Census of Antarctic Marine Life
SCAR-Marine Biodiversity Information Network

BIOGEOGRAPHIC ATLAS OF THE SOUTHERN OCEAN

EDITED BY:
Claude DE BROYER & Philippe KOUBBI (chief editors)

with Huw GRIFFITHS, Ben RAYMOND, Cédric d'UDEKEM d'ACOZ, Anton VAN DE PUTTE, Bruno DANIS, Bruno DAVID, Susie GRANT, Julian GUTT, Christoph HELD, Graham HOSIE, Falk HUETTMANN, Alexandra POST & Yan ROPERT-COUDERT

SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

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Edited by:

Claude De Broyer (Royal Belgian Institute of Natural Sciences, Brussels)
Philippe Koubbi (Université Pierre et Marie Curie, Paris)
Huw Griffiths (British Antarctic Survey, Cambridge)
Ben Raymond (Australian Antarctic Division, Hobart)
Cédric d’Udekem d’Acoz (Royal Belgian Institute of Natural Sciences, Brussels)
Anton Van de Putte (Royal Belgian Institute of Natural Sciences, Brussels)
Bruno Danis (Université Libre de Bruxelles, Brussels)
Bruno David (Université de Bourgogne, Dijon)
Susie Grant (British Antarctic Survey, Cambridge)
Julian Gutt (Alfred Wegener Institute, Helmoltz Centre for Polar and Marine Research, Bremerhaven)
Christoph Held (Alfred Wegener Institute, Helmoltz Centre for Polar and Marine Research, Bremerhaven)
Graham Hosie (Australian Antarctic Division, Hobart)
Falk Huettmann (University of Alaska, Fairbanks)
Alix Post (Geoscience Australia, Canberra)
Yan Ropert-Coudert (Institut Pluridisciplinaire Hubert Currien, Strasbourg)

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- The Université Pierre et Marie Curie (UPMC), Paris, France
- The Australian Antarctic Division, Hobart, Australia
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Contents

Preface

Famous lines from the diary of explorer Robert F. Scott, 17 January, 1912: "*Great God! This is an awful place, and terrible enough for us to have labored to it without the reward of priority. Now for the run home, and a desperate struggle*." Scott and his companions would starve, freeze, and die ten weeks later in an Antarctic blizzard, disheartened by the knowledge that Roald Amundsen had reached the South Pole a month before them. A century later, we know in much greater detail the gigantic ferocity of Antarctica. But, as the Biogeographic Atlas of the Southern Ocean proves, we also know the unpredicted diversity and fecundity of the waters around it, and that rewards of priority from Antarctic exploration are far from exhaustion.

Still, Antarctica does not yield secrets easily. To modernize our knowledge of the diversity and distribution of its marine life required five years of field work and then three years of analysis by about 140 researchers from all the other six continents. About equally men and women, they looked from the sea birds and the sea surface to the sea floor as deep as six thousand meters and into the sediments. They looked on and under the ice. They looked from the microplankton to the macroalgae, from the sponges and corals to the molluscs and the crustaceans, from the sea spiders and sea stars to the seals and the fish. They looked at animals living off heat and gases coming from the crust beneath the ocean as well as those that bask in the seasonal sun above and enjoy its photosynthesis. They looked at the uniquely Antarctic and the cosmopolitan.

To perceive the patterns and processes emerging from studying more than one million records of about ten thousand species, the fourteen editors of the Atlas organized knowledge on the evolutionary and environmental settings, and finally prepared the way for a gratifying chapter that synthesizes knowledge on the realms and regions of the Southern Ocean. Wizardly cartographers present the information in colorful maps that allow us to understand at a glance the grand carousel that whirls around Antarctica.

Meanwhile, wizardly geneticists using molecular clocks allow us to explore deep time as well as space. We learn about Antarctic ancestors, their kinships, and how past changes in the Southern Oceans may have sent species such as octopods venturing forth into the Pacific, Indian, and Atlantic oceans.

We also learn modesty, as do all who encounter high latitudes. We learn of regions still little explored, such as the sea named for Amundsen below the South Pacific, and taxa, such as the sea squirts (tunicates) and roundworms (nematodes). We also learn of threats to the life of the Southern Ocean, from fishing, tourism, pollution, and climate change, and proposals for new marine protected areas matching the richness of our hard-won knowledge.

This magnificent scholarly achievement comes to us because of organizations as well as individuals. The Census of Antarctic Marine Life (CAML) program of the global Census of Marine Life (2000-2010) fostered many expeditions that have provided observations, and the Scientific Committee on Antarctic Research Marine Biodiversity Information Network (SCAR-MarBIN) has carefully filtered and archived the data and made them accessible. Founded in 1958, SCAR initiates, develops, and coordinates research in the Antarctic region, and adds to its lustrous history with this volume. National organizations such as the such as the Australian Antarctic Division and the Royal Belgian Institute of Natural Sciences in turn make possible cooperative international efforts such as CAML and SCAR-MarBIN.

Finally, only the truly visionary and persistent succeed in Antarctica, and here we salute Claude De Broyer and Philippe Koubbi, chief editors. They together with their 140 co-authors prove conclusively that the Southern Ocean is not monotonously blank but a shining, stirring, diving world of anemone and albatross, jelly and whale, revealing Earth's history and nature and still rich with rewards for the hard labor of future explorers.

Jesse H. Ausubel
Co-Founder, Census of Marine Life
Director, Program for the Human
Environment, The Rockefeller University

Foreword

Many people unfamiliar with the Southern Ocean regard this ice-bound region as still largely unexplored biologically. This is far from the truth, for the study of the diversity and distribution of organisms in the Southern Ocean has a long and distinguished history. James Cook got close to the Antarctic continent in 1774 aboard HMS *Resolution*, although he never saw it. His reports of the abundant wildlife led to an explosion of commercial sealing activity, but sadly none of this contributed much to a wider understanding of Southern Ocean biology as the knowledge gained was of powerful commercial interest and largely remained within the community of fisherman to whom it was valuable economically.

Some Antarctic marine species were, however, described as early as the 19th century, reflecting how even the earliest voyages of exploration contributed something to science. The initial exploration of Antarctica was dominated by political, geographical and economic considerations, but even so many of the expeditions undertook biological collections and observations. These were typically fairly limited in scope and often undertaken by participants whose primary role was elsewhere. This early work was dominated by collection of shallow-water benthos and fish, although Bellingshausen did undertake some plankton tows.

Although these early collections were valuable, we can trace the dedicated scientific investigation of the Southern Ocean fauna and flora to the seminal voyages of HMS *Challenger* (1872-1876), which penetrated to the Antarctic Circle off Queen Maud Land in the Southern Indian Ocean whilst sailing eastwards in 1874. The concept of a purely scientific voyage was novel at that time and although the equipment and approach were perhaps somewhat conservative, this voyage revolutionised our understanding of the biology and chemistry of the oceans. Working up the material took a great many years, but in the end some fifty volumes of scientific findings were published, all beautifully illustrated, and these remain an important scientific resource to this day.

During the Heroic Era of Antarctic exploration, many national expeditions included biologists in their complement and these added incrementally to our knowledge. For some expeditions science was a minor component, whereas for others it was integral to the enterprise as a whole. The next significant contribution to our knowledge of Southern Ocean marine diversity, however, came from the *Discovery* Investigations. Fieldwork was initiated in 1925, based at South Georgia, and the work was intended to provide an understanding of the biology of the great whales on which the whaling industry depended. In doing so, these extensive voyages of biological oceanography covered the entire Southern Ocean and provided the single greatest advance in our understanding of the system since the voyage of HMS *Challenger*.

The legacy of this important early work can be seen in the sharp increase in the rate of description of new marine species from the Southern Ocean during the early half of the 20th century. At this time ecology as a discipline was developing rapidly, and the attention of many biologists was moving away from the documentation of new species to understanding how species interacted with each other and with their environment. Although the description of new taxa continued to be important in museums, university researchers were busy exploring this new field of ecology and the rate of description of new Antarctic taxa slowed markedly.

The later decades of the 20th century were a time when Antarctic science started to flourish and many new young researchers starting their careers in Antarctic research at this time rapidly became aware of the importance of this early work. When I started my first Antarctic work in 1970, I decided to explore aspects of the biology and physiology of the caridean decapod *Chorismus antarcticus* in the shallow waters of South Georgia. In those days there was no easy way to identify Antarctic marine invertebrates, and so to be certain I was working on the animal I thought I was, I had to find a copy of the original description by Georg Johann Pfeffer, from specimens collected by the German South Georgia expedition which was based at Moltke Harbour for the first International Polar Year in 1882/83.

In the late 20th century many funding agencies became less interested in funding primary taxonomy, but the documentation of Antarctic marine diversity remained important for many national Antarctic programmes. The next important phase in the study of Southern Ocean diversity and biogeography was the support of Antarctic marine biology by the Scientific Committee on Antarctic Research (SCAR), and in particular the EASIZ (Ecology of the Antarctic Sea Ice Zone) programme which ran for ten years from 1994. Whilst this international programme was focussed primarily on ecology, it also stimulated a considerable volume of primary taxonomic work and prompted the first comprehensive assessments of marine diversity for all of Antarctica. Whilst these assessments were valuable in themselves, they were also important in directing attention at gaps in our knowledge. In particular they identified how little was known of the fauna of the continental slope and the deep-sea around Antarctica. Other important features of the EASIZ programme were the emphasis placed on understanding the relationship between marine organisms and the oceanographic environment within which they lived, and also the evolutionary context in respect of the climatic and tectonic history of the Southern Ocean.

After the EASIZ programme had drawn to a close, the ANDEEP (Antarctic Deep-Sea Biodiversity) programme undertook a series of cruises directed specifically at improving our knowledge of the Antarctic deep-sea fauna. At about this time another significant development was the initiation, under the auspices of SCAR and hosted by Royal Belgian Institute of Natural Sciences, of an interactive database for Antarctic marine diversity, MarBIN (Marine Biodiversity Information Network). As science becomes ever more reliant on information being available on-line, SCAR-MarBIN has been instrumental in improving the quality of marine diversity data for Antarctica, and in disseminating this information to those who need it. The Southern Ocean is now part of the global information network, and no longer an isolated region of the world.

These important developments meant that when the Census of Antarctic Marine Life (CAML) was initiated, and fieldwork undertaken in conjunction with the second International Polar Year (2007/08), the stage was set for a major step forward in our knowledge and understanding of Southern Ocean marine diversity. This volume shows the extent to which this opportunity has been taken and the potential realised. CAML has delivered the single largest step in our knowledge of Antarctic marine diversity and biogeography since the first half of the 20th century. The Biogeographic Atlas has sections devoted to every major taxonomic group, with detailed maps of distribution, as well as chapters documenting the environmental background and evolutionary history, and synthetic analyses. This is a magnificent achievement and testament to the vision of those who planned and developed the programme. It will undoubtedly remain an important resource for many years to come.

Andrew Clarke
Emeritus fellow
British Antarctic Survey, Cambridge

Contributors

Jorge Acevedo, Centro de Estudios del Cuaternario Fuego-Patagonia y Antártica, Fundación (CEQUA), 21 de Mayo 1690, Punta Arenas, Chile. E-mail: jorge.acevedo@cequa.cl

Anelio Aguayo-Lobo, Departamento Científico, Instituto Antártico Chileno, Casilla 16521, Correo 9, Santiago, Chile. E-mail: aaguayo@inach.cl

David G. Ainley, H.T. Harvey & Associates Ecological Consultants, 983 University Avenue, Bldg D, Los Gatos CA 95032, USA. E-mail: dainley@penguinscience.com

A. Louise Allcock, Ryan Institute, School of Natural Sciences (Zoology), National University of Ireland Galway, University Road, Galway, Ireland. E-mail: louise.allcock@gmail.com

Séverine Alvain, UMR 8187 LOG/CNRS/Université du Littoral Côte d'Opale/Université Lille, 28 avenue Foch, BP 80, F-62930 Wimereux, France. E-mail: severine.alvain@univ-littoral.fr

Nadia Améziane, Muséum national d'Histoire naturelle, Département des Milieux et Peuplements Aquatiques, UMR 7208 MNHN-CNRS-IRD-UPMC, CP26, 57 rue Cuvier, F-75231 Paris Cedex 05, France. E-mail: ameziane@mnhn.fr

Charles D. Amsler, Department of Biology, University of Alabama at Birmingham, Birmingham, AL 35294-1170, USA. E-mail: amsler@uab.edu

Martin V. Angel, National Oceanography Centre Southampton, University of Southampton Waterfront Campus, Southampton, SO14 3ZH, UK. E-mail: mva@noc.soton.ac.uk

Claudia P. Arango, Queensland Museum, Natural Environments Program, PO Box 3300, South Brisbane, QLD 4101, Australia. E-Mail: claudia.arango@qm.qld.gov.au

Jennifer Ayers, Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 129, Hobart, Tasmania 7001, Australia. E-mail: jennifer.ayers@utas.edu.au
Australian Research Council Centre of Excellence for Climate System Science, University of New South Wales, Sydney, New South Wales 2052, Australia.

David K.A. Barnes, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: dkab@bas.ac.uk

Zeenatul Basher, Institute of Marine Science, The University of Auckland, Leigh Marine Laboratory, PO Box 349, Warkworth 0941, New Zealand. E-mail: z.basher@auckland.ac.nz

Narissa N. Bax, Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 129, Hobart, Tasmania 7001, Australia. E-mail: baxn@utas.edu.au

Daniel Beaver, Centre for Conservation Geography, Beeson Street 18, Leichardt, New South Wales 2040, Australia. E-mail: dbeaver@wwf.org.au

Mark Belchier, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: markb@bas.ac.uk

Nathaniel L. Bindoff, Antarctic Climate & Ecosystems Cooperative Research Centre, University of Tasmania, Private Bag 80, Hobart, Tasmania 7001, Australia. E-mail: n.bindoff@utas.edu.au
Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 129, Hobart, Tasmania 7001, Australia.
Australian Research Council Centre of Excellence for Climate System Science, University of New South Wales, Sydney, New South Wales 2052, Australia.

Kasia Błachowiak-Samolyk, Arctic Ecology Group, Institute of Oceanology, Polish Academy of Sciences, Powstancow Warszawy 55, PL-81-712 Sopot, Poland. E-mail: kasiab@iopan.gda.pl

Magdalena Błażewicz-Paszkowycz, Department of Polar Biology and Oceanobiology, University of Łódź, Banacha 12/16, PL-90-237 Łódź, Poland. E-mail: magdab@biol.uni.lodz.pl

Horst Bornemann, Alfred Wegener Institute Helmholz Centre for Polar and Marine Research, Am Alten Hafen 26, D-27568 Bremerhaven, Germany. E-mail: hbornemann@awi-bremerhaven.de

Samuel S. Bowser, Wadsworth Center, New York State Department of Health, Albany, NY 12201-0509, USA. E-mail: bowser@wadsworth.org

Simone N. Brandão, Zoologisches Museum, Universität Hamburg, Martin-Luther-King-Platz 3, D-20146 Hamburg, Germany. E-mail: brandao.sn100@gmail.com
Laboratório de Geologia e Geofísica Marinha e Monitoramento Ambiental-GGEMMA, and Laboratório de Biologia Pesqueira, Departamento de Geologia, Centro de Ciências Exatas, Universidade Federal do Rio Grande do Norte, Campus Universitário Lagoa Nova, CEP 59072-970, 1596 Natal, RN, Brasil
German Centre for Marine Biodiversity Research (DZMB), Senckenberg Research Institute, Hamburg, Germany

Angelika Brandt, Biocentre Grindel and Zoological Museum, University of Hamburg, Martin-Luther-King-Platz 3, D-20146 Hamburg, Germany. E-mail: abrandt@zoologie.uni-hamburg.de

Dianne Bray, Museum Victoria, GPO Box 666, Melbourne, Victoria 3001, Australia. E-mail: dbray@museum.vic.gov.au

Stephen D. Cairns, National Museum of Natural History, Department of Invertebrate Zoology, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA. E-mail: cairnss@si.edu

Romain Causse, Muséum national d'Histoire naturelle, DMPA UMR 5178, 43 rue Cuvier, F-75005 Paris, France. E-mail: causse@mnhn.fr

Jean-Benoit Charrassin, LOCEAN, Université Pierre et Marie Curie/CNRS/IRD/Muséum National d'Histoire Naturelle, Tour 45-55, 4 place Jussieu, BP 100, F-75252 Paris Cedex 05, France. E-mail: jbc@mnhn.fr

Margaret N. Clayton, School of Biological Sciences, Monash University, Victoria 3800, Australia. E-mail: margaret.clayton@monash.edu

Martin Collins, Government of South Georgia and the South Sandwich Islands, Government House, Stanley, Falkland Islands, via U.K. E-mail: macol@bas.ac.uk

Andrew J. Constable, Australian Antarctic Division, Department of Sustainability, Environment, Water, Population and Communities, Channel Highway, Kingston, Tasmania 7050, Australia. E-mail: andrew.constable@aad.gov.au
Antarctic Climate & Ecosystems Cooperative Research Centre, University of Tasmania, Private Bag 80, Hobart, Tasmania 7001, Australia.

