Diaspores of the Introduced Species *Poa annua* L. in Soil Samples from King George Island (South Shetlands, Antarctica)

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Abstract

The soil seed bank and seed germination capacity of *Poa annua* in the vicinity of the Polish Antarctic Station (South Shetlands, Antarctica) were investigated. It was documented that annual bluegrass can reproduce sexually and produce a functional seed bank of close to 5000 seeds/m^2 under maritime Antarctic conditions. Comparison of germination between *Poa annua* and two native plant species revealed that *Poa annua* seeds can germinate as fast or even faster than native species, and are more vigorous. Our studies show that in the Antarctic *Poa annua* can successfully reproduce sexually and produce fully developed, viable caryopses that are able to survive the maritime Antarctic winter, not only in a soil bank, but also directly in the previous year's inflorescences.

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Introduction

Over the past 50 years, the temperature in maritime Antarctica has been increasing more than four times faster than the Earth's average warming rate (Turner et al., 2005). This temperature increase has resulted in shortening of the winter period through earlier spring thaws and later autumn freezing, thus extending the active season for terrestrial biota (Lewis-Smith, 2001). The most vital factor is the availability of liquid water (Kennedy, 1993). Botanical responses to climate amelioration are already visible in the maritime Antarctic in the rapid increase in density and extension of distribution of indigenous vascular plant species populations (Fowbert and Smith, 1994; Vera, 2011) and in the arrival of introduced species (Chwedorzewska, 2008, 2009; Cuba-Diaz et al., 2012; Molina-Montenegro et al., 2012). The majority of documented introduced species in the Antarctic are considered human-dependent immigrants (e.g. Lewis-Smith, 1996; Olech, 1996; Pfeiffer et al., 2007; Tin et al., 2009; Chwedorzewska and Korczak, 2010; Molina-Montenegro et al., 2012).

The only introduced vascular plant species that reproduces successfully in the Antarctic is *Poa annua* (annual bluegrass) The abundance of this grass in the vicinity of the Polish Antarctic Station ''Henry Arctowski'' seems to indicate that human activity was responsible for its introduction and dissemination (Olech, 1996; Olech and Chwedorzewska, 2011). The history of *Poa annua* on King George Island reaches back to the middle 1980s (Olech, 1996). Since the first record the populations of *Poa annua* have increased markedly in density and abundance. *Poa annua* in the ''Arctowski'' oasis now seems to be more persistent than invasive, and has a restricted distribution in the area (Olech and Chwedorzewska, 2011).

Poa annua is one of the five most widely distributed plant species in the world. It is a synanthropic and pioneer species. It frequently invades heavily trafficked, closely mowed, intensively used sports turfs (Huff, 2003). This is an autogamous species, with 0–15% outcrossing, depending on environmental conditions (Ellis, 1973). Apomixis was also observed (Johnson et al., 1993). *Poa annua* has adapted to a broad range of weather conditions, from cold polar regions to hot deserts (Darmency and Gasquez, 1981; Frenot et al., 2001). The species has developed a different degree of freezing tolerance, even up to -27 °C (Dionne et al., 2010). Seeds can germinate over a wide range of environmental conditions (Vargas and Turgeon, 2004; Giełwanowska et al., 2005). Such traits help in the colonization of such harsh environments as the maritime Antarctic. The wide distribution of this species is a result of its high colonizing ability (Law, 1981; Frenot et al., 1999; Heide, 2001). *Poa annua* is native to Eurasia (Tutin, 1952, 1957). It grows and reproduces rapidly, in one season yielding even 20,000 seeds per individual, which may retain viability for several years (Hutchinson and Seymour, 1982). The species has been widely studied in the context of golf course grass. These studies indicated rapid reproduction and maintenance of a viable seed bank aiding in its persistence (Vargas and Turgeon, 2004; Lush, 1988a, 1988b). Lush

(1988a) estimated that soil from an active population of annual bluegrass contains as many as 210,000 seeds per square meter.

