Research Note

Occurrence of the Non-Native Annual Bluegrass on the Antarctic Mainland and Its Negative Effects on Native Plants

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Abstract: *Few non-native species have colonized Antarctica, although increased human activity and accelerated climate change may increase their number, distributional range, and effects on native species on the continent. We searched 13 sites on the maritime Antarctic islands and 12 sites on the Antarctic Peninsula for annual bluegrass (*Poa annua*), a non-native flowering plant. We also evaluated the possible effects of competition between* P. annua *and 2 vascular plants native to Antarctica, Antarctic pearlwort (*Colobanthus quitensis*) and Antarctic hairgrass (*Deschampsia antarctica*). We grew the native species in experimental plots with and without annual bluegrass under conditions that mimicked the Antarctic environment. After 5 months, we measured photosynthetic performance on the basis of chlorophyll fluorescence and determined total biomass of both native species. We found individual specimens of annual bluegrass at 3 different sites on the Antarctic Peninsula during the 2007–2008 and 2009–2010 austral summers. The presence of bluegrass was associated with a statistically significant reduction in biomass of pearlwort and hairgrass, whereas the decrease in biomass of bluegrass was not statistically significant. Similarly, the presence of bluegrass significantly reduced the photosynthetic performance of the 2 native species. Sites where bluegrass occurred were close to major maritime routes of scientific expeditions and of tourist cruises to Antarctica. We believe that if current levels of human activity and regional warming persist, more non-native plant species are likely to colonize the Antarctic and may affect native species.*

Keywords: *Colobanthus quitensis*, *Deschampsia antarctica*, hairgrass, non-native species, pearlwort, species competition, tourism, *Poa annua*

Resumen: *Pocas especies no nativas han colonizado la Antártica, aunque por incremento de la actividad humana y el cambio climático acelerado su número, rango de distribución y efectos sobre especies nativas pueden aumentar. Muestreamos 13 sitios en las islas Antárticas y en 12 sitios de la Península Antártica para buscar* Poa annua, *una planta anual no nativa. También evaluamos los posibles efectos de la competencia entre* P. annua *y dos especies de plantas vasculares nativas de la Antártica,* Colobanthus quitensis *y* Deschampsia antarctica*. Crecimos las especies nativas en maceteros con y sin* P. annua *bajo condiciones similares al ambiente*

Paper submitted July 28, 2011; revised manuscript accepted January 19, 2012.

Conservation Biology, Volume 26, No. 4, 717–723

DOI: 10.1111/j.1523-1739.2012.01865.x

Antártico. Después de 5 meses, medimos el funcionamiento fotosintético basado en la fluorescencia de clorofila y determinamos la biomasa total de ambas especies nativas. Encontramos individuos de P. annua *en tres sitios diferentes de la Península Antártica durante los veranos australes de 2007–2008 y 2009–2010. La presencia de* P. annua *se asoció con una reducción estadísticamente significativa en la biomasa de* C. quitensis *y* D. antarctica*, mientras que el decremento en la biomasa de* P. annua *no fue estadísticamente significativa. Similarmente, la presencia de* P. annua *redujo significativamente el funcionamiento fotosintético de las dos especies nativas. Los sitios con* P. annua *estaban cerca de rutas marítimas de expediciones científicas y cruceros turísticos. Consideramos que si persisten los niveles actuales de actividad humana y de calentamiento regional, es probable que más especies de plantas no nativas colonicen la Antártica y afecten a las plantas nativas.*

Palabras Clave: *Colobanthus quitensis*, competencia de especies, *Deschampsia antarctica*, especie no nativa, *Poa annua*, turismo

Introduction

The Antarctic continent has been isolated from other landmasses for over 25 million years, and most species of terrestrial plants and animals became extinct during major glacial advances, particularly after the end of the Miocene (Ellis-Evans & Walton 1990; Convey 2008). The Antarctic Circumpolar Current and the prevailing atmospheric circulation patterns form a strong barrier to passive transport of potential colonizers (Barnes et al. 2006; Hughes et al. 2010). Human activities are now reducing Antarctica's biological isolation (Tin et al. 2009). Low species richness and thus relatively simple community structure make Antarctic ecosystems particularly likely to change in response to colonization by non-native species (Frenot et al. 2005). Human travel is becoming a major vector for the transfer of propagules, such as seeds, eggs, and spores, of species that are not native to Antarctic ecosystems (Frenot et al. 2005; Hughes et al. 2010).