Daniel Costa, Ecology & Evolutionary Biology, University of California Santa Cruz, Santa Cruz, CA 95060, USA. E-mail: costa@biology.ucsc.edu

Mark J. Costello, Institute of Marine Science, The University of Auckland, Leigh Marine Laboratory, PO Box 349, Warkworth 0941, New Zealand. E-mail: m.costello@auckland.ac.nz

J. Alistair Crame, British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK. E-mail: jacr@bas.ac.uk

Janine Cuzin-Roudy, Observatoire Océanologique de Villefranche-sur-Mer, Université Pierre et Marie Curie - CNRS-UMR 7093, F-06230 Villefranche-sur-Mer, France. E-mail: cuzin@obs-vlfr.fr

Ian W.D. Dalziel, Institute for Geophysics, The University of Texas at Austin, PO Box 7456 Austin, TX 78713, Texas, USA. E-mail: ian@ig.utexas.edu

Bruno Danis, Marine Biology Laboratory, CP 160/15, Université Libre de Bruxelles, avenue Franklin Roosevelt 50, B-1050 Brussels, Belgium. E-mail: bruno.danis@ulb.ac.be

Bruno David, Biogéosciences, UMR CNRS 6282, Université de Bourgogne, boulevard Gabriel 6, F-21000 Dijon, France. E-mail: bruno.david@u-bourgogne.fr

Claude De Broyer, Royal Belgian Institute of Natural Sciences, rue Vautier 29, B-1000 Brussels, Belgium. E-mail: claude.debroyer@naturalsciences.be

Nicolas Desreumaux, UPMC Univ Paris 06, UMS 2348, Observatoire Océanologique, F-66650 Banyuls-sur-Mer, France. E-mail: nicolas.desreumaux@obs-banyuls.fr

H. William Detrich III, Departements of Marine and Environmental Sciences and of Biology, Marine Science Center, Northeastern University, 430 Nahant Road, Boston, MA 1908, USA. E-mail: w.detrich@new.edu

Agnès Dettaï, UMR 7205 ISYEB MNHN-CNRS-UPMC-EPHE, Département Systématique et Evolution, Muséum national d'Histoire naturelle, 43 rue Cuvier, F-75005 Paris, France. E-mail: adettai@mnhn.fr

Richard V. Dingle, St Mark's Court, Cambridge, UK. E-mail: rvdingle@aol.com

John R. Dolan, Université Pierre et Marie Curie and Centre National de la Recherche Scientifique (CNRS), UMR 7093, Laboratoire d'Océanographie de Villefranche, Marine Microbial Ecology, Station Zoologique, B.P. 28, F-06230 Villefranche-sur-Mer, France. E-mail: dolan@obs-vlfr.fr

Lucinda L. Douglass, University of Queensland School of Biological Sciences, Centre for Applied Environmental Decision Analysis, St. Lucia, Queensland 4072, Australia. E-mail: douglass.lucinda@gmail.com
Centre for Conservation Geography, Beeson Street 18, Leichardt, New South Wales 2040, Australia.

Francesco d'Ovidio, UMR 7159, LOCEAN-IPSL, CNRS/UPMC/MNHN/IRD, Université Pierre et Marie Curie, BC 10, 4 Place Jussieu, Tour 45-55, 4th floor, F-75252 Paris Cedex 5, France. E-mail: francesco.dovidio@locean-ipsl.upmc.fr

Rachel V. Downey, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: rachel.v.downey@gmail.com

Cédric d'Udekem d'Acoz, Royal Belgian Institute of Natural Sciences, rue Vautier 29, B-1000 Brussels, Belgium. E-mail: cedric.dudekem@naturalsciences.be

Guy Duhamel, Muséum national d'Histoire naturelle, Département des milieux et peuplement aquatiques, UMR 7208, CP 26, 43 rue Cuvier, F-75231 Paris, Cedex 05, France. E-mail: duhamel@mnhn.fr

Brigitte Ebbe, Alfred-Wegener-Institut Helmholtz Zentrum für Polar- und Meeresforschung, Am Handelshafen 12, Cont. A-C, D-27570 Bremerhaven, Germany. E-mail: brigitte.ebbe@awi.de

Marc Eléaume, Muséum national d'Histoire naturelle, Département des Milieux et Peuplements Aquatiques, UMR 7208 MNHN-CNRS-IRD-UPMC, CP26, rue Cuvier 57, F-75231 Paris Cedex 05, France. E-mail: eleaume@mnhn.fr

Inigo Everson, Government of South Georgia and the South Sandwich Islands, Government House, Stanley, Falkland Islands, via U.K. E-mail: j.everson@uea.ac.uk

Daphne G. Fautin, Department of Ecology and Evolutionary Biology and Natural History Museum and Biodiversity Institute, University of Kansas, 1200 Sunnyside Drive, Lawrence, KS 66045, USA. E-mail: fautin@ku.edu

Richard Feeney, Natural History Museum of Los Angeles County, 900 Exposition Boulevard, Los Angeles, CA 90007, USA. E-mail: rfreeney@nhm.org

Alexander D. Fraser, Antarctic Climate & Ecosystems Cooperative Research Centre, University of Tasmania, Private Bag 80, Hobart, Tasmania 7001, Australia. E-mail: adfraser@utas.edu.au

Verónica Fuentes, Institut de Ciències del Mar (CSIC), Passeig Marítim de la Barceloneta 37-49, E-08003 Barcelona, Spain. E-mail: vfuentes@icm.csic.es

Lisa M. Gagahan, Institute for Geophysics, Jackson School of Geosciences, The University of Texas at Austin, J.J. Pickle Research Campus, Building 196 (ROC), 10100 Burnet Road (R2200), Austin, TX 78758-4445, USA. E-mail: lisa@ig.utexas.edu

Kai H. George, Senckenberg am Meer Wilhelmshaven, Abt. DZMB, Südstrand 44, D-26382 Wilhelmshaven, Germany. E-mail: kgeorge@senckenberg.de

Rainer Gersonde, Alfred Wegener Institute, Helmholz Centre for Polar and Marine Research, Columbusstrasse, D-27568 Bremerhaven, Germany. E-mail: rainer.gersonde@awi.de

Ofer Gon, South African Institute for Aquatic Biodiversity, Private Bag 1015, 6140 Grahamstown, South Africa. E-mail: o.gon@saiab.ac.za

Andrew J. Gooday, National Oceanography Centre Southampton, University of Southampton, Waterfront Campus, European Way, Southampton SO14 3ZH, UK. E-mail: ang@noc.soton.ac.uk

Susie M. Grant, British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK. E-mail: suan@bas.ac.uk

Hedley S. Grantham, Conservation International, Betty and Gordon Moore Centre for Ecosystem Science and Economics, 2011 Crystal Dr, Suite 500, Arlington, Virginia, 22202, USA. E-mail: h.grantham@uq.edu.au

Huw J. Griffiths, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: hjg@bas.ac.uk

Mary M. Grossmann, Institute of Biogeosciences, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2-15 Natsushima-cho, Yokosuka, Kanagawa Prefecture 237-0061, Japan. E-mail: grossmann.mary@gmail.com

Elena Guerrero, Institut de Ciències del Mar (CSIC), Passeig Marítim de la Barceloneta 37-49, E-08003 Barcelona, Spain. E-mail: eguerrero@icm.csic.es

Julian Gutt, Alfred Wegener Institute, Helmholz Centre for Polar and Marine Research, Columbusstrasse, D-27568 Bremerhaven, Germany. E-mail: julian.gutt@awi.de

Stuart Hanchet, National Institute of Water and Atmospheric Research, PO Box 893, Nelson, New Zealand. E-mail: stuart.hanchet@niwa.co.nz

Freija Hauquier, Marine Biology Department, Ghent University, Krijgslaan 281 (S8), B-9000 Ghent, Belgium. E-mail: freija.hauquier@ugent.be

Charlotte Havermans, Royal Belgian Institute of Natural Sciences, rue Vautier 29, B-1000 Brussels, Belgium. E-mail: charlotte.havermans@naturalsciences.be

Christoph Held, Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Columbusstrasse, D-27568 Bremerhaven, Germany. E-mail: christoph.held@awi.de

Lenaïg G. Hemery, Muséum national d'Histoire naturelle, DMPA, UMR BOREA (Biologie des Organismes et Ecosystèmes Aquatiques), 43 rue Cuvier, CP 26, F-75231 Paris Cedex 05, France. E-mail: lhemery@mnhn.fr

Mark A. Hindell, Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 129, Hobart, Tasmania 7001, Australia. E-mail: mark.hindell@utas.edu.au

Eileen E. Hofmann, Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA 23529, USA. E-mail: hofmann@ccpo.odu.edu

Erling Holm, Department of Natural History, Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario, Canada. E-mail: erlingh@rom.on.ca

Russel R. Hopcroft, Institute of Marine Science, University of Alaska Fairbanks, 120 O'Neill, P.O. Box 757220, Fairbanks, AK 99775-7220, USA. E-mail: rrhopcroft@alaska.edu

Graham W. Hosie, Australian Antarctic Division, Channel Highway, Kingston, Tasmania 7050, Australia. E-mail: graham.hosie@aad.gov.au

Falk Huettmann, EWHALE lab, Institute of Arctic Biology, Biology & Wildlife Department, University of Alaska-Fairbanks, Fairbanks, Alaska 99775, USA. E-mail: fhuettmann@alaska.edu

Percy-Alexander Hulley, Iziko – South African Museum, P.O. Box 61, 8000 Cape Town, South Africa. E-mail: phulley@iziko.org.za

Jeroen Ingels, Plymouth Marine Laboratory, Prospect Place, The Hoe, PL1 3DH, Plymouth, Devon, UK. E-mail: jein@pml.ac.uk

Jean-Olivier Irisson, Laboratoire d'Océanographie de Villefranche. Station Zoologique, B.P. 28, Chemin du Lazaret, F-06234 Villefranche-sur-Mer Cedex, France. E-mail: irisson@obs-vlfr.fr

Michel Jangoux, Marine Biology Laboratory CP160/15, Université Libre de Bruxelles, avenue Franklin Roosevelt 50, B-1050 Brussels, Belgium. E-mail: michel.jangoux@ulb.ac.be

Dorte Janussen, Sektion Marine Evertebraten I, Forschungsinstitut und Naturmuseum Senckenberg, Senckenberganlage 25, D-61350 Frankfurt-am-Main, Germany. E-mail: dorte.janussen@senckenberg.de

Anna Jażdżewska, Laboratory of Polar Biology and Oceanobiology, University of Łódź, ul. Banacha 12/16, PL-90−237 Łódź, Poland. E-mail: jazdz@wp.pl

Nadine M. Johnston, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: nmj@bas.ac.uk

Christopher D. Jones, Antarctic Ecosystem Research Division, Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, 3333 N. Torrey Pines Court, La Jolla, CA 92037, USA. E-mail: chris.d.jones@noaa.gov

Stefanie Kaiser, Biocentre Grindel & Zoological Museum (ZIM), University of Hamburg, Martin-Luther-King Platz 3, D-20146 Hamburg, Germany. E-mail: stefanie.kaiser@uni-hamburg.de
National Oceanography Centre Southampton, University of Southampton, Waterfront Campus, European Way, Southampton SO14 3ZH, UK.

So Kawaguchi, Antarctic Climate and Ecosystems Co-Operative Research Centre, Private Bag 80, Hobart, Tasmania 7001, Australia. E-mail: so.kawaguchi@aad.gov.au

John Kitchener, Australian Antarctic Division, Department of the Environment, Channel Highway, Kingston, Tasmania 7050, Australia. E-mail: john.kitchener@aad.gov.au

Cynthia Klepadlo, Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093, USA. E-mail: cklepadlo@ucsd.edu

Karl-Hermann Kock, Institut für Seefischerei, Johann Heinrich von Thünen Institut für ländliche Räume, Wald und Fischerei, Palmaille 9, D-22767 Hamburg, Germany. E-mail: karl-hermann.kock@vti.bund.de

Philippe Koubbi, Sorbonne Universités, UMR BOREA 7208, Université Pierre et Marie Curie, Muséum national d'Histoire naturelle, 57 rue Cuvier, CP 26, F-75005 Paris, France. E-mail: philippe.koubbi@upmc.fr

Juliana H.M. Kouwenberg, Institute for Biodiversity and Ecosystem Dynamics, Faculty of Science, University of Amsterdam, Science Park 904, NL-1098 XH Amsterdam, The Netherlands. E-mail: j.h.m.kouwenberg@uva.nl

Lawrence A. Lawver, Institute for Geophysics, The University of Texas at Austin, PO Box 7456 Austin, TX 78713, USA. E-mail: lawver@ig.utexas.edu

Dhugal Lindsay, JAMSTEC, 2-15 Natsushima-cho, Yokosuka-shi, Kanagawa-ken, Japan. 237-0061. E-mail: dhugal@jamstec.go.jp

Katrin Linse, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: kl@bas.ac.uk

Susanne J. Lockhart, U.S. Antarctic Marine Living Resources Program, Antarctic Ecosystem Research Division, NOAA Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037, USA. E-mail : susanne.lockhart@noaa.gov

Luis José Lopez Abellan, Centro Oceanográfico de Canarias, Instituto Español de Oceanografía, Carretera de San Andrés s/n, E-38120 Santa Cruz de Tenerife, Spain. E-mail: luis.lopez@ca.ieo.es

Andrew J.S. Meijers, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: amidge@gmail.com

Klaus M. Meiners, Antarctic Climate & Ecosystems Cooperative Research Centre, University of Tasmania, Hobart, Australia.
Australian Antarctic Division, Department of Sustainability, Environment, Water, Population and Communities, Channel Highway, Kingston, Tasmania 7050, Australia. E-mail: klaus.meiners@aad.gov.au

Sophie Mormède, National Institute of Water and Atmospheric Research (NIWA), 301 Evans Bay Parade, Haitaitai, 6021 Wellington, New Zealand. E-mail: sophie.mormede@niwa.co.nz

Masato Moteki, Department of Ocean Sciences, Tokyo University of Marine Science and Technology, 4-5-7 Konan, Minato, Tokyo 108-8477, Japan. E-mail: masato@kaiyodai.ac.jp

Ute Mühlenhardt-Siegel, Zoologisches Museum, Biozentrum Grindel, Martin-Luther-King-Platz 3, D-20146 Hamburg, Germany. E-mail: muehsie@zoologie.uni-hamburg.de

Tomás Munilla, Unitat de Zoologia, Facultat de Biociències, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Cerdanyola del Vallès (Barcelona), Spain. E-mail: tomas.munilla@uab.es

Eugene Murphy, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: ejmu@bas.ac.uk

Louise Newman, Southern Ocean Observing System, International Project Office, Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania 7050, Australia. E-mail: louise.newman@utas.edu.au

Rob A. Nicoll, WWF Australia, GPO Box 528, Sydney NSW 2001, Australia. E-mail: rnicoll@wwf.org.au

