CCAMLR response to CBD Notification 2009-021

March 2009

In response to CBD Notification 2009-021 the following provides a compilation of information from CCAMLR relevant the objectives of the expert workshop (Ottawa, Canada, 29 September - 2 October 2009) as well as on the progress towards the 2012 target on representative networks of marine protected areas.

Contents

1. Extract from the 2005 CCAMLR Scientific Committee report relevant to Marine Protected Areas

REPORT OF THE TWENTY-FOURTH MEETING OF THE SCIENTIFIC COMMITTEE
(Hobart, Australia, 24 October to 28 October 2005)

Marine Protected Areas

3.44 At CCAMLR-XXIII, the Commission urged the Scientific Committee to proceed with work addressing the topic of MPAs as a matter of priority and reaffirmed the need to develop advice consistent with Articles II and IX of the Convention (CCAMLR-XXIII, paragraph 4.13).

3.45 A Workshop on Marine Protected Areas, endorsed by the Scientific Committee and convened by Dr Penhale, was held from 29 August to 1 September 2005 at the NOAA National Marine Fisheries Service, Silver Spring, MD, USA.

3.46 The terms of reference for the workshop (SC-CAMLR-XXIII, paragraph 3.52) were:

(i) to review current principles and practices related to the establishment of Marine Protected Areas;

(ii) to discuss how the use of Marine Protected Areas could be used to contribute to furthering the objectives of CCAMLR;

(iii) to consider proposals that are currently under development or in a conceptual phase that relate to Marine Protected Areas in the Convention Area;

(iv) to discuss the types of scientific information that may be required for the development of Marine Protected Areas to further the objectives of CCAMLR, including the identification of biophysical regions across the Convention Area.

3.47 The Scientific Committee endorsed in full the report of the workshop (Annex 7), subject to comments below. It reviewed in detail the workshop's advice to the Scientific Committee, under each of the specific terms of reference.

3.48 The Scientific Committee regretted that the relatively short notice of the workshop had created difficulties for attendance of CCAMLR Members, especially those with particular logistic or financial constraints.

3.49 Nevertheless, it welcomed the very substantial progress made on this topic at the workshop and thanked the hosts, convener, steering committee and participants for the work that made this possible.

General

3.50 The Scientific Committee noted:

(i) that MPAs were considered in relation to a definition as 'any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment' (Annex 7, paragraph 1);

(ii) that the discussion on MPAs was facilitated by a series of excellent contributions by CCAMLR Members and invited experts. These papers focused on MPAs in the conceptual sense, as well as in practice, both worldwide and within the CCAMLR Convention Area;

(iii) specific commendation for the framework used to establish the Australian national representative system of MPAs, which underpinned the establishment in the Convention Area of the Heard Island and McDonald Islands Marine Reserve (Annex 7, paragraph 122).

Review of advice from MPA Workshop

ToR (i) to review current principles and practices related to the establishment of MPAs

3.51 The Scientific Committee endorsed the advice that:

(i) there was a need to develop a strategic approach to MPA design and implementation throughout the Southern Ocean, notably in relation to a system of protected areas (Annex 7, paragraph 124);

(ii) there was a strong need for collaboration at technical and policy levels to further develop the MPA concept in the Southern Ocean. Relevant bodies in such a dialogue would include key elements of the Antarctic Treaty System (ATS)

(CEP and the ATCM) as well as SCAR, SCOR, Observers to CCAMLR, intergovernmental organisations and non-governmental organisations (Annex 7, paragraph 124).

3.52 The Scientific Committee agreed that the primary aim is to establish a harmonised regime for the protection of the Antarctic marine environment across the ATS. This may require clarification of the roles and responsibilities of the ATCM and CCAMLR in respect of the management of different human activities in the region (Annex 7, paragraph 125).

ToR (ii) to discuss how MPAs could be used to contribute to furthering the objectives of CCAMLR

3.53 The Scientific Committee noted that:

(i) Article II establishes the basic objective of CCAMLR as the conservation of Antarctic marine living resources (where conservation includes rational use) and sets out the principles by which harvesting and associated activities shall be carried out (Annex 7, paragraph 28);

(ii) Article IX further specifies the ways to give effect to the objective and principles of Article II. This article relates particularly to the development and use of conservation measures, specifically including the opening and closing of areas, regions or sub-regions for purposes of scientific study or conservation, including special areas for protection and scientific study (Annex 7, paragraph 29).

3.54 The Scientific Committee endorsed advice that:

(i) MPAs had considerable potential for furthering CCAMLR's objectives in applications ranging from protection of ecosystem processes, habitats and biodiversity, and protection of species (including population and life history stages) (Annex 7, paragraph 126);

(ii) overall, when viewed in relation to the IUCN categories of protected areas, that the Convention Area as a whole would qualify as Category IV (Habitat/Species Management Area: protected area managed mainly for conservation through management intervention). This is defined as an area of land and/or sea, subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species (Annex 7, paragraph 127);

(iii) conservation outcomes appropriate for achieving the objectives of Article II would include the maintenance of biological diversity as well as the maintenance of ecosystem processes (Annex 7, paragraph 129).

(iv) attention may need to be given to the need for, *inter alia*, protection of:

(a) representative areas – a system of representative areas would aim to provide a comprehensive, adequate and representative system of MPAs to contribute to the long-term ecological viability of marine systems, to maintain ecological processes and systems, and to protect the Antarctic marine biological diversity at all levels;

(b) scientific areas to assist with distinguishing between the effects of harvesting and other activities from natural ecosystem changes as well as providing opportunities for understanding the Antarctic marine ecosystem without interference;

(c) areas potentially vulnerable to impacts by human activities, to mitigate those impacts and/or ensure the sustainability of the rational use of marine living resources (Annex 7, paragraph 130);

(v) the process for establishing a system of protected areas will need to have regard for the objective of the Commission to achieve satisfactory fishery outcomes in terms of sustainable rational use (Annex 7, paragraph 132).

3.55 The Scientific Committee noted workshop views on the potential importance of making provision in protected area systems for the protection of spatially predictable features (such as upwellings and fronts) that are critical to the function of local ecosystems (Annex 7, paragraph 131).

3.56 Some Members expressed concern that such features and processes would need very careful definition in order to be relevant to, and applicable in, the approaches under consideration.

3.57 The Scientific Committee agreed to work toward developing a system of protected areas as set out in Annex 7, paragraphs 61 to 70, and summarised above. The general objectives for which protected areas may be established and the types of protection that could be given in accordance with Article IX are illustrated in Table 1. These types of areas could be applied anywhere within the Convention Area (Annex 7, paragraph 133).

3.58 The Scientific Committee noted that the terms used for these areas have meanings in other fora that differ from those used here. Further discussion is needed to consider the terms to be used for different types of protected areas (Annex 7, paragraph 135).

3.59 The Scientific Committee also noted that the 'Fisheries Closed Areas' are already considered by the Scientific Committee and Commission according to advice from working groups on individual fisheries.

ToR (iii) to consider proposals that are currently under development or in a conceptual phase that relate to MPAs in the Convention Area

3.60 The Scientific Committee noted that the workshop had received information on progress, relating to MPAs in the Convention Area currently under development or consideration, in respect of:

(i) Prince Edward Islands (WS-MPA-05/15)
(ii) Anvers Island, Antarctic Peninsula (WS-MPA-05/10)
(iii) Balleny Islands (WS-MPA-05/11, SC-CAMLR-XXIV/BG/25).

It noted the extensive discussion in respect of these topics (Annex 7, paragraphs 72 to 89 and 93 to 106).

3.61 Mr Pshenichnov informed the Scientific Committee that Ukraine is initiating research designed to identify the potential scope and extent of an MPA in the Argentine Islands (Antarctic Peninsula) (CCAMLR-XXIV/BG/19).

3.62 The Scientific Committee noted advice concerning elaboration of ATCM Decision 9 (2005) relating to guidelines for determining if an MPA will be of interest to CCAMLR (Annex 7, paragraphs 136 and 137).

3.63 It agreed that two approaches might assist in this:

(i) to request WG-EMM and WG-FSA to develop guidelines to indicate what percentage of the range of a known harvestable resource could be covered by protected areas within a statistical unit before CCAMLR would need to determine if a proposed protected area might impact on rational use;

(ii) to request each Member of CCAMLR to indicate which of the recent proposals from ATCM concerning protected areas with marine components should, in retrospect, have been required to be submitted to CCAMLR according to the criteria in ATCM Decision 9 (2005).

ToR (iv) to discuss the types of scientific information that may be required for the development of MPAs to further the objectives of CCAMLR, including the identification of biophysical regions across the Convention Area

3.64 The Scientific Committee endorsed advice that:

(i) key tasks needed to consider a system of protected areas to assist CCAMLR in achieving its broader conservation objectives are:

(a) a broad-scale bioregionalisation of the Southern Ocean;

(b) a fine-scale subdivision of biogeographic provinces, which may include hierarchies of spatial characteristics and features within regions, giving particular attention to areas identified in the bioregionalisation;

(c) identification of areas that might be used to achieve the conservation objectives;

(d) determination of areas requiring interim protection;

(ii) these tasks should involve an initial desktop study;

(iii) the types of data listed in Annex 7, Table 2, are those appropriate for this process (Annex 7, paragraphs 138 and 139).

3.65 The Scientific Committee endorsed the need for this process to be implemented:

(i) via a work program comprising the elements specified in Annex 7, paragraph 107 and in paragraph 3.66(3) below;

(ii) complemented by a workshop to advise on a bioregionalisation of the Southern Ocean, including, where possible, advice on smaller-scale delineation of provinces and potential areas for protection to further the conservation objectives of CCAMLR;

(iii) by establishing a Steering Committee, including members of the Scientific Committee and CEP. An important role of the Steering Committee will be to involve appropriate experts from outside the Scientific Committee and CEP with appropriate data or expertise (Annex 7, paragraphs 141 and 142).

3.66 The Scientific Committee endorsed the following terms of reference for the Steering Committee:

1. To facilitate collaboration between the CCAMLR Scientific Committee and CEP in this work.

2. To facilitate the involvement of appropriate experts in this work.

3. To coordinate and facilitate:

(i) collating existing data on coastal provinces, including benthic and pelagic features and processes;

(ii) collating existing data on oceanic provinces, including benthic and pelagic features and processes;

(iii) determining the analyses required to facilitate a bioregionalisation, including the use of empirical, model and expert data;

(iv) developing a broad-scale bioregionalisation based on existing datasets and other datasets possibly available prior to the workshop;

(v) delineating fine-scale provinces within regions, where possible;

(vi) establishing a procedure for identifying areas for protection to further the conservation objectives of CCAMLR.

4. To organise a workshop to establish a bioregionalisation for the CCAMLR Convention Area and to consolidate advice on a system of protected areas (Annex 7, paragraph 144).

3.67 It also endorsed the suggestion that CEP be invited to undertake the initial work necessary to develop a bioregionalisation of the coastal provinces, as an extension of its terrestrial bioregionalisation work, while the Scientific Committee undertakes the initial work needed to delineate the oceanic provinces. Such work would involve examination of both the benthic and pelagic systems in the respective areas (Annex 7, paragraph 143).

3.68 Notwithstanding this general agreement, Dr K. Shust (Russia) suggested that caution should be exercised in inviting outside experts and groups to attend CCAMLR workshops on this topic, believing that it would be more appropriate for these to be involved only in the intersessional correspondence and preparations for workshops and meetings.

3.69 Overall, the Scientific Committee recognised that the process summarised in paragraphs 3.64 to 3.67 has important implications in respect of budget, timetable, procedures and management.

3.70 It noted the advice of the MPA Workshop that the next workshop should be held in 2008 (Annex 7, paragraph 117). However, several Members felt that it was essential to make more rapid progress on such an important issue.

3.71 The Scientific Committee agreed that the workshop would be held independently from the working group meetings and a report provided directly to the Scientific Committee. It also agreed that the work of the Steering Committee be afforded a high priority. The Scientific Committee advised that, should the Steering Committee require preparatory meetings, it would be best for these meetings to occur in conjunction with other meetings that members of the Steering Committee may be attending, such as the meetings of the Scientific Committee or its working groups.

3.72 The Chair of the Scientific Committee was requested to consult with the Convener of the Subgroup on Protected Areas, and others as appropriate, to develop suggestions for membership of a Steering Committee and to circulate these to the Scientific Committee for approval. The Chair of the Scientific Committee was also requested to invite CEP to participate in the work of the Steering Committee and for it to nominate appropriate members.

3.73 The Commission was requested to endorse the work program, workshop and Steering Committee terms of reference outlined above. Advice was also requested on the priority (including timing) to be accorded to these undertakings (and specifically to the proposed workshop).

2. Extract from the 2006 CCAMLR Scientific Committee report relevant to Marine Protected Areas

REPORT OF THE TWENTY-FIFTH MEETING OF THE SCIENTIFIC COMMITTEE

HOBART, AUSTRALIA
23–27 OCTOBER 2006

Management of protected areas

3.29 In respect of ATCM Decision 9 (2005), the Scientific Committee recommended that, at least in the near future, all ATCM protected area proposals with marine components should continue to be provided to CCAMLR for review, unless they are clearly not required according to ATCM Decision 9 (Annex 4, paragraphs 5.11 and 5.12). In addition, to avoid potential confusion in the future, the Scientific Committee also recommended that standard terminology be adopted within CCAMLR to distinguish between 'ATCM draft management plans with marine components' and 'marine protected areas (MPAs)' *per se* (Annex 4, paragraph 5.8).

3.30 Co-conveners of the Bioregionalisation Workshop Steering Committee, Drs Penhale and Grant, presented an update on progress towards the 2007 CCAMLR Workshop on Bioregionalisation (SC-CAMLR-XXV/BG/24).

3.31 The Scientific Committee endorsed the Steering Committee's recommendation that its membership be expanded to include the conveners of the four Scientific Committee working groups and Dr W. Dinter (Germany), an additional member nominated by CEP.

3.32 Progress leading to the 2007 Bioregionalisation Workshop included several years of discussion on MPAs at WG-EMM, followed by the 2005 CCAMLR Workshop on MPAs, held in Silver Spring, USA (SC-CAMLR-XXIV, Annex 7). In 2006, the Bioregionalisation Workshop Steering Committee was formed. The 2007 workshop is viewed as a next step in the progression of endeavours leading to the establishment of a system of MPAs harmonised for the protection of the Antarctic marine environment across the Antarctic Treaty System.

3.33 Two separate components of work to be undertaken towards the development of a system of MPAs for the Convention Area were identified:

(i) technical development of methods for bioregionalisation of the Southern Ocean
(ii) consideration of methods for selection and designation of MPAs.

3.34 The focus of the 2007 Bioregionalisation Workshop will be on component (i). The aim of the workshop is to advise on a bioregionalisation of the Southern Ocean, including, where possible, advice on fine-scale subdivision of biogeographic provinces. Work on component (ii) should proceed in parallel, with submission of papers to either the Scientific Committee or its working groups. It is anticipated that further work towards the development of methods for the selection and designation of MPAs will be progressed by the Scientific Committee.

3.35 The Scientific Committee was invited to consider how individuals might contribute in advising on, and undertaking, the tasks outlined in SC-CAMLR-XXV/BG/24 in preparation for the 2007 workshop. These tasks include:

(i) identification and collation of relevant datasets which will be of use in the workshop analysis;

(ii) further development of a program of work to be undertaken during the workshop;

(iii) review of existing bioregionalisation methods and approaches;

(iv) undertaking fine-scale bioregionalisation analysis for areas of interest, particularly areas for which data are available.

3.36 Members were also encouraged to identify experts who might participate in the 2007 Bioregionalisation Workshop.

3.37 Papers addressing the topics identified in paragraph 3.35 should be submitted to the 2007 Bioregionalisation Workshop, in particular to provide reviews and background information on existing bioregionalisation methods and potential data sources.

3.38 Prof. J. Beddington (UK) noted that a bioregionalisation analysis may need to consider the effects of climate change, and that the results may need to be updated if and when new information becomes available.

3.39 Dr Constable noted that the methods adopted to undertake the bioregionalisation should be able to be used in the future to update the bioregionalisation if and when new information becomes available. He also noted that, with respect to climate change, the data from scenarios used by the Intergovernmental Panel on Climate Change could be used to explore how robust the bioregionalisation might be to changes arising from climate change.

3.40 Dr K. Shust (Russia) noted that Russia had considerable expertise in bioregionalisation based on analysis of data on the composition of fish fauna. This work resulted in the identification of eight ichthyo-geographic zones. He noted that other Members might contribute review papers based on biological, oceanographic and climatic data which would provide a basis for bioregionalisation.

3.41 Dr Constable noted that digital maps of existing bioregionalisations would be of particular value to the workshop, to allow comparison of the results of different approaches. Datasets used in the development of existing bioregionalisation work should also be made available to the workshop, in synoptic form where possible, to allow comparison with other datasets.

3.42 Prof. Moreno noted the importance of including data on the distribution of fishing effort, in order to identify areas that might be considered in the development of a system of MPAs.

3.43 The Scientific Committee congratulated the Bioregionalisation Workshop Steering Committee on its progress to date, noting its contribution to the aim to establish a harmonised regime for the protection of the Antarctic marine environment across the Antarctic Treaty System (CCAMLR-XXIV, paragraph 4.12).

3.44 Dr Constable presented SC-CAMLR-XXV/BG/7 on the outcomes of an independent Experts Workshop on Bioregionalisation of the Southern Ocean, held in Hobart, Australia, in September 2006. This workshop was hosted by WWF-Australia and the Antarctic Climate and Ecosystems Cooperative Research Centre (Hobart), and supported by Peregrine Adventures. The workshop was attended by 23 experts in their independent capacity. Members of the Bioregionalisation Workshop Steering Committee were invited to participate in the workshop, however only a few members were able to attend.

3.45 The aim of the Experts Workshop was to develop a proof of concept for a bioregionalisation of the Southern Ocean, to assist the Scientific Committee in its work on this topic.

3.46 The workshop addressed three main areas:

(i) data to be incorporated in a bioregionalisation (using physical and environmental data, including sea-ice, oceanographic characteristics and surface chlorophyll, as the primary input);

(ii) development of a statistical method for bioregionalisation, based on an approach previously presented at WG-EMM (Annex 4, paragraph 5.17), work by CEP (Environmental Domains analysis), and work by Australia and New Zealand for their respective EEZs;

(iii) expert review of the bioregionalisation outcomes based on existing knowledge of the Southern Ocean.

3.47 A method was agreed which incorporated aspects of the four approaches listed in paragraph 3.46(ii). This method integrates a statistical approach with expert knowledge, and was successful in bringing together appropriate datasets. The ease with which additional data can be included using this method was also noted.

3.48 The primary regionalisation results corresponded with existing knowledge of frontal systems in the Southern Ocean, and also identified other features, such as the Weddell Gyre, the Scotia Arc and the Kerguelen Plateau. A secondary regionalisation introduced data on sea-ice and chlorophyll, and highlighted the heterogeneity of the coastal, shelf and seasonal sea-ice areas.

3.49 The workshop made substantial progress towards a method that could be used to undertake a bioregionalisation of the Convention Area, and established a proof of concept. Further work should focus on the introduction of other (particularly biological) datasets, and finer-scale analysis for particular areas of interest.

3.50 Dr Naganobu noted that the results of the Experts Workshop were important not only for fisheries management but also for Southern Ocean science.

3.51 The Scientific Committee congratulated the experts' group on its efforts, and welcomed the outcomes of the Experts Workshop. It was noted that this type of review has relevance not only for the work of the Scientific Committee, but also in a wider context.

3.52 Dr H.-C. Shin (Republic of Korea) enquired how temporal variation could be incorporated into a bioregionalisation. Dr Constable responded that the use of average values over long time series (e.g. for synoptic satellite data) was the approach used at the Experts Workshop for incorporating a temporal component into the analysis, but that variation over both short and longer time-scales should be considered further. He noted that temporal characteristics can be incorporated into a bioregionalisation in other forms such as through measures of variability or as proportions of time that particular conditions might be met.

3.53 Dr Grant introduced SC-CAMLR-XXV/BG/19 on the potential for the achievement of MPAs using CCAMLR conservation measures. This paper noted that it is important for the Scientific Committee to identify the most appropriate tools for the achievement of MPA objectives. These could include existing area-based conservation and management tools such as closed areas, as well as other geographically defined regulations. It was further noted that ongoing efforts to define appropriate tools for the development of protected areas will contribute to component (ii) of the work identified in paragraph 3.33, which should proceed in parallel to the bioregionalisation work.

3.54 ASOC introduced SC-CAMLR-XXV/BG/30 on achieving a network of MPAs in the Convention Area. ASOC welcomed the discussions on MPAs and bioregionalisation, and expressed its desire to continue participating in work on this topic.

3.55 Belgium expressed its keen interest in supporting the efforts of CCAMLR towards the creation of a network of MPAs and noted that bioregionalisation is a crucial step in the process. In this regard, Belgium offered to host the 2007 Bioregionalisation Workshop in Brussels during the first or second week in August. The Scientific Committee welcomed and endorsed Belgium's offer and looked forward to a productive workshop.

Advice to the Commission

3.56 The Scientific Committee endorsed the Steering Committee's recommendation that its membership be expanded to include the conveners of the Scientific Committee working groups and Dr Dinter, an additional member nominated by CEP.

3.57 The Scientific Committee welcomed and endorsed Belgium's offer to host the Bioregionalisation Workshop in Brussels, in August 2007.

3. Extract from the 2007 CCAMLR Scientific Committee report relevant to Bioregionalisation

REPORT OF THE TWENTY-SIXTH MEETING
OF THE SCIENTIFIC COMMITTEE

HOBART, AUSTRALIA
22–26 OCTOBER 2007

Workshop on Bioregionalisation

3.71 The Report of the Workshop on Bioregionalisation of the Southern Ocean (Annex 9) was introduced by the Workshop Co-convener, Dr Grant. The Workshop on Bioregionalisation was held from 13 to 17 August 2007 in Brussels, Belgium. The Workshop report contains technical details on data, methods and results, as well as an Executive Summary compiled by the Workshop Co-conveners. The Scientific Committee thanked Belgium for the opportunity to progress this work and for hosting such an excellent meeting.

3.72 The primary aim of the Workshop was to advise on a bioregionalisation of the Southern Ocean, including, where possible, advice on fine-scale subdivision of biogeographic provinces (SC-CAMLR-XXV, paragraph 3.34) (Annex 9, paragraphs 10 and 11). The Workshop was organised around two subgroups considering the benthic and pelagic systems separately.

3.73 The Workshop considered available bathymetric, physical oceanographic and biological data for the pelagic bioregionalisation (Annex 9, paragraphs 39 to 64). Biological datasets considering spatial attributes of different areas were also considered, and it was determined that some of these datasets might be most appropriately used at the regional scale. Data from the Continuous Plankton Recorder (CPR) Survey, and SCAR-MarBIN were recognised as having particular value to bioregionalisation.

3.74 For the benthic bioregionalisation, the Workshop agreed that data on bathymetry, seafloor temperature and currents, geomorphology, sediments and sea-ice concentration are important. Regarding biological datasets available for the benthic bioregionalisation, the Workshop noted that for the most part, biological data are restricted to shelf areas. Data considered for inclusion in the analysis included data on benthic invertebrates from the SCAR-MarBIN network, as well as presence/absence data on demersal finfish from SCAR-MarBIN and the CCAMLR database (Annex 9, paragraphs 69 to 80).

3.75 The Workshop endorsed the general methodology used to provide a broad-scale pelagic regionalisation from the 2006 Hobart Workshop (SC-CAMLR-XXV, paragraphs 3.44 to 3.49). It was agreed that, at the broad scale, the primary bioregionalisation result from the 2006 Hobart Workshop was a good working product that could be used to inform spatial management of the Convention Area (Annex 9, paragraphs 94 and 95).

3.76 The Workshop agreed that the broad-scale pelagic regionalisation could potentially be enhanced (Annex 9, paragraph 96). Five methods of how biological data could be used to enhance the bioregionalisation were discussed (Annex 9, paragraphs 97 to 121). These included Species Habitat Modelling and the Boosted Regression Trees (BRT) method for modelling single-response variables using several environmental predictors.

3.77 The approach to a benthic bioregionalisation consisted of a three-step process, by which physical regions were first defined using the process employed by the 2006 Hobart Workshop. The biological data were then overlaid, and the classification evaluated. Further work on this classification was undertaken after the Workshop by workshop participants, using the methods described above, and incorporating additional data that was not available at the Workshop. The results of this work are described in SC-CAMLR-XXVI/BG/28.

3.78 The Workshop endorsed the broad-scale primary regionalisation result produced by the 2006 Hobart Workshop.

3.79 The Workshop was supportive of the potential for the BRT method to produce biological data layers for broad-scale and fine-scale bioregionalisation, and it was suggested that the method be submitted for technical review by WG-SAM. It was also suggested that WG-EMM and WG-FSA could be asked to review the appropriateness of the datasets to be included as response variables (biological data) and those for inclusion as environmental layers (Annex 9, paragraphs 140 to 144).

3.80 The results of the benthic bioregionalisation (Annex 9, paragraphs 145 and 146) were updated after the Workshop, to include additional physical data unavailable at the Workshop, and further evaluation of biological data layers (SC-CAMLR-XXVI/BG/28). These results show that there will be a greater heterogeneity in benthic biodiversity and ecosystem structure and function at finer scales.

3.81 A geomorphic map of the East Antarctic margin showed some key features relevant to benthic bioregionalisation, including shelf banks, depressions, steep slope areas, canyons, sediment mounds, seamounts, fracture zones and abyssal plain areas (Annex 9, paragraphs 149 to 156). Further work to extend this geomorphic classification to other areas is presented in SC-CAMLR-XXVI/BG/27.

3.82 The Workshop noted that in providing a framework for understanding spatial structure and function of ecosystems it is important to consider both biodiversity pattern information and spatially defined ecological processes (Annex 9, paragraphs 157 to 164). This can be of assistance to a spatial decision-making framework, which was used in developing the conservation plan for the Prince Edward Islands. The Workshop endorsed the approach to develop maps representing ecological processes and other features that cannot easily be incorporated into an analysis of spatial patterns.

3.83 It was noted that ecological processes can be mapped spatially in two ways:

(i) flexible processes can be mapped using spatial probability data (e.g. kernels)
(ii) fixed processes can be mapped using fixed features that define the process (e.g. geomorphic features).

3.84 The Scientific Committee endorsed the outcomes of the Workshop, as well as the follow-up work described in SC-CAMLR-XXVI/BG/27 and BG/28. It welcomed this work noting it can be used to inform spatial management, and is a primary foundation for understanding the biological and physical heterogeneity in the Southern Ocean.

3.85 The Scientific Committee endorsed the recommendations of the Workshop for further work on this topic (Annex 9, paragraphs 165 to 168):

(i) The primary regionalisation for the pelagic environment can be regarded as useful for application by CCAMLR and CEP. It was agreed that the initial regionalisation for the benthic environment should be reviewed and optimised for use by CCAMLR and CEP.

(ii) Refinements to this bioregionalisation could be made in the future as methods are improved and data acquired and analysed. Further finer-scale bioregionalisation work could be undertaken in a number of areas based on existing data.

(iii) Future work could include efforts to delineate fine-scale provinces, where possible. It was recommended that participants should submit papers to the Scientific Committee on approaches to fine-scale regionalisation, including on statistical methods and potential data sources. It was further recommended that WG-SAM should be requested to consider the statistical methods presented in Annex 9, paragraphs 140 and 141.

(iv) The inclusion of process and species information could also be considered further, particularly in the context of systematic conservation planning, and in developing a spatial decision-making framework (Annex 9, paragraph 157). This may be particularly applicable at finer scales.

3.86 It was also noted that the final term of reference agreed for the Workshop Steering Committee (to establish a procedure for identifying areas for protection to further the conservation objectives of CCAMLR) (Annex 9, Appendix A) had not been addressed in detail at the Workshop, and it was agreed that this should therefore be taken forward as an outstanding topic for consideration in further work.

3.87 The Scientific Committee agreed that the further work described in paragraphs 3.85 and 3.86 should be undertaken within the context of WG-EMM, given the existing focus within that Working Group on issues relating to Southern Ocean ecosystems and spatial management. It was recommended that Members should submit papers to WG-EMM on these topics listed in paragraphs 3.85 and 3.86, and that a new WG-EMM agenda item should be created to facilitate consideration of this work. This new agenda item should maintain flexibility in order to respond to future requests for work on this topic and other related issues.

3.88 Dr Gilbert warmly welcomed the achievements of the Workshop, and informed the Scientific Committee that he would circulate the full Workshop report to CEP Members. As a point of interest, he further noted that the Environmental Domains Analysis undertaken by CEP as a biogeographic classification system for terrestrial Antarctica had provided a useful framework for the development of a terrestrial protected area system, as well as having broader benefits for research, monitoring and reporting.

3.89 Prof. Fernholm noted the relevance of the Workshop outcomes to the recent CBD Experts Workshop on ecological criteria and biogeographic classification systems for marine areas in need of protection, and asked whether there had been any input from CCAMLR to this process. Dr Constable confirmed that some of the discussion points from both the 2007 Workshop on Bioregionalisation and the 2006 Hobart Workshop had been conveyed to the CBD meeting, and that the outcomes of this meeting, when available, may be of interest to the Scientific Committee.

4. Extract from the 2008 CCAMLR Working Group on Ecosystem Monitoring and Management report relevant to Protected Area Management

REPORT OF THE CCAMLR WORKING GROUP ON ECOSYSTEM MONITORING AND MANAGEMENT

ST. PETERSBURG, RUSSIA
23 JULY – 1 AUG 2008

FOCUS TOPIC: DISCUSSION TO PROGRESS THE IMPLEMENTATION OF SPATIAL MANAGEMENT MEASURES THAT AIM TO FACILITATE THE CONSERVATION OF MARINE BIODIVERSITY

Background

3.1 Dr Penhale, as chair of this focus topic, presented the Working Group with a review of the development of progress on the topic of area protection and the development of candidate MPAs by CCAMLR.

3.2 The Working Group recalled that during the early 2000s, the work of the Subgroup on Designation and Protection of CEMP Sites had expanded in scope to include the review of management plans containing marine areas that are submitted to CCAMLR for approval. In 2002 this subgroup was renamed as the 'Advisory Subgroup on Protected Areas' (CCAMLR-XXI, paragraph 4.17). In 2003 the revised terms of reference of this subgroup were endorsed by the Commission (CCAMLR-XXII, paragraph 4.26), and included providing advice on the implementation of MPAs that may be proposed in accordance with provisions of Article IX.2(g) of the Convention.

3.3 In 2004 the Commission addressed the topic of MPAs and urged the Scientific Committee to proceed with this work as a matter of priority. It also reaffirmed the need to develop advice on MPAs commensurate with Articles II and IX of the Convention (CCAMLR-XXIII, paragraph 4.13). This was followed by the 2005 CCAMLR Workshop on Marine Protected Areas (SC-CAMLR-XXIV, Annex 7), held in the USA. The objectives of this workshop included a discussion of how the establishment of MPAs could be used to contribute to furthering the objectives of CCAMLR, including conservation and rational use.

3.4 In 2005 the Commission endorsed the Scientific Committee's advice arising from the 2005 CCAMLR Workshop, agreeing that the primary aim was to establish a harmonised regime for the protection of the Antarctic marine environment across the Antarctic Treaty System (CCAMLR-XXIV, paragraph 4.12). It was recognised that both CCAMLR and the CEP (through Article V of the Protocol on Environmental Protection to the Antarctic Treaty) have interest in protected areas. The Commission also endorsed the Scientific Committee's work plan to hold a workshop to advise on a bioregionalisation of the Southern Ocean, including a fine-scale subdivision of biogeographic provinces (CCAMLR-XXIV, paragraph 4.17).

3.5 Plans for the Bioregionalisation Workshop progressed in 2006, including the establishment of a Steering Committee comprising members from CCAMLR and the CEP (CCAMLR-XXV, paragraph 6.1). Additionally, the Commission commented that the Bioregionalisation Workshop would be an important step in the Commission's activities to develop a representative network of MPAs (CCAMLR-XXVI, paragraphs 6.1 to 6.6). The 2007 Workshop on Bioregionalisation of the Southern Ocean was held in Brussels (SC-CAMLR-XXVI, Annex 9).

3.6 The Working Group noted that this workshop considered available bathymetric, physical oceanographic and biological data, and that benthic and pelagic systems were considered separately. The Working Group noted that the Scientific Committee had endorsed the outcome of the workshop, noting that it can be used to inform spatial management and is a primary foundation for understanding the biological and physical heterogeneity in the Southern Ocean (SC-CAMLR-XXVI, paragraph 3.71 to 3.89). The Commission endorsed the recommendations for future work on bioregionalisation and noted the Scientific Committee's view that further work should be undertaken within the context of WG-EMM, given the existing focus within that Working Group on issues relating to Southern Ocean ecosystems and spatial management (CAMLR-XXVI, paragraphs 7.18 and 7.19).

3.7 The Working Group noted the advice of the Scientific Committee with respect to the application of the BRT method toward further refinement of Southern Ocean bioregionalisation (SC-CAMLR-XXVI, paragraph 14.4(iv)), which was further explored during WG-SAM-08.

3.8 Dr Hanchet summarised the WG-SAM discussions with respect to BRTs, (SC-CAMLR-XXVII/5, paragraphs 4.13 to 4.19). The Working Group encouraged work to further develop the application of this method, which may be applicable in further work on bioregionalisation.

3.9 Dr Constable was concerned that the use of common species with the BRT approach might not be useful, and that extrapolating outside the geographic range may not be appropriate due to issues surrounding endemism.

3.10 Dr Grant questioned whether data layers from the BRT analysis should be incorporated into the current bioregionalisation maps, or used as separate layers providing information on individual species where available.

3.11 The Working Group agreed that the existing benthic and pelagic bioregionalisations were adequate, although further refinement may be undertaken as more data layers and products become available.

3.12 Dr Holt noted that data around the Southern Ocean remain relatively sparse, and that it is important to recognise the quality and quantity of data with respect to the various regions, particularly when predictive methods are used to infer data-sparse regions. Dr Siegel noted the importance of data coverage at large spatial scales.

3.13 With respect to benthic bioregionalisation, Dr Constable noted that there is a great degree of endemism and heterogeneity, and that the existing bioregionalisation is likely to be adequate for the purposes of CCAMLR. With respect to the pelagic realm, he felt that the work that has been conducted is also sufficient.

3.14 The Working Group noted that it was important that bioregionalisation incorporate not only species information, but structure and function of species assemblages as well.

3.15 Dr Grant noted that there are some aspects of ecosystem function that may not be amenable to being captured in a bioregionalisation.

