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CONTEMPORARY CHANGES IN VEGETATION OF POLAR REGIONS

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ABSTRACT: Rapid climate changes which have been observed over the recent years in both polar regions of the Earth, directly or indirectly affect vegetation dynamics. This article presents the main directions of the changes taking place in the recent years in tundra communities of both polar regions, based on original research carried out in the Arctic in Spitsbergen and in the maritime Antarctic on King George Island.

KEY WORDS: climate change, tundra communities, plant succession, glacier forefields, Antarctica, Arctic.

INTRODUCTION

In the polar regions of both hemispheres, within terrestrial ecosystems far–reaching transformations have been observed in the recent decades. Tundra communities are modified, and the main drivers of these processes are rapidly changing climatic conditions in the Arctic and Antarctic. Global climate change in the recent decades is widely documented and monitored. Global warming has been most visible from the 1970s: the average annual air temperature in the world increased by 0.35°C in the years 1901–1940, and in the years 1970–2007 by 0.55°C.

The period from 2000 to 2009 was the warmest period during the recent decades (Menne and Kennedy 2010). The rise in temperature in the northern hemisphere is accompanied by the rainfall increase. The most sudden climate changes are currently taking place in the polar regions of both hemispheres. The rapid warming trend in the Arctic has been visible since the 1990s (Przybylak 2007). In the years 1995–2005 the average annual air temperature in this region increased by more than 1°C with reference to the average from the years 1951–1990 (Przybylak 2007). Currently, it is the Arctic where the greatest global temperature increase is observed (Menne and Kennedy 2010).

Some areas in Antarctica also belong to the fastest warming regions on the Earth over the recent decades. This relates to the maritime Antarctic, especially the Antarctic Peninsula region, where during the last 50 years the temperature has risen by an average of 2°C (Turner *et al.* 2005, Convey 2006).

Much of the available data indicates that the terrestrial ecosystems of polar regions are very robust against climate change (Jónsdóttir 2005, Prach *et al.* 2010). This suggests that the period of time after which a vegetation study could be repeated must be long. However, changes in polar vegetation occur surprisingly quickly. In some areas only 20–30 years is enough to notice significant changes (Moreau *et al.* 2009, Olech 2010, Ziaja *et al.* 2011).

Recent research indicates that plant communities change their structures, and then disappear or transform into different types. Sometimes the changes affect contribution of particular species, whereas in other cases entire groups of organisms.

In 2008 comparative mapping of plant communities on the north-western coast of Sørkapp Land (South Spitsbergen) was carried out. This study was conducted on the basis of the results of comprehensive phytosociological works from the 1980s (Dubiel and Olech 1985, 1990, 1991), which resulted in creating a plant communities map of this area. A series of phytosociological relevés using the Braun-Blanquet method was performed. Their results were then compiled with the data from the previous studies (Dubiel and Olech 1991). As an effect of this comparison an updated vegetation map of the north-western Sørkapp Land was prepared (Ziaja *et al.* 2011). Mapping of plant communities, which allows creating vegetation maps of the Arctic regions, is one of the most important ways of characterizing vegetation state in a particular period. Research repeated in the same area after a period of time provides an opportunity to detect and describe vegetation changes.

The most spectacular vegetation changes in polar regions are colonization and primary succession on glaciers forefields recently denuded of ice. Glaciers recession in the Arctic and Antarctic areas is considered as one of the most important consequences of the global climate change. It is a result of both the annual air temperature increase and the decrease in snow cover (Callaghan *et al.* 2005). As a consequence of the deglaciation, large areas devoid of any vegetation are revealed from under the ice. This enables the colonization processes of dominating vegetation groups, including bryophytes, lichens and vascular plants in the newly created ecosystems.

Recent studies of colonization and primary succession were carried out in the forefields of two glaciers – the Windy Glacier on King George Island in the maritime Antarctic (Fig. 1) and the Gåsbreen in the southern Spitsbergen (Fig. 2). Fieldwork was carried out in 2006 and 2008, respectively. In both studies the chronosequence method was used. In each forefield a linear continuous transect, composed of 1x1 meter phytosociological relevés, was led from the glacier front to

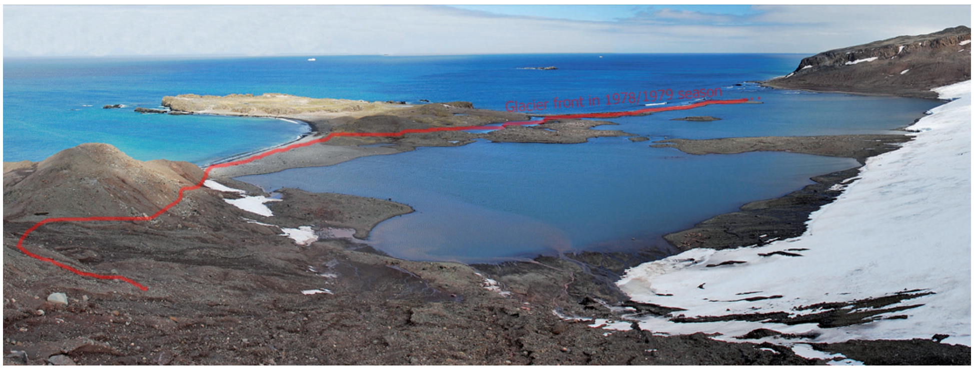

Figure 1. The Windy Glacier forefield (November 2006) – the red line marked glacier extent in 1978/79 years (Photo Piotr Angiel)