Some plants already have colonized the Antarctic region, particularly the sub-Antarctic islands (Frenot et al. 2005; Chwedorzewska 2008, 2009). Accelerated climate change (over 0.11 °C increase in temperature per decade in the last 50 years in parts of the Antarctic Peninsula) and increased human activity are increasing the number, extent, and effects of non-native species on Antarctic ecosystems (Tin et al. 2009; Hughes et al. 2010). Studies of biological invasions on sub-Antarctic islands have largely focused on the direct effects of vertebrate species, such as domestic cats, rabbits, and rats (Frenot et al. 2005).

Recent studies of invasive plants and invertebrates on sub-Antarctic islands have shown that the distributions of these species can expand rapidly, potentially altering population and ecosystem processes (Frenot et al. 2005; Chwedorzewska 2008; Convey et al. 2010, 2011). For example, over the past 50 years, creeping bentgrass (*Agrostis stolonifera* [Poaceae]) has colonized drainages on Marion Island and has excluded native plants and substantially decreased the species richness of the colonized sites (Gremmen et al. 1998). The maritime region of Antarctica, including the South Shetland Islands, has fewer reports (only 2 [Frenot et al. 2005; Chwedorzewska 2008]) of established non-native plant species than the sub-Antarctic islands because its environment impedes plant establishment. For continental Antarctica, before the present study, there was only one record of non-native plant establishment (Smith 1996; Convey 2008). Despite the central role of competition in the successful establishment of some non-native plants (Daehler 2003), no study has yet quantified the strength and effects of competition between non-native and native plant species inhabiting any region of Antarctica.

We studied the establishment and modest spread of a non-native plant species, the annual bluegrass (*Poa annua* [Poaceae]), at several sites on the Antarctic Peninsula. This species has already become widespread on several sub-Antarctic islands. We also evaluated experimentally the effects of competition between bluegrass and the 2 species of vascular plants native to Antarctica, pearlwort (*Colobanthus quitensis* [Caryophyllaceae]) and hairgrass (*Deschampsia antarctica* [Poaceae]). Finally, we considered potential vectors for bluegrass and the potential future dispersal and effects of non-native plant species in Antarctica.

Methods

We searched for bluegrass at 13 sites on the maritime Antarctic islands and 12 sites on the Antarctic Peninsula during the Chilean Scientific Antarctic Expeditions of 2007–2008 and 2009–2010 (austral summers). The area of each site we visited was between 0.3 and 1 ha. We selected sites on the basis of ease of access and the presence of tourists and logistics operators responsible for scientific activities. Bluegrass was recorded previously on various sub-Antarctic islands (e.g., Marion, Crozet, Prince Edward, Kerguelen, and Heard) and King George Island in the maritime Antarctic South Shetland Islands, but not on the Antarctic mainland (Smith 1996; Frenot et al. 2005; Chwedorzewska 2008). Bluegrass originates from Eurasia and is considered a harmful organism, crop pest, and potential seed contaminant worldwide. It is widespread and considered a weed in many temperate regions (Mengistu et al. 2000).

We performed an experiment to assess potential effects of bluegrass on pearlwort and hairgrass. We collected bluegrass, pearlwort, and hairgrass individuals from the South Shetland Islands. All individuals collected were healthy adults growing in tussocks in ice-free zones near the coast. When we uprooted a tussock, we were careful to maintain a ball of soil around the roots (approximately 500 g of soil). We transported plants in well-watered plastic boxes to growth chambers at the Universidad de Concepción (Concepción, Chile). Here, we carried out a common-garden experiment with pearlwort and hairgrass in which both species were grown in monoculture and with bluegrass.

