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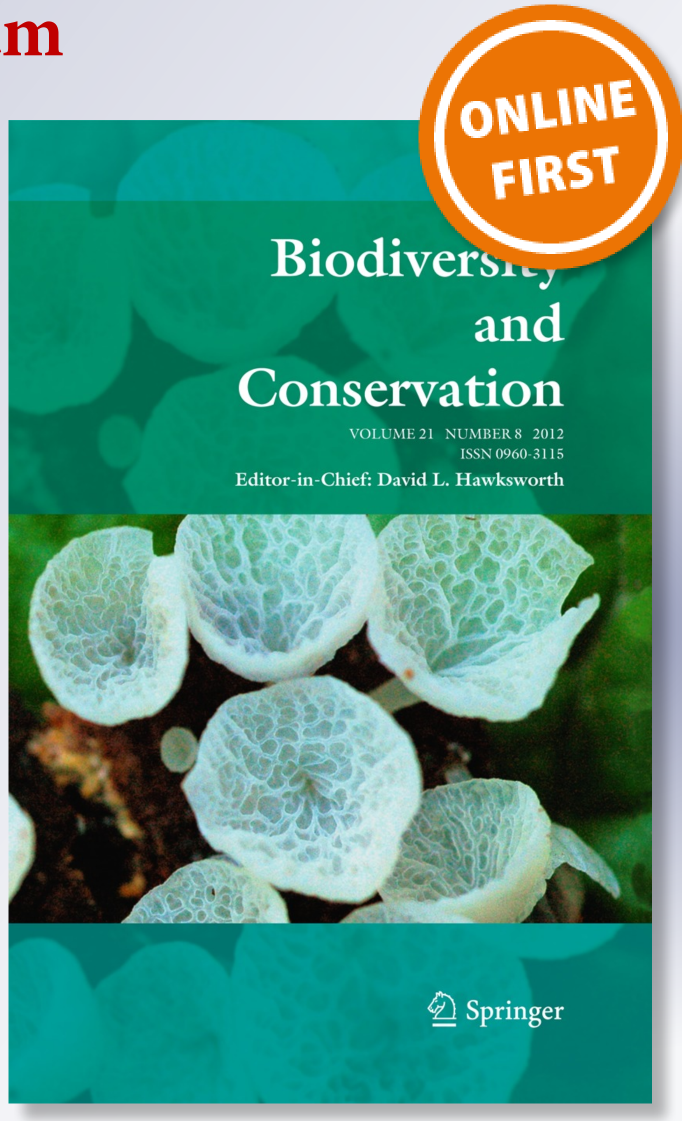

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ORIGINAL PAPER

Diaspores and phyto-remains accidentally transported to the Antarctic Station during three expeditions

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Abstract The aim of the project was to assess the size and species range of alien plant diaspores and phyto-remains transported into the Polish Antarctic Station during three Antarctic expeditions. Our study clearly demonstrates that many diaspores can be quite easily unintentionally transported in good conditions to the Antarctic. In the analyzed material there were present diaspores of invasive species. All identified species belong to 20 families. The most abundant were Asteraceae and Poaceae species. The most interesting finding was the presence of caryopses of *Poa annua*, the first alien angiosperm species which already established a stable breeding population in the Antarctic. Base on our results, we can predict that risk of establishment of anther alien plant species in the vicinity of "Arctowski" Station is very high.

Keywords Alien species · Human impact · Antarctica

Introduction

Antarctic terrestrial ecosystems are noted for their relative simplicity and are characterized by low diversity, as well as an extremely low contribution of some families, or even lack of

M. Lityńska-Zając
Institute of Archaeology and Ethnology PAS, Sławkowska 17, 31-016 Cracow, Poland
e-mail: marialitynska@gazeta.pl

K. Chwedorzewska (✉) · M. Olech · M. Korczak-Abshire
Department of Antarctic Biology, Institute of Biochemistry and Biophysics PAS, Pawińskiego 5a, 02-106 Warsaw, Poland
e-mail: kchwedorzewska@go2.pl

