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INTRODUCTION

Introduction to the special issue on the Life in Antarctica: Boundaries and Gradients in a Changing Environment (XIth SCAR Biology Symposium)

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Abstract Scientific research in Antarctica has reached maturity in recent decades. The interest in issues related to knowledge about the southern polar regions has increased significantly among researchers from all scientific and technological disciplines. Among the various fields, biology comprises perhaps the highest concentration of related activities and encompasses the most diverse research topics. This increase in the research activity has to be translated in a greater coordination research efforts. The *Scientific Committee of Antarctic Research* has positioned itself as the focal point of this activity, with the organized symposiums being the best forum to share and report progress in various fields. This was the philosophy of XIth Scientific Committee on Antarctic Research Symposium held in Barcelona in July 2013. The different contributions of the symposium developed around a main topic: "Life in Antarctica: Boundaries and Gradients in a Changing Environment". The symposium had the objective of linking the functional importance of land and water ecosystems with their bio-complexity under an ecosystem perspective. Such an approach will lead to a better understanding of Antarctic food webs, effects of human impacts (e.g., ozone hole, climate change, tourism), flexible boundaries and dynamic gradients in Antarctic ecosystems, as well as Antarctic marine biodiversity through its patterns, processes and trends.

Keywords XIth SCAR Biology Symposium · Antarctic life · Antarctic biodiversity · Terrestrial biocomplexity · Human impacts · Physical and biogeochemical processes

Introduction

The Southern Ocean has been defined from a geopolitical point of view by the Antarctic Treaty (1 December 1959) as any mass of water located south of 60° south. However, this definition does not take into account the Antarctic-specific needs in terms of oceanography, topography or biology, and nor does it include the sub-Antarctic regions. From an oceanographic point of view, the Southern Ocean is bounded on the north by the Antarctic Convergence (a natural boundary including most fronts and currents), while on the south it is bounded by the Antarctic continent. On the northern border is the Antarctic Circumpolar Current (ACC), which is placed between the Subantarctic Front (SF) to the north and the Polar Front (PF) to the south. The ACC forms a permeable barrier with little heat exchange between the warm waters of the north and the cold waters of the Southern Ocean. Therefore, there is a gradient of temperature, salinity and a very high density on both sides of the ACC.

However, from a topographical point of view, the Southern Ocean involves the Antarctic continental shelf, the continental slope associated with the abyssal plains surrounded by mid-ocean ridges such as the Atlantic-Indian, the Pacific-Antarctic or the Indian-Antarctic ridges,

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and also includes the Scotia Arc Islands and the Kerguelen Plateau. The total area comprises about 34.8 million km^2, of which up to 21 million km^2 may be covered by ice during the winter and about 7 million km^2 during the austral summer (Aronson et al. 2007). The continental shelf in Antarctica reaches an average depth of 500 m (in other oceans, typically 100–200 m), although some areas can reach 1000 m or more in depth, presumably due to the weight of the ice on the continent (Clarke and Johnston 2003). Therefore, conventionally, the 1000-m isobath has been designated the edge of the Antarctic continental shelf and the beginning of the continental slope (Clarke and Johnston 2003), while the 3000-m isobath denotes the boundary between the slopes and the abyssal plains. However, we have to take into account that there are some areas that can reach more than 7200 m in depth, as in the South Sandwich Islands Trench.

Lastly, when referring to the biogeography of the species in the Southern Ocean and its bioregionalisation, two main regions with different biological characteristics can be distinguished: the Antarctic region and the sub-Antarctic region (Hedgpeth 1969; Griffiths et al. 2009). The Antarctic region extends from the Antarctic continent to the PF, including the Scotia Arc Islands, South Georgia, Bouvet Island and the Kerguelen Plateau. The Sub-Antarctic region betweeb the PF in the south and the subtropical front in the north, exceeding ther northern SF, thus including southern Patagonia, the Falkland Islands and the waters south of Tasmania and New Zealand.

The isolation of Antarctica and the Southern Ocean from other oceans of the world developed in several stages over millions of years. The onset of the fragmentation of the supercontinent Gondwana date back 165 million years ago (Mya), but the first important stage in the isolation of Antarctica was the separation of the Antarctica–Australia and India–Madagascar blocks, which happened 100 Mya, followed by the separation of the Antarctica–Australia block and New Zealand that occurred between 95 and 75 Mya. Finally, the Tasmanian seaway opened 35 Mya and definitely separated Antarctica from Australia (Brandt et al. 2007; Rogers 2007).

