperature differences in the population locations at the season beginning are significantly greater than those at the season end. This fact, which we observed during seven seasons was illustrated in detail on example of first season in the work (Miryuta et al. 2019b). In addition, the snow cover variability dependence on air temperature was shown in the work which investigated the small-scale spatial-temporal this variability (Tarca et al. 2021). The rate of snow melting as well as the air temperature largely depends on the area in which the plant population is located. The snow melts at the season beginning are slower in some localities than in others. During the season the situation evens out due to the air temperature trend which leads to soil temperature equalization in the population locations.

We investigated the influence of two types of temperature indicators on plants: average monthly temperature (noted t) and the positive temperatures sum (noted T) by decades and months during the season. The subject of this work are average monthly temperatures (t) chosen to study their influence on plant adaptability (Pollard 1977, Corder and Foreman 2014). The algorithm of methods for United Temperature Influence Indices calculation is described in detail in the work of Ayvazyan et al. (1989), Bauman and Moskalenko (2008), and Miryuta et al. (2019b). These indices are marked I^{tk}_i. It is worth noting: in $I^{qk}i$, "+" means the prevailing synchronicity of changes in the studied biological indices, "-" means that the opposite directions of changes in these indices prevail; in I^{tk}_i, '+' means that spatial changes of most biological indices are synchronous with spatial changes of temperature variables, '-' means that spatial changes of most biological indices depend on spatial those latent variables changes that neutralize or overlap the influence of spatial temperature variables changes.

Next steps in this strategy were to compare I^{tk}_{i} set with I^{q}_{i} one to determine the temperature indices contribution to I^{q}_{i} index plant populations and populations allocation into groups affected by temperature indices or other factors that remain latent.

Results

The initial data are presented in Table 1 and Figs. 2–5. The United Quality Latent Index (UQLI, I^{qk}_{i}) of populations adaptability based on the original biological data (Table 1; Figs. 2, 3, 4) was determined by the algorithm described in detail in Miryuta et al. (2019a). The UQLI (I^{qk}_{i}) value for seven seasons is shown in Fig. 6.

i	D_i	Localization of the population	S_i, plant population number						
			17/18	18/19	19/20	20/21	21/22	22/23	23/24
1	D_1(D1)	Meteo Point*, coastal rocks of Marina Point near the meteorological station, S 65.244780°, W 64.255800°	99	155	80	66	78	89	67
2	D_2(D2)	near main station building (Coronation House), Marina Point, S 65.245700°, W 64.256400°	124	330	127	164	40	40	12
3	D_3(D3)	Leopard Tower, Penguin Point, S 65.247500°, W 64.241200°	106	110	57	121	159	155	70
4	D_4(D4)	Korabel Rock, Penguin Point, S 65.248600°, W 64.238230°	80	66	49	26	18	0	0
5	D_5(D5)	the upper terrace of the Hovorukha Dome under the Anna Hill, S 65.248260°, W 64.245240°	91	44	38	44	54	65	38
6	D_6(D6)	near the Antarctic pearlwort (*Colobanthus quitensis* (Kunth) Bartl.) point on the Roztochchia Ridge, S 65.247990°, W 64.242720°	161	57	19	45	71	58	17
7	D_7(D7)	on the Krapla Rock, S 65.247017°, W 64.243167°	500	418	382	275	530	850	506
8	D_8(D9)	on the rocky shore of the Shyia Ridge behind the large magnetic pavilion, S 65.245467°, W 64.249867°	547	1376	455	493	750	510	123
9	D_9(D10)	on Magnit Cape, costal rocks S 65.245008°, W 64.253205°	256	615	245	216	413	120	8
10	D_{10}(D11)	on the Cemetry Ridge near the pavilion of Very Low Frequencies (VLF), S 65.246170°, W 64.248250°	242	687	281	264	768	717	33
11	D_{11}(D12)	on the Gull Tower slopes on Stella Point, S 65.247450°, W 64.252740°	300	563	283	241	440	884	352

Table 1. Localization and plant number (S_i) *D. antarctica* populations, Galindez Island, Argentine Islands, seasons 2017/18 – 2023/24. * The local toponyms are provided according to Yevchun et al. (2021).

