

ANTARCTIC ~ SOUTH AMERICAN INTERACTIONS IN THE MARINE ENVIRONMENT: A COMARGE AND CAML EFFORT THROUGH THE SOUTH AMERICAN CONSORTIUM ON ANTARCTIC MARINE BIODIVERSITY

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ABSTRACT

The study of the Antarctic isolation from other continents by the Southern Ocean is relevant for understanding circulation patterns in the world oceans and atmosphere, and how biological communities have responded to past and present environmental changes. A detailed knowledge of Antarctica's past and present status is globally significant for predicting how its future may affect the Earth's System. Comparisons between Antarctica and other fragments of Gondwana, the study of climate change, and anthropogenic influences to the Antarctic environment are critical for understanding the evolution and present biological community structures in Antarctica, and their relations with the biota outside the Polar Front. The ultimate separation of Antarctica from South America happened during the Oligocene, and was responsible for the Antarctic isolation. The combination of this isolation and climate change has led to an Antarctic biota rich in endemic taxa, also in the marine environment. But how isolated is Antarctica? This major question has been raised for many years and within the research SCAR Programmes (EBA, AGCS, ACE). The potential biotic links between Antarctica and the surrounding continents, and whether faunal exchange occurs have been undertaken by more than one Census of Marine Life projects. In this context, the Antarctic-South American biodiversity latitudinal gradient is particularly interesting because of the proximity of the two continents, and the fact that they separated at a relatively short time ago about 35 million years ago. Here, we provide a historical background for the South American Consortium on Antarctic Marine Biodiversity in the scope of the Census of Antarctic Marine Life (LA CAML), its integration with the Continental Margin Ecosystems on a Worldwide Scale (COMARGE), another Census of Marine Life project, also introduce some results from these interactions and manuscripts present in this volume. The "LA CAML/ BioMantar /COMARGE Integrated Workshop and Symposium", have allowed gathering available data collected either in Antarctica, South America or both continents, which are relevant to our understanding of their associations. Approximately 10,000 species records were raised from microbes to top predators during the workshop. Nematodes had the highest number of records followed by crustaceans, annelids, molluscs, echinoderms, and several other groups, and from those about 173 species were found to be shared between Antarctica and South America. These were opportunities for scientists to exchange data, and further discuss the potential Antarctic ~ South American biodiversity connections, taking into account all the marine realms and depth range from coastal to abyssal zones (> 4000 m depth), and also the human component of these connectivities.

Keywords: Antarctic; South America; continental margin; biodiversity; pelagic; benthos; top predators.

RESUMO

INTERAÇÕES ANTÁRTICO-SUL AMERICANAS NO AMBIENTE MARINHO: UM ESFORÇO DO COMARGE E CAML ATRAVÉS DO CONSÓRCIO SUL AMERICANO SOBRE

BIODIVERSIDADE MARINHA ANTÁRTICA. O estudo do isolamento da Antártica dos outros continentes pelo Oceano Austral é relevante para a compreensão dos padrões de circulação nos oceanos de modo geral, na atmosfera e como as comunidades biológicas têm respondido às mudanças ambientais no passado e no presente. O conhecimento detalhado do estado passado e presente da Antártica é globalmente significativo para se prever como seu futuro pode afetar o sistema terrestre. Comparações entre a Antártica e outros fragmentos da Gondwana, o estudo de mudanças climáticas e influências antrópicas no ambiente antártico são críticos para a compreensão da evolução e estruturas de comunidades biológicas atuais na Antártica e sua relação com a biota fora da Frente Polar. O último continente a separar-se da Antártica foi a América do Sul, o que ocorreu no Oligoceno, fato responsável pelo isolamento da Antártica. A combinação deste isolamento e as mudanças climáticas levaram a Antártica a possuir uma biota rica em táxons endêmicos, também no ambiente marinho. Mas quão isolada é a Antártica? Esta tem sido uma das principais questões levantada por muitos anos e dentro dos programas de pesquisa do SCAR (EBA, AGCS, ACE). As potenciais conexões bióticas entre a Antártica e os continentes circundantes, e se existem trocas de fauna e flora entre eles têm sido averiguadas por mais de um dos projetos do Censo de Vida Marinha. Neste contexto, o gradiente latitudinal de biodiversidade entre a Antártica e América do Sul é particularmente interessante de ser investigado especialmente pela proximidade entre esses continentes e o fato deles terem se separado há uns 35 milhões de anos atrás. Aqui, fornecemos uma contextualização histórica para o “Consórcio Sul Americano sobre Biodiversidade Marinha no escopo do Censo de Vida Marinha Antártica – LA CAML (sigla em inglês)”, suas interações com o projeto “Ecossistemas de Margens Continentais em Escala Global (COMARGE, sigla em inglês)”, também do Censo de Vida Marinha e, além disso, apresentamos alguns resultados dessas interações e os trabalhos que compõe este volume. Os eventos “LA CAML/ BioMAntar /COMARGE Oficina de Trabalho e Simpósio Integrados”, permitiu agregar dados disponíveis coletados tanto na Antártica, quanto na América do Sul ou nos dois continentes, os quais têm se mostrado relevantes para nossa melhor entendimento de suas associações. Aproximadamente 10.000 registros de espécies de microorganismos a predadores de topo de teia alimentar foram levantados durante a oficina de trabalho. Os nematodos apresentaram o maior número de registros seguidos pelos crustáceos, anelídeos, moluscos, equinodermos e uma série de outros grupos, e de todos os registros aproximadamente 173 espécies, em princípio, são compartilhadas entre a Antártica e a América do Sul. Estas foram oportunidades para cientistas trocarem informações entre si e discutir sobre as potenciais conexões de biodiversidade entre a Antártica e América do Sul, considerando-se todos os domínios marinhos e uma amplitude batimétrica de zonas costeiras a abissais (> 4000 m de profundidade), além do componente humano dessas conectividades.

Palavras-chave: Antártica; América do Sul; margem continenta; biodiversidade; pelágico; bentos; predadores topo.