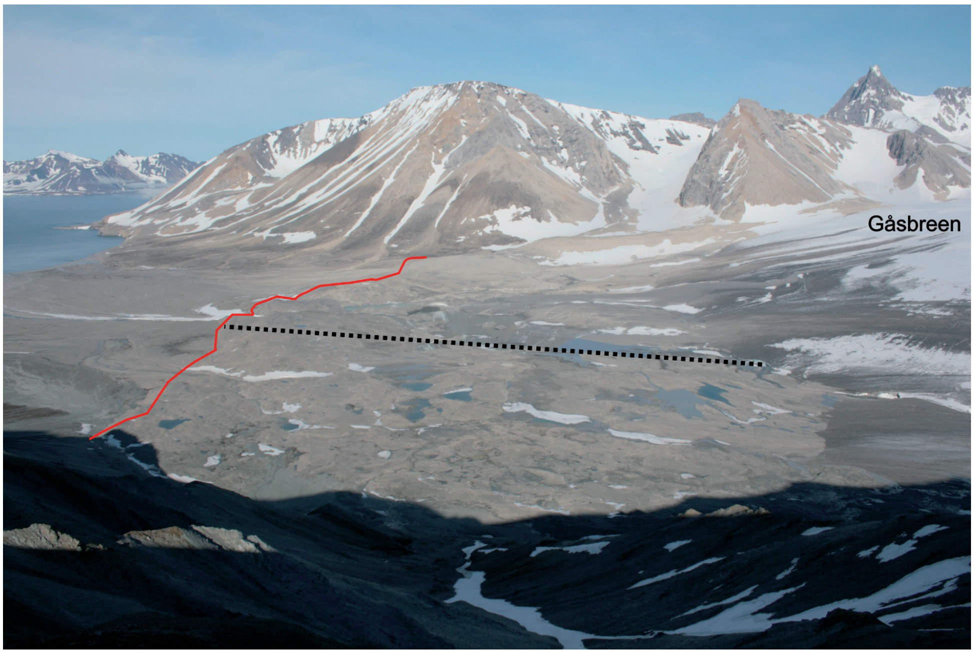

Figure 2. Transect on the Gåsbreen forefield (July 2008) – the red line marked glacier extent in 1899 year (Photo Maja Lisowska)

the oldest moraines. The relevés were performed along the transect according to the Braun-Blanquet method. For each relevé the percentage cover of vascular plants, bryophytes and lichens was determined as well as the abundance of individual species. Abiotic variables like inclination, exposure, substrate properties were also recorded. First records of particular species were marked as well. The transects were designed to cover the longest possible part of the glacier marginal zone, perpendicular to the recession line of glacier front.

Using the same research methodology in the glacier forefields both in the Arctic and Antarctic enabled a great opportunity of direct comparison of the colonization and primary succession processes between these two polar regions.

CHARACTERISTICS OF THE POLAR REGIONS VEGETATION

The severe climate of both polar regions causes the dominance of cryptogams in the tundra communities. Bryophytes and lichens are often the main component of plant communities in these areas. They are exquisitely adapted to low temperature and a very short vegetation season, long snow retention periods and to extremely nutrient-poor or even barren substrata. Thus they dominate especially in the coldest tundra zones. Bryophytes create the dominant group of organisms in wet habitats while lichens predominate in the drier ones.

In both polar regions permafrost plays an important role in development of the vegetation forms. Permafrost and slow organic matter decomposition rate cause that the soils in the Arctic and Antarctic are often at the initial stage of development, with poorly developed profile. The physical weathering process predominates over the chemical one, and freezing and thawing cycles are a common phenomenon that lead to formation of cryogenic soils, and patterned ground; the solifluction is also frequent. This favors cryptogams because they are less dependent on the substratum fertility than vascular plants. Over the last several decades the phenomenon of the permafrost thawing has been observed, which directly affects the ongoing vegetation changes.