M. Olech
Institute of Botany, Jagiellonian University, Kopernika 27, 31-501 Cracow, Poland

A. Augustyniuk-Kram
Centre for Ecological Research, Polish Academy of Sciences, M. Konopnickiej 1, Dziekanów Leśny, 05-092 Łomianki, Poland

them (Convey 2005). Antarctic tundra are predominantly cryptogamic (lichens, mosses, algae and liverworts) (Bednarek-Ochyra et al. 2000; Chwedorzewska et al. 2004, Ochyra et al. 2008; Olech 2004) and characterized by the poverty of flowering plants. Only two angiosperms thrive in harsh conditions of the maritime Antarctica climate: *Deschampsia antarctica* and *Colobanthus quitensis*. Low diversity, relatively simple community structure, and the general life history features of the native biota make Antarctic ecosystems very vulnerable to the impacts of introduced species (Convey 1996; Frenot et al. 2005; Terauds et al. 2012), particularly those that have sufficient genetic or phenotypic plasticity to enable them to adapt to the polar environment (Hughes et al. 2010a).

The rapid climate change in the western maritime Antarctic region already has significant and measurable impacts on almost all ecosystems. The consequences of these changes are generally expected to include: increased terrestrial diversity, biomass and trophic complexity, all of which contribute to more development of more complex ecosystem structure (Convey 2006). Combined with ameliorating growth conditions, the likelihood of colonisation by new populations of native and alien species is projected to increase in a warmer climate (Hughes et al. 2006; Korczak-Abshire et al. 2011). The two vascular plants native to the maritime Antarctic have provided the most studied examples of a measured biological response to the recent environmental warming in this region (McGraw and Day 1997; Gerighausen et al. 2003). In three decades some local populations have increased by as much as two orders of magnitude (Convey 1996, McGraw and Day 1997). More than a hundred non-indigenous plant species are already documented as having become established in sub-Antarctica islands (Frenot et al. 2005). There is currently only one analogous example in the Antarctic maritime zone: *Poa annua*, which is already established on King George Island (South Shetland Islands, Western Antarctic) (Olech 1996, 1998; Chwedorzewska 2008; Olech and Chwedorzewska 2011).

The Antarctic is isolated from the rest of the world by a natural barrier like oceanic and atmospheric circulation patterns around the continent that strongly limits the dispersal of organisms into and out of this region. But the extent of human activity is breaking it down (Chwedorzewska and Korczak 2010; Lee and Chown 2009a). With a considerable expansion of scientific expeditions and supporting logistics, as well as a remarkable rise of tourism in XXI century, the risk of alien species invasion increased. There is a significant number of tourists visiting the Antarctic, particularly the Scotia Arc region, but a scientific expedition bringing huge amount of cargo and equipment creates considerably higher impacts on the terrestrial ecosystems (Hughes et al. 2011; Chwedorzewska and Korczak 2010). Most stations and bases have a high probability of causing adverse influences on the terrestrial ecosystems due to their localization in coastal ice-free areas, which are also favourable to biological communities (Rakusa-Suszczewski and Krzyszowska 1991; Terauds et al. 2012).

With the current trend in regional warming in the maritime Antarctic (King et al. 2003) and a growing number of visitors, there is an increasing probability that plants, previously unable to survive due to adverse climatic conditions, will be able to become established (Chown et al. 2012b). Direct observation of diaspore migrations is very hard and possible after their establishment in the new environment. The only way to monitor the pressure of alien organisms is a detailed examination of cargo, personal luggage, clothes and equipment of people visiting Antarctic stations.

The main goal of this project was to assess the size and species range of alien diaspores and phyto-remains transported into the Polish Antarctic Station "H. Arctowski" during three Antarctic expeditions.

Materials and Methods

In three austral summer seasons: 2007/2008, 2008/2009, 2009/2010, clothes and equipment of the Antarctic Expedition participants coming to the Polish Antarctic Station "H. Arctowski" (King George Island, South Shetland Islands, 62°09′S, 58°28′W) were examined for the presence of alien diaspores and phyto-remains.

All personal field clothing, gear and equipment of expeditioners (scientists and support personnel) during three seasons were vacuumed—each sample to a separate dust bag. A new nylon stocking filter was put on the vacuum cleaner pipe to collect the bigger contaminations. Seeds and phyto-remaind stick to Velcro® fasteners on clothing, boots and outdoor items were removed with tweezers. Each collected sample was tagged, placed in a separate zip lock bag and preserved for transportation to Poland for future analysis.

All samples were analyzed in the laboratory of the Institute of Archaeology and Ethnology Polish Academy of Science in Cracow. After measuring the volume 0.5–5 cm^3, material was sorted under macroscopic binoculars. From each sample all plant material: seeds, caryopses, fruits and vegetative fragments like pieces of wood, leaves or stems, were selected.