RESUMEN

INTERACCIONES ANTÁRTICO-SUDAMERICANAS EN EL AMBIENTE MARINO: UN ESFUERZO DE LOS COMARGE Y CAML A TRAVÉS DEL CONSÓRCIO SUDAMERICANO RESPECTO A LA BIODIVERSIDAD MARINA ANTÁRTICA. El estudio del aislamiento de la Antártida de otros continentes por el Océano Austral es relevante para la comprensión de los patrones de circulación en los océanos en general, la atmósfera y cómo las comunidades biológicas han respondido a los cambios ambientales en el pasado y el presente. El conocimiento detallado de la situación pasada y presente de la Antártida es de importancia global para predecir como su futuro puede afectar al sistema terrestre. Las comparaciones entre la Antártida y otros fragmentos de Gondwana, el estudio del cambio climático y efectos antropogénicos sobre el medio ambiente antártico son fundamentales para entender la evolución y la estructura de las comunidades biológicas presentes en la Antártida y su relación con la biota fuera del Frente Polar. El último continente a romper con la Antártida fue la América del Sur, que tuvo lugar en el Oligoceno, en realidad responsable del aislamiento de la Antártida. La combinación de aislamiento y el cambio climático han llevado la Antártida a tener una biota rica en taxones endémicos, también en el medio marino. Pero,

¿cómo aislado es la Antártida? Esta ha sido una de las principales cuestiones planteadas durante muchos años y dentro de los programas de investigación del SCAR (EBA, AGCS, ACE). Las conexiones bióticas potenciales entre la Antártida y los continentes circundantes, y si hay cambios de fauna y flora entre ellos se ha investigado durante más de un proyecto del Censo de Vida Marina. En este contexto, el gradiente latitudinal de biodiversidad entre la Antártida y América del Sur es particularmente interesante para ser investigado sobre todo por la proximidad entre estos continentes y el hecho de que se separaron hay 35 millones de años atrás. Aquí, ofrecemos un contexto histórico para el “Consortio de América del Sur sobre Biodiversidad Marina en el Ámbito de Aplicación del Censo de Vida Marina Antártica - CAML LA (siglas en Inglés), sus interacciones con el proyecto “ Ecosistemas del margen continental en una escala global (por su sigla COMARGE, Inglés)”, también del Censo de Vida Marina, y además presentamos los resultados de estas interacciones y los manuscritos que hacen parte de este volumen. Los encuentros científicos “LA CAML / BioMantar / COMARGE Taller y Simposio Integrados”, han permitido agregar los datos disponibles recogidos tanto en la Antártida y en América del Sur o en los dos continentes, que han demostrado ser de interés para nuestra mejor comprensión de sus asociaciones. Alrededor de 10.000 registros de especies de microorganismos a los predadores tope de la cadena alimenticia se plantearon durante el taller. Los nematodos tuvo el mayor número de registros seguido de los crustáceos, anélidos, moluscos, equinodermos y un número de otros grupos, y de estos aproximadamente 173 especies, en principio, son compartidos entre la Antártida y América del Sur. Estos encuentros fueron oportunidades para los científicos intercambiaren información y discutieren los posibles vínculos entre la diversidad biológica de la Antártida y América del Sur, teniendo en cuenta todos los ámbitos del medio marino, y rango de profundidad desde la costa a las zonas abisales (> 4000 m de profundidad) además del componente humano de las conectividades.

Palabras clave: Antártica; América del Sur; margen continental; biodiversidad; pelágico; bentos; predadores tope.

INTRODUCTION

Antarctica split from the last fragment of the Gondwana, South America, at approximately 35 million years ago during the Oligocene (Thomson 2004). This ultimate separation was responsible for a series of events, such as the Antarctic isolation, formation of the Southern Ocean, northward flow of the Antarctic Intermediate Water (AIW) and Antarctic Atlantic Bottom Water (AABW), and the existence of numerous unique geological and physical processes observed along the northern end of the Antarctic Peninsula, e.g., an active spreading centre in the Bransfield Strait, ridge trench collision and gas hydrates on modern sediments (Barker & Burrell 1982, Barker & Thomas 2004, Pearse *et al.* 2001, Thomson, 2004, Turner *et al.* 2009). Life in the Southern Ocean has flourished in an environment characterized by glaciations and strong currents. The progressive cooling and isolation was a critical factor, which involved changes in genome and selection of several macromolecules with physical and chemical properties adequate to survival and maintenance at

sub-zero temperatures close to sea water freezing point (Peck *et al.* 2006; Pörtner *et al.* 2007, Pugh & Convey 2008). Here, Verde *et al.* (this volume) provide the example of anti-freezing glycoproteins present in body fluids of fishes as such physiological adaptation. Therefore, despite the fact that the Antarctic marine life is generally diverse and rich, many species may have a limited capacity to adapt to the recent environmental changes, as the isolation associated to the glaciation cycles has led to speciation and unique biota (Rogers *et al.* 2010).

Over the years, Antarctica has been considered one of the major natural laboratories on Earth. The region still remains relatively pristine in terms of conservation under the auspices of the Antarctic Treaty System, which has a unique political structure involving many different countries from all continents (Di Prisco & Verde, this volume). This has stimulated the best logistical and scientific practices especially during and after the last two International Polar Years, including integrated multinational and interdisciplinary efforts in order to better understand the role, interactions, and influence of the region to

the whole planet, and vice-versa (Turner *et al.* 2009). Studies on the effects of environmental changes on ecosystems, communities, populations, organisms and their diversity in different spatial and temporal scales have become urgent as the awareness of Antarctica's relevance to the functioning of the Earth system has become more evident (Turner *et al.* 2009, Gutt *et al.* 2011).

The Southern Ocean has been considered one of the best defined marine ecosystems on Earth, being limited by the Antarctic continent to the South and Polar Front to the North. The Polar Front has worked as a natural barrier to many organisms, and may be detected as deep as 1000m (Griffiths 2010). It represents a distinct biogeographical discontinuity considering that only a few epipelagic and benthic taxa can be found within and outside the Southern Ocean, at the exception of migratory birds and mammals, some mid-water and deep-sea organisms to whom the Polar Front does not represent a barrier (Griffiths *et al.* 2008, Griffiths *et al.* 2009, Griffiths 2010).

During the 2007-2008 International Polar Year, the Census of Antarctic Marine Life (CAML) and the (SCAR-MarBIN) joined efforts to gather biodiversity data, past and new, building a massive collection of information with the use of modern sampling and analysis technologies, including molecular methods and new data visualization tools (De Broyer & Danis, with 64 SCAR-MarBIN Taxonomic Editors 2011). More than 9,000 marine species and 1,000,000 distribution records for the Southern Ocean were registered in the Scientific Committee on Antarctic Research - Marine Biodiversity Information Network SCARMarBIN through the past six years, and this has been the best baseline against which future change may be evaluated (Griffiths *et al.* 2011). More than 1,500 species had parts of their genome sequenced, amongst which more than 200 marine organisms including benthic invertebrates that were found in both Polar Regions the Arctic and Antarctic (Victoria Wadley, personal communication). Many seamounts were found to act as refuges to a variety of species (Brandt *et al.* 2011) such as the archaic benthic assemblages of crinoids and brachiopods at the Admiralty Seamount in the Ross Sea (Bowden *et al.* 2011).

