Spatio-temporal variability of soil surface temperature influence on Antarctic hairgrass populations adaptation. 2. Effects of fluctuations in positive temperature acumulation on changes in biological characteristics

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Abstract

Given existing uncertainties in the understanding the role of temperature in shaping the adaptation of *Deschampsia antarctica* populations, this study investigates the impact of soil surface positive (above-zero) temperature accumulation spactial differences on biological characteristics spactial differences. The research focuses on the complex adaptability index (I^{qk}_i) and complex temperature influence index I^{Tk}_i and last one contributions to I^{qk}_i for eleven *Deschampsia antarctica* populations on Galindez Island (Argentine Islands, maritime Antarctica) over seven consecutive Antarctic summer seasons (2017/18 – 2023/24).

Key words: *Deschampsia antarctica*, I^{qk}_i, I^{Tk}_i in dynamic, Argentine Islands, maritime Antarctica

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Introduction

Climate change impacts on the planet's ecosystems represent one of the most significant challenges for humanity. Such changes are most strongly felt in the polar regions, whose biota is highly sensitive to the slightest influences of climatic variables. Understanding the impacts of climate change on Antarctic biota has become a central priority of contemporary research. (Kennicutt et al. 2014, Jones et al. 2025). Previous studies of the vascular plants response to climate change were carried out

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on the basis of the same areas network monitoring and determination of the plants number and population sizes (Fowbert and Smith 1994, Parnikoza et al. 2009, Torres-Mellado et al. 2011). Recognizing the need to continue such studies, further research require an expanded range of monitoring methods. Consequently, we are developing an approach for the annual assessment of the impacts of the Antarctic environmental factors based on the existing experimental population network of the Galindes Island monitoring sites.

It is well known that environmental factors that influence plants in terms of temperature can be described by a set of variables like average monthly temperature, the sum of positive (above-zero) temperatures accumulation, the warm season length, the season onset date, *etc*. These variables are dependendent on the illumination effect that is best described in the work by (Savenets et al. 2026). The snow melting rate and, accordingly, the date of its descent, which means the beginning of the warm season, is shown in this work to be depended on the radiation flux. The average monthly temperature for both the air and the soil surface also depends on the illumination value. Since vascular plants are affected by both average temperatures of the warm season and the positive temperatures accumulation, although often in different ways, an important factor that indirectly affects both temperature indices are light intensity and the season length, which directly depends on the snow-free period length. The sum of positive temperatures accumulation per season depends on both the average monthly temperature and the season length and, therefore, on illumination. In previous work (Miryuta et al.2025a) we studied the influences that spatial changes in the average monthly temperature had on the spatial changes in biological characteristics for each of the seven seasons. In this study, we present the results on how the spatial changes in the sum of accumulated positive temperatures impact the spatial changes in biological characteristics for each decade (10-day) period, month, and season during the seven consecutive Antarctic summer seasons.

Deschampsia antarctica primarily inhabits coastal regions of the maritime Antarctic, including the Antarctic Peninsula and associated islands well-drained soils with relatively high nutrient availability and moisture (Fasanella et al. 2017). The most interesting study in coverage terms of a measured parameters large number both biological and meteorological during the study of the Antarctic Peninsula west coast was the work (Ball et al. 2023). This work included studies along a south-north transect at regional and local spatial scales along the Antarctic Peninsula over a two years period. The studied parameters were grouped according to the habitat rigor principle such as soil composition, latitude and regional-scale meteorological conditions, including air temperature and precipitation, at 13 sites on the Antarctic Peninsula, which may affect soil communities selected from the locations of five representatives of terrestrial vegetation, including lichens and fungi (Znój et al. 2021).

In previous works it was proposed an approach for determining spatial differences in several indices of *D. antarctica* cereal populations with the consequent estimation of the complex United Quality Latent Index (UQLI, I^q_i) (Parnikoza et al. 2015, Miryuta et al. 2014, 2015, 2017). This index allows us to assess the complex adaptability in the Antarctic seasons dynamics (Miryuta et al. 2015, 2019a). The term "latent" means that I^q_i for season k is the result of plant adaptation to the abiotic and biotic conditions sum that remain implicit, *i.e.* latent.

Attempts to identify direct relationship between meteorological variables and plant adaptability indices are strongly limited by the inability to systematically record some variables across all studied populations. Considering this, it is necessary to estimate the contribution of selected measured eco-

logical indices to the I^q_i current value as the total all influences result for a certain season.

To ensure that the determined contribution adequately reflect the situation, the influence of temperature variableswas expressed in the form of a United Temperature Influence Index (I^{Tk}_i or I^{Tk}_i) on plant populations. To determine the temperature variables (including average monthly temperatures by Miryuta et al.2025a) and sums of positive temperatures accumulation) influence on plant populations, it was used the plants number in the population plants morphometric indices, the portions of reserve and protective seeds proteins that was assessed by the method described in detail in the work (Miryuta et al. 2019b, Parnikoza et al. 2018).

The purpose of this work is to research the influence of temperature variables, obtained with the loggers located at eleven sites, on the measured plant populations adaptability indices, and to determine their United Temperature Influence Index I^{Tk}_i on plant populatins and it contribution to I^{qk}_i.

Material and Methods

The research was conducted in the seven austral seasons 2017/2018 – 2023/2024.

The Galindez Island (that is central in system of Argentine Islands) was chosen for this research considering the fact of previous research conducted here (Fowbert and Smith 1994, Parnikoza et al. 2009). The distribution of plant populations included in the general G-population of Galindez Island (whole Galindez Island population) has been described in the works (Parnikoza et al. 2018, Yevchun et al. 2021) (Fig. 1).

The monitoring sites network for the regular *D. antarctica* populations research was established during 2006 – 2014 on Galindez Island (Miryuta et al. 2015), (*see* Fig. 1). The locations of the experimental populations reflected the variety of growth conditions of Antarctic hairgrass and are considered torepresented different microclimatic conditions on the island.

Biological methods in population research

The research used the plants number counting in the *D. antarctica* populations data on Galindez Island in 2017/18 – 2023/24. The interval between plants number counting in populations and sampling during this period was 1 year (Table 1s). The populations sizes of eleven experimental sites, biometrics (leaf length, inflorescence length, flower length, number of flowers in the inflorescence) were studied through seven years for eleven populations (Fig. 1s, 2s) by the methods set described in details in Miryuta et al. (2015, 2017), Parnikoza et al. (2015), Miryuta et al. (2019a). Through the same period, we studied the spectra of reserve and protective seed proteins (seeds were selected from five inflorescences taken from each population). Extraction, electrophoretic separation and densitometry were performed according to the methods detailed in (Miryuta et al. 2015). Digital photographs were analyzed by densitometry. The proportions of individual groups of seed proteins which characterisize 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. 3s. United Quality Latent Index of adaptability (UQLI, Iqki) for each plant population was calculated based on data presented in Figs. 1s, 2s, 3s. The calculation algorithm was described in detail in Miryuta et al. (2019a).

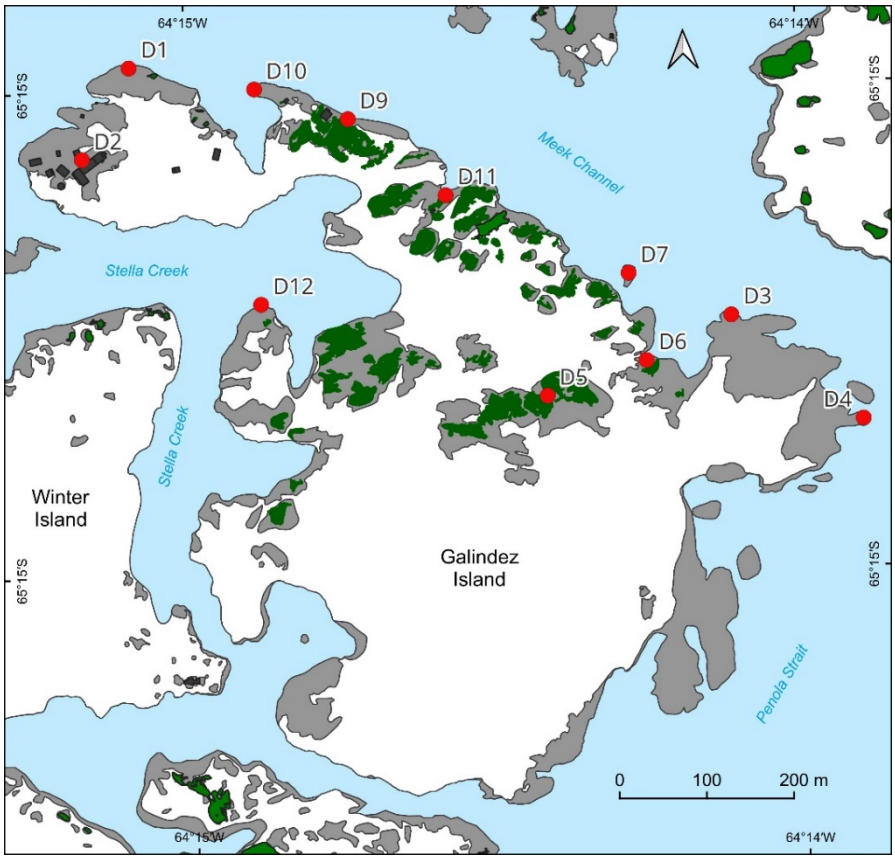

Fig. 1. Map of the studied *D. antarctica* populations' locations in the G-population fragments on the Galindez Island: D1, D2 – Marina Point; D3, D4 – Penguin Point; D5 – Carolina Point; D6 – Roztochchia Ridge; D7 – Krapla Rock; D9, D10 – Crimea Ridge; D11 – Karpaty Ridgeregion; D12 – Stella Point.

Meteorological methods of population locations research

Onset HOBO UA-002-64 temperature loggers were installed in the plots of 11 studied hairgrass populations. The soil surface temperature was recorded every 30 minutes during seven years (2017/18 – 2023/24). The curves of positive temperatures accumulated sums on the soil surface are presented in Fig. 2. The thermal indices 'average temperature of the warm season' (T^{tk}) and 'sum of positive temperatures of the warm season' (T^{Tk}) in the dynamics calculated according to the work are presented in Fig. 3. The approach is based on standard calculation of growing degree days (computed as a sum of mean daily air temperatures above 0°C). These sums are used widely in agrometeorological studies (Liu et al 2021, Paredes et al. 2025). To evaluate the influence of the local microclimate on the studied populations based on the temperature variables obtained from the loggers, the complex indices UTII (I^{Tk}_i)) were calculated based on the positive temperatures accumulation sum on the soil surface and biological adaptability indices as described in (Miryuta et al. 2019b).