Jorgen Nielsen, Statens Naturhistoriske Museum, Zoologisk Museum, Universitetsparken 15, DK-2100 København, Denmark. E-mail: jgnielsen@snm.ku.dk

Philip E. O'Brien, Department of Environment and Geography, Macquarie University, North Ryde, New South Wales 2109, Australia. E-mail: phil.obrien.ant@gmail.com

Richard O'Driscoll, National Institute of Water and Atmospheric Research (NIWA), Private Bag 14-901, Kilbirnie, Wellington, New Zealand. E-mail: richard.odriscoll@niwa.co.za

Evgeny Pakhomov, Department of Earth and Ocean Sciences, University of British Columbia, 6339 Stores Road, Vancouver, BC V6T 1Z4, Canada. E-mail: epakhomov@eos.ubc.ca

Jan Pawlowski, Department of Genetics and Evolution, University of Geneva, 30 Quai Ernest Ansermet, Sciences 3, CH-1211 Geneva, Switzerland. E-mail: jan.pawlowski@unige.ch

Helen Peat, Polar Data Centre, British Antarctic Survey, High Cross, Madingley Road, Cambridge, UK. E-mail: hjpe@bas.ac.uk

Álvaro Luis Peña Cantero, Instituto Cavanilles de Biodiversidad y Biología Evolutiva (ICBiBE), Universidad de Valencia, Apdo. Correos 22085, E-46071 Valencia, Spain. E-mail: alvaro.i.pena@uv.es

Polly A. Penhale, Office of Polar Programs, National Science Foundation, Wilson Boulevard 4201, Arlington, VA 22230, USA. E-mail: ppenhale@nsf.gov

Florian Penot, Observatoire Océanologique de Villefranche-sur-Mer, Université Pierre et Marie Curie - CNRS-UMR 7093, F-06230 Villefranche-sur-Mer, France. E-mail: florian.penot@euro-engineering.com

Victor V. Petryashov, Zoological Institute, Russian Academy of Sciences, Universitetskaya nab. 1, 199034 St. Petersburg, Russia. E-mail: viktor.petryashov@zin.ru

Richard A. Phillips, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: raphil@bas.ac.uk

Richard W. Pierce, P.O. Box 132, North Attleboro, MA 02761-0132, USA. E-mail: rw_pierce@verizon.net

Benjamin Pierrat, Biogéosciences, UMR CNRS 6282, Université de Bourgogne, boulevard Gabriel 6, F-21000 Dijon, France. E-mail: benjamin.pierrat@u-bourgogne.fr

Alexandra L. Post, Geoscience Australia, GPO Box 378, Canberra, Australian Capital Territory 2601, Australia. E-mail: alix.post@ga.gov.au

Anthony Press, Antarctic Climate and Ecosystem Cooperative Research Centre, Private Bag 80, Hobart, Tasmania 7001, Australia. E-mail: tony.press@acecrc.org.au

Carmen Primo, National Centre for Marine Conservation and Resource Sustainability, Australian Maritime College, University of Tasmania, Locked Bag 1370, Launceston, Tasmania 7250, Australia. E-mail: c.primo@amc.edu.au

Patrice Pruvost, Muséum national d'Histoire naturelle, UMR CNRS 7208 BOREA, CP 26, 43 rue Cuvier, F-75231 Paris Cedex 5, France. E-mail: pruvost@mnhn.fr

Maarten Raes, Marine Biology Department, Ghent University, Krijgslaan 281 (S8), B-9000 Ghent, Belgium. E-mail: maartenraes@yahoo.com

David Ramm, CCAMLR, 137 Harrington Street, Hobart, Tasmania 7000, Australia. E-mail: david@ccamlr.org

Ben Raymond, Australian Antarctic Division, Department of Sustainability, Environment, Water, Population and Communities, Channel Highway, Kingston, Tasmania 7050, Australia. E-mail: ben.raymond@aad.gov.au
Antarctic Climate & Ecosystems Cooperative Research Centre, University of Tasmania, Private Bag 80, Hobart, Tasmania 7001, Australia

Claude Razouls, UPMC Université Paris VI, UMS 2348, Observatoire Océanologique, F-66650 Banyuls-sur-Mer, France. E-mail: razouls@libertysurf.fr

Gabriel Reygondeau, Université Paris VI. Laboratoire d'océanographie de Villefranche, 181 Chemin du Lazaret, F-06230 Villefranche-sur-Mer, France. E-mail: gabriel.reygondeau@gmail.com
University of Olso, Centre for Ecological and Evolutionary Synthesis. University of Oslo, Problemveien 7, N-0313 Oslo, Norway.

Donna Roberts, Antarctic Climate & Ecosystems Cooperative Research Centre, University of Tasmania, Private Bag 80, Hobart, Tasmania 7001, Australia. E-mail: d.roberts@acecrc.org.au

Stephen J. Roberts, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: sjro@bas.ac.uk

Paul G. K. Rodhouse, British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK. E-mail: p.rodhouse@bas.ac.uk

Estefanía Rodríguez, Division of Invertebrate Zoology, American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024, USA. E-mail: erodriguez@amnh.org

Alex D. Rogers, Department of Zoology, University of Oxford, South Parks Road, Oxford, OX1 3PS, UK. E-mail: alex.rogers@zoo.ox.ac.uk

Yan Ropert-Coudert, Université de Strasbourg, CNRS, UMR7178, Institut Pluridisciplinaire Hubert Curien, 23 rue Becquerel, F-67087 Strasbourg, France. E-mail: yan.ropert-coudert@iphc.cnrs.fr ; docyaounde@gmail.com

Nina Rothe, National Oceanography Centre Southampton, University of Southampton, Waterfront Campus, European Way, Southampton SO14 3ZH, UK. E-mail: nr3@noc.soton.ac.uk

Michel Roux, Muséum national d'Histoire naturelle, Département des Milieux et Peuplements Aquatiques, UMR 7208 MNHN-CNRS-IRD-UPMC, CP26, rue Cuvier 57, F-75231 Paris Cedex 05, France. E-mail: michroux@wanadoo.fr

Peter G. Ryan, Percy FitzPatrick Institute of African Ornithology, DST/NRF Centre of Excellence, John Day Zoology Building, University Avenue, University of Cape Town, Rondebosch 7701, South Africa. E-mail: peter.ryan@uct.ac.za

José I. Saiz Salinas, University of the Basque Country, P.O. Box 644, E-48080 Bilbao, Spain. E-mail: ji.saiz@ehu.es

Thomas Saucède, Biogéosciences, UMR CNRS 6282, Université de Bourgogne, boulevard Gabriel 6, F-21000 Dijon, France. E-mail: thomas.saucede@u-bourgogne.fr

Stefano Schiaparelli, Dipartimento di Scienze della Terra, dell'Ambiente e della Vita (DISTAV), Università di Genova, Corso Europa 26, Genova, I-16132, Italy. E-mail: stefano.schiaparelli@unige.it

Moritz Schmid, Takuvik Joint International Laboratory, Université Laval (Canada) & CNRS (France), Département de Biologie, Université Laval, Québec G1V 0A6, Canada. E-mail: moritz.schmid@takuvik.ulaval.ca

Oscar Schofield, Coastal Ocean Observation Lab, Institute of Marine & Coastal Sciences, Rutgers University, New Brunswick, NJ 08901, USA. E-mail: oscar@marine.rutgers.edu

Myriam Schüller, Animal Ecology, Evolution & Biodiversity, Ruhr-Universität Bochum, Universitätstraße 150, D-44780 Bochum, Germany. E-mail: myriam.schueller@freenet.de

Anna Soler-Membrives, Unitat de Zoologia, Facultat de Biociències, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Cerdanyola del Vallès (Barcelona), Spain. E-mail: anna.soler@uab.cat

Michael Stoddart, Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 129, Hobart, Tasmania 7001, Australia. E-mail: michael.stoddart@utas.edu.au

Kerrie M. Swadling, Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 129, Hobart, Tasmania 7001, Australia. E-mail: k.swadling@utas.edu.au

Kunio Takahashi, National Institute of Polar Research, 10-3, Midori-cho, Tachikawa-shi, 190-8518, Tokyo, Japan. E-mail: takahashi.kunio@nipr.ac.jp

Sven Thatje, National Oceanography Centre Southampton, School of Ocean and Earth Science, University of Southampton, European Way, Southampton SO14 3ZH, UK. E-mail: svth@noc.soton.ac.uk

Laurène Trudelle, LOCEAN, UPMC/CNRS/IRD/Muséum National d'Histoire Naturelle, Université Pierre et Marie Curie, Tour 45-55, 4 place Jussieu, BP 100, F-75252 Paris Cedex 05, France. E-mail: laurene.trudelle@locean-ipsl.upmc.fr

Marino Vacchi, Institute for Environmental Protection and Research (ISPRA) c/o Institute of Marine Sciences (ISMAR), National Research Council, Viale Benedetto XV, 5, I-16132 Genoa, Italy. E-mail: marino.vacchi@isprambiente.it

Carole Vallet, Université d'Artois, Laboratoire d'Océanologie et de Géosciences, UMR 8187, 32 rue Foch, F-62930 Wimereux, France. E-mail: carole.vallet@univ-littoral.fr

Anton P. Van de Putte, Royal Belgian Institute for Natural Sciences, Operational Directorate Natural Environment, Vautierstraat 29, B-1000 Brussels, Belgium. E-mail: antonarctica@gmail.com

Ann Vanreusel, Marine Biology Department, Ghent University, Krijgslaan 281 (S8), B-9000 Ghent, Belgium. E-mail: ann.vanreusel@ugent.be

Elsa Vázquez, Departamento de Ecoloxía e Bioloxía Animal, Facultade de Ciencias do Mar, Universidade de Vigo, E-36310 Vigo, Spain. E-mail: eotero@uvigo.es

Stéphanie Vigetta, Laboratoire d'Océanographie de Villefranche, UMR CNRS 7093, BP. 28, F-06230 Villefranche-sur-Mer, France. E-mail: vigetta@obs-vlfr.fr

Victoria Wadley, Australian Antarctic Division, Channel Highway, Kingston, Tasmania 7050, Australia. E-mail: Victoria.wadley@aad.gov.au

Harold J. Walker Jr, Scripps Institution of Oceanography, University of California, San Diego 0208, La Jolla, California 92093-0208, USA. E-mail: hjwalker@ucsd.edu

Gregory J. Watkins-Colwell, Yale Peabody Museum of Natural History, 170 Whitney Avenue, Box 208118 New Haven CT 06520, USA. E-mail: gregory.watkins-colwell@yale.edu

George M. Watters, National Marine Fisheries Service, Southwest Fisheries Science Center, Protected Resources Division, 1352 Lighthouse Avenue, Pacific Grove, CA 93950, USA. E-mail: george.watters@noaa.gov

Dirk Welsford, Wildlife Conservation and Fisheries Program, Australian Antarctic Division, Channel Highway, Kingston, Tasmania 7050, Australia. E-mail: dirk.welsford@aad.gov.au

Mark Westneat, Department of Zoology and Biodiversity Synthesis Center, Field Museum of Natural History, 1400 South Lake Shore Drive, Chicago, Il 60605, USA. E-mail: mwestneat@fieldmuseum.org

Rowan J. Whittle, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: roit@bas.ac.uk

Christian Wiencke, Department Seaweed Biology, Section Functional Ecology, Alfred Wegener Institute for Polar and Marine Research, D-27570 Bremerhaven, Germany. E-mail: christian.wiencke@awi.de

Eric J. Woehler, School of Zoology, Centenary Building, Sandy Bay Campus, University of Tasmania, Private Bag 50, Hobart, Tasmania 7001, Australia. E-mail: eric.woehler@utas.edu.au

José C. Xavier, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK. E-mail: jxavier@zoo.uc.pt

Wolfgang Zeidler, South Australian Museum, North Terrace, Adelaide, South Australia 5000, Australia. E-mail: wolfgang.zeidler@samuseum.sa.gov.au

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Shane T. Ahyong (Sydney, Australia), Roger Bamber (London, United Kingdom), Nina Bednarsek (Nova Gorica, Slovenia), Marthán N. Bester (Pretoria, South Africa), Damien Cardinal (Paris, France), Andrew Clarke (Cambridge, United Kingdom), Martin Collins (Stanley, Falkland Islands), Jordi Corbera (Argentona, Spain), Astrid Cornils (Bremerhaven, Germany), Vonda Cummings (Wellington, New Zealand), Bruno Danis (Brussels, Belgium), Hans-Uwe Dahms (Seoul, Korea), Claude De Broyer (Brussels, Belgium), Maria Cristina Gambi (Naples, Italy), Sammy De Grave (Oxford, United Kingdom), Cédric d'Udekem d'Acoz (Brussels, Belgium), Rolf Gradinger (Fairbanks, AK, USA), Ofer Gon (Grahamstown, South Africa), Claudio A. Gonzàlez-Wevar (Santiago, Chile), Ken Halanych (Auburn, AL, USA), Charlotte Havermans (Brussels, Belgium), Bruce W. Hayward (Auckland, New Zealand), Max H. Hommersand (Chapel Hill, NC, USA), Tammy Horton (Southampton, United Kingdom), Graham Hosie (Hobart, Australia), Grant R.W. Humphries (Dunedin, New Zealand), Brian Hunt (Vancouver, BC, Canada), Christopher D. Jones (La Jolla, CA, USA), Stefanie Kaiser (Southampton, United Kingdom), Karl-Hermann Kock (Hamburg, Germany), Philippe Koubbi (Paris, France), Krzysztof Jażdżewski (Łódź, Poland), Phil Leat (Cambridge, United Kingdom), Florian Leese (Bochum, Germany), Anne-Nina Lörz (Wellington, New Zealand), Fabien Lombard (Villefranche-sur-Mer, France), Enrique Macpherson (Girona, Spain), Christopher Mah (Washington, DC, USA), Wojciech Majewski (Warsaw, Poland), Vadim O. Mokievsky (Moscow, Russia), Françoise Monniot (Paris, France), Lenka Nealova (London, United Kingdom), Marco Oliverio (Rome, Italy), Krzysztof Pabis (Łódź, Poland), David L. Pawson (Washington, DC, USA), Uwe Piatkowski (Kiel, Germany), Gary Poore (Melbourne, Australia), Alix Post (Canberra, Australia), Stefania Puce (Ancona, Italy), Philip R. Pugh (Southampton, United Kingdom), Keith Reid (Hobart, Tasmania), Robin Ross (Santa Barbara, CA, USA), Daniel Roccatagliata (Buenos Aires, Argentina), Stefano Schiaparelli (Genova, Italy), Volker Siegel (Hamburg, Germany), Sven Thatje (Southampton, United Kingdom), Jesus Troncoso (Vigo, Spain), Barbara Wienecke (Hobart, Australia), Jason D. Whittington (Oslo, Norway), Andrew Wright (Hobart, Australia), Moriaki Yasuhara (Reston, VA, USA), Katharina Zacher (Bremerhaven, Germany), Diego Zelaya (Buenos Aires, Argentina).

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PART 1. INTRODUCTION

1.1. The biogeography of the Southern Ocean

Claude De Broyer[1] & Philippe Koubbi[2]

[1] Royal Belgian Institute of Natural Sciences, Brussels, Belgium
[2] Sorbonne Universités, UMR BOREA 7208, Université Pierre et Marie Curie, Muséum national d'Histoire naturelle, Paris, France

1. Introduction

Biogeographic information is of fundamental importance in providing the necessary geospatial framework to the marine biodiversity knowledge and understanding, and for assessing its gaps. It is for example essential for discovering biodiversity hotspots, detecting impacts of environmental changes, monitoring biodiversity, and modelling future distributions. In the context of increasing human pressure, it appears a key resource for supporting conservation and sustainable management strategies and designing marine protected areas.

The Southern Ocean (SO) (Map 1), was the last discovered on Earth and some of its parts, far from the scientific stations and their supply-ship routes, remain unexplored. Its depths have only been sampled by a few dedicated exploratory campaigns.