Studies undertaken under the CAML and SCARMarBIN scope have shown that there are strong evidences that a single circum-Antarctic bioregion exist unified by the Antarctic Circumpolar Current (ACC), contrary to what was believed in the 60s (Griffiths 2010). The effects of climate change on Antarctic ecosystems and its communities have become more evident especially in the Antarctic Peninsula region, and even under ice-shelves, such as in Larsen B, which colapsed few years ago (Gutt *et al.* 2011). Some areas of the deep continental shelf and slope in East Antarctica have shown an extremely high abundance of organisms and diversity in the benthic environment, and questions have been raised regarding the protection of such areas even for its use on scientific purposes (Bowden *et al.* 2011).

The Antarctic benthic fauna differs from that found elsewhere, as it usually shows high diversity, high biomass and abundance of organisms (Clarke & Johnston 2003, Clarke 2008). This is possibly because the Antarctic continental shelf is deep (between around 450m to more than 1000m in some areas), and some species have evolved tolerance to a high depth range, low and variable levels of food supply, particularly low levels of energy for maintenance as temperature is low (Clarke 1991a,b, Brey *et al.* 1996, Clarke 2003, Clarke & Johnston 2003). Additionally, even at these deepest shelves, the seafloor is nourished by fresh organic matter not only from the phytoplankton, but also from algae that grow on sea ice, as these become freely available upon ice melting during summer (Hofmann *et al.* 2004). In the Southern Ocean, the dominant basic energy flow is the surface phytoplankton production followed by secondary consumption by the zooplankton (the krill being its central player), terciary consumption by pelagic organisms (e.g., squid, fish) and other predators such as seabirds and mammals (Hofmann *et al.* 2004; 2008). The decomposing organic matter flows to the seafloor and enter the benthic microbial loops and trophic web (Smith *et al.* 2006; 2008). Usually, the most productive areas are those within or associated to the zones of sea ice formation, which cover most shallow areas around Antarctica and some deep oceanic areas each winter (Hofmann *et al.* 2008; 2011).

Other Census of Marine Life (CoML) projects, such as ChEss (Chemosynthetic Ecosystems) and

CEDAMAR (through ANDEEP), revealed distinct environments and many new species to science related to hydrothermal vents, seamounts and the abyssal plain in the Antarctic region (e.g., Brandt *et al.* 2004; 2007a, b). New molecular tools have increased our comprehension on the Antarctic biota, speciation traits and gene flow between populations within and outside Antarctica (e.g., González-Wevar *et al.* 2010, 2011a, b; Allcock *et al.* 2011; Barnes & Griffiths 2011; Díaz *et al.* 2011). Eighteen expeditions were undertaken under the CAML only during the 2007-2008 International Polar Year, some of which explored the deep and under ice, unfolding new environments and bringing to light many new species (e.g., Brandt *et al.* 2007, Gutt *et al.* 2011). But even with all these efforts, the current knowledge on Antarctic biodiversity is still strongly limited by logistics and sampling technologies. Therefore, the availability of research vessels and position of research stations have influenced considerably the sampling capabilities, and inevitably our interpretation of observed diversity data and distribution patterns known today (Griffiths 2010). This means that, for instance, benthic samples have been highly restricted to the continental shelf and comparatively only a little is known from the deep-sea (Brandt *et al.* 2007a, b). Also, our taxonomic knowledge is limited by the number of specialists who work with particular groups, and the known species distributions highly reflect the sampling effort (Griffiths *et al.* 2009; Griffiths 2010).

Outside the Antarctic region, another CoML Project, Continental Margins Ecosystems on a Worldwide Scale (COMARGE), has been developed with the acknowledgement that the biodiversity of continental margins have a high degree of structural and functional complexity, and diversity (Levin *et al.* 2010). Continental margins are active regions ecologically, geologically, chemically, and hydrodynamically, and this is also true for the margin surrounding the Antarctic continent. Fundamental patterns of species distribution first observed and explained in the context of monotonous slopes only recently, with higher resolution bathymetry and increased bottom sampling, have been re-evaluated in light of the recognized heterogeneity of the margins worldwide (Levin *et al.* 2010).

COMARGE has dealt with two different scales of heterogeneity: 1) the fragmented habitats of high biomass production and/or distinctive species composition collectively termed Hotspots (e.g., deep cold-water coral reefs, cold seeps, canyons, oxygen minimum zones) and the influence of geological, geochemical, and biogenic habitat heterogeneity on biodiversity (Levin *et al.* 2010; Cordes *et al.* 2010; Menot *et al.* 2010a); and 2) the environmental variability found along latitude and depth gradients, whereby at a global scale the project has aimed at verifying, refining, and better understanding biological patterns already observed in well studied regions, e.g., sharp decrease in biomass with depth, changes in species composition with depth, and a maximum in species richness occurring at middle to lower slope depths (Menot *et al.* 2010a). In the latter perspective, COMARGE has collected and synthesized existing data to provide general underlying elements related to the processes regulating biodiversity, and generate hypotheses to be tested at new localities (Menot *et al.* 2010b; Olu *et al.* 2010). In order to study unexplored regions, evaluate latitudinal trends and especially poleward trends in biodiversity patterns along continental margins, COMARGE has gained from baseline surveys carried out by oil companies off the coasts of Africa (Sibuet & Vangriesheim 2009) and South-America (Lavrado & Brasil a, b 2010) for example, and from the interactions with other two CoML projects, Arctic Ocean Diversity (ArcOD) and CAML.