3.16 The Working Group agreed that it is very difficult to include all aspects into a single bioregionalisation map, and that such information on species distributions and ecosystem processes may be more appropriately utilised as separate data layers, for example as may be used in a systematic conservation planning process.

3.17 Dr Naganobu agreed that the topic is highly complex, and that it is currently in a relatively early stage relative to terrestrial bioregionalisation studies. He noted that there are still great uncertainties with respect to basic environmental indices in the Southern Ocean, and that more research should be directed toward basic tasks to better elucidate these indices.

3.18 Dr Constable noted that the existing bioregionalisation maps could be used to help identify areas of interest. Although these areas of interest may change in character over time, they are unlikely to change significantly in their location. Bioregionalisation maps could therefore be used to highlight key areas in which small-scale patterns could then be investigated further. Dr Holt noted the importance of establishing criteria for the identification of areas of interest.

3.19 Dr Spiridonov noted that other schemes of bioregionalisation can be interpreted in terms of oceanographic boundaries. He drew attention to a publication written by a physical oceanographer (Maslennikov, 2003) that has been produced in Russian. He indicated that it may be valuable in better constructing a bioregionalisation of the Southern Ocean. He inquired as to the possibility of having the book translated, so that it would be more useful for the Working Group as a whole.

3.20 The Working Group agreed that this publication could provide valuable additional insights into factors that influence bioregionalisation and encouraged Russia to pursue mechanisms to have the book translated into English.

Identifying vulnerable marine ecosystems

3.21 The Working Group noted Conservation Measure 22-06 and recalled that the working groups were tasked by the Scientific Committee to collaborate in work that includes methods to identify VMEs, develop operational definitions of what constitutes significant harm to VMEs and mitigate impacts (SC-CAMLR-XXVI, paragraph 14.9). There were three papers tabled for consideration towards addressing these topics.

3.22 WG-EMM-08/37 presented a risk management framework for avoiding significant adverse impacts of bottom fishing gear on VMEs. This approach is proposed for implementing the requirements of Conservation Measure 22-06 and based on the discussion by the Scientific Committee last year. The framework is similar to that used by ad hoc WG-IMAF to minimise the risk of longline mortality on seabirds. The framework has three parts:

(i) Risk analysis –

Evaluation of

(a) current and proposed fishing activities in specified area including method and footprint (spatial and temporal extent, frequency);

(b) evidence of potential VMEs in an area of proposed fishing activity, with associated uncertainty;

(c) expected scale of interactions between fishing activities and VMEs, with associated uncertainty;

(d) possible impact of interactions on VMEs, with associated uncertainty;

(e) potential for recovery of VMEs following fishing disturbance, with associated uncertainty.

(ii) Options to eliminate risk –

Management options will be evaluated for the degree to which the risks will be reduced. Such options could include specific at-sea activities based on operational indicators and by-catch or spatial management. Research activities will be specified, when needed, to help identify suitable alternatives for eliminating risk and/or to evaluate the effectiveness of specific management options.

(iii) Review –

This aims to determine whether the measures for eliminating risk need to be updated, revised and/or supplemented. The plans for reviews would include timelines and the data requirements for undertaking such reviews.

3.23 In support of the risk analysis, WG-EMM-08/37 proposed the use of a risk analysis matrix, which relates the qualitative likelihood of an interaction with VMEs and the qualitative and semi-quantitative consequence of the impact of bottom fishing on VMEs. The paper noted that this matrix allows for gear- and operation-specific consideration of what might be vulnerable, knowing that taxa and habitats will have different vulnerabilities depending on the types of gear and the scale of the fishing operations. Importantly, consideration needs to be given to whether species and habitats have low resistance and/or low resilience to disturbance caused by fishing activities.

3.24 WG-EMM-08/37 also used publicly available databases, including SCAR MarBIN, to begin the development of a CCAMLR-specific guide to categories of VMEs and associated qualitative life-history characteristics of benthic taxa in the CAMLR Convention Area.

3.25 The Working Group agreed that a risk analysis framework represents a sensible approach to implementing Conservation Measure 22-06, and thanked the author for tabling this paper for consideration by WG-EMM. It recommended the author continue developing this approach, along with other interested members, for use by WG-FSA.

3.26 The Working Group recalled that the endorsed aim for managing interactions with non-target species was, in order of priority (SC-CAMLR-XXII, paragraphs 4.135 and 4.136 and Annex 5, paragraph 5.230):

(i) avoidance
(ii) mitigation
(iii) catch limits.

3.27 The Working Group noted that the vast majority of Antarctic benthic invertebrate species exhibit slower growth rates and longer life spans than their global counterparts. Further, different parts of the Southern Ocean are likely to exhibit different benthic properties, processes and disturbance regimes, and these should be considered and integrated into the risk framework. As a consequence, further precaution may be required in managing bottom fisheries between different areas of the Southern Ocean.

3.28 The Working Group noted that specific longline gear configuration (e.g. Spanish system, dropline, trotline) will most likely result in differences in the degree of interaction with the seabed, as was indicated by TASO (SC-CAMLR-XXVII/BG/6, paragraph 2.10). These factors should be further explored at the 2008 meeting of WG-FSA. The Working Group recommended that strategies used to limit the impact of gear types on benthos and benthic communities, such as the current requirement that longline gear deployments in some exploratory fisheries be limited to depths greater than 550 m, could be further explored. The Working Group indicated that by-catch information from longlines using different configurations could be useful toward identifying VMEs.

3.29 Mr B. Weeber (New Zealand) informed the Working Group that New Zealand held a workshop on VMEs as part of its notification process for fishing in the Ross Sea in the 2008/09 season. A report of this workshop, along with a proposed definition of

VMEs and preliminary assessment of potential impact by the longline fishery for *Dissostichus* spp. by the New Zealand fishery in the Ross Sea, will be included in their notification and presented at the upcoming meeting of WG-FSA.

3.30 The Working Group agreed that Antarctic benthic invertebrate ecosystems have not historically been on the agendas of WG-EMM and WG-FSA.

3.31 Dr Jones noted that it is important to begin a process for reducing the uncertainty in our knowledge on the types of taxonomic groups and habitats that may be vulnerable to CCAMLR bottom fisheries. He also noted that there are a number of publications and individual databases that might help in this regard, such as numerous records of gorgonian or antipatharian communities in the Southern Ocean (Barry et al., 2003). He proposed that a workshop be held to help bring these data together, and to provide guidance on the following points that are necessary to reduce uncertainty on the potential for CCAMLR bottom fisheries for causing significant adverse impacts on VMEs:

(i) vulnerability of Southern Ocean benthic taxa to CCAMLR bottom fisheries;

(ii) characterisation of habitats and habitat-forming taxonomic groups and rare taxa that would be consistent with a VME, including methods for assisting in identifying the extent of habitats based on distributions and densities of habitat-forming taxonomic groups;

(iii) methods for identifying potential locations of vulnerable taxa;

(iv) indicators that could be used by fishing vessels to signal when they are fishing on VMEs;

(v) quality of available data, such as in the SCAR MarBIN database, for this purpose.

3.32 Dr Jones also proposed that the workshop be held under the auspices of CCAMLR and include Antarctic benthic invertebrate specialists.

3.33 The Working Group agreed that a workshop of this nature is urgently needed, and should include benthic invertebrate specialists, gear specialists, scientific observers and other key CCAMLR scientists. Such a workshop could be held in conjunction with TASO, WG-FSA, or under alternative arrangements. In addition to information collected through research expeditions on potential locations of VMEs, the Working Group agreed that information collected by observers on invertebrate by-catch would be critical for the workshop to evaluate the levels of interaction between demersal fishing gears and benthic habitats in the Convention Area.

3.34 WG-EMM-08/38 presented a notification of two VMEs that were detected within Division 58.4.1, SSRU H. Evidence is based on direct video observation during the CEAMARC-CASO cruise conducted from December 2007 to January 2008. Camera transects were <2 n miles apart; thus, there is some degree of uncertainty associated with the extent of the VME. The paper suggested a buffer zone of 5 n miles around the observed area to mitigate the effect of spatial inaccuracy. Included in WG-EMM-08/38 is a proposed pro forma that could be used to notify the Scientific Committee and working groups when a VME is detected. The pro forma includes elements that detail the type of VME, the evidence used to detect the VME, the location of observations and the data repository.

3.35 Dr Naganobu questioned whether the content of the notification in WG-EMM-08/38 was meant to proceed directly into a conservation measure. He was concerned that the process of notifying the presence of a VME in the Convention Area is overly simplified, and felt that only video/photo observations are not strong enough evidence. He felt that the information contained in WG-EMM-08/38 was preliminary and the observations should be recorded as initial information.

3.36 Some Members indicated that these notifications are part of the obligations of Members under Conservation Measure 22-06. Dr Constable noted that the notifications provide the detail of the locations of two VMEs and a suggested strategy for ensuring fishing does not cause significant adverse impacts on them. The Working Group also noted that it was the responsibility of the Commission for deciding on the management of VMEs.

3.37 Dr Jones noted that there are potentially three methods of detecting VMEs in the Southern Ocean: direct, indirect and predicted (WG-EMM-08/37), with ‘direct’ providing the strongest evidence. He felt that the information provided in WG-EMM-08/38 represented direct, clear indications of the presence of two VMEs in Division 58.4.1, SSRU H.

3.38 The Working Group endorsed the approach of providing information on a potential VME outlined in WG-EMM-08/38. This information could potentially be used to update the VME registry that was adopted by the Scientific Committee. The Working Group noted that the method for approval of adding a VME to the VME registry identified in Conservation Measure 22-06 would need to be further considered by the Scientific Committee.

3.39 WG-EMM-08/18 provided an overview of the New Zealand IPY-CAML survey of the Ross Sea region of Subarea 88.1 that was conducted in February–March 2008. The paper described the benthic survey of distribution and abundance of benthic assemblages for shelf, slope, seamount and abyssal sites in the Ross Sea region by means of sled, beam trawl, video transects and multicorer. The paper noted that the results of this benthic sampling will be useful for better understanding the distribution and abundance of benthic invertebrates found in VMEs. The authors noted that, combined with physical data, this may be useful for prediction of other areas where VMEs may occur. A summary report of the distribution of benthic invertebrates found in VMEs collected during this and previous surveys will be prepared for the 2008 meeting of WG-FSA.

3.40 Dr Jones noted that modelling approaches, such as the BRT method, may be useful for predicting where VMEs may exist within the Ross Sea outside of where the survey sampled.

3.41 Dr Constable emphasised the urgency to adopt and refine methods that can be used to ensure that risks to VMEs are reduced so that future fishing activities do not adversely impact VMEs, given that damaged VMEs will likely take a long time to recover, and that the cumulative effects of fishing will increase the risk of damaging VMEs. The Working Group agreed that cumulative impacts are very important, and that the rate of regeneration of the taxa that comprise VMEs is likely to be on a very long time scale.

3.42 Dr Spiridonov noted that the impact of bottom longlining is very poorly understood, and although documenting by-catch is important, the Working Group should also be concerned about the quality of the information. He suggested that photographs of benthic by-catch should be taken by observers.

3.43 The Working Group noted that the information on invertebrate by-catch contained in the CCAMLR database is generally at a variable level of taxonomic resolution and may be of limited value with respect to identifying potential VMEs.

3.44 The Working Group agreed on the need to establish levels of appropriate taxonomic groupings, including those that are considered vulnerable, to inform scientific observers as to the appropriate level of sampling. The Working Group noted that there are taxonomic guides being developed for Southern Ocean observers, and some of these should be available for review at WG-FSA.

Defining candidate marine protected areas

3.45 The Working Group recalled that recent discussions by CCAMLR and the CEP have concluded that the issues of where and how to establish a system of marine areas for the conservation of biodiversity in the Southern Ocean should be addressed as a matter of priority (CCAMLR-XXIII, paragraph 4.13; CEP, 2006, paragraphs 94 to 101).

3.46 Recent work on this topic has addressed a number of theoretical aspects, including bioregionalisation analysis (SC-CAMLR-XXVI, Annex 9), the potential for using conservation measures to achieve protection of marine biodiversity (SC-CAMLR-XXV/BG/19), and the definition of criteria for selecting areas for protection (SC-CAMLR-XXVI/BG/24).

3.47 The Working Group noted that a number of methods could be used for designing a representative system of MPAs, including, *inter alia*, bioregionalisation, and ‘systematic conservation planning’.

3.48 The Working Group considered the attributes of a process based on systematic conservation planning. In 2007 the Bioregionalisation Workshop had highlighted systematic conservation planning as an appropriate process by which important areas for conservation could be selected and designed (SC-CAMLR-XXVI, Annex 9). This process requires the definition of conservation objectives and uses spatial information on biodiversity patterns, ecosystem processes and human activities to identify the areas that should be included within a protected-area system in order to achieve the defined objectives.

3.49 Dr Trathan introduced WG-EMM-08/49 which provided a worked example of how the systematic conservation planning methodology might be applied in identifying important areas for conservation in the pelagic environment, using Subarea 48.2 (South Orkney Islands) as a pilot study area. The aim of WG-EMM-08/49 was not to identify areas for protection or management at this stage, but rather to test the utility of this methodology, and to demonstrate the types of data and the range of decisions that would be required to undertake such an analysis.

3.50 WG-EMM-08/49 demonstrated that systematic conservation planning is an objective and transparent methodology that assists in the identification of options for spatial protection of biodiversity and other valuable features. The systematic conservation planning process can be summarised into six stages:

(i) define the planning region (broad area of interest in which the study will be undertaken), and divide this into a grid of ‘planning units’;

(ii) compile relevant ecological data relating to the biodiversity of the planning region;

(iii) set conservation targets;

(iv) review existing conservation areas within the planning region;

(v) select additional conservation areas;

(vi) implement conservation actions.

3.51 WG-EMM-08/49 used MARXAN software to focus on steps (i) to (v) of the above process, and provided an illustration of how important marine areas for conservation might be identified using currently available data. Step (vi) was not considered as part of this study.

3.52 The Working Group noted that MARXAN software has been widely used for systematic conservation planning in a range of habitats worldwide.

3.53 The Working Group noted that, for using MARXAN, it is important to consider a combination of objectives, and not simply individual species or habitats. It noted that the use of MARXAN aims to optimise all conservation objectives at a minimum cost and that costs can be evaluated in a variety of units; potentially these could include such metrics as habitat area, financial cost or CPUE. The analysis described in WG-EMM-08/49 aimed to achieve all of the conservation objectives set in the pilot study in the smallest possible area, thus looking for areas in which more than one conservation objective can be met in the same location.

3.54 The Working Group noted that the results described in WG-EMM-08/49 are largely consistent with expected outcomes based on existing knowledge of the ecological processes in the study region. It therefore concluded that important pelagic areas for conservation could be identified using the methodology described in this pilot study, and on the basis of currently available information.

3.55 The Working Group noted that the systematic conservation planning approach requires data on a range of species and ecological processes, and that input is needed from scientific experts to define which datasets, and which parameters, are most appropriate for inclusion in the analysis. If required, data on human activities such as scientific research activities, fishing and tourism, could be incorporated. However, the Working Group recognised that the spatial distribution of existing human activities may change in the future and therefore a strategic network of representative MPAs should not simply consider those areas where existing human activities are ongoing.

3.56 The Working Group noted that a critical step in systematic conservation planning was the development of appropriate conservation objectives, and that this must be done on a scientific basis with input from appropriate experts as far as possible. The Working Group agreed that if systematic conservation planning were to be used, then conservation objectives would need to be developed in light of the objectives set out by the 2005 CCAMLR Workshop (SC-CAMLR-XXIV, Annex 7). Such objectives would also need to take into account criteria defined by Annex V to the Protocol on Environmental Protection.

3.57 WG-EMM-08/49 focused on the pelagic environment as an example, however the Working Group agreed that it would be valuable to undertake similar analyses for the benthic environment. Once this has been completed, pelagic and benthic results could feasibly be considered together, to identify areas that may be important for conservation in both environments.

3.58 The Working Group noted that the outcomes from a systematic conservation planning process could be used to complement existing management tools such as SSMUs. MARXAN is one of a suite of tools that might be employed to assist with identifying important areas for conservation, but it cannot be used in isolation. Results from MARXAN do not provide a definitive 'solution' to the question of where important areas for conservation are located, but the outcomes can be helpful in informing decision-making.

3.59 The Working Group therefore endorsed the use of MARXAN as one feasible method for undertaking systematic conservation planning.

3.60 The Working Group noted that key outcomes of the 2007 Bioregionalisation Workshop had been the primary and secondary maps of pelagic bioregions (SC-CAMLR-XXVI, Annex 9, Figures 3 and 4), and that some of these data had been used in the analysis described in WG-EMM-08/49. The secondary regionalisation map shows that there is a high level of heterogeneity in Subarea 48.2, and the Working Group noted that other such heterogeneous areas also exist elsewhere in the Southern Ocean (Figure 12). The Working Group recognised that many of these heterogeneous areas occur in regions of complex bathymetry and in areas where ecosystem processes are thought to be complex. It agreed that these areas should be given priority in more closely examining how a representative system of protected areas could be identified.

3.61 The Working Group therefore agreed that it should, as a priority, initiate a process to develop representative systems of MPAs across these areas. Therefore, Members were encouraged to use appropriate methodologies to further this work, using, *inter alia*, bioregionalisation and/or systematic conservation planning.

3.62 The Working Group noted that further work would contribute to the development of 'best-practice' guidance, which could then be employed in the selection of important areas for conservation of marine biodiversity, and the implementation of appropriate conservation actions.

Developing a harmonised approach

3.63 The Working Group noted that both CCAMLR and the CEP have obligations for protecting marine biodiversity. A system for establishing protected areas exists under Annex V of the Protocol on Environmental Protection, with a mechanism for approval by CCAMLR of such areas with a marine component. CCAMLR has also initiated a process to identify and establish areas to protect marine biodiversity.

3.64 The Working Group agreed on the importance of cooperation between CCAMLR and the CEP, to improve approaches for area protection by both bodies and to develop further means for practical cooperation.

3.65 WG-EMM-08/52 summarised the CEP discussions on the proposal for a Joint SC-CAMLR-CEP Workshop to be held in 2009, immediately prior to the CEP XII meeting in Baltimore, USA. The CEP has nominated its chair and two vice-chairs as representatives on a joint workshop steering group, and recommended that this group should be convened as soon as practical.

3.66 The Working Group agreed that the topics identified by the CEP for possible consideration by the joint workshop were important topics of mutual interest. The issues of protected areas and spatial management measures were recognised as being of particular relevance. The Working Group also noted that there are synergies between the CCAMLR bioregionalisation work and the CEP Environmental Domains Analysis for Terrestrial Antarctica.

3.67 The Working Group further agreed that the proposed joint workshop should not address these topics in substantive detail, but that it should focus on the development of mechanisms for practical cooperation.

3.68 The Working Group agreed to support the proposal for a joint workshop, and to support the attendance of the SC-CAMLR working group conveners. Members were also encouraged to consider the attendance of other individuals who would be able to contribute to these discussions.

3.69 The Working Group recommended that the Scientific Committee should discuss the types of information that would be most useful for presentation to the workshop on behalf of SC-CAMLR, and to provide advice on this to the working group conveners in preparation for the workshop. Further discussion on the development of an agenda and practical arrangements for the workshop are reported in paragraphs 8.19 and 9.1 to 9.5.

Work plan

3.70 The Working Group agreed that further work to progress the implementation of spatial management measures for the conservation of marine biodiversity should include:

(i) further development of the BRT method;

(ii) a workshop to be held under the auspices of CCAMLR to bring together data on the types of taxonomic groups and habitats that may be vulnerable to CCAMLR bottom fisheries, and to provide guidance on points that are necessary to reduce uncertainty on the potential for CCAMLR bottom fisheries for causing significant adverse impacts on VMEs (paragraph 3.31);

(iii) initiation of processes to develop representative systems of MPAs across the priority areas identified in Figure 3.1, using, *inter alia*, bioregionalisation and/or systematic conservation planning;

(iv) identification of the types of information that would be most useful for presentation to the Joint SC-CAMLR-CEP Workshop on behalf of SC-CAMLR, and consideration of the attendance of individuals who would be able to contribute to the workshop discussions.

Key points for consideration by the Scientific Committee and its working groups

3.71 The Working Group recalled that recent discussions by CCAMLR and the CEP have concluded that the issues of where and how to establish a system of marine areas for the conservation of biodiversity in the Southern Ocean should be addressed as a matter of priority (CCAMLR-XXIII, paragraph 4.13; CEP IX Final Report, paragraphs 94 to 101) (paragraph 3.45).

3.72 The Working Group agreed that the existing benthic and pelagic bioregionalisations developed by the 2007 Bioregionalisation Workshop were adequate, although further refinement may be undertaken. The Working Group encouraged work to further develop the BRT method (paragraphs 3.7 and 3.8).

3.73 The Working Group agreed that a risk-analysis framework represents a sensible approach to implementing Conservation Measure 22-06. It recommended that this approach should continue to be developed for use by WG-FSA.

3.74 The Working Group agreed that a workshop should be held under the auspices of CCAMLR to bring together data on the types of taxonomic groups and habitats that may be vulnerable to CCAMLR bottom fisheries, and to provide guidance on points that are necessary to reduce uncertainty on the potential for CCAMLR bottom fisheries for causing significant adverse impacts on VMEs (paragraph 3.31).

3.75 The Working Group endorsed the approach of providing information on a potential VME outlined in WG-EMM-08/38. It noted that the approval of the addition of a notification of a VME to the VME registry would require endorsement of the Scientific Committee.

3.76 The Working Group noted that a number of methods could be used for designing a representative system of MPAs, including, *inter alia*, bioregionalisation and/or systematic conservation planning (paragraphs 3.48 to 3.58). It endorsed the use of MARXAN software as one feasible method for undertaking systematic conservation planning (paragraph 3.59).

3.77 The Working Group agreed that it should, as a priority, initiate a process to develop representative systems of MPAs across the priority areas identified in Figure 12 (paragraphs 3.60 and 3.61). Therefore, Members were encouraged to use appropriate methodologies to further this work, using, *inter alia*, bioregionalisation and/or systematic conservation planning.

3.78 The Working Group agreed on the importance of cooperation between CCAMLR and the CEP and agreed to support the proposal for a Joint SC-CAMLR-CEP Workshop, which will address topics related to protected areas and spatial management measures.

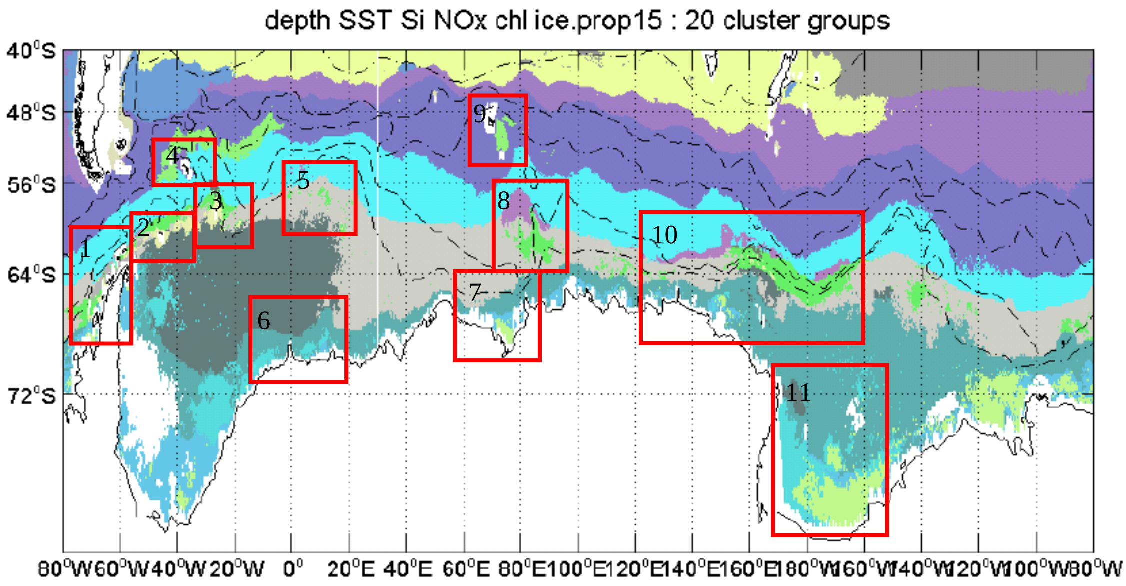

Figure 12: Secondary regionalisation agreed by the CCAMLR Bioregionalisation Workshop (2007) (analysis based on depth, SST, silicate concentration, nitrate concentration, surface chlorophyll-*a* and ice concentration). Red boxes show areas of highest heterogeneity, which have been identified by the Working Group as priority areas for identifying MPAs as part of a representative system (numbers refer to area descriptions, and are not in any order of priority). 1 = Western Antarctic Peninsula, 2 = South Orkney Islands, 3 = South Sandwich Islands, 4 = South Georgia, 5 = Maud Rise, 6 = Eastern Weddell Sea, 7 = Prydz Bay, 8 = BANZARE Bank, 9 = Kerguelen, 10 = Northern Ross Sea / East Antarctica, 11 = Ross Sea shelf. (This figure is available in colour on the CCAMLR website.)

5. Extract from the 2008 CCAMLR Scientific Committee report relevant to Bioregionalisation

REPORT OF THE TWENTY-SEVENTH MEETING OF THE SCIENTIFIC COMMITTEE

HOBART, AUSTRALIA
27-31 OCTOBER 2008

Management of protected areas

3.50 The WG-EMM Chair summarised the discussion and advice derived from the Focus Topic 'to progress the implementation of spatial management measures that aim to facilitate the conservation of marine biodiversity' (Annex 4, paragraphs 3.1 to 3.78).

3.51 Some Members expressed concern about the priority areas identified by WG-EMM for further work on the development of MPAs (Annex 4, Figure 12), since the process of secondary bioregionalisation has not been completed (SC-CAMLR-XXVI, Annex 9, Figure 4).

3.52 Dr X. Zhao (China) stated that China is a new member of the Commission, and was not involved in Scientific Committee's previous work on bioregionalisation; he expressed his sincere appreciation of all the inputs made by those Members actively involved. He further noted that, since there are still some concerns and different views from the floor, he encouraged further work by WG-EMM to consolidate different views on this issue.

3.53 It was noted that Figure 12 in Annex 4 was based on an analysis which had previously been recognised to demonstrate heterogeneity in marine ecosystems (SC-CAMLR-XXV, paragraph 3.48). Figure 12 simply identifies areas which show a high level of heterogeneity and are therefore likely to contain complex biological and environmental characteristics. In order to better utilise limited resources available to CCAMLR, these complex areas were considered by the WG-EMM to be appropriate regions in which to focus further work on the development of MPAs.

3.54 It was further noted that focused work on the topic of MPAs began in 2000 and that progress to date has included scientific research and modelling activities, several workshops and discussions within the Scientific Committee and its working groups and the Commission (e.g. CCAMLR-XXVI, paragraph 7.18). The reports of these meetings and workshops were noted as information resources.

3.55 The Scientific Committee:

(i) recalled that recent discussions by CCAMLR and the CEP have concluded that the issues of where and how to establish a system of marine areas for the conservation of biodiversity in the Southern Ocean should be addressed as a matter of priority (CCAMLR-XXIII, paragraph 4.13; CEP IX Final Report, paragraphs 94 to 101) (Annex 4, paragraph 3.71);

(ii) agreed that the existing benthic and pelagic bioregionalisations developed by the 2007 Bioregionalisation Workshop were adequate for use in such work, although further refinement may be undertaken, and encouraged work to further develop the BRT method (Annex 4, paragraph 3.72);

(iii) noted that a number of methods could be used for designing a representative system of MPAs, including, *inter alia*, bioregionalisation and/or systematic conservation planning, and endorsed using MARXAN as one feasible method for undertaking the latter (Annex 4, paragraph 3.76);

(iv) agreed that it should, as a priority, continue the process of consolidating scientific views to maintain a common basis for the development of representative systems of MPAs, as agreed by the Commission (CCAMLR-XXVI, paragraph 7.18). The development of representative systems of MPAs should focus on, but not be limited to, the priority areas identified by WG-EMM in Figure 12 of Annex 4. Therefore, Members were encouraged to use appropriate methodologies to further this work (Annex 4, paragraph 3.77).

6. Report Of The CCAMLR Workshop On Marine Protected Areas (Silver Spring, MD, USA, 29 August to 1 September 2005)

ANNEX 7

REPORT OF THE CCAMLR WORKSHOP ON MARINE PROTECTED AREAS

(Silver Spring, MD, USA, 29 August to 1 September 2005)

CONTENTS

REPORT OF THE CCAMLR WORKSHOP ON MARINE PROTECTED AREAS
(Silver Spring, MD, USA, 29 August to 1 September 2005)

INTRODUCTION

At CCAMLR-XXIII held in 2004, the Commission addressed the topic on Marine Protected Areas (MPAs[1]) and urged the Scientific Committee to proceed with this work as a matter of priority. It also reaffirmed the need to develop advice on MPAs commensurate with Articles II and IX of the Convention (CCAMLR-XXIII, paragraph 4.13).

2. The Scientific Committee endorsed in principle the concept of a CCAMLR workshop on MPAs, developed its draft terms of reference and requested that the Chair of the WG-EMM Subgroup on Protected Areas, Dr P. Penhale (USA), act as Convener for the workshop (SC-CAMLR-XXIII, paragraphs 3.52 and 3.53). Intersessional tasks included the creation of a steering committee to develop the agenda and the suggested papers, as well as to identify the appropriate venue and timing of the workshop. The Scientific Committee also recommended that the workshop include invited experts, to take advantage of the large body of MPA knowledge that could be used to promote the goals of CCAMLR (SC-CAMLR-XXIII, paragraph 3.51).

3. The Steering Committee worked during the intersessional period. Based on the view of the Steering Committee, the Convener suggested that the workshop be held in 2005 before CCAMLR-XXIV. The proposal was circulated both to Members of the Commission and the Scientific Committee and received no objections. The workshop was held from 29 August to 1 September 2005 (NOAA National Marine Fisheries Service, Silver Spring, MD, USA).

OPENING OF THE WORKSHOP

4. Dr S. Murawski, Chief Science Adviser to the NOAA National Marine Fisheries Service, welcomed participants of the workshop. He highlighted the unique opportunity and challenges for CCAMLR to further its objective by applying MPAs not only as a tool for conservation and management of resources but also for monitoring general response of the Antarctic ecosystem to environmental and human-induced changes. In particular, the use of MPAs by CCAMLR would be most important in the light of the CCAMLR approach to ecosystem management.

ADOPTION OF AGENDA AND WORKSHOP ORGANISATION

5. The workshop Convener, Dr Penhale, advised participants on the workshop organisation. The draft agenda of the workshop was considered and adopted (see Appendix I). The agenda addressed all items listed in the workshop terms of reference agreed

[1] In the general context provided by IUCN: 'any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment'.

by the Scientific Committee (SC-CAMLR-XXIII, paragraph 3.52). The lists of workshop participants and papers considered are appended (see Appendix II and Appendix III respectively). Ms L. Kimball (IUCN) participated in the workshop as an invited expert. The workshop report was prepared by Dr A. Constable (Australia), Dr N. Gilbert and Miss J. McCabe (New Zealand), Prof. J. Croxall and Ms S. Grant (UK), Dr R. Holt and Ms P. Toschik (USA) and Dr E. Sabourenkov (Secretariat).

WORKSHOP OBJECTIVES

6. The following terms of reference for the workshop were agreed by the Scientific Committee (SC-CAMLR-XXIII, paragraph 3.52):

(i) to review current principles and practices related to the establishment of MPAs;

(ii) to discuss how the use of MPAs could be used to contribute to furthering the objectives of CCAMLR;

(iii) to consider proposals that are currently under development or in a conceptual phase that relate to MPAs in the Convention Area;

(iv) to discuss the types of scientific information that may be required for the development of MPAs to further the objectives of CCAMLR, including the identification of biophysical regions across the Convention Area.

7. The Convener reiterated that the workshop was organised to develop advice to the Scientific Committee on the application of MPAs commensurate with Articles II and IX of the Convention.

REVIEW OF CURRENT PRINCIPLES AND PRACTICES RELATED TO THE ESTABLISHMENT OF MPAS

General principles and guidelines

8. The workshop considered several papers that had been presented (WS-MPA-05/4, 05/6, 05/14 and COFI/2005/8). The workshop noted in particular that IUCN's paper on MPAs in the CCAMLR context (WS-MPA-05/4), which was introduced by Ms Kimball, provided helpful guidance and background information on many of the issues under consideration, including definitions of MPAs, and the international context for MPA designation.

9. Ms Grant presented WS-MPA-05/13 which reported on the SCAR Biology Symposium MPA workshop (July 2005, Curitiba, Brazil). This workshop highlighted, in particular, the potential for SCAR to contribute toward the collation of scientific data for the development of MPAs. The importance of monitoring programs in contributing towards an improved understanding of the potential benefits of MPAs was also noted.

10. Against the background of IUCN's paper, the workshop discussed the meaning of the term 'marine protected area' and agreed that it encompassed a range of mechanisms that could be used to help meet the objectives of Article II of CCAMLR. These included provisions available under CCAMLR and the Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol).

11. Dr R. Brock (USA) introduced 'Issues to Consider Before Jumping on the MPA Bandwagon' (WS-MPA-05/14) which provided practical advice on the process for MPA creation. This highlighted the importance of clearly articulating objectives for MPA designation, and of early consultation with a broad range of stakeholders. The paper also suggested that a successful MPA should be of sufficient size to achieve its goals, and its design should incorporate mechanisms to ensure effective monitoring and enforcement. The paper also noted that in order to ensure flexibility and to incorporate all stakeholders' views, the drawing of MPA boundaries might well be the final stage in the process.

12. Dr Constable introduced 'Guidelines for Establishing the Australian National Representative System of Marine Protected Areas (NRSMPA)' (WS-MPA-05/6). He noted that the notion of regional marine planning was a direct result of Australia's Oceans Policy and indicated that the NRSMPA had three key elements, referred to as the CAR system:

- Comprehensiveness – the need to include the full range of ecosystems across each bioregion;
- Adequacy – appropriately sized MPAs to ensure protection of ecological viability and integrity of populations, species and communities;
- Representativeness – sufficient MPAs to reflect the biotic diversity of marine ecosystems.

13. Dr Constable highlighted the importance of the precautionary approach built into the principles for developing the NRSMPA, and noted that the absence of scientific certainty was not considered sufficient reason to avoid designating MPAs. He also drew attention to the criteria contained in the NRSMPA for the identification and selection of MPAs (see WS-MPA-05/6, pp. 10 and 11).