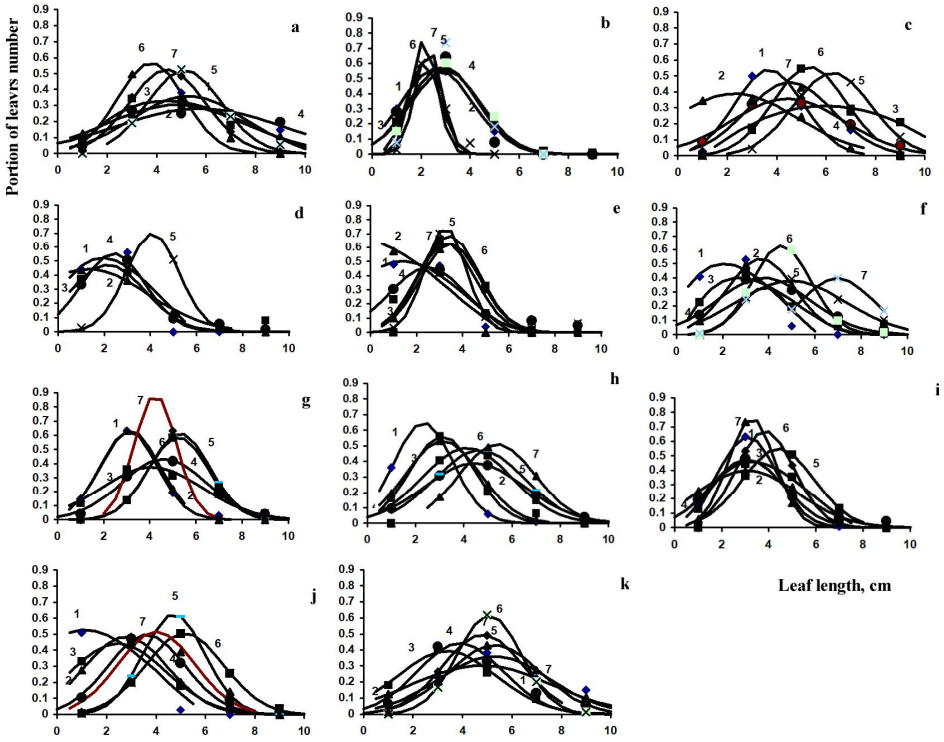

Fig. 2. Density functions of a leaf length of *D. antarctica* plants from populations: *a* - D1, *b* - D2, *c* - D3, *d* - D4, *e* - D5, *f* - D6, *g* - D7, *h* - D9, *i* - D10, *j* - D11, *k* - D12 (Gaussian model), Galindez Island, Argentine Islands, in seasons 2017/2018 (1), 2018/2019 (2), 2019/2020 (3), 2020/2021 (4), 2021/2022 (5), 2022/2023 (6), 2023/2024 (7).

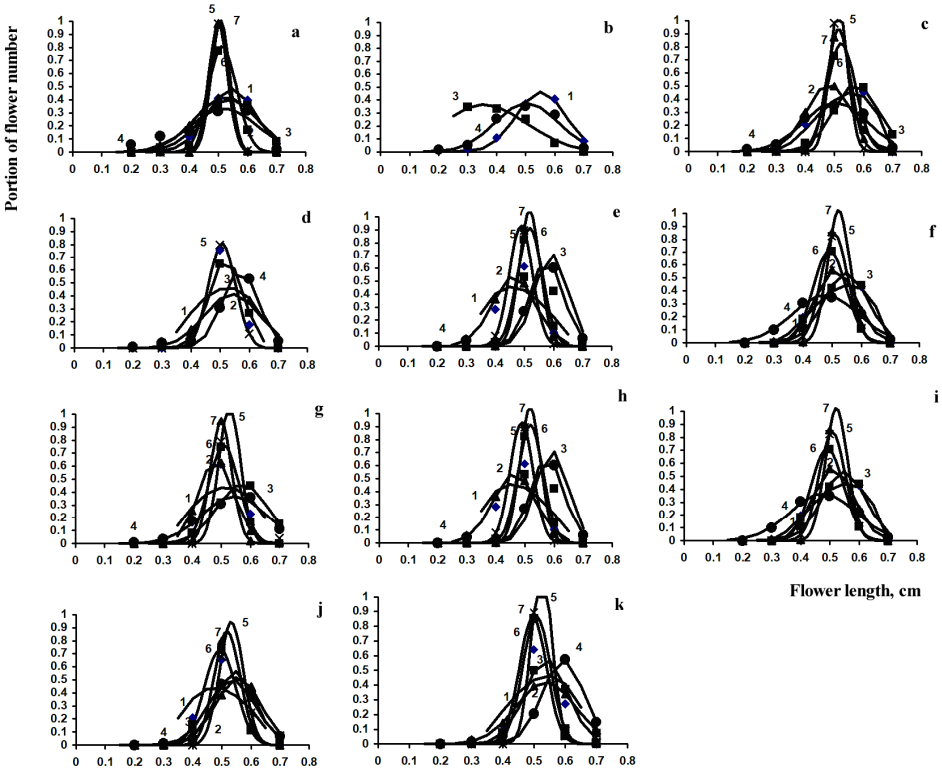

Fig. 3. Density functions of a flower length of *D. antarctica* plants from populations: *a* - D1, *b* - D2, *c* - D3, *d* - D4, *e* - D5, *f* - D6,*g* - D7, *h* - D9, *i* - D10, *j* - D11, *k* - D12 (Gaussian model), Galindez Island, Argentine Islands, in seasons 2017/2018 (1), 2018/2019 (2), 2019/2020 (3), 2020/2021 (4), 2021/2022 (5), 2022/2023 (6) , 2023/2024 (7).