Plant material was found in 78 samples. Identification of seeds and fruits was based on a comparison with samples in a reference collection of the Institute of Archaeology and Ethnology PAS laboratory, as well as the herbarium of the Department of Paleobotany, W. Szafer Institute of Botany PAS and specialist literature (Klan 1947; Kowal 1953; Sajak 1958; Wojciechowska 1966, 1972; Dörter 1968; Kowal and Rudnicka-Sternowa 1969; Swarbrick and Raymond, 1970a, 1970b; Rudnicka-Sternowa 1972; Conolly 1976; Rymkiewicz 1979; Cappers et al. 2006, 2009).

Vegetative parts, including pieces of wood, were indentified according to their anatomic structures (e.g., Schweingruber 1990). Each fragment of wood was broken along three anatomical sections and examined microscopically, using a metallographic microscope. Identifications were made by comparison with anatomical atlases and specimens in a reference collection. Detailed information was obtained by studying one hundred slides with a scanning electron microscope.

Cumulative degree days for low-temperature vascular plant species (assuming that species can germinate, survive and grow above −5 °C; Bannister 2007) were calculated based on meteorological data for "Arctowski" oasis from our database. The risk index for "Arctowski" oasis were calculated according Chown et al. (2012a).

Results

During three seasons seventy-eight samples were collected. The distribution of plant material among the samples was irregular. In one sample there were many plant species recorded, whereas there were almost no plant remains in others.

In general, plant material was very well preserved and contained intact diaspores, sometimes with traces of mechanic damage on the external surface. In total, 214 plant fragments were found (Table 1), among them there were 114 diaspores. In eleven samples (14 %) there were no diaspores. In average there were 1.7 diaspores per expeditioner (per person carrying seeds). There were 49 diaspores of species occur in cold region like Arctic and sub-Antarctic.

The majority of plant material was assigned to forty-six species. Based on wood analysis only one tree species was identified as pine *Pinus sylvestris* (Table 2).

Table 1 Type and number of plant remains preserved in 78 analyzed samples

Type of specimens	Numbers of specimens
Wood	5
Spikelet	34
Leaves	26
Stem	5
Fruit scale	3
Seed	22
Fruit	71
Needle	26
Cone	1
Caryopsis	21
Total	214

Incompletely preserved specimens were determined to a genus, some only to the family level (Tables 3, 4).

The analyzed diaspores belong mainly to herbaceous plants, only one species of tree (*Betula pendula*) was represented in the collected seed material. But in vegetative remains wood fragments of *Pinus sylvestris*, linden (genus *Tilia*) and birch (genus *Betula*) were identified. In the collected material there were also identified needles of *Pinus sylvestris* and some hard to determine fragments of needles belonging to a species from Coniferae family. We also found fragments of a larch cone *Larix decidua.*

Straw fragments belonging to Poaceae were present in numerous samples. Also a lot of unidentified fragments of leaf blades, characteristic to *Dicotyledoneae* were found in numerous samples. The whole material contained a lot of unidentified phyto-remains.

All identified species belong to twenty families, representing plants from Dicotyledoneae and Monocotyledoneae (Table 3). Asteraceae and Poaceae families were the most abundant in genera: 9 and 7, respectively. The same families were also the most abundant in species: Asteraceae—10 and Poaceae—6. The most diaspore and phyto-remain specimens belonged to Poaceae and Pinaceae families, but Pinaceae were represented mostly by vegetative fragments, like needles. In the collected material diaspores of Asteraceae family accounted significant participation. The most numerously represented species was *Echinochloa crus-galli* (caryopses and spikelet). The Polygonaceae was represented by two genera, including five species (ten diaspores).

The average cumulative annual degree days during three summer season was about 1,450. The relative risk of alien vascular plants establishing for “Arctowski” oasis was high and after normalization (to provide a probability of risk from 0 to 1) reach about 0.81.