Statistical methods for D. antarctica populations research

A comprehensive fitness index (United Quality Latent Index (UQLI, I^q_i) of adaptability) based on the above indices for eleven populations in the seven seasons dynamics was calculated in the research. The initial data of biological indices (Table 1s, Figs. 1s, 2s, 3s) are given in the Supplementary Materials. The United Quality Latent Index (UQLI, I^q_i) of plant population adaptability were determined on the original biological data basis accoding to the algorithm described in detail in (Miryuta et al. 2019a). The UQLI (I^q_i) describes the multi-level response of populations to variations in the microenvironmental conditions of all types of their growth in nature based on available measurements characterizing the plant population (Miryuta et al. 2017, 2019a). However, it does not allow to assess the influence of the certain environmental factors.

The calculated values of the United Quality Latent Index (UQLI, I^q_i) for plant adaptability to external conditions in eleven populations were used for annual comparisons over the last seven seasons against temperature variables, following the previously described methodology (Parnikoza et al. 2018, Miryuta et al. 2019b). These indices were determined taking into account the fact that the spatial temperature differences in the population locations at the season onset are significantly greater than those at the season termination through the different snow melting rate (Tarca et al. 2021). This fact, which we observed during seven seasons, was illustrated the first season in the work (Miryuta et al. 2019b).

The accumulated sums of positive soil surface temperatures (T), selected for studying their influence on plant adaptability, were calculated using a defined set of methods (Pollard 2009, Corder and Foreman 2014). The algorithm of this set of methods, applicable for the United Temperature Influence Indices calculation, is described in detail in the work (Ayvazyan et al. 1989, Bauman and Moskalenko 2008, Miryuta et al. 2019b).

These indices are marked as 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.

In the next step, I^k_i set with I^q_i were compared in order to determine the temperature indices contribution to the I^q_i and populations allocation into groups influenced by temperature-related or other latent factors.

Results

The initial meteorological data are presented in Fig. 2.

To compare temperature indices, we used two thermal indices - 'average temperature of the warm season' and 'accumulated sum of positive temperatures of the warm season' - calculated using the method described in the work (Savenets et al. 2023). The dynamics of these thermal indices are shown in Fig. 3. The series of these indices were compared using the regression technique. The results are presented in Table 1.

The initial biological data are presented in Table 1s and Fig. 2s – 3s (cited by Miryuta et al. 2025a).

The United Quality Latent Index (UQLI, I^q_i) of populations adaptability based on the

original biological data (Table 1s, Figs. 1s, 2s, 3s) was determined by the algorithm described in detail in (Miryuta et al. 2019a). The UQLI (I^{q}_{i}) values for seven seasons in eleven populations are shown in Fig. 4.

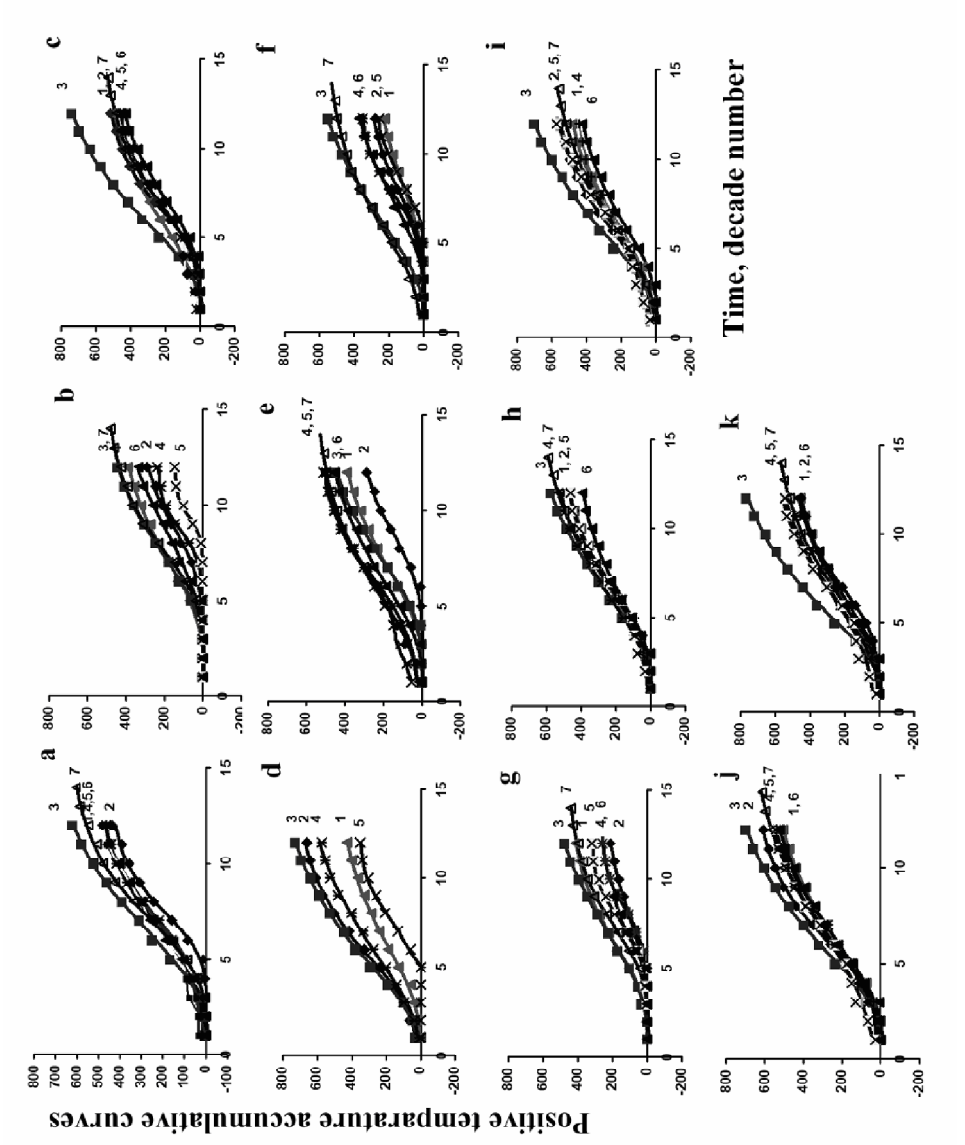

Fig. 2. The curves of the accumulated sums of positive temperatures (T) by decades (10-days) in the summer seasons 2017/18 (1), 2018/19 (2), 2019/20 (3) and 2020/21 (4), 2021/22 (5), 2022/23 (6), 2023/24 (7) for locations of *D. antarctica* populations: *a* - D1, *b* - D2, *c* - D3, *d* - D4, *e* - D5, *f* - D6, *g* - D7, *h* - D9, *i* - D10, *j* - D11, *k* - D12. *Numbering of decades*: **1** - 11-1, **2** - 11-2, **3** - 11-3, **4** - 12-1, **5** - 12-2, **6** - 12-3, **7** - 01-1, **8** - 01-2, **9** - 01-3, **10** - 02-1, **11** - 02-2, **12** - 02-3, where the first digit means the month, the second one means the decade of the month. Accumulation curves were selected using the MMF function (y=(ab+cxd)/(b+xd)), which belongs to the class of sigmoidal models by program CurveExprt 1.3.

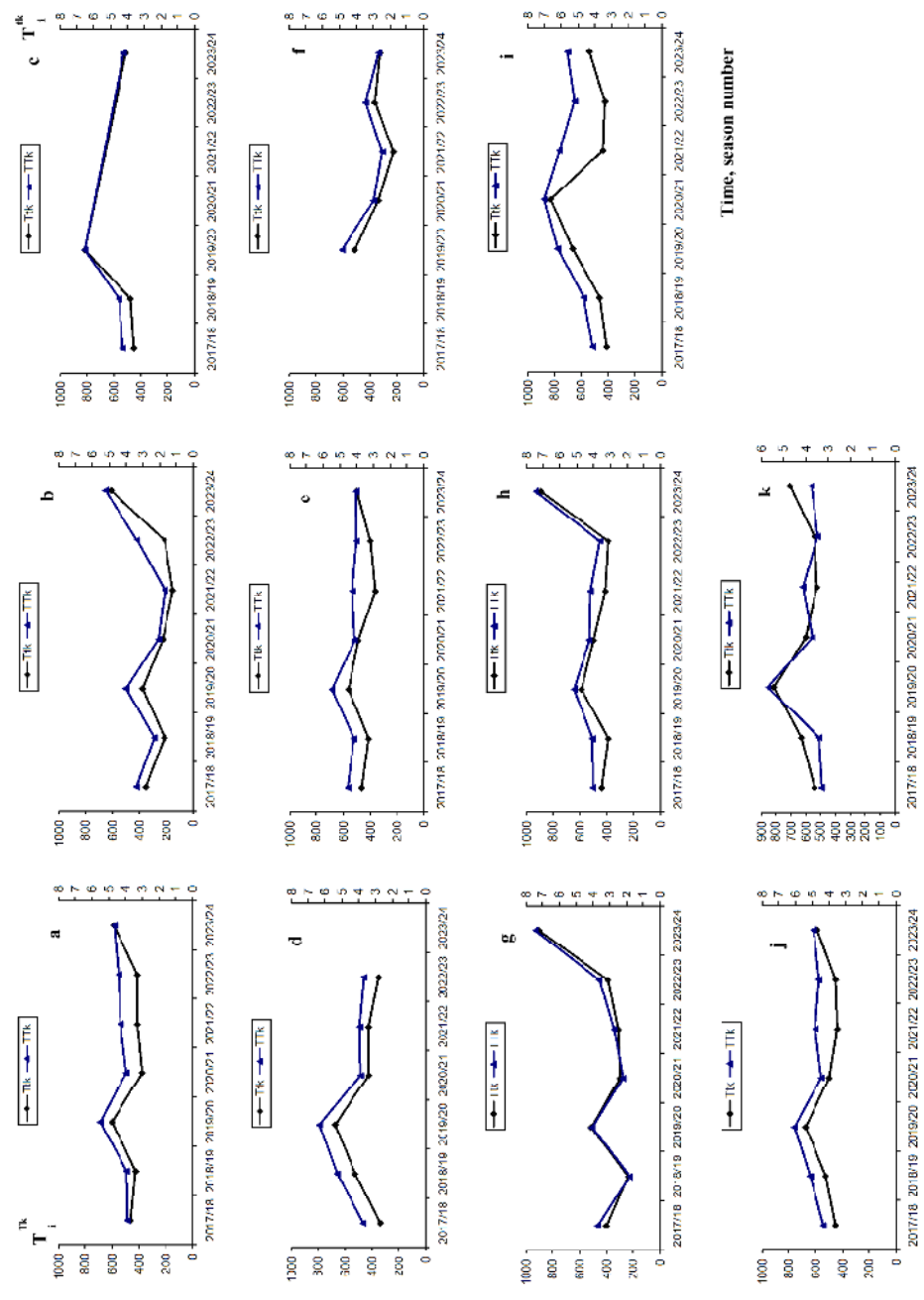

Fig. 3. The interannual changes of the thermal indices ('average temperature of the warm season' (T^{tk}) and 'sum of positive temperatures of the warm season' (T^{Tk}) for the seasons 2017/2018 (*k*=1), 2018/2019 (*k*=2), 2019/2020 (*k*=3), 2020/2021 (*k*=4), 2021/2022 (*k*=5), 2022/2023 (*k*=6), 2023/2024 (*k*=7), Galindez Island, Argentine Islands for locations of *D. antarctica* populations: *a* - D1, *b* - D2, *c* - D3, *d* - D4, *e* - D5, *f* - D6, *g* - D7, *h* - D9, *i* - D10, *j* - D11, *k* - D12 (cited by Savenets et al. 2023).