In areas characterized by low primary production and very slow decomposition processes, the availability of soil nutrients is almost negligible. However, the additional sources of macroelements, locally enriching the soil, occur. The presence of numerous seabirds whose excrements fertilize the area around their breeding colonies determines development of the specific plant communities known as ornithocoprophilous ones. They are formed by species preferring a high content of minerals, especially nitrogen, in the substratum. The stability of these communities is directly connected with constant supply of fertilizer. Changes in seabird populations can directly influence the structure of ornithocoprophilous vegetation.

DIFFERENCES IN THE VEGETATION OF THE POLAR REGIONS

Despite many similarities, the Arctic and Antarctic have many features that significantly differentiate tundra vegetation of both these regions.

Among all these features the most important is the difference in diversity of vascular plant species. There are about 1800 species of flowering plants in the Arctic (Callaghan *et al.* 2005). Even in the coldest areas of arctic tundra, dominated mostly by cryptogams, a single species of vascular plants can be found. The warmer tundra zones are characterized by the increasing contribution of vascular plants, and among grasses, sedges and cushion plants, dwarf shrubs occur there.

In Antarctica only two native vascular plant species are found – a grass *Deschampsia antarctica* (*Poaceae*) and *Colobanthus quitensis* which is a member of the *Caryophyllaceae* family. Occurrence of both these species is limited only to the maritime Antarctic, while on the Antarctic continent they are completely absent. The substantial geographical isolation of this region is responsible for its exceptionally deficiency in species. In contrast to Antarctica, there was a significant species migration between North America, Asia, Europe and the Arctic area during the Pleistocene glaciations and it also occurs nowadays.

The second important difference is the lack of herbivores in Antarctica, on the contrary to the Arctic region where large populations of animals, both birds and mammals, whose diet includes mosses, lichens and vascular plants, play an important role in tundra formation. The influence of reindeer, caribou and geese is the most visible.

Figure 3. The ornithocoprophilous communities and penguin colonies (Photo Maria Olech)

In both polar regions the presence of numerous seabird breeding colonies is an important factor determining formation of specific plant communities. However, in the Antarctic areas this factor is of a far greater importance than in the Arctic. The presence of huge breeding colonies of different penguin species, located on the plateaus and rocky ledges, causes development of ornithocoprophilous tundra communities (Fig. 3).

CHANGES IN THE ARCTIC VEGETATION

In recent decades far-reaching changes of the arctic tundra communities are observed. Global climate warming and what follows increase in primary production stimulate the growth of herbivores population that have led to significant structural changes in the tundra communities of the Arctic regions. The results of comparative studies carried out after 25 years within the same area as previously in the south of Spitsbergen (Ziaja *et al.* 2011) indicate vast changes in structures of plant communities due to increasing reindeer pressure (Fig. 4). The rapid expansion of reindeer, from 1 or 2 animals in the 1980s to over 100 in 2000 (Ziaja 2002), and later to even about 170 individuals observed during the research in 2008, had greatly influenced the structure and distribution of plant communities. One of the

Figure 4. The reindeer herd in Sørkapp Land in 2008 year (Photo Michał Węgrzyn)