We filled 60 300-mL plastic pots with soil taken from the South Shetland Islands at the time of plant collection. To minimize damage to roots, we carefully separated individuals from the tussocks. The fresh biomass (i.e., not including dried parts of a plant) and physiological status of experimental plants (see later) was determined before transplantation and after the completion of the experiment. Each of 2 treatments had 15 replicates (pots). Treatments consisted of 15 pots with 10 pearlwort or 10 hairgrass plants and 15 pots with 5 bluegrass growing with 5 pearlwort or 5 hairgrass. We transferred pots to growth chambers with 20 h light and 4 h dark photoperiods at 4 °C. We administered 50 mL of water to each pot every 8 days. Levels of light, temperature, and water inside the growth chambers were similar to natural conditions in the Antarctic Peninsula during the 2007–2008 austral summer (M.A.M-M., unpublished data). The experiment lasted 5 months (November to March), which is the length of the growing season in the Antarctic Peninsula.

Competition can be inferred from decreased photosynthesis (Niu et al. 2005) as measured by chlorophyll fluorescence (Maxwell & Johnson 2000). We measured chlorophyll fluorescence with a pulse-amplitude modulated fluorometer (FMS 2, Hansatech, Instruments, Norfolk, U.K.). We placed green tissue that appeared to be healthy from each individual ($n = 10$ plants/pot) in the dark for 30 min. We placed the entire pot in the dark to ensure maximum photochemical efficiency (i.e., transfer of luminous energy into chemical energy). We measured photochemical efficiency of the photosystem II within the thylakoid membranes of the chloroplast (Fv/F_{max}, where $Fv = [F_{max}\text{–}F_{min}]$, F_{max} is maximum fluorescence yield, and F_{min} is minimum fluorescence yield) as a photosynthetic performance parameter (Maxwell & Johnson 2000). We compared initial biomass and level of photosynthesis between treatments with one-way analysis of variance (ANOVA). Because neither initial biomass nor photosynthetic performance were significantly different between treatments (with and without bluegrass presence) for both hairgrass ($F_{1,28} = 0.21$, $p = 0.69$ and $F_{1,28} = 0.19$, $p = 0.62$, respectively) and pearlwort ($F_{1,28} = 0.11$, $p = 0.82$ and $F_{1,28} = 0.79$, $p = 0.64$, respectively), we assessed differences between treatments at the end of the experiment with one-way ANOVA.

We calculated the relative competition intensity index (RCI) (Grace 1995) between pearlwort or hairgrass and bluegrass. The response variable was biomass of each species at the end of the experiment (B_{sp}). Before recording the final biomass, we washed roots of all plants to remove the soil. Thus, we assessed the competitive effect of bluegrass on both native species ($RCI_{pearlwort} = [B_{pearlword}\text{control}–B_{pearlwort}\text{bluegrass}]/B_{pearlwort}\text{control}$; $B_{haigrass} = [B_{hairgrass}\text{control}–B_{haigrass}\text{bluegrass}]/B_{hairgrass}$ control), and we assessed the resistance to invasion of native species by measuring its effect on bluegrass ($RCI_{bluegrass} = [B_{bluegrass}\text{monoculture}–B_{bluegrass}\text{with native}]/B_{bluegrass}\text{monoculture}$).

Finally, we attempted to identify potential dispersal vectors for bluegrass. We determined the spatial association between the newly discovered and the most heavily used maritime transport routes and tracks (from South America to the Antarctic region) of cruise ships and military and scientific vessels. The number of trips in 2000–2010 was compiled from the Chilean Navy, Argentinean Navy, Chilean Antarctic Institute, and publicly accessible databases from a range of national scientific programs and various tour operators working in Antarctica (IAATO 2008).

Results

During the 2007–2008 austral summer, we found an individual bluegrass in 2 separate locations on the Antarctic Peninsula (Fig. 1). The first was adjacent to General Bernardo O'Higgins station (63°19′S; 57°54′W), northern Graham Land, and the second was near Gabriel González Videla station (64°49′S; 62°51′W) in Paradise Bay. We did not visit the sites during the 2008–2009 summer, but during the 2009–2010 summer, we found 2 additional individuals in a new location near Almirante Brown station (64°52′S; 62°54′W), also in Paradise Bay. There was also a modest increase in abundance of bluegrass at the 2 locations where it was recorded in 2007–2008. Two and 4 individuals were observed in the 2009–2010 summer, respectively. We believe these increases indicate persistence and recruitment, not new introductions. All individuals near Chilean stations were eradicated after the 2009–2010 summer growing season.