14. The workshop agreed that the NRSMPA, and in particular the CAR principles, provided a candidate approach to the designation of MPAs that may have application in terms of principles and criteria, to CCAMLR's consideration of MPAs in the Southern Ocean.

15. The workshop considered two papers that provided worked examples of processes that had been followed to establish MPAs in the Southern Ocean. WS-MPA-05/7, submitted by Australia, provided information on the establishment of an MPA around Heard Island and McDonald Islands (HIMI), and WS-MPA-05/15, submitted by South Africa, provided information on the Prince Edward Islands MPA. The workshop agreed that these provided useful case studies on the establishment of MPAs within the CCAMLR Convention Area, albeit within existing EEZs.

16. Within the CCAMLR context, the workshop recognised the need to develop a strategic approach to MPA design and implementation throughout the Convention Area, notably in relation to a system of protected areas developed later in the report (paragraphs 66 to 70).

17. The workshop also recognised that there was a strong need for collaboration at technical and policy levels to further develop the MPA concept in the Convention Area. Relevant bodies in such a dialogue would include key elements of the Treaty System (CEP and the ATCM) as well as SCAR, SCOR, Observers to CCAMLR, intergovernmental and non-governmental organisations. It was also noted that, in many cases, CCAMLR Parties were also Parties to other international arrangements within which the issue of high-seas MPAs was being considered and that opportunities therefore existed to exchange information and expertise with such external agencies and organisations.

Economics of MPAs

18. Prof. Croxall introduced this topic and referred to a paper by the Royal Society for the Protection of Birds (WS-MPA-05/08) on the economics of MPAs. Participants were also directed to a paper on the worldwide cost of MPAs (Balmford et al., 2004 – see Appendix III). The workshop agreed that the Scientific Committee should be aware of the background material available on economic aspects of MPAs.

19. The workshop noted that costs associated with MPAs lay firstly with their selection and designation and secondly with their management and enforcement. It was agreed that, potentially, considerable additional costs could be associated with the acquisition of scientific data for the designation of MPAs as well as with the implementation of monitoring programs associated with MPAs. However, it was also recognised that current CCAMLR initiatives already involved compliance and enforcement and so additional costs might not be substantial.

20. The workshop noted also that it might be possible to harness funding through initiatives such as the World Bank and the Global Environmental Facility to assist with the research necessary to underpin MPA selection and designation.

Current instruments and agreements

21. Dr Gilbert presented WS-MPA-05/12 on legal considerations surrounding the designation of MPAs in Antarctica. Mr E. McIvor (Australia) presented WS-MPA-05/9 on the process for the establishment of MPAs by CCAMLR and the Antarctic Treaty Parties. This paper also included a proposal to establish a geographical reference line (e.g. 1 n mile from the coast or the 100 m isobath) to assist in determining whether ASPA or ASMA proposals under Annex V to the Protocol needed to be submitted to CCAMLR.

22. However, the workshop suggested that establishing a harmonised regime for the protection of the Antarctic marine environment across the ATS should be the primary aim but recognised that there would need to be a division between ATCM and CCAMLR on the management of different human activities in the region.

23. The workshop noted the applicability of current ATS instruments to the designation of MPAs in the Southern Ocean and the relationship between those provisions under Annex V to the Protocol and those under Article IX of CCAMLR. The workshop recalled that ATCM Decision 9 (2005) set out the criteria under which protected area proposals under the Protocol

that included a marine component needed to be submitted to CCAMLR for approval. However, it was recognised that the conditions under which these criteria were triggered needed further consideration and coordination.

24. Ms Grant introduced a paper which was previously submitted to WG-EMM and the Scientific Committee (SC-CAMLR-XXIII/BG/30) and later revised for publication. It discussed the applicability of international conservation agreements to the establishment of MPAs in Antarctica. Certain commitments and decisions from agreements such as the Convention on Biological Diversity (CBD) and the World Summit on Sustainable Development (WSSD) have relevance to MPA development under CCAMLR, particularly with regard to the commitments of most CCAMLR Members under these instruments. Specific decisions relate to the development of guidelines and criteria for MPAs, and improved processes for their implementation. Other species-specific agreements such as ACAP may also have relevance in providing mechanisms to strengthen protection for particular species.

25. Participants noted that additional background could be found in the IUCN's publication on international oceans governance and the 2005 information paper prepared by the IUCN on the international legal regime on the high seas and seabed beyond the limits of national jurisdiction (Kimball, 2001 – see Appendix III).

Research papers/summary papers/abstracts

26. The workshop also noted a number of other papers provided as background to its discussion (see Appendix III, List of Documents).

THE USE OF MPAS TO FURTHERING THE OBJECTIVES OF CCAMLR

Principles involved in the identification of potential MPAs in the Convention Area

27. The objectives of CCAMLR, for which the use of MPAs (in the broadest sense) could be appropriate, derive principally from Articles II and IX of the Convention.

28. Article II establishes the basic objective of CCAMLR as the conservation of Antarctic marine living resources (where conservation includes rational use) and sets out the principles by which harvesting and associated activities shall be carried out.

29. Article IX further specifies the ways to give effect to the objective and principles of Article II. This Article relates particularly to the development and use of conservation measures, specifically including the opening and closing of areas, regions or sub-regions for purposes of scientific study or conservation, including special areas for protection and scientific study.

30. Under this provision, CCAMLR has used closed areas to support its precautionary approach to managing finfish fisheries. These have been established for specific purposes not related to MPAs.

31. Article IX also enjoins CCAMLR: (i) to take such other measures as necessary to fulfil the objective of the Convention, including those concerning the effects of harvesting and associated activities on components of the marine ecosystem other than harvested populations (e.g. dependent and associated species); (ii) to take full account of any relevant measures in regulations established or recommended by ATCMs pursuant to Article IX of the Antarctic Treaty.

32. In general, and particularly in the CCAMLR context, there is widespread evidence of the known or potential benefits of MPAs for, *inter alia*, the: (i) conservation (including restoration) of biodiversity; (ii) minimisation of detrimental effects of harvesting on non-target species; and (iii) protection (including restoration) of age classes, life-history stages, stocks and populations of species targeted by harvesting.

33. In addition, the workshop recognised that, in common with other international organisations with responsibility for the conservation and management of marine living resources on the high seas, CCAMLR had particular responsibility (not least as an organisation with the attributes of a regional fisheries management organisation but with a wider conservation mandate) for participating in the current international discussions on the use of MPAs to further such objectives.

34. Furthermore the workshop noted: (i) the existing commitments (e.g. in respect of WSSD, CBD, World Parks Congress etc.) of many, if not most, Members of CCAMLR to the establishment of representative networks of MPAs; (ii) the agreement of FAO to assist its members to achieve the WSSD target with respect to representative networks of MPAs and to develop technical guidelines for defining, implementing and testing of MPAS; (iii) the obligations of all Members of CCAMLR in respect of the Madrid Protocol.

35. Annex V (Article 3.2) of the Madrid Protocol contains the requirement to establish a system of ASPAs to include, *inter alia*:

(i) areas kept inviolate from human interference so that future comparisons may be possible with localities that have been affected by human activities;

(ii) representative examples of major terrestrial, including glacial and aquatic, ecosystems and marine ecosystems;

(iii) areas with important or unusual assemblages of species, including major colonies of breeding native birds or mammals;

(iv) the type locality or only known habitat of any species;

(v) areas of particular interest to ongoing or planned scientific research.

36. Overall, therefore, the workshop concluded that MPAs had considerable potential for furthering CCAMLR's objective in applications ranging from protection of ecosystem processes, habitats and biodiversity, to protection of species (including population and life history stages).

37. However, it was recognised that, given the diversity of potential benefits deriving from MPAs and the variety of different types of MPA (including the many different management practices that they could include), considerable clarity would be needed in specifying the precise objectives of using MPAs in the Convention Area.

38. In the specific context of fishery-related MPAs, the advice in the FAO COFI paper (COFI/2005/8), particularly in paragraphs 5 to 7, should be carefully considered, together with assessments deriving from MPA reviews by other relevant bodies.

39. Given the nature and scale of many processes and systems in the Southern Ocean, the emphasis of any attempt to create networks protecting ecosystem processes, representative areas, species or populations, is likely to require approaches that are flexible and medium to large scale, and that involve specific management measures relevant to the requirements of populations with substantial seasonal movements or changes in abundance. It will be particularly challenging to develop systems and networks to address the requirements of wide-ranging, long-lived taxa with complex life cycles and breeding systems.

40. However, there may be a need for CCAMLR to consider the adequacy of arrangements for the appropriate protection of certain spatially-restricted habitats with unique and/or highly diverse biological assemblages, such as seamounts (SC-CAMLR-XXIII, paragraph 3.31).

41. In this context it was noted that WS-MPA-05/4 contained a reference to a decision by NEAFC to close to fishing with all types of bottom fishing gears certain seamounts within its area of application. Details of the selection and designation procedure used by NEAFC, and by other relevant organisations, may be of relevance to CCAMLR.

42. Dr Constable noted that consideration of measures to mitigate impacts on benthic assemblages needed to include all bottom fishing practices, including trawling and longlining.

Examples of protected areas in the Convention Area

43. The workshop considered various general and specific examples of protected areas currently in force in the Convention Area.

44. Ms Grant introduced a paper which was previously submitted to WG-EMM and the Scientific Committee (SC-CAMLR-XXIII/BG/28) and later revised for publication. It listed current and proposed MPAs within the CCAMLR Convention Area. This paper demonstrates that almost all existing ASPAs and ASMAs are small, coastal areas that do not contribute to the objectives of CCAMLR, and have little relevance to CCAMLR-related activities. Furthermore, these existing areas make little contribution to the development of a representative system of MPAs under the requirements of the Madrid Protocol.

45. However, terrestrial or nearshore sites of scientific interest to CCAMLR (i.e. CEMP sites) highlight the importance of joint consideration by both CCAMLR and CEP.

46. The workshop also noted that the IWC has extended the designation of its Southern Ocean Sanctuary to 2014.

47. The workshop agreed that, overall, when viewed in relation to the IUCN categories of protected areas, the Convention Area as a whole would qualify as Category IV (Habitat/Species Management Area: protected area managed mainly for conservation through management intervention). This is defined as an area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species.

48. Dr Constable presented WS-MPA-05/7, outlining the process undertaken by the Australian Government to identify and declare the HIMI Marine Reserve an IUCN Category I protected area, under the Australian Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

49. In preparing a report on the conservation values of the HIMI EEZ, the Australian Antarctic Division had reviewed available, though in some cases limited, physical and biological data to define 13 biophysical units within the EEZ (report summary appended to the paper). The report identified that the HIMI region contains conservation values of global importance, and values which are unique within the Australian EEZ, including benthic habitat, the foraging range of land-based marine predators and nursery grounds for commercial fish species.

50. With consideration given to known and potential threats to the conservation values, the Australian NRSMPA principles (comprehensive, adequate and representative) and criteria for identification of MPAs (outlined in WS-MPA-05/6) were used to identify a possible reserve configuration that would:

- provide for protection of the marine and terrestrial conservation values;
- contribute to integrated and ecologically sustainable management of the HIMI region;
- provide scientific reference areas;
- add to the NRSMPA.

51. Consultation on the Reserve proposal with government, conservation groups and fishing industry stakeholders indicated the need for further investigation of particular areas where there was insufficient data to make a definite case for protection or fishing access. This resulted in the declaration of a conservation zone under the EPBC Act and the establishment of a three-year program, overseen by stakeholders, to provide protection of those areas while studies are undertaken to further assess the conservation values and fisheries resource potential of the area. On completion of the assessment, a decision will be made by the Minister for the Environment and Heritage over whether to add the conservation zone areas to the Reserve.

52. The conservation report also identified a number of questions for further investigation, including to consider the effects of current and future activities in the area, to determine the need to refine the Reserve configuration to better facilitate protection of the values.

53. The process to establish the Reserve was referred to the workshop as a model for CCAMLR consideration, because:

(i) the Reserve is in the CCAMLR Convention Area (Division 58.5.2), and was declared as part of a representative system of MPAs (the NRSMPA) within a substantial marine jurisdiction (Australian);

(ii) the Reserve and adjacent comprehensively managed (IUCN Category 'IV+' protected area equivalent) commercial fishery effectively collectively comprise a multiple-use MPA;

(iii) the declaration process involved comprehensive and transparent consultation throughout with relevant stakeholders, government agencies, conservation and industry non-governmental organisations;

(iv) Reserve compliance is supported by comprehensive regional, national and international arrangements for compliance and enforcement.

54. Mr McIvor referred the workshop to the HIMI website www.heardisland.aq for further information regarding the Reserve and its management plan and the HIMI Conservation Zone.

55. The workshop commended the specific procedures and frameworks for planning biodiversity conservation outlined in the Guidelines for Establishing the Australian National Representative System of MPAs, which had underpinned the establishment of the HIMI Marine Reserve. It recognised that the principles involved, notably those relating to CAR, together with the use of precautionary approaches and wide consultation with appropriate interest groups, combined with flexible decision-making and review procedures, and the capacity to designate areas for interim protection, were fundamental to the development of protected area networks in regional seas. Such principles were recognised as being fundamental to similar undertakings in high-seas areas.

56. The specific example of the process leading to the declaration of the HIMI Marine Reserve was also recognised to be a model of the practical implementation of the relevant procedures. The workshop noted that this approach should have widespread applicability to any part of the Convention Area wherein the application of MPAs (in the widest sense) was deemed appropriate.

57. It was noted that, in relation to IUCN protected area categories, the marine reserve within HIMI is an IUCN Category I. The remainder of the area would be equivalent to at least Category IV with conservation zones incorporating additional provisions.

58. Dr D. Nel (South Africa) indicated that South Africa had made considerable use of the framework provided by the HIMI example in developing its approaches to the designation of MPAs around the Prince Edward Islands. He enquired whether the CAR approach was able to incorporate consideration of maintenance of ecological processes, as well as contribute to the long-term sustainability of the fishery in the area.

59. Dr Constable indicated that the Australian NRSMPA explicitly incorporates maintenance of ecosystem processes as part of its primary goal. The sustainability of fishing is covered across a number of legal jurisdictions. It is intended that the NRSMPA contribute to a formal management framework for a broad spectrum of human activities, one of which is fisheries.

60. The workshop noted that the approaches developed by Australia offered advantages that may be useful to the development of approaches to establishing a network of MPAs within the Convention Area. These include: (i) flexibility, including the development of interim measures and provisions, recognising the benefit of improved scientific data on which

to develop more permanent designations and provisions; (ii) wide and continuing consultation with all interest groups, in particular to ensure appropriate balance between the sustainable use of marine living resources and minimising the effects of known or potential environmentally damaging activities; and (iii) matching levels of constraint on access to, and operation within, MPAs to the perceived importance of the conservation and/or biodiversity values of the area and to the level of scientific data available.

61. The workshop agreed that conservation outcomes appropriate for achieving the objectives in CCAMLR Article II would include the maintenance of biological diversity[2] as well as the maintenance of ecosystem processes.

62. It was agreed that attention may need to be given to the need for, *inter alia,* protection of:

(i) representative areas[3];

(ii) scientific areas to assist with distinguishing between the effects of harvesting and other activities from natural ecosystem changes as well as providing opportunities for understanding the Antarctic marine ecosystem without interference;

(iii) areas potentially vulnerable to impacts by human activities, to mitigate those impacts and/or ensure the sustainability of the rational use of marine living resources.

63. It was noted that some areas in the Southern Ocean may have predictable features that are critical to the function of local ecosystems. The workshop agreed that such areas would be appropriate to be included in a system of protected areas. Some participants felt that this should be considered as an objective in its own right, as follows:

> The protection or maintenance of important ecosystem processes, in locations where those processes are amenable to spatial protection.

64. The workshop also considered the need for the Commission to achieve satisfactory fishery outcomes in terms of sustainable rational use. The process for establishing a system of protected areas will need to have regard for this objective of the Commission.

65. In the context of the discussion below an area would need to be defined according to geographic coordinates as well as depth. This is because some areas may not need to encompass the entire water column in order to achieve their objectives.

66. The conservation outcomes listed in paragraphs 62 and 63 are consistent with the criteria identified in the Madrid Protocol, Annex V, Article 3 that might be used to establish ASPAs, and with CCAMLR Article II. Protection of these areas would need to be indefinite or for a sufficiently long term to satisfy their objectives, such as for scientific reference areas. These areas would be equivalent to IUCN Category I areas. Recalling the discussion on the

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2 'Biological diversity' means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Convention on Biological Diversity).

3 A system of representative areas would aim to provide a comprehensive, adequate and representative system of MPAs to contribute to the long-term ecological viability of marine systems, to maintain ecological processes and systems, and to protect the Antarctic marine biological diversity at all levels.

HIMI Marine Reserve and the Australian NRSMPA (paragraphs 48 to 60), the workshop agreed that there was a need for the use of protected areas to satisfy the general CAR requirements.

67. For the purposes of this workshop, such areas are termed ‘Specially Protected Areas’. This term and those used below for other types of areas have meanings in other forums that are not the same meanings as those used here. The workshop recommended that the Scientific Committee or Commission consider the terms to be used for the different forms of closed areas (as in CCAMLR Article IX) identified here. It also noted that the Commission will need to correspond with the ATCM over how to harmonise the implementation of CCAMLR closed areas as discussed here.

68. In addition to Specially Protected Areas, some areas may be identified as candidates for special protection but need more information before a conclusion on protection can be reached. In this case, the workshop agreed that interim protection would be needed to implement CCAMLR’s precautionary approach. During this period, fisheries exploration and scientific activity would be limited to that needed to obtain data required to finalise consideration of its need for protection. Such interim protection would not be indefinite but should be sufficient to ensure protection of future options while the process is completed. Here, these areas are termed ‘Conservation Zones’. Such interim protection could be short or long term, according to the agreed period required to decide on protection.

69. Closed areas, specifically for achieving outcomes for fisheries, would be considered separately to this process by the respective working groups of the Scientific Committee. These areas are termed ‘Fisheries Closed Areas’.

70. The general objectives for which protected areas may be established and the types of protection that could be given in accordance with CCAMLR Article IX are illustrated in Table 1. These types of areas could be applied anywhere within the Convention Area.

PROPOSALS THAT ARE CURRENTLY UNDER DEVELOPMENT OR IN A CONCEPTUAL PHASE THAT RELATE TO MPAS IN THE CONVENTION AREA

71. Several papers were submitted to the workshop addressing MPAs in the Convention Area currently under development or in a conceptual phase.

Area around Prince Edward Islands

72. Dr Nel introduced WG-MPA-05/15, submitted by South Africa, which provided an update on the status of outlining the development process and status of an MPA around the Prince Edward Islands.

73. The development of the Prince Edwards Islands MPA benefited from the example of the HIMI Marine Reserve, and Dr Nel commended Australia for its excellent work.

74. The Prince Edward Islands area suffered huge impacts from IUU fishing in late 1990s due to the lack of offshore enforcement capacity. This led to a movement to extend the special nature reserve from the low-water mark to include a no-fishing marine area, which currently extends out to 12 n miles. An MPA including and extending beyond 12 n miles will be established to combat IUU fishing and allow ecosystem recovery; increased compliance and patrols will help enforce the MPA.

75. South Africa is implementing a three-phase conservation plan. The initial phase was the creation of a geographic information system with relevant data layers. This was followed by a stakeholder consultation workshop in June 2005, where important biological and physical processes and habitats were identified. Currently South Africa is conducting analyses of the data and is creating a final conservation plan. South Africa noted it is taking a phased approach for the MPA declaration, additional information regarding the MPA will be announced during the next year.

76. Objectives for this MPA include reduction of IUU fishing, allowing Patagonian toothfish to recover from overexploitation, reducing threats to albatrosses and petrels, reducing and avoiding impacts to the benthic habitat from destructive fishing practices, and setting aside reference habitat to inform future management. These objectives support CCAMLR principles by conserving representative habitats, ecosystem integrity, reducing impacts of IUU fishing, providing a fisheries replenishment zone, and providing a source of scientific benchmarks.

77. Participants agreed that this proposal clearly stated the objectives for the MPA and these objectives were consistent with CCAMLR principles.

78. Consistent with the modern concept of zoning in MPAs, complete protection from all extractive impacts will be identified for some areas in the Prince Edwards Islands, while others will be zoned with various levels of protection.

79. Participants agreed that to be successful in establishing MPAs, support from organisations in adjacent areas is essential. Support from CCAMLR in the case of EEZ-based MPAs would be useful. MPAs will also need the support of other agencies internationally, e.g. those that impact seabirds and foraging grounds outside the CAMLR Convention Area.

80. The ecosystem processes being conserved in the Prince Edward Islands MPA extend outside the South African EEZ to the high seas and the EEZs of other CCAMLR Members. South Africa noted it would welcome complementary efforts to extend the protected area.

81. The workshop commended the South African approach in designing the Prince Edward Islands MPA.

82. South Africa will conduct further biodiversity surveys in the area during 2006/07.

Area around Anvers Island, Antarctic Peninsula

83. Ms Toschik introduced WS-MPA-05/10, submitted by the USA, which summarised a conceptual phase proposal for an ASMA in the Anvers Island area, which may include a large

marine component. This paper led to discussion on the specific area around Anvers Island, the generic process of MPA development, and creation of a checklist to aid in interpretation of ATCM Decision 9 (2005).

84. The workshop noted that it would be useful for CCAMLR Members with data relevant to the Anvers Island marine area to share these data with the originators of the proposal in order for them to decide whether to submit the MPA proposal to CCAMLR or not.

85. However, it was noted that, in respect of krill, a very small portion of the krill population range in the South Atlantic would likely be included within an Anvers Island ASMA. Even when considered at the SSMU level, only a small portion of the area utilised by krill would be encompassed. Consequently, establishment of an ASMA in the Anvers Island area would be unlikely to impact krill fishing at all and therefore would not be of interest to CCAMLR.

86. Ms Toschik noted the desire of the USA to prevent duplication of effort and streamline the plan for both ATCM and CCAMLR requirements, if submission to both organisations is necessary.

87. Several participants wondered if an Anvers Island ASMA would be of interest to CCAMLR based on ATCM Decision 9 (2005). However, the size of the ASMA has not yet been defined.

88. The workshop noted that an Anvers Island ASMA may be of relevance to CCAMLR in terms of future CEMP sites, based on the long-term research in the area. However, the establishment of an ASMA now would not preclude the establishment of an overlapping CEMP site in the future. It was noted that data from this region have been submitted to the CEMP database in the past, although it was never designated a CEMP site.

89. Participants generally agreed that an ASMA around Anvers Island would be more appropriate than solely a CEMP site designation, because it will include terrestrial and marine components, and it is necessary to balance science, tourism, and fishing interests in the area.

Interpretation of ATCM Decision 9 (2005)

90. The workshop agreed on the need to further elaborate on ATCM Decision 9 (2005) with clear guidelines for determining if a protected area will be of interest to CCAMLR. This would help prevent the referral to CCAMLR of proposals for areas which would not have a discernable impact on CCAMLR interests.

91. Unlike proposals in the past, the proposal for Anvers Island has an area overlapping with the range of krill, in order to encompass penguin foraging areas. As a result there may have been a perceived impact on the fishing range of the krill fishery. The workshop agreed that if the range of krill within a CCAMLR statistical unit taken up in protected areas was only small, then it was unlikely to impact on the rational use of krill in that statistical area. It therefore agreed that it would be useful if general guidelines could be developed to indicate what percentage of the range of krill could be covered by protected areas within a statistical unit before CCAMLR would need to determine if a proposed protected area might impact on rational use. This same approach could also be used for other target species.

92. The workshop agreed that experiences with recent and current proposals could be used to develop a whole set of guidelines. CCAMLR Members could be asked to indicate whether or not those proposals should have been submitted to CCAMLR, and this information could then be used to help develop the guidelines. This would allow CCAMLR to continue the review of proposals for protected areas, but would generate clearer guidance for the review of future proposals, and consequently reduce the workload of CCAMLR.

Balleny Islands area

93. Dr B. Sharp (New Zealand) introduced WS-MPA-05/11, submitted by New Zealand, which presented scientific justification for an MPA around the Balleny Islands. Dr Sharp clarified that this paper was not a proposal, but rather a scientific justification for an MPA around the Balleny Islands.

94. The paper provided scientific justification for an MPA to protect ecosystem structure and function as well as representative habitats. It noted the presence of regionally important top predator populations foraging in the vicinity of the islands, and the existence of tightly coupled trophic relationships in the larger regional ecosystem. The paper further noted that the area has high krill production, and provides regionally important habitat for both juvenile krill and juvenile toothfish. The establishment of an MPA in the area was therefore seen as a means of protecting key predator foraging resources (especially during breeding season), and safeguarding the integrity of ecosystem processes in an area that contributes to the function and value of the regional fisheries and wider ecosystem.

95. Dr K. Shust (Russia) noted that the Balleny Islands do not have broad continental shelves, and they have a steep slope that is not good for bottom trawling or longlining. A longline prohibition is already in place for 10 n miles around the islands, and the area does not currently have a strong fishery. He noted that this ecosystem is not directly linked with the Ross Sea. He also noted that the islands and surrounding waters are covered with ice, making the area difficult to access not only for tourists, but also for scientists. For these reasons, he did not foresee negative impacts on this ecosystem.

96. Dr Shust also asked for further justification for the suggested 50 n mile boundary.

97. Dr Sharp clarified that the 50 n mile boundary was a general approximation, based on foraging ranges of high trophic level marine predators, not a definitive decision. This distance may shift as the scientific information available is further considered.

98. Dr M. Naganobu (Japan) was strongly concerned about the concept introduced in the New Zealand paper. He requested that the workshop consider the following three points:

(i) There is not much survey data around Balleny Islands compared to the South Shetland Islands and South Georgia. Japan has interests and has conducted research in the area around the Balleny Islands and the Ross Sea. He suggested that New Zealand should continue to survey around the Balleny Islands, similar to research programs such as US AMLR long-term surveys, and UK long-term surveys in the South Shetland Islands and South Georgia, where very detailed data have been collected.

(ii) The value of fishing grounds and other human-use values around the Balleny Islands should be considered in the context of developing an MPA in the area. Reports regarding krill density and fish stocks could be referenced. The area around the Balleny Islands has potential value as a fishing resource for humans. This resource should be considered under the concept of rational use in CCAMLR Article II.

(iii) An MPA around the Balleny Islands would differ from past ASPA projects in that is not closely associated with centres of intense scientific research.

99. It was noted that the Balleny Islands MPA concept is the first time CCAMLR has considered a substantial initiative for a relatively large area within the Convention Area but outside an EEZ.

100. The workshop also recognised that there may be merit in considering interim protection for the values New Zealand seeks to protect, and to provide time for further assessment, as demonstrated with zoning in the HIMI Marine Reserve.

101. Participants agreed that what constitutes sufficient data needs to be specified, and measures that can be taken in the interim while data collection is ongoing should be identified. It was also noted that those calling for additional data collection and research should clearly identify the objectives and criteria for such work.

102. Prof. C. Moreno (Chile) noted that when an ecosystem/community is perturbed, it is never restored to exactly the same condition as it was in the past. To conserve this area is a mechanism to retain the actual essence of ecosystem processes. An MPA in the Balleny Islands area could help the fishery in the area to be sustainable in the long term, and to maintain elements of the ecosystem that are under threat from increasing human activities. It was noted that the scientific justification provided by New Zealand contained most of the elements that science offers for people to take a position on this problem.

103. Some participants noted that protection of the Balleny Islands would protect the recruitment zone for toothfish and krill, which has not happened in any other Antarctic fishery.

104. Many participants congratulated New Zealand on its excellent paper. Dr Gilbert noted his appreciation for the feedback provided and, following a suggestion, agreed to form an informal contact group to meet at the upcoming CCAMLR meetings with interested parties to discuss the options for further developing an MPA in the vicinity of the Balleny Islands.

105. Dr Naganobu expressed concern about the proposed informal consultations because a definite proposal by New Zealand has not yet been made.

106. However, the workshop noted that it is important to engage interested parties and generate as much feedback as possible at this early stage of MPA consideration, and it was noted that no additional formal meetings were planned, although an informal contact group will be formed.

SCIENTIFIC INFORMATION REQUIRED FOR THE DEVELOPMENT OF MPAS AND IDENTIFICATION OF BIOPHYSICAL REGIONS ACROSS THE CONVENTION AREA

107. The workshop considered the scientific work needed for considering a system of protected areas to assist CCAMLR in achieving its broader conservation objectives. The key tasks in this process (not necessarily to be undertaken sequentially) would be:

- a broad-scale bioregionalisation[4] of the Southern Ocean;
- a fine-scale subdivision of biogeographic provinces, which may include hierarchies of spatial characteristics and features within regions[5], giving particular attention to areas identified in the bioregionalisation;
- identification of areas that might be used to achieve the conservation objectives identified in paragraph 62;
- determination of areas requiring interim protection.

108. The workshop agreed that these tasks should be attempted with a 'desktop study'[6] in the first instance. It was noted that a number of organisations and individuals are already proceeding with analyses that might facilitate the large-scale bioregionalisation as well as small-scale delineation of provinces, such as for Heard Island and McDonald Islands, Prince Edward Islands and the Ross Sea. It also agreed that the designation of protected areas need not wait for an entire system to be specified.

109. Table 2 lists the types of data that might be used in a process to determine key bioregions and provinces in a bioregionalisation of the Southern Ocean. The table is drawn from Table 1 of WS-MPA-05/15 on the work being undertaken for determining a large MPA around South Africa's sub-Antarctic Prince Edward Islands. It also draws on the material and approach used in developing the conservation report on the Heard Island region indicated in WS-MPA-05/7. As described in WS-MPA-05/15, these data can be used to delineate

4 Bioregionalisation is a process to classify marine areas from a range of data on environmental attributes. The process results in a set of bioregions, each reflecting a unifying set of major environmental influences which shape the occurrence of biota and their interaction with the physical environment. Reference: adapted from 'Interim biogeographic regionalisation for Australia (IBRA)' 1997 (www.deh.gov.au/parks/nrs/ibra).
A recent marine bioregionalisation process is described in 'Australia's South-east Marine Region: A User's Guide to Identifying Candidate Areas for a Regional Representative System of Marine Protected Areas' by Commonwealth of Australia 2003
(www.deh.gov.au/coasts/mpa/southeast/publications/identifying/index.html).
An example of bioregionalisation outcomes can be seen in Butler, A., P. Harris, V. Lyne, A. Heap, V. Passlow and R. Smith. 2001. An interim, draft bioregionalisation for the continental slope and deeper waters of the South-east Marine Region of Australia. Report to the National Oceans Office, CSIRO Marine Research and Geoscience Australia
(www.oceans.gov.au/pdf/SE%20Bioregionalisation%20Final%20Report.pdf).

5 See Butler et al. (2001) for a description of the hierarchy of classifications within biogeographic provinces.

6 A 'desktop study' is the collation and synthesis of existing data and information, including expert knowledge, o undertake analyses and draw conclusions on a topic of interest. It does not include the acquisition of new field data or the undertaking of extensive statistical and modelling development.

important patterns, areas in which important processes occur and areas where pressures may be arising now and/or in the future. The workshop noted that some data may contribute to understanding one or more of the patterns, processes and/or pressures.

110. Dr Gilbert showed how these types of data can be used to create a bioregionalisation by describing the Environmental Domains Analysis of the Antarctic Continent presented to CEP by New Zealand in 2005. The workshop agreed that such an approach would be useful for combining the data into a single analysis but recognised that expert input would be essential.

111. Dr Sharp cautioned that care needs to be taken in the use of particular terrestrial classification algorithms if applied to a bioregionalisation of dynamic marine environments.[7]

112. The workshop agreed that a variety of statistical techniques could be used to integrate the data and that experts in this area would need to correspond to determine an appropriate method for underpinning a bioregionalisation of the Southern Ocean.

113. A difficulty identified by the workshop is that the biological data will not have a universal coverage like data on geomorphology, ocean, climate and ice. It was considered unlikely to restrict the larger-scale bioregionalisation. However, it will be likely that some regions will be able to be subdivided into provinces before others because of differences in availability of small-scale data. Nevertheless, an important task will be to determine areas that may need to be given interim protection so that existing activities do not compromise the long-term conservation of biodiversity while the process elaborated below is undertaken.

114. The workshop agreed that the process identified above will require a Steering Committee, including members of the Scientific Committee and CEP. It would be useful if the work in paragraph 107 could be progressed for a workshop. The aim of the workshop would be to advise on a bioregionalisation of the Southern Ocean, including, where possible, advice on smaller-scale delineation of provinces and potential areas for protection to further the conservation objective of CCAMLR. To that end, the workshop requested the Scientific Committee consider whether this work should be progressed within the work program of WG-EMM or whether it should be an independent process.

115. An important role of the Steering Committee will be to involve appropriate experts from outside the Scientific Committee and CEP that could have data or expertise useful for the bioregionalisation.

116. In developing this work program and recognising the relative expertise of the Scientific Committee and CEP, the workshop suggested that CEP be invited to undertake the initial work necessary to develop a bioregionalisation of the coastal provinces, as an extension of its terrestrial bioregionalisation work, while the Scientific Committee undertakes the initial work needed to delineate the oceanic provinces. Such work would involve examination of both the benthic and pelagic systems in the respective areas.

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[7] A similar algorithm to that used for the Antarctic Environmental Domains Analysis was applied in the New Zealand EEZ. The resulting classification does not always capture the important biological contrasts due to the difficulties involved in the integration of different types of data (e.g. biological versus physical, pattern versus process, large-scale versus small-scale) in an automated process.

117. As a result of these discussions, the workshop identified the following steps in the process leading to a workshop in 2008, noting that some of this work could occur in parallel rather than sequentially:

(i) collate existing data on coastal provinces, including benthic and pelagic features;

(ii) collate existing data on oceanic provinces, including benthic and pelagic features;

(iii) determine the statistical analyses required to facilitate a bioregionalisation, including the use of empirical, model and expert data;

(iv) develop a broad-scale bioregionalisation based on existing datasets and other datasets possibly available prior to the workshop;

(v) delineate fine-scale provinces within regions, where possible;

(vi) establish a procedure for identifying areas for protection to further the conservation objectives of CCAMLR.

118. The workshop recommended that the Steering Committee be given the following terms of reference:

1. To facilitate collaboration between the CCAMLR Scientific Committee and CEP in this work.

2. To facilitate the involvement of appropriate experts in this work.

3. To coordinate and facilitate:

    (i) collating existing data on coastal provinces, including benthic and pelagic features and processes;

    (ii) collating existing data on oceanic provinces, including benthic and pelagic features and processes;

    (iii) determining the analyses required to facilitate a bioregionalisation, including the use of empirical, model and expert data;

    (iv) developing a broad-scale bioregionalisation based on existing datasets and other datasets possibly available prior to the workshop;

    (v) delineating fine-scale provinces within regions, where possible;

    (vi) establishing a procedure for identifying areas for protection to further the conservation objectives of CCAMLR.