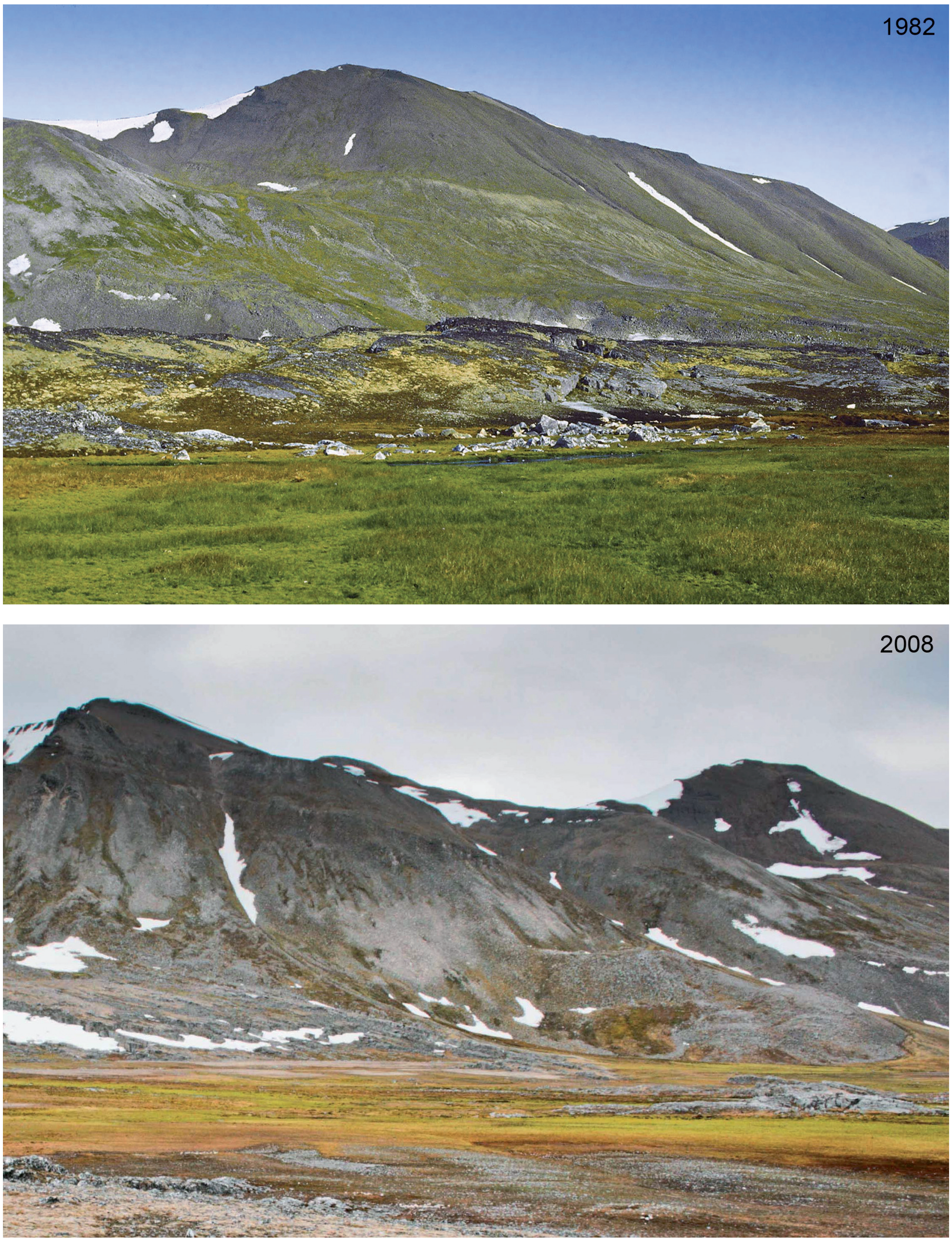

Figure 5. General view of tundra vegetation in the central part of western Sørkapp Land (the Hornsundneset coastal plain and the Sergeijevfjellet mountain massif)
1982 – in the foreground the *Carex subspathacea* community; in the background – the *Flavocetraria nivalis – Cladonia rangiferina* community with visible patches of yellow fruticose lichens;
2008 – strongly change the same habitat, under the influence of a large population of reindeer – patches of fruticose lichen disappeared completely in the tundra communities
(Photos Maria Olech, 1982 and Maja Lisowska 2008).

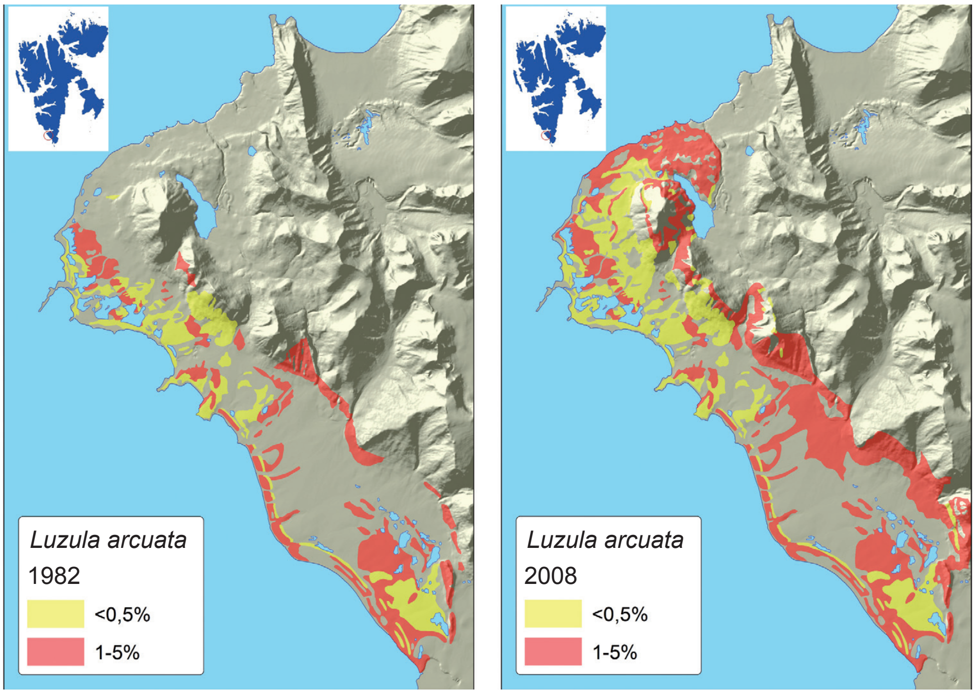

Figure 6. Percentage *Luzula arcuata* occurrence in plant communities in 1982 and 2008 in Sørkapp Land

most spectacular changes occurring in the study area was a complete degradation of fruticose ground lichen population within the *Flavocetraria nivalis-Cladonia rangiferina* community (Fig. 5). The fruticose lichens, being the main components of this community, were entirely eliminated due to reindeer grazing. The substratum fertilization by reindeer was an additional factor causing decline in occurrence or even disappearance of these lichens. Currently, only on very steep slopes and in places unavailable for reindeer penetrating, large and undamaged thalli of these lichens can be found. In the patches of degraded *Flavocetraria nivalis-Cladonia rangiferina* community, expansion of the sedge *Luzula arcuata* (Fig. 6) was observed. Previously its area of occurrence was most likely limited by the fruticose lichens, whereas the disappearance of competition allowed this sedge to spread in tundra communities.