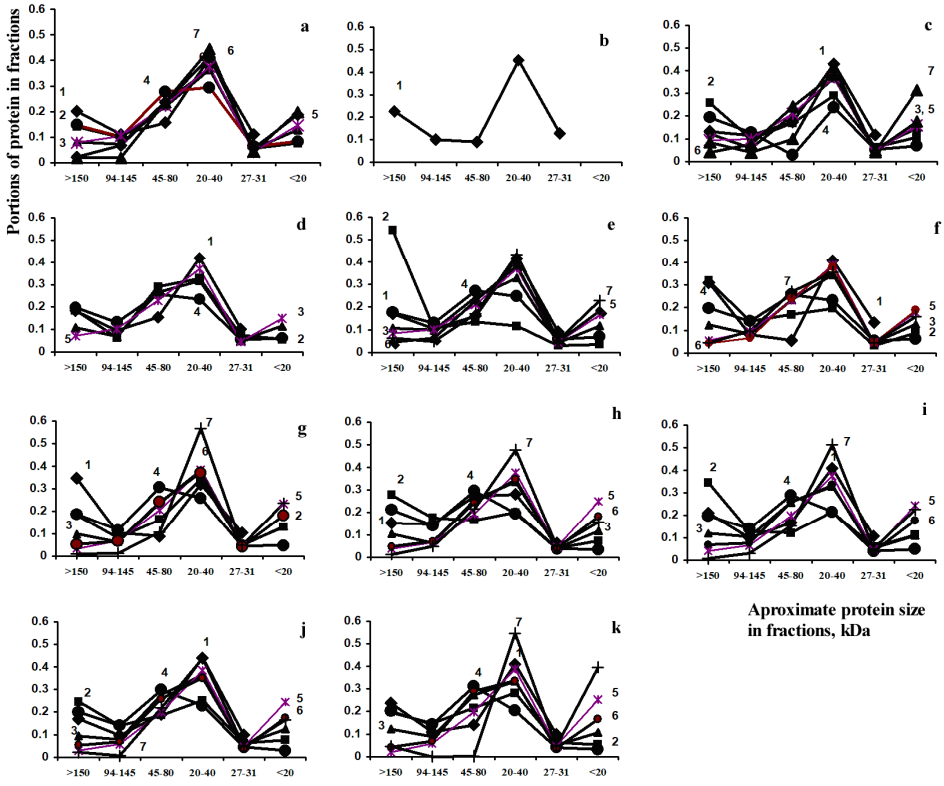

Fig. 4. The values of the different protein fractions in *D. antarctica* seeds from populations: *a* - D1, *b* - D2, *c* - D3, *d* - D4, *e* - D5, *f* - D6, *g* - D7, *h* - D9, *i* - D10, *j* - D11, *k* - D12, Galindez Island, Argentine Islands, seasons 2017/2018 (1), 2018/2019 (2), 2019/2020 (3), 2020/ 2021 (4), 2021/2022 (5), 2022/2023 (6), 2023/2024 (7). Fractions of protective and reserve proteins correspond 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 fully formed prolamins and low molecular weight dehydrins - less than 20 kDa.

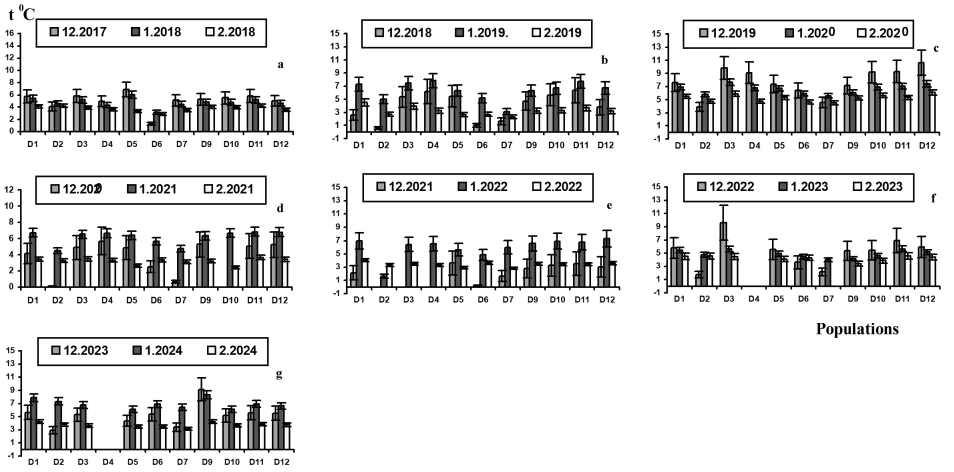

Fig. 5. Average monthly local temperature near native vascular plants (°C) of *D. antarctica* populations in seasons **a** - 2017/2018, **b** - 2018/2019, **c** - 2019/2020, **d** - 2020/2021, **e** - 2021/2022, **f** - 2022/2023, **g** - 2023/2024.

