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ANTARCTIC HERB TUNDRA COLONIZATION ZONES IN THE CONTEXT OF ECOLOGICAL GRADIENT OF GLACIAL RETREAT

Key words: Antarctic herb tundra formation, colonization zones, King George Island

Inroduction

Only 2 species of vascular plants can be found in the native recent flora of the Maritime Antarctic: *Deschampsia antarctica* Desv. (Poaceae) and *Colobanthus quitensis* (Kunth) Bartl. (Caryophyllaceae) [9]. Both species form the following associations of Antarctic herb tundra formation: *Deschampsia antarctica-Colobanthus quitensis*, *Deschampsia antarctica* and *Deschampsia antarctica-Polytrichum piliferum* [11, 13, 14]. Mosses (Bryophyta) are a significant part of the latter association. Usually lichens are not included in Antarctic herb tundra formation, they are considered to form separate associations [11, 13]. Island glaciers continue to melt and new territories are released from ice in the consequence of warming in Maritime Antarctic [12]. Glacier expansions, which alternated by warming periods, are known to have occurred in Antarctic since Pliocene [7]. Glacial areas altered periodically during Quaternary climate fluctuations [20] reducing or expanding areas available for vegetation. Present retreat of the Ecology glacier in the environs of the H. Arctowski Polish Antarctic Station (King George Island, South Shetland Archipelago) forms an environmental gradient from the edge of the glacier to the ocean coast. Thus, studying the peculiarities of Antarctic herb tundra formation in this gradient became the goal of the current investigation. We tried to elucidate vegetation colonization zones in the direction from the ocean coast to the edge of the glacier.

Methods

Study area

During the 30-th Polish and the 10-th Ukrainian expeditions (09.11.2005—09.02.2006) nine stationary study plots (Fig. 1) were established near the Polish Antarctic H. Arctowski Station at the King George Island of South Shetland Islands. The coordinates of the plots were determined using portative GPS.

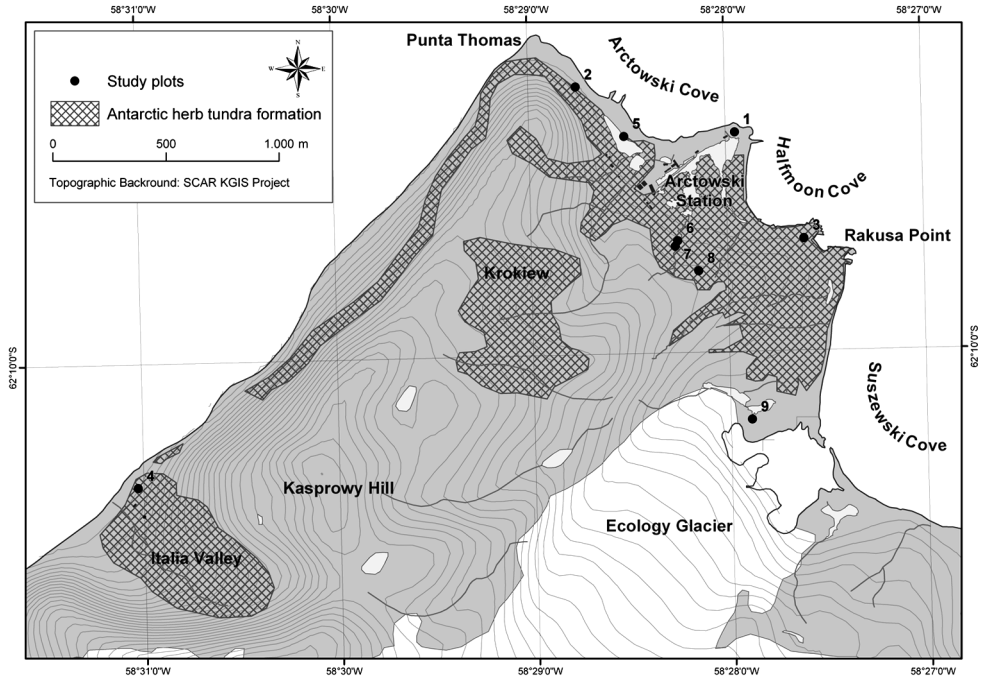

Fig. 1. General distribution of Antarctic herb tundra formation and research sites in the environs of Arctowski Station, King George's Island, South Shetland Islands (our own data in consideration of data from de Carvalho et al. [5])

As a criterion to select a plot we used presence of at least one species of vascular plants that determine the Antarctic herb tundra formation. The plots were established at different distances between the glacier and coastal zone in order to cover the whole gradient of environmental conditions on the ice-free area. The survey did not cover the bottom of the central hollow (so-called Krokiew, Fig. 1), which was not accessible during the investigation.