The views on Antarctic's isolation has changed considerably especially over the last decades taking into account not only the physical processes involved (Turner *et al.* 2009), but also the substantial concurrence of a few elements of the fauna and flora, including benthic organisms, mostly on the genus and family levels (Arntz *et al.* 2005; 2006; Clarke *et al.* 2005; Gutt and Arntz, this volume), but in some cases also at species levels (e.g., Barboza *et al.*, Fortes & Absalão, both in this volume). The workshop and symposium named as "Antarctic ~ South American Interactions in the Marine Environment - ASAI" were carried out as a joint effort between COMARGE and CAML through the "South American Consortium on Antarctic Marine Biodiversity" (a CAML sub-project more commonly known as LA CAML, Latin

American CAML) in order to evaluate and potentially integrate available data sampled either in Antarctica, South America or both continents, exchange data, and compile integrated documents showing the state of the art on potential Antarctic and South American biodiversity connections. This was undertaken considering all marine realms including top predators, pelagic and benthic organisms. Therefore, here we provide a historical background for these meetings, show their overall results, and present this volume as an International Polar Year (IPY) contribution to these CoML projects (COMARGE and CAML), to the South American Network on Antarctic Marine Biodiversity (BioMAntar), all its involved South American IPY projects, and also to the SCAR programme Evolution and Biodiversity in Antarctica (EBA).

HISTORICAL BACKGROUND

A South American Consortium on Marine Antarctic Biodiversity for the Census of Marine Life was implemented in Latin America in 2005 as a sub-project of the Census of the Antarctic Marine Life (CAML). This was done in order to promote the integration of Antarctic scientific activities between Argentina, Brazil, Chile, Ecuador, Peru, Uruguay and Venezuela especially during the International Polar Year.

The consortium became known as Latin American CAML (LA CAML), after its first workshop named '1a. Oficina Latino-Americana para o Census of Antarctic Marine Life (OLA CAML)' undertaken in Concepcion (Chile), and has played a major role in networking and improving the interactions between scientists, government representatives, and administrators from the South American Antarctic Programmes for the past six years. As the LA CAML was established, a series of activities were adopted in order to promote the integration of the South American investigations related to Antarctic biodiversity. The work involved: facilitation of the international cooperation efforts in order to establish and/or strengthen the relationship between governmental institutions, Antarctic programmes and the scientific community; opening opportunities to improve the

integration of South American scientific and logistical activities and the elaboration of multilateral projects; promoting activities of Education and Outreach through talks, courses, media communication (TV, newspapers, internet), workshops, participation in official South American Antarctic meetings, data input into SCARMarBIN and OBIS; and promoting interactions with other CoML projects such as CEDAMAR, and especially COMARGE.

The LA CAML exchanges resulted in the formation of a multinational project named 'Rede Sul Americana sobre a Biodiversidade Marinha Antártica - BioMAntar' (South American Network on Antarctic Marine Biodiversity) that was approved by the Brazilian Council for Research and Technological Development (CNPq/PROSUL), and which lasted from October 2007 until August 2010. For the first time in the South American Antarctic research history, Antarctic administrative and scientific representatives from each country met in the same room to discuss and identify common interests and science projects, which could potentially cooperate during IPY, and effectively plan for future interactions. A data matrix on logistical and science projects details was built, and from this, thematic areas with potential for international cooperation related to Antarctic biodiversity were chosen.

The LA CAML / BioMAntar scientific team has been structured in the framework of three thematic subprojects based on the above-mentioned matrix: 1) the Pelagic Realm (plankton and oceanography); 2) the Benthic Realm (microorganisms to megafauna); and 3) the Top Predators (cetaceans, pinnipids and seabirds). Their activities included the standardisation of sampling protocols, data input into the information system linked to CAML, the SCARMarBIN, academic and research exchange, elaboration of scientific documents, and establishment of a series of education and outreach activities related to the CAML in South America (Table 1). A synthesis of the South American Antarctic marine biodiversity past georeferenced data has been summarized by Lanna *et al.* (2009), and this has helped in the identification of gaps and potential for interactions amongst scientists. Most South American Antarctic data come from the Antarctic Peninsula region (Figure 1).

Table 1. LA CAML / BioMAntar: main interactions between countries according to research interests and working groups. P: Pelagic Realm; B: Benthic Realm; T: Top Predators.

Interaction	Argentina	Brazil	Chile	Ecuador	Perú	Uruguay	Venezuela
Argentina							
Brazil	P, T						
Chile	P, T	T, B					
Ecuador	T	P, B	T				
Perú	P, T	P, B	T	T			
Uruguay	P	P, B	T	P	T		
Venezuela		B				P, B	