i	D_i	n	R^2	$F_{1,n-2}$	$F_{1,n-2}$ (α=0.05)	R
1	D_1(D1)	7	**0.6373**	8.785	6.61	**0.798**
2	D_2(D2)	7	**0.856**	29.720	6.61	**0.925**
3	D_3(D3)	4	0.9549	11.888	18.51	0.977
4	D_4(D4)	5	**0.9486**	63.519	10.13	**0.974**
5	D_5(D5)	7	0.405	3.405	6.61	0.636
6	D_6(D6)	5	0.9212	2.043	10.13	0.96
7	D_7(D7)	7	**0.9767**	209.590	6.61	**0.988**
8	D_8(D9)	7	**0.9718**	172.305	6.61	**0.986**
9	D_9(D10)	7	**0.6467**	9.150	6.61	**0.804**
10	D_{10}(D11)	7	**0.7289**	13.445	6.61	**0.853**
11	D_{11}(D12)	7	0.5551	6.240	6.61	0.746

Table 1. Correlations between thermal indices 'average temperature of the warm season' and 'accumulated sums of positive temperatures of the warm season' in dynamics for 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) for *D. antarctica* populations: D1, D2, D3, D4, D5, D6, D7, D9, D10, D11, D12, Galindez Island, Argentine Islands.

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

Table 2. Number of zero crossings in the United Quality Latent Index of plant population adaptability (I^{qk}_i) of *Deschampsia antarctica* populations and United Temparature Influance Index on this populations (I^{Tk}_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).

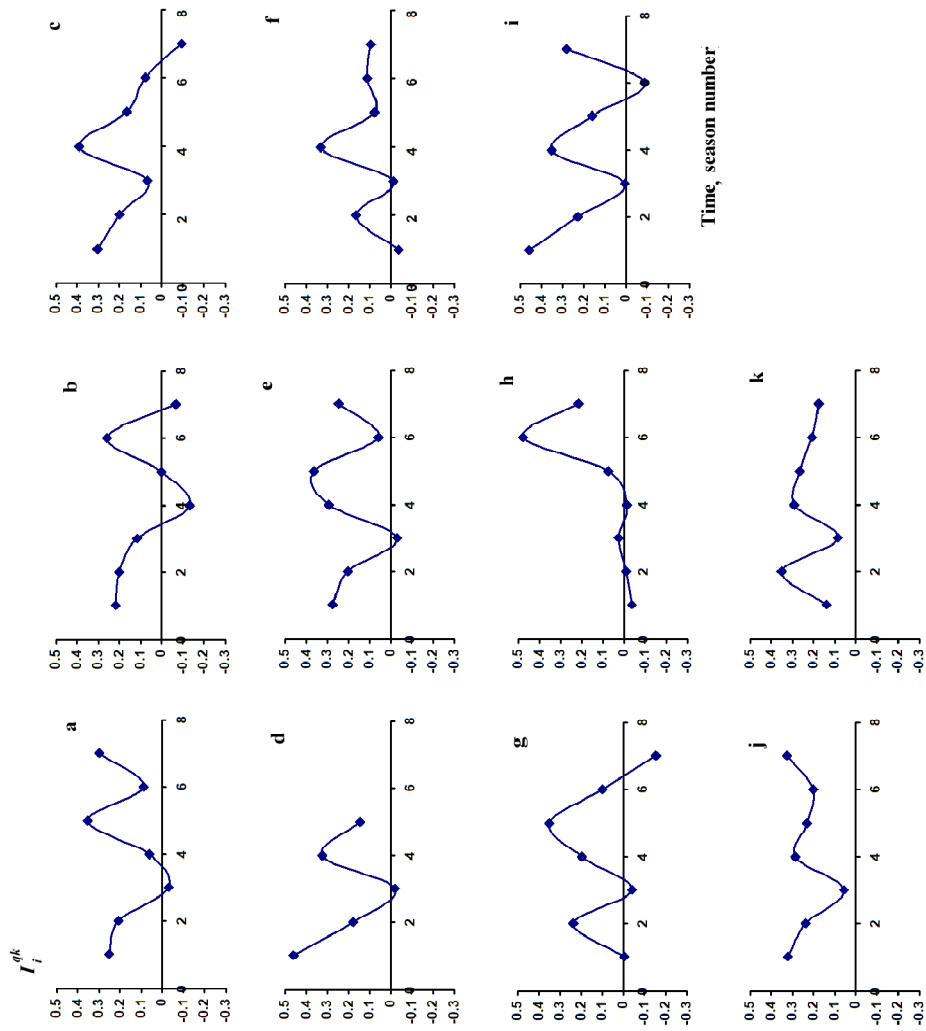

Fig. 4. The dynamic of United Quality Latent Index (UQLI, I^q_i) of population adaptability for the eleven studied *D. antarctica* populations from Galindez Island: *a* - D1, *b* - D2, *c* - D3, *d* - D4, *e* - D5, *f* - D6, *g* - D7, *h* - D9, *i* - D10, *j* - D11, *k* - D12 in seasons 2017/2018 (*k*=1), 2018/2019 (*k*=2), 2019/2020 (*k*=3), 2020/2021 (*k*=4), 2021/2022 (*k*=5), 2022/2023 (*k*=6), 2023/2024 (*k*=7).

The United Temparature Influance Index (I^{Tk}_i) on plant populations based on the original biological data (Table 1s, Figs. 1s, 2s, 3s) and the sum of positive temperatures accumulation (T) (Fig. 2) was determined by the algorithm described in detail in Miryuta et al. (2019b). The UTII (I^q_i) values for seven seasons in eleven populations are shown in Fig. 5. The value of $I^{Tk}_i = (I^{k1}_i + I^{k2}_i + I^{k3}_i + I^{k4}_i)/4$ is the four-month average value of the United Temperature Influence Index on the population adaptability indices for *k*-th season.

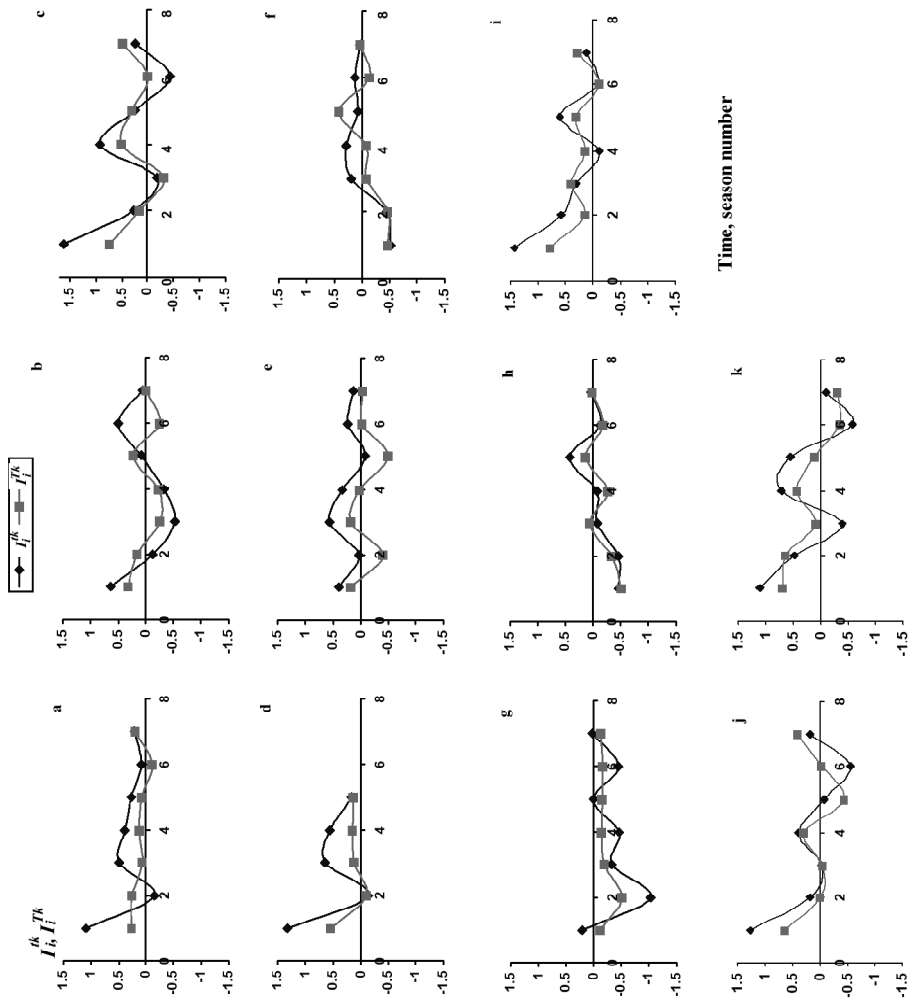

Fig. 5. The dynamics of United Temparature Influance Index on this populations (I^{tk}_{i} and I^{Tk}_{i}) on plant population for the eleven studied *D. antarctica* populations from Galindez Island: *a* - D1, *b* - D2, *c* - D3, *d* - D4, *e* - D5, *f* - D6, *g* - D7, *h* - D9, *i* - D10, *j* - D11, *k* - D12 in 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).

The results of the UQLI (I^{q}_{i}) and UTII (I^{Tk}_{i}) by sign change occurred comparison for eleven populations under the transition between seasons 2017/2018→2018/19→ 2019/2020→2020/21→2021/22→2022/23 →2023/24 (Fig. 4) 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.

A data series comparison of UQLI (I^{q}_{i}) and UTII (I^{Tk}_{i}) was carried out based on these data shown in Fig. 4, 5 (Table 3).