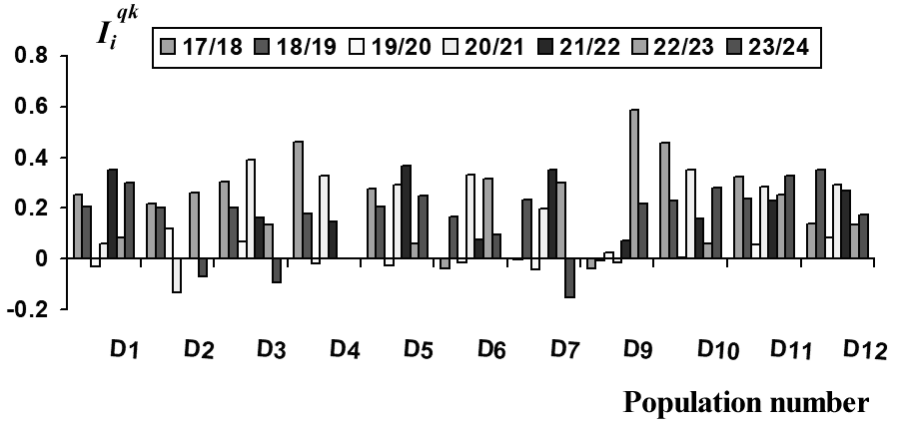

Fig. 6. The United Quality Latent Index (UQLI, $I^{qk}{}_i$) of population adaptability for the eleven studied *D. antarctica* populations from Galindez Island in seasons t_1 – 2017/2018, t_2 – 2018/2019, t_3 – 2019/2020, t_4 – 2020/2021, t_5 – 2021/2022, t_6 – 2022/2023, t_7 – 2023/2024.

The results of the UQLI ($I^{qk}{}_i$) by sign change occurred comparison for 11 populations in the seasons 2017/2018→2018/2019→2019/2020→2020/2021→2021/2022→2022/2023→2023/2024 (Fig. 6) which denoted ($t_1 \rightarrow t_2 \rightarrow t_3 \rightarrow t_4 \rightarrow t_5 \rightarrow t_6 \rightarrow t_7$) are presented in Table 2.

United Temperature Influence Index UTII ($I^k{}_i$) based on the original biological is presented in Fig. 1, 2, 3, Table 1) and average monthly local temperature near plants in Fig. 5. United Temperature Influence Index on the main plant's characteristics for each population in seven seasons are shown in Fig. 3. $I^k{}_i = (I^{k1}{}_i + I^{k2}{}_i + I^{k3}{}_i)/3$ is the three-month average value of the United Temperature Influence Index on the population adaptability indices for *k*-th season.

i	D_i	$t_1 \rightarrow t_2 \rightarrow t_3 \rightarrow t_4 \rightarrow t_5 \rightarrow t_6 \rightarrow t_7$	Transitions number
1	D_1(D1)	+→+→-→+→+→+→+	2
2	D_2(D2)	+→+→+→-→0→+→-	3
3	D_3(D3)	+→+→+→+→+→+→-	1
4	D_4(D4)	+→+→-→+→+	2
5	D_5(D5)	+→+→-→+→+→+→+	2
6	D_6(D6)	-→+→-→+→+→+→+	3
7	D_7(D7)	-→+→-→+→+→+→+→-	4
8	D_8(D9)	-→-→+→-→+→+	3
9	D_9(D10)	+→+→+→+→+→+	0
10	D_{10}(D11)	+→+→+→+→+→+→+	0
11	D_{11}(D12)	+→+→+→+→+→+→+	0

Table 2. Number of zero crossings in the United Quality Latent Index of plant population adaptability (I^{qk}_i) of *Deschampsia antarctica* populations in the seasons 2017/2018 (k=1), 2018/2019 (k=2), 2019/2020 (k=3), 2020/2021 (k=4), 2021/2022 (k=5), 2022/2023 (k=6), 2023/2024 (k=7).