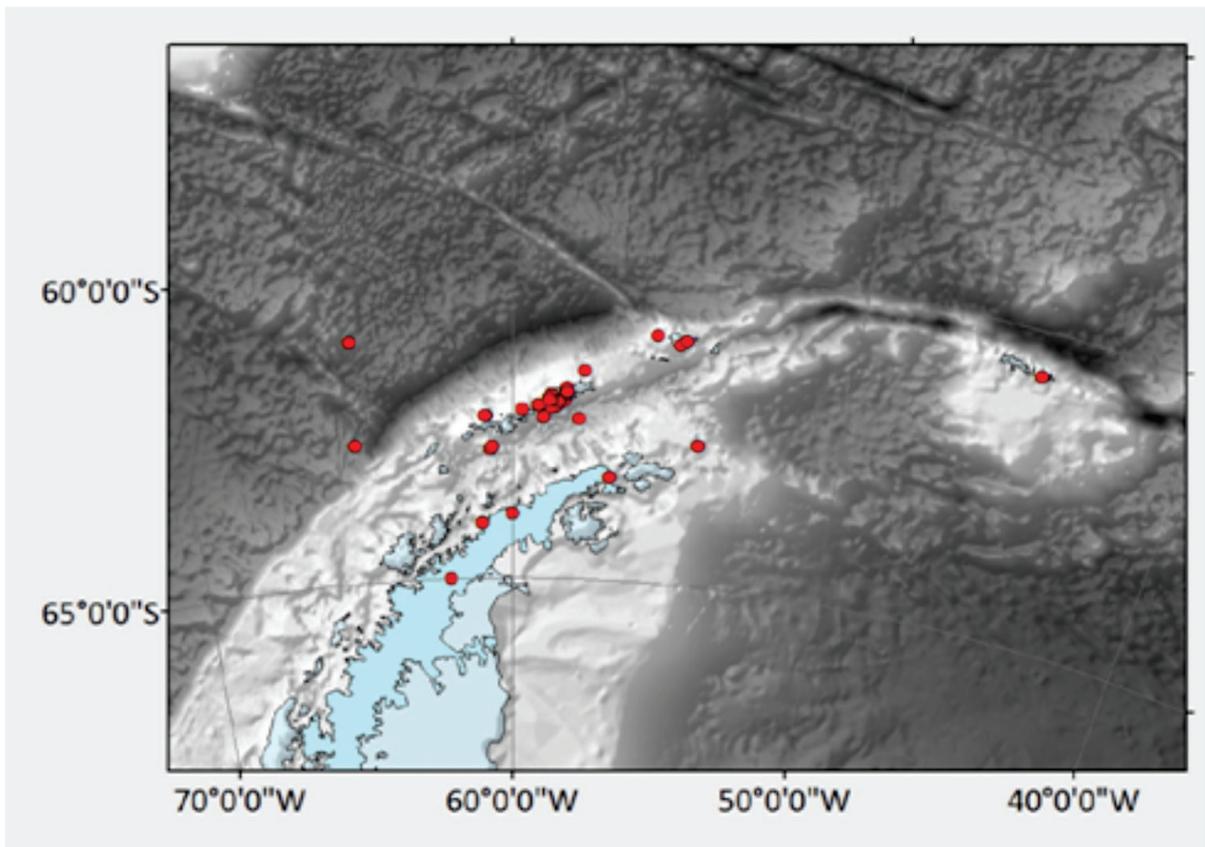


Figure 1. South American Antarctic marine biodiversity geo-referenced data points sampled from grey literature, regional and international journals. (Lanna *et al.* 2009)

The Pelagic Realm working group identified that the South American countries, mainly Argentina, Brazil and Peru have complementary data on plankton, and these were sampled continuously at different timescales, but which could be combined for further analysis, especially in the Bransfield Strait and Drake Passage (Viviana Alder, Virginia M. Tavano and Gladys Cardenas, personal communication). These South American scientists respectively from Argentina (through the IPY project 'DRAKE BIOSEAS' related to the seasonality of the Drake Passage pelagic ecosystem, its biodiversity, food webs, environmental change and human impact, present and past), Brazil (through the High Latitude Oceanography Group/GOAL working on the 'Southern Ocean Studies for Understanding Global-CLIMATE Issues / SOS-CLIMATE' IPY project involving a study on the role of phytoplankton in the CO₂ balance and Biological Pump), and Peru (through the project COPEPOD concerned with krill ecology) have much data especially on microplankton (e.g., Olguín & Alder 2011) and krill in relation to physical parameters over large time series. Although an integration of all this available information would be very useful, it would require a much longer time to be processed, and at this stage, unfortunately, could not be included in this volume. However, the pelagic realm here is represented in the manuscripts by Verde *et al.*, which discusses the evolutionary adaptations in Antarctic fish, and later in the volume by Rodrigues *et al.*, which discusses the Antarctic fish metabolic responses as biomarkers for environmental impact assessments, considering that human activities in Antarctica are of great concern, especially in the Antarctic Peninsula region, which is closest to South America.

The Benthic Realm working group has identified several areas for potential South American cooperation (Table 2), some of which lasted in the course of IPY and beyond through new cooperative or even joint project proposals. Some examples are the CNPq Brazilian funded projects: 'Instituto Nacional de Ciência e Tecnologia de Pesquisas Ambientais Antárticas – INCT-APA', Brazil interacting especially with Argentina, Chile, Ecuador, Peru, and Uruguay; and '**S**OUTHERN **O**CEAN **B**ENTHIC **O**BSERVING **S**YSTEM: Marine Biodiversity in relation to Evolutionary and Oceanographic Processes

between Antarctic and South America (SOBE)', Brazil in cooperation with Argentina, Chile, Ecuador; and others. The Benthic Realm group has undertaken a special effort at Admiralty Bay, King George Island, considering the location of the Brazilian 'Comandante Ferraz' and Peruvian 'Machu Picchu' research stations, the Ecuadorian Refuge 'República del Ecuador', and the fact that the bay was chosen by CAML and SCARMarBIN as a case study also in a joint effort with Poland and Belgium (see Sicinski *et al.* 2010). Some South American studies from this group have already been published in different journals, including the CAML Deep Sea Research Part II special volume (e.g., Díaz *et al.* 2011; González-Wevar *et al.* 2011a, b; Nakayama *et al.* 2011; Olguín & Alder 2011; and Sicinski *et al.* 2011b). Here in this volume, two syntheses manuscripts represent some of the syntheses from the Benthos working group, both related to two conspicuous benthic taxa, the echinoderms (Barboza *et al.*, this volume) and molluscs (Fortes & Absalão, this volume).

The Top Predators working group was the largest, and early in our work it was divided into three sub-groups: 1) Cetaceans (mainly whales) concerned with observation and data sampling especially in the Gerlasche-Bransfield region (Acevedo *et al.* 2007; Dalla Rosa *et al.* 2008; Secchi *et al.* 2009; Robbins *et al.* 2011); 2) Pinnipeds (seals) concerned with demography reproduction and trophic ecology data in relation to environmental variables (Aguayo-Lobo *et al.*, this volume); and 3) Birds, studying time series on biology, reproductive behaviour, migration, impacts on human activities on the colonies and other aspects of animals contamination and stress (two examples in this volume by Costa *et al.* and Krüger *et al.*).

The progress and achievements of the BioMAntar/LA CAML could be summarized as follows: (1) Education and Outreach (E&O): participation in disseminating activities on Antarctic marine biodiversity through talks, interviews, books, folders and video screenplay with several partners; (2) Organizing meetings on South American strategies for Antarctic Research: seven international workshops and the ASAI symposium; (3) Participation in several international meetings, also involving other Census of Marine Life (CoML) programmes; (4) Establishment of a link between South American Antarctic programmes with the SCAR Southern

Table 2. Benthic Working Group: study areas, research themes, logistical and funds available, potential for South American cooperation including Venezuela with an interface with another Census of Marine Life Project, the **Natural Geography in Shore Areas (NAGISA)**.