Photosynthesis and growth of native plant species were affected by the presence of bluegrass. After 5 months, pearlwort and hairgrass individuals growing with bluegrass had significantly lower photosynthetic performance (Fv/Fm) than individuals growing with conspecifics (pearlwort: $F_{1,28} = 178.67$, $p < 0.001$; hairgrass: $F_{1,28} = 149.24$, $p < 0.001$) (Fig. 2). Similarly, both native species showed significantly lower biomass increase when growing with bluegrass (pearlwort:

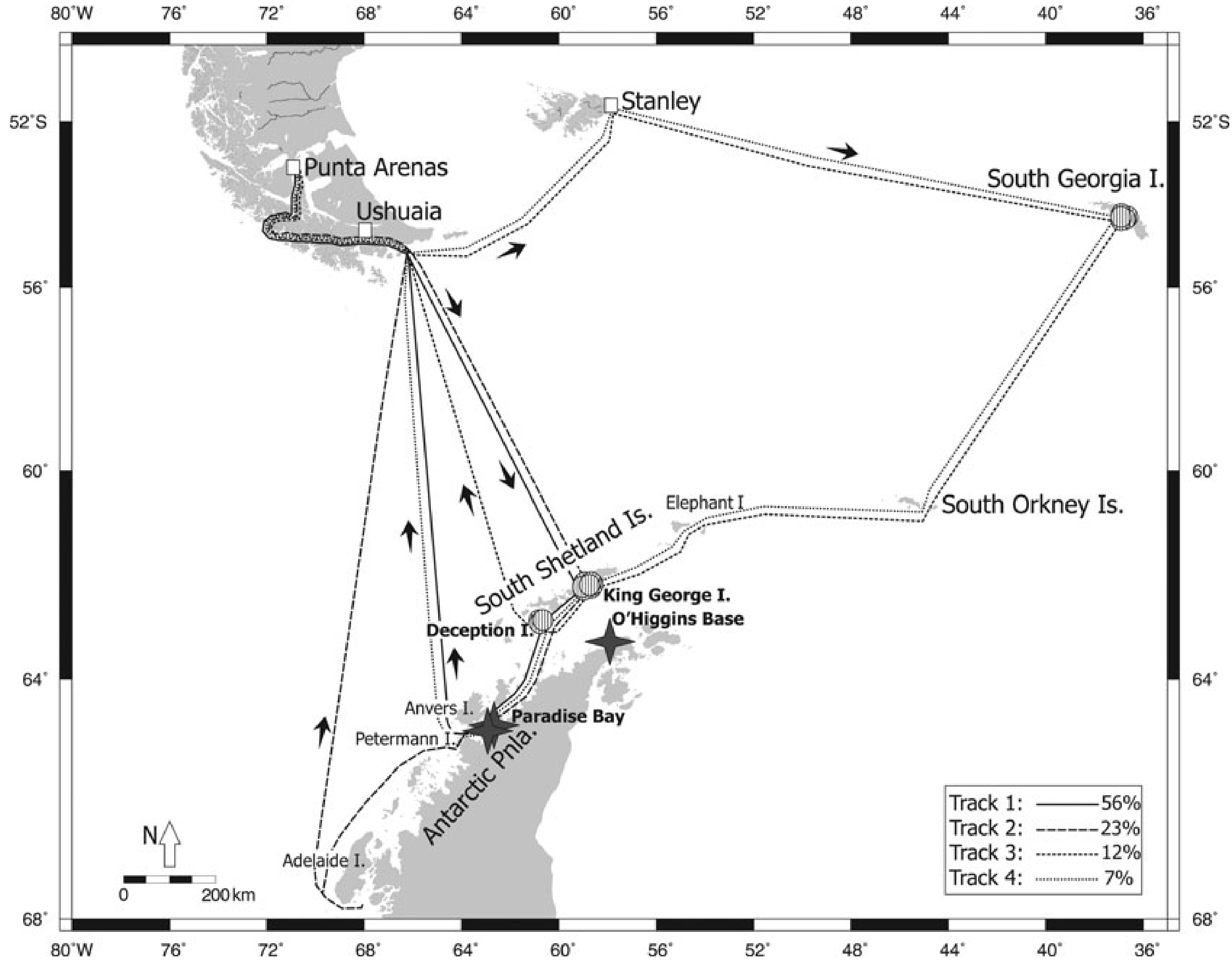

Figure 1. *Sites on the Antarctic continent and neighboring regions of the Southern Ocean where bluegrass was recorded previously (circles) and where we found new occurrences (stars). The 4 main maritime routes of transport and tracks of cruise ships that visit this region are shown. Differences in the percentage of trips among main routes are denoted with different types of lines (sources: Costin & Moore 1960; Corte 1961; Longton 1966; Young 1971; Walton & Smith 1973; Walton 1975; Pratt & Smith 1982; Convey 1996; Olech1996; Smith 1996; Chown & Block 1997; Frenot et al. 1997, 2005, 2008; Gremmen & Smith 1999; McIntosh & Walton 2000; Gerighausen et al. 2003; Gianoli et al. 2004; Scott & Kirkpatrick 2005; Chwedorzewska 2008; Hughes et al. 2010).*