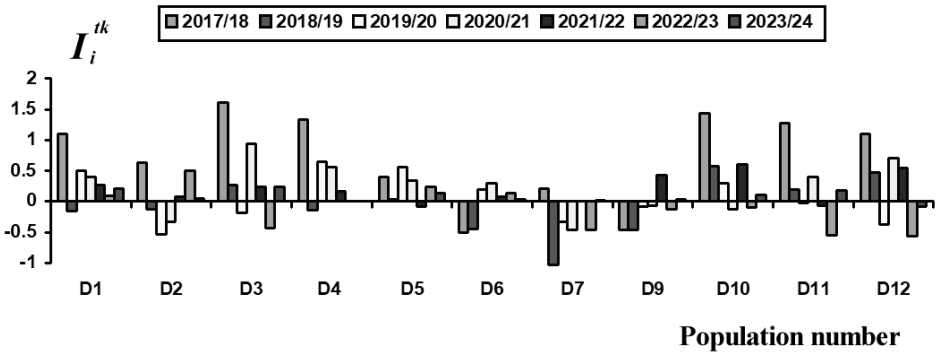

Fig. 7. United Temperature Influence Index UTII (I^{tk}_i) on the *D. antarctica* studied populations plants for each season: 2017/2018 (k=1), 2018/2019 (k=2), 2019/2020 (k=3), 2020/2021 (k=4), 2021/2022 (k=5), 2022/2023 (k=6), 2023/2024 (k=7).

Sharp change in the I^{tk}_i values by sign change occurred comparison for 11 populations in the seasons 2017/2018→2018/2019→2019/2020→2020/2021→2021/2022→2022/2023→2023/2024 (Fig. 7) which denoted ($t_1 \rightarrow t_2 \rightarrow t_3 \rightarrow t_4 \rightarrow t_5 \rightarrow t_6 \rightarrow t_7$) are presented in Table 3.

A data series comparison of UQLI (I^{qk}_i) and UTII (I^{tk}_i) was carried out based on these data shown in Figs. 6, 7 (Table 4).

i	D_i	$t_1 \rightarrow t_2 \rightarrow t_3 \rightarrow t_4 \rightarrow t_5 \rightarrow t_6 \rightarrow t_7$	Transitions number
1	D_1(D1)	+→-→+→+→+→+→+	2
2	D_2(D2)	+→-→-→-→+→+→+	2
3	D_3(D3)	+→+→-→+→+→-→+	4
4	D_4(D4)	+→-→+→+→+	2
5	D_5(D5)	+→+→+→+→-→+→+	2
6	D_6(D6)	-→-→+→+→+→+→+	1
7	D_7(D7)	+→-→-→-→-→+	2
8	D_8(D9)	-→-→-→-→+→-→+	3
9	D_9(D10)	+→+→+→-→+→-→+	4
10	D_{10}(D11)	+→+→-→+→-→-→+	4
11	D_{11}(D12)	+→+→-→+→+→-→-	3

Table 3. Number of zero crossings in the United Temperature Influence Index ($I^{qk}{}_i$) on *Deschampsia antarctica* populations in the seasons 2017/2018 (k=1), 2018/2019 (k=2), 2019/ 2020 (k=3), 2020/2021 (k=4), 2021/2022 (k=5), 2022/2023 (k=6), 2023/2024 (k=7).

Table 4. ▶ United Temperature Influence Index contributions on *D. antarctica* populations of G-population (UTII, $I^{tk}{}_i$) to the United Quality Latent Index of plant population adaptability (UQLI, $I^{qk}{}_i$) in the seasons 2017/2018 (*k*=1), 2018/2019 (*k*=2), 2019/2020 (*k*=3), 2020/2021 (*k*=4), 2021/2022 (*k*=5), 2022/2023 (*k*=6), 2023/2024 (*k*=7).

Notes: $I^{qk}{}_i$ is a United Quality Latent Index of population adaptability(UQLI) and $I^{tkl}{}_i$ is a United Temperature (local temperature near plants) Influence Index (UTII) on population adaptability indices; *i* is the population number in the G-population, *k* is the season number, *l* is the month number in the *k* season, $I_i^{tk} = \frac{1}{m}\sum_{l=1}^{m} I_i^{tkl}$ is the UTII average value on the population adaptability indies for the *k* season, where *m* is the number of those $I^{tkl}{}_i$ values that were taken into account when calculating $I^{tk}{}_i$, *n* - the number of studied populations with a significant correlation coefficient between $I^{q}{}_i$ and $I^{tkl}{}_i$ or $I^{tk}{}_i$, respectively, R^2 - the square of the correlation coefficient, $F_{1,n-2}$ - the test value, $F_{1,n-2}$ (p=0.05) - the upper 5% limit F-distribution, R is the correlation coefficient, equivalent to the corresponding influence index ($I^{tkl}{}_i$ or $I^{tk}{}_i$) contribution to $I^{qk}{}_i$.