Its biodiversity - adapted to extreme conditions of life - appears unique and at the same time vulnerable to effects of global change such as climate warming, UV exposure and ocean acidification. In places, the region is warming more rapidly than the global ocean average and the Southern Ocean acts as a sentinel in detecting the impact of environmental changes upon marine ecosystems. It is also well recognized that it plays a critical role in the global ocean circulation, biogeochemical cycles and climate by connecting the ocean basins and the upper and lower limbs of the ocean overturning circulation (Rintoul *et al.* 2009).

The extensive exploration and assessment of the Southern Ocean biodiversity by the Census of Antarctic Marine Life programme (CAML 2005-2010; see Chapter 1.2) and the intense compilation and validation efforts of biogeographic data by the SCAR Marine Biodiversity Information Network (www.biodiversity.aq ; see Chapter 2.1) and other Antarctic data centres provided a unique opportunity, a strong collaborative framework and the appropriate momentum to attempt to synthesise the current biogeography knowledge of the Southern Ocean. This new synthesis was able to draw on vastly improved occurrence datasets from recent decades, as well as on new insights provided by molecular and phylogeographic approaches, and new methods of analysis, visualisation, modelling and prediction of biogeographic distributions.

2. Mapping the Southern Ocean biodiversity patterns

2.1. Historical background

Since James Cook's second voyage in 1772-1775, which allowed the first descriptions of Antarctic animals (the birds of South Georgia by Forster, from 1777), the naturalists onboard a number of pioneer Antarctic exploratory expeditions progressively revealed the composition of the unique Southern Ocean biodiversity (see Fogg 1992).
(Fig. 1)

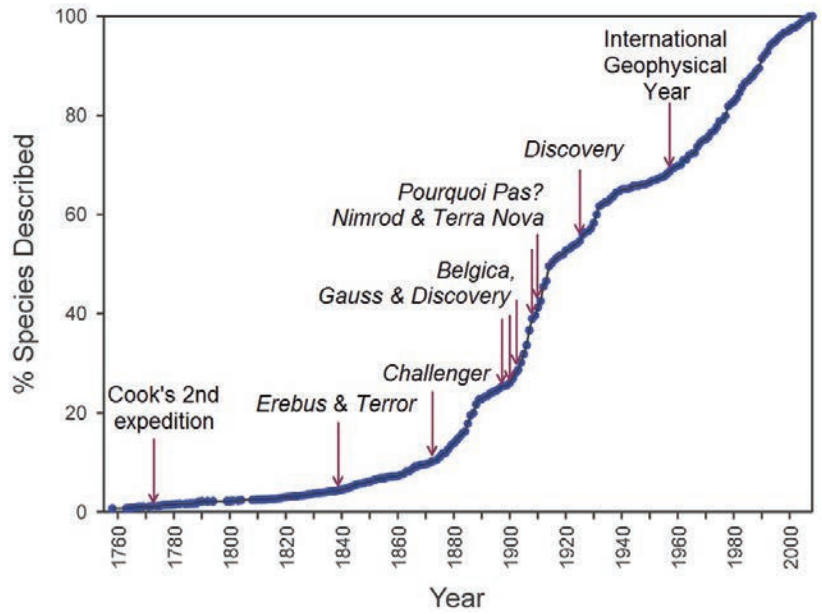


Figure 1 Rate of description of Southern Ocean species (from Griffiths 2010)

The very first attempt to characterise the Southern Ocean zoogeography may be that of Allen (1878), who, on the basis of mammal distribution, distinguished 8 main zoogeographical regions ("realms") on Earth. He named the last one the "Antarctic or South Circumpolar Realm" that was described as follows: *"The Antarctic Realm …embraces not only the Antarctic Zone, but a large part of the cold south-temperate… It will hence include not only the few small groups of Antarctic Islands, but also Tierra del Fuego and the Falkland Islands, …, while some of its characteristic forms also extend to New Zealand, and even Australia and the Cape of Good Hope. The only mammals that can be considered as strictly characteristic of this region are Pinnipeds and Cetaceans, of which several genera of each are almost wholly restricted to it."*

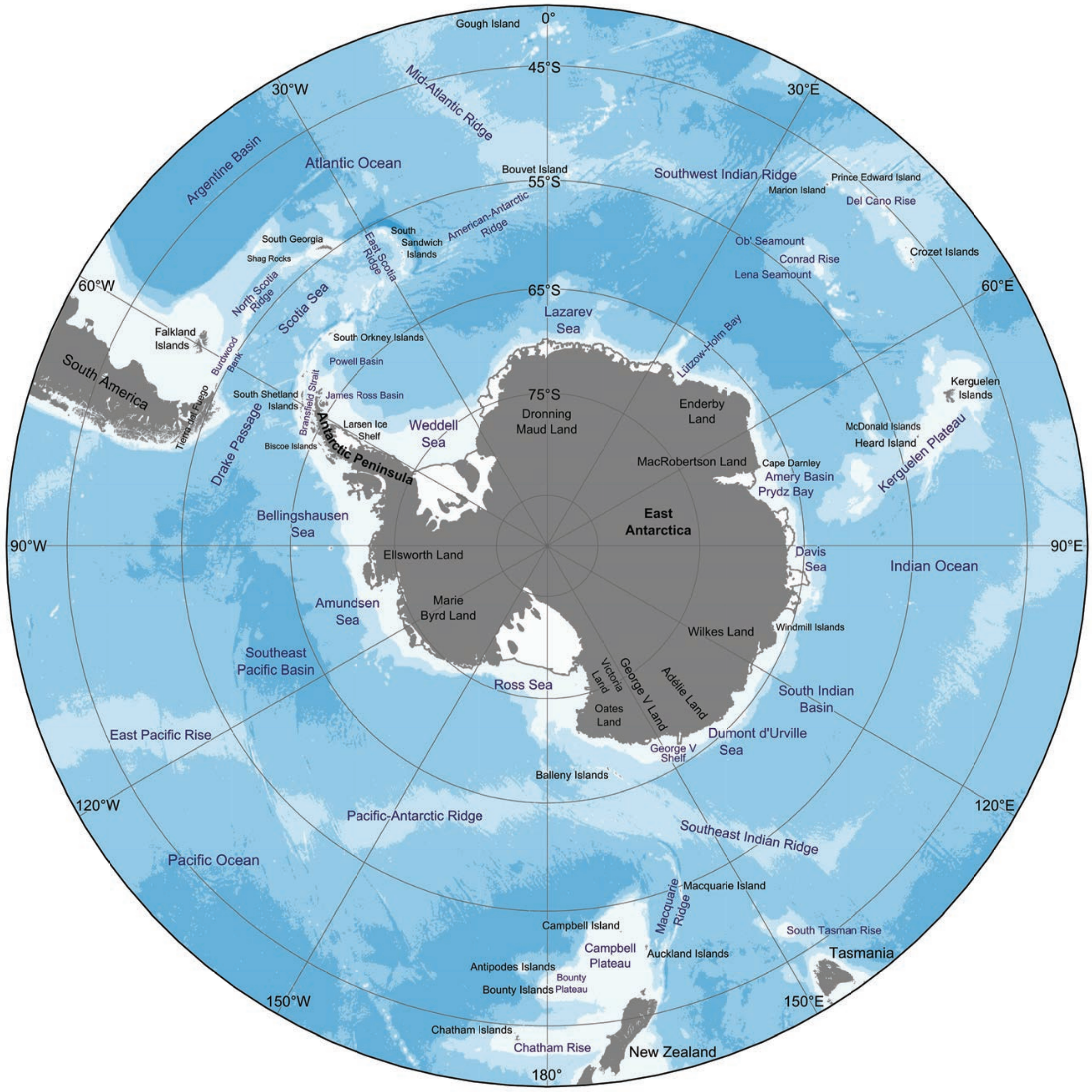
Few years later, in his "Principles of Zoogeography" (1884), Gill, relying mostly on fish data and records along the southern South American coasts, distinguished an "Antarctalian Realm" that *"may cover the antipodal ocean up the isocryme of 44°F"* [i.e. 6.7°C] and a "Notalian Realm", the south temperate realm, that *"may provisionally be said to extend from the southern isocryme of 68° to that of 44°"* [i.e. 20°C to 6.7°C]. It seems that Gill was the first to introduce an obvious reference to sea surface temperatures.

At the end of the 19th century, the important results of the *Challenger* voyage in 1872-1876 were published, describing parts of the fauna of Kerguelen, Heard, Crozet and Prince Edward Islands. The results of the German Polar Expedition to South Georgia in 1882-83, in particular Pfeffer 1890, were also available. This allowed Ortmann (1896) in his influential "Grundzüge der Marinen Tiergeographie" to attempt a first generalisation of the SO fauna distribution patterns. For the benthos of the "littoral life zone" (which limit was set at the depth to which daylight is able to penetrate, which was "*about 400 m*") he distinguished an "Antarctic Region" (without stipulating its precise northern limits) with "*numerous local faunas*", which comprised: 1. A supposed coastal circumpolar fauna (fairly unknown); 2. A "Chilean-Patagonian" fauna, which may likely include South Georgia, South Orkney and South Shetland Islands; 3. A (South African) "Cape" fauna; 4. An "Australian-New Zealand" fauna. An Antarctic Region was also recognised for the "pelagic life zone", which was divided in two sub-regions: the "Antarctic-circumpolar sub-region" under sea ice influence, and the "Notal-circumpolar subregion". He did not define precisely "notal" (see Baur 1896), but in a footnote he referred to the (loose) concept originally introduced by Gill (1884). The term "notal" was subsequently used inconsistently by some Russian workers but was unambigously rejected by Hedgpeth (1970).

Taking advantage of a new wealth of faunistic data collected by the Antarctic "heroic age" expeditions at the turn of the century (*Belgica, Valdivia, Southern Cross, Gauss, Antarctic, Discovery*, *Scotia*, *Français, Pourquoi Pas*, *Terra Nova,…*), Ekman (1935, 1953), in his seminal "Zoogeography of the Sea", was the first to summarise Southern Ocean distributions in a comprehensive biogeographic scheme. Relying on both the hydrographic framework (in particular the sea surface temperatures) and mostly echinoderm and fish records, he divided the Southern Ocean shelf and slope fauna (<1000 m) into two main regions: an Antarctic Region and an Antiboreal Region, the latter corresponding to the Sub-Antarctic Region of subsequent authors such as Hedgpeth (1969). The Antarctic Region, with a suggested northern limit at the Antarctic Convergence, was subdivided into two sub-regions (or provinces): the "Low Antarctic", which includes South Georgia and the Shag Rocks Bank, and the "High Antarctic" which includes the rest of the region. The High Antarctic was in turn subdivided into a "West Antarctic" sub-region (Weddell Sea, Peninsula and Scotia Arc islands) and the "East Antarctic" including the Ross Sea and the regions lying south of Australia.

His Antiboreal Region comprised a South American well-defined sub-region, several isolated oceanic islands and a possible Kerguelen sub-region. The South American sub-region includes south Chile from about 40-42°S, Tierra del Fuego, and the Patagonian shelf, which northern limit "*may possibly be put as far north as Rio de la Plata mouth"* (36°S), although Norman (1937), relying on the fish fauna, placed the boundary of his "Patagonian Region" at 42°S. Ekman noted the great similarity of the Falkland fauna with the Patagonian fauna. He grouped among the Antiboreal oceanic islands: Gough Island, Prince Edward and Marion Islands, Crozet Islands, Auckland and Campbell Islands (noting nevertheless their close affinities with New Zealand) and Macquarie Island, recognizing, however, that their fauna was still poorly known and that they do not form a homogeneous faunal region. Kerguelen Islands (grouped with Heard and McDonald Islands) is considered a transitional, mixed region with strong endemism (about 50%) as well as strong affinities both with the Antarctic but even stronger with cold temperate regions.

A general scheme for the littoral regions of the southern cold temperate and Antarctic zones was proposed by Knox (1960), based on wide information about oceanographic conditions and distribution patterns of shallow-water organisms. His occurrence dataset of macroalgae and several animal groups was limited to distribution data obtained to the lower depth limit of algal growth, which may restrict the comparison with previous and following studies taking also into account the deeper shelf benthos. After characterising the littoral zonation patterns of an array of species typical of the various southern regions considered (Table 1), Knox (1960) distinguished an Antarctic Region with two provinces: the Antarctic Province, which includes Bouvet and Heard Islands as well as the South Sandwich Islands, and the South Georgia Province, considered a very distinctive biogeographic unit. Within the Antarctic Province, two sub-provinces are further recognized: the Scotian sub-province comprising Antarctic Peninsula and the Scotia Arc, while the Ross Sea and

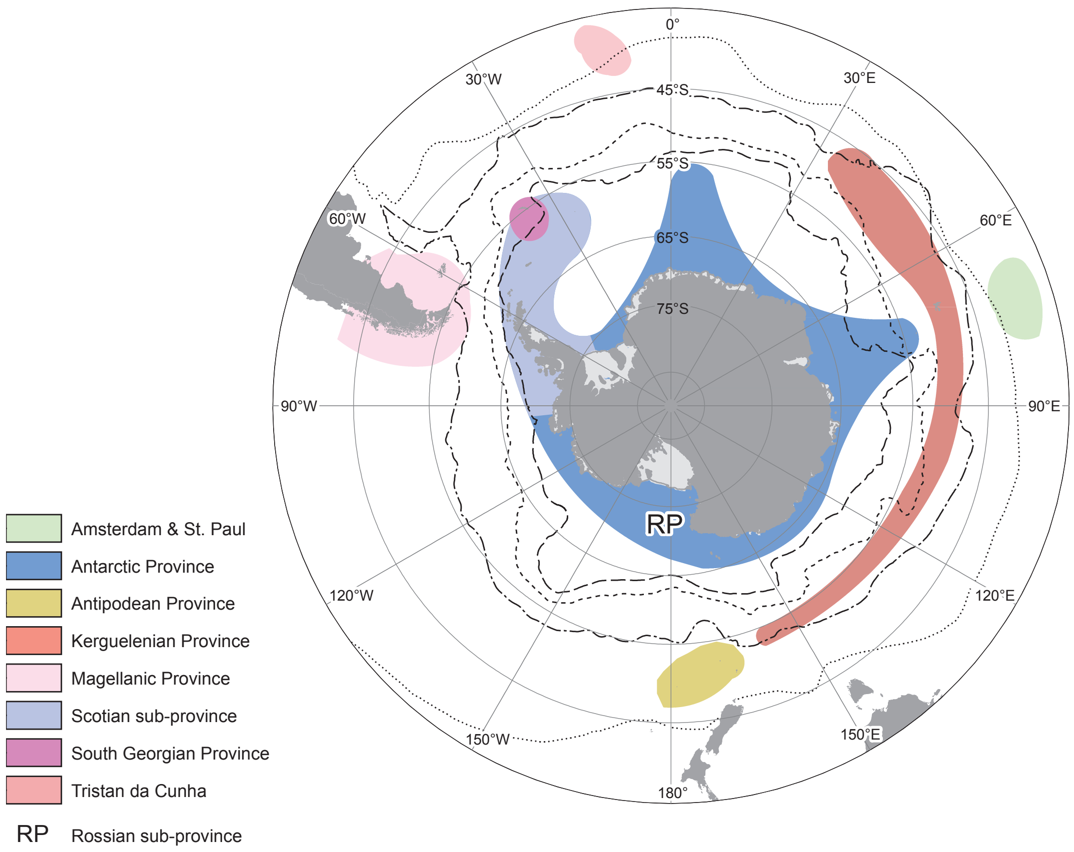


Introduction Map 1 General map of the Southern Ocean.