All plots are briefly described in Table 1.

Study approach

The size of the plots varied from 9 m2 (1, 4, 5, 8, 9) to 4 m2 (2, 3) to 1 m2 (6, 7) due to the relief specifics. Phytocenological relevees were made for each site and its environs. Species diversity for Bryophyta (mosses and liverworts) and macrophyte alga was also studied. The samples of mosses and liverworts were identified using standard methods and specific identification keys [2, 15, 17]. Individual cover was noted for every species of vascular plants at the plots. The age structures of both vascular plants' populations were determined according to the scheme shown in Figures 2, 3.

An satellite photo of the area of the Arctowski Station and a topographic map at a scale of 1:12.500 by R. Pudelko [16] were used for the analysis of relief,

Table 1. **Main characteristics of the studying plots**

Site	GPS coordinates and higher under sear level	Inclination, °	Distance to shore, m	Material	Exposition	Short description
1	S 62°09.480′ W 58°27.953′ 2 m a.s.l.	5	20	rock	east	4 m distance to a Wujka freshwater lake; the rock has a flat cavity towards the sea; Mosaic bird guano supply
2	S 62°09.366′ W 58°28.757′ 4 m a.s.l.	5-10	14	rock	east	On the rock between the oil tank and freshwater lake mountain relief; Mosaic bird guano supply
3	S 62°09.734′ W 58°27.611′ 6 m a.s.l.	5	7	rock	west	In the hollow of Rakusa Point rocks; large supply of penguin colony guano
4	S 62°04.984′, W 58°23.490′ 10 m a.s.l.	5	150	rock	north	On Italia Valley at the bottom of a mountain slope; Mosaic bird guano supply
5	S 62°09.485′, W 58°28.516′ 1 m a.s.l.	—	13	gravel	—	On the eastern flat part of the coast, under the rock, near a fresh water lake; when melt waters rise the site turns into an island; Mosaic bird guano supply
6	S 62°09.735′, W 58°28.253′ 20 m a.s.l.	5-10	350	gravel	north-east	On a slope a glacial melt water stream flows through the slope; Mosaic bird guano supply
7	S 62°09.748′, W 58°28.267′ 21 m a.s.l.	5-10	350	gravel	north-east	On a slope, and a glacial meltwater stream flowing through the slope; Mosaic bird guano supply
8	S 62 ° 09.807′, W 58°28.15′ 50 m a.s.l.	5	350	rock	eastern	Near the Puchalski memorial, on the edge of a mountain slope; Mosaic bird guano supply
9	S 62°10.161′, W 58°27.893′ 10 m a.s.l.	—	360	gravel	—	On the north-east from Ecology Glacier on a flat surface of a small hill: according to the map of 2002 [16], this area was covered with glacier in 1979; ASPA 128 area; Minimum bird guano supply

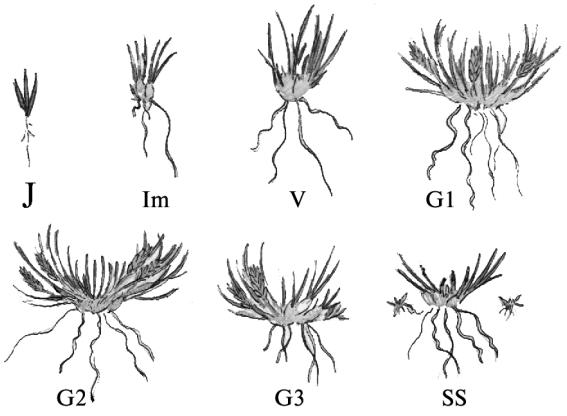

Fig. 2. Age structure of *D. antarctica*. Here and on the fig. 2: *J* — juvenile, *Im* — immature, *V* — virginile plants, *G1* — young generative, *G2* — middle generative, *G3* — old generative, *SS* — subsenile plants, (own data)

hydrological network and mapping. The photo was kindly granted by A.B. Pereira (Brazil). We also used King George Island GIS project background.