The each population probability distributions of matching into the asynchronous group during seven seasons when analyzing the data comparing I^{qk}_{i} with I^{tkl}_{i} and I^{Tkl}_{i} (where t is the average monthly temperature, T is the accumulated sum of the positive temperatures for all months of the seven summer seasons) are shown in Fig. 6.

index sets pairs	n	R^2	$F_{1,n-2}$	$F_{1,n-2}$ (α=0.05)	R	Populations in which $I^{qk}{}_i$ has a different dependence on $I^{Tk}{}_I$ than the rest of the methapopulation populations
$I^{q1}{}_i - I^{T11}{}_i$	8	0.7164	**15.156**	5.99	**0.846**	D1, D2, D12
$I^{q1}{}_i - I^{T12}{}_i$	11	0.8721	**61.371**	5.12	**0.934**	
$I^{q1}{}_i - I^{T13}{}_i$	10	0.8413	**42.408**	5.32	**0.917**	D2
$I^{q1}{}_i - I^{T14}{}_i$	9	0.7525	**21.280**	5.59	**0.867**	D4, D12
$I^{q1}{}_i - I^{T1}{}_i$	11	0.6939	**20.403**	5.12	**0.833**	
$I^{q2}{}_i - I^{T21}{}_i$	9	0.5329	**7.987**	5.59	**0.73**	D4, D5
$I^{q2}{}_i - I^{T22}{}_i$	6	0.78	**14.180**	7.71	**0.883**	D2, D5, D7, D9, D11
$I^{q2}{}_i - I^{T23}{}_i$	9	0.6423	**14.368**	5.59	**0.801**	D5, D7
$I^{q2}{}_i - I^{T24}{}_i$	9	0.615	**12.776**	5.59	**0.784**	D1, D7
$I^{q2}{}_i - I^{T2}{}_I$	9	0.7967	**31.352**	5.59	**0.893**	D5, D7
$I^{q3}{}_i - I^{T31}{}_i$	11	0.0407	0.378	5.12	0.201	
$I^{q3}{}_i - I^{T32}{}_i$	11	0.5468	**10.863**	5.12	**-0.739**	
$I^{q3}{}_i - I^{T33}{}_i$	5	0.8601	**18.444**	10.13	**0.927**	D2, D3, D4, D5, D9, D11
$I^{q3}{}_i - I^{T34}{}_i$	7	0.71	**12.240**	6.61	**-0.843**	D1, D2, D6, D7
$I^{q3}{}_i - I^{T3}{}_i$	9	0.5511	**8.596**	5.59	**-0.742**	D7, D12
$I^{q4}{}_i - I^{T41}{}_i$	9	0.7557	**21.651**	5.59	**0.869**	D4, D5
$I^{q4}{}_i - I^{T42}{}_i$	9	0.6198	**11.410**	5.59	**0.787**	D6, D7
$I^{q4}{}_i - I^{T43}{}_i$	8	0.7562	**18.612**	5.99	**0.870**	D2, D7, D11
$I^{q4}{}_i - I^{T44}{}_i$	9	0.8645	**44.660**	5.59	**0.930**	D5, D10
$I^{q4}{}_i - I^{T4}{}_i$	11	0.5881	**12.852**	5.12	**0.767**	
$I^{q5}{}_i - I^{T51}{}_i$	7	0.7141	**12.490**	6.61	**-0.845**	D1, D2, D4, D9
$I^{q5}{}_i - I^{T52}{}_i$	6	0.8533	**23.268**	7.71	**-0.924**	D1, D2, D7, D10, D12
$I^{q5}{}_i - I^{T53}{}_i$	7	0.9026	**37.068**	6.61	**-0.95**	D1, D6, D9, D11
$I^{q5}{}_i - I^{T54}{}_i$	11	0.059	0.567	5.12	-0.243	
$I^{q5}{}_i - I^{T5}{}_i$	7	0.7043	**11.910**	6.61	**-0.839**	D1, D10, D11, D12
$I^{q6}{}_i - I^{T61}{}_i$	10	0.6827	**17.216**	5.32	**0.826**	
$I^{q6}{}_i - I^{T62}{}_i$	7	0.6666	**9.995**	6.61	**0.816**	D2, D7, D9
$I^{q6}{}_i - I^{T63}{}_i$	7	0.6255	**8.350**	6.61	**-0.791**	D6, D9, D12
$I^{q6}{}_i - I^{T64}{}_i$	9	0.6676	**14.056**	5.59	**-0.817**	D7*
$I^{q6}{}_i - I^{T6(1+2)}{}_i$	9	0.5378	**8.148**	5.59	**0.733**	D2
$I^{q6}{}_i - I^{T6(3+4)}{}_i$	10	0.5148	**8.488**	5.32	**-0.717**	
$I^{q6}{}_i - I^{T6}{}_i$	10	0.0219	0.176	5.32	0.148	
$I^{q7}{}_i - I^{T71}{}_i$	6	0.8272	**19.148**	7.71	**-0.910**	D1, D2t, D7, D9, D12
$I^{q7}{}_i - I^{T72}{}_i$	7	0.7278	**13.370**	6.61	**0.853**	D2, D3, D6, D7
$I^{q7}{}_i - I^{T73}{}_i$	8	0.6729	**12.342**	5.99	**-0.820**	D2, D7, D11
$I^{q7}{}_i - I^{T74}{}_i$	7	0.7011	**11.730**	6.61	**0.837**	D2t, D3, D9, D12
$I^{q7}{}_i - {}^1I^{T7}{}_i$	5	0.9015	**27.456**	10.13	**0.949**	D2t, D3, D5, D6, D9, D12
$I^{q7}{}_i - {}^2I^{T7}{}_i$	6	0.7441	**11.632**	7.71	**-0.863**	D1, D2, D7, D10, D11

Table 3. United Temperature Influence Index ($I^{Tk}{}_i$) contributions on *D. antarctica* populations of G-population to the United Quality Latent Index of plant population adaptability ($I^{qk}{}_i$) 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 Table 3: $I^{qk}{}_i$ is a United Quality Latent Index of population adaptability (UQLI) and $I^{Tkl}{}_i$ is a United Temperature (the accumulated sums of the positive temperatures (T) on the soil surface) 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*-th 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*-th 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 $I^{Tk}{}_i$ respectivly, 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 opulation has been destroyed by penguins in the 2022/2023 season (k=6).

i	D_i	n	R^2	$F_{1,n-2}$	$F_{1,n-2}$ (α=0.05)	R
1	D_1(D1)	7	0.0695	0.375	6.61	0.264
2	D_2(D2)	7	0.2172	1.385	6.61	0.466
3	D_3(D3)	7	**0.7113**	12.320	6.61	**0.843**
4	D_4(D4)	5	**0.8852**	23.133	10.13	**0.941**
5	D_5(D5)	7	**0.864**	31.765	6.61	**0.930**
6	D_6(D6)	7	0.4844	4.695	6.61	0.696
7	D_7(D7)	7	**0.7053**	11.965	6.61	**0.840**
8	D_8(D9)	7	**0.7493**	14.945	6.61	**0.866**
9	D_9(D10)	7	**0.7095**	12.210	6.61	**0.842**
10	D_{10}(D11)	7	0.5384	5.830	6.61	0.734
11	D_{11}(D12)	7	**0.6803**	10.640	6.61	**0.825**

Table 4. Correlations between $I^{tk}{}_i$ and $I^{Tk}{}_i$ in dynamics 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) for *D. antarctica* populations: D1, D2, D3, D4, D5, D6, D7, D9, D10, D11, D12, Galindez Island, Argentine Islands.

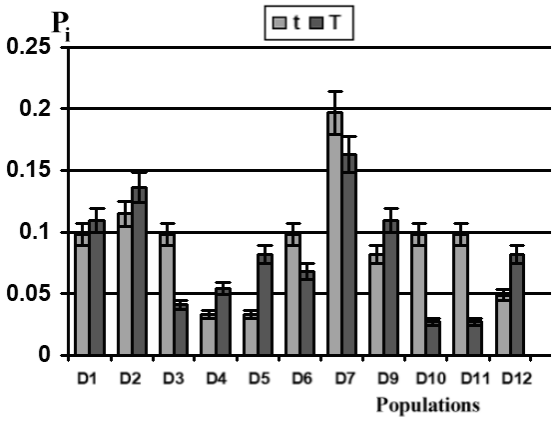

Fig. 6. The *D. antarctica* populations probability of matching into the asynchronous group (P_i) through seven seasons by average monthly temperature (t) and the accumulated sum of positive temperatures (T).

Discussion

This work is the second in a series of works under the same title, which takes into account spatial differences in biological and temperature variables of G-population populations in the dynamics of Antarctic summer seasons. Unlike the first work (Miryuta et al. 2025a), that investigated the temperature variable 'mean monthly temperature', the focus was on the temperature variable 'accumulated sum of positive temperatures' and its influence on the set of adaptability parameters of plant populations.

The curves of positive temperatures accumulation in the plant population locations changed from season to season (*see* Fig. 2). Therefore, we first resorted to the following analysis. There are several temperature indices which influence on some plants biological characteristics. As can be seen Fig. 3 and Table. 1 significant correlations between the dynamics of two thermal indices were observed in the populations locations D1 (80%), D2 (93%), D4 (97%), D7 (99%), D9 (99%), D10 (80%), D11 (85%) (Table 1). The remaining populations have significant differences for various reasons. In particular, in the populations' location D3 and D6, it was not possible to determine both thermal indices in three and two seasons, respectively, due to birds that covered the loggers during the nesting season. In localities D5 and D12, this could be due to differences in the length of certain seasons (for example, k=5, 6, 7) (Fig. 3e, k).

The spatio-temporal approach was due to the fact that temperature variables at the beginning of the summer season in the population locations differed more than at the season end due to different rates of snow melting (Tarca et al. 2021), which is often a consequence of differences in illumination (Savenets et al. 2026). The duration of snow cover varies greatly depending on the microrelief, which on Galindez Island plays a greater role than the distance to sea surfaces (Savenets et al. 2026, Table 2s, [2]). For example, according to the illumination data taken from the loggers, it can be said that in populations D5 and D12 the warm season k=5 was shorter due to early cooling and precipitation in the snow form in the second half of February, and seasons k=6, 7 were shorterdue to late snow melting in November. The populations biological adaptability indices respond differently to changes in both the average monthly temperature and the sum of accumulated positive temperatures, as well as to changes in other external factors during the season. The G-population adaptability index dynamics under such approach will look like the dynamics of changes in the response of each population to environmental change (Fig. 4, 5). This study started with the analysis of changes in the complex plant adaptability index of different populations I^q_i which reflects the reaction to both measured and latent indices of environmental influence on plants (Fig. 4).