The total isolation of Antarctica is considered effective only after the opening of the Drake Passage, which separates the Antarctic Peninsula from the southern tip of Patagonia and Tierra del Fuego. The dating of this event is controversial, and estimates range between 40 and 15 Mya. Some researchers claim that the complete opening of the Drake Passage was already effective before the establishment of the Tasmanian seaway (Brandt et al. 2007), while others maintain that the formation of the Drake Passage was a process that lasted between 29 and 15 Mya, although it is believed that a flow of proto-ACC was already present since the opening of the region of Tasmania, coinciding with the beginning of the Antarctic glaciation during the Tertiary (Katz et al. 2011).

However, Antarctica is not composed from a single continental block. It is believed that, before the Antarctic glaciation during the early Cenozoic ($\sim$60 Mya), there was a maritime communication between the proto-Ross Sea and the proto-Weddell Sea through the passage located between the Eastern and Western blocks of Antarctica. This trans-Antarctic passage would remain open until the Oligocene or even the middle Miocene (20 Mya). Since then, at least two events to reopen this passage have been noted from the geological record, one during warming Pliocene (4 Mya) and the other during the past 1.1 Mya (Barnes and Hillenbrand 2010).

In the current configuration of continents and oceans, the Southern Ocean plays a key role in global hydrodynamics, contributing significantly to the income of cold and oxygen-rich water in the global thermohaline circulation form. The ACC is the only current that flows completely around the world. With a length of 20,000 km, the ACC goes through the Atlantic, Indian and Pacific Oceans, besides acting as a channel for the exchange of temperature and salinity from one ocean to another (Turner et al. 2009). The Antarctic Circumpolar Current is the dominant surface current in this region and is mainly influenced by the Antarctic winds blowing from west to east.

The sinking of water that extends around Antarctica beyond the continental shelf and slope, to form Antarctic Bottom Water (AABW), oxygenates most of the ocean floor globally (Orsi et al. 1999), and provides a fairly uniform cold environment that allows the survival of benthic organisms. The Southern Ocean has three main areas for the origin of the AABW: the Weddell Sea, the Sea of Dumont d'Urville and the Ross Sea. Studies on deep octopus species (Strugnell et al. 2008) suggest that, during the formation of the global thermohaline circulation (thanks to AABW exportation), the evolutionary radiation of deep fauna originated from Antarctica to the rest of the oceans.

As in most oceans, primary productivity in the Southern Ocean is mainly a function depending on brightness. But in these latitudes, primary productivity is very low during the austral winter and at its highest during spring, reaching values of up to 0.1 mg Chl/l (Turner et al. 2009). This fact is due to the marked seasonal variation in sunlight, although the water temperature remains fairly constant throughout the year. Despite the fluctuating water column dynamics, benthic biomass is very important in the Antarctic continental shelf throughout the year. In early spring, phytoplankton coming from the melting season is not immediately consumed by zooplankton in areas where currents are weaker. This phytoplankton settles to the bottom of the continental shelf and forms the so-called "food banks" or "green carpet", thus creating a potential food for benthic organisms (Gutt et al. 1998; Turner et al. 2009). The currents continuously resuspend the high nutritional quality organic matter, creating a constant food source for benthic suspension feeders (Smith et al. 2006). These Antarctic suspension feeders are also able to feed on small particles, in contrast to their counterparts in other latitudes where suspension feeders only feed on zooplankton (Orejas et al. 2003).

Thanks to the resuspension due to tidal currents and the quality nutrition of the sediment, there are almost constant benthic trophic conditions throughout the whole year. These events provide the basis for a new model that helps to explain the high biomass of benthic communities around Antarctica even when food intake to the euphotic zone is scarce because the ocean's surface is covered by ice during the winter months. During the austral winter, feeding processes occurring on the seabed can be the key to understand the high productivity of the system at the beginning of spring and the high biomass of the benthic ecosystem (Gili et al. 2006).

Thus, the organic material would be available all year round for the Antarctic benthos of the continental shelf. The flow of organic matter generated mainly at the beginning of spring seems to be higher during spring and decreases subsequently throughout the summer and fall to be minimal in winter when most of the Southern Ocean is covered by ice. The organic material not consumed in spring will be accumulated in the "food banks" and will be resuspended during the whole year by tidal currents (Turner et al. 2009).