Formation of new plant communities is observed in the areas recently revealed from under the ice where rapid recession of glaciers takes place. Deglaciation is continuously uncovering large areas devoid of any vegetation, and there colonization and primary succession of cryptogams as well as vascular plants is observed. In recent decades more and more studies of colonization and succession processes have been carried out in forefields of the Arctic glaciers. The first research in Svalbard area was conducted in the mid-twentieth century (Kuc 1964). In the 1970s the studies on vegetation and soil types in the forefield of the Werenskiöldbreen nearby the Polish

Polar Station had been initiated (Fabiszewski 1975, Pirożnikow and Górniak 1992) and currently they are still being continued (Wojtuń *et al.* 2008). Since the 1980s also the glaciers forefields in the vicinity of the international research station in Ny Ålesund on the north-west coast of Spitsbergen have been intensively investigated. The studies on vascular plant succession in the middle Spitsbergen were carried out by Ziaja and Dubiel (1996).

Problems associated with changes of vascular plant communities are the best examined issues related to primary succession in Svalbard. Other groups of organisms which create vegetation of the glacier marginal zones – bryophytes, and especially lichens, were often treated collectively. These cryptogams are a significant component of tundra communities forming in the glacier forefields, so the information complementation on this issue is important. In 2008 studies on colonization and primary succession processes including bryophytes and lichens were carried out in the forefield of Gåsbreen in the Hornsund area (Lisowska 2011). The chronosequence method was used along a linear continuous transect of phytosociological relevés from the glacier front to the oldest moraines (Fig. 7). The picture of vegetation changes along the whole glacier forefield was obtained. The colonization process begun in the area denuded of ice about 25 years ago. Vascular plants were the first to colonize fresh moraines, and also predominant within communities among transect. Next, bryophytes appeared with *Bryum pseudotriquetrum* and *Brachythecium turgidum* as pioneers. Lichens were recorded as the last group of organisms. The first colonizing lichens were the epilithic species *Polyblastia cupularis* and *Protoblastenia rupestris*. In older parts of the transect small species of the genera *Polyblastia*, *Thelidium* and *Verrucaria* were supported by species with larger thalli, e.g, *Xanthoria elegans* and *Aspicilia* spp. The occurrence of other moss species was also observed in the older part of the forefield, including dominant in abundance *Andraea blyttii*. The ground lichens were recorded only at the edge of the glacier marginal zone. In general the sequence of appearance of consecutive organism groups in the forefield of Gåsbreen proved to be similar to these observed in other areas of Spitsbergen (Hodkinson *et al.* 2003, Moreau 2005). However, the differences in species composition of vegetation, resulting mainly from composition of tundra communities surrounding investigated forefields, were noticed.

CHANGES IN ANTARCTIC VEGETATION

Studies on dynamics of tundra communities are carried out in the Antarctic in connection with climate changes occurring in this region. However, most investigations concern only selected taxonomic groups which contribute to tundra creating (Lewis Smith 1993, 2001, Wynn-Williams 1996), while a comprehensive phytosociological analyses, needed to show the essence of the issue, are still

