Census of Antarctic Marine Life
SCAR-Marine Biodiversity Information Network

BIOGEOGRAPHIC ATLAS OF THE SOUTHERN OCEAN

CHAPTER 9.3. ASSESSING STATUS AND CHANGE IN SOUTHERN OCEAN ECOSYSTEMS. Constable A., Costa D., Murphy E., Hofmann E., Schofield O., Press A., Johnson N.M., Newman L., 2014.

In: De Broyer C., Koubbi P., Griffiths H.J., Raymond B., Udekem d'Acoz C. d', et al. (eds.). Biogeographic Atlas of the Southern Ocean. Scientific Committee on Antarctic Research, Cambridge, pp. 404-407.

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

THE BIOGEOGRAPHIC ATLAS OF THE SOUTHERN OCEAN

The "Biogeographic Atlas of the Southern Ocean" is a legacy of the International Polar Year 2007-2009 (www.ipy.org) and of the Census of Marine Life 2000-2010 (www.coml.org), contributed by the Census of Antarctic Marine Life (www.caml.aq) and the SCAR Marine Biodiversity Information Network (www.scarmarbin.be; www.biodiversity.aq).

The "Biogeographic Atlas" is a contribution to the SCAR programmes Ant-ECO (State of the Antarctic Ecosystem) and AnT-ERA (Antarctic Thresholds- Ecosystem Resilience and Adaptation) (www.scar.org/science-themes/ecosystems).

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)

Published by:

The Scientific Committee on Antarctic Research, Scott Polar Research Institute, Lensfield Road, Cambridge, CB2 1ER, United Kingdom (www.scar.org).

Publication funded by:

- The Census of Antarctic Marine Life (Albert P. Sloan Foundation, New York)
- The TOTAL Foundation, Paris.

The "Biogeographic Atlas of the Southern Ocean" shared the *Cosmos Prize* awarded to the Census of Marine Life by the International Osaka Expo'90 Commemorative Foundation, Tokyo, Japan.

Publication supported by:

- The Belgian Science Policy (Belspo), through the Belgian Scientific Research Programme on the Antarctic and the "biodiversity.aq" network (SCAR-MarBIN/ANTABIF)
- The Royal Belgian Institute of Natural Sciences (RBINS), Brussels, Belgium
- The British Antarctic Survey (BAS), Cambridge, United Kingdom
- The Université Pierre et Marie Curie (UPMC), Paris, France
- The Australian Antarctic Division, Hobart, Australia
- The Scientific Steering Committee of CAML, Michael Stoddart (CAML Administrator) and Victoria Wadley (CAML Project Manager)

Mapping coordination and design: Huw Griffiths (BAS, Cambridge) & Anton Van de Putte (RBINS, Brussels)

Editorial assistance: Henri Robert, Xavier Loréa, Charlotte Havermans, Nicole Moortgat (RBINS, Brussels)

Printed by: Altitude Design, Rue Saint Josse, 15, B-1210, Belgium (www.altitude-design.be)

Lay out: Sigrid Camus & Amélie Blaton (Altitude Design, Brussels).

Cover design: Amélie Blaton (Altitude Design, Brussels) and the Editorial Team.

Cover pictures: amphipod crustacean (*Epimeria rubrieques* De Broyer & Klages, 1991), image © T. Riehl, University of Hamburg; krill (*Euphausia superba* Dana, 1850), image © V. Siegel, Institute of Sea Fisheries, Hamburg; fish (*Chaenocephalus* sp.), image © C. d'Udekem d'Acoz, RBINS; emperor penguin (*Aptenodytes forsteri* G.R. Gray, 1844), image © C. d'Udekem d'Acoz, RBINS; Humpback whale (*Megaptera novaeangliae* (Borowski, 1781)), image © L. Kindermann, AWI.

Online dynamic version :

A dynamic online version of the Biogeographic Atlas is available on the SCAR-MarBIN / AntaBIF portal : atlas.biodiversity.aq.

Recommended citation:

For the volume:

De Broyer C., Koubbi P., Griffiths H.J., Raymond B., Udekem d'Acoz C. d', Van de Putte A.P., Danis B., David B., Grant S., Gutt J., Held C., Hosie G., Huettmann F., Post A., Ropert-Coudert Y. (eds.), 2014. Biogeographic Atlas of the Southern Ocean. Scientific Committee on Antarctic Research, Cambridge, XII + 498 pp.

For individual chapter:

(e.g.) Crame A., 2014. Chapter 3.1. Evolutionary Setting. In: De Broyer C., Koubbi P., Griffiths H.J., Raymond B., Udekem d'Acoz C. d', *et al.* (eds.). Biogeographic Atlas of the Southern Ocean. Scientific Committee on Antarctic Research, Cambridge, pp. xx-yy.

ISBN: 978-0-948277-28-3.

9.3. Assessing status and change in Southern Ocean ecosystems

Andrew Constable[1,2,8], Dan Costa[3], Eugene Murphy[4], Eileen Hofmann[5], Oscar Schofield[6], Anthony Press[2], Nadine M. Johnston[4] & Louise Newman[7]

[1]Australian Antarctic Division, Kingston, Tasmania, Australia
[2]Antarctic Climate and Ecosystem Cooperative Research Centre, Hobart, Tasmania, Australia
[3]Ecology & Evolutionary Biology, University of California Santa Cruz, CA, USA
[4]British Antarctic Survey, Cambridge, UK
[5]Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA, USA
[6]Coastal Ocean Observation Laboratory, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, NJ, USA
[7]Southern Ocean Observing System International Project Office, Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania, Australia

1. Introduction

Southern Ocean ecosystems have been changing since the near extirpation of seals starting in the 1800s and the overexploitation of many whale species and benthic finfish in the mid-20th century. Since the late 1960s, significant changes to Southern Ocean habitats, probably resulting from the depletion of ozone over the Antarctic, have been observed including increased westerly winds (Turner *et al.* 2009b) and a movement south of their location indicated by the Southern Annular Mode (Turner *et al.* 2009a), the extent and timing of sea ice advance and retreat, (although varying greatly from positive to negative regionally (Stammerjohn *et al.* 2008, Turner *et al.* 2009a); abrupt loss of ice shelves (Cook *et al.* 2005, Cook *et al.* 2010); freshening of Antarctic Bottom Water and surface waters near the continent, a southward shift in the Antarctic Circumpolar Current fronts, along with a changed eddy field (Meredith *et al.* 2006, Sallée *et al.* 2010, Sokolov *et al.* 2009). Increased CO_2 in the atmosphere has also led to a decrease in ocean pH (Turner *et al.* 2009a). The Southern Ocean is expected to substantially change in the coming decades as a result of climate change and ocean acidification (Turner *et al.* 2009a).