4. To organise a workshop to establish a bioregionalisation for the CCAMLR Convention Area and to consolidate advice on a system of protected areas.

119. In discussing these scientific requirements, the workshop noted the potential synergies in the future between this work and work undertaken in WG-FSA and WG-EMM on the spatial components of fisheries and ecosystem function (e.g. areas of high productivity, foraging areas, movement and dispersal patterns).

ADVICE TO THE SCIENTIFIC COMMITTEE

120. In accordance with instructions from the Commission (CCAMLR-XXIII, paragraph 4.13) and the Scientific Committee (SC-CAMLR-XXIII, paragraphs 3.51 to 3.53), the CCAMLR Workshop on Marine Protected Areas met at NOAA National Marine Fisheries Service in Silver Spring, MD, USA, from 29 August to 1 September 2005. Terms of reference are provided in paragraph 6.

121. The workshop agreed that advice on the application of MPAs as related to Articles II and IX of the Convention would be provided to Members at the 2005 meeting of the Scientific Committee.

Term of reference (i) to review current principles and practices related to the establishment of MPAs

122. The workshop agreed that the NRSMPA, which included three elements referred to as the comprehensive, adequate and representative (CAR) system, provided one candidate approach to the designation of MPAs that may have applications in terms of principles and criteria, to CCAMLR's consideration of MPAs in the Southern Ocean (paragraphs 12 to 14).

123. The workshop noted that South Africa's Prince Edward Islands MPA process also provided a useful case study on the establishment of MPAs within the CCAMLR Convention Area (paragraph 15).

124. Within the CCAMLR context, the workshop recognised the need to develop a strategic approach to MPA design and implementation throughout the Southern Ocean notably in relation to a system of protected areas described below (paragraphs 16 and 66 to 70). It also recognised that there was a strong need for collaboration at technical and policy levels to further develop the MPA concept in the Southern Ocean. Relevant bodies in such a dialogue would include key elements of the Treaty System (CEP and the ATCM) as well as SCAR, SCOR, Observers to CCAMLR, intergovernmental and non-governmental organisations (paragraph 17).

125. The workshop suggested that establishing a harmonised regime for the protection of the Antarctic marine environment across the ATS should be the primary aim but recognised that there would need to be a division between ATCM and CCAMLR on the management of different human activities in the region (paragraph 22).

Workshop Term of Reference (ii) to discuss how the use of MPAs could be used to contribute to furthering the objectives of CCAMLR

126. Given the noted benefits of MPAs and the existing commitments of many, if not most, Members of CCAMLR to the establishment of representative networks of MPAs (e.g. in respect of the WSSD, the CBD, World Parks Congress etc.), the workshop concluded that MPAs had considerable potential for furthering CCAMLR's objective in applications ranging from protection of ecosystem processes, habitats and biodiversity, to protection of species (including population and life history stages) (paragraphs 32 to 36).

127. The workshop agreed that, overall, when viewed in relation to the IUCN categories of protected areas, the Convention Area as a whole would qualify as Category IV (Habitat/Species Management Area: protected area managed mainly for conservation through management intervention). This is defined as an area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species (paragraph 47).

128. The workshop commended the specific procedures and frameworks for planning biodiversity conservation outlined in the Guidelines for Establishing the Australian National Representative System of MPAs (NRSMPA), which had underpinned the establishment of the HIMI Marine Reserve. It recognised that the principles involved, notably those relating to CAR, together with the use of precautionary approaches and wide consultation with appropriate interest groups, combined with flexible decision-making and review procedures, and the capacity to designate areas for interim protection, were fundamental to the development of protected area networks in regional seas. They would be equally essential to similar undertakings in high-seas areas (paragraphs 48 to 60).

129. The workshop agreed that conservation outcomes appropriate for achieving the objectives in CCAMLR Article II would include the maintenance of biological diversity as well as the maintenance of ecosystem processes (see paragraphs 61 to 64 for detail).

130. It was agreed (paragraph 62) that attention may need to be given to the need for, *inter alia,* protection of:

- representative areas;
- scientific areas to assist with distinguishing between the effects of harvesting and other activities from natural ecosystem changes as well as providing opportunities for understanding the Antarctic marine ecosystem without interference;
- areas potentially vulnerable to impacts by human activities, to mitigate those impacts and/or ensure the sustainability of the rational use of marine living resources.

131. It was noted that some areas in the Southern Ocean may have predictable features that are critical to the function of local ecosystems. The workshop agreed that such areas would be appropriate to be included in a system of protected areas. Some participants felt that this should be considered as an objective in its own right, as follows (paragraph 63):

> The protection or maintenance of important ecosystem processes, in locations where those processes are amenable to spatial protection.

132. The workshop also considered the need for the Commission to achieve satisfactory fishery outcomes in terms of sustainable rational use. The process for establishing a system of protected areas will need to have regard for this objective of the Commission (paragraph 64).

133. The workshop recommended that the Scientific Committee work toward developing a system of protected areas described in paragraphs 61 to 70. The general objectives for which protected areas may be established and the types of protection that could be given in accordance with Article IX are illustrated in Table 1. These types of areas could be applied anywhere within the Convention Area.

134. The workshop advised that some areas may be identified as candidates for special protection but that it needs more information before a conclusion on protection can be reached. In this case, it agreed that interim protection would be needed (paragraph 68).

135. The workshop recognised that the term 'Specially Protected Areas' and other similar terms as provided in Table 1 and discussed in paragraphs 66 to 70 have meanings in other forums that are not the same meanings as those used in this report. The workshop recommended that the Scientific Committee or Commission consider the terms to be used for the different forms of closed areas identified and consult with the ATCM over how to harmonise the implementation of CCAMLR closed areas.

Term of reference (iii) to consider proposals that are currently under development or in a conceptual phase that relate to MPAs in the Convention Area

136. The workshop recommended that CCAMLR consider clarifying implementation of ATCM Decision 9 (2005), with clear guidelines for determining if a marine protected area will be of interest to CCAMLR. Identifying guidelines in terms of a percent of area occupied by a known harvestable resource and encompassed in a protected area that would be of interest to CCAMLR would be useful. These guidelines could be incorporated into a whole set of guidelines described below (paragraphs 90 and 91).

137. The workshop agreed that experiences with recent and current proposals could be used to develop a whole set of guidelines. CCAMLR Members could be asked to indicate whether or not those proposals should have been submitted to CCAMLR, and this information could then be used to help develop the guidelines. This would allow CCAMLR to continue the review of proposals for protected areas, but would generate clearer guidance for the review of future proposals, and consequently reduce the workload of CCAMLR (paragraph 92).

Term of Reference (iv) to discuss the types of scientific information that may be required for the development of MPAs to further the objectives of CCAMLR, including the identification of biophysical regions across the Convention Area

138. The workshop identified key tasks needed in considering a system of protected areas to assist CCAMLR in achieving its broader conservation objectives. These are (not necessarily to be undertaken sequentially) (paragraph 107):

- a broad-scale bioregionalisation of the Southern Ocean;

- a fine-scale subdivision of biogeographic provinces, which may include hierarchies of spatial characteristics and features within regions, giving particular attention to areas identified in the bioregionalisation;

- identification of areas that might be used to achieve the conservation objectives identified in paragraphs 61 to 70 (see paragraph 133);

- determination of areas requiring interim protection.

139. The workshop agreed that these tasks should be attempted with a desktop study in the first instance. Finally, Table 2 lists the types of data that might be used in a process to determine key bioregions and provinces in a bioregionalisation of the Southern Ocean (paragraphs 107 to 109).

140. The workshop noted that an important task will be to determine areas that may need to be given interim protection so that existing activities do not compromise the long-term conservation of biodiversity while the process elaborated below is undertaken (paragraph 113).

141. The workshop agreed that the process identified above will require a Steering Committee, including members of the Scientific Committee and CEP. It would be useful if the work in paragraph 107 could be progressed for a workshop. The aim of the workshop would be to advise on a bioregionalisation of the Southern Ocean, including, where possible, advice on smaller-scale delineation of provinces and potential areas for protection to further the conservation objective of CCAMLR. To that end, the workshop requested the Scientific Committee consider whether this work should be progressed within the work program of WG-EMM or whether it should be an independent process (paragraph 114).

142. An important role of the Steering Committee will be to involve appropriate experts from outside the Scientific Committee and CEP that could have data or expertise useful for the bioregionalisation (paragraph 115).

143. In developing this work program and recognising the relative expertise of the Scientific Committee and CEP, the workshop suggested that CEP be invited to undertake the initial work necessary to develop a bioregionalisation of the coastal provinces, as an extension of its terrestrial bioregionalisation work, while the Scientific Committee undertake the initial work needed to delineate the oceanic provinces. Such work would involve examination of both the benthic and pelagic systems in the respective areas (paragraph 116).

144. The workshop recommended (paragraph 118) that the Steering Committee be given the following terms of reference:

1. To facilitate collaboration between the CCAMLR Scientific Committee and CEP in this work.

2. To facilitate the involvement of appropriate experts in this work.

3. To coordinate and facilitate:

   (i) collating existing data on coastal provinces, including benthic and pelagic features and processes;

   (ii) collating existing data on oceanic provinces, including benthic and pelagic features and processes;

   (iii) determining the analyses required to facilitate a bioregionalisation, including the use of empirical, model and expert data;

   (iv) developing a broad-scale bioregionalisation based on existing datasets and other datasets possibly available prior to the workshop;

   (v) delineating fine-scale provinces within regions, where possible;

   (vi) establishing a procedure for identifying areas for protection to further the conservation objectives of CCAMLR.

4. To organise a workshop to establish a bioregionalisation for the CCAMLR Convention Area and to consolidate advice on a system of protected areas.

CLOSE OF THE WORKSHOP

145. The report of the workshop was adopted.

146. Dr Penhale congratulated all participants on the successful conclusion of the workshop and thanked them for their contribution. She especially thanked the rapporteurs for producing the workshop report.

147. The participants joined Prof. Croxall in thanking the US National Science Foundation, the NOAA National Marine Fisheries Service and Dr Penhale and her team, particularly Ms R. Tuttle, Mr R. Williams and Ms Toschik, for organisation and hosting the meeting, and providing outstanding support.

148. The meeting was closed.

Table 1: Illustration of the types of closed areas that could be used by CCAMLR for protection or conservation, noting the need to define areas in geographic coordinates and depth.

Objective	Type of area
Representativeness	Specially Protected Areas Conservation Zones*
Protection of areas vulnerable to human activities	Specially Protected Areas Conservation Zones* Fisheries Closed Areas
Science	Specially Protected Areas Conservation Zones* Fisheries Closed Areas
Protection of ecosystem function	Specially Protected Areas Conservation Zones* Fisheries Closed Areas

* In the application of the CCAMLR precautionary approach, interim measures may be required for candidate areas while being considered; in this case Conservation Zones could be established.

Table 2: List of types of data that might be used in a process to determine key bioregions and provinces in a bioregionalisation of the Southern Ocean. These data can be used to delineate important patterns, areas in which important processes occur and areas where pressures may be arising now and/or in the future.

Category	Specific types of data
Geology and geomorphology	Bathymetry Geological zones – coastal formations, islands, seamounts, plateaus, banks, ridges, canyons Substratum
Ocean	Sea-surface heights Temperature and salinity Biogeochemistry Fronts and gyres Currents (surface, midwater, deep) Upwelling areas
Climate	Wind shear and direction Pressure systems Temperature
Ice	Ice shelves Sea-ice coverage and progression
Biota (distribution, abundance, movement)	Sessile and sedentary benthos including habitat forming features Surface chlorophyll Secondary producers Demersal species (e.g. nototheniids) Small mesopelagic species (krill, myctophids) Large mesopelagic species – finfish (e.g. icefish), squid Marine mammals Birds
Outcomes of dynamic models	Outputs from existing ocean models
Existing and/or potential pressures	Existing fishing patterns Target and by-catch statistics Pollution Climate change Ocean noise Shipping activity Introduced species Tourism and/or national operations potentially impacting on marine species or ecosystems

APPENDIX I

AGENDA

CCAMLR Workshop on Marine Protected Areas
(Silver Spring, MD, USA, 29 August to 1 September 2005)

Introduction

Opening of the workshop
    Welcome to participants
    Overview of facilities, computer support, rapporteurs etc.

Adoption of the agenda and organisation of the workshop

Workshop objectives

Terms of reference for the workshop

(i) to review current principles and practices related to the establishment of MPAs

    general principles and guidelines
    current instruments/agreements
    economics
    examples in the Convention Area
    research papers/summary papers/abstracts

(ii) to discuss how the use of MPAs could be used to contribute to furthering the objectives of CCAMLR

    Articles II and IX of the Convention
    principles involved in the identification of potential MPAs in the Convention Area
    examples in the Convention Area

(iii) to consider proposals that are currently under development or in a conceptual phase that relate to MPAs in the Convention Area

    area around Prince Edward Islands
    southwest Anvers Island and vicinity
    the Balleny Islands and vicinity

(iv) to discuss the types of scientific information that may be required for the development of MPAs to further the objectives of CCAMLR, including the identification of biophysical regions across the Convention Area

    follow-up from discussions in term of reference (iii)
    identification of representative marine habitats

Recommendations for future work

Conclusion of the workshop.

APPENDIX II

LIST OF PARTICIPANTS

CCAMLR Workshop on Marine Protected Areas
(Silver Spring, MD, USA, 29 August to 1 September 2005)

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APPENDIX III

LIST OF DOCUMENTS

CCAMLR Workshop on Marine Protected Areas
(Silver Spring, MD, USA, 29 August to 1 September 2005)

WS-MPA-05/1	MPA Workshop Terms of Reference
WS-MPA-05/2	List of participants
WS-MPA-05/3	List of documents
WS-MPA-05/4	Marine protected areas in the context of CCAMLR: a management tool for the Southern Ocean IUCN information paper Submitted by IUCN
WS-MPA-05/5	A compilation of abstracts relating to marine protected areas and fisheries management IUCN information paper Submitted by IUCN
WS-MPA-05/6	Guidelines for establishing the [Australian] National Representative System of Marine Protected Areas Submitted by Australia
WS-MPA-05/7	The Heard and McDonald Islands Marine Reserve Delegation of Australia
WS-MPA-05/8	RSPB – The economics of marine protected areas
WS-MPA-05/9	Improving the process for the establishment of marine protected areas by CCAMLR and Antarctic Treaty Parties Delegation of Australia
WS-MPA-05/10	Progress on an Antarctic Specially Managed Area: Southwest Anvers Island and vicinity Delegation of the USA
WS-MPA-05/11	Scientific justification for a marine protected area designation around the Balleny Islands to protect ecosystem structure and function in the Ross Sea region, Antarctica: progress report Delegation of New Zealand
WS-MPA-05/12	Legal considerations surrounding the establishment of marine protected areas in Antarctica Delegation of New Zealand

WS-MPA-05/13	SCAR Biology Symposium (Curitiba, Brazil, 25 to 29 July 2005) Workshop on Marine Protected Areas (27 July) S. Grant (United Kingdom)
WS-MPA-05/14	Issues to consider before jumping on the marine protected area (MPA) bandwagon R.J. Brock and J.A. Uravitch (USA)
WS-MPA-05/15	Progress towards the declaration of a large marine protected area around South Africa's sub-Antarctic Prince Edward Islands D. Nel, A. Lombard, T. Akkers, J. Cooper and B. Reyers (South Africa)

Other CCAMLR documents

CCAMLR-XXIII/BG/22	Towards the creation of a marine protected area around South Africa's sub-Antarctic Prince Edward Islands Delegation of South Africa
SC-CAMLR-XXIII/BG/28 (Revised August 2005)	Summary tables of current and proposed Antarctic marine protected areas Delegation of the United Kingdom
SC-CAMLR-XXIII/BG/29	The biology, ecology and vulnerability of seamount communities Delegation of the United Kingdom
SC-CAMLR-XXIII/BG/30 (Revised: in press)	The applicability of international conservation instruments to the establishment of marine protected areas in Antarctica Delegation of the United Kingdom

Other papers

COFI/2005/8	Marine protected areas (MPAs) and fisheries
Balmford et al., 2004	Balmford, A., P. Gravestock, N. Hockley, C.J. McClean and C.M. Roberts. 2004. The worldwide cost of marine protected areas. *PNAS*, 101 (26): 9694–9697.
Blyth et al., 2004	Blyth, R.E., M.J. Kaiser, G. Edwards-Jones and P.J.B. Hart. 2004. Implications of a zoned fishery management system for marine benthic communities. *J. Appl. Ecol.*, 41: 951–961.
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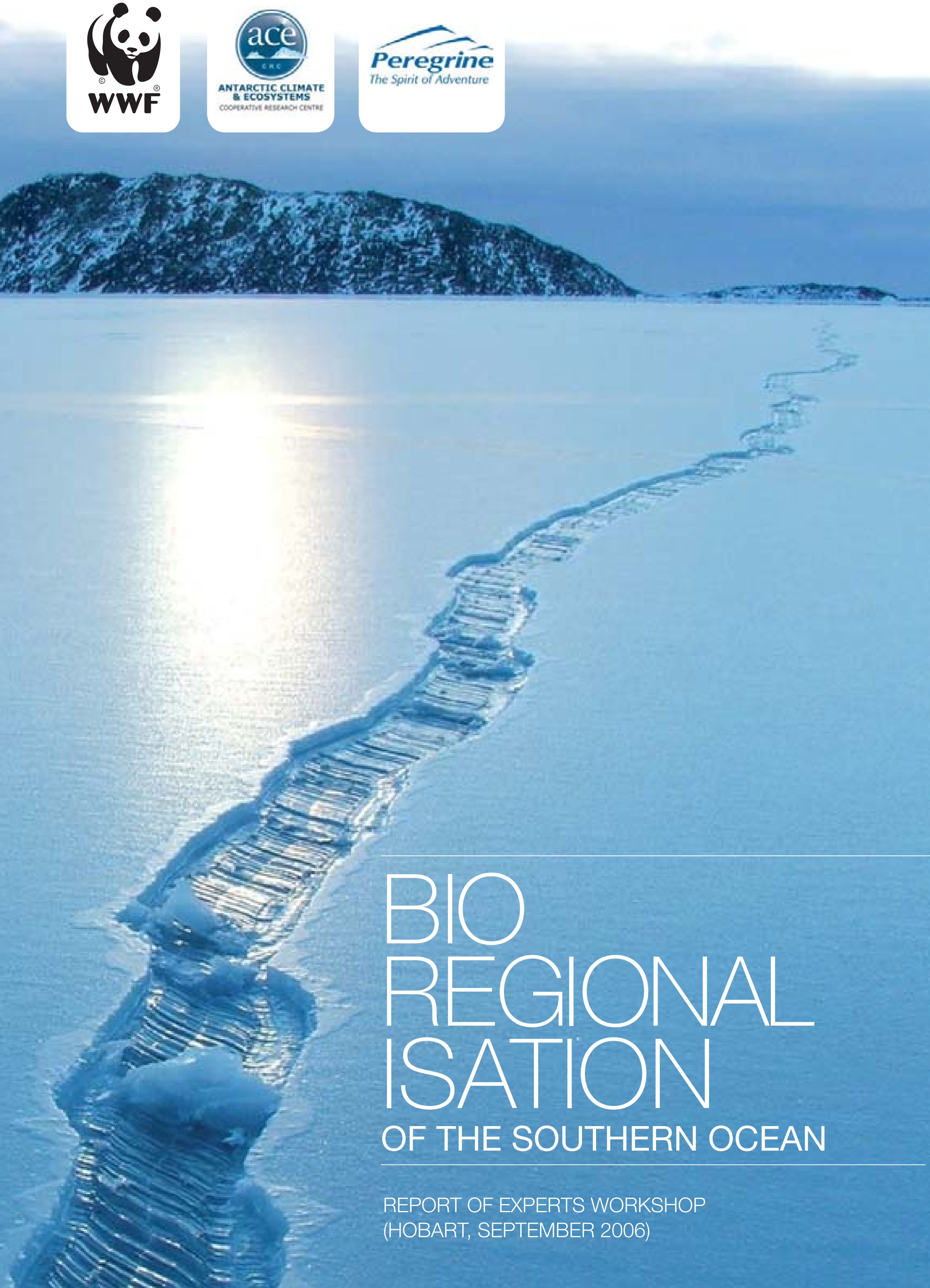
7. Report of the 2006 CRC/WWF Experts workshop on bioregionalisation of the Southern Ocean



BIO REGIONAL ISATION OF THE SOUTHERN OCEAN

REPORT OF EXPERTS WORKSHOP
(HOBART, SEPTEMBER 2006)

Report prepared by: Susie Grant, Andrew Constable, Ben Raymond and Susan Doust. Additional contributing authors: Roger Hewitt, Harry Keys, John Leathwick, Vincent Lyne, Rob Massom, Matt Pinkerton, Ben Sharp and Phil Trathan.

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The CD attached to this report includes appendices, analysis tools, data and maps (including a GIS database) referred to in the report.

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Responsible Tourism is a fundamental platform of Peregrine's operations. In line with this principle of sustainability, Peregrine has funded this report in the belief that it provides a foundation for the understanding and long-term conservation of Antarctica's important habitats and wildlife.

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The authors wish to thank all of the participants in the 2006 Experts Workshop, whose expertise and thoughtful input provided the material and outcomes for this report, as well as reviews of the manuscript. A full list of participants can be found at the end of the report.

Cover photo: © Paul Dudley courtesy Australian Government Antarctic Division

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Acronyms and abbreviations

ACC	Antarctic Circumpolar Current
ATCM	Antarctic Treaty Consultative Meeting
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CEP	Committee for Environmental Protection
CPR	Continuous Plankton Recorder
LME	Large Marine Ecosystem
MPA	Marine Protected Area
PAR	Photosynthetically active radiation
PF	Polar Front
SACCF	Southern Antarctic Circumpolar Current Front
SAF	Subantarctic Front
SC-CAMLR	Scientific Committee for the Conservation of Antarctic Marine Living Resources
SSH	Sea surface height
SST	Sea surface temperature
STF	Subtropical Front

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Executive Summary

In September 2006, twenty-three scientists from six countries attended an Experts Workshop on Bioregionalisation of the Southern Ocean held in Hobart, Australia. The workshop was hosted by the Antarctic Climate and Ecosystems Cooperative Research Centre, and WWF-Australia, and sponsored by Peregrine. The workshop was designed to assist with the development of methods that might be used to partition the Southern Ocean for the purposes of large-scale ecological modelling, ecosystem-based management, and consideration of marine protected areas. In 2005, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and its Scientific Committee (SC-CAMLR) considered that a bioregionalisation of the Southern Ocean was needed to underpin the development of a system of marine protected areas in the Convention area.

The aim of the workshop was to bring together scientific experts in their independent capacity to develop a ‘proof of concept’ for a broad-scale bioregionalisation of the Southern Ocean, using physical environmental data and satellite-measured chlorophyll concentration as the primary inputs. Work included presentation of background information, computer-based analysis undertaken in small groups, and plenary discussion on the methods, data and results. Workshop participants are listed at the end of this report.

At the conclusion of the workshop, a method had been agreed upon that could be used to take the bioregionalisation work forward. Consensus was achieved on a draft physical regionalisation, and progress was made in determining how to include additional (e.g. biological) data for a more complete bioregionalisation. This report outlines the key results of the workshop, and highlights some of the issues discussed.

An understanding of the spatial characteristics of large ecosystems such as the Southern Ocean is important for the achievement of a range of scientific, conservation and management objectives. Bioregionalisation is a process that aims to partition a broad spatial area into distinct spatial regions, using a range of environmental and biological information. The process results in a set of bioregions, each with relatively homogeneous and predictable ecosystem properties. The properties of a given bioregion should differ from those of other regions in terms of species composition as well as the attributes of its physical and ecological habitats.

Classification of regions based only on biological data is often impractical at larger scales because of insufficient geographic coverage, even though there may be sufficient data to subdivide smaller-scale portions of those regions. Physical and satellite-observed data generally have better spatial and temporal coverage and greater availability than biological data. These can be used to help characterise regions on the basis of environmental properties, physical processes, primary production, and habitat type.

Initial discussions during the workshop focused on defining the major physical processes in the Southern Ocean, and their relationships with ecological processes. A key aspect of undertaking an ecologically meaningful regionalisation is to understand how important ecological processes correspond to the physical and satellite-observed parameters, and whether these parameters are appropriate for use as proxies or surrogates. This may depend in part on the end-use application of the analysis, and the scale at which the analysis is being undertaken.

Environmental data used as the primary input for analysis during this workshop were chosen based on their spatial coverage across the Southern Ocean. The datasets considered included bathymetry, sea ice concentration and extent, sea surface temperature, sea surface height, chlorophyll *a* concentration, nutrient data (silicate, nitrate and phosphate), and insolation (photosynthetically active radiation - PAR).

A series of presentations on approaches to bioregionalisation that have been undertaken elsewhere (terrestrial Antarctica, Australia, New Zealand) allowed detailed consideration of the relative benefits of different methods. The analytical methods used by Lyne and Hayes (2005), Leathwick et al. (2006a) and Raymond & Constable (2006) were used as starting points for the analysis during the workshop. These methods were refined into a single methodology, In September 2006, twenty-three scientists from six countries attended an Experts Workshop on Bioregionalisation of the Southern Ocean held in Hobart, Australia. The workshop was hosted by the Antarctic Climate and Ecosystems Cooperative Research Centre, and WWF-Australia, and sponsored by Peregrine. The workshop was designed to assist with the development of methods that might be used to partition the Southern Ocean for the purposes of large-scale ecological modelling, ecosystem-based management, and consideration of marine protected areas.

following workshop discussions and practical explorations of the methods.

Issues examined included the choice of data and extraction of relevant parameters to best capture ecological properties, the use of data appropriate for end-user applications, and the relative utility of taking a hierarchical, non-hierarchical, or mixed approach to regionalisation. The final method involved the use of a clustering procedure to classify individual sites into groups that are similar to one another within a group, and reasonably dissimilar from one group to the next, according to a selected set of parameters (e.g. depth, ice coverage, temperature). This approach shared strong similarities to several previous regionalisation methods, including Lyne and Hayes (2005) and Leathwick et al. (2006a).

The workshop established a proof of concept for bioregionalisation of the Southern Ocean, demonstrating that this analysis can delineate bioregions that agree with expert opinion at the broad scale. Consensus was reached on which of the trial bioregionalisations were the most ecologically and statistically meaningful according to expert opinion.

The workshop concluded that a statistical, hierarchical approach was the most useful in displaying the different levels of similarity and providing choices on the degree to which the region might be subdivided on the basis of the chosen datasets. The datasets were divided into primary and secondary datasets, reflecting

the primary properties of the region and the secondary environmental properties that might provide smaller-scale subdivisions to reflect the spatial heterogeneity of the Southern Ocean ecosystem.

The primary datasets used in this analysis were depth, sea surface temperature, silicate and nitrate. These highlighted the different environmental characteristics of large regions including the continental shelf and slope, frontal features (Subantarctic Front, Polar Front, Southern Antarctic Circumpolar Current Front), the deep ocean, banks and basins, island groups and gyre systems. Other primary datasets that could be usefully considered in future analyses were identified by the workshop, and included sea surface height and insolation.

The secondary datasets used in the analysis were ice concentration and mean chlorophyll *a* values. The addition of these datasets suggested smaller-scale spatial heterogeneity within the regions particularly in the continental shelf and slope areas, and the seasonal ice zone. These results highlighted the need for further analysis at the secondary level.

The final stages of the analysis included discussion on how well the defined regions corresponded to our present knowledge of the Southern Ocean. Experts provided information on the patterns and features that they would expect to see, according to current observations and understanding, and these largely concurred with the outcomes of the analysis.

Finally, workshop participants discussed priorities for future work, including the development of further methods to deal with uncertainty, understanding of inter- and intra-annual variation, validation of results, the incorporation of additional data (particularly biological datasets) and finer-scale analysis of particular areas of interest.

This workshop established a 'proof of concept' for bioregionalisation of the Southern Ocean. Continuation of this work will be an important contribution to the achievement of a range of scientific, management and conservation objectives, including large-scale ecological modelling, ecosystem-based management, and the development of an ecologically representative system of marine protected areas.

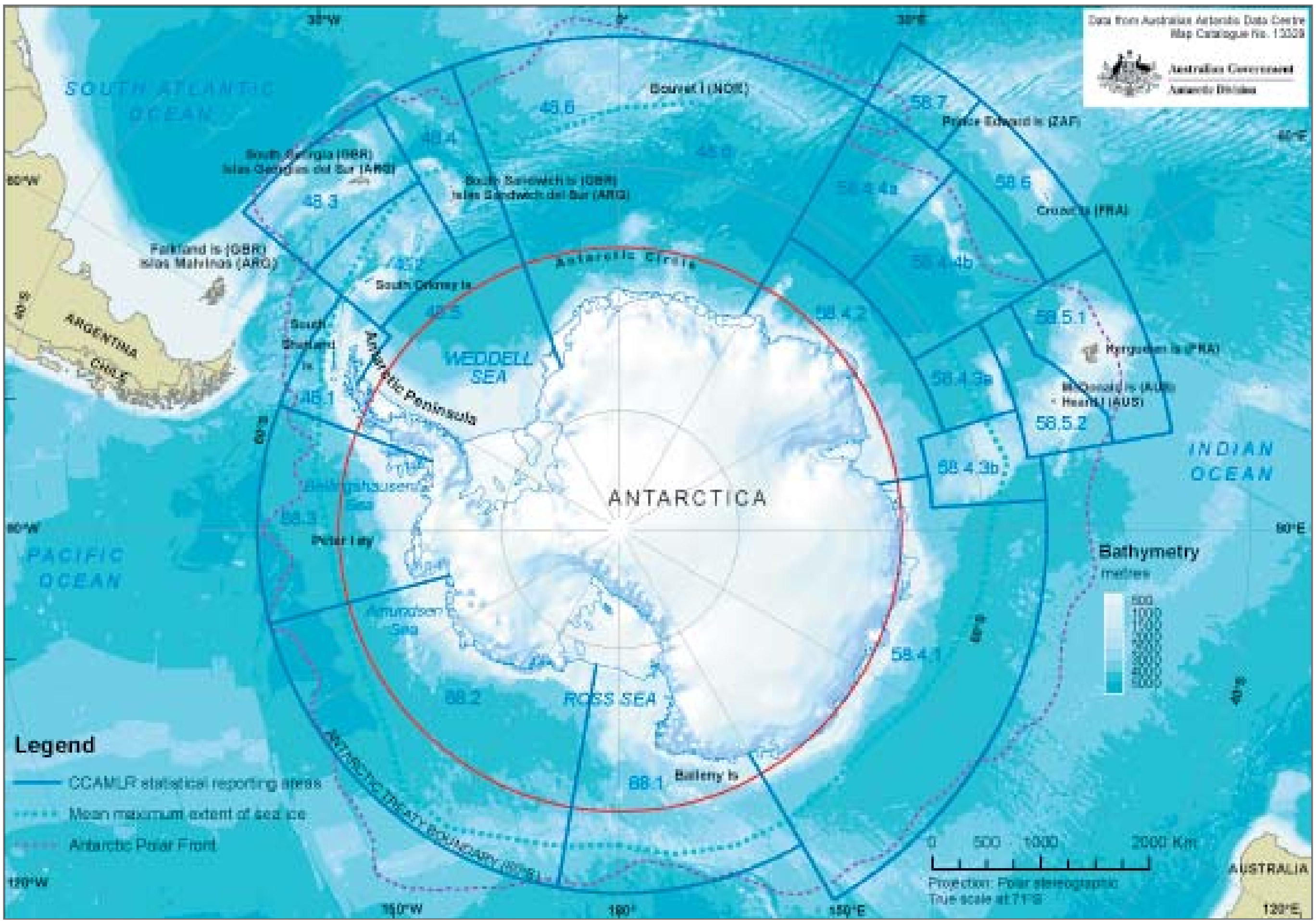

FIGURE 1: Map of Antarctica and the Southern Ocean. (Data from Australian Antarctic Data Centre)

1. Introduction

The Southern Ocean covers around 10% of the world's ocean surface, and includes some of the most productive marine regions on Earth. Although they are among the least-studied, the seas around Antarctica are a critical component of the global climate system and marine ecosystem.

An understanding of the spatial characteristics of large ecosystems such as the Southern Ocean is important for the achievement of a range of scientific, management and conservation objectives including ecological modelling, ecosystem-based management of living resources, and the establishment of an ecologically representative system of marine protected areas.

Bioregionalisation is a process that aims to partition a broad spatial area into distinct spatial regions, using a range of environmental and biological information. The process results in a set of bioregions, each with relatively homogeneous and predictable ecosystem properties. The properties of a given bioregion should differ from those of other regions in terms of species composition as well as the attributes of its physical and ecological habitats. Bioregionalisation can assist in providing information on the location and distribution of species and their habitats, and is an important foundation for efforts to further understand, conserve and manage activities in the marine environment.

Attempts to classify large ocean areas into meaningful management units have been carried out for coastal and shelf areas worldwide, for example in the definition of Large Marine Ecosystems (LMEs) (Sherman and Alexander, 1986; Sherman and Duda, 1999), Marine Ecoregions (Spalding et al., 2006), and the use of LMEs together with biogeochemical provinces (Platt and Sathyendranath, 1988; 1993; Longhurst, 1998) to define global regions for ecosystem-based fisheries management (Pauly et al., 2000).

In 2005, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and its Scientific Committee (SC-CAMLR) identified a series of key tasks to assist in developing a comprehensive and ecologically representative system of marine protected areas (MPAs) (SC-CAMLR-XXIV, 2005). A broad-scale bioregionalisation of the Southern Ocean was identified as an important first step in this process. CCAMLR agreed that this process will need to be undertaken in cooperation with the Committee for Environmental Protection (CEP), which reports to the Antarctic Treaty Consultative Meeting (ATCM).

In 2006, WWF initiated a project to undertake some of the initial work towards a broad-scale bioregionalisation, in partnership with the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC, Australia) and sponsored by Antarctic expedition cruise operator, Peregrine. The aim of this work has been to develop a 'proof of concept' for a broad-scale bioregionalisation of the Southern Ocean based on synoptic environmental data in the first instance.

As part of this work program, an Experts Workshop was held in Hobart, 4-8 September 2006, to review and expand upon the initial developmental work provided by Raymond and Constable (2006). This document provides a report of that workshop, detailing:

- background to the workshop and bioregionalisation in the Southern Ocean;
- an agreed approach to bioregionalisation;
- an example of a regionalisation for the Southern Ocean based on synoptic environmental data; and
- future work towards a bioregionalisation of the Southern Ocean.