* - no temperature data in February 2022/2023 season (k=6);

** - D4 population has been destroyed by penguins in the 2022/2023 season (k=6).

index sets pairs	n	R^2	$F_{1,n-2}$	$F_{1,n-2}$ (α=0.05)	R	Populations in which $I^q{}_i$ has a different dependence on $I^t{}_i$ than the rest of the G-population
$I^{q1}{}_i - I^{t11}{}_i$	11	0.7681	**29.808**	5.12	**0.876**	
$I^{q1}{}_i$ - $I^{t12}{}_i$	11	0.5777	**12.312**	5.12	**0.76**	
$I^{q1}{}_i$ - $I^{t13}{}_i$	11	0.5657	**11.727**	5.12	**0.752**	
$I^{q1}{}_i - I^{t1}{}_i$	11	0.7307	**24.417**	5.12	**0.855**	
$I^{q2}{}_i - I^{t21}{}_i$	5	0.8148	**13.200**	10.13	**0.90**	D1, D2, D3, D7, D9, D10
$I^{q2}{}_i$ - $I^{t22}{}_i$	10	0.5318	**9.088**	5.32	**0.73**	D7
$I^{q2}{}_i$ - $I^{t23}{}_i$	6	0.6604	**7.780**	7.71	**0.81**	D1, D2, D4, D7, D11
$I^{q2}{}_i - I^{t2}{}_i$	9	0.6144	**11.151**	5.59	**0.78**	D6, D7
$I^{q3}{}_i - I^{t31}{}_i$	10	0.8677	**52.472**	5.32	**-0.93**	D7
$I^{q3}{}_i$ - $I^{t32}{}_i$	10	0.6896	**17.328**	5.32	**-0.83**	D7
$I^{q3}{}_i$ - $I^{t33}{}_i$	6	0.9152	**43.168**	7.71	**-0.956**	D1, D2, D6, D7, D11
$I^{q3}{}_i - I^{t3}{}_i$	11	0.5036	**9.135**	5.12	**-0.71**	
$I^{q4}{}_i - I^{t41}{}_{i4}$	10	0.5245	**8.824**	5.32	**0.72**	D7
$I^{q4}{}_i$ - $I^{t42}{}_i$	10	0.6841	**17.328**	5.32	**0.83**	D7
$I^{q4}{}_i$ - $I^{t43}{}_i$	8	0.8314	**81.846**	5.99	**0.91**	D5, D10, D11
$I^{q4}{}_i - I^{t4}{}_i$	9	0.7217	**18.151**	5.59	**0.85**	D7, D10
$I^{q5}{}_i - I^{t51}{}_i$	7	0.6901	**11.135**	6.61	**0.831**	D2, D7, D9, D10
$I^{q5}{}_i - I^{t52}{}_i$	6*	0.845	**21.808**	7.71	**-0.919**	*D6, D7, D2*, D3*, D4**
$I^{q5}{}_i - I^{t53}{}_i$	8	0.5656	**7.812**	5.99	**-0.752**	D2, D6, D9
$I^{q5}{}_i - I^{t54}{}_i$	6	0.8878	**31.652**	7.71	**-0.942**	*D1, D2, D9, D10, D11*
$I^{q5}{}_i - I^{t5}{}_i$	5	0.7876	**11.124**	10.13	**0.887**	D5, D7, D9, D10, D11, D12
$I^{q6}{}_i - I^{t61}{}_i$	7**	0.6936	**11.320**	6.61	**0.833**	D2, D6, D11
$I^{q6}{}_i - I^{t62}{}_i$	6**	0.6611	**7.804**	7.71	**0.813**	D2, D3, D6, D7
$I^{q6}{}_i - I^{t63}{}_i$	8**	0.6097	**9.372**	5.99	**-0.781**	D3, D12
$I^{q6}{}_i - I^{t64}{}_i$	6**	0.7727	**13.596**	7.71	**-0.879**	D6, D7*, D10, D12
$I^{q6}{}_i - I^{T6(1+2)}{}_i$	5**	0.8791	**21.813**	10.13	**0.938**	D2, D3, D6, D7, D11
$I^{q6}{}_i - I^{T6(3+4)}{}_i$	6**	0.7286	**10.740**	7.71	**-0.854**	D3, D6, D10, D12
$I^{q6}{}_i - I^{t6}{}_i$	5**	0.7847	**10.935**	10.13	**0.886**	D1, D2, D5, D6, D10
$I^{q7}{}_i - I^{t71}{}_i$	6	0.9537	**82.392**	7.71	**-0.977**	D1, D2t, D5, D9, D10
$I^{q7}{}_i - I^{t72}{}_i$	9	0.5579	**8.834**	5.59	**0.747**	D3, D9
$I^{q7}{}_i - I^{t73}{}_i$	8	0.7755	**20.724**	5.99	**-0.881**	D1, D7, D11
$I^{q7}{}_i - I^{t74}{}_i$	8	0.612	**9.462**	5.99	**0.782**	D2t, D3, D12
$I^{q7}{}_i - I^{t7}{}_i$	8	0.5809	**8.316**	5.99	**0.768**	D2t, D3, D12