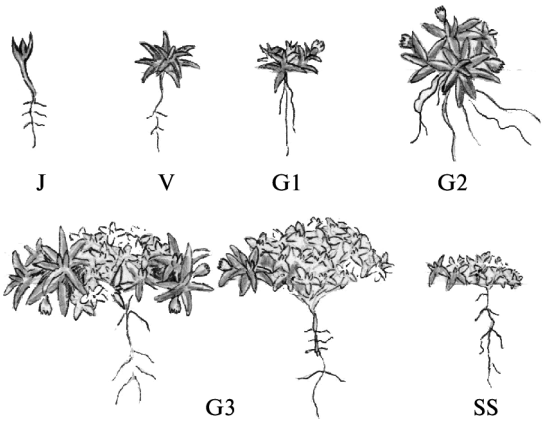

Fig. 3. Age structure of *C. quitensis*

Results and Discussion

The area near Arctowski Station is unique in comparison with other ice-free territories on King George Island. First of all the originality of this area is determined by relief: mountain ridges form a peculiar enclosed «quadrangle» (Krokiew, Fig. 1); depressions join the ridges (Italia Valley and coastal depressions near the station). Meltwater flow is isolated from the «quadrangle» by its south-eastern walls (Fig. 4).

Water balance on the majority of ice-free territory near Arctowski Station is formed by thawing permafrost and snow that accumulates in the «quadrangle». Melt waters from the «quadrangle» form six creek watersheds [18]. The water flows along the walls of mountain ridges framing the «quadrangle» to the coast. A lot of moisture is accumulated at the bottom of the «quadrangle», thus establishing favourable conditions for the existence of Antarctic herb tundra formation. Notably, coastal localities of Antarctic herb tundra are additionally moistened by the ocean air [18].

At present time there is distinct evidence of expansion of the tundra into the areas adjacent to the glacier (Fig. 1; the 9th plot is located on the territory where the glacier was noted in 1979 [16]).

According to the environmental gradient from the edge of the glacier to the ocean coast, we divided the research sites into three localities. We supposed that their localization demonstrates subsequent stages of postglacial colonization. These localities were conventionally named as colonization zones. The first zone (I) included plots 1—5 (coastal localities), the second one (II) — plots 6—8, which are equally remote from the coastal line and glacier. Only the plot 9 belongs to the third zone (III) near Ecology Glacier where the environment is quite homogenous. Only the site 9 belongs to the third zone (III) near Ecology Glacier where the environment is quite homogenous.

Notably, vascular plants as well as Bryophyta were found in all three colonization zones. All three taxa along with lichens seem to be primary colonizers in all studied sites. Also, *C. quitensis* was scarce in comparison with *D. antarctica* in all zones, probably because its reproductive success and rate of ramification were lower regardless of the growth zone.

Zone I is characterized by considerable moistening and swamping. Total vegetation cover varied from 56 to 98 %; green alga *Prasiola crispa* (Lightf.) Menegh