An understanding of the spatial characteristics of large ecosystems such as the Southern Ocean is important for the achievement of a range of scientific, conservation and management objectives. Bioregionalisation is a process that aims to partition a broad spatial area into distinct spatial regions, using a range of environmental and biological information. The process results in a set of bioregions, each with relatively homogeneous and predictable ecosystem properties. The properties of a given bioregion should differ from those of other regions in terms of species composition as well as the attributes of its physical and ecological habitats.

1.1 What is bioregionalisation?

Large ecosystems can be partitioned at a range of spatial scales, according to their physical, environmental and biological characteristics. Variation in climate, topography and other physical factors forms different habitat types, which in turn support different species and communities. Biological diversity varies throughout this geographic space, and may be further influenced by factors such as the availability of nutrients and food, as well as human activities.

For example, forests, deserts and grasslands have different physical and environmental attributes, and contain different habitat types and communities of species. These different regions may occur adjacent to one another; however, each differs from the others in terms of physical and ecological characteristics. Some species may range across more than one region, whereas others will be more restricted in their range, according to their ability to live in particular habitat types or ecological conditions. For example, cacti are uniquely adapted to live only in desert conditions, while certain ubiquitous grasses are found in parts of the forest and the grassland, as well as the desert. Migrating birds may travel across all three regions, while deer inhabit the forest and the grassland but not the desert, and tree-dwelling mammals remain exclusively in the forest.

Boundaries between regions may be sharp, for example at the interface between a forest and adjacent alpine areas. Features such as the tree-line reflect the limit of tolerance by certain species to a particular set of physical conditions. However, boundaries may also be gradual, such as in the margins of a desert, where habitats and species from both the desert and the neighbouring grassland gradually blend across a wide transitional area. Transitional areas between adjacent ecosystems, regions or habitats are known as ecotones, and species may be found in decreasing numbers as they reach the edge of their range. Bioregionalisation provides a simplified interpretation of these physical and ecological boundaries. It endeavours to separate, say, desert, grassland and forest by drawing boundaries between them such that the attributes within each of the bounded areas are primarily desert, grassland and forest respectively.

This terrestrial analogy provides a simplified description of the bioregionalisation concept, and its utility in providing pragmatic solutions to complex ecological problems. Apart from the edges of rocky reefs, regional boundaries in the oceans are likely to be less sharp (or more ‘fuzzy’), and they may be more mobile or variable because of the fluid nature of the marine environment. Regionalisation of marine ecosystems is also more complex because of their three-dimensional nature. However, marine ecosystems can nevertheless be partitioned using the principles described above to provide a simplified interpretation spatial differences in their environmental characteristics, habitat types and ecological boundaries.

Defining regions

Regions are generally defined using a combination of qualitative (expert opinion, descriptive data) and quantitative statistical analyses. A range of data on physical, environmental and biological properties can be incorporated into a regionalisation analysis, according to data availability and coverage, and specific end-use applications. Statistical procedures for undertaking a regionalisation attempt to partition a broad spatial area into discrete regions, each with relatively homogeneous and predictable ecosystem properties, but sometimes occurring in more than one geographic location (Leathwick et al. 2003). The properties of a given region (both species composition as well as attributes of the physical and ecological habitats) should differ from those of adjacent regions.

Regions can be defined according to the range of species or communities that inhabit them. Indicator species may also be used, where individual species are known to exclusively inhabit a certain type of region. For example, certain species of desert snake, grassland lizard and forest frog might be used as indicators to define these regions.

Alternatively, physical and environmental information can be used to define regions using qualitative methods (e.g. Bailey, 1996). Topography, altitude, substratum and temperature are among the variables which influence the characteristics and structure of habitats and their associated species and communities. An understanding of the spatial extent of different environmental conditions and physical habitats can provide further information on the ecological properties likely to be found in each area, and thus the types of communities or species which might occur there. As a simplified example, the distribution of freshwater habitats may give some indication of where frogs are likely to be found. This is particularly useful where biological information is unavailable. Information on the distribution of frogs over a large area may be impractical to obtain, however freshwater ponds could

be more easily identified using aerial photography.

Approaches to defining regions may also vary according to the particular application of a bioregionalisation analysis. For example, a manager interested in the conservation of reptiles may choose to define regions according specifically to the distribution of snakes and lizards, whereas an agricultural scientist might be more interested in the division of regions according to substratum type and topography.

Bioregions may also be defined at different spatial scales, according to the biological, physical or environmental characteristics of interest, and the scale of the data being used in the analysis (e.g. Bailey, 1996). The forest, grassland and desert may be encompassed within a much larger unit; for example all of these regions would be found in southern Africa. Within a particular region, there may also be finer-scale ecosystem divisions. For example, within a forest region, a mountain will support different vegetation with increasing altitude. Different forest communities may be found higher up the mountain, reflecting changes in topography and climatic conditions. At an even finer scale, features such as mountain streams, valleys and rocky outcrops may result in different forest communities occurring at the same altitude. Smaller scale ecosystems or regions can be seen as nested within ecosystems of a higher order, thus occurring within a hierarchical system.

Clearly, the final regionalisation will be dictated by the spatial detail required and the specific attributes needing to be captured in the subdivision. Nevertheless, a regionalisation needs to show generally how those attributes are nested within the larger scale heterogeneity of the system. This helps to appreciate whether areas with similar properties but separated in space may be influenced by different external environmental and ecological drivers at their boundaries.

Approaches to bioregionalisation in the marine environment have included the use of physical oceanographic parameters (e.g. ocean water masses, fronts, gyres and wave energy), geomorphology (e.g. depth, substratum, sediment characteristics and disturbance regimes), biological oceanography (e.g. primary and secondary production), fish stock distribution and abundance (e.g. areas of aggregation and fishing patterns), benthic communities (e.g. distribution and community structure) and marine mammals and birds (e.g. primary feeding and breeding locations).

Classification of regions based only on biological data is often impractical at larger scales because of insufficient geographic coverage, even though there may be sufficient data to subdivide smaller-scale portions of those regions (Belbin, 1993). Physical and satellite-observed data generally have better spatial and temporal coverage and greater availability than biological data. These can be used to help characterise regions on the basis of environmental properties, physical processes, primary production, and habitat type.

An important aspect of undertaking an ecologically meaningful regionalisation is therefore to understand how important ecological processes correspond to physical parameters, and whether those parameters are appropriate for use as proxies or surrogates. This may not require much ecological detail in the first instance, since physical and environmental data can provide an understanding of environmental heterogeneity which will inevitably affect the ecology of a region.

Photograph © Roger Kirkwood, courtesy Australian Government Antarctic Division

1.2 Bioregionalisation in the Antarctic context

Bioregionalisation of the Southern Ocean has relevance in a variety of applications within different scientific fields and for conservation and management across the Antarctic Treaty System. An understanding of spatial ecosystem characteristics is necessary to achieve a range of objectives in the Antarctic context, including:

- ecosystem modelling;
- ecosystem-based management of marine living resources;
- effective and systematic planning and management of other human activities;
- identification of biodiversity units and areas of high conservation value;
- establishment of a comprehensive and ecologically representative system of MPAs; and
- directing further research.

Recent discussions within the CCAMLR Scientific Committee (SC-CAMLR-XXIV) and the Committee for Environmental Protection (CEP IX) have agreed the importance of undertaking a bioregionalisation of the Southern Ocean, and highlighted the need to work together in achieving this common objective.

CCAMLR

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) applies to all marine living resources within the area south of a line approximating to the Polar Front. The Convention Area is divided into three sectors corresponding to the adjacent Atlantic, Indian and Pacific oceans. These sectors are referred to as Statistical Areas 48, 58 and 88 respectively, and each is further divided into statistical subareas for catch reporting and management purposes (see Figure 1). Statistical subareas were defined on the basis of ocean characteristics, fish stock distributions and the location of fishing activities (Everson, 1977; Kock, 2000), thus providing one example of an existing bioregionalisation of the Southern Ocean. Subareas are used in catch reporting, and enable the implementation of conservation and management measures regionally or for individual stocks.

The primary objective of CCAMLR is the conservation of Antarctic marine living resources, where conservation includes rational use. CCAMLR has pioneered a precautionary, ecosystem approach to marine living resource management, and defines the Antarctic marine ecosystem as "the complex of relationships of Antarctic marine living resources with each other and with their physical environment".[1]

In 2005, the CCAMLR Workshop on MPAs considered the scientific work required for development of a system of protected areas to assist CCAMLR in achieving its conservation objectives. A broad-scale bioregionalisation of the Southern Ocean was identified as an important first step in this process (SC-CAMLR-XXIV, 2005).

CCAMLR has identified a series of key tasks to be undertaken towards bioregionalisation:

- collation of existing data, including benthic and pelagic features and processes;
- determination of statistical analyses required to facilitate a bioregionalisation, including use of empirical, model and expert data;
- development of a broad-scale bioregionalisation of the Southern Ocean, based on existing datasets; and
- delineation of fine-scale provinces within regions, where possible.

As part of this ongoing work, CCAMLR will hold a workshop in 2007 with the aim of providing advice on a bioregionalisation of the Southern Ocean, including, where possible, advice on smaller-scale delineation of provinces and potential areas for protection to further the conservation objective of CCAMLR. This workshop will involve members of both the CCAMLR Scientific Committee and the CEP, as well as external experts (SC-CAMLR-XXIV, 2005).

Committee for Environmental Protection

The Antarctic Treaty and its Protocol on Environmental Protection apply to the area south of 60°S, thus covering a smaller marine area than CCAMLR. The Environmental Protocol deals with environmental impact assessment, conservation of Antarctic flora and fauna, waste disposal and management, prevention of marine pollution, and area protection and management. The Committee for Environmental Protection (CEP) provides advice and recommendations to the ATCM in connection with the implementation of the Environmental Protocol.

Annex V of the Environmental Protocol states that Parties shall seek to identify a series of Antarctic Specially Protected Areas (ASPAs) (including marine and terrestrial areas) within a 'systematic environmental-geographic framework'[2]. This term has been defined as: "a method of classifying or organising subsets of environmental and geographic characteristics such as different types of ecosystems, habitat, geographic area, terrain, topography, climate, individual features and human presence into geographic regions. Each region would be distinctive or in some way different from other regions but some might have characteristics in common." (ATCM XXIV/WP012, 2001).

The bioregionalisation work proposed by CCAMLR corresponds closely to current efforts by the CEP to elaborate a systematic environmental-geographic framework, in particular through the terrestrial Antarctic Environmental Domains Analysis being undertaken by New Zealand for the Antarctic continent (Morgan et al., 2005).

In outlining the work programme for bioregionalisation, CCAMLR recognised the relative expertise of the CEP, and suggested that the CEP should be invited to undertake the initial work necessary to develop a bioregionalisation of the coastal provinces, as an extension of its terrestrial bioregionalisation work. At its meeting in 2006, the CEP undertook to engage fully with CCAMLR on this work, and agreed on the importance of such an analysis in contributing to its conservation and management objectives (CEP IX, 2006).

[1] CCAMLR, Article 1
[2] Protocol on Environmental Protection, Annex V, Article 3(2)

1.3 Antarctica and the Southern Ocean

Southern Ocean characteristics

The Southern Ocean extends across a total area of almost 35 million km^2, and consists of distinct provinces that differ physically and chemically (e.g. temperature, sea ice, nutrients and currents), as well as ecologically. It is characterised by deep basins, separated by large, mid-oceanic ridges and containing prominent plateaus and island groups.

Two major currents dominate the Southern Ocean system. The Antarctic Circumpolar Current (ACC) (or "West Wind Drift") flows eastwards around the continent, driven by the prevailing westerly winds. The ACC forms a unique link connecting all of the world's major oceans through an unbroken water mass surrounding the Antarctic continent, (Orsi et al., 1995). However, its path is influenced by topographic features such as the Kerguelen Plateau and the Scotia Arc, which deflect fronts and generate eddies. Closer to the continent, easterly winds form a series of clockwise gyres (the largest of these being in the Ross Sea and Weddell Sea) that combine to form the westward flowing Antarctic Coastal Current, also known as the "East Wind Drift".

The Subtropical Front (STF) marks the northernmost extent of the ACC, separating warmer, more saline subtropical waters from fresher, cooler subantarctic surface waters (Orsi et al., 1995). Further south, the majority of ACC water is transported in the Subantarctic Front (SAF), and also in the Polar Front, which marks the transition to very cold and relatively fresh Antarctic

Surface Water, and separates Southern Ocean waters from the Atlantic, Pacific and Indian oceans to the north. The Polar Front also marks the northerly limit of many non-migrating Antarctic species (Knox, 1994), including Antarctic krill (*Euphausia superba*), the staple food of many of the Southern Ocean's seabirds, marine mammals and fish. Closer to the Antarctic continent, upwelling of very dense, cold abyssal waters occurs at the southern boundary of the ACC.

The Southern Ocean plays an important role in the global ocean circulation system. Figure 2 shows the relationships between the frontal systems and the greater patterns of ocean circulation. Of note are the extremely cold winds blowing off the Antarctic Ice Sheet which cool the coastal waters. In certain recurrent locations (coastal polynyas), these create high rates of sea ice formation. This in turn leads to the formation of cold, dense saline water that sinks to form Antarctic Bottom Water. This complex system also sees a continual surface expression in the Southern Ocean of the global ocean's normally deep nutrient layer, which is the primary reason for the sustained high productivity in the region. In the tropics, this nutrient layer only reaches the surface through upwelling.

The continental shelf surrounding Antarctica is unusually deep compared to elsewhere in the world, as a result of scouring by ice shelves and crustal depression caused by the weight of continental ice (Clarke, 1996). The continental shelf is generally narrow, except in large embayments such as the Ross Sea and Weddell Sea.

The Southern Ocean is covered by a band of largely seasonal sea ice that extends from a maximum southerly extent of ~75^{o}S northwards as far as ~55^{o}S at its maximum extent. The width of this band is highly variable, ranging from a few hundred kilometres in the Indian Ocean sector to ~1600 km in the Weddell Sea. Given the relatively narrow width of the continental shelf surrounding the Antarctic continent, a large proportion of the Antarctic ice cover occurs over deep ocean, where it is exposed to a zone of strong cyclone activity and ocean waves and swell. The latter create a well-developed circumpolar marginal ice zone, which effectively protects the inner pack from incoming ocean wave energy.

The coastal zone is complex, with sea ice distribution and characteristics (of both pack and fast ice) being affected by coastal configuration and the presence of grounded icebergs, which are in turn closely linked to bathymetry (Massom et al., 2001). Coastal

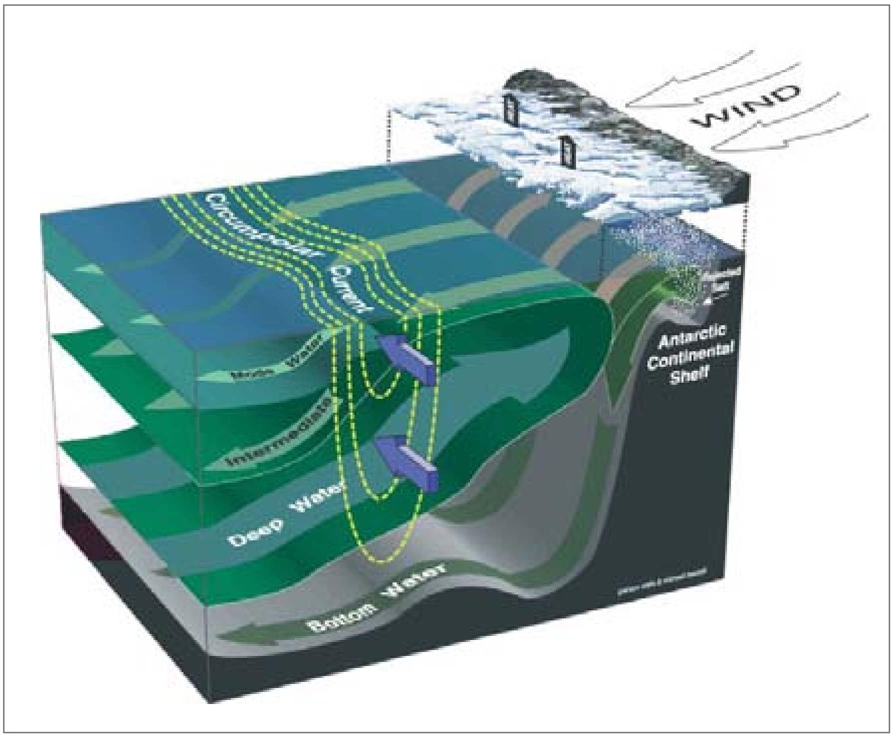

FIGURE 2: Three-dimensional structure of water masses, showing relationship between the ACC and deep water (Figure reprinted with permission from: Rintoul, 2000).

polynyas (large areas of open water) occur around the continent (Arrigo and van Dijken, 2003), and there are also two deep water polynyas in the Weddell and Cosmonaut seas (Morales Maqueda et al., 2004). Polynyas constitute major regional sea ice "factories", sites of major water-mass modification and, in places, enhanced biological activity.

The seasonal cycle of sea ice advance and retreat is one of the major drivers of physical and ecological processes in the Southern Ocean. On the hemispheric scale, the sea ice cover in winter interacts with key oceanic and biological boundaries such as the continental shelf break, the southern boundary of the Antarctic Circumpolar Current (Tynan, 1998) and the Antarctic Divergence, the latter being an important zone of upwelling. The areal extent of Antarctic sea ice varies annually by a factor of ~5, from a maximum of 18-20 x 10^6 km^2 in September-October to 3-4 x 10^6 km^2 each February. As such, it is predominantly a seasonal sea ice zone, although large regions of perennial ice persist in the western Weddell Sea, Amundsen Sea and Ross Sea and southwest Pacific Ocean though summer (Gloersen et al., 1992).

The major features driving the dynamics of sea ice are shown in Figure 3.

The Antarctic Peninsula region is the only Antarctic sector to have experienced a rapid warming trend over the past 50 years, of ~0.5^{o}C per decade (Vaughan et al., 2001). Moreover, the West Antarctic Peninsula (WAP) region is the only Antarctic sector to have experienced a statistically significant decreasing trend in sea ice areal extent since 1978 (see inset in Figure 3, from Kwok and Comiso, 2002). Recent results imply that this change may result from changes in dynamic (i.e., wind-driven) forcing (Massom et al., 2006). These factors, combined with the profound impact of the Antarctic Peninsula as a meridional blocking feature that extends to low latitudes and oceanic characteristics, suggest that the WAP region should be treated as a separate regime.

Forming an important habitat for a wide range of organisms specifically adapted to its presence, sea ice plays a dominant defining role in structuring high-latitude marine ecosystems (Ackley and Sullivan, 1994; Brierley and Thomas, 2002; Eicken, 1992; Lizotte and Arrigo, 1998; Nicol and Allison, 1997), and on a variety of scales. The most productive areas of the Southern Ocean lie in the Seasonal Ice Zone, between the maximum northern extents of sea ice in winter and summer. Here in particular, Antarctic krill and other planktonic organisms support an abundance of fish, birds, seals and whales. In addition, the ice edge is typically a region of enhanced biological activity during the melt season in particular (Nicol and Allison, 1997; Smith and Nelson, 1986; Smith et al., 1988; Sullivan et al., 1993).

Although in the past characterised as simple, the Antarctic food web involves complex relationships between primary producers and higher predators, as well as abiotic factors. The Antarctic ecosystem is characterised by

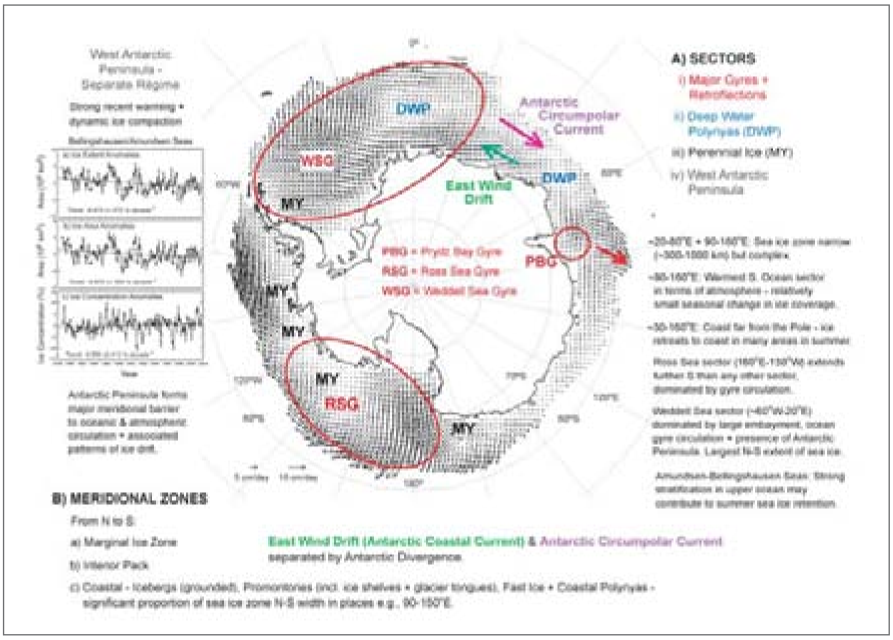

FIGURE 3: Map of climatological (mean) satellite-derived sea ice motion for 1997 (courtesy US National Snow and Ice Data Center; Fowler, 2003), with broad-scale sea ice sectors superimposed. Explanations are provided in the figure. The motion vectors are projected to a 25 x 25 km resolution grid. Dominant features in the climatological ice drift pattern are 3 major ocean gyre systems, the westward-drifting Antarctic Coastal Current and eastward flowing Antarctic Circumpolar Current, with regions of retroflection associated with the ocean bathymetry i.e., ocean bathymetric "steering". Figure by R. Massom.

strong seasonal cycles and major food-web differences that are intimately related to the annual sea ice growth-decay cycle and sea ice conditions, as well as associated ocean dynamics (mixing), water density and nutrient availability (Garrison and Mathot, 1996; Legendre et al., 1992; Lizotte, 2001).

Existing regionalisations for the Southern Ocean

The Southern Ocean has been divided into large-scale regions before, primarily based on physical characteristics such as frontal features (Orsi et al., 1995; Longhurst, 1998) and ice dynamics (Tréguer and Jacques, 1992). Information on the distribution of species has been used in biogeographic classifications of benthic fauna (Ekman, 1953; Hedgpeth, 1970; Dell, 1972), and also by CCAMLR in the definition of statistical subareas on the basis of fish stock distribution (Everson, 1977) (see Figure 1).

In the southern Indian Ocean, some smaller scale regionalisations have been attempted in the development of a bioregionalisation in Australian waters to assist in regional marine planning (Lyne et al. 2005), the designation of marine reserves (Meyer et al. 2000), and benthic habitat mapping (Beaman and Harris, 2005).

Early biogeographic classifications for the Southern Ocean delineated large-scale provinces according to the distribution of benthic fauna (Hedgpeth, 1970; Dell, 1972). More recent studies have largely confirmed these broad-scale patterns regions, although there are now thought to be significant differences between the benthic faunas of East and West Antarctica (Clarke and Johnston, 2003). A recent study on the biodiversity and biogeography of subantarctic mollusca (Linse et al., 2006), using species from the continental shelf areas (0-1000 m), identified the following distinct sub-regions in the Southern Ocean: Antarctic Peninsula, Weddell Sea, Dronning Maud Land, Enderby Land, Wilkes Land, Ross Sea, and the independent Scotia arc and subAntarctic islands (Figure 4). These divisions have also been used by WWF and The Nature Conservancy (TNC) in a study to synthesise existing classifications into a system of Marine Ecoregions of the World (Spalding et al., 2006).

Tréguer and Jacques (1992) defined five functional units south of the Polar Front on the basis of ice and nutrient dynamics. This work demonstrated the role of ice dynamics in controlling phytoplankton initiation and growth, and the nutrient regimes that discriminate each of these units. Defined units include the Polar Front Zone, located between approximately 60°S and 55°S, and the Permanently Open Ocean Zone which lies between the Polar Front and the maximum northern extent of winter sea ice. The Seasonal Ice Zone is located between the northern limits of the pack-ice in winter and in summer, while the Coastal and Continental Shelf Zone is adjacent to the Antarctic continent. The Permanent Ice Zone incorporates ocean areas under ice shelves.

Orsi et al. (1995) described large-scale frontal features of the ACC, based on historical hydrographic data. Gradients in ocean surface properties were used to define three major fronts within the ACC which separate water masses and flow characteristics. These are shown in Figure 5.

Longhurst (1998) proposed a global system of ocean classification based on a simple set of environmental variables (sea surface temperature, mixed layer depth, nutrient dynamics and circulation) together with planktonic algal ecology. In this classification scheme (Figure 6) the Southern Ocean includes two provinces in the Westerly Winds Biome between approximately 40ºS and 50ºS (South Subtropical Convergence Province and SubAntarctic Water Ring Province) and two in the Antarctic Polar Biome between 50ºS and the continental coast (Antarctic Province and Austral Polar Province).

The LME classification system defines the Southern Ocean as a single unit (Sherman and Duda, 1999), while several other classifications define only a small number of concentric rings around the continent. However, the Southern Ocean has a variety of distinct provinces within these larger regions which differ in their chemical, physical and ecological characteristics, and which show considerable longitudinal, as well as latitudinal variation. Improved data coverage and availability through satellite imaging, and improved understanding of ocean characteristics through ecosystem modelling makes it now possible to elaborate on these previous regionalisations using a wider range and broader coverage of data.

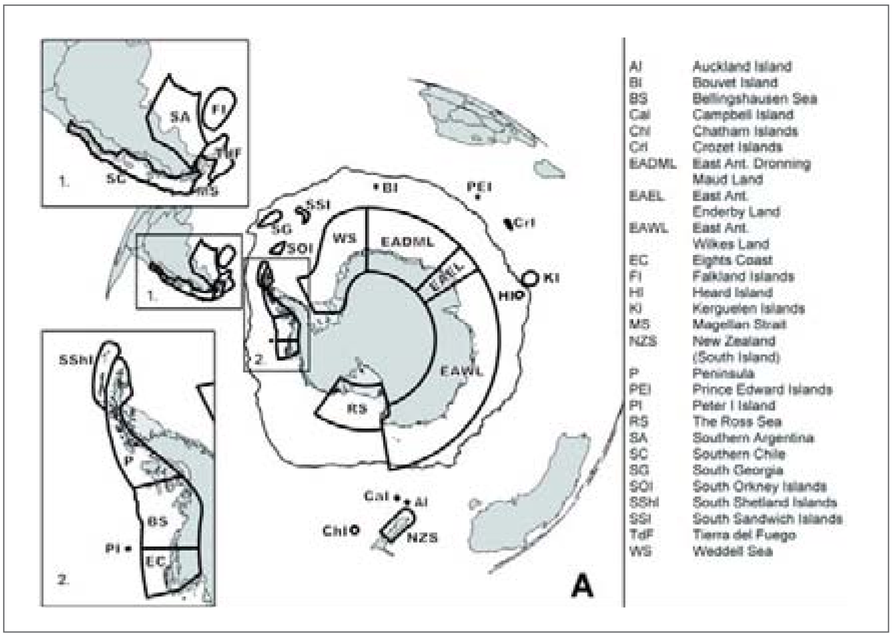

FIGURE 4: Biogeographic areas of the Southern Ocean defined by Linse et al. (2006), using distribution records for shelf (0-1000 m) species of shelled gastropods and bivalves
(Figure reprinted with permission from: Linse *et al*, 2006)

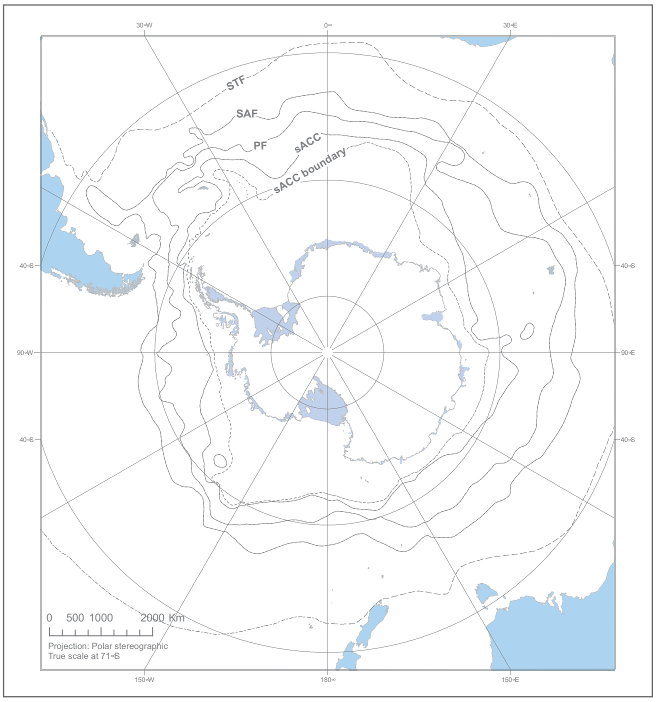

FIGURE 5: Fronts of the Southern Ocean, as defined by Orsi et al. (1995)

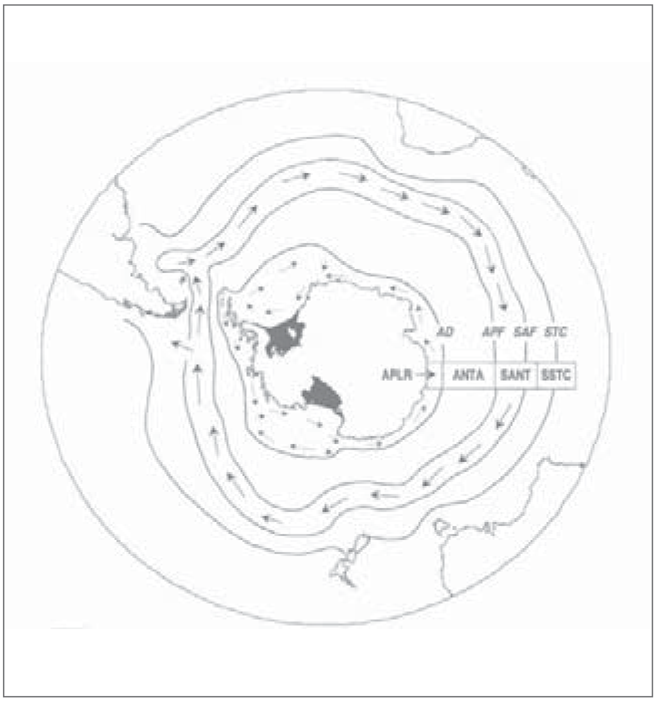

FIGURE 6: Classification of the Southern Ocean, Longhurst (1998)
(Reprinted from: Ecological Geography of the Sea, A.R. Longhurst. Copyright (1998), with permission from Elsevier)

1.4 Experts Workshop

The aim of the Experts Workshop was to review the methods for identifying major provinces, collate available synoptic datasets, and to gain input and recommendations from experts on the process and the results. In particular, the workshop aimed to develop a "proof of concept" for a broad-scale bioregionalisation of the Southern Ocean, using physical and environmental data as the primary input.

A list of the workshop participants is provided at the end of this report.

Specific objectives of the workshop were to:

- review and assess the processes developed to date and the proposed methods;
- discuss and make recommendations on data types to be included in a broad-scale bioregionalisation;
- collate appropriate datasets;
- apply the approved method(s) to the Southern Ocean using available datasets, to test and validate the process and produce a 'proof of concept' including maps of the defined broad-scale provinces;
- assess preliminary results and broad-scale provinces, given present knowledge of the Southern Ocean.
- provide recommendations on products to be developed, including the final report, maps, illustrations, datasets and a GIS (or other) database; and
- provide recommendations on datasets and/or method(s) that might be used to develop further fine-scale bioregionalisations.

The workshop was held over five days, and included background presentations, plenary discussion, and computer-based analysis in small groups.

At the start of the workshop, background presentations were given on some of the major physical processes in the Southern Ocean, and initial discussion focused on the relationships between physical and ecological processes. A series of presentations were also given on approaches to bioregionalisation that have been undertaken elsewhere, which allowed detailed consideration of the application of different methods.

Participants then investigated different aspects of data analysis and refinement of methods in small groups, focusing initially on their regions of particular expertise (e.g. South Atlantic, East Antarctica, Ross Sea) and later looking at the Southern Ocean as a whole. Selected physical datasets were provided for use in the initial analysis, and others were made available by participants during the week. The analytical methods used by Lyne and Hayes (2005), Leathwick et al. (2006a) and Raymond and Constable (2006) were used as starting points for the analysis during the workshop. These methods were refined into a single methodology, following workshop discussions and practical explorations of the methods. Appendix I gives further details on the background and technical aspects of each of these methods.

The final stages of the workshop included discussion on how well the defined regions corresponded to our present knowledge of the Southern Ocean. Priorities were identified for further work on issues including uncertainty, understanding of inter- and intra-annual variation, validation of results, the use of additional data (particularly biological datasets) and finer-scale analysis of particular areas of interest.

The Southern Ocean covers around 10% of the world's ocean surface, and includes some of the most productive marine regions on Earth. Although they are among the least-studied, the seas around Antarctica are a critical component of the global climate system and marine ecosystem.

2. Approach to bioregionalisation

This section describes the approach to bioregionalisation that was used as a starting point for the workshop discussions and analysis. Descriptions of each step are presented here, together with background information on issues that must be considered. Further technical detail is provided in Appendix II. A summary of the final method adopted is presented in Section 3.

The regionalisation process can be partitioned into the following steps:

1. Identify the ecological patterns and processes that have relevance to the end-use application of the regionalisation
2. Identify the major environmental drivers or properties that control these patterns and processes, and extract relevant parameters describing those properties
3. Pre-process the data (e.g. normalise, transform, smooth)
4. Compile a data matrix of individual sites (rows) by properties (columns)
5. Apply a clustering procedure to group sites with similar properties
6. Post-process the clusters to meet any application-specific constraints on the regions (e.g. minimum size)
7. Expert review of the regions to ensure suitability for the application.

This process can be iterative. Ideally, the initial process will establish the mechanisms by which new data and/or knowledge could be incorporated into revisions of the bioregionalisation, although this would be expected to assist more in establishing or revising smaller scale subdivisions rather than altering the higher level bioregionalisation.

Figure 7 is a schematic representation of the bioregionalisation process, illustrating how data selected to reflect ecological processes can be used to define bioregions.