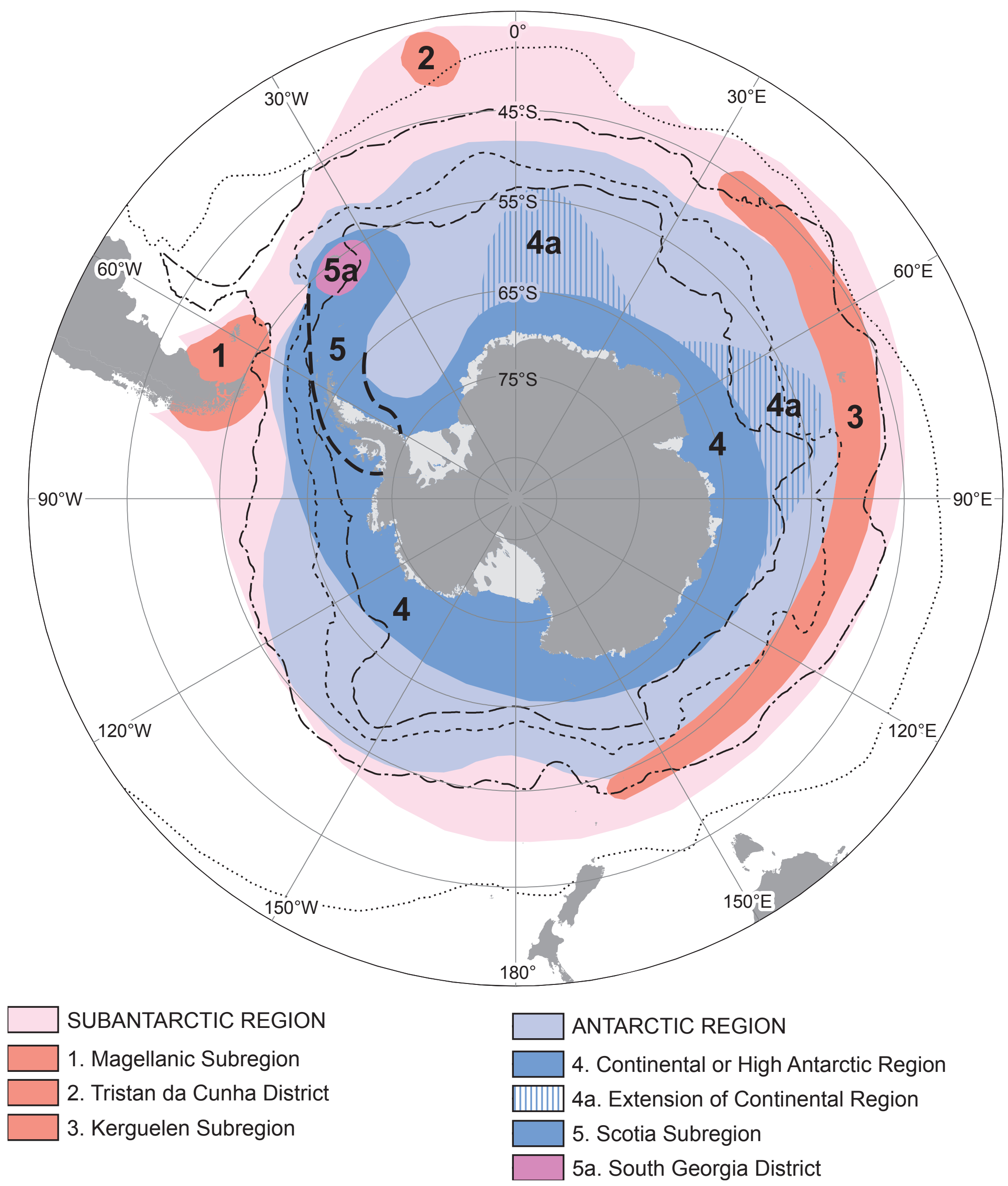
The place-names used in the Atlas are based on the following gazetteers: SCAR Composite Gazetteer: https://data.aad.gov.au/aadc/gaz/scar/ , GEBCO Gazetteer of undersea feature names: http://www.ngdc.noaa.gov/gazetteer/ , and USGS: United States Board of Geographic Names: http://geonames.usgs.gov/antarctic/

Table 1 Characteristics of the water masses of the southern temperate and Antarctic regions with the corresponding biogeographic provinces (from Knox 1960)

Characteristic temperature range	Characteristic salinity range	WATER MASS	BIOGEOGRAPHIC PROVINCE			
			New Zealand sector	South Australian sector	South American sector	South African sector
Winter: 3 to 11,5°C Summer: 5,5 to 14,5°C	34,0 to 34,5‰	Subantarctic cold temperate	Antipodean	Kerguelenian	Magellanic	Kerguelenian
Mean range: 1.3 to 3.7°C		Transitional zone			Georgian	
Winter: -1,8 to 0,5°C Summer: -1,0 to 3,5°C	33,0 to 34,0‰	Antarctic	Rossian sub-P.	Antarctic	Scotian sub-P.	Antarctic



Introduction Map 2 Biogeographic division of the littoral zone of the southern cold temperate and Antarctic regions according to Knox (1960).



Introduction Map 3 Biogeographic divisions of the Southern Ocean according to Hedgpeth (1969).

adjacent regions are considered to be a separate Rossian sub-province. In the sub-Antarctic or cold temperate regions, the Kerguelenian Province is formed by the scattered islands of Prince Edward and Marion, Crozet, Kerguelen and Macquarie, and the Subantarctic islands near New Zealand are considered the Antipodean Province. The southernmost part of South America and the Falkland Islands constitutes the Magellanic Province (Map 2).

Summarising the early works on Antarctic zoogeography done by ichthyologists (in particular Regan 1914 and Nybelin 1947) and relying on his more recent findings, Andriashev (1965) proposed a scheme based on coastal fishes, comprising an Antarctic Region with a Glacial Sub-Region and a Kerguelen Sub-Region. The Glacial Sub-Region comprised a South Georgian Province (South Georgia, South Sandwich Islands and Bouvet Island) and a Continental Province, which was in turn subdivided into an East Antarctic District (including the coasts from the eastern Ross Sea to the western Weddell Sea) and a West Antarctic District (Antarctic Peninsula, South Shetland and South Orkney Islands). His Kerguelen Sub-Region included Marion Island, the Crozet Islands, Kerguelen and Heard Islands, and Macquarie Island. At the difference of previous biogeographic schemes, Andriashev did not retain the sub-Antarctic islands into a Sub-Antarctic Region but kept them in a large Antarctic Region. This view was subsequently supported by DeWitt (1971).

Although recognising that biogeographical regionalisation should ideally be carried out on the basis of distribution patterns of whole communities of organisms and should not be based only on data from any one group, Kussakin (1967) proposed a biogeography of Antarctic and sub-Antarctic waters based on his extensive studies on isopods and tanaids. These brooding peracarid crustaceans have poor dispersal capabilities and thus can be useful biogeographical indicators. Relying on endemism data and records down to 2000 m depth, and using Preston's index to calculate affinities between localities, his zonation scheme retained three main regions: the Antarctic, Kerguelen and Patagonian Regions. The Antarctic Region comprised an East Antarctic Province extending from the eastern Weddell Sea to Eights Coast (at about 100°W), a Graham or West Antarctic Province (Bellingshausen Sea, Antarctic Peninsula, South Shetland and South Orkney Islands), and a South Georgia Province (South Georgia, Shag Rocks, South Sandwich Islands, and possibly Bouvet Island). The Kerguelen Region included a Macquarie Province, a Kerguelen Province (with Kerguelen and Heard Islands) and a Marion Province (with Marion, Prince Edward and Crozet Islands). The Patagonian Region comprised a Magellan Province (south Chile from 40-42°S, south Argentina from 40°S, Tierra de Fuego and Falkland Islands), an Arauca Province (central Chile) and an Argentinian Province (from 40°S to north of Rio de la Plata).

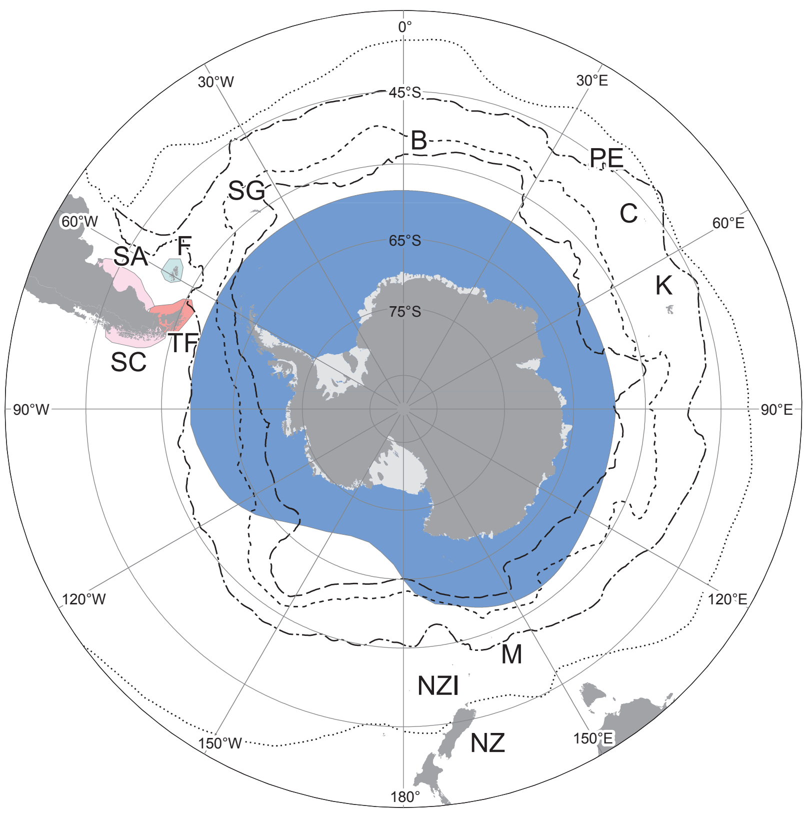
2.2. The Antarctic Map Folio Series (1967-1978) and beyond

The first comprehensive effort to systematically map the distribution of the Southern Ocean biota is due to the "Antarctic Map Folio Series" published by the American Geographical Society (1967-1978). At the same period, the "Biology of the Antarctic Seas" monographs (1964-1995, in the Antarctic Research Series, published by the American Geophysical Society) substantially contributed to document the Antarctic and sub-Antarctic biodiversity and its distribution. Five Antarctic Map Folios were devoted to marine biodiversity: the biogeography of macroalgae was covered by Balech *et al.* (1968), the invertebrates by Bushnell & Hedgpeth (1969), the fish by DeWitt (1971), the birds by Watson *et al.* (1971), and the mammals by Brown *et al.* (1974).

Resulting from these efforts, Hedgpeth (1969, 1970) biogeographic synthesis was the first modern attempt to establish the SO biological regionalisation on the basis of a largely documented and diverse dataset – the occurrence records of 17 benthic and 4 pelagic invertebrate taxonomic groups. Hedgpeth recognised two main Antarctic and Sub-Antarctic Regions. The Antarctic Region extended south of the Antarctic Convergence (as suggested initially by Ekman and essentially valid for plankton) and divided into a Continental or High Antarctic Sub-Region (with an extension to Bouvet Island and a second one to Heard Island), and a Scotia Sub-Region (Peninsula and Scotia Arc Islands) with a separate district (or sub-province) for South Georgia. The Sub-Antarctic Region included a Magellanic sub-Region, a large Kerguelen Sub-Region and a separate district for Tristan da Cunha and Gough Islands (Map 3).

Hedgpeth's biogeographic scheme, which was very close to Knox (1960)'s proposal for littoral regions, was widely accepted by subsequent workers analysing patterns at the level of the whole benthic fauna (e.g., White 1984; Arntz *et al.* 1997; Clarke & Johnston 2003) or at the level of particular taxa.

Soon after Hedgpeth's contributions (1969, 1970, 1971), Dell (1972) published a comprehensive analysis of the Antarctic benthos, and critically reviewed the previous biogeographic schemes. He supported in general Hedgpeth's scheme, but at the same time drew attention to the difficulties to properly define and delineate biogeographic provinces valid for many different organisms, bathymetric regions, or isolated islands. His view of the East Antarctic sub-region, including part of the Weddell and Bellingshausen Seas, is similar to Kussakin's view. In contrast to the findings of Hedgpeth and Knox, he considered Heard Island – located south of the Antarctic Convergence - as essentially sub-Antarctic, like Kerguelen and Macquarie Islands.



Introduction Map 4 The Antarctic and sub-Antarctic biogeographic regions according to Briggs & Bowen (2012). South American Provinces: SC : Southern Chile, TF : Tierra del Fuego, SA : Southern Argentina, and F : Falkland Islands. Sub-Antarctic Provinces: SG: South Georgia, B: Bouvet Island, PE: Prince Edward Islands, C: Crozet Islands, K: Kerguelen Islands, and M: Macquarie Island. Antipodes Province: NZI (Auckland, Antipodes, Campbell and Bounty Islands), NZ: New Zealand Province. The blue area indicates the cold Antarctic Region.

From a detailed analysis of the benthic Amphipoda (450 spp., 2151 records) and the Polychaeta (558 spp., 4476 records), Knox & Lowry (1977) attempted a biogeographic synthesis of the Antarctic shelf benthos (<500 m). Their affinity matrix differentiated 4 distinct areas in the Southern Ocean: 1. The Sub-Antarctic area, which includes the Auckland and Campbell Islands, Macquarie Island, Kerguelen and Heard Islands, and the Prince Edward Islands; 2. The East Antarctic area, which includes the Ross Sea, the Adélie Coast and the Davis Sea; 3. The Scotia area, which includes South Georgia and the islands of the Scotia Arc, plus the South Shetland Islands and the islands along the western coast of the Antarctic Peninsula; 4: The Magellanic area, composed of the southern tip of South America, the Falkland Islands and the Burdwood Bank.

Briggs (1974, 1995) established a system of coastal and shelf provinces for the world ocean, which was largely based on fish distributions and defined by their degree of endemism (of >10%). For the Southern Ocean the system was recently reviewed by Briggs & Bowen (2012) relying in particular on the new inputs provided by Linse *et al.* (2006), Clarke *et al.* (2007) and Griffiths *et al.* (2009). They distinguished in their "Cold-Temperate and Polar Southern Hemisphere" zone, 4 regions and 13 provinces as follows: 1. South American Region, with 4 provinces: Southern Chile, Tierra del Fuego, Southern Argentina, Falkland Islands; 2. New Zealand–Australian Region, with 3 provinces: Tasmania, New Zealand, Antipodes; 3. Sub-Antarctic Region, with 6 provinces: South Georgia, Bouvet, Crozet, Prince Edward, Kerguelen, Macquarie; 4. Antarctic Region considered a single entity, without provincial subdivision, following the suggestion by Griffiths *et al.* (2009) (Map 4).

This selective "historical" review, focusing mostly on benthos, showed the difficulties in adopting consistent concepts, methodology and terminology for establishing biogeographical subdivisions, but this has been a recurrent topic in biogeography (see the review of the biogeographic province concept by Lomolino *et al.* 2010).

Since Ekman (1953), all workers agreed on a latitudinal division between the southern part of the SO, the Antarctic zone located south of the Polar Front (or Antarctic Convergence), and a sub-Antarctic zone located north of the Polar Front, but with different northern limits and components according to the data used. Within the Antarctic zone, most authors recognised for the benthos a continental ("high Antarctic") biogeographic unit around the continent and a longitudinal division into a "West Antarctic" part, including the Peninsula and (some of) the Scotia Arc Islands, and an "East Antarctic" part, of various extent but always including the Ross Sea. South Georgia is generally considered a distinct biogeographic unit, within the Antarctic zone. Within the sub-Antarctic zone, the southernmost South American shelf is always clearly individualised (with however different northern limits), and the various oceanic islands were grouped in different ways according to the taxa investigated and the level of their knowledge. Several authors identified the West Wind Drift (now Antarctic Circumpolar Current) as the main potential dispersal factor for the sub-Antarctic fauna, which may explain the faunal links between South America and the eastward sub-Antarctic islands or between New Zealand and South America.