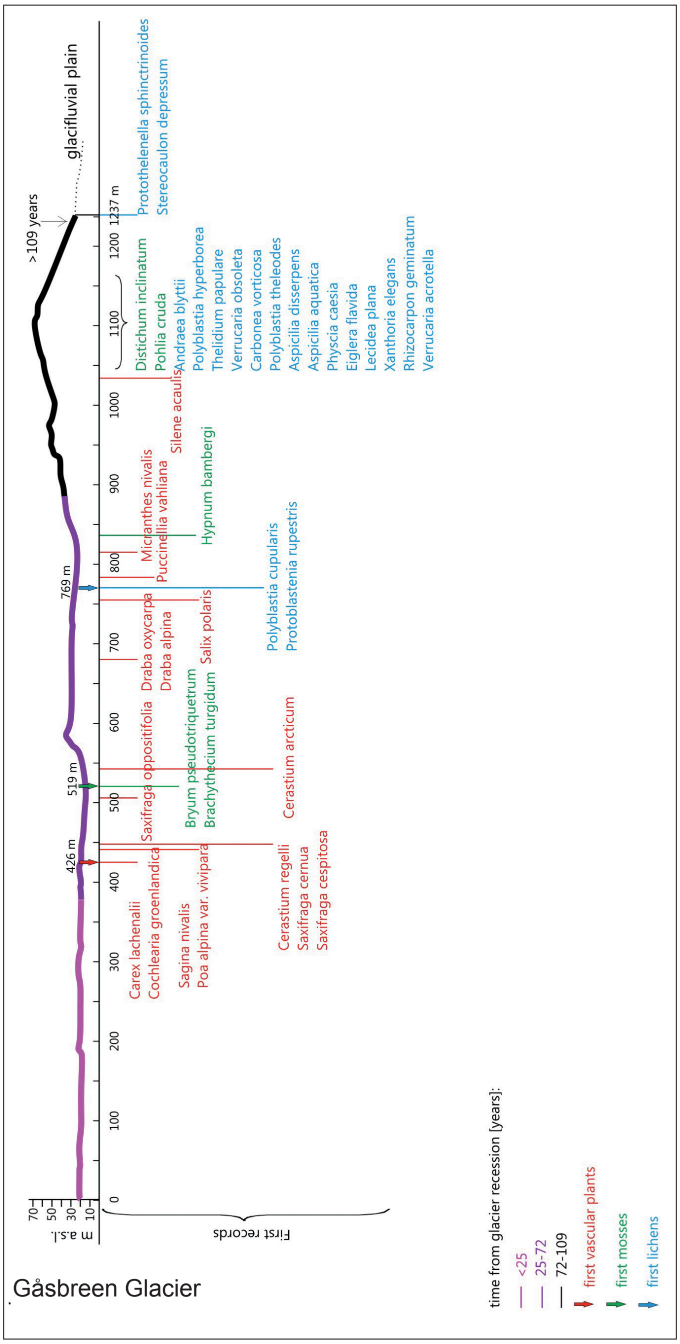

Figure 7. Plant succession along transect in the Gåsbreen forefield

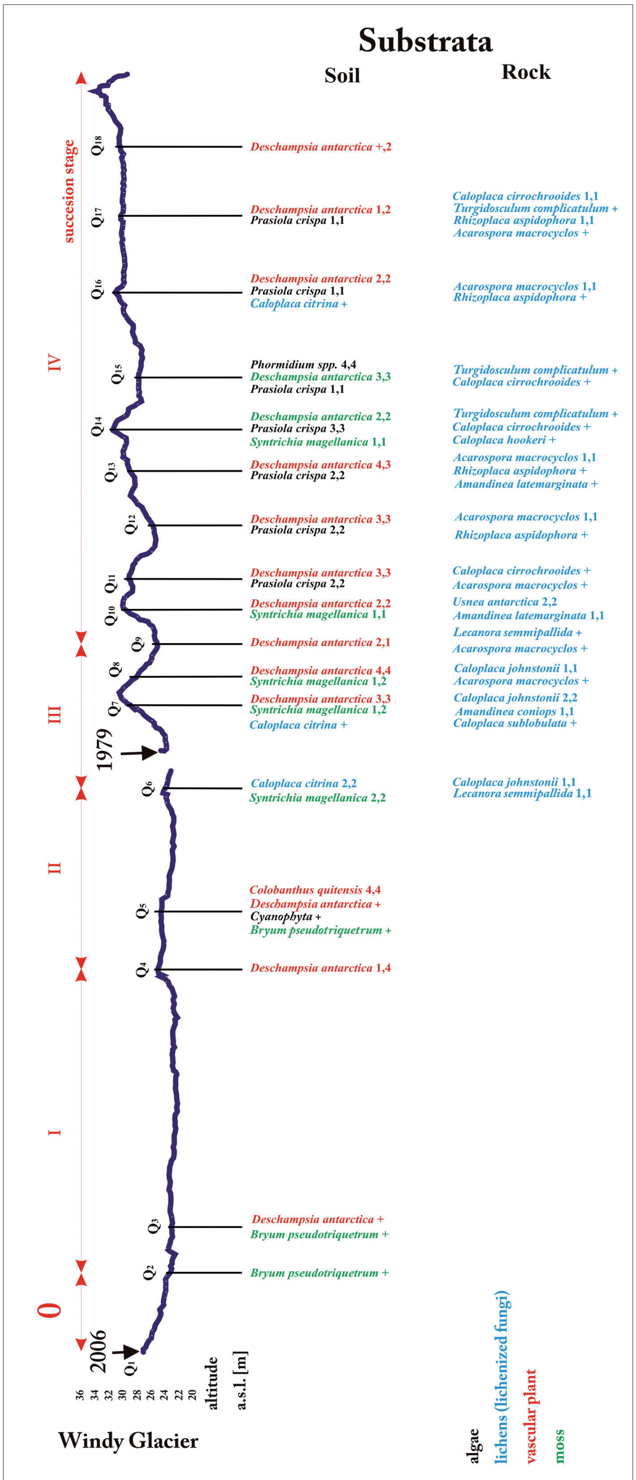

Figure 8. Plant succession along transect in the Windy Glacier forefield

lacking. The most spectacular vegetation changes due to local climate warming are observed in the forefields of retreating glaciers in the maritime Antarctic. The deglaciation process creates new uncovered from under the ice areas for colonization and primary succession as well as for formation of tundra communities.