In recent decades, changes in biota and the potential role of change in habitats have been identified (e.g. the role of sea ice, Massom *et al.* 2010) but the actual mechanisms of change remain poorly understood for many components of the ecosystem (Constable *et al.* submitted). The prognoses for change in the structure and function of Antarctic and Southern Ocean ecosystems in response to climate change and recovery of marine mammals are regionally specific due to regional differences in the manifestations of climate change (Constable *et al.* submitted). For example, a switch from a krill-based food web to a copepod- and fish-based food web in times of low krill abundance (Waluda *et al.* 2010, Murphy *et al.* 2012c) suggests that the latter may become more common in the future in the south Atlantic (Shreeve *et al.* 2009, Trathan *et al.* 2012). The prognosis for Antarctic krill overall is ambiguous, as factors that could impact directly on krill vary regionally, and because they are able to adapt physiologically and behaviourally (Schmidt *et al.* 2011). New research also shows that larval krill survival may be negatively affected by increasing ocean acidity (Kawaguchi *et al.* 2011), adding further complexity to these assessments.

Some key trends in distribution and abundance of bird populations (penguins and flying birds) have been linked to recent change (e.g. Barbraud *et al.* 2001, Forcada *et al.* 2005, Jenouvrier *et al.* 2005, Trathan *et al.* 2012). However, the ecological pathways of impact on marine mammals and birds may be difficult to determine because higher predator populations are less sensitive to small-scale spatial and temporal variability of lower trophic levels, e.g. the contrasting changes in Adelie and other penguin populations (Trivelpiece *et al.* 2011, Nicol *et al.* 2012, Smith Jr. *et al.* 2012).

2. Why good estimates of change are needed

Despite the historical changes to the ecosystem, the Southern Ocean remains the easiest region to separate the ecosystem impacts of climate change and ocean acidification from direct anthropogenic effects — many other regions have continuing and confounding effects of pollution, catchment and coastal zone modification and fisheries (Constable *et al.* 2009). A monitoring and assessment programme in the Southern Ocean would play an important role in evaluating and estimating the magnitudes and rates of change in global marine ecosystems, testing predictions from climate model scenarios of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2001, Meehl *et al.* 2007, Rosenzweig *et al.* 2007) and, thereby, provide a sound basis for signalling future changes in ecosystems in the Southern Ocean and beyond. Identifying changes in ecosystem productivity and dynamics is fundamental to achieving ecologically sustainable Antarctic krill fisheries and the conservation of Antarctic marine life as a whole (Constable *et al.* 2011, Murphy *et al.* 2012a, Murphy *et al.* 2012b).

A great difficulty in interpreting the cause of changes is the absence of integrated measurements of a suite of variables across the range of physical and biological properties of Antarctic and Southern Ocean ecosystems (Murphy *et al.* 2008, Constable *et al.* 2009, Rintoul *et al.* 2011). Moreover, attention needs to be given to estimating how regional differences and intra- and inter-annual variability may impact the use of these indicators for assessing long-term trends in the ecosystems (Constable *et al.* 2006, 2011). Conversely, the regional differences of climate change impacts on habitats in the Southern Ocean provide opportunities for determining how changes in habitats (positive and negative) will impact on ecosystems as a whole.

Future impacts of climate change on marine ecosystems are being predicted using a combination of expert views and simulation models (Hitz *et al.* 2004, Sarmiento *et al.* 2004). Predictions to date have focussed on shifts in distribution and abundance of biological populations in marine systems driven by temperature (Harley *et al.* 2006). However, both abiotic and biotic changes and responses are expected to be significantly more complex (Melbourne-Thomas *et al.* 2013). For example, survival and condition of many organisms may be more affected by changes in ocean chemistry or by disruptions to food-web dynamics than by changes in temperature (Harley *et al.* 2006, Clarke *et al.* 2007, Constable *et al.* submitted).

Observations are needed to unambiguously validate the conclusions from modelling and forecasting studies. Such a programme is essential for monitoring how the role of Southern Ocean ecosystems in the Earth System is changing, as well as for appropriately setting both ecosystem-based catch limits for krill and finfish species in the region (SC-CAMLR 2011) and conservation requirements for threatened, endangered or recovering species, such as whales and albatross.

3. The Challenge

The great challenge is to assess the status and trends of Southern Ocean marine ecosystems overall, against which change in ecosystem structure and function can be unambiguously assessed in the future. This challenge includes being able to assess the likelihood of different states in the future. There are three subsidiary questions to this challenge:

1. How should status and trends in those ecosystems be assessed and reported and how will the likelihood of future states be assessed?
2. What are the gaps in knowledge that are required to be able to undertake these assessments?
   a. what is the current status of Antarctic and Southern Ocean ecosystems overall?
   b. what are the critical processes, mechanisms and feedbacks that directly influence the population responses of biota to change in their habitats?
3. What observations need to be taken that will indicate a change in state of those ecosystems and provide suitable input to, validation or correction of assessments?

4. International Context

A number of current international initiatives provide the means for coordinating this work. The ability to undertake integrated circumpolar ecosystem programmes of this kind is demonstrated by past successful programmes such as BIOMASS (El-Sayed 1994) and, more recently, the International Polar Year (Krupnik *et al.* 2011). The biogeographic atlas forms an important milestone in helping deliver what is needed to estimate change in Southern Ocean ecosystems. The current initiatives are outlined here.