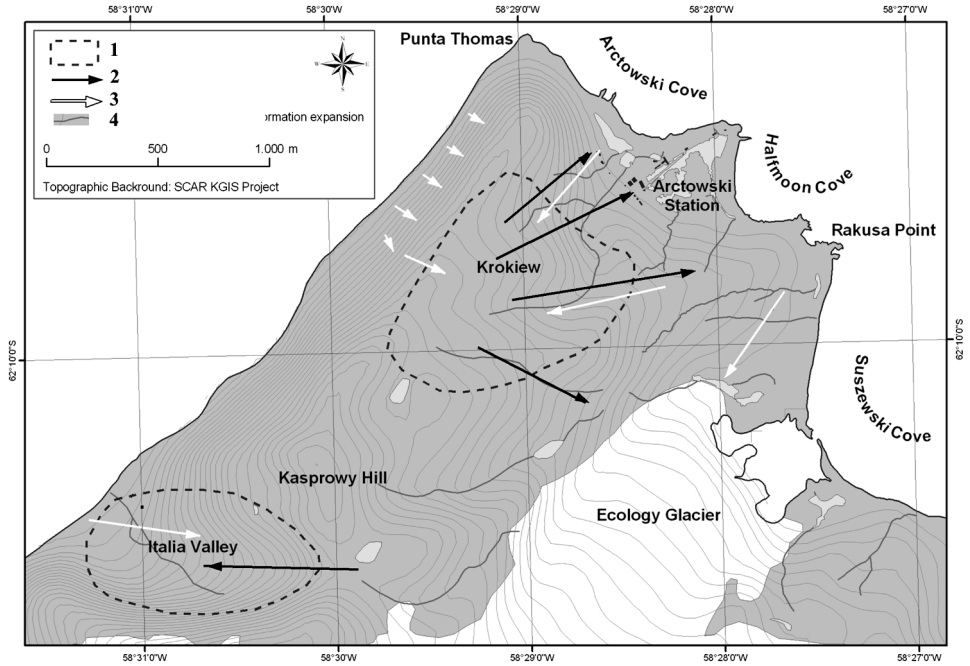

Fig. 4. The scheme of surface water flow in the area near Arctowski station, King George's Island, the South Shetland Islands. Symbols indicate: 1 — main sources of melt water, 2 — large streams, 3 — directions of melt water flow, 4 — possible directions of Antarctic herb tundra formation expansion on the territories, which became free from glacier (they also indicate directions of ecological conditions gradient formation)

was present. This zone was the first one to become free from the glacier and is relatively stable. The glacier only slightly affects this zone, as it is separated from it by high mountain ridges. As a result of warm current running along the western coast of Antarctic Peninsula this zone could have remained free from the glacier even during the period of maximal Pleistocene glaciation. Perhaps, gradual expansion of the formation to the nearby territories during continuous glacial retreat occurred from this very area.

Coastal localities of *Deschampsia antarctica — Polytrichum piliferum* association, found at the Fildes Peninsula [8], hardly depend on glacial water because of the considerable distance from the edge of glacial sheet. We assume that they are similar to zone I on the area around Arctowski Station.

Zone II is characterized by moderate moistening, as melt water is drained into streams, flowing to the ocean along the hollows. Total vegetation cover was 100 % in all sites here. About a half of it formed by Bryophyta; *D. antarctica* considerably prevailed over *C. quitensis* (5:1, respectively).

Zone III is situated outside the coastal area at the edge of the glacier and is a rocky postglacial moraine, 5—10 m a.s.l. Total vegetation cover here was about 56 % (50 % for mosses, 3 % for *D. antarctica* and 3 % for *C. quitensis*).

Thus, colonization zones can be identified on the basis of certain parameters. The first one is combined vegetation cover of both species of vascular plants. At the same time, individual cover of *D. antarctica* and *C. quitensis* cannot be used to identify a colonization zone (see Table 2).

Another parameter is reflected by the variety of higher plants. Thus, the maximal diversity of mosses and presence of liverworts was observed in zone II, as compared with the other two ones (Table 3).

One can thus suppose that at the present time Zone II is the most favourable for the *Deschampsia antarctica — Polytrichum piliferum* association of Antarctic herb tundra formation, probably due to optimal combination of humidity and insolation.

Table 2. **Total and individual cover of *D. antarctica* and *C. quitensis* in the study plots**

Colonization zone	Site	General vegetation cover	Cover of *D. antarctica*	Cover of *C. quitensis*
I	1	63 %	30 %	3 %
	2	58 %	5 %	3 %
	3	80 %	25 %	25 %
	4	100 %	65 %	30 %
	5	98 %	95 %	—
II	6	100 %	50 %	10 %
	7	100 %	90 %	10 %
	8	100 %	25 %	5 %
III	9	56 %	3 %	3 %

Noteworthy, all plots greatly differed in steepness and exposition of slopes and the distribution of the tundra formation, which corresponds with data in the literature [13].

Table 3. **The composition of mosses and liverworts species in the study plots according to the colonization zones**

Species	Colonization zone		
	I	II	III
Sanionia georgico-uncinata (Müll. Hal.) Ochyra & Hedenäs	+	+	
Polytrichum piliferum Hedw.		+	
Polytrichastrum alpinum (Hedw.) G.L. Sm.		+	
Pohlia nutans (Hedw.) Lindb.	+	+	
Pohlia drummondii (Müll.Hal.) A.L. Andrews			+
Ceratodon purpureus (Hedw.) Brid.			+
Syntrichia princeps (De Not.) Mitt.	+		+
Cephaloziella varians (Gottsche) Steph.		+	
Barbilophozia hatcheri (A. Evans) Loeske		+	

To find the most optimal zone for these species' existence in the environs of H. Arctowski Station we analysed population parameters of *D. antarctica* and *C. quitensis* in all plots. The analysis of age structure shows that adult (G2) and old (G3) generative plants dominated in *D. antarctica* population of zone I. In zones II and III there were much more pregenerative (J, Im and V stages) plants (Fig. 2); here dominates the invasion strategy. It reflects the invasive nature of *D. antarctica* of both zones and its potential ability to occupy new areas and reproduce. This was not so for *C. quitensis*.