Long term studies on colonization and succession in the glacier forefields are carried out on King George Island in the Admiralty Bay region (Olech 2010).

For example, detailed studies of vegetation colonisation were conducted in the forefield of the Windy Glacier (Fig. 8), using classical phytosociological transect methods. All major groups of plants and fungi taking part in colonization were taken into consideration. Several years since the regression of the glacier, the beginning of colonization process, in about 50 meters from the glacier front, is clearly visible. The pioneer species that appeared first were the moss *Bryum pseudotriquetrum*, and then the grass *Deschampsia antarctica* (I stage of succession). In the second stage of succession the dominance of *Colobanthus quitensis* in the patches of ground communities was marked. The first rock-inhabiting lichens (*Caloplaca johnstoni*, *C. sublobulata, Lecanora* spp.) appeared in the third stage of succession. The huge influence of penguin colonies, which occur in the Patelnia Peninsula region, was revealed in the fourth stage. On rocks the ornithocoprophilous communities of epilithic lichens dominated, while on soil the grass *Deschampsia antarctica* with the nitrophilous algae (*Prasiola crispa*, *Phormidium* spp.) and mosses (e.g. *Syntrichia magellanica*) were prominent.

A similar succession patterns are observed in the forefields of other glaciers (Olech 2008, Olech and Massalski 2001).

In order to obtain more accurate data base for monitoring of ongoing changes of the tundra communities in the Antarctic, phytosociological research and vegetation mapping of the areas free of ice were conducted.

Phytosociological methodology is perfect for monitoring vegetation condition and following changes in composition and distribution of vegetation communities over the particular time. Vegetation map is a vulnerable source of information about plant communities inventory, their location and distribution in terrain. The map of tundra communities distribution in the Windy Glacier forefield (Fig. 9) will provide a basis for future comparative research on changes due to climate warming. Before mapping, phytosociological relevés were performed according to the classical Braun-Blanquet method.

DISCUSSION

The models forecasting the trends of climate changes in coming decades suggest further increase in air temperature in the Arctic (Callaghan *et al.* 2005). The annual rainfall will also increase in this area. The association between vegetation changes in the Arctic and the climate warming has been confirmed in a series of experiments conducted since the 1990s (Walker *et al.* 2006).