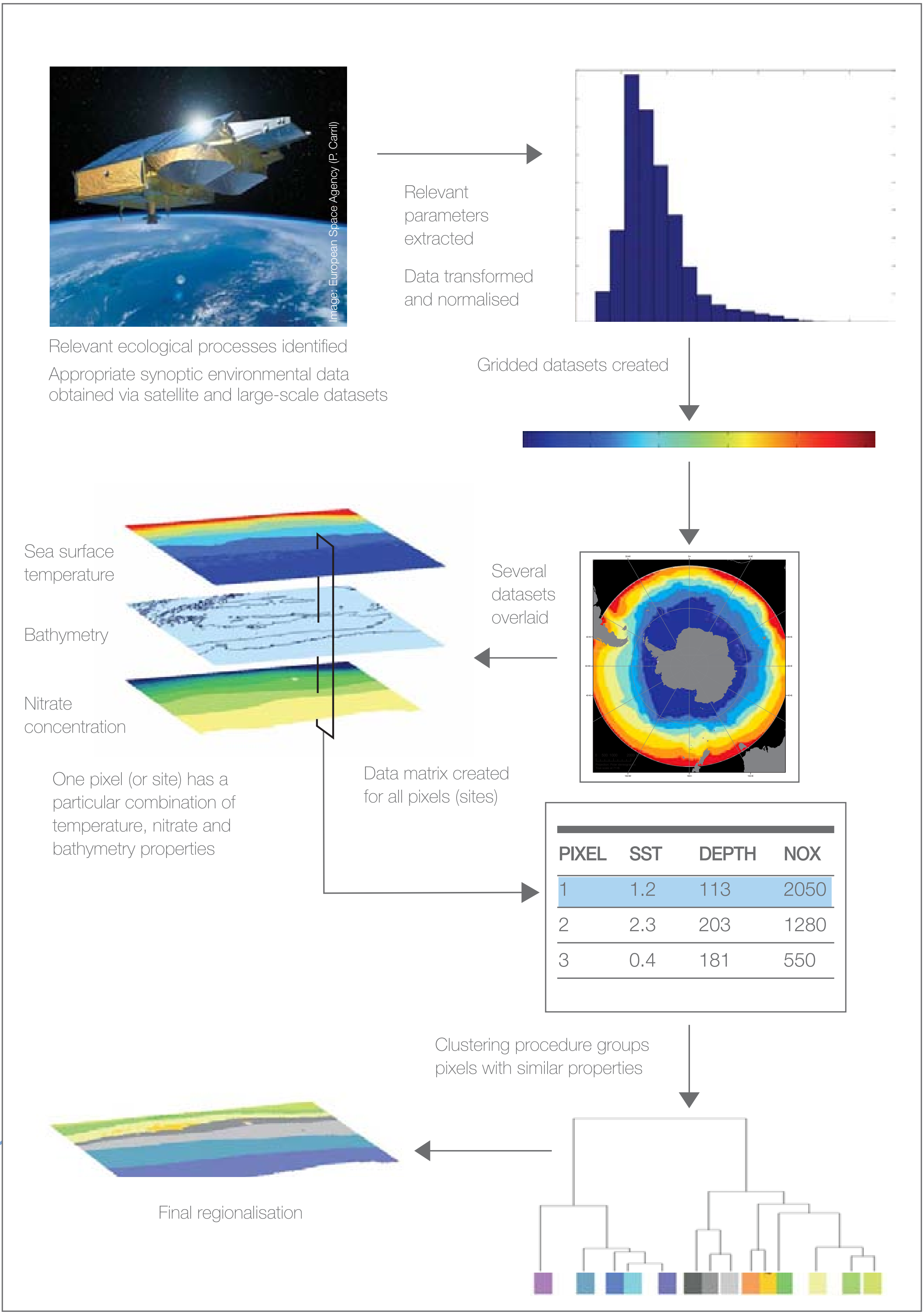

FIGURE 7: Schematic representation of the bioregionalisation process

2.1 Identifying properties to be captured

An important first step in the bioregionalisation analysis is to identify distinct ecological processes and their defining properties. The identification of ecological processes to be captured in the regionalisation is likely to be driven by the requirements of a particular end-use application.

Ideally, a bioregionalisation would delineate units that, depending on the scale, clearly separate habitats, communities and ecosystems. In this ideal world, populations would reside wholly within these areas. In reality, there is considerable complexity that needs to be addressed because of the different relationships that species have with the environment and other biota (Andrewartha & Birch 1984). A bioregionalisation aims to capture the properties of the important relationships rather than, necessarily, simply trying to circumscribe the distributions of whole populations of species.

This concept is illustrated in Figure 8. Some species will be found closely aligned with environmental gradients. Other species will appear in areas with high levels of perturbation, such that environmental factors are mixed and ever changing in their relative distributions. Yet others will exploit the diversity of patches in fringing habitats and ecotones. For mobile species, some taxa will be found across most areas but only some areas will be important to them as feeding or reproductive areas. An important step in the process is to determine how to accommodate environmental gradients and overlaps in the regionalisation.

The marine environment comprises three dimensions – geographic space and depth. Distribution of biota in the pelagic environment is mostly determined by the potential productivity in the water masses and the movement of those water masses in space and depth. The benthic environment has additional features reflecting variation in the depth, substratum types and roughness of the seafloor, and the degree to which this promotes interaction with the pelagic realm. These features are often considered to the primary drivers of environmental heterogeneity. Secondary drivers are more ephemeral or changing over time. In the Antarctic, they would also include other features of the environment such as the annual cycle of advance and retreat of the sea ice zone.

A bioregionalisation would generally try to represent the heterogeneity in ecosystem structure and function, which primarily would subdivide areas according to the magnitude of productivity and its predictability in time. Further subdivision would relate to the diversity of habitats and the relationships of species and food-webs to those habitats. The process will need to differentiate between areas with relatively constant features from those that are highly variable, even though they may have similar mean values. This is because a region with a large amount of disturbance can accommodate different assemblages involving opportunistic species as well as those that require long-term stability. Some areas in a bioregionalisation may need to represent large areas of habitat discontinuity or disturbance, which could be important regions in themselves. As a result of these considerations, a goal for a bioregionalisation is to capture not only the differences in diversity and the suite of ecosystem relationships, but also the potential differences in environmental stability.

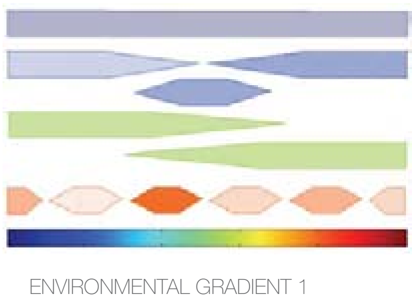

FIGURE 8(a): distribution of species with respect to a single environmental gradient, say temperature. Each polygon represents a different taxon, colours represent similar taxa. Width of bars represents relative abundance for a taxon.

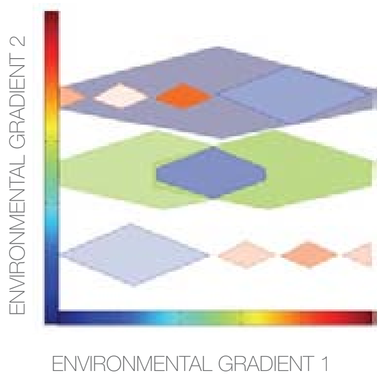

FIGURE 8(b): as for (a) but with distributions relative to two environmental gradients - distributions on gradient 1 are as in (a). A general discontinuity between species distributions in (a) might be roughly at the midpoint (green on the environmental gradient). In (b) the separation between groups of taxa becomes clearer on the second gradient.

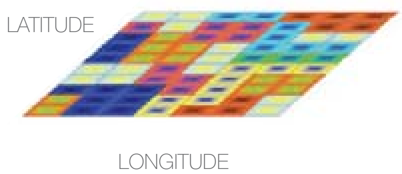

FIGURE 8(c): The environmental conditions form a patchwork in geographic space which can result in regions of similar environmental conditions being separated geographically. Here, parallelograms represent spatial areas with colours representing two environmental parameters (outer colour is from environmental gradient 1 and inner colour is from gradient 2). Each area is expected to have a species composition consistent with that composition at the intersection of two respective environmental gradient colours in (b).

FIGURE 8: Conceptual diagram illustrating potential relationships between species along gradients of environmental parameters.

Photograph by Brian Ball, Australian Government Antarctic Division © Commonwealth of Australia

2.2 Classification method

The intent of a regionalisation is to partition the study area into a set of discrete spatial regions, each with relatively homogeneous ecosystem properties. In the bioregionalisation analysis, regions are selected by grouping sites with particular characteristics. In some cases there may be specific, known characteristics that can be used to delineate region boundaries, such as water temperature changes across oceanic fronts. Another example is to separate the continental shelf from the continental slope by choosing an appropriate bathymetric contour, say 1000 m. Generally, however, the expectation is that the regions will reflect a natural clustering of the environmental or biotic data.

Clustering algorithms are well suited to bioregionalisation analysis, as they are designed to partition a large data set into a number of subsets, each with relatively similar properties that differ from those of the other subsets. In the context of a regionalisation, the clustering process takes sites (or cells) from a grid in geographic space. Each site has associated ecological properties (physical and/or biotic data) and this information is used to group together sites with relatively similar ecological properties.

Those groupings (which are calculated in ‘environmental space’, i.e. based only on environmental properties, and ignoring spatial information) are then projected back into geographic space in order to find the spatial extents of the resulting regions. Thus, the regions are discrete in environmental space, but may be scattered or fragmented in geographical space (i.e. there may be several regions with the same properties located in different geographic areas).

Choosing clustering algorithms

There are a large number of clustering algorithms that could potentially be used, all of which have assumptions or limitations that may preclude their use in particular circumstances or with particular types of data. Thus, the outcomes of the bioregionalisation could be influenced by the choice of the algorithm. The aim is to develop a clustering process that is consistent with the data and for which the results are likely not to change much with alternative clustering algorithms. Consideration will need to be given, inter alia, to algorithm assumptions, complexity, and accuracy.

It is important to make the distinction between the clusters that are produced by a clustering algorithm, and the regions that are formed from those clusters. A cluster is a group of sites that are considered to have similar environmental properties. However, because the clustering process is based on environmental similarity (and not spatial information), a single cluster may contain sites that are spatially separated. A region is thus considered to be a group of sites that belong to the same cluster, but which also form a contiguous spatial area. A single cluster may produce a number of regions, each of which have the same general properties, but which are spatially distinct.

Clustering algorithms are often based around the concept of a dissimilarity metric, which (in the context of a regionalisation) is used to calculate how dissimilar two sites are, given their ecosystem properties (physical or biological data). The clustering of sites into regions is carried out in such a way that the intra-region dissimilarity of sites is low (i.e. sites within a region are similar to each other) relative to inter-region dissimilarities. Dissimilarity-based clustering methods can be broadly divided into hierarchical or non-hierarchical schemes. Further information on these schemes, and the issues related to selecting clustering algorithms, is provided in Appendix II.

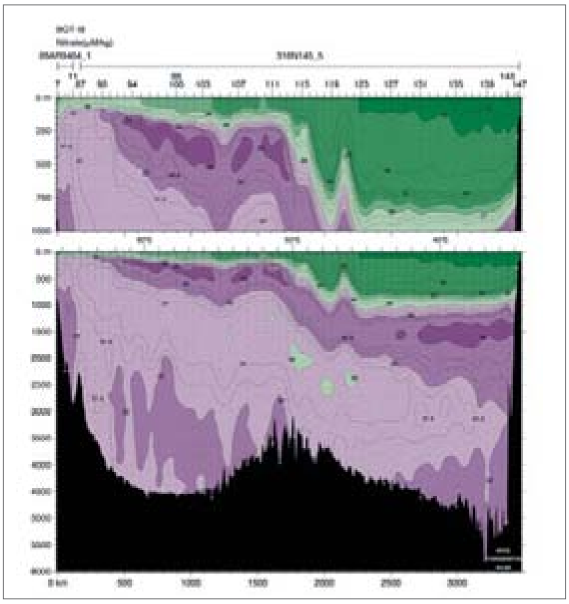

FIGURE 9: Water mass profile of nitrate concentration from Antarctica to the tropics, showing surface expression of the nutrient layer in the Southern Ocean. (Figure from http://woceSOatlas.tamu.edu. Orsi and Whitworth, 2005)

2.3 Variables that capture properties

Once the relevant physical properties have been identified, appropriate data must be selected to be included in the analysis. The data that are used in the clustering method should be matched to the ecological patterns and processes and spatial and temporal scales that are important to the end-use application. However, there is considerable latitude for choice within this broad guideline. Importantly, the data used in the clustering procedure will not necessarily be the raw observations from field sampling. The data may be transformed or be analysed within a model (processing algorithm) to provide the necessary inputs to clustering. For example, ice concentration maps can be routinely obtained from satellite passive microwave data (since 1978). However, daily ice concentration or mean concentration over time might not alone be indicative of the ecological processes of importance. The amount of time an area is free of significant concentrations of sea ice over the course of a year may be more important in terms of productivity in an area or the amount of time the area might be open to feeding activity of birds, seals and whales. Data availability and the choices of subsequent processing algorithms may impose some constraints on the types of data that can be used.

Figure 9 demonstrates how a particular variable (nitrate concentration) can capture environmental properties (surface expression of nutrients) across a broad spatial area.

Once relevant data have been collated, the study area is divided into a grid of sites (or interpolated from point observations), at a sufficiently fine spatial scale to enable appropriate resolution of the final areas. Descriptive statistics – such as means, variances, and other ecologically relevant information, including rates of change of parameters – are computed from the input data at a site level. Site data may be further processed if necessary. This might include spatial or temporal smoothing of the data in order to ensure that the data provides information at an appropriate scale for the regionalisation. The algorithms for selecting areas often also require data to be normalised so that variables with different measurement units can be statistically combined.

Variables of comparable type but measured on different scales are often normalised to a similar scale, say 0 to 1, while preserving the rates of change between different levels of the variable that need to be maintained in the analysis. Alternatively variables might be transformed where biological changes are greater in one part of the gradient, e.g., a log transformation might be used with ocean depth, given that rates of biological turnover are rapid near the ocean surface, but decrease with progression to deeper waters. Care needs to be taken to ensure that the properties of the variables and their relationships to other variables are not altered in the process. Variables that influence multiple ecological processes will reflect different aspects of those processes depending on how they are incorporated into the analyses.

The spatial and temporal scales of the data should be appropriate to the desired scale of the areas. Data with fine-scale spatial or temporal structure may need to be smoothed for use in broad-scale regionalisations. For pelagic applications, the selection of spatial regions is complicated by the depth structure of the water column and temporal variability at seasonal and longer timescales. A hierarchical approach is often used to assist in resolving problems of scale. The levels of the hierarchy can represent either spatial scales, or different ecological processes. A process-oriented hierarchy often has an approximate spatial structure due to the spatial scales of the processes.

To illustrate the concept of temporal variability at seasonal timescales, Figure 10 shows the mean monthly chlorophyll *a* concentrations for each month during summer (December to March). The seasonal variability of this property must be taken into account when using such data to capture ecological processes. Nevertheless, Figure 10 shows that certain areas maintain high levels of chlorophyll *a* concentration throughout this period, and thus a summer mean value may be appropriate for use in a bioregionalisation analysis.

Further information on scaling and weighting of variables is provided in Appendix II.

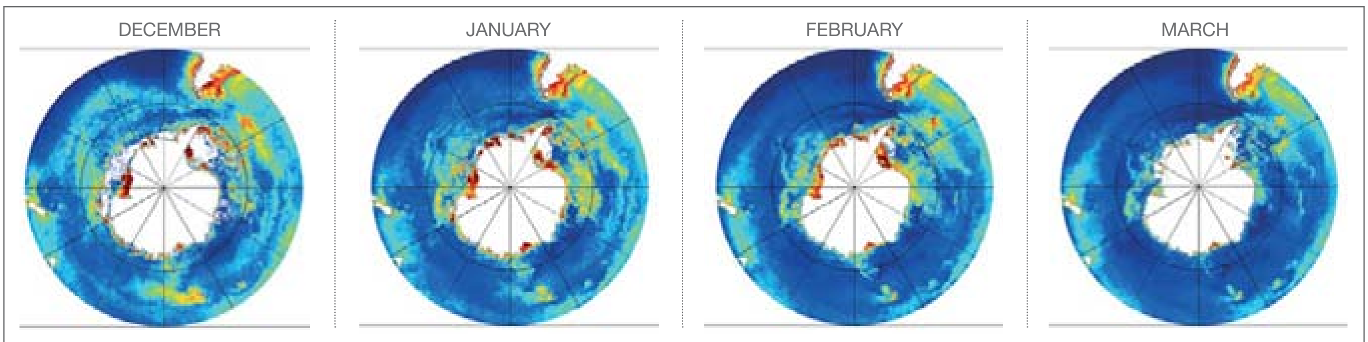

FIGURE 10: Mean monthly chlorophyll *a* concentrations for each month during summer (Dec-Mar) (Images provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE)

2.4 Uncertainty

A regionalisation requires an assessment of the uncertainties in the locations of the boundaries between areas. In addition, as assessment should be made of whether the heterogeneity within an area is not sufficiently great that the area should not be differentiated from one or more of its neighbours.

Here, the term “uncertainty” is used to describe the effects of a number of different processes, including imprecision in data (for example measurement error, and bias due to incomplete or unbalanced observations), model uncertainty (uncertainty within models that have been used to derive one variable from others, such as climatologies or primary productivity models), and epistemic uncertainty (lack of knowledge of how to go about the regionalisation process; Raymond and Constable 2006). Each of these can affect the resulting region boundaries. Note that stochastic, seasonal, or other temporal or spatial variability in data represents the temporal or spatial variability of the underlying ecosystem processes, and is not treated as uncertainty. However, if it is not clear how this variability should be incorporated into the regionalisation (e.g. should summer or annual means be used?) then this would, in turn, be a source of uncertainty.

A key output of an uncertainty analysis would be an assessment of the uncertainty in region boundary locations. This would indicate to end-users where they might expect the region boundaries to change if the data or analysis methods were to be updated or changed.

Photograph by John Kelly, Australian Government Antarctic Division © Commonwealth of Australia

3. Physical regionalisation

3.1 Summary of adopted method

The classification method adopted during the workshop was a mixed non-hierarchical and hierarchical approach. The classifications were performed on a 1/8th degree grid, covering the marine area from 80°S to 40°S. The full set of 720,835 grid cells was subjected to a non-hierarchical clustering to produce 40 clusters. The mean data values for each of the 40 clusters was calculated and a hierarchical classification was then performed to produce a dendrogram and the final clustering.

Sites with missing data were excluded from the analyses. These were principally sites shallower than 200 m depth, for which the chosen nutrient data did not apply. These excluded sites are shown in the maps as white. Future work will need to fill in these missing cells, for example by considering their other attributes.

Primary regionalisation

The primary regionalisation used the following datasets:

- bathymetry (log10 transformed)
- sea surface temperature (SST)
- nitrate (NOx) concentration
- silicate (Si) concentration

Descriptions of each of these datasets are provided in Appendix III.

The workshop agreed that the ocean water masses combined with topography of the ocean floor were likely to define the primary features of the Southern Ocean and coastal Antarctic systems. Sea surface temperature was included as a proxy for the different water masses of the Southern Ocean (Figure 11). Topography (captured by bathymetric data) was included because of the clear ecological differentiation of the shelf, slope and abyssal regions as well as its influence on upwelling, eddying and as a potential source of iron. Bathymetry (Figure 12) was transformed (log10) to give most weight to the shallower areas less than 2500 m with a greater opportunity to differentiate the shelf break and slope.

Silicate and nitrate concentrations (Figures 13 and 14) were included to provide information on nutrient characteristics. Silicate concentration also provides a measure of actual primary production (particularly in diatom-dominated areas), since silicate is taken up during photosynthesis in the production of diatom shells. The silicate layer was found to be particularly useful for accurately differentiating water masses reflecting plankton communities in deeper water and along the various fronts. The nitrate and silicate climatologies at the 200 m depth layer were used rather than the surface layer as this is a better indicator of available nutrients, whereas surface nutrients are likely to be depleted in areas of nutrient-limited productivity. However, the use of the 200 m depth layer resulted in missing data in the shelf areas of less than 200 m depth.

Sea surface height (SSH) and insolation (mean summer climatology of photosynthetically-active radiation (PAR) at the ocean surface) were considered as additional primary variables that would have utility in defining frontal systems and productivity respectively, however they were not used at this stage because of insufficient time, and because the currently available datasets were incomplete. These datasets should be considered in future analyses.

Physical environmental data used as the input for analysis during the workshop were chosen based on their spatial coverage across the Southern Ocean. The datasets considered included bathymetry, sea ice concentration and extent, sea surface temperature, sea surface height, chlorophyll *a* concentration, nutrient data (silicate, nitrate and phosphate), and insolation (photosynthetically active radiation - PAR).

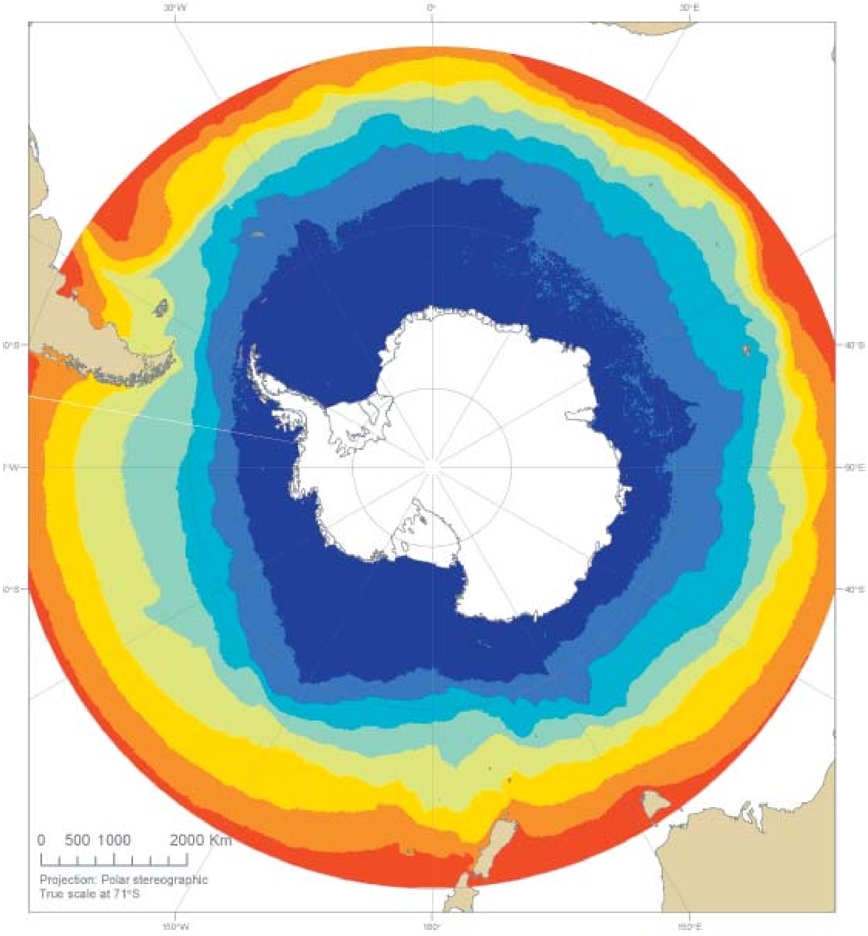

FIGURE 11: Mean annual sea surface temperature (SST). Monthly values from NOAA Pathfinder satellite annual climatology, averaged over the period 1985-1997 (Casey and Cornillon 1999)

Temperature (°C)

- -1.95 - -0.13
- -0.12 - 2.01
- 2.02 - 4.46
- 4.47 - 6.83
- 6.84 - 9.05
- 9.06 - 11.18
- 11.19 - 13.40
- 13.41 - 18.22

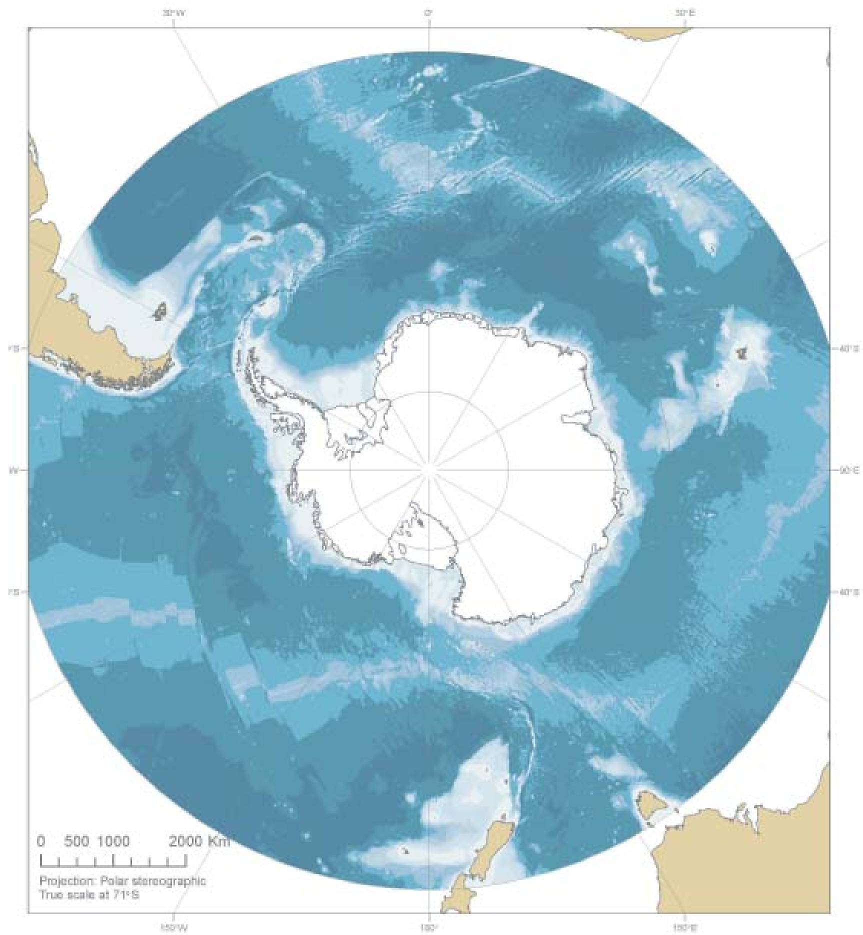

FIGURE 12: Bathymetry of the Southern Ocean. Depth data from the GEBCO digital atlas (IOC, IHO and BODC, 2003).

Depth (metres)

- 0 - 500
- 500 - 1000
- 1000 - 1500
- 1500 - 2000
- 2000 - 2500
- 2500 - 3000
- 3000 - 4000
- 4000 - 5000
- > 5000

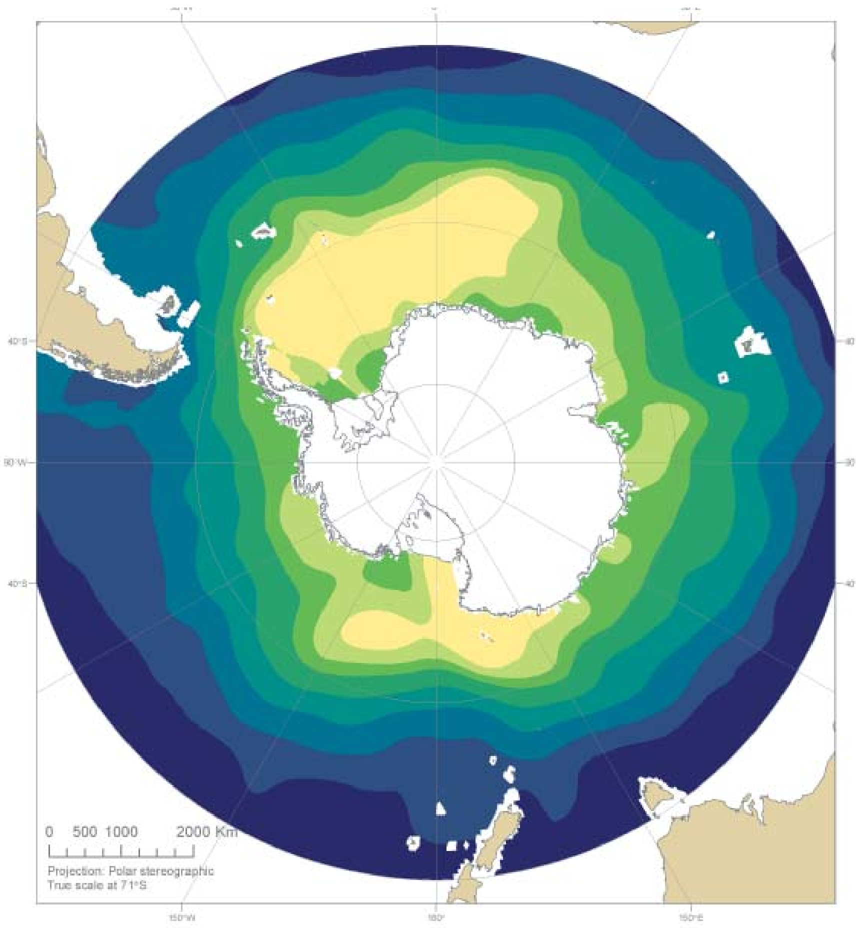

FIGURE 13: Silicate concentration (at 200 m depth). Climatology from the WOCE global hydrographic climatology (Gouretski and Koltermann, 2004)

Si (umol/kg)

- 2.47 - 4.58
- 4.59 - 7.96
- 7.97 - 18.08
- 18.09 - 38.76
- 38.77 - 64.93
- 64.94 - 76.74
- 76.75 - 86.87
- 86.88 - 110.08

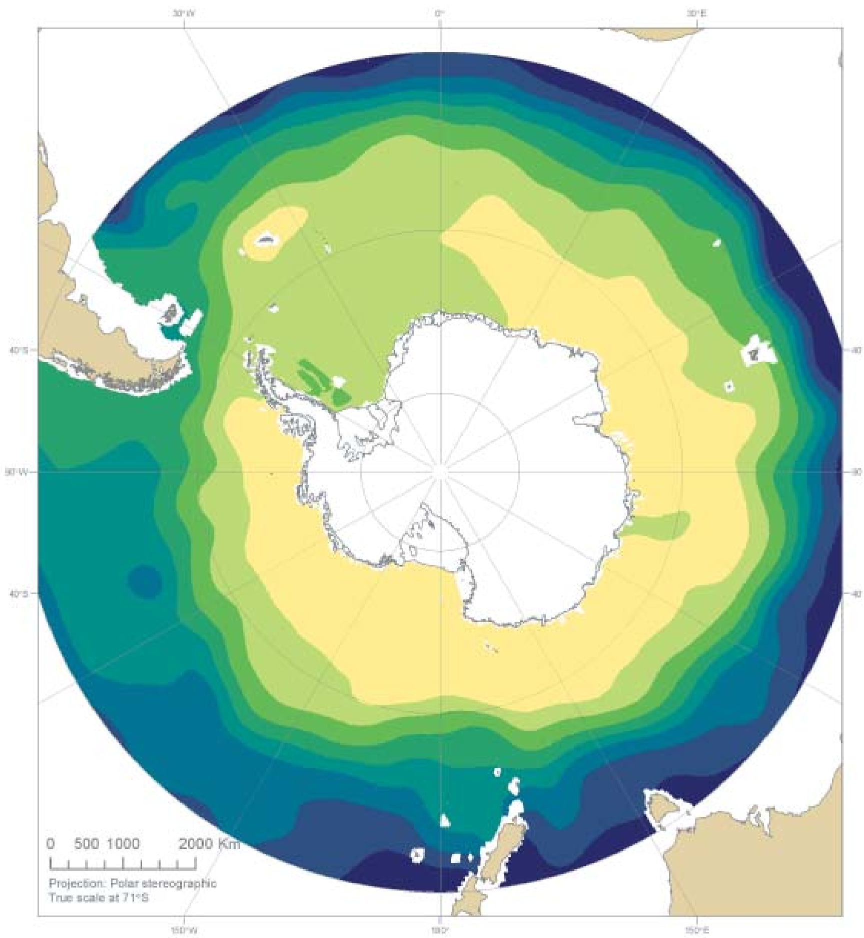

FIGURE 14: Nitrate concentration (at 200 m depth). Climatology from the WOCE global hydrographic climatology (Gouretski and Koltermann, 2004)

NOx (umol/kg)

- 5.55 - 12.40
- 12.41 - 15.58
- 15.59 - 18.65
- 18.66 - 21.72
- 21.73 - 25.38
- 25.39 - 29.27
- 29.28 - 32.34
- 32.35 - 35.65

Secondary regionalisation

The Workshop agreed that the bioregionalisation should ideally differentiate first between the main divisions of coastal Antarctica (shelf and slope areas), sea ice zone and northern open ocean waters before further subdividing according to secondary features. Nevertheless, two potential components of a secondary classification were explored to determine if there is sufficient spatial heterogeneity to warrant a further subdivision.

Sea ice was considered to modify the pelagic environment both in terms of the potential for primary production as well its influence on the distribution of marine mammals and birds. The impact of sea ice on the environment was explored using a data layer comprising the number of days an area was covered by at least 15% concentration of sea ice (Figure 15).

The concentration of satellite-observed sea surface chlorophyll was explored using a data layer comprising log transformed chlorophyll *a* densities (Figure 16). The chlorophyll distribution was truncated at 10 $mg.m^{-3}$ (where all values greater than 10 were made equal to 10), because the variability in higher order productivity most likely results from variability in the range from 0-10 $mg.m^{-3}$. While chlorophyll *a* concentration may not reflect primary production absolutely, it was considered to be a suitable proxy for the purposes of exploring spatial heterogeneity in primary production at the large scale.

Descriptions of each of these datasets are provided in Appendix III.