4.1. Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED)

ICED (http://www.iced.ac.uk) is an international programme that aims to determine the major controls on the dynamics of Southern Ocean ecosystems and the potential for feedbacks as part of the Earth System (Murphy *et al.* 2008). It is associated with the Scientific Committee on Antarctic Research (SCAR), the Scientific Committee on Oceanic Research (SCOR) and other international programmes. It is part of the International Geosphere-Biosphere Programme's "Integrated Marine Biogeochemistry and Ecosystem Research" project (IGBP IMBER).

ICED has three main scientific objectives, which are (i) to understand the structure and dynamics of ecosystems in the Southern Ocean and how they are affected by, and feedback to, climate processes, (ii) to understand how ecosystem structure and dynamics interact with biogeochemical cycles in the Southern Ocean, and (iii) to determine how ecosystem structure and dynamics should be incorporated into management approaches for sustainable exploitation of living resources in the Southern Ocean. Its core activity areas will directly contribute to assessing status and trends of Southern Ocean ecosystems and providing a capability for assessing the likelihood of future states. These core activities include the development of ecosystem models, synthesis of historical datasets and the development and coordination of fieldwork.

ICED has a project, the Southern Ocean Sentinel, hereafter termed 'the Sentinel', which will utilise the models and field activities in an ongoing integrated programme to assess status, trends and likelihood of future states of Southern Ocean ecosystems as a whole. It has close synergies with other international initiatives within the Southern Ocean science community, as well as the broader Earth System community.

ICED is closely linked to another IMBER programme, Climate Impacts on Oceanic Top Predators (CLIOTOP), particularly in relation to its work on marine mammals. The general objective of CLIOTOP (http://www.imber.info/index.php/Science/Regional-Programmes/CLIOTOP) is to organise a large-scale worldwide comparative effort aimed at elucidating the key processes involved in the impact of both climate variability (at various scales) and fishing on the structure and function of open ocean pelagic ecosystems and their top predator species. The ultimate objective is the development of a reliable predictive capability for the dynamics of top predator populations and oceanic ecosystems that combines both fishing and climate (i.e. environmental) effects. CLIOTOP is in its second phase with an emphasis on developing scenarios of the evolution of oceanic ecosystems under anthropogenic and natural forcings in the 21st century (Hobday *et al.* 2013).

4.2. Southern Ocean Observing System (SOOS)

SOOS (http://www.soos.aq) was established to better coordinate routine observing of the Southern Ocean in order to improve our ability to detect and interpret Southern Ocean change across a range of variables and disciplines (Rintoul *et al.* 2011). It has associations with all international programmes undertaking scientific research in the Southern Ocean. SOOS has six overarching themes in its strategy: (1) the role of the Southern Ocean in the planet's heat and freshwater balance, (2) the stability of the Southern Ocean overturning circulation, (3) the role of the ocean in the stability of the Antarctic ice sheets and their contributions to sea level rise, (4) the future and consequences of Southern Ocean carbon uptake, (5) the future of Antarctic sea ice, and (6) the impacts of global change on Southern Ocean ecosystems. The sixth theme is complementary to ICED Southern Ocean Sentinel and will be important in observing trends in Southern Ocean ecosystems.

4.3. Scientific Committee on Antarctic Research (SCAR) programmes

SCAR (http://www.scar.org) has a number of programs contributing to understanding change in the Southern Ocean.

The SCAR Life Sciences programme helps coordinate priorities for Antarctic ecosystem research. These priorities have generally centred on understanding the patterns of biodiversity in Antarctica and the Southern Ocean, and the drivers of change in structure and dynamics of ecosystems. Recently, two programmes have been adopted to further this work. The State of the Antarctic Ecosystems (AntEco) programme aims to explain the biodiversity of Antarctica, how it evolved/arrived in the region, its ecology and threats to its persistence in the region. The Antarctic Thresholds — Ecosystem Resilience and Adaptation (Ant-ERA) programme aims to determine the biological processes in Antarctic ecosystems and to define the thresholds for biota along with their resistance and resilience to change.

SCAR also has a Southern Ocean Continuous Plankton Recorder Survey (SO-CPR), which was established in 1991 to map the spatio-temporal variation in biodiversity, distribution and abundance of plankton (Hosie *et al.* 2003). It is a key component of the Southern Ocean Observing System, and is a founding contribution to the Global Alliance of CPR Surveys (GACS, www.globalcpr.org), which allows Southern Ocean observations to be placed in a global context.

4.4. Scientific Committee for the Conservation of Antarctic Marine Living Resources (SC-CAMLR)

SC-CAMLR (http://www.ccamlr.org/en/science/science) provides scientific advice to the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR; Constable *et al.* 2000). As part of its remit, it coordinates the CCAMLR Ecosystem Monitoring Program (CEMP; Agnew 1997). At present, CEMP has a primary focus on monitoring ecosystem components that affect or are affected by Antarctic krill, *Euphausia superba*. This is because krill is the focus of the largest fishery in the Southern Ocean, and therefore, changes in krill abundance/distribution could impact on most marine mammal and bird species in the region because of their dependence on Antarctic krill as prey.