Discussion

Phyto-remains and diaspores were found mainly on clothing, gear and equipment of expeditioners that had spent the previous six months in Poland, thus the probability that the majority of the investigated plant material originated from this region was very high. In our study average number of seed per person carrying plant diaspors were lower than in Chown et al. 2012a, thus probably because about half of investigated people spend about forty

Table 2 Species identified on the basis of well preserved plant material collected in the Antarctic

S. no	Familly	Species	Numbers of specimens	Type of specimens	Present in Arctic	Present in sub-Antarctic
1	Asteraceae	*Cirsium arvense*	2	Fruit	Indigenous EH/ alien WH	Alien
2	Asteraceae	*Galinsoga parviflora*	2	Fruit	–	–
3	Asteraceae	*Hieracium* cf. *glaucinum*	1	Fruit	–	–
4	Asteraceae	*Lactuca serriola*	6	Fruit	–	–
5	Asteraceae	*Leontodon autumnalis*	2	Fruit	Indigenous	–
6	Asteraceae	*Leontodon hispidus*	1	Fruit	–	–
7	Asteraceae	*Leucanthemum vulgare*	7	Fruit	Indigenous EH/ alien WH	Alien
8	Asteraceae	*Picris hieracioides*	1	Fruit	–	–
9	Asteraceae	*Sonchus arvensis*	1	Fruit	Indigenous EH/ alien WH	–
10	Apiaceae	*Chaerophyllum hirsutum*	6	Fruit	–	–
11	Apiaceae	*Pastinaca sativa*	1	Fruit	–	–
12	Betulaceae	*Betula pendula*	3	Husk	–	–
13	Betulaceae	*Betula pendula*	6	Fruit	–	–
14	Caryophyllaceae	*Lychnis flos-cuculi*	1	Seed	–	–
15	Chenopodiaceae	*Chenopodium album*	5	Seed	Indigenous EH/ alien WH	–
16	Cyperaceae	*Carex disticha*	1	Fruit	Indigenous EH/ alien WH	–
17	Cyperaceae	*Schoenus ferrugineus*	1	Fruit	–	–
18	Cyperaceae	*Schoenus* cf. *nigricans*	1	Fruit	–	–
19	Fabaceae	*Trifolium arvense*	2	Seed	–	–
20	Fabaceae	*Trifolium* cf. *campestre*	1	Seed	–	–
21	Lamiaceae	*Nepeta cataria*	1	Fruit	Alien	–
22	Lamiaceae	*Nepeta pannonica*	8	Fruit	–	–
23	Linaceae	*Linum usistatissimum*	2	Seed	–	–
24	Papaveraceae	*Papaver somniferum*	3	Seed	–	–
25	Plantaginaceae	*Plantago lanceolata*	3	Seed	Indigenous EH/ alien WH	Alien
	Plantaginaceae	*Plantago major*	1	Seed	Indigenous EH/ alien WH	–
25	Pinaceae	*Larix deciduas*	1	Cone	–	–
26	Pinaceae	*Pinus sylvestris*	2	Wood	–	–
27	Pinaceae	*Pinus sylvestris*	25	Needle	–	–
30	Poaceae	*Anthoxanthum odoratum*	1	Spikelet	Indigenous EH/ alien WH	–
31	Poaceae	*Avena sativa*	1	Spikelet	–	–
32	Poaceae	*Avena sativa*	1	Caryopses	–	–

Table 2 continued

S. no	Familly	Species	Numbers of specimens	Type of specimens	Present in Arctic	Present in sub-Antarctic
33	Poaceae	*Bromus secalinus*	1	Spikelet	Alien	–
34	Poaceae	*Bromus secalinus*	1	Caryopses	Alien	–
35	Poaceae	*Echinochloa crus-galli*	10	Spikelet	–	–
36	Poaceae	*Echinochloa crus-galli*	2	Caryopses	–	–
37	Poaceae	*Poa annua*	1	Spikelet	Indigenous EH/alien WH	Alien
38	Poaceae	*Poa annua*	5	Caryopses	Indigenous EH/alien WH	Alien
39	Poaceae	*Setaria pumila*	3	Spikelet	–	–
40	Poaceae	*Setaria pumila*	1	Caryopses	–	–
41	Polygonaceae	*Polygonum aviculare*	1	Fruit	Indigenous EH/alien WH	–
42	Polygonaceae	*Polygonum lapathifolium* subsp. *lapathifolium*	1	Fruit	Alien	–
43	Polygonaceae	*Polygonum persicaria*	3	Fruit	Indigenous EH/alien WH	–
44	Polygonaceae	*Rumex acetosa*	3	Fruit	Indigenous EH/alien WH	–
45	Polygonaceae	*Rumex acetosella*	2	Fruit	Indigenous EH/alien WH	Alien
46	Ranunculaceae	*Ranunculus acris*	1	Fruit	Indigenous EH/alien WH	–
47	Ranunculaceae	*Ranunculus repens*	1	Fruit	Indigenous EH/alien WH	Alien
48	Rosaceae	*Fragaria vesca*	1	Fruit	Indigenous	–
49	Rosaceae	*Geum urbanum* L.	1	Fruit	–	–
50	Rosaceae	*Potentilla norvegica*	1	Fruit	Indigenous EH/alien WH	–
51	Rubiaceae	*Galium aparine*	4	Fruit	Indigenous	Alien
52	Solanaceae	*Solanum nigrum*	2	Seed	–	–
53	Urticaceae	*Urtica dioica*	1	Seed	Indigenous	–