2.3. The last decades: time of biodiversity

Probably triggered by the application of the Rio Convention on Biological Diversity (1992) and the threats of environmental change impacts, the last two decades have seen a strong resurgence of interest for biodiversity issues and the development of macroecological approaches. An important number of biogeographic studies of Antarctic taxa were published, some quite recently in connection with the Atlas project and the development of online, open-access biodiversity databases, such as SCAR-MarBIN/ANTABIF and OBIS (www.iobis.org). We may cite the following examples, limited to contributions dealing with the whole SO benthic fauna of selected taxonomic groups: sponges : Downey *et al.* (2012) ; hydrozoans: Peña Cantero & Garcia Carroscosa (1999); sea-anemones: Rodriguez *et al.* (2007) ; cephalopods: Collins & Rodhouse (2006); gastropods and bivalves : Linse *et al.* (2006), Clarke *et al.* (2007) ; pycnogonids : Munilla & Soler Membrives (2009), Griffiths *et al.* (2011) ; crustaceans : De Broyer *et al.* (2003); mysids : Petryashov (2007); amphipods : De Broyer & Jazdzeswki (1996), De Broyer *et al.* (2007) ; isopods : Brandt (1992, 1999); decapods : Gorny (1999), Boschi & Lavio (2005); bryozoans : Barnes & Griffiths (2008), Hayward (1995) ; ophiuroids: Martín-Ledo & López-González (2014); echinoids : David *et al.* (2005); ascidians: Primo & Vasquez (2007). This renewed interest in biodiversity patterns was noticeable also in plankton, fish (e.g. Gon & Heemstra 1990) or top predators studies. For the zooplankton, the SCAR "Continuous Plankton Recorder (CPR) Survey" (see Chapter 10.3) recently published the "Zooplankton Atlas of the Southern Ocean" (Mc Leod *et al.* 2010).

We will not try to summarize here the various findings of these recent contributions as most of their authors were invited to write a synthesis chapter in this Atlas.

Other recent studies on spatial patterns were oriented toward particular ecosystems, or regions of the Southern Ocean, e.g., Brandt *et al.* (2009) and Kaiser *et al.* (2011) on bathymetric distribution of benthos, Barnes *et al.* (2006) and Hogg *et al.* (2011) on South Georgia biodiversity, Arntz *et al.* (2006) on Bouvet island, Barnes *et al.* (2008) on South Orkney archipelago biodiversity, or Koubbi *et al.* (2011) on the d'Urville Sea demersal and pelagic fish fauna, to cite just a few.

Some more general overviews of patterns and processes of the SO biodiversity distribution were provided by Clarke (2008); Griffiths (2010); Convey *et al.* (2012, 2014); and Kaiser *et al.* (2013). In addition, Griffiths *et al.* (2009) attempted to generalise the SO benthic biogeography.

The first insights to the Southern Ocean deep sea biogeography were given by Brandt *et al.* (2007a, b, 2012) reporting the significant results of the ANDEEP campaigns in the deep basins of the Weddell and Scotia Seas. These investigations revealed high level of unknown abyssal biodiversity and showed that bathymetric and biogeographic trends varied between taxa. They also indicated that the Antarctic abyssal fauna has stronger links with other oceanic abyssal basins (particularly in the Atlantic) than with the Antarctic shelf fauna, but this is mainly valid for taxa with good dispersal capabilities. On the contrary, the poor dispersers include many species with high apparent SO endemism.

2.4. Ecosystem biogeography or the macroecological approach

Departing from the classical faunistic and floristic approach of biogeography, i.e. the "compositionist" approach, there were recent attempts to establish biogeographic classifications by reference to the characteristics of regional marine ecosystems, shaped by hydrographic features, oceanographic and bio-geochemical processes (i.e. the "functionalistic" approach).

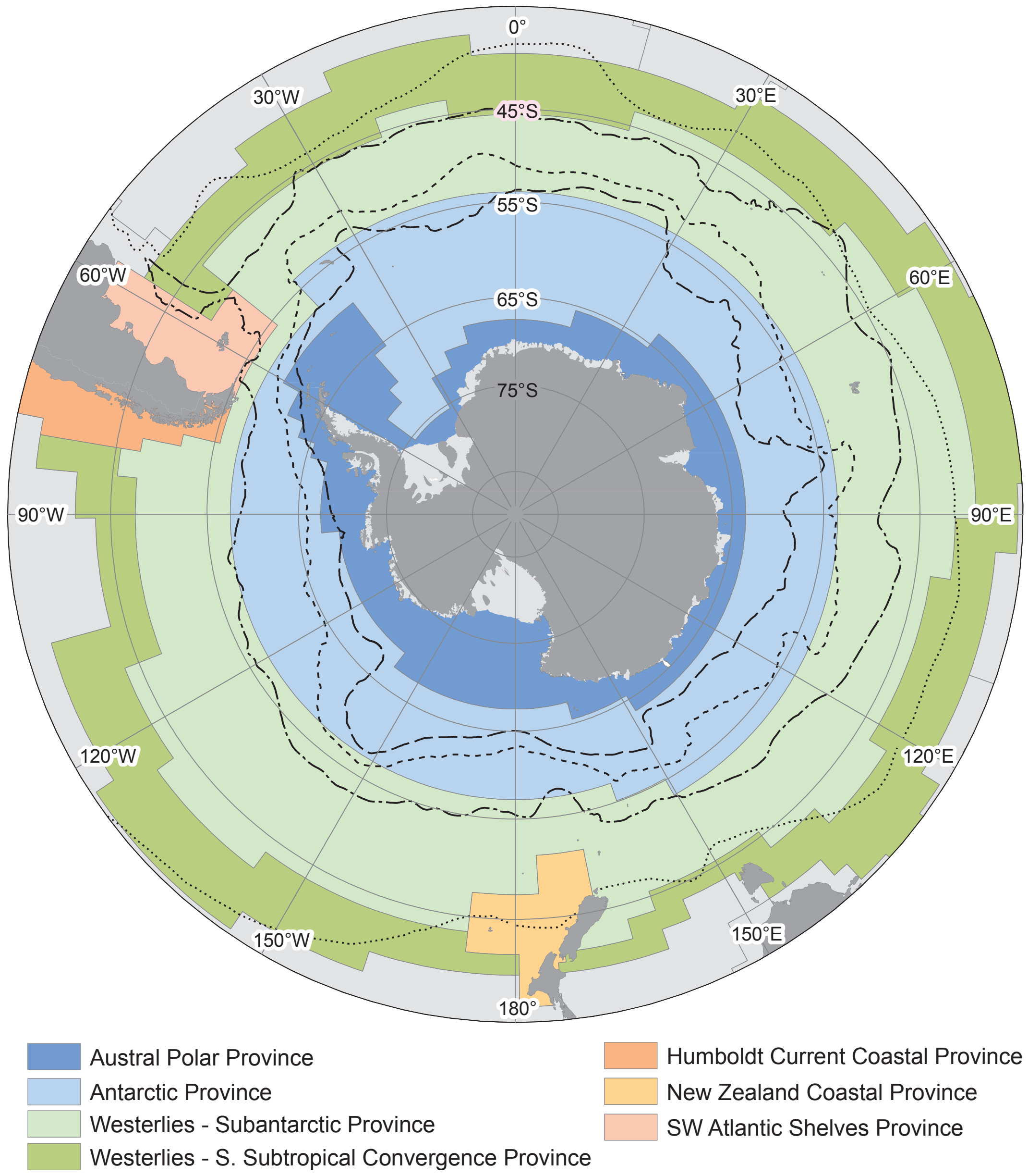
The "ecological geography of the sea". Longhurst (2007) proposed a new "ecological geography of the sea" based on regional oceanographic characteristics and on pelagic bio-geochemical data obtained from satellite imagery and *in situ* data. This classification, mostly applicable to the pelagic realm, identified seven biogeochemical provinces south of the Sub-Tropical Front, among the 50 provinces in 4 major biomes (Polar, Westerlies, Trades and Coastal) detected in the global ocean.

Within the "Polar Biome", two provinces have been defined south of the Polar Front. The "Austral Polar Province" comprises the seasonally ice-covered sea from the coasts of the continent to the level of the Antarctic Divergence at 60-65°S and includes the Antarctic Peninsula as well as the Scotia Arc islands of South Orkney, South Sandwich and South Georgia. The "Antarctic Province" is an annular province lying between the Antarctic Divergence and the Polar Front at about 55°S, which is synonymous with the southern branch of the Antarctic Circumpolar Current (ACC). The Bouvet, Kerguelen and Heard islands are attributed to this province.

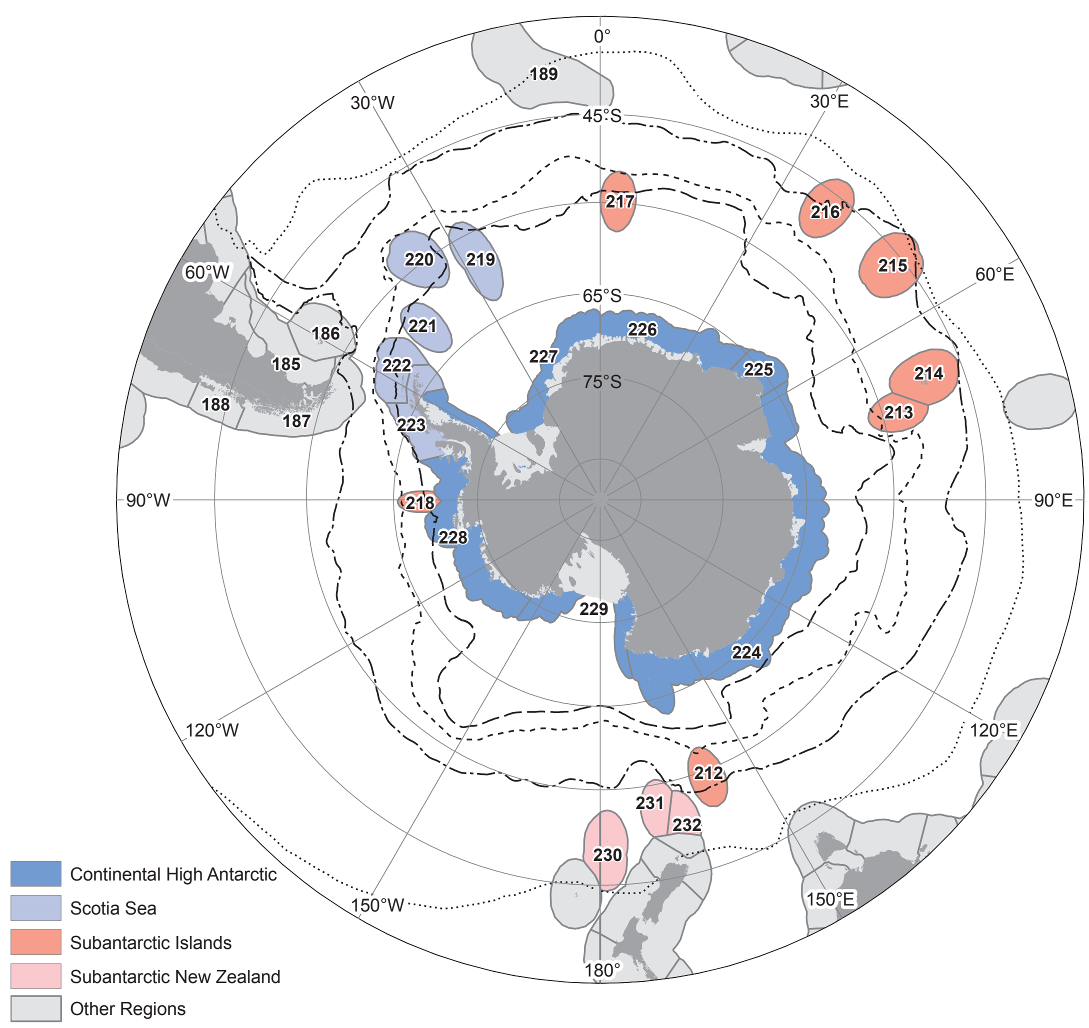
North to the Polar Biome lies the "Antarctic Westerly Winds Biome", which includes the "Sub-Antarctic Water Ring Province" that is formed by the northern flow of the circumpolar ACC lying between the Sub-Tropical Front and the Polar Front and covering the Sub-Antarctic Zone and the Polar Frontal Zone. It is circled to the north by the "South Sub-Tropical Convergence Province" that covers the entire Sub-Tropical Convergence Zone at about 35-45°S, marking the boundary between waters of sub-Tropical and sub-Antarctic origin. The Patagonian shelf and the Falkland plateau are parts of the "Southwest Atlantic Shelves Province" within the "Atlantic Coastal Biome". This province extends from the latitude of Mar del Plata (38°S) to the tip of Tierra del Fuego at 55°S. On the Pacific side, the south Chilean waters are included in the "Humboldt Current Coastal Province" within the "Pacific Coastal Biome". The sub-Antarctic islands of New Zealand on the Campbell and Bounty plateaus are parts of the "New Zealand Coastal Province" within the same "Pacific Coastal Biome" (Map 5).

The Large Marine Ecosystems of the World. With a perspective to support the application of practical management issues for the marine ecosystem goods and services, the system of "Large Marine Ecosystems" (LME) (http://www.lme.noaa.gov) was conceived by a number of regional experts to classify relatively large marine regions (on the order of 200,000 km2 or greater), characterized by distinct bathymetry, hydrography, productivity, and trophic relationships. Based on these four ecological criteria, 64 LME's have been delineated around the

Southern Ocean realm: Continental High Antarctic province: 224. East Antarctic Wilkes Land; 225. East Antarctic Enderby Land; 226. East Antarctic Dronning Maud Land; 227. Weddell Sea; 228. Amundsen/Bellingshausen Sea; 229. Ross Sea. **Scotia Sea province**: 219. South Sandwich Islands; 220. South Georgia; 221. South Orkneys Islands; 222. South Shetland Islands; 223. Antarctic Peninsula. **Sub-Antarctic Islands province:** 212. Macquarie Island; 213. Heard and McDonald Islands; 214. Kerguelen Islands; 215. Crozet Islands; 216. Prince Edward Islands; 217. Bouvet Island; 218. Peter I Island. **Sub-Antarctic New Zealand province**: 230. Bounty and Antipodes Islands. 231. Campbell Island; 232. Auckland Island.**Temperate South America realm: Magellanic province:** 185. Patagonian Shelf; 186. Falklands/ Malvinas; 187. Channels and Fjords of Southern Chile; 188. Chiloense. (map source: http://www.worldwildlife.org/ science/ecoregions/marine/item1266.html)