Terrestrial biocomplexity: function and linkages in land and water ecosystems

Antarctic terrestrial environments show the resistance and resilience of life under some of the most extreme climatic conditions in the world as well as remarkable adaptations to the combination of different climatic factors. As such, it is not surprising that multiple aspects of the biology and diversity of these communities have been intensively studied for many years.

The amount of information about terrestrial Antarctic diversity has recently fostered its use to check the effect of the main climatic drivers (Colesie et al. 2014). Our knowledge about Antarctic diversity has also been dramatically improved in recent years thanks to expeditions to some remote areas in Continental Antarctic (Demetras et al. 2010; Seppelt et al. 2010; Green et al. 2011). At the same time, continuous technical advances allow automatic monitoring of plant activity under the most extreme conditions (Raggio et al. 2014).

The impact of both global warming and human activity in the field is clearly one of the most interesting topics in Antarctic terrestrial ecosystem research (Hogg and Wall 2011). A wider extension in the distribution of the two Antarctic vascular plants, *Collobanthus quitensis* and *Deschampsia antarctica*, has been reported (Hill et al. 2011), together with some evidence of the occurrence of non-native species especially in the maritime Antarctic and the archipelagos of the Scotia arc (Convey 2008). However, these records are far from yet being a general feature but rather exceptions that ring alarms about possible forthcoming more dramatic changes. Increased activity of tourist operators in some places of the maritime Antarctic is also another matter of concern. Disturbance by trampling of the fragile moss and lichen communities has been monitored (Pertierra et al. 2013), and protocols to avoid contamination and transfer of plant propagules by humans have been developed (Huiskes et al. 2014).

The terrestrial Antarctic ecology community is now more interconnected than ever before, as evidenced by the multiple collaborations that are being established among different groups coordinated by the big SCAR umbrella programs (ANTERA, ANTECO).

Antarctic freshwater ecosystems are considered sentinels of changes in the watersheds because they integrate (and amplify) the changes that are taking place in the watershed at different scales: from geomorphology to biology and chemistry in the catchment (Quesada and Velazquez 2012). Liquid water availability is one of the most important limiting factors in Polar Regions for non-marine biota (Kennedy 1993). Changes in climatic conditions in Polar Regions will most probably affect water availability with unpredictable changes in biological communities. This is why the changes in the presence of water, both in duration and quantity, can explain, at least partially, the variations observed in the distribution of non-marine organisms. Most likely, the interactions between the different organisms will also be altered and the biocomplexity of these ecosystems can be modified after reaching some tipping points in the length of the liquid water season and the temperature in the season. It is thus foreseeable that less psychrophilic organisms, such as fungi, will be capable of colonizing and thriving in ecosystems where they were minoritary. New molecular techniques are opening interesting perspectives regarding the microbial distribution and functionality in Polar Regions (Varin et al. 2010) and allow setting benchmarks for diversity changes also at microbial and viral levels. Recent findings show unprecedented viral diversity in non-marine Antarctic ecosystems (López-Bueno et al. 2009) and impressive ecosystem connectivity at the global scale (Aguirre de Cárcer et al. 2015). These new findings and those to come in the future will provide answers to key questions on ecosystem functioning and evolution.

Integrated perspectives on Antarctic marine ecosystems: from krill to top predators

Over the last decades, Antarctica has been affected by deep environmental changes. The western coast of the Antarctic Peninsula is one of the places on Earth where the temperature has increased more and more rapidly in the last 50 years (Meredith and King 2005). On average, an increase of 0.5° per decade has been detected (Turner et al. 2009). As a consequence, sea ice extent has been reduced in this region (Stammerjohn et al. 2008; Fan et al. 2014). Such changes have directly affected the food webs and declines of some organisms such as krill have been reported (Atkinson et al. 2004; Flores et al. 2012), while other organisms such as salps have increased their numbers (Atkinson et al. 2004). In other Antarctic regions such as the Ross Sea, the scenario is quite different with an increase in the sea-ice extent (Fan et al. 2014) and a decrease in the number of the ice-free days (Stammerjohn et al. 2012), while also producing environmental effects in this region affecting the food web.