It should be noted here, that accidental nitrification, which obviously effects the individual cover of *D. antarctica* and *C. quitensis* and the diversity of other plants, considerably hampers all efforts to identify colonization zones and to search for optimum ones. Mosaic supplies of organic substances by birds and sea mammals produce heterogeneity even within a single hypothetic colonization zone. Moreover, it forms an additional ecological gradient that is described in detail in [19]. We think that variability of population status of *C. quitensis* is caused mainly by heterogeneity of organic supply. Another indicator of the heterogeneity is the expansion of green alga *Prasiola crispa*, which is known to be a marker for high nitrification [19]. The presence of both nitrophilous species is of intrazonal nature.

Conclusions

1. Distinct colonization zones were revealed as a result of heterogeneity analysis of vascular plants formation in ecological gradient from the edge of the glacier to the ocean.

2. Three colonization zones can be distinguished in the study area. Possibly, zone I is the initial one, and zone II, which is equally distanced from the ocean and glacier, is optimal for higher plants at the present time.

3. Zone III, which is the closest to the glacier, reflects the expansion of Antarctic herb tundra formation to new areas released from the glacier.

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КОЛОНІЗАЦІЙНІ ЗОНИ ТРАВ'ЯНОЇ ТУНДРИ АНТАРКТИКИ В ЕКОЛОГІЧНОМУ ГРАДІЄНТІ ПОСТГЛЯЦІАЛЬНИХ ТЕРИТОРІЙ

Досліджено залежність поширення антарктичної тундри в градієнті екологічних умов, який сформувався у процесі відступу льодовиків. Протягом 30-ї польської та 10-ї української експедицій, з 09.11.2005 по 09.02.2006 р., закладено дев'ять стаціонарних ділянок, які охоплювали практично весь спектр умов вільної від льоду території біля польської антарктичної станції Г. Арцтовського на острові Короля Георга (Південні Шотландські о-ви). За особливостями трав'яних угруповань, які залежать від екологічних умов у градієнті відстані від краю льодовика, виділено три окремі колонізаційні зони. Ймовірно, зона I (прибережні локалітети) є вихідною колонізаційною зоною; зона II, рівновіддалена від льодовика й океану, — оптимальна для існування судинних рослин на сучасному етапі; зона III, найближча до краю льодовика, що тане, відображає експансію антарктичної трав'яної тундрової формації на нові території.

Ключові слова: антарктична трав'яна тундра, колонізаційні зони, острів Короля Георга.

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КОЛОНИЗАЦИОННЫЕ ЗОНЫ ТРАВЯНОЙ ТУНДРЫ АНТАРКТИКИ В ЭКОЛОГИЧЕСКОМ ГРАДИЕНТЕ ПОСТЛЕДНИКОВЫХ ТЕРРИТОРИЙ

Изучена зависимость распространения антарктической тундры в градиенте экологических условий, сформировавшихся в процессе отступления ледников. Во время 30-й польской и 10-й украинской экспедиций, с 09.11.2005 по 09.02.2006 г., заложено девять стационарных площадок, которые охватывали практически весь спектр условий свободной ото льда территории в окрестностях польской антарктической станции Г. Арцтовского на острове Короля Георга (Южные Шотландские о-ва). Основываясь на особенностях травяных сообществ, зависящих от экологических условий в градиенте расстояния от края ледника, выделено три колонизационные зоны. Вероятно, зона I (прибрежные локалитеты) — исходная зона колонизации; зона II, равноотдаленная от ледника и океана, оптимальна для сосудистых растений на современном этапе; зона III, расположенная в непосредственной близости от края отступающего ледника, отражает экспансию антарктической травяной тундровой формации на новые территории.

Ключевые слова: антарктическая травяная тундра, колонизационные зоны, остров Короля Георга.