5. Approaches

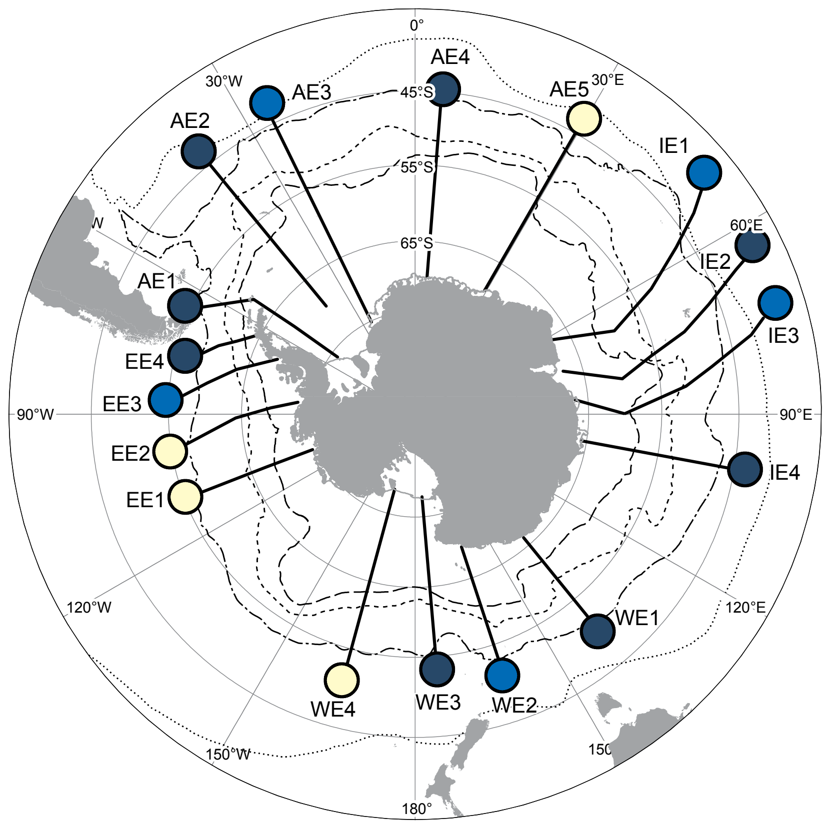
In its simplest form, the status of Antarctic and Southern Ocean marine ecosystems is determined by the relative abundances of the different taxa, taking account of different habitats, trophic levels, and seasonal variability in abundance. Trends in populations need to be described in relation to sources of interannual variability, so that differences over time can be attributed to random events, or systemic changes (physical or biological) that may be cyclical or longer term trends. Relating observations to the true state of an ecosystem is a major challenge in an assessment. This is particularly true for analyses across many taxa, habitats and the varying temporal and spatial scales at which different components of the ecosystem operate. Techniques are usually employed so that not all taxa in an ecosystem need to be observed in order to assess biodiversity or the relative abundance of taxa at different trophic levels. However, some understanding is needed of how these summary observations relate to the overall status of taxa in the ecosystem.

Beyond the empirical data and assessments of status and trends, we also need an understanding of the key ecological processes (or "drivers", or "forcings") that directly or indirectly cause the ecosystem dynamics. This knowledge enables an understanding of the consequences of assessments for the Earth System, and also for achieving management objectives. The combination of knowledge on status, trends and processes, along with natural variability, enables the development of dynamic models of the ecosystem. These models can then be used to project from the current state to explore possible future states under various scenarios and therefore enable assessments of the likelihood that those states might arise in the future. This process can take account of historical perturbations, such as whaling and sealing, in assessing the likelihood of future states. For example, knowledge of the present status and ecology of whales provides the basis for determining the future trajectory of whales and their potential to directly and indirectly impact on other parts of the ecosystem.

5.1. Current status

Knowledge on the current state of Southern Ocean ecosystems is mostly derived from integrated ecosystem studies on the Antarctic Peninsula and South Georgia, along with expert syntheses across disparate data sets for other regions (see This Volume; Rogers *et al.* 2012, Constable *et al.* submitted). This can be combined with the benchmarking of the state of krill from the CCAMLR (2000) survey in the Atlantic Sector (Watkins *et al.* 2004), and the BROKE (1996; Nicol *et al.* 2000) and BROKE West (2006; Nicol *et al.* 2010) surveys in East Antarctica. Other work in the past decade also provides a solid foundation for identifying gaps and how to achieve a benchmark for Antarctic and Southern Ocean ecosystems as a whole, including a workshop held jointly between the Scientific Committees of CCAMLR and the International Whaling Commission (SC-CAMLR and SC-IWC 2008) and subsequent publications on primary production (Strutton *et al.* 2012), zooplankton (Atkinson *et al.* 2012b), krill (Atkinson *et al.* 2012a), finfish (Kock *et al.* 2012), penguins (Ratcliffe *et al.* 2011) and seals (Southwell *et al.* 2012).

Impacts on the physical environment of climate change are expected to differ between regions in the Southern Ocean. Synchronised studies between regions, in a similar way to that undertaken in World Ocean Circulation Experiment (Siedler *et al.* 2001), Southern Ocean GLOBEC (Hofmann *et al.* 2011) and the IPY (Krupnik *et al.* 2011), can provide a natural experiment to test hypotheses about direct and indirect ecosystem responses to changing physical environments. Apart from the southwest Atlantic and the west Antarctic Peninsula, the overall status of the marine ecosystems, as a foundation for assessing ecological dynamics and change, is not well known (Constable *et al.* submitted). The ICED Sentinel and SOOS are using existing regional datasets and programmes, synoptic data (e.g, from satellites and integrative models), and work in this volume to develop a means for benchmarking Southern Ocean ecosystems as a whole, towards developing integrated ecosystem measurements of status and trends in these ecosystems. It is envisaged that a coordinated field programme to benchmark the ecological status of Southern Ocean ecosystems could be developed for 2020 or soon after utilising satellite observations, ship-based transects and integrated studies (Map 1) coupled with land-based programmes to monitor foraging activities and diets of seals, penguins and flying birds at key locations in the different regions.



Assessing Ecosystems Map 1 Map showing possible transects (black lines) for measuring biological and ecosystem parameters in the Southern Ocean. Transects take account of latitudinal and longitudinal variation in production and in regional differences in biology and food webs and the latitudinal range of oceanic, cryospheric and atmospheric conditions, including spatial variation in productivity, in each region. Initials indicate regions and transect numbers: EE = East Pacific sector ecosystem transect; AE = Atlantic sector ecosystem transect west; IE = Indian sector ecosystem transect, WE = West Pacific sector ecosystem transect. Red dots represent locations where long-term datasets on land-based predators have been obtained. Dark blue dots represent transects that could be feasible for repeated sampling within current operational activity. Lighter blue dots represent transects that could be done repeatedly but with some operational adjustments. Light dots represent desirable transects but not easily undertaken within the current operations.