Such changes in the lower or middle trophic levels have affected the meso and top predators in both the Antarctic Peninsula and the Ross Sea region. For instance, a decline of some species of penguins, as the chinstrap penguin (*Pygoscelis antarctica*) and the Adélie penguin (*P. adeliae*), have been reported in the Antarctic Peninsula (Carlini et al. 2009; Trivelpiece et al. 2011; Barbosa et al. 2012), while in the Ross Sea, the Adélie penguin has increased or decreased in numbers depending of the sea-ice trends (Smith et al. 1999; Ainley et al. 2010).

Krill is an intermediate step between primary producers and high trophic consumers and thus provides crucial information about the Antarctic Ocean food web (Marchant and Murphy 1994). Research on krill and top predators has received great attention in recent years (i.e., Ross et al. 2008; Trivelpiece et al. 2011). However, most of the studies of these two components of the Antarctic ecosystem have been carried out independently of each other, and an ecosystemic perspective is needed to fully understand how current changes are affecting the ecological interactions of the different components of the Antarctic trophic web.

Human impacts on Antarctic ecosystems: from global change to small-scale impacts

In spite of its isolation, the Antarctic continent has been affected by direct and indirect human activity for about two centuries. This pressure has been very relevant for some species (whaling and sealing activities) (e.g., Jackson et al. 2014), but in most parts of the continent the effects have been small. The intense industrialization of the world brought new compounds and new hazards to Earth ecosystems, and Antarctica was not an exception. The global distribution of substances, exemplified by the ozone hole distribution, is bringing substances to Antarctica produced in the northern hemisphere which are accumulated at high concentrations due to the polar amplification (Cabrerizo et al. 2014), with unknown ecological effects.

Extractive activities, although well regulated by the Antarctic Treaty, may also represent a threat to Antarctic, mainly marine, ecosystems due to illegal, unreported and unregulated fishing activities (https://www.ccamlr.org/en/compliance/illegal-unreported-and-unregulated-iuu-fishing). Another human activity that may represent an impact in Antarctica is tourism, by interacting with Antarctic ecosystems both directly by trampling or stressing the fauna or indirectly by bringing propagules of new species to the continent. The direct human impact by visitors, both scientists and tourists, is being evaluated, but datasets are not large enough to quantify the effects on ecosystems. The effects of trampling on vegetation and unvegetated soils have been quantified (Tejedo et al. 2012; Pertierra et al. 2013), and have been considered for managing touristic visits (Chile 2012; Spain 2013).

The presence of propagules of invasive species has also been quantified and considered as threats for the native species (Chown et al. 2012), because reports of species introduction are increasing in some Antarctic regions (Hughes et al. 2015a). However, the effects on native ecosystems have not yet been measured. A topic that deserves attention is the introduction of microbial taxa by visitors. At the moment, there are no available data about the possibility of humans as vectors of microorganisms, but certainly the increasing mobility of humans (both scientists and tourists) may represent a risk of artificial homogenization of microbial communities, compromising native populations as potential producers of biotechnologically relevant compounds (Hughes et al. 2015b). The potential stress that visitors produce over animals has also been scarcely quantified, and existing reports are controversial (Coetzee and Chown 2014), but there is agreement that human disturbance can have negative effects on wildlife.

Physical and biogeochemical processes in the Antarctic ecosystem: flexible boundaries and dynamic gradients

Ongoing climate change pace is pushing ecosystems to unprecedented circumstances, and this is especially evident in some Antarctic regions. This situation is scientifically challenging because addressing the effects and consequences of such environmental pressure requires comprehensive multidisciplinary questions and approaches able to fully assess physical and biogeochemical processes that shape ecosystem development. As a consequence of such pressure, boundaries between systems such as the terrestrial and marine, the interface between the water column and the seabed, and the macro- and microbial recycling loops of sea-ice and ocean sectors and the temperate and high latitude regions are also changing.

Melting of glaciers is affecting the coastal zone, especially off the Antarctic Peninsula and the adjacent islands, where the input of freshwater and glacially derived sediments is modifying the planktonic community composition (Dierssen et al. 2002) and the benthos through iceberg scouring (Gutt 2001) and increased water turbidity (Barnes and Conlan 2007). If organisms of the planktonic community change, e.g., from krill- to salp-dominated (Atkinson et al. 2004) based on warming experiments, the microbial community may acquire a more important role in carbon recycling in the water column. This is due to the appearance of phytoplankton communities dominated by smaller cells, decreasing the absorption of CO_2, increasing the dissolved organic carbon production which is translated in more bacterial production, and leading to a heterotrophication of the system (Duarte et al. 2005; Morán et al. 2006). Then, the biological pump may be altered reducing the carbon transport to the seafloor, where, in the absence of macrobenthos microorganisms living there, these may also become more important actors in the biogeochemical cycles.