Countries	Uruguay	Ecuador	Perú	Chile	Venezuela	Brazil
Sampling sites	Colins Bay, King George Island	Greenwich Island	Mackellar, King George Island	Sub-Antarctic region, and Antarctic Peninsula	King George Island	Admiralty Bay, King George Island, and Deception Island
Types of organisms	Macrobenthos	Microphytobenthos and benthic fauna	Macrobenthos and macroalgae	Echinoderms, molluscs, and polychaetes	Macrobenthic fauna and macroalgae	Microbiology, Microphytobenthos and benthic fauna
Subject area	Monitoring, biodiversity, ecology	Monitoring, biodiversity, ecology, biogeography	Variability and distribution	Micro/Macro-evolution, biodiversity, conservation.	Biodiversity, conservation	Monitoring, diversity, ecology and biogeography
Cooperation	Brazil and Venezuela	Brazil	Brazil	With all in relation to molecular biology	Uruguay	Peru, Ecuador and Chile

Ocean–Continuous Plankton Recorder (CPR) Survey Programme (McLeod *et al.* 2010), and for this purpose, the LA CAML promoted training courses in Australia and Brazil in order to train South American researchers to operate de CPR in the Southern Ocean, and jointly sampled Antarctic waters in the Peninsula region for two consecutive summers; (5) Scientific exchange activities including joint field work in Antarctica between most countries where sampling protocols, some equipment, vessels and stations were shared among the South American scientists; (6) Polar Science training courses involving young scientists in Antarctic research carried out in Ecuador; (7) input of the South American Antarctic marine biodiversity available data (especially past data in grey literature) into the SCARMarBIN; (8) participation in scientific publications where at least five manuscripts were included in the major CAML synthesis – a Deep Sea Research Part II Special Volume, this special volume at the *Oecologia Australis*, and also a Field Guide on Antarctic Marine Organisms, which is being edited in two parts, the first volume on marine mammals and birds ready for publication, and another on phytoplankton and benthos still under preparation.

The LA CAML closure from all its activities within the scope of the Census of Antarctic Marine Life will end in August 2011, when the Pelagic and Benthos

realm field guides should be ready for publication. Apart from the publications some legacies were left as the collaboration continues amongst many LA CAML scientists in recently funded projects. Also, the participation of South America in the Scientific Committee on Antarctic Research activities has increased, and many young scientists from South America have engaged in Antarctic research as a result from the LA CAML. An example is the involvement of several young scientists in the Association of Polar Early Career Scientists (APECS) (see Annex 1- Letter to the Editors by Ivar do Sul *et al.* in this volume).

ANTARCTIC ~ SOUTH AMERICAN INTERACTIONS IN THE MARINE ENVIRONMENT (ASAI): THE WORKSHOP AND SYMPOSIUM

The “LA CAML / BioMantar / COMARGE Integrated Workshop” represented an opportunity for scientists to gather available data sampled either in Antarctica, South America or both continents, which could be relevant for the better understanding of their relationship. The workshop involved 55 researchers from 13 countries, including South, Central and North America, and Europe, who have worked on different marine realms (top predators, pelagic and benthic)

and also on atmosphere, oceanography, glaciology, and geology (Annex 2). During the meetings, several aspects of the environment provided the background for the biological discussions by physical and earth science specialists. Although this volume is mostly biological in its content, aspects of how polar atmospheric variations can affect the lower latitudes were discussed by Correia taking into account the relevance of instrument networks.

In the past, several questions were raised and pursued in relation to the theme (e.g., Arntz & Rios 1991; Piepenburg *et al.* 2002; Arntz *et al.* 2005; Lorwich *et al.* 2005; Montiel *et al.* 2005; Ramos-Esplá *et al.* 2005; Zelaya 2005; Linse *et al.* 2006; Kim & Thurber 2007; Primo & Vázquez 2007; Hunter & Halanych 2008, amongst others). Participants to the workshop brought lists of species, photographs of organisms from Antarctic or South America, georeferenced data sampled from these continents in order to distinguish which species were restricted to the Peninsula region, which were circumpolar, which were shared with South America, and which were cosmopolitan from the available lists. Gaps were identified, and it was clear that despite the advances in our deep sea knowledge, more information is required from the South American deep-sea margins, as well as from Antarctica, comparisons should take into account depth range of species occurrences, geophysical

and biological processes including their different time scales (for instance, see Table 3), involved in connectivity between both continents. Data synthesis in the form of spreadsheets for SCARMarBIN and COMARGE databases were produced and analysed during the event. These showed that approximately 10,000 new records are readily available for input into the databases, but the ultimate decision to do so remain with responsible scientists.

Data from different taxa were provided for discussions during the workshop and synthesized for preliminary discussions as in Figures 2 and 3. Nematodes had the highest number of species followed by crustaceans, annelids, molluscs, echinoderms, and several other groups. A total of 173 species from those reported in the workshop were found to be shared between Antarctica and South America (Table 4). However, it became clear that much work is still necessary, and some of these findings were undertaken on echinoderms and molluscs as shown by Barboza *et al.* and Fortes & Absalão in this volume. Besides, further molecular analyses would be required to pursue the testing of connectivity hypothesis as emphasized by Gutt & Arntz towards the end of this volume, and also exemplified by some recent work on *Nacella* spp. by González-Wevar *et al.* (2010; 2011a, b), and shallow and deep sea echinoids of the genus *Sterechinus* by Díaz *et al.* (2011).

Table 3. Temporal scales of physical and biological processes in effect in the oceans (personal communication by J. H. Muelbert, based on information from Perry & Ommer, 2003).

Temporal scale	Physical processes	Biological processes (life cycles)
Millions of years	Thermohaline circulation (global)	
Hundreds of years	Oceanic circulation (within one ocean)	
Tens of years	Oceanic and coastal circulation	Life span of mammals, fish and some invertebrates (e.g., echinoderms)
Annual	Seasonal cycles	Life span of fish and some invertebrates
Weeks to months	Gyres and eddies	Zooplankton
Days	Heat transfer	Phytoplankton
Seconds to hours	Energy transfer	Some elements of the phytoplankton, bacteria, Archaea

Table 4. Number of taxa shared between Antarctica and South America according to data presented at the ASAI Workshop. These have been further reviewed for some of the groups (see Barboza *et al.* and Fortes & Absalão in this volume), so that number in this table could be underestimated.