EH Eastern Hemisphere

WH Western Hemisphere

days at the sea, travelling from Poland to the Station with limited contact with plant propagules.

There were identified some species common in agriculture areas, such as cereal weeds: *Bromus secalinus* and root crops weeds: *Galinsoga parviflora, Setaria pumila* and *Echinochloa crus-galli*, or species characteristic for ruderal communities: *Chenopodium album*. Species characteristic for natural communities, like forests and meadows: *Leucanthemum vulgare* and *Lychnis flos-cuculi,* were also present in the analyzed material. Three species of crop plants: linen *Linum usitatissimum*, poppy *Papaver somniferum* and oat *Avena*

Table 3 The genus identified on the basis of poorly preserved plant material collected in the Antarctic

Genus	Family	Numbers of specimens	Type of specimens
Betula	Betulaceae	2	Wood
Carex	Cyperaceae	2	Fruit
Crepis	Asteraceae	1	Fruit
Melica	Poaceae	1	Fruit
Melica	Poaceae	1	Spikelet
Tilia	Tiliaceae	1	Wood

Table 4 Identified families or groups of poorly preserved plant collected in the Antarctic

Families or groups	Type	Numbers of specimens
Cerealia	Caryopses	8
Coniferae	Needle	1
Dicotyledones	Leaf	18
Fabaceae	Seed	1
Poaceae	Spikelet	16
Poaceae	Leaf	8
Poaceae	Stem	5
Poaceae	Caryopses	3

sativa, commonly used for food products like pastry or muesli, were found. But among collected material were also present species with range covering polar regions of Northern Hemisphere like for example: *Leontodon autumnalis*, *Carex disticha* or *Poa annua*. Some of them are highly invasive e.g., *P. annua* or *Cirsium arvense* (www.cbd.int/invasive/database.shtml) and already establish in sub-Antarctic. A lot of identified species are native to cold region of Eastern Hemisphere and alien to Western Hemisphere (Table 2).

The most interesting finding was the presence of caryopses and remains of spikelet of *P. annua* in the analysed material. There were several reports of alien plants occurring close to Antarctic stations (e.g., Smith 1996; Hughes et al. 2010a; Hughes and Convey 2010; Chwedorzewska 2009; Hughes and Convey 2010), but only *P. annua* has survived specific maritime Antarctic conditions for many years and established a stable breeding population (Olech and Chwedorzewska 2011). *Poa annua* is one of the most widely distributed plants in the world, native to Eurasia (Tutin 1952). It is a synanthropic and pioneer species (Huff 2003), adapted to a broad range of climate conditions (e.g., Frenot et al. 2001) and able to colonize such harsh environments as the maritime Antarctic. Initially *P. annua* was recorded in the Polish Antarctic Station H. Arctowski King George Island (62°09′S and 58°28′W) in 1985. Followed by a gradual increase of the *P. annua* population size, first the colonization of synantrophic places (Olech 1996, 1998), then of the forefield of retreat glacier areas (Olech and Chwedorzewska 2011) by this grass took place.

Finding caryopses in the analysed material seems to support the genetic analysis of *P. annua* population from "Arctowski". This investigation points out that the Antarctic population was probably founded by multiple introduction from different sources (Chwedorzewska 2008). This evidence supports the hypothesis of constant flow of fresh genetic material of this species to the vicinity of the station, which is reflected by an astonishingly high genetic variability in the introduced population (Chwedorzewska 2008; Chwedorzewska and Bednarek 2012). *Poa annua's* independent establishment were also documented at General Bernardo O'Higgins (63°19′S; 57°54′W), Gabriel Gonzalez Videal (64°49′S; 62°51′W) and Almirante Brown Stations (64°52′S; 62°54′W). Thus located along the Antarctic Peninsula and associated archipelagoes (Chown et al. 2012a, Molina-Montenegro et al. 2012). In the analyzed material there were also diaspores of other invasive species, for example: *Cirsium arvense* and *Galinsoga parviflora* (www.cbd.int/invasive/database.shtml).