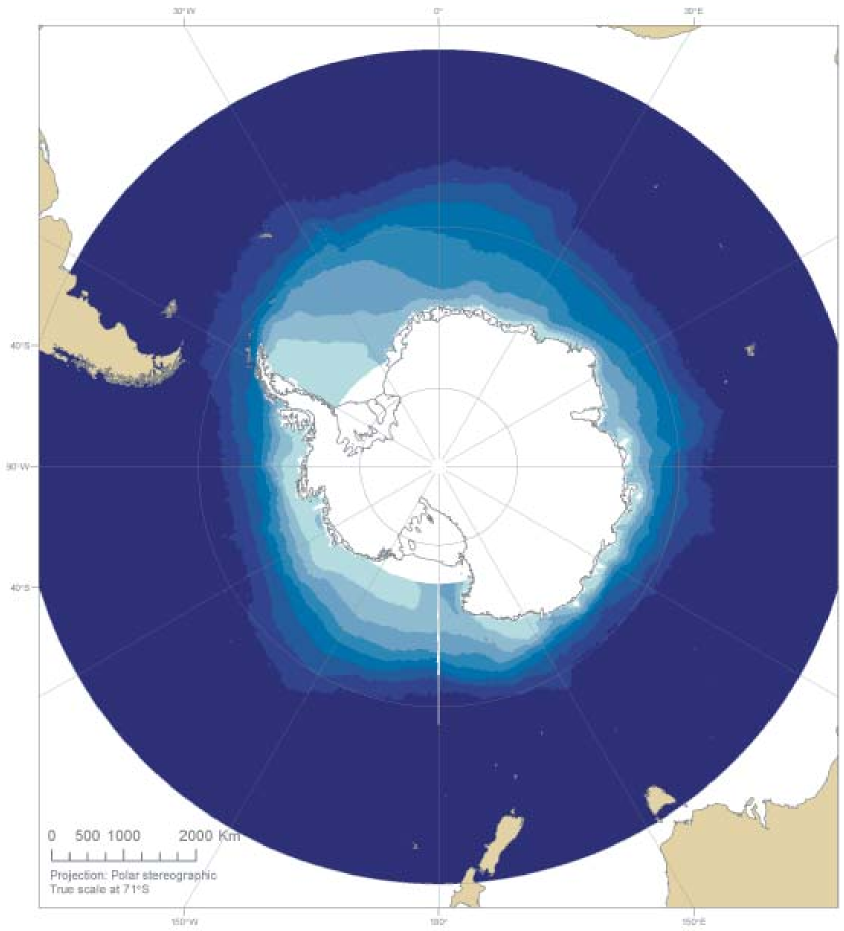

FIGURE 15: Proportion (0-1) of the year for which the ocean is covered by at least 15% sea ice. Calculated from satellite-derived estimates of sea ice concentration spanning 1979–2003. (Comiso, 1999

Proportion (0-1)

- 0
- 0.01 - 0.08
- 0.09 - 0.31
- 0.32 - 0.49
- 0.50 - 0.63
- 0.64 - 0.76
- 0.77 - 0.91
- 0.92 - 1

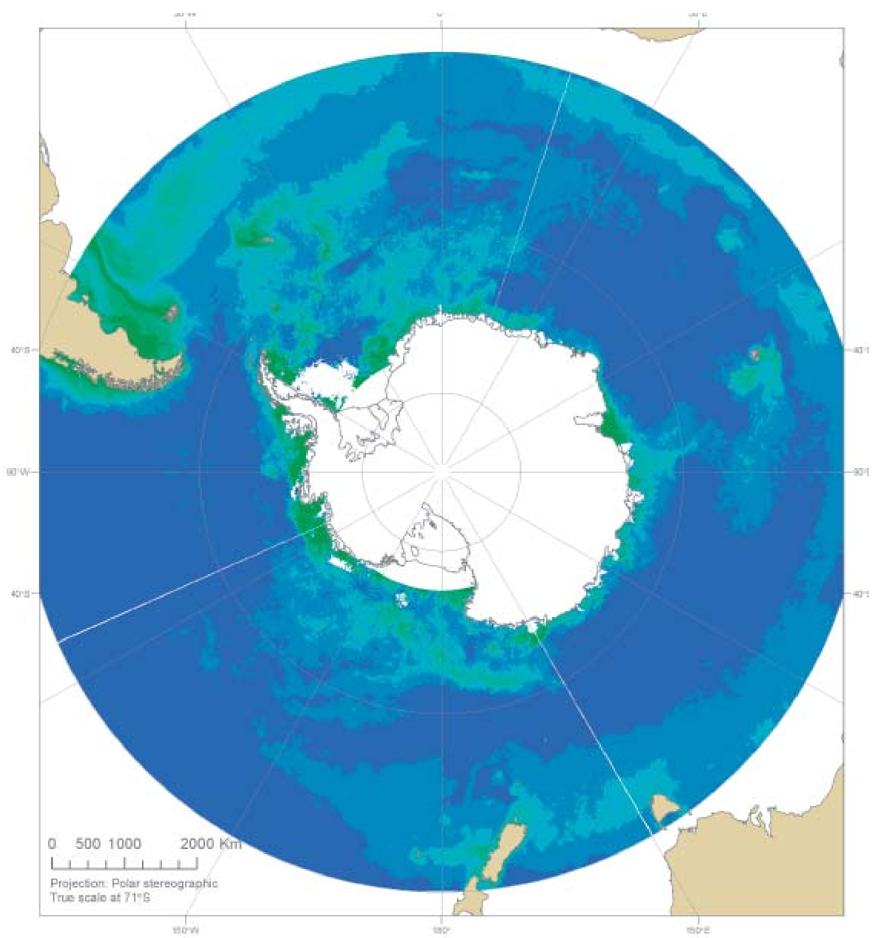

FIGURE 16: Mean summer (DEC-FEB) surface chlorophyll-*a* concentrations. Summer means (1998-2004) from SeaWiFS.

Chlorophyll-*a* concentration ($mg.m^{-3}$)

- 0.06
- 0.07 - 0.22
- 0.23 - 0.37
- 0.38 - 0.53
- 0.54 - 0.68
- 0.69 - 0.99
- 1.00 - 1.77
- 1.78 - 39.80

Photograph by Nick Gales, Australian Government Antarctic Division © Commonwealth of Australia

3.2 Results of Southern Ocean bioregionalisation

Primary regionalisation

The results of the primary regionalisation are shown in Figures 17 (dendrogram) and 18 (map). The physical properties of each region are shown in Table 1. This regionalisation clearly differentiates, at the highest levels, between coastal Antarctica (including embayments), the sea ice zone and the northern open ocean waters. The analysis highlights the different environmental characteristics of large regions including the continental shelf and slope, frontal features (Subantarctic Front, Polar Front, Southern Antarctic Circumpolar Current Front), the deep ocean, banks and basins, island groups, and gyre systems.

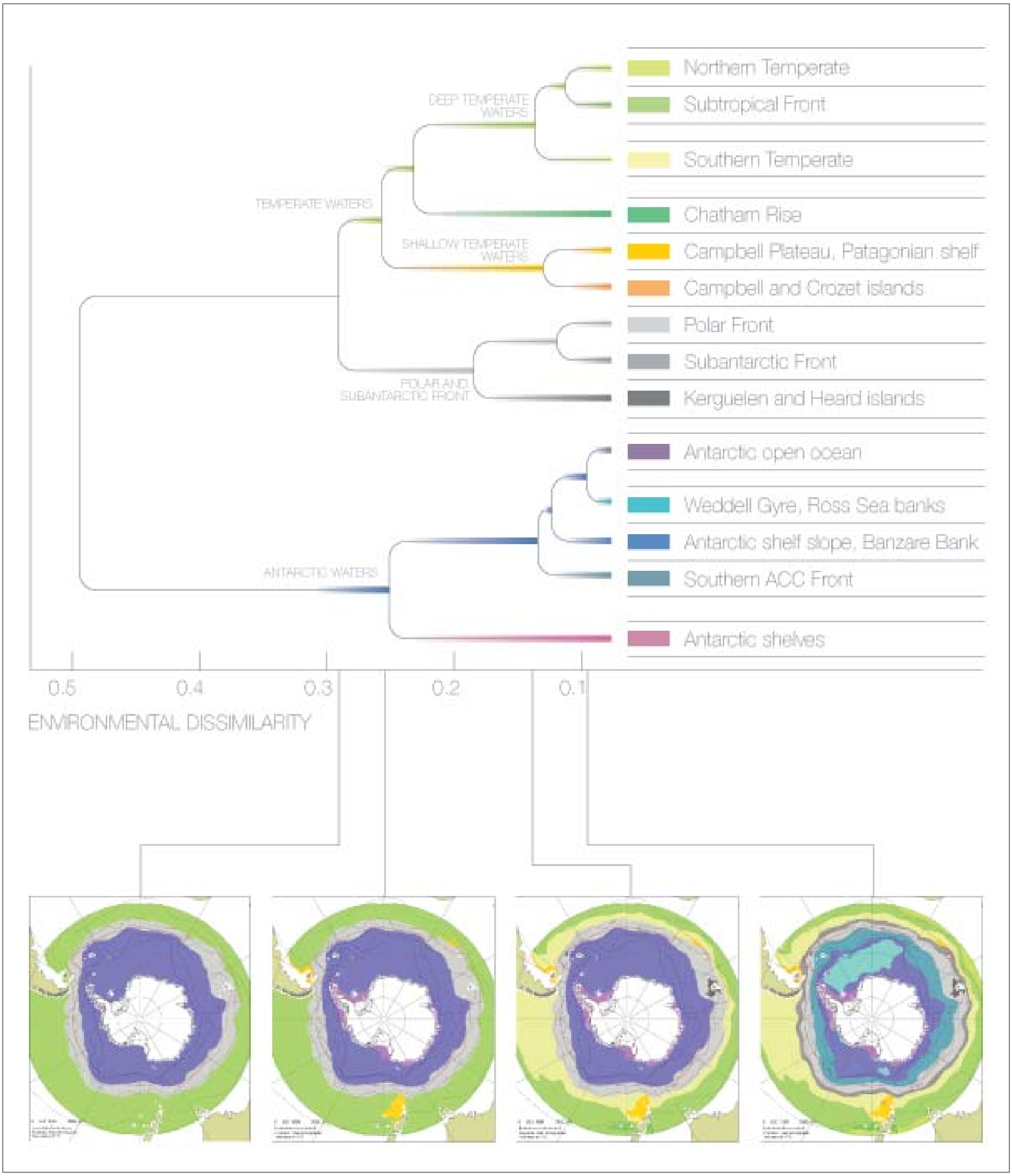

FIGURE 17: Dendrogram for primary (14-cluster) regionalisation, with thumbnail maps showing regionalisations at different stages of the hierarchy

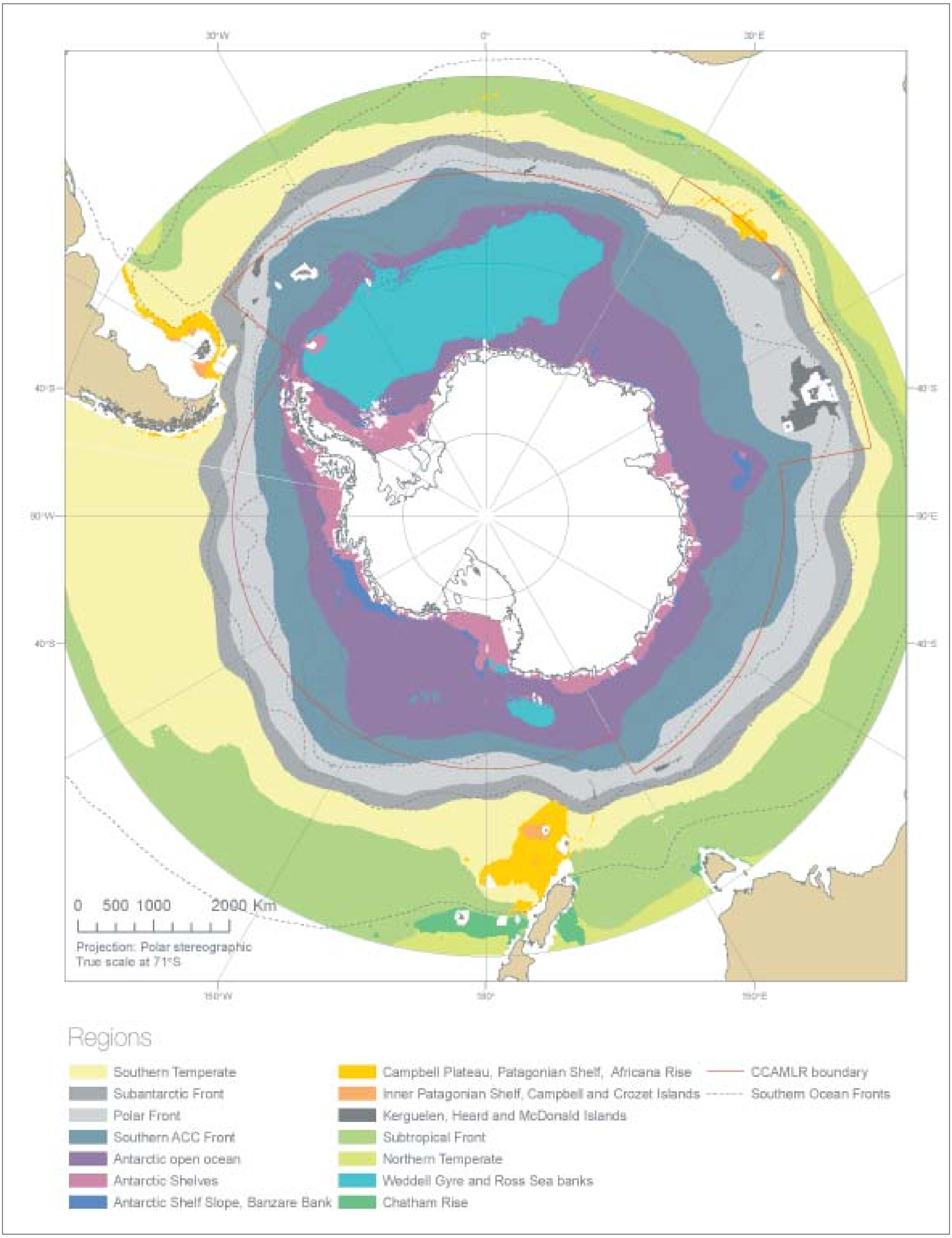

FIGURE 18: Primary regionalisation of the Southern Ocean based on: depth, sea surface temperature (SST), silicate (Si) and nitrate (NOx) concentrations (14 cluster groups) (white areas represent cells with missing data that were not classified in these analyses).

TABLE 1: Physical properties (mean and standard deviation of data values) of regions shown in Figure 18 (14 cluster groups based on primary datasets)

REGION NAME	Number of grid cells	Depth mean (m)	Depth SD	SST mean (°C)	SST SD	Si mean (µmol/kg)	Si SD	NOx mean (µmol/kg)	NOx SD
Southern Temperate	110567	-4119.952	821.342	8.681	1.854	7.998	2.402	20.919	1.616
Subantarctic Front	40180	-3917.738	921.884	5.840	0.791	15.231	2.582	25.158	1.052
Polar Front	83006	-4134.095	732.582	3.539	0.999	28.382	6.492	29.236	1.815
Southern ACC Front	108053	-4109.261	818.366	0.945	0.872	56.089	9.814	32.370	1.503
Antarctic Open Ocean	136360	-3612.533	897.680	-0.682	0.535	79.593	5.804	33.169	1.374
Antarctic Shelves	30767	-520.048	213.352	-1.149	0.380	82.044	9.211	32.356	1.821
Antarctic Shelf Slope, BANZARE Bank	6508	-1455.466	389.636	-1.227	0.434	79.961	2.946	33.599	1.343
Campbell Plateau, Patagonian Shelf, Africana Rise	7451	-1034.451	427.437	8.453	1.129	7.876	2.582	20.898	1.735
Inner Patagonian Shelf, Campbell & Crozet islands	913	-343.482	109.436	7.742	0.827	8.084	2.233	20.857	1.427
Kerguelen, Heard & McDonald Islands	2294	-1270.202	734.782	3.360	0.818	25.846	4.024	29.279	1.318
Subtropical Front	94234	-4461.472	788.887	11.804	1.511	4.607	1.235	15.257	2.062
Northern Temperate	9946	-4163.621	951.003	15.496	0.774	4.336	0.727	10.154	1.667
Weddell Gyre & Ross Sea banks	52905	-4466.641	762.290	-0.680	0.333	98.163	5.615	31.965	0.553
Chatham Rise	3025	-1568.439	858.953	14.361	0.802	4.112	0.610	12.061	1.453

Uncertainty

The time available to the workshop did not permit a rigorous analysis of uncertainty. However, a limited analysis was undertaken to investigate the uncertainty associated with the clustering algorithm. Figure 19 illustrates this uncertainty. Uncertainty was computed by first calculating the difference between the environmental characteristics of a grid cell and the average environmental characteristics of the cluster to which it was assigned. (Each grid cell is assigned to the cluster to which it is most environmentally similar). A second difference was then computed, this time between the environmental characteristics of a grid cell and the average environmental characteristics of the next-most similar cluster. The first difference value was then divided by the second. Thus, high uncertainty values (red, close to 1) indicate that a grid cell lies on the environmental boundary between two different clusters, and so its allocation to one or the other is less certain than for a grid cell that is strongly typical of the cluster to which is has been allocated. Note that this uncertainty analysis considers only a specific subset of the possible sources of uncertainty in the regionalisation (specifically, to do with the allocation of grid cells to particular clusters).

Secondary regionalisation

The secondary regionalisation incorporated two additional datasets to reflect properties that further modify the marine environment. The impact of sea ice on the environment was explored using a data layer comprising the proportion of the year (0-1) that an area was covered by at least 15% concentration of sea ice. The concentration of satellite-observed sea surface chlorophyll was explored using a data layer comprising log transformed chlorophyll densities.

The ice and chlorophyll data were incorporated both separately and in a single classification, and the results of these analyses are displayed in Appendix IV. The preliminary results of this analysis using a large number of clusters, based on both ice and chlorophyll, are presented in Section 3.3 for three sectors of the Southern Ocean. This exploratory classification is of use in illustrating the heterogeneity arising from these properties at a smaller scale than that of the primary regionalisation, however further work is needed to identify the appropriate level of regional separation using these secondary datasets, and to determine whether other datasets could be used to assist this process.

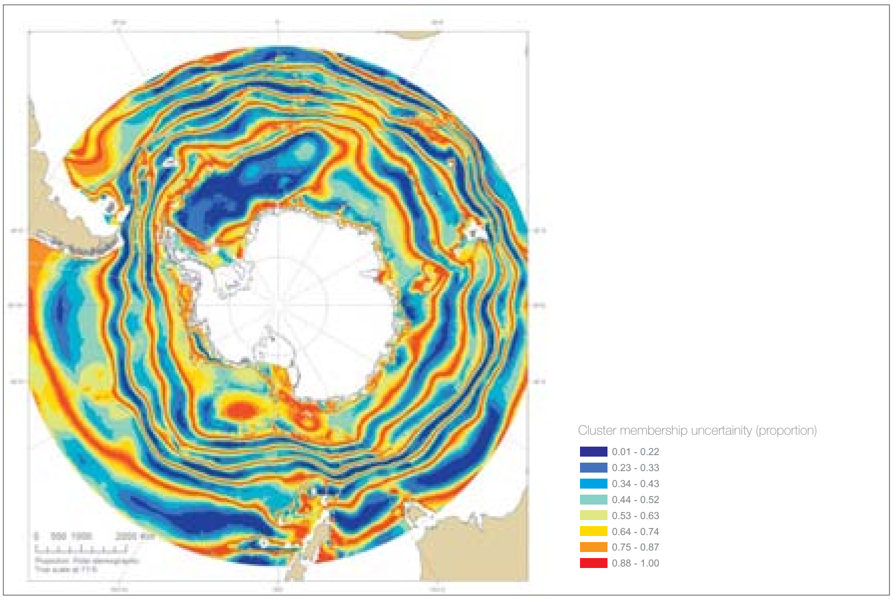

FIGURE 19: Map showing scaled uncertainty for the primary (14-cluster) classification

3.3 Expert review of bioregionalisation results

An assessment of the final results was carried out by expert review to determine if the defined regions were consistent with present knowledge of the ecosystem. The following sections describe the defined regions in further detail, focusing separately on the Atlantic, Indian and Pacific ocean sectors (CCAMLR Statistical Areas 48, 58 and 88, respectively). For each sector, a map of the regions defined by the primary regionalisation is overlain with information on known large-scale physical and ecological features such as fronts, gyres, seamounts and maximum sea ice extent. In addition, maps showing an example of a secondary regionalisation (using ice and chlorophyll data to define 40 clusters for the Southern Ocean) illustrate the high degree of smaller-scale heterogeneity arising from patchiness in chlorophyll and sea ice concentrations, particularly in shelf areas and the seasonal ice zone.

South Atlantic (Area 48)

The Atlantic sector is characterised by the narrowing of the ACC as it passes through Drake Passage between South America and the Antarctic Peninsula. In the west, strong currents, eddies and mixing associated with the ACC and the Weddell-Scotia Confluence (WSC) occur in the vicinity of the Scotia Arc. In the central and eastern areas, there is a greater contribution of the Weddell gyre and a broadening of the ACC. A large continental shelf area is present in the great embayment of the Weddell Sea, along with a number of ice shelves. These features are captured well in the primary regionalisation. The Atlantic sector is also dominated by strong seasonal cycles, manifest by changing irradiance and seasonal sea-ice cover. The bathymetry of the southwest Atlantic steers the flow of the ACC northwards, carrying polar waters to more northerly latitudes than elsewhere in the Southern Ocean. This transport is critical to the local marine systems around some of the more northerly SubAntarctic island groups where large colonies of many land-based predators breed.

The southwest Atlantic is possibly the most studied of all the areas in the Southern Ocean. It has higher productivity than other areas. Extensive summer phytoplankton blooms, particularly around some of the island chains, probably result from the mixing of micronutrients with surface waters through the flow of the ACC and the WSC as they pass over the Scotia Arc. A range of zooplankton species including Antarctic krill (*Euphausia superba*), consume this primary production. In turn, these taxa are consumed by numerous species of nekton, seabirds and marine mammals. The resulting biodiversity is possibly higher than elsewhere in the Southern Ocean.

Zooplankton community structure in the southwest Atlantic appears to be dependent upon the timing of the seasonal sea-ice retreat (Ward et al., 2003). Sea-ice influences the timing of reproduction; a late retreat delays reproduction and reduces population sizes of a number of zooplankton species. During years of normal sea-ice retreat copepods are more advanced, and there are also higher abundances of krill larvae. This implies that the seasonal environment critically influences the biogeography of zooplankton communities in the southwest Atlantic. As a consequence, multi-year datasets that encompass years of differing environmental

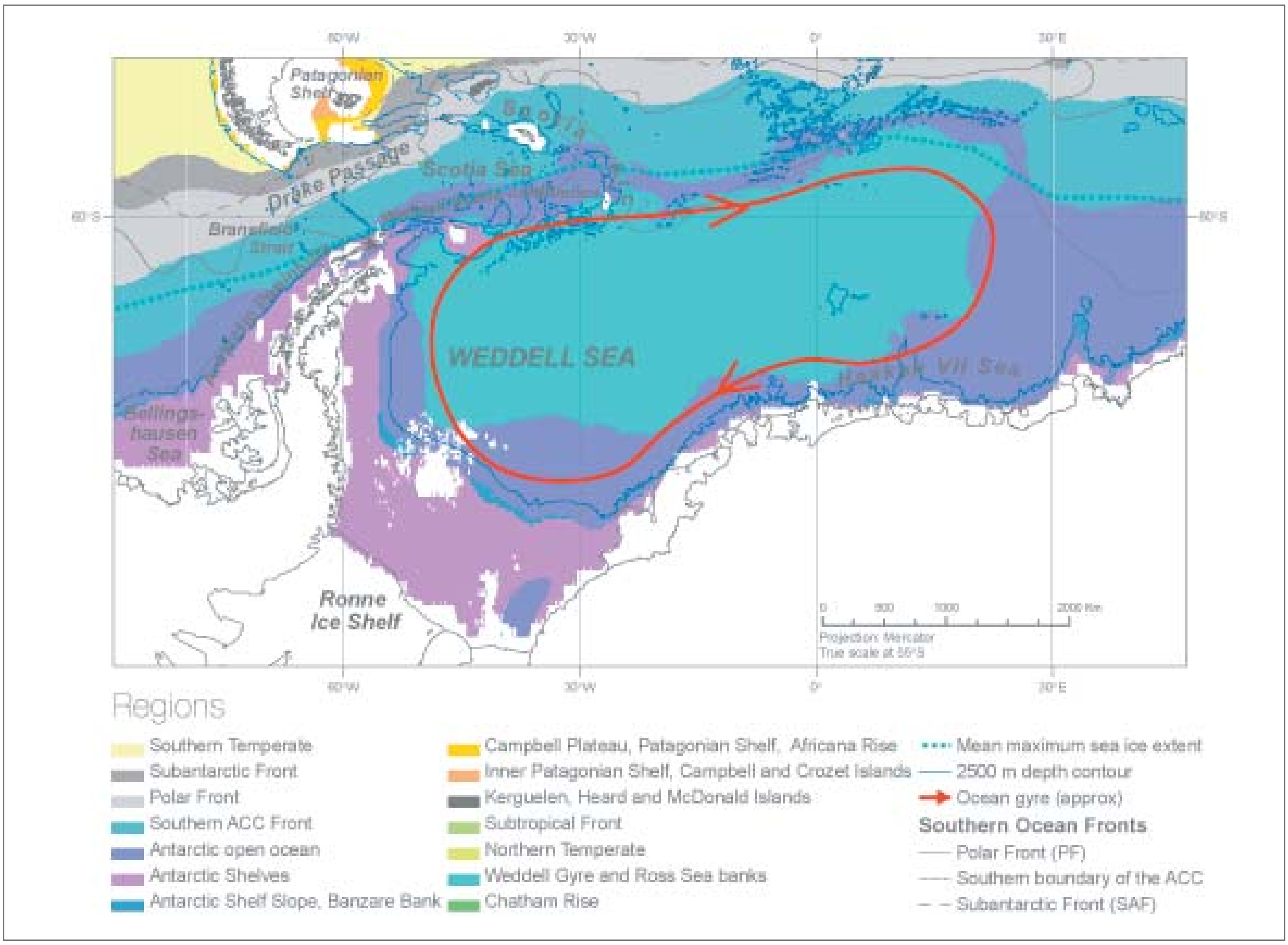

FIGURE 20: Map showing primary regionalisation for the South Atlantic sector (Area 48), with major physical features

conditions are likely to provide broader and more generic descriptions of community structure in the southwest Atlantic than do single year synoptic surveys.

A number of such analyses are now available, which reveal that (multi-year) sampling of zooplankton species across the ACC to the northwest of South Georgia form four community groupings, and that these are geographically consistent with the different water masses identified on the basis of temperature and salinity properties. Copepods are the largest contributors to total abundance within these groupings. All groups can be characterised by varying proportions of a relatively small subset of species, many of which are present throughout the region. Other species are characteristic of particular groups. The close physical and biological coupling observed across the ACC confirms that frontal zones, and particularly the Polar Front, are features across which community properties change in the Atlantic sector.

Small and mesopelagic zooplankton species also play a major role in the southwest Atlantic. Small copepods form approximately 75% of total copepod abundance in the upper ocean layers across all major oceanographic zones. These species show a continuum of temperature ranges, and there is no evidence that the Polar Front is a major biogeographic boundary to their distribution. Indeed, several important species reach maximum numbers in this area. Total copepod abundance is thus higher in the vicinity of the Polar Front than in any other region (Atkinson and Sinclair, 2000).

Larger zooplankton species such as Antarctic krill and salps (mainly *Salpa thompsoni*) are also major grazers in the Southern Ocean and particularly in the productive southwest Atlantic sector where krill biomass forms more than 50% of Southern Ocean krill stocks. Spatially, summer krill density correlates positively with chlorophyll *a* concentrations. Temporally, within the southwest Atlantic, summer krill densities correlate positively with sea-ice extent the previous winter. Summer food and the extent of winter sea ice are thus key factors in the high krill densities observed in the southwest Atlantic Ocean. Salps, by contrast, occupy the extensive lower-productivity regions of the Southern Ocean and tolerate warmer waters than krill (Atkinson et al., 2004).

The secondary regionalisation shows the patchiness in primary production and ice cover around the coastal region as well as the patchiness in primary production in the oceanic areas and around the islands of the Scotia Arc. The pattern of clusters from Antarctic Peninsula area to South Sandwich Island area matches well with the spatial distribution of krill length composition cluster groups observed during CCAMLR-2000 survey (Figure 5 of Sigel et al. 2004). Also, the influence of the Weddell Gyre on the productivity and water properties of the Bransfield Strait (Amos, 2001) is apparent.

Figures 20 and 21 show the primary and secondary regionalisations for the South Atlantic sector. (Note that the colours used in the secondary regionalisation do not relate to those in the primary regionalisation).

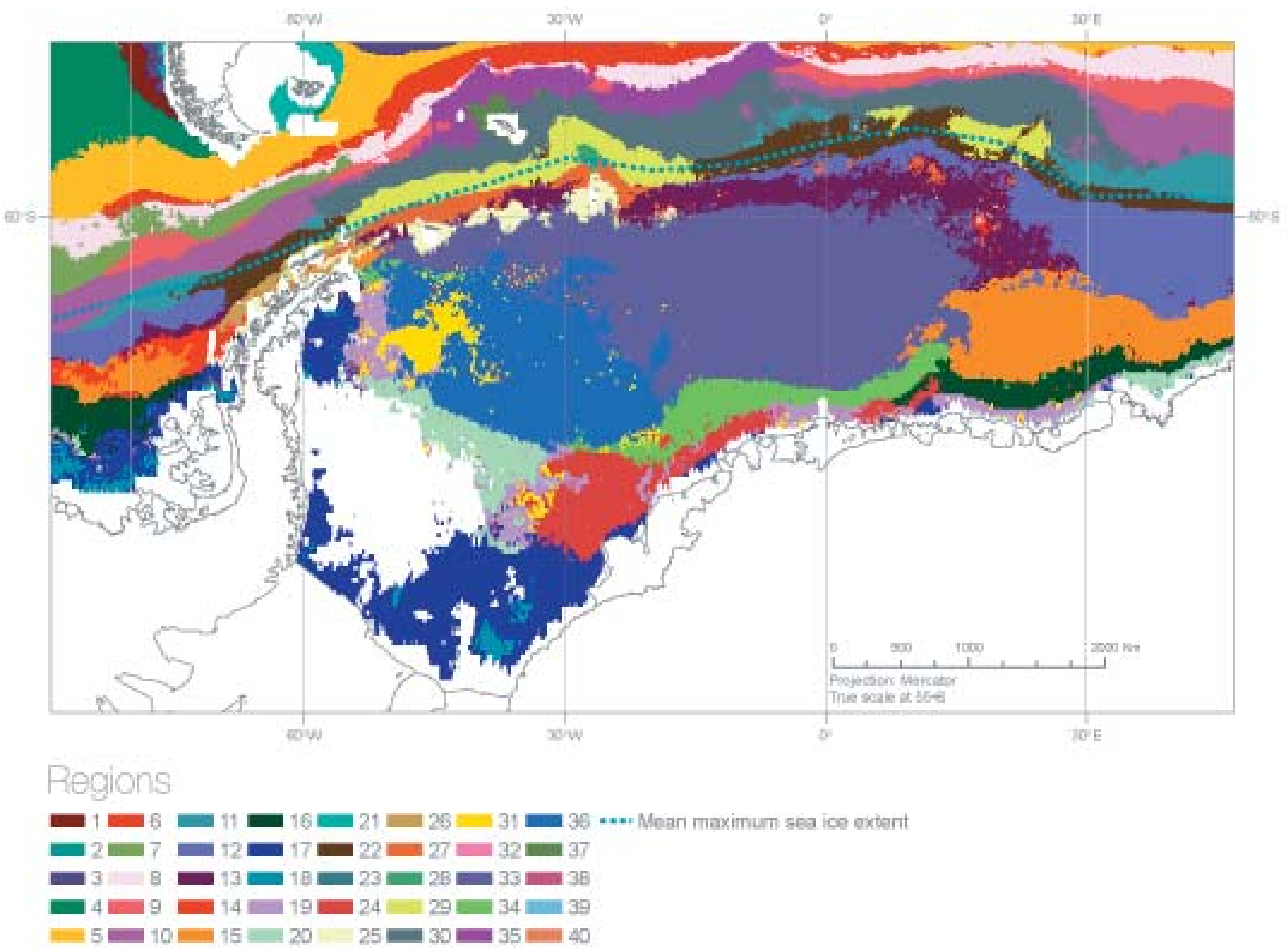

FIGURE 21: Map showing secondary regionalisation for the South Atlantic sector (Area 48)

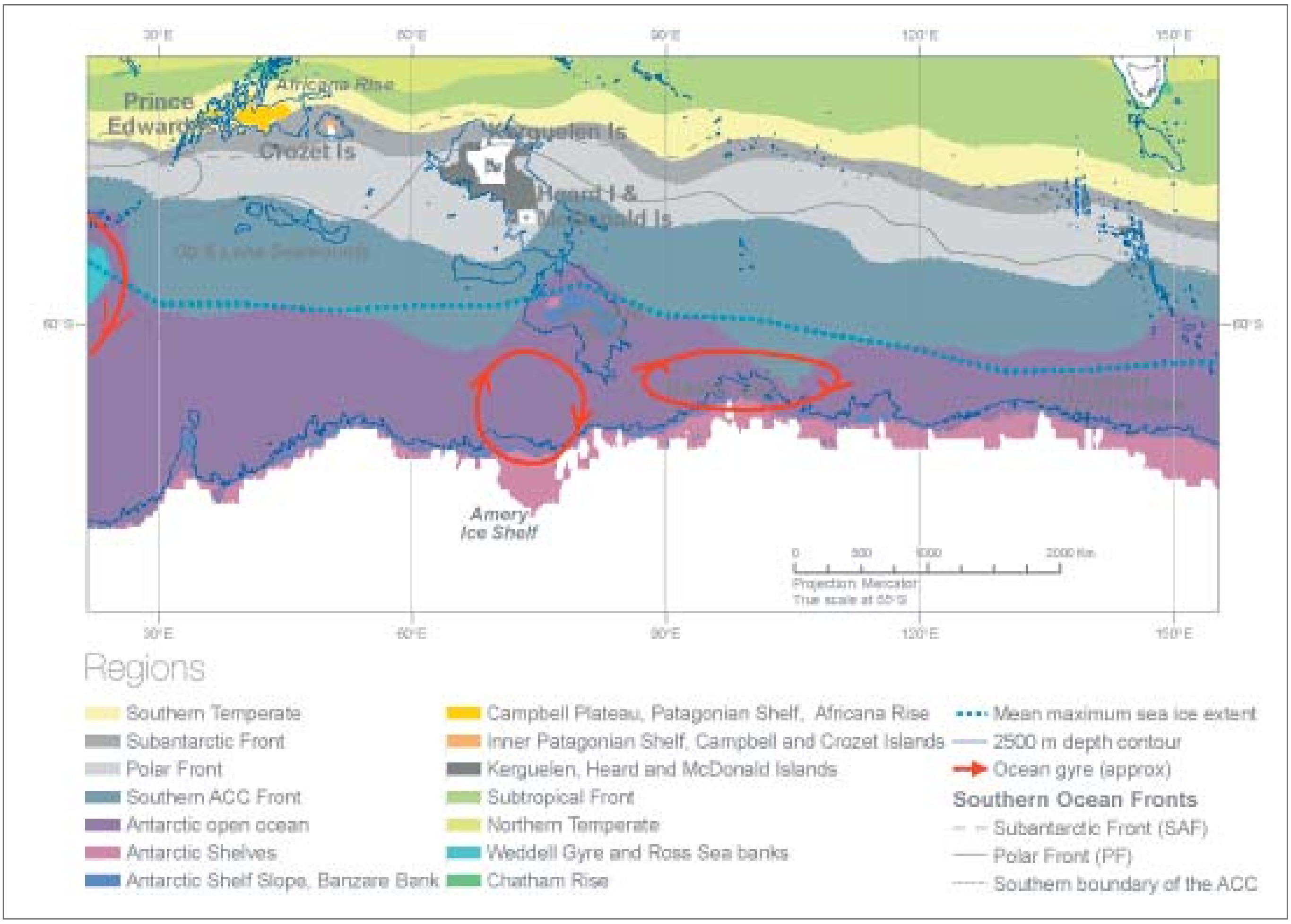

FIGURE 22: Map showing primary regionalisation for the Indian Ocean sector (Area 58), with major physical features

Indian Ocean (Area 58)

The Indian Ocean sector extends in the west from the eastern margins of the Weddell Gyre across the Indian Ocean with a gradual movement of the Polar Front from the north to the south. The flow of the ACC is disrupted by the greater Kergeulen Plateau, including BANZARE Bank, causing formation of many branches of the fronts. A set of subantarctic islands and banks are found in the western part of the sector between 45°S and 55°S. Gyres are present close to the small embayment of Prydz Bay, and also east of BANZARE Bank. These general features are evident in the primary classification.