Information about the soil seed bank of Earth's coldest regions originates mainly from research conducted in the Arctic (e.g. Cooper et al., 2004) and alpine communities (e.g. Diemer and Prock, 1993; Marcante et al., 2009). This research concludes that not very numerous, tundra plant species develop a viable seed bank enabling them to reestablish after disturbance events. Some seed bank research has also been conducted in the southern hemisphere, revealing the ability of formation of soil seed banks by subantarctic tundra plant species at the southern limits of South America (Arroyo et al., 2004). However, both these systems differ substantially from the maritime Antarctic, where vascular plant species richness is irrelevant. There is only limited information about the soil seed bank in the Antarctic (McGraw and Day, 1997; Ruhland and Day, 2001). Both studies indicate that native Antarctic species develop a persistent soil seed bank of under 6000 seeds/m^2.

The objective of this study was to estimate the seed reservoir of *Poa annua* in the vicinity of the Polish Antarctic Station. Our question was whether the annual bluegrass produces a functional seed bank in Antarctic conditions, which together with changing climate may in the future influence local vegetation dynamics. We also wanted to compare the germinability of seeds between *Poa annua* and two native vascular plants, *Deschampsia antarctica* Desv. and *Colobanthus quitensis* (Kunth) Bartl. to check if *Poa annua* has a potential advantage over the native species in seed germination and colonization of ice-free land.

Material and Methods

ANALYSIS OF SOIL SEED BANK OF POA ANNUA

Soil sampling was conducted at the end of the austral summer 2009/2010, on the west shore of Admiralty Bay in the vicinity of H. Arctowski Station and the area of Antarctic Specially Protected Area 128 (King George Island, South Shetland Islands, 62°10′S, 58°30′W). Two methods of soil seed bank estimate were used; therefore, two sets of samples (86 samples each) were collected from the area occupied by the population of *Poa annua* at the Antarctic Station. Each sample (50 mm diameter, 50 mm deep, and about 100 mL of soil volume) was taken from the very vicinity of a *Poa annua* clump (20–50 mm) at the southern exposure. Therefore, each set of samples amounted to around 0.17 m^2 of soil surface and around 8.4 L of collected soil. After collection, one set of samples for soil seed bank estimate with the ''extraction'' method was air dried and transported at 4 °C to the laboratory. Subsequently, we separated samples on sieves of mesh size 2 mm and 0.5 mm. From a 0.5–2 mm soil fraction we extracted seeds under a stereoscopic microscope. Only intact seeds were counted. The other set of samples for soil seed bank estimate with the ''germination'' method was frozen upon collection at −20 °C and transported to the laboratory. Subsequently, we dried all samples at 10 °C and separated them on sieves of mesh size 2 mm and 0.25 mm. We placed the sieved soil in separate containers for each sample. A 0.25–2 mm soil fraction was spread evenly as a thin layer on the top of a <0.25 mm soil fraction. Containers were watered as required and placed in a climate control chamber with a 16 h day at 16 °C and an 8 h night at 10 °C to promote germination. We checked seed germination every week for 13 weeks.

COMPARISON OF GERMINATION BETWEEN THREE SPECIES

In order to compare the germination of *Poa annua* seeds with the other two native angiosperms (*Deschampsia antarctica* and *Colobanthus quitensis*) in January 2010 mature seeds with no traces of mechanical damage were collected from the previous year's inflorescences. All seeds were moist due to snow cover. Germination tests were performed on 300 *Poa annua* seeds, 300 *Deschampsia antarctica* seeds, and 200 *Colobanthus quitensis* seeds in the station laboratory directly after seed collection. Seeds were placed in 9-cm-diameter Petri dishes on wet filter paper saturated with distilled water and sealed to prevent excessive water loss and were placed in about 20 °C during the light period and 4 °C during the dark period. Germination was checked every day for 8 weeks (duration of germination experiment was restricted by weather conditions). After the experiment the plant material was incinerated. Pairwise comparisons of Kaplan-Meier survival probability curves between *Poa annua* and the other species were performed with Cox-Mantel test using Statistica 9 (StatSoft, 2009).

Results

SOIL SEED BANK SIZE OF POA ANNUA

We extracted 1032 seeds from soil samples analyzed with the ''extraction'' method. The mean seed density corresponded to 4847 ± 695 (mean ± SD) per square meter (Table 1). In the ''germination'' method altogether 12 seeds germinated from 7 samples. This corresponded to 58.7 ± 12.65 (mean ± SD) seeds per square meter. All except one seed germinated within 4 weeks after the start of the experiment. We did not find any correlation between seed count per sample assessed with the ''extraction'' and ''germination'' methods.