Phylum	Class	Shared
Annelida	Polychaeta	12
Arthropoda	Malacostraca	19
Bryozoa	Stenolaemata	1
Chordata	Actinopterygii	20
Cnidaria	Anthozoa incertae sedis	1
	Hexacorallia	3
	Crinoidea	2
	Echinoidea	11
Echinodermata	Holothuroidea	2
	Astroidea + Ophiuroidea	62
	Mollusca	Bivalvia
Mollusca	Cephalopoda	1
	Gastropoda	10
	Nematoda	Adenophorea
Porifera	Demospongiae	5
	Hexactinellida	1
	TOTAL	173

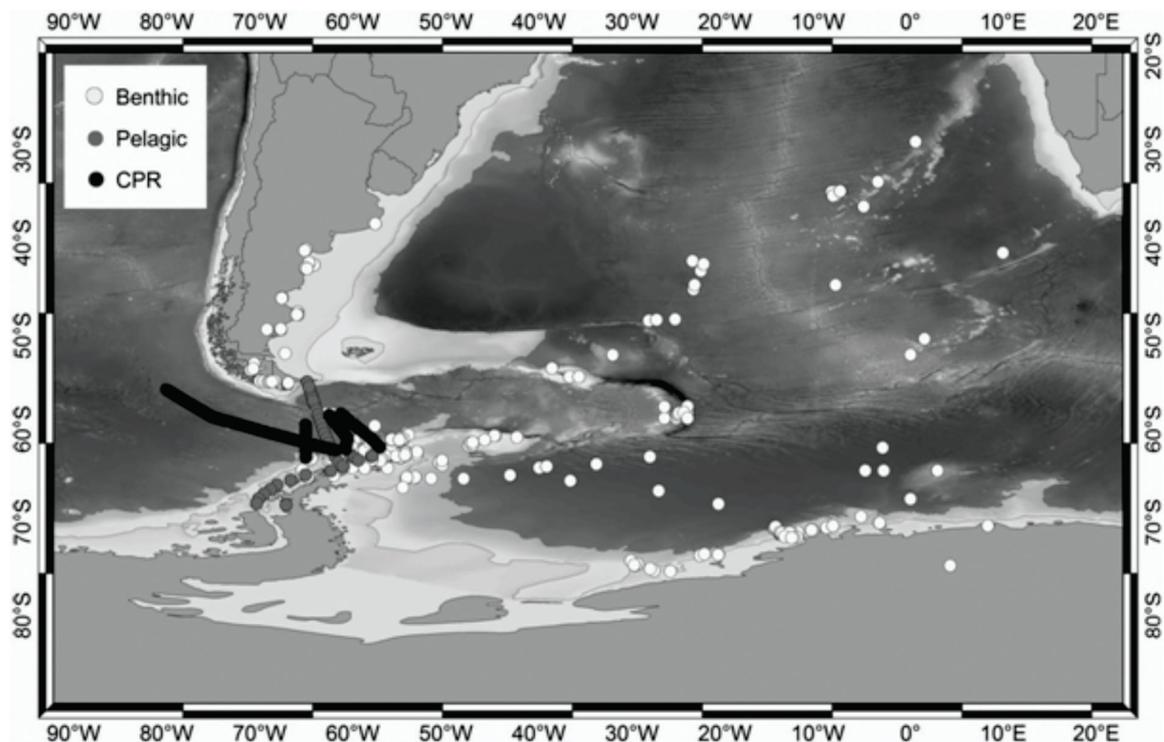


Figure 2. Data points from all biodiversity information provided by the ASAI participants based on the three main LACAML / BioMantar working groups (Pelagic: Pelagic realm and Top Predators; and Benthic Realm), but also including the Continuous Plankton Recorder (CPR) routes sampled during IPY through the South American effort in cooperation with Graham Hosie from the Australian Antarctic Division. Based on map built by Huw Griffiths during the ASAI workshop.

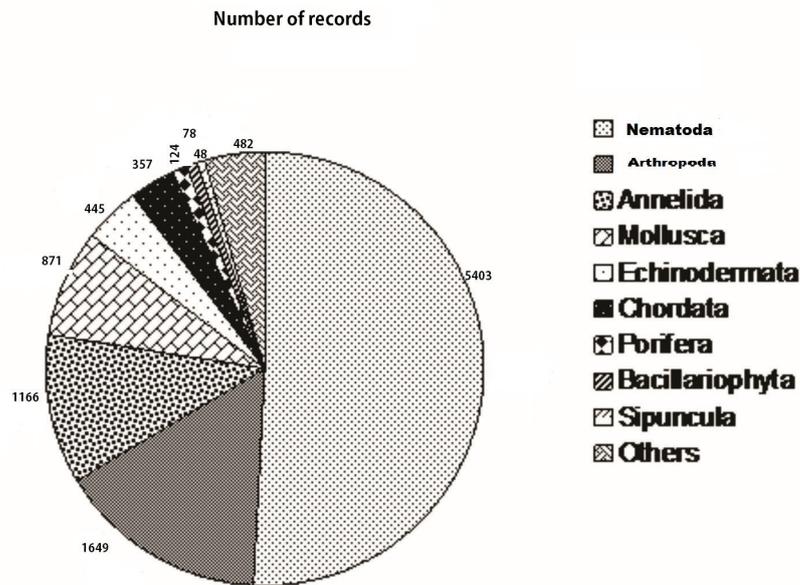


Figure 3. Summary of data provided for the ASAI workshop discussions: number of records per different taxa. Others represent the following taxa: Chlorophyta; Bryozoa; Cnidaria; Rhodophyta; Ochrophyta; Ascomycota; Gamma-Proteobacteria; Nemertea; Bacteroidetes; Bryophyta; Echiura; Brachiopoda; Firmicutes; Gracilicutes; Priapula; Proteobacteria; Heterokontophyta; Sarcomastigophora; Alpha-Proteobacteria; Cephalorhyncha; Ciliophora; Dinoflagellata; Granuloreticulosa.

An interesting outcome from the ASAI symposium, which was organized to present the results from the workshop to a wider audience and allow students and young scientists to participate in the discussion, was the debate on human activities and their impacts in the Antarctic environment. This has been highlighted here by the possible links between Antarctica and South America in relation to plastic marine debris pollution by Ivar do Sul *et al.*

TOWARDS THE FUTURE

Organisms found on the continental shelves may differ considerably from those in the slopes and deepest zones in the Southern Ocean. Kaiser *et al.* (2011) found a rich and complex fauna on slopes near the Scotia Arc and Antarctic Peninsula suggesting that this large and little known environment could have been important for post-glacial recolonisation. The Southern Ocean biodiversity is generally high, although species spatial distributions vary among distinct taxonomic groups (Clarke & Johnston 2003). A common limit for the shelf fauna occurs between 1500 to 2000m, possibly reflecting the depression of the Antarctic continent because of the ice sheet weight (Thatje *et al.* 2008). This physical feature

combined with the isothermal water column led to different taxa to possess a wide depth distribution (Thatje *et al.* 2008, Kaiser *et al.* 2011). Also, this limit may be interpreted as an evolutionary adaptation or pre-adaptation to the oscillations in the extension of the ice shelf during the Antarctic glacial-interglacial cycles (Clarke 2003, Thatje *et al.* 2005, 2008).