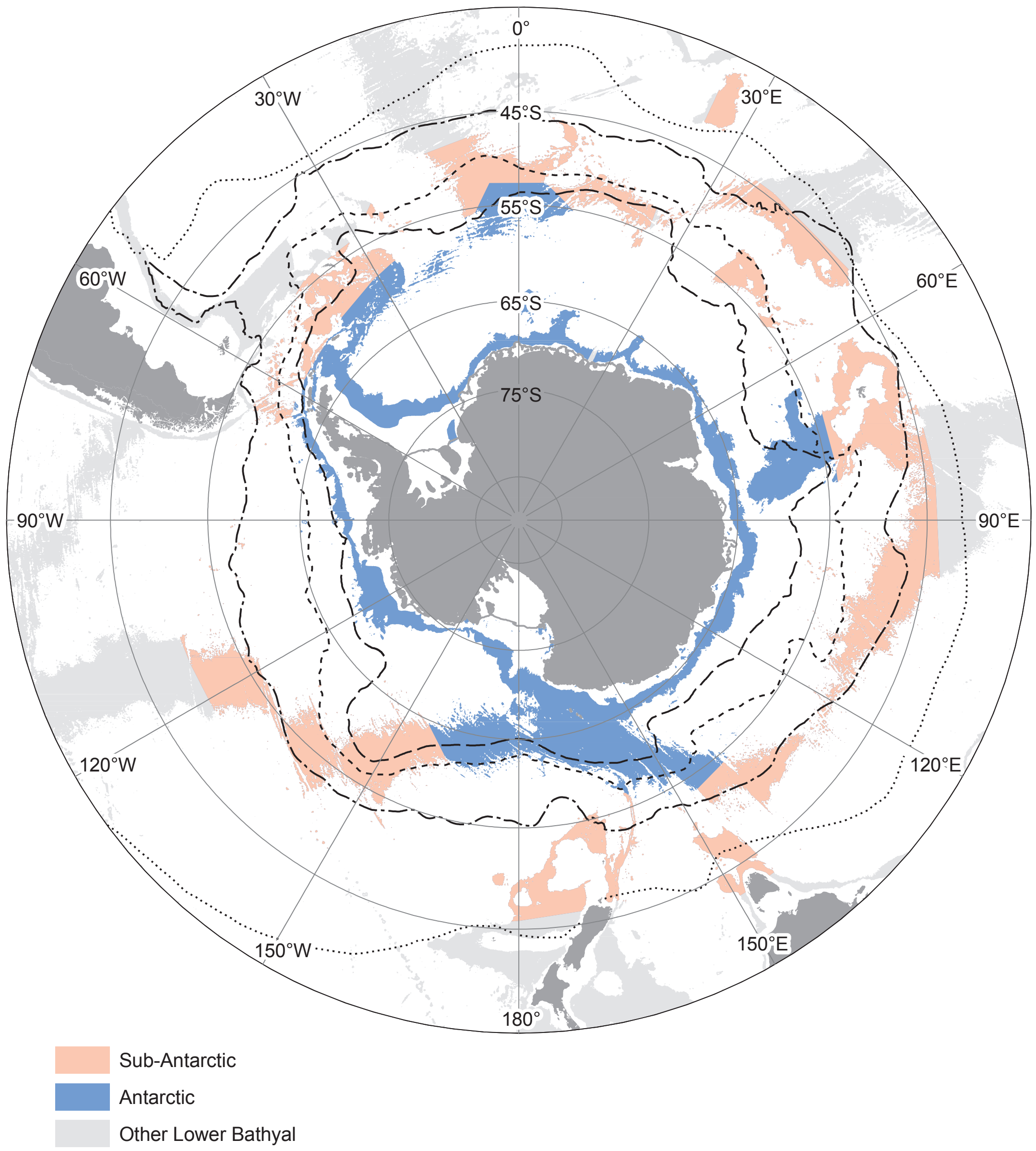


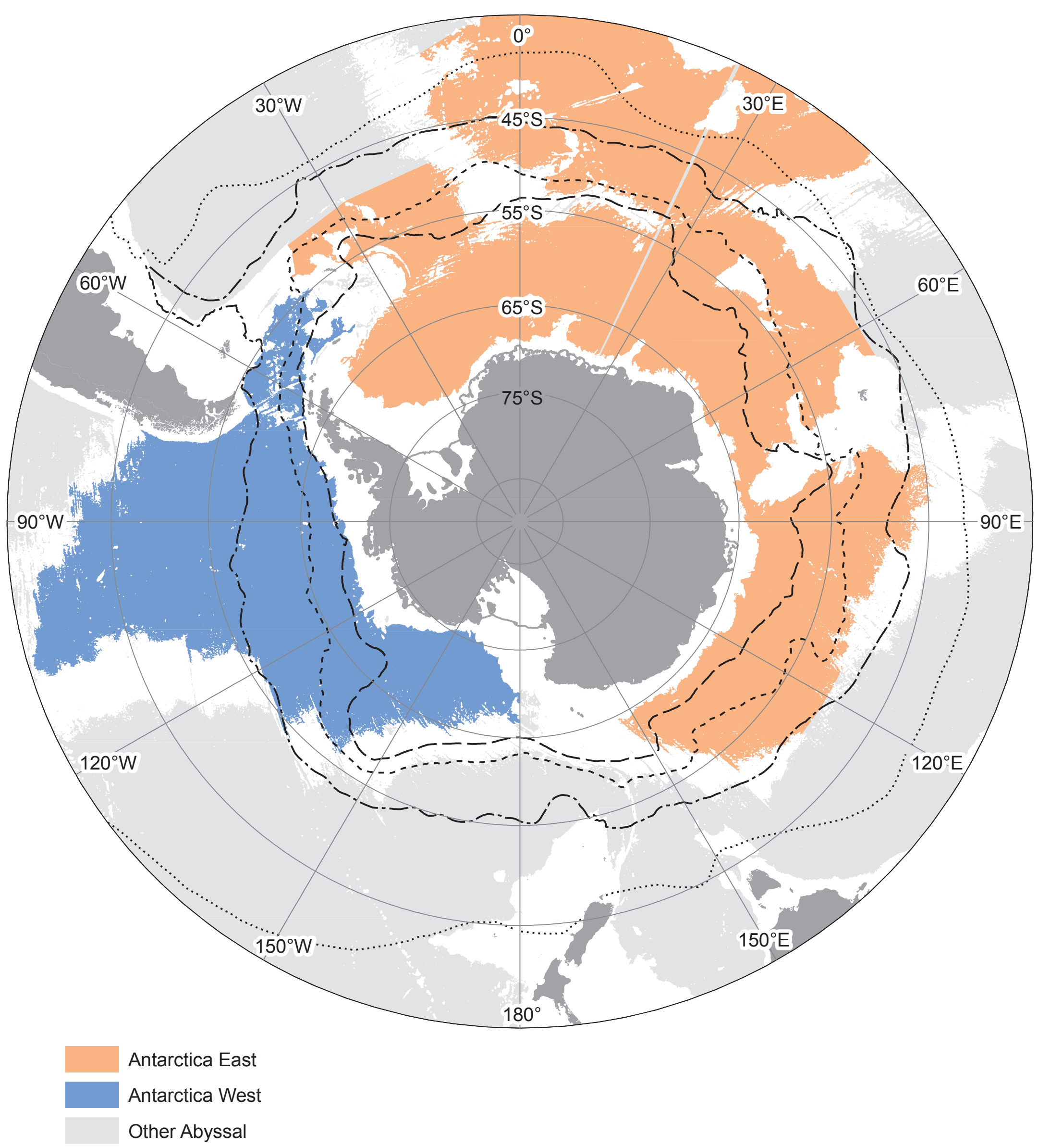
Introduction Map 5 The biogeochemical provinces of the Southern Ocean according to Longhurst (2007).



Introduction Map 6 The Southern Ocean marine ecoregions according to Spalding *et al.* (2007).The numbering of ecoregions followed the "MEOW" nomenclature.

Introduction Map 7 The bathyal provinces (801 to 3500 m) of the Southern Ocean according to Watling *et al.* (2013). The Antarctic Province encompasses all the slope and ridge areas around the Antarctic continent connected by Circumpolar Deep Water. The Sub-Antarctic Province extends northward around the Southern Ocean, encompassing a 10–20° of latitude band from 40–45°S to 55–60°S; defined by the extent of 1–2°C Circumpolar Deep Water.





Introduction Map 8 The abyssal provinces (>3500 m) of the Southern Ocean according to Watling *et al.* (2013). The Antarctica East Province include the areas where very cold bottom water flows into the adjacent basins (Cape, Agulhas, Natal, Crozet, and South Indian Basins). The Antarctica West Province includes the Amundsen Plain in the region from the Ross Sea to the Antarctic Peninsula and north to the Antarctic-Pacific Ridge and the Southeast Pacific Basin.

ocean coastal margins. The Antarctic LME (# 61) includes the shelf around the continent (with the Peninsula) to a depth of 1000 m. The Patagonian Shelf (LME # 14) extends from the southernmost tip of South America to north of the mouth of Rio de la Plata and includes the Falkland Islands.

The "Marine Ecoregions of the World". Aiming at supporting global and regional strategies for the conservation and sustainable use of marine resources, the "Marine Ecoregions of the World" (MEOW) system consists of a bioregionalisation of coastal and shelf areas (Spalding *et al*. 2007). MEOW is a nested system of 12 realms, 62 provinces and 232 ecoregions, based on "*taxonomic configurations influenced by evolutionary history, patterns of dispersal, and isolation*". The Southern Ocean is classified as one realm comprising 4 provinces (Continental High Antarctic, Scotia Sea, Sub-Antarctic Islands, Sub-Antarctic New Zealand) sub-divided into 21 ecoregions, mostly based upon Linse *et al.* (2006) results (Map 6).

The deep ocean floor. As largely confirmed by the ANDEEP results (see supra), the SO deep sea fauna clearly exhibits different composition and distribution patterns than the coastal and shelf faunas. Watling *et al.* (2013) proposed a deep-sea biogeographic classification for the lower bathyal and abyssal benthos of the global ocean. After reviewing existing classifications and data, they conducted a comprehensive analysis of high-resolution data of depths, water mass characteristics (temperature, salinity and dissolved oxygen) and particulate organic flux to the seafloor, encompassing two large bathymetric zones: the lower bathyal, set at 801–3500 m, and the abyssal, 3501–6500 m. Due to the limitation of available biotic data, these physical and chemical proxies were selected as potential good predictors of the distributions of deep-sea floor organisms. This process resulted in the delineation of 14 lower bathyal and 14 abyssal provinces, which are "*to be considered as hypothetical*", and "*need to be tested with species distribution data*" (Maps 7, 8).

3. The Biogeographic Atlas project

Taking advantage of an unprecedented amount, availability, diversity, and quality of biogeographic data, and of new conceptual and methodological developments in biogeography, the Atlas contributors have attempted to establish a benchmark of the Antarctic and sub-Antarctic biogeography knowledge, covering a large number of species and assemblages from the phyto- and zooplankton, macroalgae and zoobenthos, nekton, and birds and mammals top predators. More than 140 contributors (biogeographers, taxonomists, ecologists, molecular biologists, IT experts, environmental dataset providers, modellers, and GIS experts) contributed to the Atlas, under the aegis of SCAR.

This Biogeographic Atlas is based on the analysis of more than 1.07 million occurrence records of 9064 validated species from ~434,000 distinct sampling stations. It presents a collection of 66 syntheses describing the distribution patterns and processes of a significative representation of Southern Ocean organisms, illustrated by more than 800 selected distribution maps. The Atlas covered the Southern Ocean at large, south of the Sub-Tropical Front, but focused in particular to the Southern Ocean *s.s.*, the Antarctic region, south of the Antarctic Polar Front. Most analyses and syntheses relied on data south of 40°S; however, some few studies were limited to the Southern Ocean *s.s.*

Preceding the analysis and synthesis phases, the first and fundamental step of the Atlas project was to compile and database all occurrence records available from the literature (since the very beginning of Antarctic exploration), from museum collections, as well as from CAML and other recent Antarctic sampling campaigns. This required facing problems of data discovery, data quality assessment, correct interpretation and standardisation, and, vitally, required significant validation effort by numerous experts. It is important here to emphasize the key role of basic descriptive taxonomy in gaining these results. Despite being often disregarded by funding agencies, morphology-based taxonomical identification remains an essential step in biodiversity studies, and has to be supported in conjunction with molecular taxonomy in an integrative approach (see De Broyer & Danis 2011).

This wealth of expert-validated data has been made publicly available on the SCAR-MarBIN/ANTABIF portal (www.biodiversity.aq), allowing further improvements and additions, as well as multiple uses and applications, including in particular the predictive modelling of biogeographic distributions in face of the potential impacts of environmental changes.

This "Biogeographic Atlas of the Southern Ocean" is primarily intended to fulfil the needs of biogeographic information for science, conservation, monitoring and sustainable management of the Southern Ocean, in the context of environmental changes and increasing human pressure.

In addition to this printed version, a digital dynamic version of this Atlas with further functionalities is developed on the www.biodiversity.aq portal.

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1.2. The Census of Antarctic Marine Life (CAML)

Michael Stoddart

Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania, Australia

In 2000 the Alfred P. Sloan Foundation in New York launched a Census of Marine Life, an ambitious ten-year long international project that was to examine the world's oceans and log the occurrence and demise of marine species. Its principal objective was to assess the state of marine biodiversity at the start of the 21st century to enable predictions to be made about what species might inhabit oceans in the future. By supporting scientific coordination, rather than putting ships in the water, the Foundation leveraged over USD 650 million in total outlays. The Census ran until a final meeting in October 2010 in the Royal Society in London at which outcomes from the six ocean realms under study were presented. In total, some 2700 scientists from 80 nations participated in the Census, undertaking 540 research expeditions and producing over 2600 publications. A quarter of a million new species have been identified and recorded and there remain about three times that number waiting to be processed.

The ocean realm "Ice Ocean; Arctic and Antarctic" was the responsibility of two projects – Arctic Ocean Diversity (ArcOD) for the north of the globe, and the Census of Antarctic Marine Life (CAML) for the south. Both projects worked closely together and engaged in a number of joint initiatives. CAML started its activities mid-way through the Census, in 2005, following a decision to hold a third International Polar Year (IPY) in 2007–2009. The Scientific Committee on Antarctic Research (SCAR) accepted a proposal from its Life Sciences committee that CAML should go ahead as one of fifteen biological projects to be undertaken in Antarctica during the IPY; in the event CAML turned out to be the largest of them. The Alfred P. Sloan Foundation provided a grant of USD 1.4 million from 2005 until 2010 to SCAR for purposes of scientific co-ordination of CAML. SCAR contracted with the Australian Antarctic Division based in Hobart, Australia, to co-ordinate and manage the project, and appointed an international Steering Committee to oversee it and report back on progress. The Steering Committee met for the first time in Bremerhaven in October 2004 to write a scientific justification for Foundation support and in early 2005 Dr. Victoria Wadley was appointed as Project Manager. Working with Professor Michael Stoddart, Chief Scientist of Australia's Antarctic research program as CAML's Administrator, an initial workshop was held in Brussels in June 2005. This meeting set the broad objectives for CAML. The Steering Committee, supplemented by a number of experts, met annually or in some years more frequently, and held its last meeting at a Final Symposium held in Genoa, Italy, in May 2009. At this meeting decisions were made about final publications.

The main source of funds for CAML came from the National Antarctic Programs of a number of countries who, with a commitment to support the IPY, agreed to provide ship-time and research staff to work on CAML projects. France, Japan, New Zealand, Australia, UK, USA and a consortium of Latin-American countries provided research voyages dedicated to CAML; many other countries provided periods of ship-time for CAML work (Map 1). A conservative estimate of the value of National Antarctic program support to CAML is over USD 60 million, through their support of infrastructure and personnel. Thirty countries and fifty institutions participated on, and following, eighteen research voyages that delivered CAML data. The Washington Declaration on the International Polar Year and Polar Science, made at Baltimore, USA, in April 2009 urged *"states, national and international scientific bodies, and other interested parties to cooperate to deliver a lasting legacy from the IPY, and to support appropriate infrastructures to achieve this.."* and called upon *"states, organisations, scientists, and other stakeholders to continue to engage with young people to cultivate the next generation of polar scientists, and to communicate with the general public to develop an awareness of the importance of polar research for life in all regions of the world..".* In both respects CAML achieved considerable success and can be confident it has materially advanced understanding of the biodiversity of the high latitude Southern Ocean.

CAML quickly established a series of scientific goals, as follows:

1. Undertake a species inventory of high-latitude Southern Ocean slopes and abyssal plains
2. Undertake an inventory of benthic fauna under disintegrating ice shelves
3. Undertake an inventory of plankton, nekton and sea-ice associated biota at all levels of biological organisation from viruses to vertebrates
4. Assess critical habitats for Antarctic top predators
5. Develop a coordinated network of interoperable databases for all Antarctic marine biodiversity data.

In addition CAML participated strongly in the Barcode of Life Data System (BOLD). Over 11,500 sequences (C01) from more than 2,330 morpho-species in 18 phyla have already been completed, providing a solid basis for future research.