GERMINATION OF POA ANNUA AND TWO NATIVE ANGIOSPERM SPECIES

Germination tests of freshly collected seeds showed that first germination occurred after 7 days for *Poa annua*, 1 day for *Colobanthus quitensis*, and 13 days for *Deschampsia antarctica* (Fig. 1). No seeds germinated after the 16th day of the experiment. The mean germination success at the end of the test was 45% for *Poa annua*, 35% for *Colobanthus quitensis*, and 14% for *Deschampsia antarctica*

TABLE 1

Characteristics of soil seed bank of *Poa annua* in the vicinity of Polish Antarctic Station ''Henry Arctowski.''

Assessment method	Seed count (seeds)	Mean seed density (seeds/m^2)	Standard deviation seed density (seeds/m^2)
Extraction	1032	4847	695
Germination	12	58.7	12.65

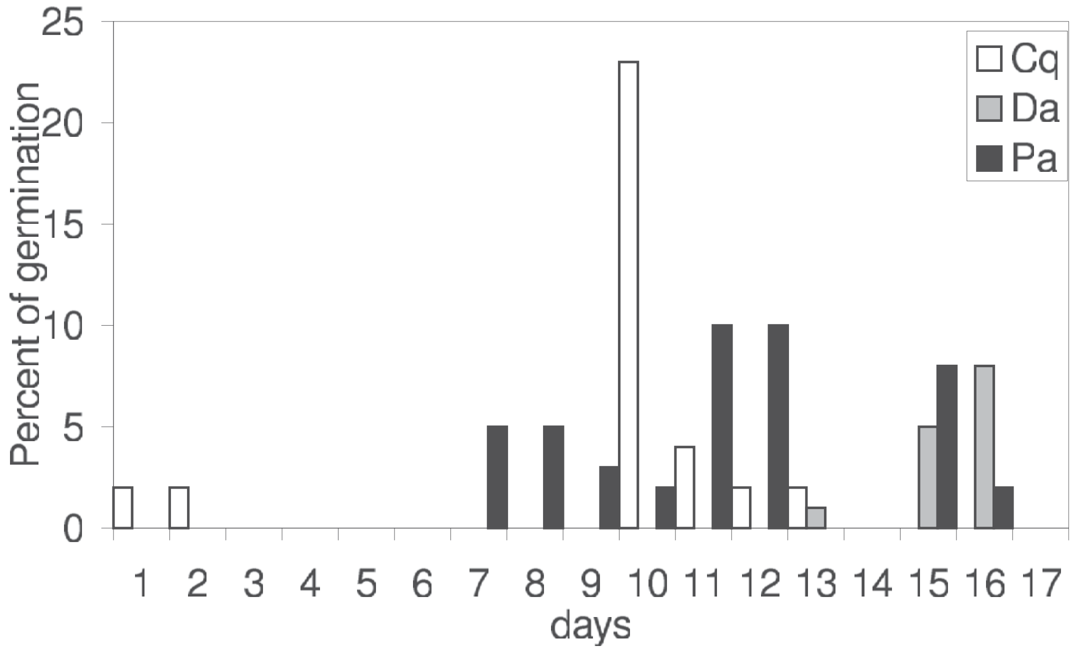

FIGURE 1. Comparison of germination between three species occurring in the vicinity of Polish Antarctic Station ''Henry Arctowski'': *Poa annua* (Pa), *Colobanthus quitensis* (Cq), and *Deschampsia antarctica (Da).*

psia antarctica. Mean germination time for seeds that germinated during our experiment was, respectively, 11.2, 9.4, and 15.4 days. There were significant differences between the germination probability curves of *Poa annua* and *Deschampsia antarctica* (Cox-Mantel test $C = 9.149$, $p < 0.00001$). No significant differences were found between *Poa annua* and *Colobanthus quitensis* (Cox-Mantel test $C = 1.699$, $p > 0.08$).