In some areas, sea-ice is losing seasonal extent leading to a reduction of habitat for several related species and affecting the global climate regulation. The southward displacement of the polar front may also alter the Earth's climate, modify community composition of plankton (Flores et al. 2012; Wang et al. 2014) and benthos (Thatje et al. 2005a) and facilitate the intrusion of non-local species from more northern regions, which is also taking place due to the growing tourism in the islands off the Antarctic Peninsula (Frenot et al. 2005).

These examples make evident the modification of boundary lines between systems and demonstrate that the best approach to fully understand the extent of environmental pressure on the Antarctic ecosystems is through cooperation between countries and scientists from different disciplines.

Antarctic science benefits from advances in several research fields such as the development in genetics and genomics mainly for determining microbial diversity (Grzymski et al. 2012), and biological maritime and meteorological remote observations (Clarke et al. 2005); however, in situ measurements and experimentation with new and traditional tools are giving an important impulse to it (Isla et al. 2009; Vaqué et al. 2009) The more we learn from Antarctica, the more we acknowledge the need of incorporating scientists and instruments from several disciplines working simultaneously in different places—the optimum would be a true pan-Antarctic approach, given that climate change is not affecting the continent at the same pace. At present, we lack this possibility but SCAR symposia and related projects as (e.g., *Antarctic Thresholds–Ecosystem Resilience and Adaptation*; Gutt et al. 2012) provide helpful bases to share up to date knowledge, meet people and stimulate international cooperation by setting conditions to better understand the dynamics of the ongoing change in Antarctic boundaries (Fig. 1).

Antarctic marine biodiversity: patterns, processes and trends in an ancient ecosystem

As mentioned before, the final breakup between Antarctica and South America was completed after the opening of the Drake Passage. This fact allowed the formation of the ACC and the establishment of the PF, both effectively working as barriers (or filters) for wildlife migration in both directions. Unlike other large marine ecosystems, the continental shelf waters around Antarctica resemble a closed basin isolated from other shelf areas of the southern hemisphere by distance, by current patterns and by seawater temperatures. The Southern Ocean is characterized by the relative constancy, not stability, of its physical conditions (Arntz et al. 1994). We find low but stable temperatures, low salinity fluctuations and limited continental drainage. However, certain conditions such as the light regime, the sea-ice cover, the effect of the iceberg scouring, the ice shelves or the change of currents and circulation patterns, fluctuate greatly. The Antarctic benthic ecosystem (like those of the deep sea) compared to other marine benthic ecosystems shows remarkably constant physical conditions; however, it is exposed to more physical variability and disturbance than had previously been thought (Arntz et al. 1994). These conditions of isolation have been developed over the last 40 million years, during which marine life has adapted to a new habitat, and their distribution areas have been reduced. Endemism rates are as high as 97 % in some marine groups. However, despite the improved sampling and the new approaches of molecular phylogeny and phylogeography, the origin of the current fauna of the Southern Ocean remains a controversial issue.

There are currently two theories that attempt to explain the origin of Antarctic wildlife: polar submersion and evolutionary emergence (Aronson et al. 2007). The first suggests that some shallow-water taxa would have moved