5.2. Assessing status, trends and likelihood of future states

Methods for summarising the status and trends of ecosystems are in the process of being developed (SC-CAMLR 2008, Shin *et al.* 2010) and are now moving beyond summaries of the status of individual taxa to summaries of collective indices, such as size spectra (Jennings *et al.* 2005, Jennings *et al.* 2008). Some methods have been developed for combining multiple measures into a single index that can show time trends relative to specific causes of change (Mare *et al.* 2000). The challenge this technique raises, is how to determine which indices will reflect overall status of the ecosystems and provide useful summaries for describing trends that can be used by managers and policy makers (Fulton *et al.* 2005).

Ecosystem models are yet to be developed that can be used to assess the likelihood of future states, although the requirements for the models are now well established (SC-CAMLR 2004, SC-CAMLR and SC-IWC 2008, see Murphy *et al.* 2012a for discussion). Such models will also be useful for informing what observations need to be taken to measure trends in these ecosystems.

5.3. Observing change in Antarctic and Southern Ocean ecosystems

Regular integrated observations of Southern Ocean ecosystems are available on the western margins of the Antarctic Peninsula and from the Scotia arc. Land-based activities are available in other regions as part of the CCAMLR CEMP, or as regular monitoring activities such as at Kerguelen and Crozet Islands (e.g. Barbraud *et al.* 2012). Regular ship-based observations are also available (e.g., the Continuous Plankton Recorder Survey (Hosie *et al.* 2003); but these are mostly opportunistic and are not necessarily integrated with land-based observations or other ship-based activities. Observations of the physical system are generally further advanced than for biology (Rintoul *et al.* 2011). Improved integration of ecosystem observations along with improved coverage through CEMP, SOOS, and ICED Sentinel will be central to improved assessments of status, trends and ecological processes in Southern Ocean ecosystems, as well as giving greater capacity for validating ecosystem models.

5.4. Critical ecosystem processes

Since the work of the BIOMASS programme in the 1980s (El-Sayed 1994), a number of internationally coordinated programmes have sought to better quantify the critical ecosystem processes in Southern Ocean such as factors affecting primary production (the role of iron) and the relative importance of different trophic pathways, the role of sea ice as habitat for krill and other biota, factors that affect the breeding phenology of marine mammals and birds and drivers of availability of prey. These have included Southern Ocean GLOBEC (Hofmann *et al.* 2011), the Discovery 2010 programme (Tarling *et al.* 2012), and most recently ICED (Murphy *et al.* 2008). This work is essential for providing the theoretical and quantitative underpinnings for the development of ecosystem models (Murphy *et al.* 2012a, Murphy *et al.* 2012b).

6. General

The IPY has provided a strong stimulus to setting up ongoing observations and assessments of status and trends in the Southern Ocean. Current work is leading towards an integrated field assessment of the ecological status of Southern Ocean ecosystems as a whole, using standard methods for biological monitoring. This will help standardise the relative differences between regions and provide consistent foundation against which future change will be measured. In this process, ecosystem models can not only support the assessments but will help provide a guide as to what measures need to be taken to indicate overall status of Southern Ocean ecosystems. It is envisaged that existing initiatives and further developmental work over the next 5 years will build on the programmes already underway for the west Antarctic Peninsula, Scotia Arc and CEMP. This work is expected to result in a fully integrated cost-effective programme to measure status and trends in Southern Ocean marine ecosystems overall that could begin with a benchmarking of these ecosystems around 2020.

Acknowledgements

This is CAML contribution # 145.

References

Agnew, D.J., 1997. The CCAMLR ecosystem monitoring programme. *Antarctic Science*, **9**, 235–242.

Atkinson, A., Nicol, S., Kawaguchi, S., Pakhomov, E.A., Quetin, L., Ross, R., Hill, S., Reiss, C., Siegel, V., Tarling, G., 2012a. Fitting *Euphausia superba* into Southern Ocean food-web models: a review of data sources and their limitations (submitted to the 2008 Joint CCAMLR-IWC Workshop). *CCAMLR Science,* **19**, 219–245.

Atkinson, A., Ward, P., Hunt, B.P.V., Pakhomov, E.A., Hosie, G.W., 2012b. An overview of Southern Ocean zooplankton data: abundance, biomass, feeding and functional relationships (submitted to the 2008 Joint CCAMLR-IWC Workshop). *CCAMLR Science*, **19**, 171–218.

Barbraud, C, Weimerskirch, H., 2001. Emperor penguins and climate change. *Nature,* **411**,183–186.

Barbraud, C., Rolland, V., Jenouvrier, S., Nevoux, M., Delord, K., Weimerskirch, H., 2012. Effects of climate change and fisheries bycatch on Southern Ocean seabirds: a review. *Marine Ecology Progress Series,* **454**, 285–307.

Clarke, A, Murphy, E.J., Meredith, M.P., King, J.C., Peck, L.S., Barnes, D.K.A., Smith, R.C., 2007. Climate change and the marine ecosystem of the western Antarctic Peninsula. *Philosophical Transactions of the Royal Society B-Biological Sciences,* **362**, 149–166.

Constable A.J., 2006. Setting management goals using information from predators. In: Boyd, I.L., Wanless, S., Camphuysen, C.J., (eds.). *Top predators in marine ecosystems.* Cambridge: Cambridge University Press, pp 324–346.

Constable A.J., 2011. Lessons from CCAMLR on the implementation of the ecosystem approach to managing fisheries. *Fish and Fisheries*, **12**, 138–151. doi:10.1111/j.1467-2979.2011.00410.x.

Constable, A.J., de la Mare, W.K., Agnew, D.J., Everson, I., Miller, D., 2000. Managing fisheries to conserve the Antarctic marine ecosystem: practical implementation of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). ICES *Journal of Marine Science,* **57**, 778–791.

Constable, A.J., Doust, S., 2009. *Southern Ocean Sentinel - an international program to assess climate change impacts on marine ecosystems*: report of an international workshop, Hobart, April 2009. ACE CRC, Commonwealth of Australia & WWF-Australia, 81 pp.