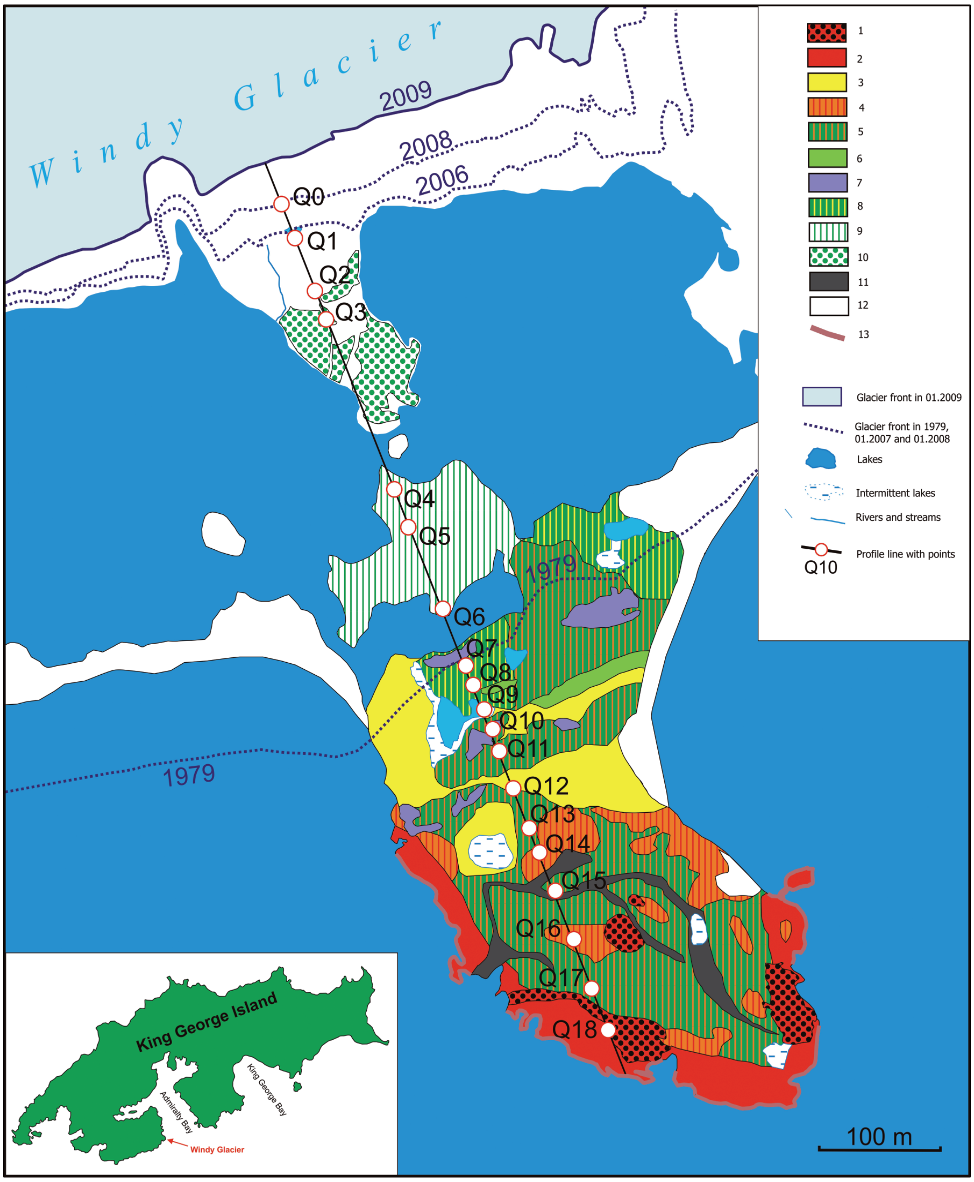

Figure 9. Plant communities in the Windy Glacier forefield (January/February 2009)
1 – Penguin colonies; 2 – *Caloplaca cirrochrooides – Turgidosculum complicatulum* community; 3 – *Deschampsia antarctica – Prasiola crispa* community; 4 – Mosaic composed of ornithocoprophilous lichen communities and *Caloplaca cirrochrooides – Turgidosculum complicatulum* community; 5 – Mosaic composed of *Deschampsia antarctica – Prasiola crispa* and ornithocoprophilous lichen communities; 6 – *Deschampsia antarctica – Colobanthus quitensis* community; 7 – Terricolous lichen communities with *Usnea antarctica*; 8 – *Deschampsia antarctica, Colobanthus quitensis and Prasiola crispa* community; 9 – *Colobanthus quitensis and Deschampsia antarctica* community; 10 – Scarce *Deschampsia antarctica and Colobanthus quitensis*; 11 – Mats of algae *Phormidium* spp. and *Prasiola crispa*; 12 – Without plants.

Experiments simulating the impact of warming on tundra vegetation, indicate further expansion of shrubs and disappearance of ground lichens and mosses (Walker *et al.* 2006). The movement of northern timberline will continue to the north, leading to the decline in the tundra communities area (Callaghan *et al.* 2005). Global climate changes directly affect not only vegetation but also the entire ecosystem.

Near the northern timberline areas, e.g. in Alaska, the expansion of dwarf shrubs is observed (Sturm *et al.* 2001). These authors also recorded a marked increase in the extent and density of the spruce forest, which can indicate the movement of timberline northward. The shrub expansion is also observed in much of Arctic Canada and in Scandinavia and possibly Russia and Siberia (Tape *et al.* 2006). The authors suggest that a pan-Arctic expansion of shrubs is underway.

The ongoing changes in tundra vegetation in recent decades are controlled by extremely complex factors. The result of such state is a great variety of observed changes, as well as the fact that not in all parts of the Arctic they are clearly visible (Prach *et al.* 2010, Daniëls *et al.* 2011).

A very important change is a complete degradation of fruticose ground lichens communities in the warmer regions of the Arctic (Cornelissen *et al.* 2001). In Alaska a significant decline in coverage and biomass of ground lichens was recorded in recent decades (Joly *et al.* 2009). It is associated with a number of factors, including both reindeer and caribou influence as well as the vascular plants competition. The warmer climate favors the development of vascular plants and enhances the competition between them and lichens.

Long term studies on dynamics of tundra ecosystem due to climatic changes carried out in the maritime Antarctic (Chwedorzewska 2010), especially in the Antarctic Peninsula region, indicate rapid transformations of the Antarctic tundra communities (Olech 2010). Among others the shrinkage of the glaciers extents or disappearance of communities preferring moist substratum, especially bryophytes, were observed. The decrease in the substrate humidity causes overgrowing of mossy communities by the grass *Deschampsia antarctica*. In this Antarctic region the modifications of tundra communities towards grassification are noticed (Olech 2010).

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