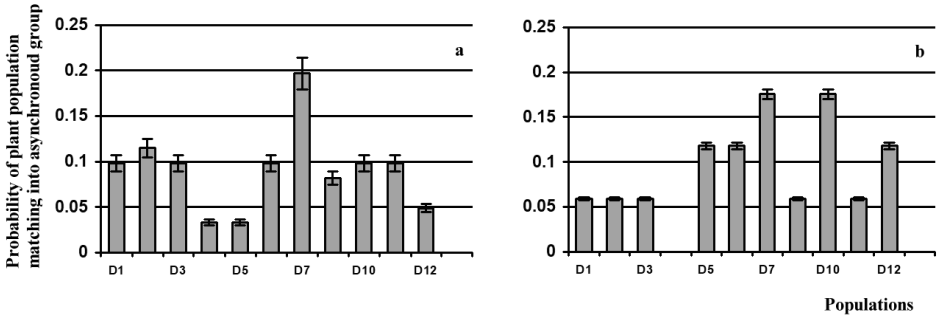

Fig. 8. The probability of plant populations matching into asynchronous group by average monthly temperature (t) during seven seasons for **a** – all seasons months, **b** - all seasons.

Discussion

In this study, we considered the spatial differences in the biological and temperature variables of the local populations of G-population in the months of each season. Such an approach was used due to the fact that temperature variables at the summer season beginning in the population locations differ more than at the season end through the different speed of snow melting (Tarca et al. 2021). Biological population adaptability indices respond differently to changes of temperature and other external factors during the season. The G-population adaptability index dynamic under such a strategy will look like the dynamics of the change in each population response to the changing environment. We have begun the analysis with the changes in the plant adaptability complex index of different populations UQLI (I^{qk}_{i}) because it to the both measured and latent indices environmental influence on plants.

Two types of temperature variables are used in agrometeorology: the average monthly temperature and the sum of positive temperatures accumulation for each decade of the season. We used the first of them in this study (Fig. 5). The latter one and their comparison will be focused in a forthcoming study. Spatial differences of such meteorological variables as the average monthly temperature for each season month were determined. They were compared with the spatial differences of such indices as morphometric indices (*see* Figs. 2, 3), the relative content of protective and reserve seed proteins (Fig. 4) and the plants number (Table 1) for the studied populations. In order to calculate the indices of I^{qk}_{i} (Fig. 6), I^{kl}_{i} (Fig. 7) we used algorithms from Miryuta et al. (2019a, b). We considered only the influence of the temperature variables, their effect on the plants development.

The identification of the reasons associated with the changes in the UQLI sign in the populations may be related to the fact that at the summer season beginning, there is a temperature field that differs in the populations locations, and which is equalized during the season. This may be due to the different snow melting speed which was also accompanied by high variability in air humidity and several more latent factors. The factors can be both abiotic (humidity, salinity, soil composition, wind load, shading or openness to sunlight and others) and biotic (rhizosphere bacteria and plant endophytes composition) (Bulgarelli et al. 2013, Prekrasna et al. 2022, Miryuta et al. 2024).

The fluctuation dynamics in average monthly temperatures during the season in each of 11 plant population locations is different for each of the seven seasons according to data presented in Fig. 5. We did not analyze the intraseasonal average monthly temperature fluctuation dynamics in different seasons. Instead, we analyzed the influence of intraseasonal spatial temperature fluctuations on the spatial various biological characteristic's fluctuations (Figs. 2, 3, 4) in the form of United Temperature Influence Index for each *i*-population I^k_i (UTII) in the off-season dynamics. In this form, the influence of spatio-temporal fluctuations in average monthly temperatures on biological characteristics fluctuations was presented in Fig. 6.

Positive I^k_i contributions to I^{qk}_{i} in seasons k=1, 2, 4, 5, 6, 7, were accompanied by a negative contribution observed in season k=3 (Table 4), similarly for December, January and February (l=1, 2, 3) of season k=3. For season k=5, a positive contribution is observed for November (l=1), a negative contribution is observed for December, January and February (l=2, 3, 4), for k=6, a positive contribution is observed for November and December (l=1, 2), a negative correlation is observed for January and February (l=3, 4), for k=7 a positive contribution is observed for December and February (l=2, 4), a negative contribution is observed for November and January (l=1, 3). Perhaps, negative I^k_i contributions to I^{qk}_{i} were observed in those months and seasons when plants worked to change the composition of rhizosphere bacteria.