Constable, A.J., Melbourne-Thomas, J., Barbraud, C., Barnes, D., Bindoff, N., Boyd, P., Brandt, A., Corney, S.P., Costa, D.P., Davidson, A., Ducklow, H., Emmerson, L., Fukuchi, M., Gutt, J., Hindell, M.A., Hofmann, E., Hosie, G., Iida, T., Johnston, N., Kawaguchi, S., Koubbi, P., Lea, M-A., Makhado, A., Massom, R., Meiners, K., Meredith, M., Murphy, E., Nicol, S., Richerson, K., Riddle, M.J., Rintoul, S.R., Smith, W. Jr, Southwell, C., Stark, J., Takahashi, K., Trathan, P., Welsford, D., Weimerskirch, H., Wienecke, B., Wolf-Gladrow, D., Ziegler, P., Westwood, K., Wright, S., submitted. Change in Southern Ocean ecosystems. *Global Change Biology*.

Cook, A.J., Fox, A.J., Vaughan, D.G., Ferrigno, J.G., 2005. Retreating glacier fronts on the Antarctic Peninsula over the past half century. *Science,* **308**, 541–544.

Cook, A.J., Vaughan, D.G., 2010. Overview of areal changes of the ice shelves on the Antarctic Peninsula over the past 50 years. *Cryosphere,* **4**, 77–98.

El-Sayed, S.Z., 1994. *Southern Ocean Ecology: The BIOMASS Perspective.* Cambridge: Cambridge University Press, Cambridge, xxi pp, 399 pp.

Forcada, J, Trathan, P.N., Reid, K, Murphy, E.J., 2005. The effects of global climate variability in pup production of Antarctic fur seals. *Ecology,* **86**, 2408–2417.

Fulton, E.A., Smith, A.D.M., Punt, A.E., 2005. Which ecological indicators can robustly detect effects of fishing? *ICES Journal of Marine Science,* **62**, 540–551.

Harley, C.D.G., Hughes, A.R., Hultgren, K.M., Miner, B.G., Sorte, C.J.B., Thornber, C.S., Rodriguez, L.F., Tomanek, L., Williams, S.L., 2006. The impacts of climate change in coastal marine systems *Ecology Letters,* **9**, 228–241.

Hitz, S, Smith, J., 2004. Estimating global impacts from climate change. *Global Environmental Change-Human and Policy Dimensions,* **14**, 201–218.

Hobday, A.J., Young, J.W., Abe, O., Costa, D.P., Cowen, R.K., Evans, K., Gasalla, M.A., Kloser, R., Maury, O., Weng, K.C., 2013. Climate impacts and oceanic top predators: moving from impacts to adaptation in oceanic systems. *Reviews in Fish Biology and Fisheries,* **10**. doi:10.1007/s11160-013-9311-0.

Hofmann, E.E., Wiebe, P.H., Costa, D.P., Torres, J.J., 2011. Introduction to understanding the linkages between Antarctic food webs and the environment: a synthesis of Southern Ocean GLOBEC studies. *Deep Sea Research II,* **58**, 1505–1507.

Hosie, G.W., Fukuchi, M., Kawaguchi, S., 2003. Development of the Southern Ocean Continuous Plankton Recorder survey. *Progress in Oceanography,* **58**, 263–283.

IPCC., 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 892 pp.

Jennings, S., Dulvy, N.K., 2005. Reference points and reference directions for size-based indicators of community structure. *ICES Journal of Marine Science,* **62**, 397–404.

Jennings, S., Melin, F., Blanchard, J.L., Forster, R.M., Dulvy, Nicholas, K., Wilson, R.W., 2008. Global-scale predictions of community and ecosystem properties from simple ecological theory. *Proceedings of the Royal Society of London, Series B - Biological Sciences,* **275,** 1375–1383.

Jenouvrier, S, Weimerskirch, H, Barbraud, C, Park, Y.H., Cazelles, B., 2005. Evidence of a shift in the cyclicity of Antarctic seabird dynamics linked to climate. *Proceedings of the Royal Society of London,Series B - Biological Sciences,* **272**, 887–895.

Kawaguchi, S., Kurihara, H., King, R., Hale, L., Berli, T., Robinson, J.P., Ishida, A., Wakita, M., Virtue, P., Nicol, S., Ishimatsu, A., 2011. Will krill fare well under Southern Ocean acidification? *Biology Letters*, **7**, 288–291.

Kock, K.-H., Barrera-Oro, E., Belchier, M., Collins, M.A., Duhamel, G., Hanchet, S., Pshenichnov, L., Welsford, D., Williams, R., 2012. The role of fish as predators of krill (*Euphausia superba*) and other pelagic resources in the Southern Ocean (submitted to the 2008 Joint CCAMLR-IWC Workshop). *CCAMLR Science,* **19**, 115–169.

Krupnik, I., Allison, I., Bell, R., Cutler, P., Hik, D., López-Martínez, J., Rachold, V., Sarukhanian, E., Summerhayes, C. (eds.), 2011. *Understanding Earth's Polar Challenges: International Polar Year 2007–2008.* University of the Arctic, Rovaniemi, Finland /CCI Press (Printed Version), Edmonton, Alberta, Canada and ICSU/WMO Joint Committee for International Polar Year 2007–2008, 724 pp.

Mare, de la, W.K., Constable, A.J., 2000. Utilising data from ecosystem monitoring for managing fisheries: development of statistical summaries of indices arising from the CCAMLR Ecosystem Monitoring Program. *CCAMLR Science,* **7**, 101–117.

Massom, R.A, Stammerjohn, S.E., 2010. Antarctic sea ice change and variability - Physical and ecological implications. *Polar Science,* **4**, 149–186.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.J., Zhao, Z.-C., 2007. Global Climate Projections.*in* Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., and Miller, H.L. (eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK & New York, USA: Cambridge University Press, 996 pp.

Melbourne-Thomas, J., Constable, A., Wotherspoon, S., Raymond, B., 2013. Testing paradigms of ecosystem change under climate warming in Antarctica. *PLos One,* **8(2)**, e55093. doi:10.1371/journal.pone.0055093.

Meredith, M.P., Hogg, A.M.. 2006. Circumpolar response of Southern Ocean eddy activity to a change in the Southern Annular Mode. *Geophysical Research Letters* **33(16)**, L16608. doi:10.1029/2006GL026499.