$F_{1,36} = 20{,}417.8, p < 0.001$; hairgrass: $F_{1,36} = 14{,}760.1, p < 0.001$) (Fig. 2). The biomass of pearlwort and hairgrass decreased by 26% and 32%, respectively, when grown with bluegrass. In contrast, the biomass of non-native bluegrass decreased by 2% and 5% when grown with pearlwort and hairgrass, respectively.

Four transportation routes accounted for 98% of total traffic (Fig. 1). With one exception, all the Antarctic islands and peninsular locations where bluegrass has been recorded, as documented in earlier reports and in this study, lie along these routes (Fig. 1). The exception is the location at the General Bernardo O'Higgins station, northern Antarctic Peninsula, which is visited by Chilean supply vessels.

Discussion

Annual bluegrass is 1 of the 2 non-native vascular plant species that has established in the Antarctic islands (Smith 1996; Chwedorzewska 2008). Healthy individuals of *Poa pratensis* were found at Cierva Point (64°02′S; 61°02′W) during the summer growing season of 1960–1961 (Corte 1961, cited in Smith 1996). *P. pratensis* is not known to have spread beyond this site as of 1995 (Smith 1996), although its current status is unknown. With rapid climate change occurring in some parts of Antarctica, in particular the Antarctic Peninsula and the Scotia arc (Convey et al. 2009), greater numbers of successful dispersal and establishment events are likely to occur (Bergstrom &