The change in the I^{qk}_i sign occurs during the dynamics in all populations exept D11 and D12 as can be seen from Fig. 4 and Table 2. The reasons for the change in the I^{qk}_i sign in populations in the dynamics of the seasons may be associated with changes in both abiotic (temperature, humidity, salinity, soil composition, wind load, shading or openness to sunlight, *etc*.) and biotic (composition of the rhizosphere bacterial community and plant endophytes) factors (Bulgarelli et. al. 2013, Prekrasna et al. 2022, Miryuta et al. 2024). The above works considered both the temperature factors influence on rhizosphere bacterial communities and the relationships between bacterial communities and Antarctic hairgrass plants populations located on the corresponding sites. In particular the influence of plants on the bacterial communities composition and vice versa was shown. The temperatures the influence indices on bacterial communities and on plant populations

during the season k=1 did not correlate with each other. Regarding the bacterial communities influence on plant populations for the 9 studied sites it can be said that different indices of different plant populations z(t1) responded to the corresponding bacterial communities x(t) influence differently, which was reflected in the values of the complex indices $I^{1}{}_{i}$(z). Unfortunately, there is a great lack of work on the temperature factors influence dynamics on rhizosphere bacterial communities. We assumed that the quantitative composition of bacterial communities changes slowly and checked how spatial differences in temperature in seasons k=2, 3 affect spatial differences in the quantitative composition of bacterial communities in season k=1. Against the background of the greatest synchrony for all studied populations (positive correlation) of the indices $I^{1}{}_{i}$(x) with $I^{rb1}{}_{i}$(x), $I^{1}{}_{i}$(z) with $I^{rb1}{}_{i}$(z) and $I^{1}{}_{i}$(z) with $I^{q1}{}_{i}$ (z) in season k=1, in season k=2 exceptions to the general synchrony appeared both for the contributions of $I^{2}{}_{i}$ (z) to $I^{rb2}{}_{i}$(z) and $I^{2}{}_{i}$ (z) to $I^{q2}{}_{i}$(z) with a general positive correlation, and for the contributions of $I^{3}{}_{i}$ (z) to $I^{rb3}{}_{i}$(z) and $I^{3}{}_{i}$ (z) to $I^{q3}{}_{i}$(z) with a general negative correlation. These calculations led us to believe that there is an interaction between plant populations and bacterial communities possibly through signaling molecules in response to season soil surfacetemperature changes. In this work, we considered the influence on plant populations only the accumulated sums of positive temperatures and the remaining factors remained latent.

We used the accumulated sums of positive temperatures for each decade in the summer season with the curves constructed on it's basis in this work (Fig. 2). Spatial differences in these meteorological variables were determined for each decade and each season. They were compared with spatial differences in such adaptability indices as morphometric indices (Fig. 1s, 2s), relative content of protective and reserve seed proteins (Fig. 3s) and number of plants (Table 1s) for the studied populations. To calculate the $I^{qk}{}_{i}$ (Fig. 4), $I^{Tkl}{}_{i}$ (Fig. 5) indices, algorithms from the articles (Miryuta et al. 2019a, b) were used and biology data presented in the work (Miryuta et al. 2025a) also. Only the influence of temperature variables (accumulated sums of positive temperatures) on plant development was taken into account, the remaining influencing factors remained latent in this work.

The curves of the accumulated sums of positive temperatures differed in each of the seven seasons for 11 localities of plant population growth according to the data presented in Fig. 2. The data of both thermal indices had an oscillating character (Fig. 3). We did not analyze the intraseasonal dynamics of their changes over different seasons. Instead, we analyzed the influence of intraseasonal spatial changes in the accumulated sums of positive temperatures on spatial changes of various biological characteristics (Fig. 1s, 2s, 3s) in the form of the United Temperature Influence Indx each i-th population $I^{Tkl}{}_{i}$ (UTII) in interseasonal dynamics. In this form the influence of spatio-temporal changes in the accumulated sums of positive temperatures on the changes in biological characteristics is presented in Fig. 5. The seasonal dynamics in the $I^{Tkl}{}_{i}$ signs are presented in Table 2 from which it can be seen that the change in the $I^{Tkl}{}_{i}$ sign in some populations precede the changes in the $I^{qk}{}_{i}$ sign.

We noticed that against the background of positive contributions $I^{Tk}{}_{i}$ to $I^{qk}{}_{\mathrm{i}}$ in seasons k=1, 2, 4, negative contributions were observed in seasons k=3, 5. In season k=6, this contribution has a positive value for the first two months sum and a negative value for the sum of the third and fourth months. In season k=7, the G-population was divided into two groups: populations D1, D2, D7, D10, D11 belong to the group with $I^{Tk}{}_{i}$ to $I^{qk}{}_{\mathrm{i}}$ a positive contribution, and populations D2t, D3, D5, D6, D9, D12 belong to the group with a negative contribution (Table 3). It was shown that $I^{tk}{}_{i}$ contributions to $I^{qk}{}_{\mathrm{i}}$ were not always positive for individual months and decades. Negative

contributions were observed in season k=3, except for months l=1, 3, decades d=1, 2, 3, 9, as well as in some individual months and decades of season k=5, except for month l=4, and decades d=1, 2, 5, 11, k=6, except for months l=1, 2, and decades d=1, 2, 3, 4, 5, 6, 9, k=7, except for months l=2, 4, and decades d=1. 4, 5, 7, 11 (Table 2s). Perhaps, negative I^{Tk}_i to I^{qk}_i contributions were observed in those decades, months and seasons when plants worked on changing the rhizosphere bacteria composition.

Comparison of the complex indices of the both temperature variables influence on the plant populations adaptability indices (Fig. 5) showed a significant similarity of the I^{tk}_i and I^{Tk}_i for influence for D3, D4, D5, D7, D9, D10, D12 populations and a different influence for D1, D2, D6, D11 populations (Table 4). In addition, these series do not coincide with the series of matching into the asynchronous group by t and T where the populations D3, D6, D7, D10, D11 match into the first group more often, and D1, D2, D4, D5, D9, D12 into the second (Fig. 6).

Populations whith a different dependence than linear one I^{qk}_i on I^{Tk}_i unlike the rest of the G-population populations were abbreviated as 'asynchronous' as in the first part of this study (Miryuta et al.2025a). The probability of plant populations matching into the asynchronous group by the average monthly temperature (t) and the accumulated sums of positive temperatures (T) for all months of the season and all seasons over seven seasons is presented in Fig. 6.

The composition of asynchronous group, which did not match into the G-population populations by belonging to the linear function (synchrony), changed during the summer season months over the studed seven seasons. Population D7 most often matched into the asynchronous group by both indices I^{tk}_i and I^{Tk}_i (Fig. 6). It is interesting to note that the dynamics of the two studied thermal indices (T^{tk} and T^{Tk}) for this locality turned out to be similar with high reliability (0.988) (Table 1). This allows us to cautiously assume that the latent index may be humidity in the D7 case, since this population is located on the Krapliya Island shell and suffered from excessive humidity. The next most frequently matching into the asynchronous group was population D2, which suffered from delayed snow melting. The dynamics of the two studied thermal indices (T^{tk} and T^{Tk}) for this locality turned out to be similar with high reliability (0.925) (Table 1). It was found that the probability of matching into the asynchronous group according to the I^{tk}_i index is higher than that according to the I^{Tk}_i index in populations D3, D6, D7, D10 and D11. For the remaining populations, the situation is the opposite, D5 and D12 stand out in particular perhaps due to the striking difference in the thermal indices T^{tk} and T^{Tk} (Figs. 2, 6, Table 1). In general, it can be highlited that populations matching into the asynchronous group lag behind the entire G-population or are ahead of it in their development due to local conditions.

Conclusions

Eleven localities with the *D. antarctica* plant populations were studied simultaneously by meteorological (two thermal variables, with the priority of the accumulated sums of positive temperatures), morphometric, biochemical, and ecological methods during seven seasons 2017/18 – 2023/24. Based on these data, the united temperature (accumulated sums of positive temperatures) influence index on plants (I^{Tkl}_i) and the united quality latent index (I^{qk}_i) were calculated. The contributions of I^{Tkl}_i to I^{qk}_i were calculated and analyzed during seven seasons. This allowed us to find out that the populations of the G-population develop unevenly depending on microconditions. In

particular, individual populations with different frequencies converged into an asynchronous group, the populations of which did not coincide with the general trend of development of the rest of the G-population. It also turned out that the contributions of $I^{Tkl}{}_i$ to $I^{qk}{}_i$ are not always positive. Negative contributions were observed in seasons k=3, 5. In season k=6 this contribution has a positive value for the sum of the first two months and a negative value for the two months at the end of the season. In season k=7 the G-population was divided into two groups: populations D1, D2, D7, D10, D11 belong to the group with a positive contribution $I^{Tkl}{}_i$ to $I^{qk}{}_i$, and populations D2t, D3, D5, D6, D9, D12 belong to the group with a negative contribution k=5, 6, 7. Comparison of the complex indices of the both temperature variables influence on the plant populations adaptability indices showed a significant similarity of the $I^{tk}{}_i$ and $I^{Tk}{}_i$ for influence for D3, D4, D5, D7, D9, D10, D12 populations and a different influence for D1, D2, D6, D11 populations. In addition, these series do not coincide with the series of matching into the asynchronous group by t and T where the populations D3, D6, D7, D10, D11 match into the first group more often, and D1, D2, D4, D5, D9, D12 into the second. This means that it makes sense to study the influence of both temperature variables on the plant populations adaptability indices in order to obtain more information about the each population plants.

The *Deschampsia antarctica* population on Galindez Island (G-population) is quite heterogeneous in terms of the existence conditions of individual populations. The individual plant populations reaction to the global warming process is also different. The snow melting process acceleration led to the drying of plants in those localities where they previously had enough moisture. The plants recovered in populations that previously suffered from excessive moisture (D2, D7). The growth penguin population as a evident cosiquense of global warming led to their Galindez Island occupation for nesting. As a result, two populations first transfered through the chaotic attractor state in 2021 (D4) and 2024 (D6) (Miryuta et al. 2025b) and were finally destroyed by penguins in 2023 and 2026, respectively. Regarding the plants populations future fate on Gadindez Island we think that they will continue to respond to changes in external conditions both local and global in an individual way that is, heterogeneously.