Taking into account the role of the producers in the oceans, these respond to the changes within an integrated system of connections biologically modulated (Hofmann *et al.* 2004, 2008, 2011). The Antarctic slope and abyssal zones commonly receive an input from the water masses that sink south of the Polar Front and carry fresh organic matter from the surface primary production, detritus, and algae produced in the ice (Smith *et al.* 2008). There are evidences that the loss of Antarctic sea ice affect in multiple ways the trophic web in a cascade effect (Hofmann *et al.* 2011). Long term, climate change represent a potential risk to the survival of Antarctic marine communities known today (Aronson *et al.* 2007, Hofmann 2011). Some species, populations and /or communities may be substituted in such way that it becomes even more fundamental that habitats are modeled, based not only on the knowledge of physical and biological processes operating in the ecosystems,

but also on the physiological and molecular responses at cellular level, as these represent a reaction from life forms to the environmental changes (Verde *et al.* and Rodrigues *et al.*, this volume).

The Antarctic fairly pristine environment is supported by its species richness and diversity, continuous speciation in certain taxa and the high levels of endemism (Clarke & Johnston 2003). Great concern is raised when the exploration of sea resources in deep zones may result in dramatic losses, as the source for some conspecific populations may not exist in adjacent margins, despite a few evidences for the existence of links between taxa found in other ocean basins (Clarke *et al.* 2005; Arntz *et al.* 2006). In terms of species richness, some groups are fairly conspicuous such as nematodes, picnogonids, amphipods, isopods, polychaetes, molluscs, echinoderms, ascidians amongst others (Aronson *et al.* 2007), as also observed through the ASAI results. Conversely, groups that are normally diverse in lower latitudes, may be less diverse in the Antarctic region such as gastropods, pelecipods, decapods, and teleostean fish (Aronson *et al.* 2007).

Barriers to the movement of organisms may be more significant to smaller organisms living in the upper layers of the oceans limited by oceanographic processes, but at the same time, deeper water masses and currents may favour long distance dispersal in a combination of biological and physical processes at different time scales (Table 3) and traits (e.g., Pearse & Lockhart 2004, Thatje *et al.* 2005; Peck *et al.* 2006; Thornhill *et al.* 2008). Also, in a large time scale, assemblages of Antarctic marine organisms reflect the influence of macro-evolutionary events, invasions, extinctions, tectonic processes as well as climate change (Clarke *et al.* 2004; Aronson *et al.* 2007). Conversely, in smaller scales, organisms are subject to ecological factors such as predation, habitat features, and food supply (Clarke *et al.* 2004, Clarke *et al.* 2008). These two time scales are simply extremes of a continuum through which there is an exchange between the relative importance of ecological and evolutionary factors (Clarke 2008).

The biogeography of various marine groups present in the Southern Ocean, especially those with a high dispersal capacity (e.g., even invertebrates that have larval stages in their life cycles), may be influenced by long distance dispersion mediated through complex meso-scale circulation processes (tens to hundreds

of kilometers) associated to the ACC (Clarke *et al.* 2005; Barnes *et al.* 2006, Thornhill *et al.* 2008). Gyres and eddies originated at the ACC may allow several species to break the Polar Front. This is the possible reason for the presence of Antarctic krill in the Chilean fjords (Clarke *et al.* 2005), and a variety of diatoms (pelagic and those usually associated to the ice) found in the estuaries at the West of Tasmania (Clarke *et al.* 2005), as well as the copepod commonly found in the Sub-Antarctic, *Acartia* sp., observed with brachyurans and anomurans in the South Shetland Islands (Clarke *et al.* 2005).

Studies in the North Water, eastern Canadian Arctic (Galand *et al.*, 2009) have also suggested that the oceanic circulation strongly affect microbial distribution and that water masses are crucial for the stratification of microbial communities observed in the marine environment. This may define a connection of both diversity and function of microbial communities in South America and Antarctica or even indicate that shifting currents and water masses boundaries may change microbial diversity patterns and may lead to changes in the geography of microbial-driven biogeochemical processes and associated oceanic production. In the long term, and following the flow direction of the water masses, if no other physical barrier exists, it is possible that many organisms slowly colonize further distances breaking the Polar Front. This is possibly the case of some Antarctic and South American shared species that occur in the deep sea, some of which reported during the ASAI. Also, recent molecular studies have supported the hypothesis that the start of the Antarctic Circumpolar Current was a key event, which induced vicariant speciation in several taxa (González-Wevar *et al.* 2010 and authors therein).

Polar habitats and their biota are an integral part of the Earth System, also influencing the pace and nature of the environmental changes (Di Prisco & Verde, this volume). As we better comprehend the responses from these Antarctic communities, they may show some relevant alert signs to the impacts on ecosystems. Although some of these signs may be also perceived in other parts of the world in lower latitudes, in some cases, they may be masked by the high levels of diversity and more direct effects of human activities (Ivar do Sul, this volume).

The Antarctic Peninsula, Scotia Arc and sub-Antarctic regions including the southern part

of South America (where rapid air and ocean temperature changes have occurred) are relevant to the formation of water masses that flow through the South American deep margins (Turner *et al.* 2009). Some of these water masses upwell in the Pacific and Atlantic increasing biological resources outside the Polar Front far from the Antarctic region (Rintoul *et al.* 2001, Piola & Matano 2009, Turner *et al.* 2009). Considering the proximity of South America from Antarctica and Southern Ocean, it has become even more urgent that we pay attention to biological and geophysical processes in these regions.

The ASAI contributions have advanced some basic information on different groups of organisms from South America and Antarctica, adding to the conclusion that the Southern Ocean is far from being totally isolated. Potentially, it may even receive some colonizers, naturally or human induced (Aronson *et al.* 2007; also anthropogenic potential invasions with plastics exemplified by Ivar do Sul *et al.*, this volume), from lowest latitudes warmest waters, as future changes in climate and water temperatures may facilitate the establishment of outside populations in Antarctica. But, from microbes to large predators, further studies using modern techniques and ‘omics’ tools are necessary to model what might happen to them (as suggested by Gutt & Arntz, this volume), and also to the likely deep sea biodiversity pump to other ocean basins. The international cooperation becomes fundamental as stated by Di Prisco & Verde (this volume), if we are to better understand how the Antarctic marine biodiversity relates to that from other ocean basins and continental margins. The LA CAML / BioMantar / COMARGE efforts have certainly left some legacies, especially with respect to the establishment of new cooperation projects, and a much closer scientific and academic relationship amongst South American Antarctic researchers.

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