Murphy, E.J., Cavanagh, R.D., Hofmann, E.E., Hill, S.L., Constable, A.J., Costa, D.P., Pinkerton, M.H., Johnston, N.M., Trathan, P.N., Klinck, J.M., Wolf-Gladrow, D.A., Daly, K.L., Maury, O., Doney, S.C., 2012a. Developing integrated models of Southern Ocean food webs: Including ecological complexity, accounting for uncertainty and the importance of scale. *Progress in Oceanography,* **102**, 74–92.

Murphy, E.J., Cavanagh, R.D., Johnston, N.M., Reid, K., Hofmann, E.E., (eds.), 2008. Integrating Climate and Ecosystem Dynamics in the Southern Ocean: A Circumpolar Ecosystem Program: Science Plan and Implementation Strategy. *GLOBEC Report* 26, *IMBER Report* 2, iii pp., 68 pp.

Murphy, E.J., Hofmann, E.E., 2012b. End-to-end in Southern Ocean ecosystems. *Current Opinion in Environmental Sustainability,* **4**, 264–271.

Murphy, E.J., Watkins, J.L., Trathan, P.N., Reid, K., Meredith, M.P., Hill, S.L., Thorpe, S.E., Johnston, N.M., Clarke, A., Tarling, G.A., Collins, M.A., Forcada, J., Atkinson, A., Ward, P., Staniland, I.J., Pond, D.W., Cavanagh, R.A., Shreeve, R.S., Korb, R.E., Whitehouse, M.J., Rodhouse, P.G., Enderlein, P., Hirst, A.G., Martin, A.R., Briggs, D.R., Cunningham, N.J., Fleming, A.H., 2012c. Spatial and Temporal Operation of the Scotia Sea Ecosystem. In: Rogers, A.D., Johnston, N.M., Murphy, E.J., Clarke, A. (eds.), *Antarctic Ecosystems: An Extreme Environment in a Changing World*. Blackwell Publishing, Ltd, pp. 160–212.

Nicol, S., Meiners, K., Raymond, B., 2010. BROKE-West, a large ecosystem survey of the South West Indian Ocean sector of the Southern Ocean, 30°E–80°E (CCAMLR Division 58.4.2). *Deep-Sea Research II,* **57**, 693–700.

Nicol, S., Pauly, T., Bindoff, N.L., Strutton, P.G., 2000. "BROKE" a biological / oceanographic survey off the coast of East Antarctica (80–150°E) carried out in January-March 1996. *Deep-Sea Research II: Topical Studies in Oceanography,* **47(12–13)**, 2281–2298.

Nicol, S., Raymond, B., 2012. Pelagic Ecosystems in the Waters off East Antarctica (30°E–150°E). In: Rogers, A.D., Johnston, N.M., Murphy, E.J., Clarke, A. (eds.). *Antarctic Ecosystems: An Extreme Environment in a Changing World*. John Wiley & Sons, Ltd, pp. 243–254.

Ratcliffe, N., Trathan, P., 2011. A review of the diet and at-sea distribution of penguins breeding