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Web sources / Other sources

[1] ScionImage
http://scion-image.software.informer.com/4.0/

[2] absence of steady snow cover
https://uaj.uac.gov.ua/index.php/uaj/article/view/843/712

Supplementary Materials

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)	65.244780 S, 64.255800 W, coastal rocks at Marina Point * near the meteorological station – Meteo Point (*Deschampsia antarctica* 0.5%, mosses 0.5-40%: *Sanionia georgicouncinata* (Müll.Hal.) Ochyra & Hedenäs**, *Bryum pseudotriquetrum* (Hedw.) G.Gaertn., B.Mey. & Scherb., *Pohlia nutans* (Hedw.) Lindb., *Polytrichum strictum* Brid., *Warnstorfia fontinaliopsis* (Müll.Hal.) Ochyra, gravel, 4 m a.s.l.)	99	155	80	66	78	89	67
2	D_2 (D2)	65.245642 S, 64.257253 W, Marina Point, near the main station building (*D. antarctica* 25%, mosses 65%: *Pohlia nutans*, *Sanionia georgicouncinata, Bryum pseudotriquetrum, Syntrichia magellanica* (Mont.) R.H.Zander, gravel, 12 m a.s.l.)	124	330	127	164	40	40	12
3	D_3 (D3)	65.247500 S, 64.241200 W, Leopard Tower, Penguin Point (northern coast, limited guano input from the nearest penguin colony, *D. antarctica* 4–19%, *Prasiola crispa* (Lightf.) Kütz. 1%, gravel, 7 m a.s.l.)	106	110	57	121	159	155	70
4	D_4 (D4)	65.248600 S, 64.238230 W, Korabel Rock, Penguin Point (eastern coast, limited guano input from the nearest penguin colony, *D. antarctica* 5%, mosses <1%: *Bryum pseudotriquetrum, Synrichia magellanica*, *Prasiola crispa* <1%, limpet shells and gravel, 10 m a.s.l.)	80	66	49	26	18	0	0
5	D_5 (D5)	65.248260 S, 64.245240 W, the upper terrace of the Hovorukha Dome under the Anna Hill (Woozle Hill top) (no visible guano input, *D. antarctica* 5%, mosses 45%: *Sanionia georgicouncinata, Andreaea regularis* Müll. Hal. *Polytrichum strictum,* gravel, 45 m a.s.l.)	91	44	38	44	54	65	38
6	D_6 (D6)	65.247990 S, 64.242720 W, near the *Colobanthus quitensis* (Kunth) Bartl. population, Roztochchia Ridge (*D. antarctica* 3%, mosses 47–57%: *Brachythecium austrosalebrosum* (Müll. Hal.) Kindb., *B. austroglareosum* (Müll. Hal.) Kindb., *Sanionia georgicouncinata, Bryum pseudotriquetrum, Syntrichia magellanica, Pohlia cruda* (Hedw.) Lindb., *Bartramia patens* Brid., gravel, 15 m a.s.l.)	161	57	19	45	71	58	17

7	D_7 (D7)	65.247017 S, 64.243167 W, on the Krapla Rock (*D. antarctica* 1-30%, mosses <1%: *Brachythecium austrosale-brosum*, *Bryum pseudotriquetrum, Sanionia georgicouncinata, Syntrichia magellanica,* gravel, limpets, 3 m a.s.l.)	500	418	382	275	530	850	506
8	D_8 (D9)	65.245467 S,.249867 W, on the rocky shore of the Shyia Ridge behind the large magnetic pavilion (*D. antarctica* 1–10%, mosses & liverworts 9–10%: *Syntrichia magellanica, Sanionia georgicouncinata, Pohlia nutans, Schistidium antarctici* (Cardot) L. Savicz & Smirnova*, Ceratodon purpureus* (Hedw.) Brid.*, Polytrichastum alpinum* (Hedw.) G.L.Sm., *Pohlia cruda, Andreaea regularis, Orthogrimmia sessitana* (De Not.) Ochyra & Żarnowiec, *Barbilophozia hatcheri* (A. Evans) Loeske*,* gravel, 14 m a.s.l.)	547	1376	455	493	750	510	123
9	D_9 (D10)	65.245008 S, 64.253205 W, on Magnit Point of the coastal rock (*D. antarctica* 4–24%, mosses 1%: *Sanionia georgicouncinata, Bryum pseudotriquetrum, Syntrichia magellanica*, limpet shells, 3 m a.s.l.)	256	615	245	216	413	120	8
10	D_{10} (D11)	65.246170 S, 64.248250 W, on the Cemetery Ridge near the pavilion of Very Low Frequencies (*D. antarctica* 4–30%, mosses 1–10%: *Polytrichastum alpinum, Pohlia nutans, Pohlia cruda, Sanionia georgicouncinata*, *Syntrichia magellanica, Ceratodon purpureus, Bucklandiella sudetica* (Hurv.) Bednarek-Ochyra & Ochyra*, Bryum pseudotriquetrum, Andreaea regularis*, limpets, gravel, 17 m a.s.l.)	242	687	281	264	768	717	33
11	D_{11} (D12)	65.247450 S, 64.252740 W, on the Gull Tower slopes on Stella Point (*D. antarctica* 1–40%, mosses 4–10%: *Sanionia georgicouncinata*, *Pohlia nutans, Pohlia cruda, Polytrichum strictum, Bucklandiella sudetica, Syntrichia magel-lanica, Andreaea regularis, Orthogrimmia sessitana, Ceratodon purpureus, Hymenoloma crispulum* (Hedw.) Ochyra*,* gravel and limpet shells, 10 m a.s.l.)	300	563	283	241	440	884	352

Table 1s. Localization and plant number (S_i) *D. antarctica* populations, Galindez Island, Argentine Islands, seasons 2017/18 – 2023/24 (cited by Miryuta et al. 2025b). *Note:* * – The local toponyms are provided according to Yevchun et al. (2021). ** – The species are provided according to Ochyra et al. (2008). The voucher bryophyte collections cited in this account are stored in the bryophyte section of the herbarium in the W. Szafer Institute of Botany, Polish Academy of Sciences, in Kraków (KRAM).

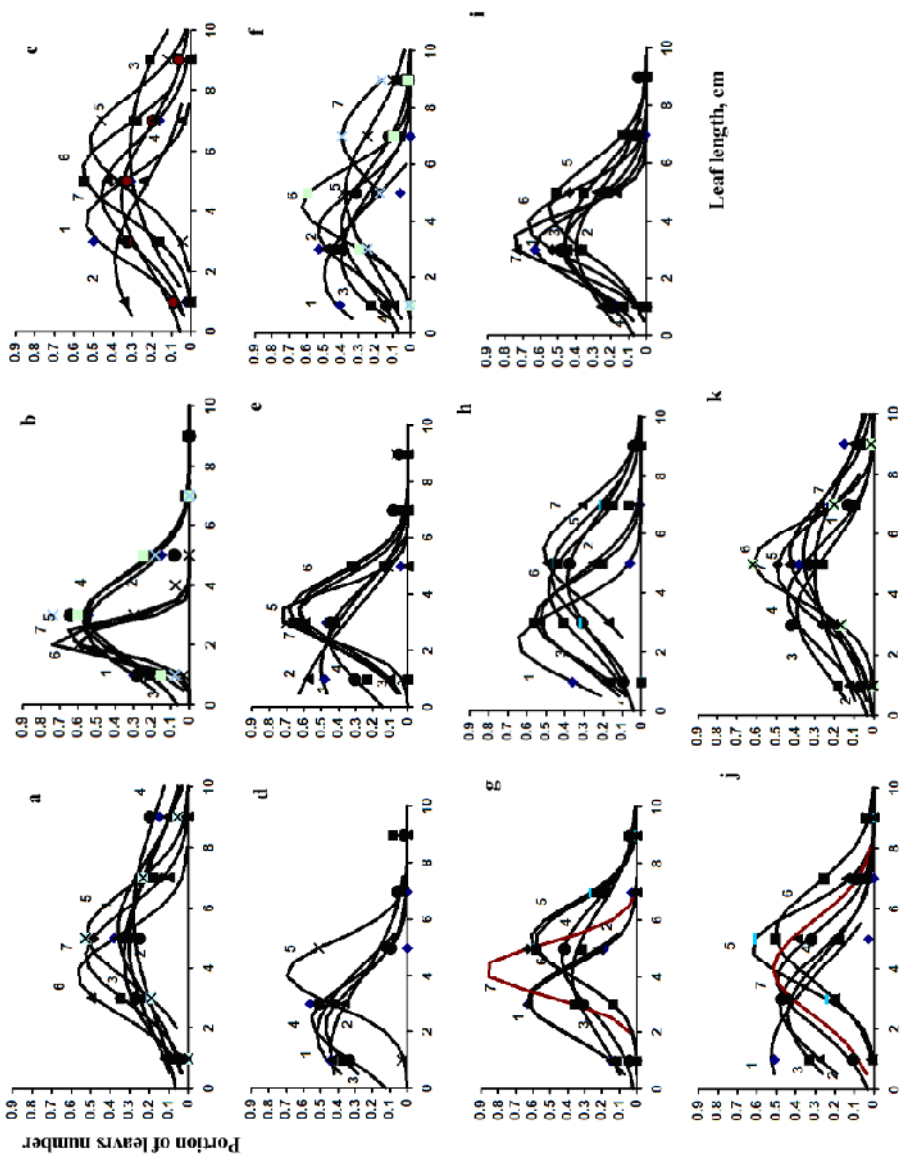

Fig. 1s. Density functions of a leaf length of *D. antarctica* plants from populations: *a* - D1, *b* - D2, *c* - D3, *d* - D4, *e* - D5, *f* - D6, *g* - D7, *h* - D9, *i* - D10, *j* - D11, *k* - D12 (Gaussian model), Galindez Island, Argentine Islands, in seasons 2017/2018 (1), 2018/2019 (2), 2019/2020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