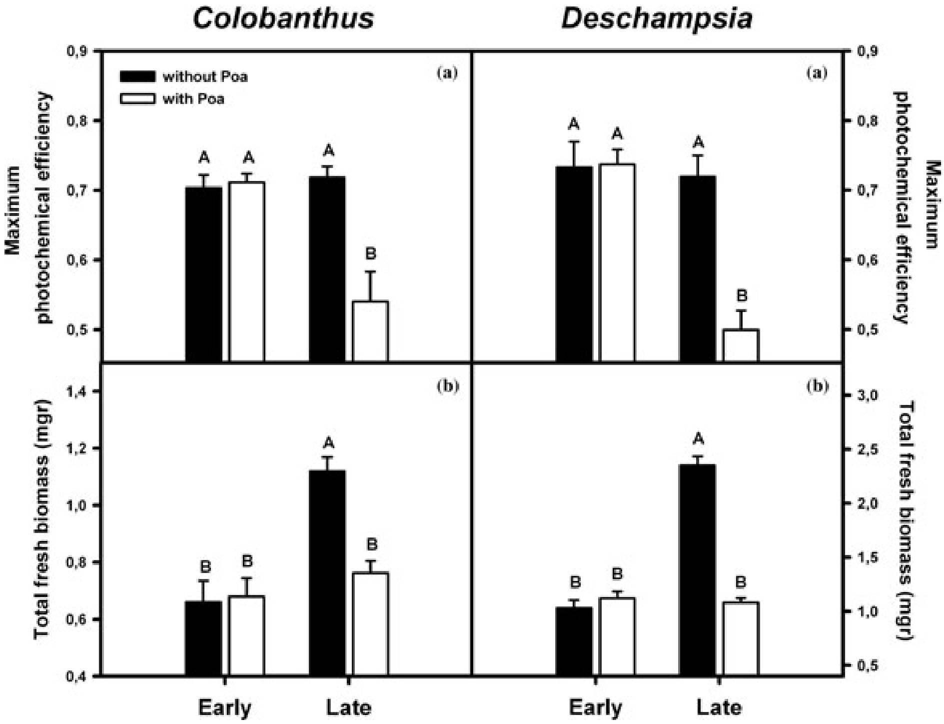

Figure 2. *Mean (SE) (a) maximum photochemical efficiency and (b) total fresh biomass (i.e., living tissue) of the native Antarctic plants, pearlwort (*Colobanthus quitensis*) and Antarctic hairgrass (*Deschampsia antarctica*) growing in association with the non-native plant annual bluegrass (*Poa annua*) (black bars) or in monoculture (white bars) at early and late stages (0 and 5 months, respectively) of the experiment. Significant differences between treatment means are denoted with different letters (Tukey test,* $\alpha = 0.05$*).*

Chown 1999; Frenot et al. 2005). Current climate-change trends are expected to increase the probability of spread of plant species across the Antarctic Peninsula, and locally large increases in abundance and geographic extents of 2 native flowering plants have been recorded (Fowbert & Smith 1994; Parnikoza et al. 2009). For example, in a recent study, Torres-Mellado et al. (2011) found an increase of 22% in the abundance of these plants and more than 7 new plant clusters. The expected climate-driven expansion of plant distributions applies both to the native flora and to any new species that becomes established, whether by natural or human-assisted means.

Non-native plants may pose a substantial threat to native species (Daehler 2003). We demonstrated for the first time the potentially negative effects of a non-native plant on the native vascular flora of Antarctica. The marked asymmetry of competitive effects between bluegrass and native plants suggests that the future spread of this non-native species across Antarctica may result in decreased growth of both pearlwort and hairgrass. Bluegrass now occurs on more than 6 sub-Antarctic islands (Frenot et al. 2005), and we have demonstrated it has the potential to further expand its distribution on the Antarctic mainland.

In recent decades the atmospheric and oceanic barriers to dispersal around Antarctica (Barnes et al. 2006) have been increasingly circumvented by the rapid increase in human activities. Introduction routes are largely associated with movement of people and cargo in association with national scientific programs and tourist operations (e.g., Tin et al. 2009). The number of tourists has increased nearly 5-fold since 1992 (IAATO 2008; Lynch et al. 2010), and government operators are responsible for approximately 5000 scientists and support staff visiting the continent annually. Many tourist and research vessels undertake activities on sub-Antarctic islands and then visit a range of Antarctic locations. Without strict controls, such operations may transport non-native and potentially invasive species that may be able to tolerate the Antarctic environment (Frenot et al. 2005; Convey 2008).

Climate change is likely to enhance the physiological performance and the competitive ability of non-native species that colonize Antarctica, either by moving naturally over long distances or through human assistance, and effects on Antarctic terrestrial ecosystems within which they become established will be unavoidable. Some initiatives been established to avoid the arrival and spread of non-native propagules (Hughes et al. 2010; Hughes & Convey 2010), and the issue of introduced propagules is now receiving serious attention within the Committee for Environmental Protection of the Antarctic Treaty System. Prevention is generally preferable to eradication. However, once establishment of a non-native species is reported, the most practical and effective action is immediate eradication (Hughes & Convey 2012). We, therefore, strongly recommend that the newly established plants of bluegrass reported here be removed by the operators responsible for the respective research stations, as we have done at the Chilean scientific stations.

Acknowledgments

We are grateful to R.M. Callaway, B.R. Broitman, K.J. Chwedorzewska, M.A. Nuñez, and D.M. Richardson for helpful and constructive comments on an earlier version of the manuscript. We also thank Y. Frenot and S.L. Chown for providing pivotal references. We thank the Chilean and Argentinean Navy for providing information about the routes of transport and tracks of cruise ships. We acknowledge the financial support of the Chilean Antarctic Institute (project T-14-08) and especially thank E. Flores for logistic support during the Antarctic expeditions. The final stage of manuscript writing was supported by the Comisión Nacional de Investigación Científica y Tecnología (MEC-80090005 project). This is a contribution to the Evolution and Biodiversity in Antarctica research program sponsored by the Scientific Committee on Antarctic Research. Marco A. Molina-Montenegro dedicates this article to Felissa (rest in peace).

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