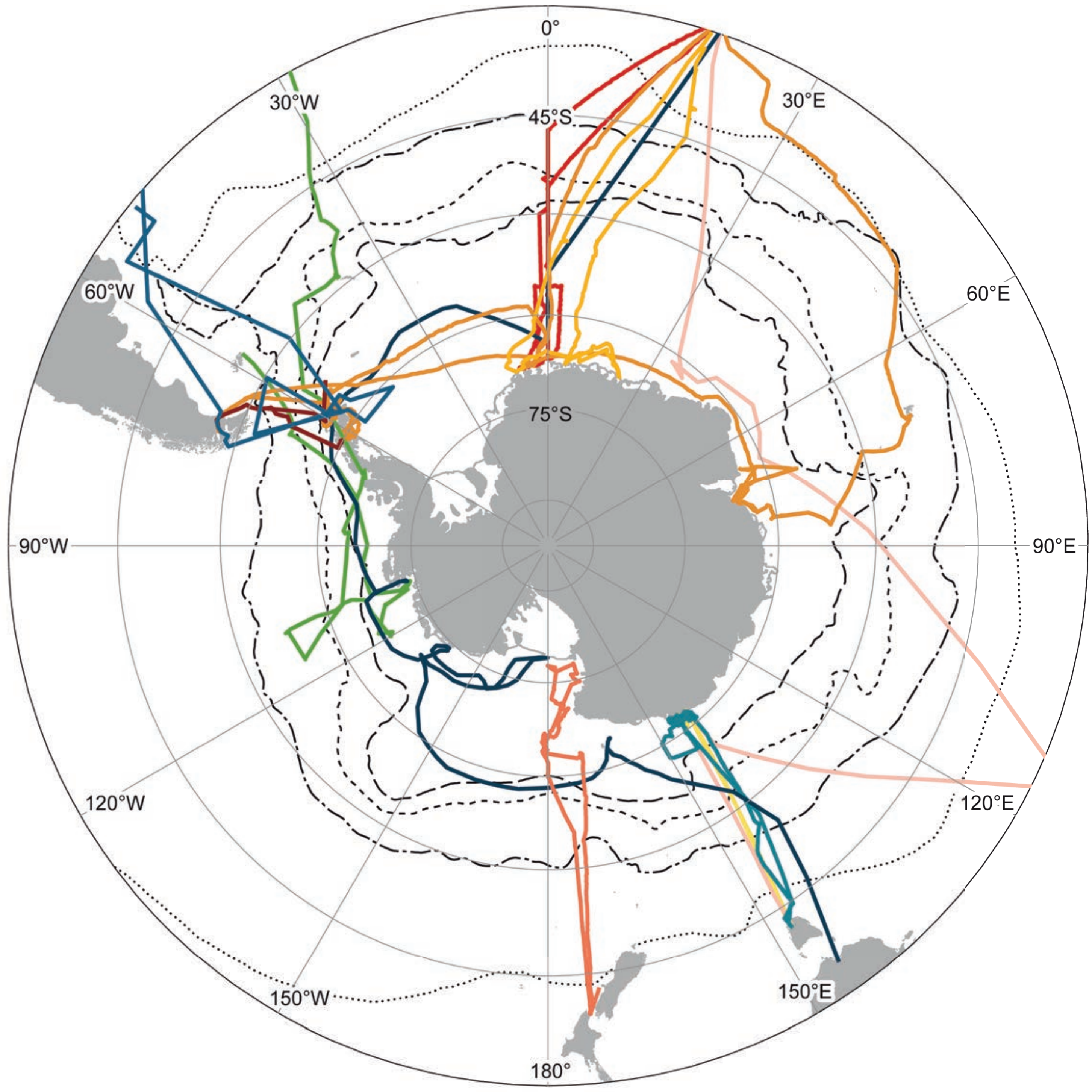
A key element in CAML's success as a project was its close association with SCAR's Marine Biodiversity Information Network (SCAR-MarBIN, www.scarmarbin.be), a data portal initiated by the Royal Belgian Institute of Natural Sciences in Brussels, implemented by the Belgian Biodiversity Platform and supported financially by the Belgian Science Policy Office. It was accepted by SCAR as the main repository for marine biodiversity data in 2005. SCAR-MarBIN became CAML's database. SCAR-MarBIN has recently transmogrified into an Antarctic Biodiversity Information facility (AntaBIF), financially supported by a number of countries with ongoing interests in Antarctic marine biodiversity. SCAR-MarBIN established data protocols and developed a suite of analytical tools for interrogating the data. A register of Antarctic marine species currently carries information on over 25,000 taxa (De Broyer *et al*. 2013), and almost 3 million occurrence data records (http://www.marinespecies.org/rams/, www.biodiversity.aq). The mass of data is growing since then, with data quality assured by an international editorial panel. Many successful ventures are springing from this central data portal, including a dynamic Antarctic field guides system (http://afg.biodiversity.aq), the Biogeographic Atlas of the Southern Ocean. CAML (http://atlas.biodiversity.aq) or the Microbial Antarctic Resource System (http://mars.biodiversity.aq). CAML succeeded in drawing together over 200 distributed databases for inclusion in SCAR-MarBIN, and captured publications dating from the very beginning of Antarctic exploration. It catalogued the largest collection of marine biodiversity data in Russia, at the Zoological Institute of St Petersburg, adding almost 300 publications and about 1.7 million data items relating to over 15,000 taxa occurrences. This is only one example of data that might otherwise be lost or inaccessible, which are now preserved for permanent access by the scientific community.

A significant legacy of CAML is a series of special publications that have appeared over recent years, stemming from CAML's association with national Antarctic programs, e.g. "BIOPEARL Expedition in the Scotia Sea" (Linse 2008), "Antarctic Biology in the 21st Century" (Fukuchi *et al*. 2010), "Cooperative East Antarctic Marine Census CEAMARC" (Hosie *et al*. 2011), "Diversity and Change in the Southern Ocean Ecosystems" (Schiaparelli & Hopcroft 2011).

Many other papers appeared in the normal scientific literature, including in several special IPY and CoML publications (e.g. Bathmann 2010, Gutt *et al.* 2010, Danis *et al.* 2013, Schiaparelli *et al*. 2013). Together these publications carry almost 161 papers on Antarctic marine biodiversity.

The need to understand the marine diversity of the high latitude Southern Ocean didn't stop with CAML. Knowing what is there, and the environmental conditions that support the biota is still needed for the successful conservation management of the region, and for understanding the consequences of climate change. SCAR has initiated two new major Scientific Research Programs (SRP): the "Status of the Antarctic Ecosystem" (AntEco), and "Antarctic Thresholds – Ecosystem Resilience and Adaptations" (AnT-ERA). These complementary programs are successors to the long-running SRP Evolution and Biodiversity of Antarctica (EBA), of which CAML was a part. Ant-Eco seeks to "*understand the patterns of biodiversity across the marine environments, as well as the terrestrial, limnological and glacial marine environments within the Antarctic, sub-Antarctic and Southern Ocean regions."* AnT-ERA will examine "*the current biological processes in all Antarctic ecosystems, to define their thresholds and thereby determine resistance and resilience to change."* CAML has contributed much groundwork to these new programs, ensuring a solid base for future studies.

When SCAR's Steering Committee met for the first time in Bremerhaven in 2004 few people could have imagined how CAML would grow and capture the imagination of countless people around the world. Through the highly efficient media arm of the Census of Marine Life, CAML scientists gained much international exposure for their work and reached out to the general public about the need for an awareness of what cannot be seen beneath the sea's surface. The Washington Declaration asked no more of us, and we delivered. We are still delivering, with the Biogeographic Atlas being our latest initiative.



Map 1

- *Akademik Fedorov*, 2007/08
- *Ary Rongel*, 2007/08
- *Aurora Australis*, 2007/08
- *James Clark Ross*, 2007/08
- *L'Astrolabe*, 2007/08
- *Papanin*, 2008-2009
- *Polarstern*, 2006/07
- *Polarstern*, 2007/08
- *Tangaroa*, 2007/08
- *Umitaka Maru*, 2007/08
- *Yuzhmorgeologiya*, 2007/08

CAML Map 1 Tracks of selected CAML-dedicated cruises

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Huw Griffiths (BAS, Cambridge) and Anton Van de Putte (RBINS, Brussels) prepared the map. This is CAML contribution # 89.

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THE BIOGEOGRAPHIC ATLAS OF THE SOUTHERN OCEAN

Scope

Biogeographic information is of fundamental importance for discovering marine biodiversity hotspots, detecting and understanding impacts of environmental changes, predicting future distributions, monitoring biodiversity, or supporting conservation and sustainable management strategies.

The recent extensive exploration and assessment of biodiversity by the Census of Antarctic Marine Life (CAML), and the intense compilation and validation efforts of Southern Ocean biogeographic data by the SCAR Marine Biodiversity Information Network (SCAR-MarBIN / OBIS) provided a unique opportunity to assess and synthesise the current knowledge on Southern Ocean biogeography.

The scope of the Biogeographic Atlas of the Southern Ocean is to present a concise synopsis of the present state of knowledge of the distributional patterns of the major benthic and pelagic taxa and of the key communities, in the light of biotic and abiotic factors operating within an evolutionary framework. Each chapter has been written by the most pertinent experts in their field, relying on vastly improved occurrence datasets from recent decades, as well as on new insights provided by molecular and phylogeographic approaches, and new methods of analysis, visualisation, modelling and prediction of biogeographic distributions.

A dynamic online version of the Biogeographic Atlas will be hosted on www.biodiversity.aq.

The Census of Antarctic Marine Life (CAML)

CAML (www.caml.aq) was a 5-year project that aimed at assessing the nature, distribution and abundance of all living organisms of the Southern Ocean. In this time of environmental change, CAML provided a comprehensive baseline information on the Antarctic marine biodiversity as a sound benchmark against which future change can reliably be assessed. CAML was initiated in 2005 as the regional Antarctic project of the worldwide programme Census of Marine Life (2000-2010) and was the most important biology project of the International Polar Year 2007-2009.

The SCAR Marine Biodiversity Information Network (SCAR-MarBIN)

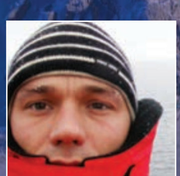
In close connection with CAML, SCAR-MarBIN (www.scarmarbin.be, integrated into www.biodiversity.aq) compiled and managed the historic, current and new information (i.a. generated by CAML) on Antarctic marine biodiversity by establishing and supporting a distributed system of interoperable databases, forming the Antarctic regional node of the Ocean Biogeographic Information System (OBIS, www.iobis.org), under the aegis of SCAR (Scientific Committee on Antarctic Research, www.scar.org). SCAR-MarBIN established a comprehensive register of Antarctic marine species and, with biodiversity.aq provided free access to more than 2.9 million Antarctic georeferenced biodiversity data, which allowed more than 60 million downloads.

The Editorial Team

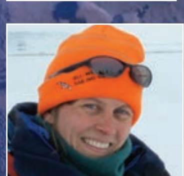
Claude DE BROYER is a marine biologist at the Royal Belgian Institute of Natural Sciences in Brussels. His research interests cover structural and ecofunctional biodiversity and biogeography of crustaceans, and polar and deep sea benthic ecology. Active promoter of CAML and ANDEEP, he is the initiator of the SCAR Marine Biodiversity Information Network (SCAR-MarBIN). He took part to 19 polar expeditions.

Huw GRIFFITHS is a marine Biogeographer at the British Antarctic Survey. He created and manages SOMBASE, the Southern Ocean Mollusc Database. His interests include large-scale biogeographic and ecological patterns in space and time. His focus has been on molluscs, bryozoans, sponges and pycnogonids as model groups to investigate trends at high southern latitudes.

Cédric d'UDEKEM d'ACOZ is a research scientist at the Royal Belgian Institute of Natural Sciences, Brussels. His main research interests are systematics of amphipod crustaceans, especially of polar species and taxonomy of decapod crustaceans. He took part to 2 scientific expeditions to Antarctica on board of the *Polarstern* and to several sampling campaigns in Norway and Svalbard.

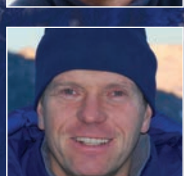


Bruno DANIS is an Associate Professor at the Université Libre de Bruxelles, where his research focuses on polar biodiversity. Former coordinator of the scarmarbin.be and antabif.be projects, he is a leading member of several international committees, such as OBIS or the SCAR Expert Group on Antarctic Biodiversity Informatics. He has published papers in various fields, including ecotoxicology, physiology, biodiversity informatics, polar biodiversity or information science.

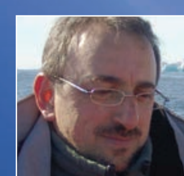


Susie GRANT is a marine biogeographer at the British Antarctic Survey. Her work is focused on the design and implementation of marine protected areas, particularly through the use of biogeographic information in systematic conservation planning.

Christoph HELD is a Senior Research Scientist at the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven. He is a specialist in molecular systematics and phylogeography of Antarctic crustaceans, especially isopods.

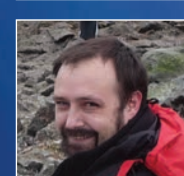


Falk HUETTMANN is a 'digital naturalist' he works on three poles (Arctic, Antarctic and Hindu-Kush Himalaya) and elsewhere (marine, terrestrial and atmosphere). He is based with the university of Alaska-Fairbank (UAF) and focuses primarily on effective conservation questions engaging predictions and open access data.



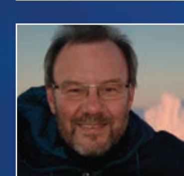
Philippe KOUBBI is professor at the University Pierre et Marie Curie (Paris, France) and a specialist in Antarctic fish ecology and biogeography. He is the Principal Investigator of projects supported by IPEV, the French Polar Institute. As a French representative to the CCAMLR Scientific Committee, his main input is on the proposal of Marine Protected Areas. His other field of research is on the ecoregionalisation of the high seas.

Ben RAYMOND is a computational ecologist and exploratory data analyst, working across a variety of Southern Ocean, Antarctic, and wider research projects. His areas of interest include ecosystem modelling, regionalisation and marine protected area selection, risk assessment, animal tracking, seabird ecology, complex systems, and remote sensed data analyses.

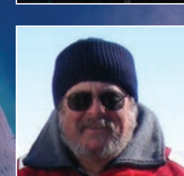


Anton VAN DE PUTTE works at the Royal Belgian Institute for Natural Sciences (Brussels, Belgium). He is an expert in the ecology and evolution of Antarctic fish and is currently the Science Officer for the Antarctic Biodiveristy Portal www.biodiversity.aq. This portal provides free and open access to Antarctic Marine and terrestrial biodiversity of the Antarctic and the Southern Ocean.

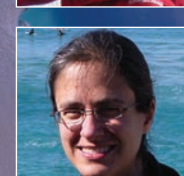
Bruno DAVID is CNRS director of research at the laboratory BIOGÉOSCIENCES, University of Burgundy. His works focus on evolution of living forms, with and more specifically on sea urchins. He authored a book and edited an extensive database on Antarctic echinoids. He is currently President of the scientific council of the Muséum National d'Histoire Naturelle (Paris), and Deputy Director at the CNRS Institute for Ecology and Environment.



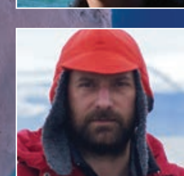
Julian GUTT is a marine ecologist at the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, and professor at the Oldenburg University, Germany. He participated in 13 scientific expeditions to the Antarctic and was twice chief scientist on board Polarstern. He is member of the SCAR committees ACCE and AnT-ERA (as chief officer). Main focii of his work are: biodiversity, ecosystem functioning and services, response of marine systems to climate change, non-invasive technologies, and outreach.



Graham HOSIE is Principal Research Scientist in zooplankton ecology at the Australian Antarctic Division. He founded the SCAR Southern Ocean Continuous Plankton Recorder Survey and is the Chief Officer of the SCAR Life Sciences Standing Scientific Group. His research interests include the ecology and biogeography of plankton species and communities, notably their response to environmental changes. He has participated in 17 marine science voyages to Antarctica.



Alexandra POST is a marine geoscientist, with expertise in benthic habitat mapping, sedimentology and geomorphic characterisation of the seafloor. She has worked at Geoscience Australia since 2002, with a primary focus on understanding seafloor processes and habitats on the East Antarctic margin. Most recently she has led work to understand the biophysical environment beneath the Amery Ice Shelf, and to characterise the habitats on the George V Shelf and slope following the successful CAML voyages in that region.



Yan ROPERT COUDERT spent 10 years at the Japanese National Institute of Polar Research, where he graduated as a Doctor in Polar Sciences in 2001. Since 2007, he is a permanent researcher at the CNRS in France and the director of a polar research programme (since 2011) that examines the ecological response of Adélie penguins to environmental changes. He is also the secretary of the Expert Group on Birds and Marine Mammals and of the Life Science Group of the Scientific Committee on Antarctic Research.