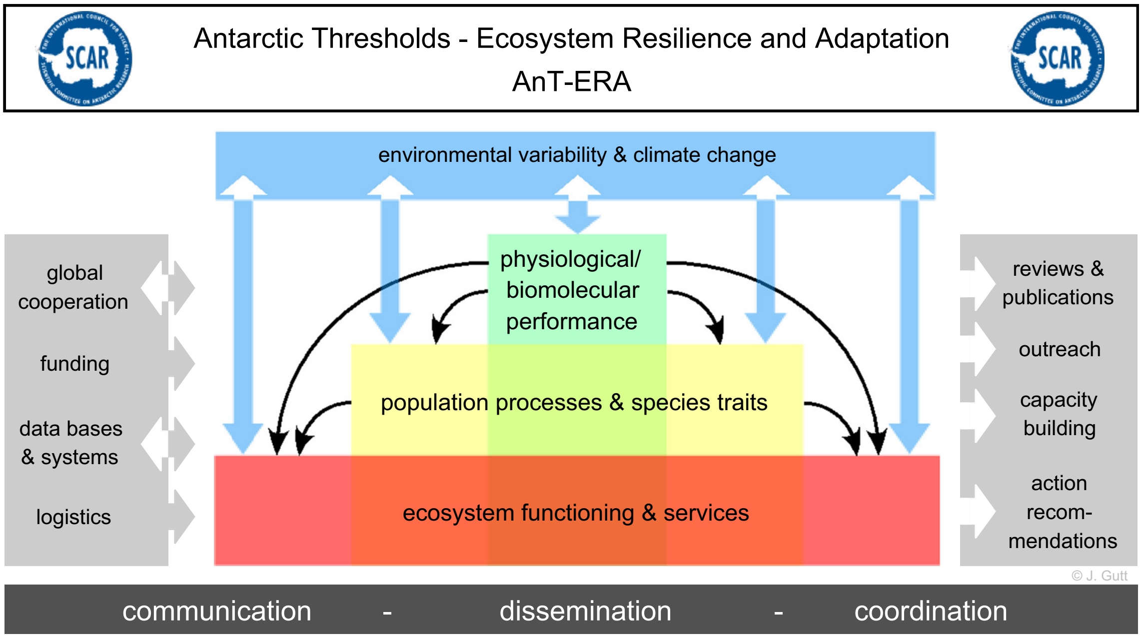

Fig. 1 Structure of the scientific research programme Antarctic Thresholds–Ecosystem Resilience and Adaptation (Ant-ERA) of the Scientific Committee of Antarctic Research (SCAR)

to deeper areas, while the second one suggests the contrary, that taxa from the deep and abyssal waters would have colonized the Antarctic continental shelf (Brandt et al. 2007). The two theories are not mutually exclusive, as since the creation of the Southern Ocean, dispersal and diversification of Antarctic wildlife has evolved in one direction (submersion) or another (emersion) depending on the degree of isolation that has supported the Southern Ocean. These patterns are clearly linked to the glacial history of Antarctica. Brey et al. (1996) showed that many continental shelf taxa in Antarctica have bathymetric ranges larger than their counterparts from other regions. This suggests that the movement in and out of deeper waters, driven by glacial cycles, may represent the general wildlife evolutionary history. During the ice age, the continental shelf's ice coverage increased, eroding the bottom and in some cases also eradicating the benthic ecosystems. Antarctic wildlife has experienced a succession of glacial and interglacial periods, with several authors wondering how this fauna has persisted in these environments. In this scenario, it would have been some wildlife associated with continental shelf refugia, and others associated to continental slopes (Gili et al. 2006).

The advance of the ice shelf during the ice age led to the extinction of the continental shelf fauna, and during the interglacial period (melting) those shelves already free of ice (and partially or totally devoid of life) would be re-colonized by the fauna associated to the continental slope. The euribatic distribution of these species would have been an adaptative response to the glacial and interglacial periods. In short, faunal exchange between the continental shelf and the deep waters of Antarctica is largely due to the generally deeper nature of the shelves, and due to the absence of a strong thermal gradient between the deep and shallow areas in the Southern Ocean.

In the late nineteenth century, the Challenger Expedition (1872–1876) took place, the first expedition with scientific purposes, which explored the ocean floor and brought new insights into descriptive oceanography and the distribution of marine benthic fauna. In 1882, the First International Polar Year was held in which more than a dozen countries participated, and thanks to which polar research was promoted. During subsequent years, great expeditions were carried out, such as the Deutschen Tiefsee Expedition (1898–1899), the Deutschen Südpolar Expedition (1901–1903), the Swedish Antarctic Expedition (1901–1903), the Discovery Expedition (1901–1904), the Seconde Expeditione Antarctique Française (1908–1910), and the Australasian Antarctic Expedition (1911–1914). All of them contributed exceptionally to the knowledge of Antarctic natural history.

Fauna from the Antarctic regions, which are subjected to extreme polar conditions, show high physiological adaptations, which can lead them to use certain reproductive strategies (Clarke 1992), or be absent like decapods, which would not have been able to adapt (Aronson and Blake 2001). Today, Antarctica is home to an exceptionally rich, abundant and highly endemic biodiversity (Kükenthal 1924; Arntz et al. 1994; Clarke and Johnston 2003; Brandt et al. 2007), especially in areas of the continental shelf and around the Sub-Antarctic islands, which are considered to be one of biodiversity "hot spots" in the world.