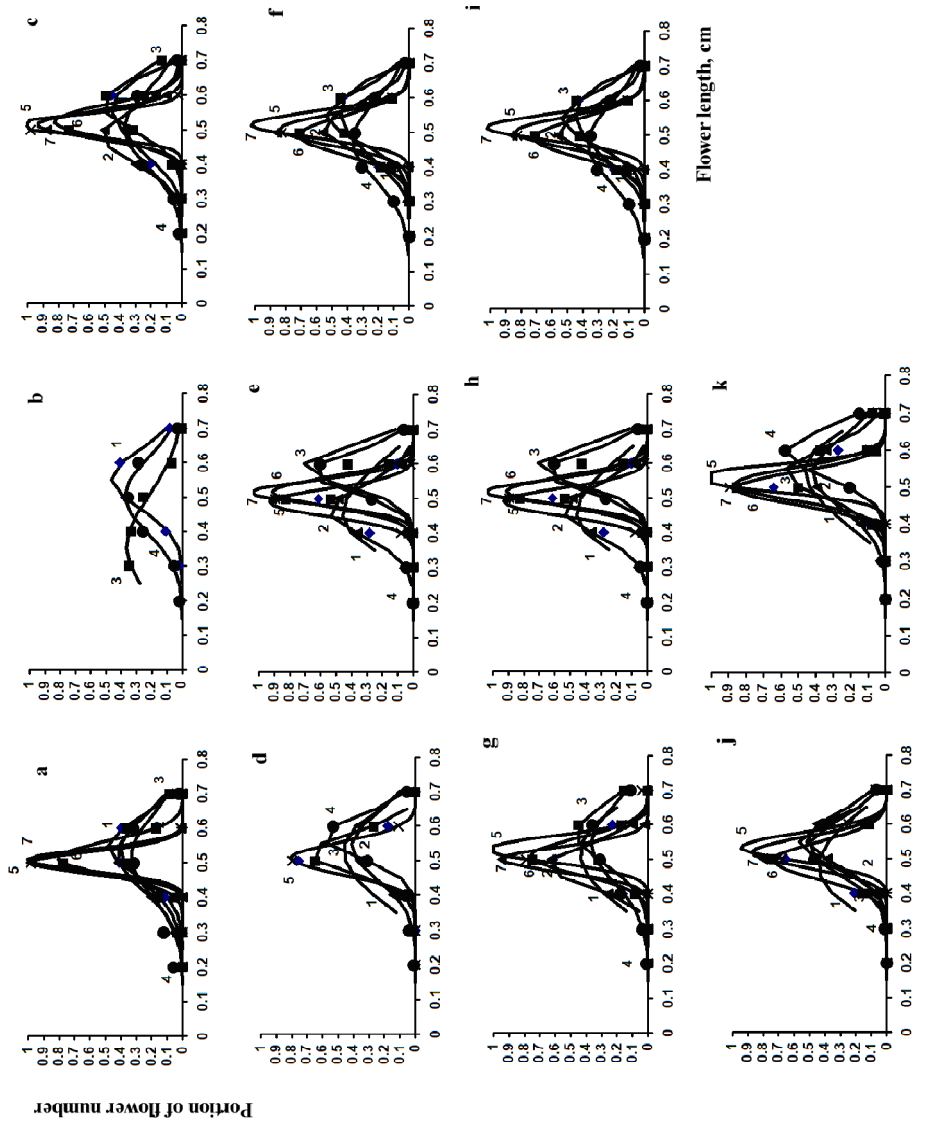

Fig. 2s. Density functions of a flower length of *D. antarctica* plants from populations: *a* - D1, *b* - D2, *c* - D3, *d* - D4, *e* - D5, *f* - D6, *g* - D7, *h* - D9, *i* - D10, *j* - D11, *k* - D12 (Gaussian model), Galindez Island, Argentine Islands, in seasons 2017/2018 (1), 2018/2019 (2), 2019/2020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

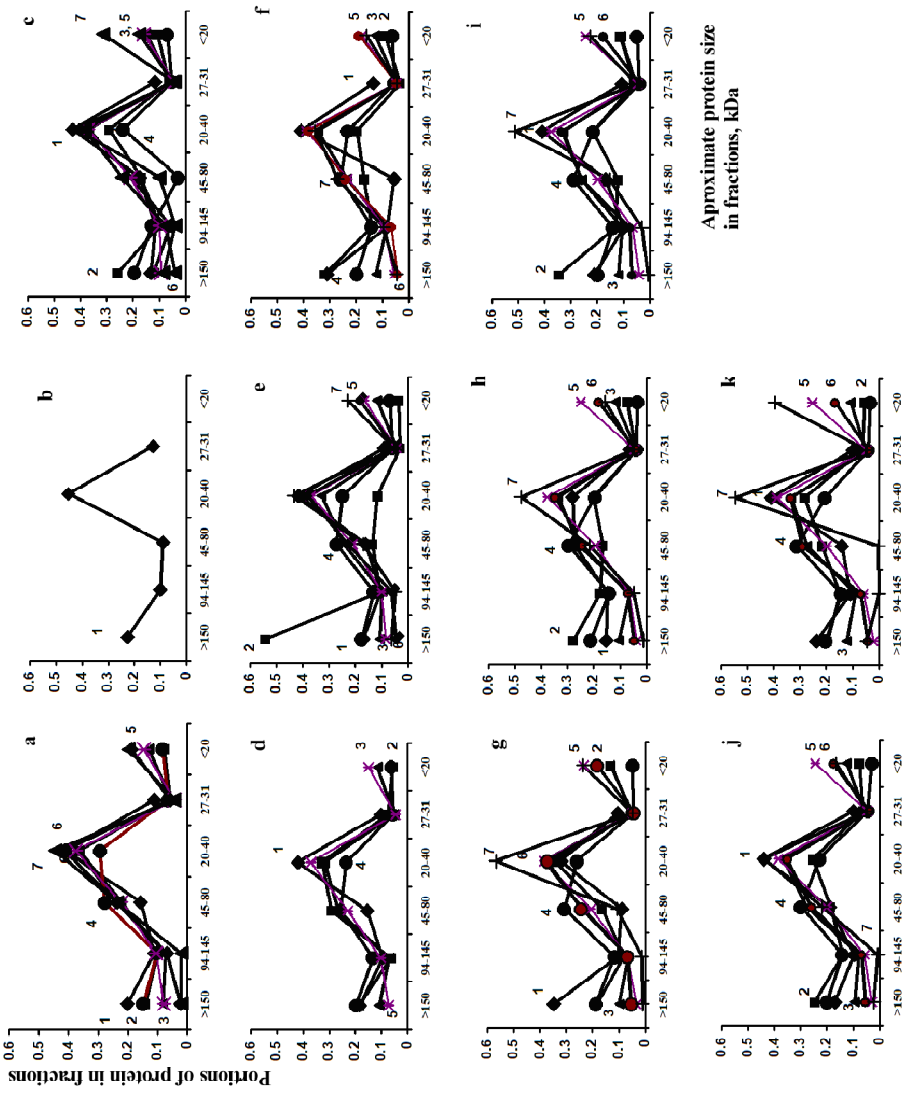

Fig. 3s. The values of the different protein fractions portions in *D. antarctica* seeds from populations: *a* - D1, *b* - D2, *c* - D3, *d* - D4, *e* - D5, *f* - D6, *g* - D7, *h* - D9, *i* - D10, *j* - D11, *k* - D12, Galindez Island, Argentine Islands, seasons 2017/2018 (1), 2018/2019 (2), 2019/2020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

Season	Pairs of indices sets	n	R^2	R	$F_{1,n-2}$	$F_{1,n-2}$ (α=0.05)	*d*	Populations in which $I^{qk}{}_i$ has a different dependence on $I^{Tk}{}_i$, than the G-population rest
1	2	3	4	5	6	7	8	9
2017/18	$I^{q1}{}_i - I^{T111}{}_i$	11	0.4888	**-0.699**	8.604	5.12	1	
	$I^{q1}{}_i - I^{T112}{}_i$	10	0.5863	**0.766**	11.336	5.32	2	D1
	$I^{q1}{}_i - I^{T113}{}_i$	10	0.8413	**0.917**	42.408	5.32	3	D2
	$I^{q1}{}_i - I^{T121}{}_i$	11	0.8188	**0.905**	40.671	5.12	4	
	$I^{q1}{}_i - I^{T122}{}_i$	11	0.8142	**0.902**	39.438	5.12	5	
	$I^{q1}{}_i - I^{T123}{}_i$	11	0.8334	**0.913**	45.018	5.12	6	
	$I^{q1}{}_i - I^{T131}{}_i$	11	0.6641	**0.815**	17.793	5.12	7	
	$I^{q1}{}_i - I^{T132}{}_i$	10	0.7088	**0.842**	21.906	5.32	8	D5
	$I^{q1}{}_i - I^{T133}{}_i$	10	0.7013	**0.837**	18.784	5.32	9	D5
	$I^{q1}{}_i - I^{T141}{}_I$	8	0.6089	**0.78**	9.342	5.99	10	D4, D5, D11
	$I^{q1}{}_i - I^{T142}{}_i$	8	0.6081	**0.779**	9.312	5.99	11	D5, D7, D12
	$I^{q1}{}_i - I^{T143}{}_i$	10	0.7482	**0.865**	23.768	5.32	12	D1
2018/19	$I^{q2}{}_i - I^{T211}{}_i$	9	0.6713	**0.819**	14.280	5.59	1	D4, D5
	$I^{q2}{}_i - I^{T212}{}_i$	7	0.9326	**0.966**	69.185	6.61	2	D4, D5, D11, D12
	$I^{q2}{}_i - I^{T213}{}_i$	11	0.00002	0.0044	0	5.12	3	
	$I^{q2}{}_i - I^{T221}{}_i$	11	0.0025	0.22	0.027	5.12	4	
	$I^{q2}{}_i - I^{T222}{}_i$	5	0.8751	**0.935**	21.018	10.13	5	D2, D4, D5, D6, D7, D11
	$I^{q2}{}_i - I^{T223}{}_i$	6	0.7655	**0.875**	13.056	7.71	6	D2, D5, D7, D10, D11
	$I^{q2}{}_i - I^{T231}{}_i$	9	0.5372	**0.733**	8.127	5.59	7	D1, D7
	$I^{q2}{}_i - I^{T232}{}_i$	7	0.7792	**0.883**	17.645	6.61	8	D1, D2, D5, D7
	$I^{q2}{}_i - I^{T233}{}_i$	9	0.7695	**0.877**	23.366	5.59	9	D5, D7
	$I^{q2}{}_i - I^{T241}{}_I$	8	0.532	**0.729**	6.822	5.99	10	D2, D5, D7
	$I^{q2}{}_i - I^{T242}{}_i$	6	0.7809	**0.884**	14.256	7.71	11	D4, D7, D9, D11, D12
	$I^{q}{}_i - I^{T243}{}_i$	8	0.5645	**0.751**	7.776	5.99	12	D1, D3, D7
2019/20	$I^{q3}{}_i - I^{T311}{}_i$	11	0.059	0.24	0.567	5.12	1	
	$I^{q3}{}_i - I^{T312}{}_i$	7	0.6458	**0.804**	9.115	6.61	2	D1, D3, D7, D10
	$I^{q3}{}_i - I^{T313}{}_i$	5	0.7772	**0.882**	10.464	10.13	3	D2, D3, D5, D6, D7, D10
	$I^{q3}{}_i - I^{T321}{}_i$	9	0.6604	**-0.813**	13.615	5.59	4	D3, D7
	$I^{q3}{}_i - I^{T322}{}_i$	11	0.5036	**-0.71**	9.135	5.12	5	
2019/20	$I^{q3}{}_i - I^{T323}{}_i$	11	0.573	**-0.757**	12.078	5.12	6	
	$I^{q3}{}_i - I^{T331}{}_i$	8	0.8428	**-0.918**	32.166	5.99	7	D2, D7, D12
	$I^{q3}{}_i - I^{T332}{}_i$	7	0.7116	**-0.844**	12.335	6.61	8	D1, D2, D6, D7
	$I^{q3}{}_i - I^{T333}{}_i$	8	0.7729	**0.879**	20.418	5.99	9	D2, D3, D11
	$I^{q3}{}_i - I^{T341}{}_I$	8	0.6475	**-0.805**	11.022	5.99	10	D1, D2, D7
	$I^{q3}{}_i - I^{T342}{}_i$	8	0.7974	**-0.893**	19.680	5.99	11	D1, D6, D7
	$I^{q3}{}_i - I^{T343}{}_i$	8	0.6225	**-0.789**	9.894	5.99	12	D2, D11, D12
2020/21	$I^{q4}{}_i - I^{T411}{}_i$	9	0.8396	**0.916**	36.638	5.59	1	D4, D5
	$I^{q4}{}_i - I^{T412}{}_i$	9	0.76	**0.873**	22.169	5.59	2	D4, D5
	$I^{q4}{}_i - I^{T413}{}_i$	8	0.6914	**0.832**	13.440	5.99	3	D1, D6, D9 (D10*)
	$I^{q4}{}_i - I^{T421}{}_i$	8	0.7907	**0.889**	22.668	5.99	4	D6, D7 (D10*)
	$I^{q4}{}_i - I^{T422}{}_i$	7	0.6186	**0.787**	8.110	6.61	5	D3, D6, D7 (D10*)
	$I^{q4}{}_i - I^{T423}{}_i$	9	0.7203	**0.849**	18.025	5.59	6	D7
	$I^{q4}{}_i - I^{T431}{}_i$	10	0.6869	**0.829**	17.552	5.32	7	D7
	$I^{q4}{}_i - I^{T432}{}_i$	9	0.6614	**0.813**	13.671	5.59	8	D7, D10
	$I^{q4}{}_i - I^{T433}{}_i$	7	0.7793	**0.883**	17.655	6.61	9	D2, D4, D7, D11
	$I^{q4}{}_i - I^{T441}{}_I$	9	0.8085	**0.899**	29.554	5.59	10	D5, D10
	$I^{q4}{}_i - I^{T442}{}_i$	9	0.6996	**0.836**	16.303	5.59	11	D1, D10