The results presented in the work (Miryuta et al. 2024) and conclusion about positive I^k_i contributions to I^{qk}_{i} are valid for the studied season (k=1). This does not mean that the influence of plant populations on the composition of the rhizosphere bacterial community cannot be observed in another season. In recent research, special attention is drawn to the bacteria mediating soil processes influance on the nutrients availability context. Moreover, there are also functional consequences of these interactions on ecosystem responses to environmental changes, in addition to the roots influences on rhizosphere bacterial communities (Ahkami et al. 2017, Garcia and Kao-Kniffin 2018, Paterson and Mwafulirwa 2022).

The populations in which I^{qk}_i has a different dependence on I^k_i than the rest populations of the G-population were referred to 'asynchronous' for short. The probability of plant populations matching into asynchronous group by average monthly temperature for all season months and all seasons through seven seasons are presented in Fig. 8.

The composition of asynchronous group whidth has not matched into the G-population by synchronicity was varied during the three months of the summer season in the last seven seasons. The population D7 was most often matched into asynchronous group that allows us to cautiously assume that in case this latent index may be humidity. This population is located on the Krapla Rock shell and suffers from excessive humidity. The next most frequent population to match into the asynchronous group was D2 population, which suffers from a delay in snowmelt. In general, it can be said that populations natching into the asynchronous group lag behind the entire G-population or ahead of it in their development due to local conditions.

A different picture is observed when analyzing the probabilities of matching into asynchronous group of populations for the seven-season dynamics for the full summer season, when the spatial temperature field has leveled off. Most often, populations D7 and D10 are matched to the asynchronous group. Most likely, this happens in population D7 due to excessive humidity, and in population D10 due to the penguins invasion. In the remaining populations of this group, lag behind the entire synchronous group or ahead of it the may occur due to changes in the composition of rhizosphere bacteria

in the corresponding loci.

At first glance the white, cold and monotonous Antarctic region has quite diverse regional ecological conditions. However, researchers usually study their objects in particular vascular plants, in some specific local conditions, *e.g.* in the vicinity of their country station. This results in a set of studied corresponding species characteristics and a set of methods for their study. For example, *D. antarctica* has much longer leaves and larger peduncles and quite rarely has inflorescences on Nelson Island (South Shetland Islands) than on Galindez Island (Argentine Islands, the maritime Anatrctica). In the area of the Polish station "Arctowski" on King George Island (South Shetland Islands) hairgrass plants grow in quite specific conditions: either continuous carpets or fairly diffuse curtains. Growth conditions are reflected in the plant's parameters and their populations. The populations of the South Shetland Islands are very different from the populations of the Argentine Islands-Kyiv Peninsula region. For a comparative assessment of the population's success from different regions, it is necessary to develop a certain parameter set. For some populations from the Point Thomas (Polish Arctowski station location), we first applied the UQLI determination algorithm with a certain set of input data on the example of one season (Parnikoza et al. 2015). Applying it for seasons set in the case of the Argentine Islands allowed us to expand the list of parameters and find their dependence on the microclimate indices. As for non-vascular plants the application of our method is also possible for them, but in this case the question arises of finding parameters that change quickly enough and respond to environmental influences. Such parameters can be the chlorophyll content of mosses, which affects the values of multispectral indices and reflects the physiological state of bryophytes while as for lichens it is probably worth relying on the cover index and physiological reactions of the phytobiont.

Conclusions

Eleven *D. antarctica* plant populations were researched according to population size, plant morphometric parameters, reserve seed proteins composition and soil surface temperature in the population's locations in the 2017/18, 2018/19, 2019/20, 2020/21, 2021/22, 2022/23, 2023/24 seasons. A strategy based on considering spatial differences in temperature variables which decrease during the season and spatial differences of biology characteristics was applied.

The contribution of United average monthly Temperature Influence Index on the plants adaptation indices during the summer months of the Antarctic season (I^{k}_{i}) into I^{qk}_{i} throgh seven ceasons was calculated and analysed. The local populations of the G-population were found to develop unevenly depending on micro conditions. In particular, individual populations with different frequencies matched into an asynchronous group, the populations of which didn't match of the general development trend of the G-population rest. The I^{k}_{i} contributions to I^{qk}_{i} were shown be not always positive. Negative contributions were observed in the season k=3 (2019/20) and in some individual months of the seasons k=5, 6, 7. This means that the spatial temperature differences influence on plants populations throughout the season has not been constant by sign (plus or minus) for the last three seasons. This confirms the unevenness and individuality of plant responses in variable macro-conditions multiplied by variations in micro-conditions.

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