Discussion

INTRODUCED SPECIES IN ANTARCTICA

The number of alien species introduced temporarily in the Antarctic is still small (Lewis-Smith, 1996, Chwedorzewska, 2009). It is noteworthy that plant species introduced even in imported soil from site of origin did not persist longer than a couple of winter periods (Corte, 1961; Holdgate, 1964). Only *Poa annua* has survived at Arctowski Station since 1985 and seems to have established a stable population (Olech, 1998; Olech and Chwedorzewska, 2011). Our latest studies show that a lot of non-indigenous propagules entered the Arctowski Station via cargo, personal clothing, and equipment of expeditioners (Lityńska-Zając et al., 2012; Chwedorzewska et al., 2013). This clearly demonstrates that many intact diaspores can be quite easily unintentionally transported to the Antarctic. The most interesting finding was the presence of caryopses of *Poa annua* (Lityńska-Zając et al., 2012). Therefore, the growth of the local population of this species may be a result of enriching the existing gene pool by newcomers (Chwedorzewska and Bednarek, 2012).

SOIL SEED BANK IN ANTARCTIC CONDITIONS

A seed bank is an important life history trait for many plant species (e.g. Baskin and Baskin, 2001; Bochenek et al., 2010). This strategy enables species to endure suboptimal environmental conditions in the form of living diaspores (Thompson and Grime, 1979). When the conditions improve, seeds buried in soil germinate and replenish standing populations. Seeds dispersed on a site may therefore change the appearance of a plant community after a change in environmental conditions. Research in Italian Alps showed that, with climate warming ranges of alpine species expanded (Parolo and Rossi, 2008). With increased touristic traffic also, species from the subantarctic tundra (Arroyo et al., 2004) may contribute to the soil seed bank of the Antarctic Peninsula region. Thirteen out of fifteen species from the subantarctic region studied by Arroyo et al. (2004) showed the potential to form a soil seed bank. It might be only a matter of time when some of those species reach Antarctica and contribute to the local vegetation.

Poa annua can develop a substantial seed bank in optimal conditions (Lush, 1988a), which aids in dispersal and persistence of this species on a site. With the changing climate in maritime Antarctica (Convey, 2006), seeds of this species deposited over time may contribute to extent vegetation. Our research shows that the size of the *Poa annua* seed bank is comparable to the size of the *Deschampsia antarctica* seed reservoir, and about five times larger than the seed bank of *Colobanthus quitensis* (data for native Antarctic species—see Ruhland and Day, 2001). The difference in seed bank size assessment with the ''germination'' and ''extraction'' methods may be the result of transporting the seeds for the germination method in -20 °C. Although air temperature in the Antarctic falls well below -20 °C, soil temperature may be higher due to the insulation of snow cover. Nevertheless, seeds germinating from the soil samples indicate that *Poa annua* present at the site has developed high levels of freezing tolerance and confirm the findings of Dionne et al. (2010). Following the worst scenario, *Poa annua* being a fertile species (Lush, 1988b) may dominate the soil seed bank and compete with two indigenous species of vascular plants in the Antarctic.

GERMINATION SUCCESS OF POA ANNUA *IN MARITIME ANTARCTICA—FIRST STEP TO INVASION?*

Germination trials of *Poa annua* seeds show that in harsh Antarctic conditions the species is able to produce large amounts of mature, viable seeds, which can germinate relatively quickly and easily. Germination characteristics of *Poa annua* did not differ significantly from the germination of *Colobanthus quitensis*. First germination for *Colobanthus quitensis* occurred faster, but for only a small percent of seeds. The germination success, mean germination time, and germination probability curves were relatively similar for both species. We found higher discrepancies between the germination characteristics of *Poa annua* and *Deschampsia antarctica*. The time of first germination and mean germination time were both shorter for *Poa annua* giving the species the advantage of an earlier start in the short growing season in the Antarctic. Those traits may, however, present a disadvantage in exposing newly germinated seedlings to colder conditions. There might also be an interaction between earlier germination and higher germination capacity favoring the strategy presented by *Poa annua* over the later germination with lower germination success of *Deschampsia antarctica*. We may therefore speculate that *Deschampsia antarctica* might be more prone to competition pressure of annual bluegrass than *Colobanthus quitensis*.

Conclusion

Poa annua as an alien species in the Antarctic tundra can successfully reproduce generatively with almost 50% of fully developed, viable caryopses, which can survive the maritime Antarctic winter not only in the soil seed bank, but also directly on the previous year's inflorescence. Seeds can germinate as fast or even faster than native species and are more vigorous. This preliminary research suggests that *Poa annua* may pose a serious threat to the sensitive polar terrestrial ecosystem, which lacks competitive abilities, but more detailed and more complex studies are needed. Moreover, much more intensive efforts should be taken to stop new introductions.

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