within the CAMLR Convention Area (submitted to the 2008 Joint CCAMLR-IWC Workshop). *CCAMLR Science,* **18,** 75–114.
Rintoul, S.R., Sparrow, M., Meredith, M.P., Wadley, V., Speer, K., Hofmann, E., Summerhayes, C., Urban, E., Bellerby, R., 2011. *The Southern Ocean Observing System: initial science and implementation strategy*. SCAR-SCOR, Cambridge, UK, 74 pp.
Rogers, A.D., Johnston, N.M., Murphy, E.J., Clarke, A. (eds.) 2012. *Antarctic Ecosystems: An Extreme Environment in a Changing World*. John Wiley & Sons, Ltd, xiv pp., c32 pp., 538 pp.
Rosenzweig, C., Casassa, G., Karoly, D.J., Imeson, A., Liu, C., Menzel, A., Rawlins, S., Root, T.L., Seguin, B., Tryjanowski, P., 2007. Assessment of observed changes and responses in natural and managed systems. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, pp. 79–131.
Sallée, J.-B., Speer, K.G., Rintoul, S.R., 2010. Zonally asymmetric response of the Southern Ocean mixed-layer depth to the Southern Annular Mode. Nature Geosciences, **3**, 273–279. doi:10.1038/NGEO812
Sarmiento, J.L., Slater, R., Barber, R., Bopp, L., Doney, S.C., Hirst, A.C., Kleypas, J., Matear, R., Mikolajewicz, U., Monfray, P., Soldatov, V., Spall, S.A., Stouffer, R., 2004. Response of ocean ecosystems to climate warming. *Global Biogeochemical Cycles* **18**, GB3003, doi:10.1029/2003GB002134.
SC-CAMLR, 2004. Annex 4, Appendix D: Report of the Workshop on plausible ecosystem models for testing approaches to krill management. *Report of the Twenty-third Meeting of the Scientific Committee*. Commission for the Conservation of Antarctic Marine Living Resources, Hobart, Australia, pp. 231–337.
SC-CAMLR, 2008. Annex 4: Report of the Working Group on Ecosystem Monitoring and Management. *Report of the Twenty-seventh Meeting of the Scientific Committee.* Commission for the Conservation of Antarctic Marine Living Resources, Hobart, Australia, pp. 175–304.
SC-CAMLR, 2011. *Report of the thirtieth meeting of the Scientific Committee for the Conservation of Antarctic Marine Living Resources (SC-CAMLR XXX).* CCAMLR, Hobart, Australia, iii pp., 184 pp.
SC-CAMLR, SC-IWC, 2008. Report of the joint CCAMLR-IWC Workshop to review input data for Antarctic marine ecosystem models, Hobart Australia 11–15 August 2008. Annex 12. *Report of the Twenty-seventh Meeting of the Scientific Committee, Part II.* Commission for the Conservation of Antarctic Marine Living Resources, Hobart, Australia, 119 pp.
Schmidt, K., Atkinson, A., Steigenberger, S., Fielding, S., Lindsay, M.C.M., Pond, D.W., Tarling, G.A., Klevjer, T.A., Allen, C.S., Nicol, S., Achterberg, E.P., 2011. Seabed foraging by Antarctic krill: Implications for stock assessment, bentho-pelagic coupling, and the vertical transfer of iron. *Limnology and Oceanography,* **56,** 1411–1428.
Shin, Y-J., Shannon, L.J., 2010. Using indicators for evaluating, comparing and communicating the ecological status of exploited marine ecosystems. 1. The IndiSeas project. *ICES Journal of Marine Science,* **67,** 686–691.
Shreeve, R.S., Collins, M.A., Tarling, G.A., Main, C.E., Ward, P, Johnston, N.M., 2009. Feeding ecology of myctophid fishes in the northern Scotia Sea. *Marine Ecology-Progress Series,* **386**, 221–236.
Siedler, G., Church, J., Gould, J. (eds.), 2001. Ocean circulation and climate: observing and modelling the global ocean. *International Geophysics Series*, 77. San Diego: Academic Press, xix pp., 715 pp.
Smith Jr., W.O., Ainley, D.G., Cattaneo-Vietti, R., Hofmann, E.E., 2012. The Ross Sea Continental Shelf: regional biogeochemical cycles, trophic interactions, and potential future changes. In: Rogers, A.D., Johnston, N.M., Murphy, E.J., Clarke, A. (eds.). Antarctic ecosystems: an extreme environment in a changing world. Chichester, UK: J. Wiley & Sons. doi:10.1002/9781444347241.ch7.
Sokolov, S., Rintoul, S.R., 2009. Circumpolar structure and distribution of the Antarctic Circumpolar Current fronts: 1. Mean circumpolar paths. *Journal of Geophysical Research: Oceans,* **114**, 1–19.
Southwell, C., Bengtson, J., Bester, M., Blix, A.S., Bornemann, H., Boveng, P., Cameron, M., Forcada, J., Laake, J., Nordøy, E., Plötz, J., Rogers, T., Southwell, D., Steinhage, D., Stewart, B.S., Trathan, P., 2012. A review of data on abundance, trends in abundance, habitat use and diet of ice-breeding seals in the Southern Ocean (submitted to the 2008 Joint CCAMLR-IWC Workshop). *CCAMLR Science,* **19**, 49–74.
Stammerjohn, S.E., Martinson, D.G., Smith, R.C., Yuan, X., Rind, D., 2008. Trends in Antarctic annual sea ice retreat and advance and their relation to El Nino–Southern Oscillation and Southern Annular Mode variability. *Journal of Geophysical Research,* **113,** CO3S90. doi:10.1029/2007JC004269.
Strutton, P.G., Lovenduski, N.S., Mongin, M., Matear, R., 2012. Quantification of Southern Ocean phytoplankton biomass and primary productivity via satellite observations and biogeochemical models (submitted to the 2008 Joint CCAMLR-IWC Workshop). *CCAMLR Science*, **19**, 247–265.
Tarling, G.A., Ward, P., Atkinson, A., Collins, M.A., Murphy, E.J., 2012. DISCOVERY 2010: Spatial and temporal variability in a dynamic polar ecosystem. *Deep-Sea Research Part II - Topical Studies in Oceanography,* **59**, 1–13.
Trathan, P.N., Forcada, J., Murphy, E.J., 2012. Environmental forcing and Southern Ocean marine predator populations. In: Rogers, A.D., Johnston, N.M., Murphy, E.J., Clarke, A. (eds.), *Antarctic Ecosystems*. Blackwell Publishing, Ltd, pp. 335–354.
Trivelpiece, W.Z., Hinke, J.T., Miller, A.K., Reiss, C.S., Trivelpiece, S.G., Watters, G.M., 2011. Variability in krill biomass links harvesting and climate warming to penguin population changes in Antarctica. *Proceedings of the National Academy of Sciences of the United States of America,* **108**, 7625–7628.
Turner, J., Bindschadler, R., Convey, P., di Prisco, G., Fahrbach, E., Gutt, J., Hodgson, D., Mayewski, P., Summerhayes, C. (eds.), 2009a. *Antarctic climate change and the environment*. SCAR, Cambridge UK, xxviii pp., 526 pp.
Turner, J, Comiso, J.C., Marshall, G.J., Lachlan-Cope, T.A., Bracegirdle, T., Maksym, T., Meredith, M.P., Wang, Z., Orr, A., 2009b. Non-annular atmospheric circulation change induced by stratospheric ozone depletion and its role in the recent increase of Antarctic sea ice extent. *Geophysical Research Letters,* **36**, L08502. doi:10.1029/2009GL037524
Waluda, C.M., Collins, M.A., Black, A.D., Staniland, I.J., Trathan, P.N., 2010. Linking predator and prey behaviour: contrasts between Antarctic fur seals and macaroni penguins at South Georgia. *Marine Biology*, **157**, 99–112.
Watkins, J.L., Hewitt, R., Naganobu, M., Sushin, V., 2004. The CCAMLR 2000 Survey: a multinational, multi-ship biological oceanography survey of the Atlantic sector of the Southern Ocean. *Deep Sea Research Part II,* **51**, 1205–1213.

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.

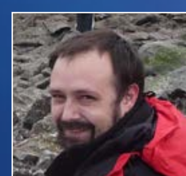
Susie GRANT is a marine biogeographer at the British Antarctic Survey. Her work is focused on the design and implementation of marine protected areas, particularly through the use of biogeographic information in systematic conservation planning.

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.

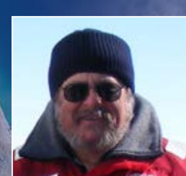
Ben RAYMOND is a computational ecologist and exploratory data analyst, working across a variety of Southern Ocean, Antarctic, and wider research projects. His areas of interest include ecosystem modelling, regionalisation and marine protected area selection, risk assessment, animal tracking, seabird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

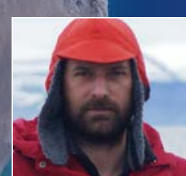
Bruno DAVID is CNRS director of research at the laboratory BIOGÉOSCIENCES, University of Burgundy. His works focus on evolution of living forms, with and more specifically on sea urchins. He authored a book and edited an extensive database on Antarctic echinoids. He is currently President of the scientific 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.