	$I^{q45}{}_i - I^{T443}{}_i$	8	0.6954	**0.834**	13.698	5.99	12	D3, D9, D11
2021/22	$I^{q5}{}_i - I^{T511}{}_i$	6	0.8808	**0.94**	29.556	7.71	1	D3, D4, D5, D6, D7
	$I^{q5}{}_i - I^{T512}{}_i$	6	0.8762	**-0.94**	28.312	7.71	2	D1, D4, D5, D11, D12
	$I^{q5}{}_i - I^{T513}{}_i$	6	0.8762	**-0.94**	28.312	7.71	3	D1, D4, D5, D11, D12
	$I^{q5}{}_i - I^{T521}{}_i$	10	0.0532	-0.23	0.448	5.32	4	D4*
	$I^{q5}{}_i - I^{T522}{}_i$	9	0.03	0.17	0.217	5.59	5	D3*, D4*
	$I^{q5}{}_i - I^{T523}{}_i$	11	0.2001	-0.45	2.250	5.12	6	
	$I^{q5}{}_i - I^{T531}{}_i$	7	0.8392	**-0.92**	26.095	6.61	7	D1, D6, D10, D11
	$I^{q5}{}_i - I^{T532}{}_i$	8	0.7403	**-0.86**	17.106	5.99	8	D1, D6, D11
	$I^{q5}{}_i - I^{T533}{}_i$	8	0.664	**-0.81**	11.856	5.99	9	D1, D3, D4
	$I^{q5}{}_i - I^{T541}{}_I$	6	0.6662	**-0.82**	7.984	7.71	10	D1, D2, D6, D9 D10
	$I^{q5}{}_i - I^{T542}{}_i$	6	0.8634	**0.93**	25.284	7.71	11	D1, D5, D6, D9, D10
	$I^{q5}{}_i - I^{T543}{}_i$	9	0.6022	**-0.78**	10.598	5.59	12	D1, D9
2022/23	$I^{q6}{}_i - I^{T611}{}_i$	9	**0.7807**	**0.884**	24.920	5.59	1	D6
	$I^{q6}{}_i - I^{T612}{}_i$	9	**0.5307**	**0.728**	7.917	5.59	2	D9
	$I^{q6}{}_i - I^{T613}{}_i$	7	**0.6212**	**0.788**	8.200	6.61	3	D3, D5, D10
	$I^{q6}{}_i - I^{T621}{}_i$	5	**0.8121**	**0.901**	12.966	10.13	4	D1, D3, D10, D11, D12
	$I^{q6}{}_i - I^{T622}{}_i$	10	0.0068	0.082	0.056	5.32	5	
	$I^{q6}{}_i - I^{T623}{}_i$	7	**0.7046**	**0.839**	11.925	6.61	6	D2, D7, D9
	$I^{q6}{}_i - I^{T631}{}_i$	5	**0.9494**	**-0.974**	56.289	10.13	7	D2, D3, D10, D11, D12
	$I^{q6}{}_i - I^{T632}{}_i$	7	**0.685**	**-0.828**	10.875	6.61	8	D3, D7, D10
	$I^{q6}{}_i - I^{T633}{}_i$	10	0.0079	0.089	0.064	5.32	9	
	$I^{q6}{}_i - I^{T641}{}_I$	7	**0.7162**	**-0.847**	12.620	6.61	10	D3, D5, D7*
	$I^{q6}{}_i - I^{T642}{}_i$	6	**0.8969**	**-0.947**	27.276	7.71	11	D6, D7*, D10, D12
	$I^{q6}{}_i - I^{T643}{}_i$	7	**0.6875**	**-0.829**	11.000	6.61	12	D7*, D10, D11
2023/24	$I^{q7}{}_i - I^{T711}{}_i$	**					1	
	$I^{q7}{}_i - I^{T712}{}_i$	6	**0.8566**	**-0.926**	23.896	7.71	2	D1, D2, D2t, D7, D12
	$I^{q7}{}_i - I^{T713}{}_i$	7	**0.8812**	**-0.939**	37.09	6.61	3	D1, D3, D7, D12
	$I^{q7}{}_i - I^{T721}{}_i$	7	**0.9446**	**0.972**	85.255	6.61	4	D3, D6, D7, D12
	$I^{q7}{}_i - I^{T722}{}_i$	8	**0.5205**	**0.721**	6.615	5.99	5	D5, D9, D12
	$I^{q7}{}_i - {}^1I^{T723}{}_i$	6	**0.8732**	**0.934**	27.544	7.71	6	D1, D2t, D3, D5, D12
	$I^{q7}{}_i - {}^2I^{T723}{}_i$	5	**0.8264**	**-0.909**	14.280	10.13	6	D2, D6t, D7, D9, D10, D11
	$I^{q7}{}_i - I^{T731}{}_i$	9	**0.8621**	**0.928**	43.764	5.59	7	D2, D5
	$I^{q7}{}_i - {}^1I^{T732}{}_i$	4	**0.9327**	**-0.966**	27.722	18.51	8	**D1, D5, D10**, D2, D7, D9, D11
	$I^{q7}{}_i - {}^2I^{T732}{}_i$	4	**0.9991**	**0.999**	2220.222	18.51	8	**D1, D5, D10**, D2t, D3, D6, D12
	$I^{q7}{}_i - {}^1I^{T733}{}_i$	6	**0.9182**	**-0.986**	44.9	7.71	9	D1, D2, D7, D9, D11
	$I^{q7}{}_i - {}^2I^{T733}{}_i$	5	**0.8668**	**0.931**	19.524	10.13	9	D2t, D3, D5, D6, D10, D12
	$I^{q7}{}_i - I^{T741}{}_I$	6	**0.6824**	**-0.826**	8.596	7.71	10	D1, D7, D9, D10, D11
	$I^{q7}{}_i - I^{T742}{}_i$	9	**0.6195**	**0.787**	11.396	5.59	11	D3, D9
	$I^{q7}{}_i - {}^1I^{T643}{}_i$	5	**0.9858**	**-0.993**	208.17	10.13	12	**D1**, D5, D7, D9, D10, D11
	$I^{q7}{}_i - {}^2I^{T643}{}_i$	5	**0.8851**	**0.941**	23.109	10.13	12	**D1**, D2, D2r, D3, D6, D12

Table 2s. Contributions of the United Temperatures Influence Index on plant adaptability indices (UTII$^+$ or $I^{Tk}{}_i$) to the United Quality Latent Index of *D. antarctica* populations adaptability (UQLI or $I^q{}_i$) of Galindez Island, Argentine Islands. *Notes*: $I^{qk}{}_i$ is United Quality Latent Index of population adaptability, $I^{Tkl}{}_i$ is United Temperatures Influence Index on plant adaptability indices, T is soil surface positive temperatures accumulated sum; *i* is the population number in the G-population, *k* is the summer season number, *l* is the month number in the summer season, $I_i^{Tk} = \frac{1}{m}\sum_{l=1}^{m} I_i^{Tkl}$ where *m* is the number of those $I^{Tkl}{}_i$ values that gave a significant contribution to $I^{qk}{}_I$, $I^{Tk}{}_i$ is the average value of

United Temperatures Influence Index on the plant adaptability indices in summer season, *d* is the decade number in the summer season, $I_i^{Tk} = \frac{1}{p}\sum_{d=1}^{p} I_i^{Tkld}$, where *p* is the number of those $I^{Tkld}{}_i$, values that gave a significant contribution to $I^{qkl}{}_i$, *n* – the number of studied populations that have a significant correlation coefficient between $I^{qk}{}_i$ and $I^{Tkl}{}_i$ or $I^{Tk}{}_i$, respectively, R^2 – the square of the correlation coefficient, $F_{1,n-2}$ – the test value, $F_{1,n-2}$ (α=0.05) – the top 5 % of the F-distribution limit, R is the correlation coefficient equivalent to the contribution of the corresponding influence index to $I^{qk}{}_i$.
$^1I^{Tkld}{}_i$ is the value of the United impact index of the positive temperatures accumulation of on the population adaptability indices for the season decade, which belong to the synchronous group, which gives a negative contribution to $I^{qk}{}_i$;
$^2I^{Tkld}{}_i$ is the value of the United impact index of the positive temperatures accumulation of on the population adaptability indices for the season decade, which belong to the synchronous group, which gives a positive contribution to $I^{qk}{}_i$;
Populations marked in bold in column 9 belong to the asynchronous group.
* populations for which data from temperature sensors were lost in the corresponding month (most often this happens in December, during the bird nesting season), and therefore they are removed from the analysis
** missing data due to later snowmelt.
populations for which data from temperature sensors were lost in the corresponding month (most often this happens in December, during the bird nesting season), and therefore they are removed from the analysis.