There are three land masses extending from the Southern Ocean to the Antarctic continent, whose associated continental shelves represent a possible way of colonization or dispersion for organisms to and/or from the Antarctic continent. From South America, the Scotia Arc curves through the islands to the northernmost extension of Antarctica, the Antarctic Peninsula. New Zealand and Australia provide a more fragmented path through the Indo-Malay Archipelago. Although South Africa is a long way from Antarctica, it provides a point of contact of the surface waters in the north from the Indian Ocean on its eastern side and the Atlantic on the western (Dell 1972). However, all taxa are not equally represented and many species of the Southern Ocean are still far from being discovered and formally described.

One of the features in the benthic fauna of the Southern Ocean is the absence of large predators (sharks or decapod crustaceans belonging to Brachyura and Anomura groups) or by their low diversity (teleost fishes, rays) in the high Antarctic region (Aronson and Blake 2001; Thatje et al. 2005b; Aronson et al. 2007). These predators have disappeared or their diversity has been reduced in the Antarctic continental shelf as a result of glaciation processes, and their having no physiological ability to withstand the current low temperatures. The absence of these large predators led to an increase in the abundance of other groups, such as starfishes and crinoids, in certain areas of the Antarctic continental shelf (Aronson and Blake 2001). Benthic marine fauna, which represents 88 % of animal species known in the Southern Ocean, consists mainly of benthic invertebrates, of which suspension feeders (Arntz et al. 1994; Gutt et al. 2004; Gili et al. 2006) are dominant. The most representative groups of suspension feeders are sponges, tunicates, bryozoans, cnidarians and echinoderms. Many of these organisms provide suitable surfaces for epibionts (Gutt 2000). Predation in Antarctica is mainly due to mobile predators, such as anemones, starfishes, gastropods, isopods, and pycnogonids and nemerteans (Aronson and Blake 2001).

However, in recent years, the presence of large predators in Antarctica has been noted, especially anomuran decapods. These have been located around Bouvet Island, on the slopes of the continental shelf of the Antarctic Peninsula and in the Bellingshausen Sea (Thatje et al. 2005a, 2008). These decapods come from sub-Antarctic waters through the surrounding abyssal plains and along the Scotia Arc Islands (Thatje et al. 2005a). Some specimens of subantarctic species of crabs (brachyuran crustaceans) were identified in the late 1980s near King George Island (South Shetland Islands), probably carried in the ballast water of a ship (Barnes et al. 2006). The success of these invasions is assumed to be due to the warming waters in West Antarctica (Barnes et al. 2006; Aronson et al. 2007; Thatje et al. 2008). If these phenomena persist, the benthic marine fauna of the Antarctic continental shelf will suffer the consequences of these large predators, firstly those groups with few predators, such as starfishes and crinoids.

Despite the increase of oceanographic expeditions from the late twentieth century, benthic diversity in the Southern Ocean is still far from fully known (Brandt et al. 2007; Rogers 2007; De Broyer et al. 2011). Some Antarctic regions of the continental shelf have been little explored, for example, between the Weddell Sea and Prydz Bay or between the Davis Sea and Dumont d'Urville. In addition, the knowledge about the fauna that inhabits the deep basins surrounding the Antarctic continental shelf is still very poor. ANDEEP campaigns (Antarctic benthic deep-sea biodiversity) have been devoted to these environments in the Atlantic sector of the Southern Ocean (Brandt et al. 2007).

Since the late twentieth century, many researchers interested in benthic diversity in the Southern Ocean were surprised to discover that some taxa had a hidden diversity, which was revealed by molecular studies. Examples of complex cryptic species are molluscs (Linse et al. 2007; Allcock et al. 2011), amphipods (Havermans et al. 2011), echinoderms (Ward et al. 2008), annelids (Schüller 2011) and nemerteans (Thornhill et al. 2008). The use of molecular tools to standardize comparisons "barcoding" and phylogeography has been shown to produce valuable sources of information which often reveal this hidden diversity. However, other studies have shown a certain molecular genetic homogeneity within the Antarctic benthos, revealing a great capacity for dispersal and genetic exchange between isolated populations (Raupach et al. 2010; Arango et al. 2011).

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