The range of the diaspores introduced by expeditions is very wide. Most of them seem not to create a real threat for the Antarctic ecosystem, like for example schizocarps of *Galium aparine* adopted to zoochory or antropochory, or cultivated species like *Linum usitatissimum* and *Papaver somniferum*. Seeds of the two last-named species are commonly used for pastries, and could be transported with bread. These are expected to be unviable after baking. But some species numerously represented in the collected material diasporas, like these from Asteraceae family, which are adopted to anemochory, may disperse relatively easily by strong Antarctic winds. If they have the ecophysiological features required for survival in the polar environment, they could create a potential threat.

The way of reproduction is also very important in the potential invasiveness of species in the Antarctic. Species that reproduce vegetatively or are self-pollinated or anemophilous have a better chance to establish a breeding population than entomophilus species, due to the fact that in the whole Antarctic indigenous free-living entomofauna is extremely rare, with the lack of groups of pollinating insects. Only two native species of Diptera (Chironomidae) are found on the western shore of the Antarctic Peninsula and the associated archipelagos (Vernon et al. 1998) *Parochlus steinenii* and *Belgica antarctica* (Usher and Edwards 1985) and two non-native terrestrial invertebrates: *Eretmoptera murphyi* Schaeffer and *Christensenidrilus blocki* Dozsa-Farkas and Convey (Hughes and Worland 2010) found on Signy Station (South Orkney Islands). But according to our experience, through supply of the research stations a wide range of alien invertebrates can be accidentally transported in viable state and ultimately introduced to the Antarctic (Chwedorzewska in prep.). So, the two functional groups of alien organisms reached this region simultaneously: entomophilus plants and pollinator insects, which could potentially create a new synergy. On the local scale it already happens in the sub-Antarctic, where two representatives of a new ecological functional group—pollinating insects: *Eristalis croceimaculata* Jacobs (*Diptera*: *Syrphidae*) and *Calliphora vicina* Robineau-Desvoidy (*Diptera*: *Calliphoridae*) were established (Convey et al. 2010).

The range of the species found in our studies was similar to that found by Lee and Chown (2009b) in connection with materials required to construct Halley VI Antarctic Station (Dronning Maud Land) and by Chown et al. (2012a). A high proportion of species were from the taxa including globally invasive species, the most represented families were Poaceae and Asteraceae (Lee and Chown 2009b). However, alien plants are not as extensively established in the maritime Antarctic as they are on sub-Antarctic islands (Bergstrom and Smith 1990). In the sub-Antarctic Islands Frenot et al. (2005) already recorded 108 alien vascular plants and likewise the most abundant families were Poaceae (39), Asteraceae (20). They have not only survived but also spread and successfully competed with native species (Frenot et al. 1999, 2001; Gremmen and Smith 1999; Gremmen et al. 1998), thus they may serve as a potential source of exotic biota to the ameliorating maritime Antarctic.

Our study clearly demonstrates that many diaspores can be quite easily unintentionally transported in good condition to the Antarctic (Hughes et al. 2010a, b). After crossing the dispersal barrier, the next question is whether these species would be able to cross the next philological barrier and survive in harsh conditions of the polar regions. According to Chown et al. (2012a) the region of the Antarctic Peninsula and Scotia Arc archipelagos are predicted to have the highest risk of alien plant establishment, due to such factors like annual cumulative degree days for plant (measure of environmental suitability), risk index (based on propagule pressure and origin, and climate suitability of the ice-free area). Our results are in agreement with Chown's et al. (2012a) estimates. Thus, spatial location (at the Antarctic Peninsula region) and quite intensive human pressure: both tourist and expeditioner (Chwedorzewska and Korczak 2010), favourable microclimate condition (Kejna 2008), big ice-free area (about 25 km^2), newly exposed big glacial forelands, put "Arctowski" oasis in the highest risk group. Substantiation of this assessment is provided by rapid grow and spread of population of *P. annua* (Olech and Chwedorzewska 2011).

Thus, we can predict that in a very near future next flexible plant species characterized by a very wide ecological amplitude, high adaptation capabilities and diverse ways of reproduction may conquer changing environmental conditions and colonize the "Arctowski" oasis. Estimated risk of this incident is very high.

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