Ice shelves are present along the coastal margins, including in Prydz Bay. Also, a number of polynyas occur along the coast (Arrigo and van Dijken, 2003; Massom et al., 1998), some of which are substantial contributors to production of sea ice and deep water formation. The annual progression and retreat of sea ice is uninterrupted in this region, extending to 60°S, although the winter sea ice extent is greater in the west than in the east.

Most research has occurred to the west of 60°E, although a recent survey of krill and associated environmental parameters (Jan-March 2006 - 30°E to 80°E) completed synoptic coverage of the coastal region from 30°E to 150°E (Nicol et al., 2000; 2006). These surveys suggest that productivity is higher and, along with Antarctic krill, *Euphausia superba*, extends further to the north in the area to the west of approximately 115°E (south of 60°S) compared to east of this longitude. Salps are found to the north of this krill distribution. This is evident in the secondary classification with a greater diversity of regions in the area of higher productivity between 115°E and Prydz Bay. This is also coincident with the evidence for an eastern gyre hypothesised by Nicol et al. (2000). The pattern of clusters around 30-80°E (south of 60°S) matches well the spatial pattern of krill length composition cluster groups found in recent surveys (Figure 12 of Nicol et al., 2006). These surveys also identified the higher densities of Antarctic krill, *Euphausia superba*, associated with the shelf break. This region also is indicated well in the secondary classification. The neritic community over the continental shelf is dominated by the crystal krill *Euphausia crystallorophias*, which are never found as adults to the north of the shelf break.

A number of studies have characterised the zooplankton assemblages in the Southern Indian Ocean and their association with fronts (e.g. Hosie 1994a; 1994b; Hosie et al., 1997; Chiba et al. 1999; 2001; Hoddell et al., 2000; Hosie et al., 2000; Hunt and Hosie, 2003; 2005; 2006a; 2006b). Continuous Plankton recorder (CPR) monitoring, primarily between 60 and 160°E from spring to autumn, have identified a number of breaks in the distribution of zooplankton taxa with fronts identified by Orsi et al. (1995). The SAF is a major biogeographic boundary for plankton with separate communities north and south of the front (Hunt and Hosie, 2003). Some changes in composition occur at the Polar Front, in particular the northern branch of the PF. A number of distinct zooplankton assemblages can also be defined south of the PF-N. These assemblages are identified more by subtle variation in the abundance or proportion of species rather than changes in species

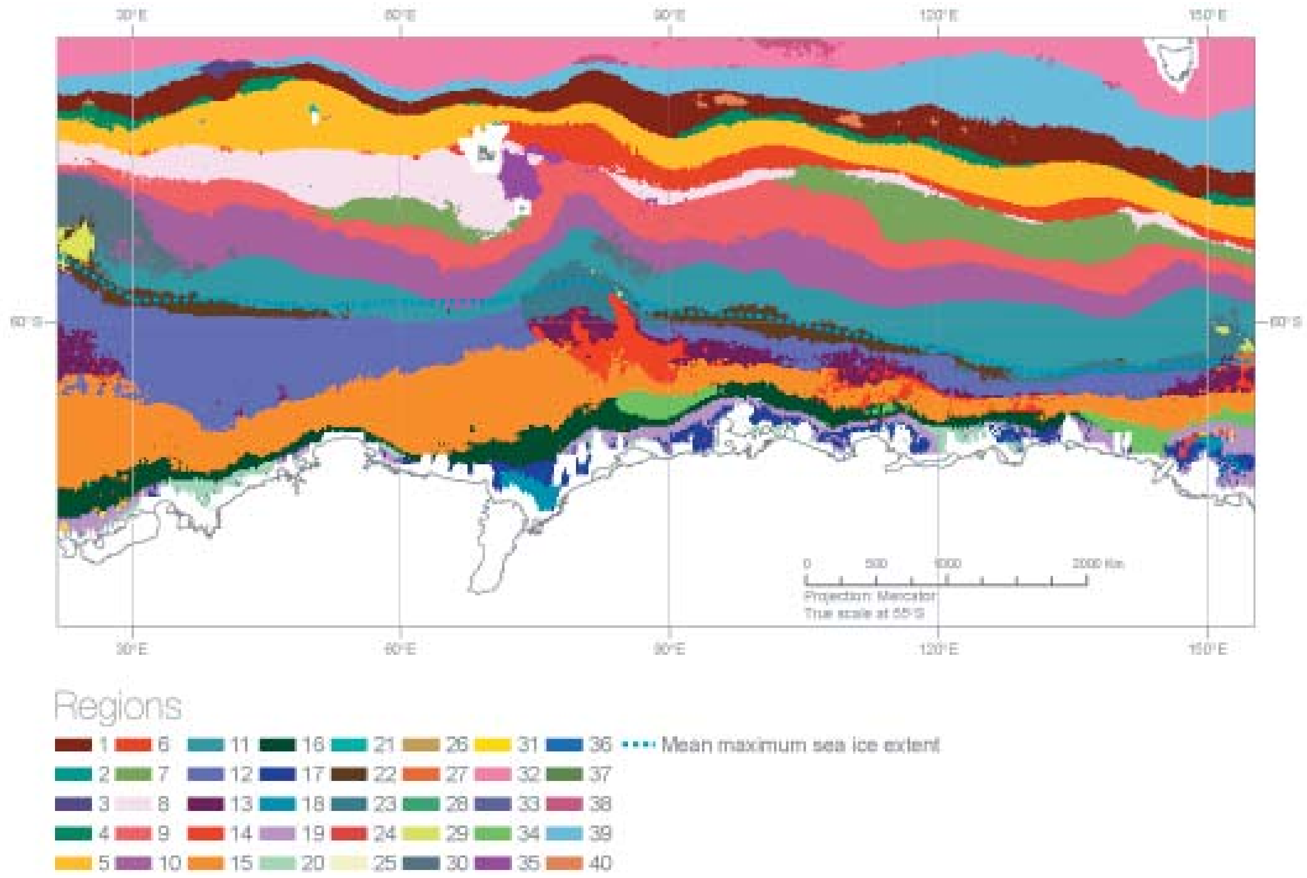

FIGURE 23: Map showing secondary regionalisation for the Indian Ocean sector (Area 58)

composition (Hunt and Hosie, 2005). The Polar Fontal Zone (SAF and PF) is often reported as an area of elevated primary production which then declines south of the PF. This is probably true for phytoplankton, and certainly many vertebrate predators forage in this area. However, the CPR survey has consistently shown that zooplankton abundance increases substantially south across the SAF and remain high though the Southern Ocean to a point between 60 to 62°S where zooplankton abundance declines suddenly (Hosie et al., 2003). The upper 20 m of the water column in the area further south usually remains almost devoid of zooplankton. This decline approximates the position of the SACCF (Orsi et al., 1995) although a link is yet to be established. Overall, the patterns displayed in the secondary classification correspond to the patterns of zooplankton described here.

Figures 22 and 23 show the primary and secondary regionalisations for the Indian Ocean sector. (Note that the colours used in the secondary regionalisation do not relate to those in the primary regionalisation).

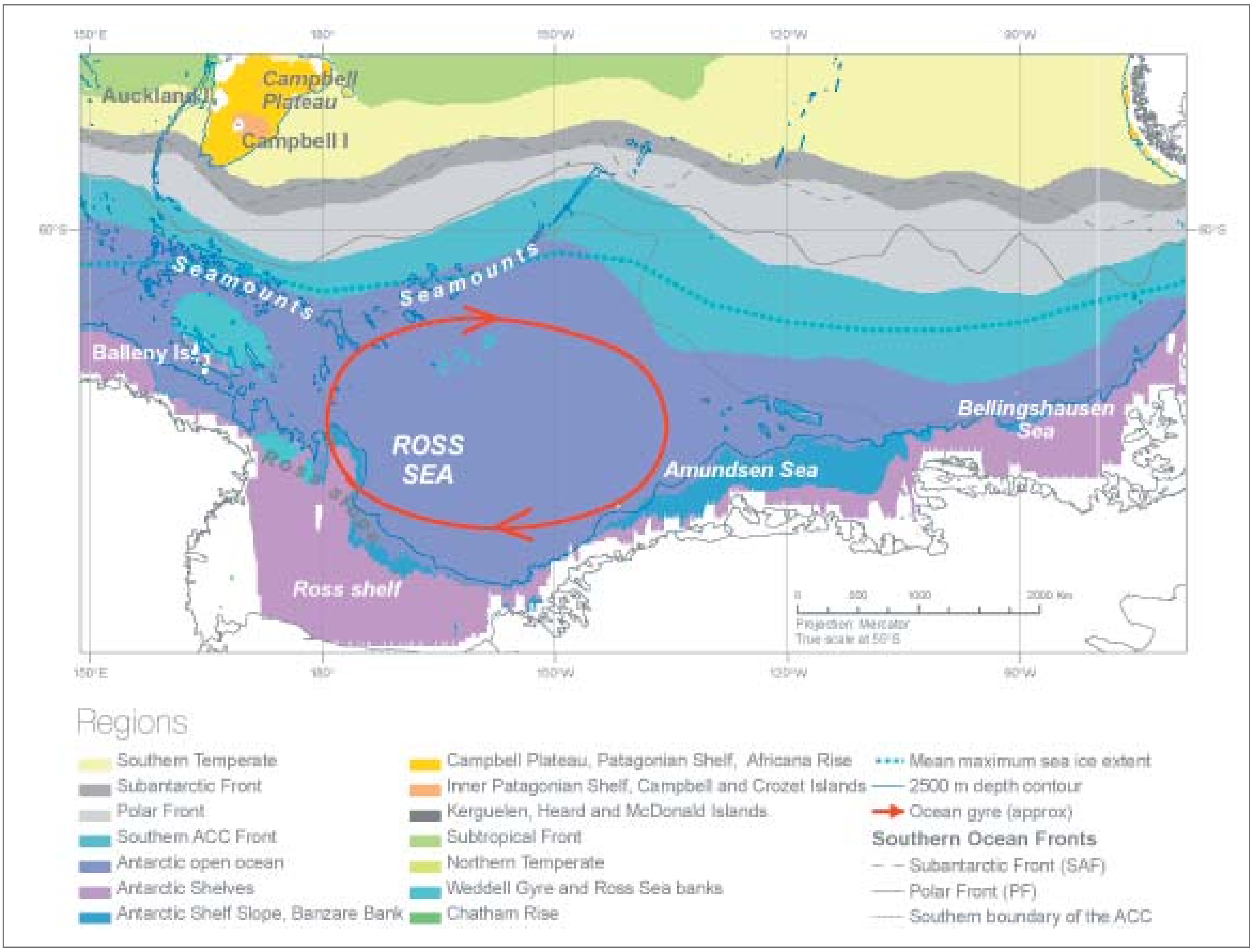

FIGURE 24: Map showing primary regionalisation for the Pacific Ocean sector (Area 88), with major physical features

Pacific Ocean (Area 88)

The Pacific sector is similar in ocean characteristics to the Indian Ocean sector except for the interaction with Ross Sea and its associated gyre. The inner Ross Sea over the continental shelf has characteristics distinct from those of the ACC. The western part of the Ross Sea has a complex shelf and slope area along with the Balleny Islands and ridges of seamounts extending to the north (the Macquarie Ridge extending to the Campbell Plateau) and to the east. A clockwise current flows within the area shallower than the 500 m isobath, and the East Wind Drift current flows in the opposite direction along the continental shelf break. Upwelling of Circumpolar Deep Water also occurs along this shelf break (Ainley, 2002). Seasonal polynyas in the western shelf area play an important role in the distribution of phytoplankton, zooplankton, fish, birds and seals. The concentration of top predators in the Ross Sea coincides with the marginal ice zone that rings the Ross Sea Polynya. This area is dominated by diatoms, while the central, open water portion of the polynya is dominated by Phaeocystis (Ainley et al., 2006). The primary classification identifies the Ross Sea shelf and slope areas. Features such as the Ross Sea polynya are not captured in the primary classification, but these may be reflected in the heterogeneity of the secondary classification.

Further to the east in the Pacific Sector is a narrowing of the ACC towards the Drake Passage. Also, the seasonal sea ice zone narrows in the eastern part of the Bellingshausen Sea. The primary classification captures the major ocean and coastal features, although it does not reflect the ocean ridges in the eastern part of the sector.

The separation of subtropical and subantarctic waters as well as distinguishing the Campbell Plateau from the ocean environment is supported by research on productivity of the region (Boyd et al. 1999; Murphy et al. 2001) and fish assemblages (Bradford-Grieve et al. 2003). Although these general differences are retained in the secondary classification, the wider Campbell Plateau is not differentiated from the southern temperate waters. This may be because of the lack of differentiation in the chlorophyll data used here.

The secondary classification does identify the heterogeneity of the environment associated with the island and ridge system in the eastern part of the sector. It also identifies the expected complexity in the Ross Sea Gyre and its relationship to the coastal system. These results reflect studies documenting the variation in diversity and ecological processes in the region (Bradford-Grieve and Fenwick 2001; Pinkerton et al., 2006; Sharp, 2006). For example, *Euphuasia superba* is found to the north of the shelf break while the neritic fauna is dominated by *Euphausia crystallorphias* and *Pleuragramma antarcticum*.

Figures 24 and 25 show the primary and secondary regionalisations for the Pacific Ocean sector. (Note that the colours used in the secondary regionalisation do not relate to those in the primary regionalisation).

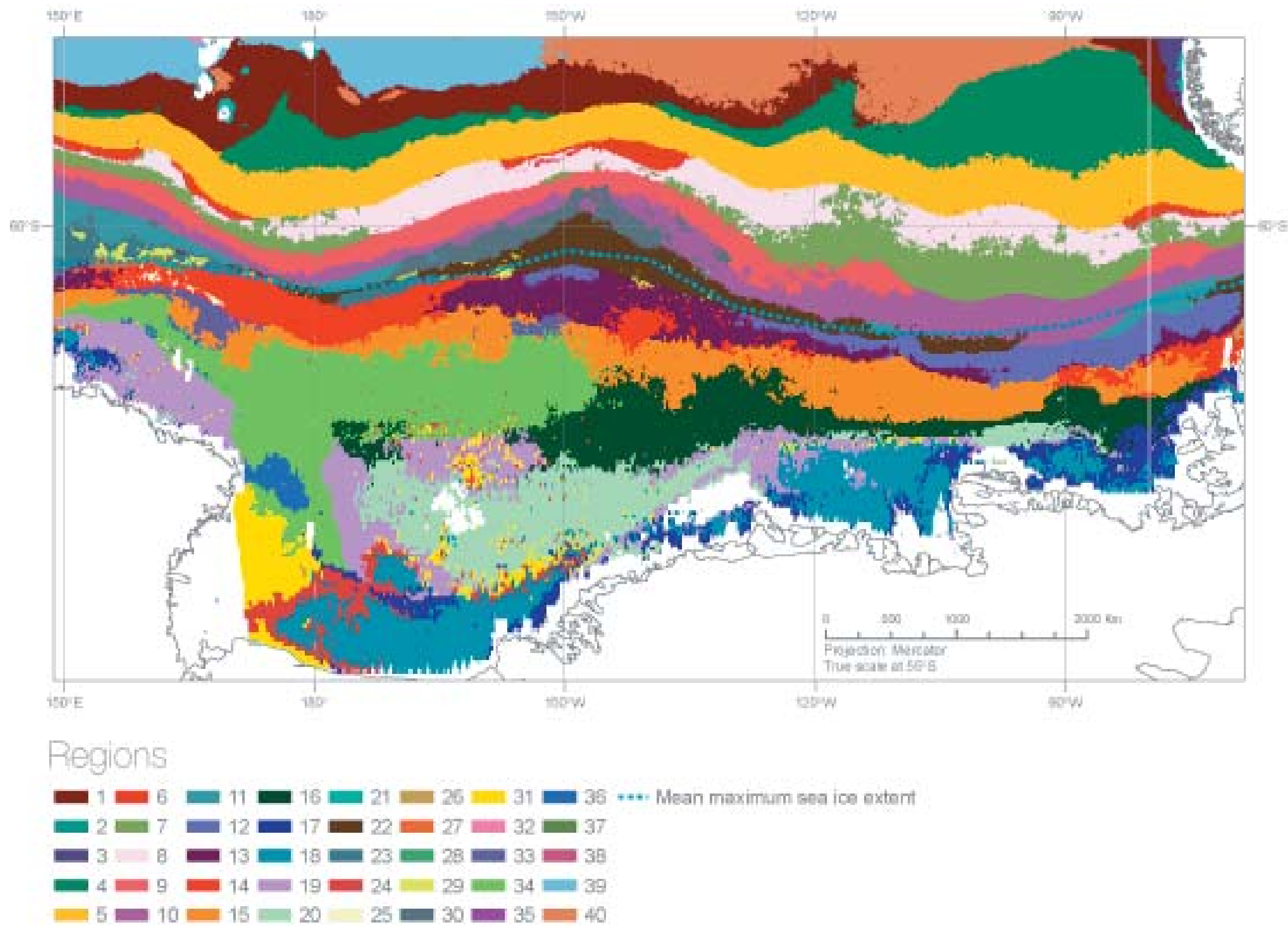

FIGURE 25: Map showing secondary regionalisation for the Pacific Ocean sector (Area 58)

The primary regionalisation of the Southern Ocean highlights the different environmental characteristics of large regions including the continental shelf and slope, frontal features (Subantarctic Front, Polar Front, Southern Antarctic Circumpolar Current Front), the deep ocean, banks and basins, island groups and gyre systems. The addition of secondary datasets suggests smaller-scale spatial heterogeneity within the regions, particularly in the continental shelf and slope areas, and the seasonal ice zone.

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4. Future work

The workshop identified a range of areas in which future work might be directed in order to produce a final bioregionalisation for the Southern Ocean. Priorities included the incorporation of additional (particularly biological) datasets, and finer-scale analysis of particular areas of interest. It also identified that the statistical methods might be refined further. However, the workshop was satisfied that the proof of concept developed is sufficient to undertake the tasks identified by CCAMLR and the CEP.

Further data could be used to update or refine the draft broad-scale primary regionalisation (for example using additional datasets such as insolation (PAR) and sea surface height). Datasets used in this analysis might also be refined, for example using derived datasets such as a 'silicate depletion' data layer (reflective of primary production) derived by subtracting silicate at the surface from silicate at 200 m depth.The remotely-sensed PAR data are confounded by the inability to distinguish ice cover from cloud cover, however they might be transformed to represent biologically relevant variation in available light, by combining PAR data and ice data.

The addition of sea ice and chlorophyll *a* datasets in the exploratory secondary classifications illustrated the high level of heterogeneity arising from these parameters. Refinement of the analysis and data used at the secondary classification level is needed to identify the appropriate level of regional separation at a smaller scale using these secondary datasets, and to identify whether other datasets could be used to assist this process. In particular, sea ice is a major driver of ecosystem processes in the Southern Ocean (see Section 1.3), and the inclusion of variables representing sea ice dynamics will be important in finer-scale regionalisation analyses.

The draft regionalisation presented in this report is pelagic, however it may also be necessary to undertake a benthic regionalisation. Further consideration should be given to the relationships between the benthic and pelagic systems, and the utility of separating the two systems in the context of bioregionalisation analysis.

A range of potential biological datasets (for use in future analyses) were identified during the workshop (see Appendix V), but it will be necessary to identify which of these would be of most value. Data 'compendia' may be of assistance in providing information on inter-annual and seasonal variability, which can then be further analysed according to the defined objectives. Indicator species might also be investigated for their potential utility in providing further input to the analysis. In the longer term, the compilation of comprehensive biological data sets may allow the use of more sophisticated analytical approaches such as Generalised Dissimilarity Modelling (GDM – Ferrier et al. in press). This performs an integrated statistical analysis of biological and environmental data, using information on species turnover rates to identify the optimal weighting and transformation of environmental variables to be used in defining the classification.

It may be important to consider stochastic, temporal or spatial variability in defining bioregions in order to ensure that the outcome is robust to uncertainties and variability. Further work towards understanding (and, where possible, reducing) different types of uncertainty in the data, models or methods will help the classification process.

A bioregionalisation will inevitably be based on the best scientific evidence available at the time. Further refinement could be achieved by adding biological and environmental data as it becomes available, thereby reducing uncertainties. One source of refinement will be to add more biological data to test the relationship between physical and environmental surrogates and the ecological processes they are thought to represent. This is likely to be needed at finer-scale resolution of the bioregionalisation.

The most important avenue for further work will be to undertake a finer-scale regionalisation than that presented here. This might initially be focused in areas where more data is available, such as in the southwest Atlantic. The addition of datasets on chlorophyll *a* and sea ice extent illustrated the complexity of the coastal, shelf and seasonal ice areas, in relation to these parameters. These regions are likely to have additional complexity corresponding to other ecological processes and species distributions, and should be a priority for further research.

5. Conclusions

This workshop established a 'proof of concept' for bioregionalisation of the Southern Ocean. Further work within the frameworks of CCAMLR and the CEP will be an important contribution to the achievement of a range of scientific, management and conservation objectives, including large-scale ecological modelling, ecosystem-based management of human activities in the marine environment, and the development of ecologically representative protected area systems. Continuing work on this topic also has the potential to inform and contribute to the further development of bioregionalisation analysis as a tool for conservation and management in the global context.

List of Appendices (provided on CD)

APPENDIX I: Approaches to bioregionalisation – examples presented during the workshop

- Antarctic Environmental Domains Analysis (Harry Keys and Fraser Morgan, Department of Conservation, New Zealand)
- CCAMLR Small-Scale Management Units for the fishery on Antarctic krill in the Southwest Atlantic (Roger Hewitt, NOAA, USA)
- Australian National Bioregionalisation: Pelagic Regionalisation (Vincent Lyne and Donna Hayes, Department of the Environment and Heritage and CSIRO)
- Selecting Marine Protected Areas in New Zealand's EEZ (John Leathwick, NIWA, New Zealand)

APPENDIX II: Technical information on approach to bioregionalisation

APPENDIX III: Descriptions of datasets used in the analysis

APPENDIX IV: Results of secondary regionalisation using ice and chlorophyll data

APPENDIX V: Biological datasets of potential use in further bioregionalisation work

APPENDIX VI: Details of datasets, Matlab code and ArcGIS shapefiles included on the CD

List of workshop participants

PARTICIPANT	EXPERTISE	AFFILIATION
Dr. Ian Ball	Mathematical modelling, MPA selection	ACE CRC, AGAD, Australia
Ms. Kendall Benton	Support	WWF-Australia
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Dr. Susan Doust	Support, CCAMLR	AGAD, Australia
Dr. Susie Grant	Support, marine protected areas, CCAMLR, CEP	UK
Dr. Roger Hewitt	Krill biology, ecosystem ecology	SW Fisheries Centre, NOAA, USA
Dr. Graham Hosie	Zooplankton ecology; CPR program	AGAD, Australia SCAR representative
Dr. So Kawaguchi	Krill biology, ecosystem ecology	ACE CRC, AGAD, Australia
Dr. Harry Keys	Bioregionalisation, Antarctic regional classification	DOC, NZ
Dr. John Leathwick	Statistical modelling, bioregionalisation, MPA selection	NIWA, Hamilton, NZ
Dr. Gilly Llewellyn	Support, classification, regionalisation, marine protected areas	WWF-Australia
Dr. Vincent Lynne	Statistician, bioregionalisation	CSIRO MAR, Hobart, Australia
Dr. Enrique Marschoff	Krill biologist (larvae), CCAMLR	Argentina
Dr. Rob Massom	Sea ice, remote sensing	ACE CRC, Australia
Mr. Ewan McIvor	Environmental policy	AGAD, Australia
Dr. Denzil Miller	Observer	CCAMLR Secretariat
Dr. Mikio Naganobu	Krill biology, ecosystem ecology	Japan
Dr. Steve Nicol	Krill biology, ecosystem ecology	ACE CRC, AGAD, Australia
Dr. Matt Pinkerton	Ecosystem modelling, remote sensing	NIWA, NZ
Dr. Ben Raymond	Modelling, data visualisation	ACE CRC, AGAD, Australia
Dr. Steve Rintoul	Physical oceanography, remote sensing	ACE CRC, Australia
Dr. Eugene Sabourenkov	Observer	CCAMLR Secretariat
Dr. Ben Sharp	Marine biologist, marine protected area research	MFish, NZ
Dr. Sergei Sokolov	Physical oceanography, remote sensing	ACE CRC, Australia
Mr. Rick Smith	Statistician, bioregionalisation	CSIRO MAR, Hobart, Australia
Dr. Pete Strutton	Primary production, remote sensing	Oregon State University, USA
Dr. Phil Trathan	Ecosystem and predator ecology, CCAMLR	BAS, UK

Bioregionalisation (or Regionalisation)

A process that aims to partition a broad spatial area into distinct spatial regions, using a range of environmental and biological information. The process results in a set of bioregions, each with relatively homogeneous and predictable ecosystem properties. The properties of a given bioregion should differ from those of adjacent regions in terms of species composition as well as the attributes of its physical and ecological habitats. The term regionalisation may be used interchangeably (or sometimes to refer to an analysis undertaken using only physical data).

Bioregion (or Region)

A spatial compartment defined on the basis of its biological and/or physical properties. Each bioregion (or region) reflects a unifying set of major environmental influences which shape the occurrence of biota and their interaction with the physical environment. The term region may be used interchangeably (or sometimes to refer to spatial compartments which have been defined using only physical data).

Classification

The process of partitioning a broad spatial area into distinct regions. Also used to refer to the specific step within that process during which the actual allocation of sites to regions occurs, usually through a statistical process such as cluster analysis

Ecological process

In the context of this report, an ecological process is any process that affects the dynamics of a species

Hierarchy (spatial and statistical)

In the context of bioregionalisation, this term may be used to refer to spatial or ecological hierarchy, or statistical hierarchy.

Spatial or ecological hierarchy refers to the different levels of scale or ecological processes within a large area. A hierarchy may be nested, whereby smaller scale units or processes are nested within large scale units.

Statistical hierarchy has relevance in dissimilarity-based clustering methods, where an iterative approach is undertaken to group sites together into regions. All sites are initially allocated to their own regions. At each iteration of the process (or each step down the hierarchy), the two most similar regions are merged together, until at the end of the process there is only one region, which contains all of the sites. This is often displayed in dendograms.

Parameter

Information extracted from data. For example, sea ice concentration is a variable from which the parameters of 'proportion of year when the ocean is covered by at least 15% ice' or 'areas with greater than 50% ice coverage' can be extracted.

Property

This term is used here to describe the defining characteristics or attributes of a particular ecological process, or of a given region.

Proxy

A parameter that can be used to provide similar information or patterns to another parameter or variable, usually used when desired data (e.g. the distribution of species) are unavailable, or where one parameter can be used in the place of several others in order to simplify the analysis.

Site

In the context of bioregionalisation analysis, a site is the smallest unit of analysis. The study area is divided into a grid of sites, at sufficiently fine scale to enable appropriate resolution of the final areas. Each site will have a particular set of parameters, according to the input data.

Synoptic

This term is used to describe data that have broad and continuous spatial coverage (e.g. across the entire Southern Ocean). Here, synoptic data may also refer to summaries of the observed conditions over time (e.g. mean monthly values averaged to obtain an annual mean). Synoptic data may be obtained through satellite remote-sensing, or through model climatologies generated from observed values.

Uncertainty

In the context of bioregionalisation analysis, uncertainty refers to the effects of imprecision in data (e.g. measurement error), uncertainty within models used to derive variables (e.g. climatology models), and epistemic uncertainty (potential errors in the chosen method). Each of these types of uncertainty can affect the resulting region boundaries.

Variable

Variables are physical or environmental data from which specific parameters can be extracted. For example, sea ice concentration is a variable from which the parameters of 'proportion of year when the ocean is covered by at least 15% ice' or 'areas with greater than 50% ice coverage' can be extracted.

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8. Report of 2007 CCAMLR Bioregionalisation workshop

REPORT OF THE WORKSHOP

(available in English only)

CONTENTS

REPORT OF THE WORKSHOP ON BIOREGIONALISATION OF THE SOUTHERN OCEAN
(Brussels, Belgium, 13 to 17 August 2007)

INTRODUCTION

Opening of the Meeting

The CCAMLR Workshop on Bioregionalisation of the Southern Ocean was held in Brussels, Belgium, from 13 to 17 August 2007. The Workshop was convened by Drs P. Penhale (USA) and S. Grant (UK).

2. The Co-conveners welcomed all participants and, in particular, the invited experts:

- Dr B. Danis, SCAR-MarBIN, Royal Belgian Institute of Natural Sciences
- Dr G. Hosie, SCAR, Australian Government Antarctic Division
- Dr M. Kahru, Scripps Institution of Oceanography, USA
- Dr M. Vierros, United Nations University, Institute of Advanced Studies, Japan.

3. Special thanks were extended to Belgium, in particular, to Mr A. de Lichtervelde and his team from the Federal Public Service Public Health, Food Chain Security and Environment, for their warm hospitality, financial support and hosting of the Workshop.

Adoption of the agenda and organisation of the meeting

4. The Workshop agenda was prepared based on the Workshop terms of reference as agreed by the Scientific Committee (SC-CAMLR-XXIV, paragraph 3.66):

1. To facilitate collaboration between the CCAMLR Scientific Committee and CEP in this work.

2. To facilitate the involvement of appropriate experts in this work.

3. To coordinate and facilitate:

   (i) collating existing data on coastal provinces, including benthic and pelagic features and processes;

   (ii) collating existing data on oceanic provinces, including benthic and pelagic features and processes;

   (iii) determining the analyses required to facilitate a bioregionalisation, including the use of empirical, model and expert data;

   (iv) developing a broad-scale bioregionalisation based on existing datasets and other datasets possibly available prior to the Workshop;

   (v) delineating fine-scale provinces within regions, where possible;

(vi) establishing a procedure for identifying areas for protection to further the conservation objectives of CCAMLR.

4. To organise a Workshop to establish a bioregionalisation for the CCAMLR Convention Area and to consolidate advice on a system of protected areas (SC-CAMLR-XXIV, Annex 7, paragraph 144).

The adopted agenda is in Appendix A.

5. The Workshop participants are listed in Appendix B. The documents submitted to the Workshop are listed in Appendix C.

6. The report of the meeting was prepared by Workshop participants. The report includes sections on Data, Methods and Results, focusing separately on benthic and pelagic discussions within each section.

WORKSHOP BACKGROUND

7. Participants recalled the 2005 CCAMLR Workshop on MPAs (2005 MPA Workshop) as background for the present bioregionalisation effort. In 2005, the Scientific Committee endorsed the advice from the Workshop that conservation outcomes appropriate for achieving the objectives of CCAMLR Article II would include the maintenance of biological diversity, as well as the maintenance of ecosystem processes (SC-CAMLR-XXIV, paragraph 3.54(iii)). The Scientific Committee also endorsed the advice of the 2005 MPA Workshop that attention may need to be given to, *inter alia*, the protection of (SC-CAMLR-XXIV, paragraph 3.54(iv)):

(i) representative areas – a system of representative areas would aim to provide a comprehensive, adequate and representative system of MPAs to contribute to the long-term ecological viability of marine systems, to maintain ecological processes and systems, and to protect the Antarctic marine biological diversity at all levels;

(ii) scientific areas to assist with distinguishing between the effects of harvesting and other activities from natural ecosystem changes as well as providing opportunities for understanding of the Antarctic marine ecosystem without interference;

(iii) areas potentially vulnerable to impacts by human activities, to mitigate those impacts and/or ensure the sustainability of the rational use of marine living resources.

8. The Scientific Committee had also noted the views of the 2005 MPA Workshop on the potential importance of making provision in protected area systems for the protection of spatially predictable features (such as upwellings and fronts) that are critical to the function of local ecosystems (SC-CAMLR-XXIV, paragraph 3.55 and Annex 7, paragraph 131).

9. The Scientific Committee further agreed that key tasks needed, in particular, to consider a system of protected areas to assist CCAMLR in achieving its broader conservation objectives are (SC-CAMLR-XXIV, paragraph 3.64):

(i) a broad-scale bioregionalisation of the Southern Ocean;

(ii) a fine-scale subdivision of biogeographic provinces, which may include hierarchies of spatial characteristics and features within regions, giving particular attention to areas identified in the bioregionalisation;

(iii) identification of areas that might be used to achieve the conservation objectives;

(iv) determination of areas requiring interim protection.

10. In 2006, the following two separate components of work to be undertaken towards the development of a system of MPAs for the Convention Area were identified (SC-CAMLR-XXV, paragraph 3.33):

(i) technical development of methods for bioregionalisation of the Southern Ocean
(ii) consideration of methods for selection and designation of MPAs.

11. The Scientific Committee decided that the focus of the 2007 Bioregionalisation Workshop should be on technical development of methods for bioregionalisation of the Southern Ocean. The aim of the 2007 Bioregionalisation Workshop should be to advise on a bioregionalisation of the Southern Ocean, including, where possible, advice on fine-scale subdivision of biogeographic provinces (SC-CAMLR-XXV, paragraph 3.34). Consequently, the Scientific Committee recognised that the 2007 Bioregionalisation Workshop will essentially focus on component (i) in paragraph 10 above. It recognised that work on component (ii) should proceed in parallel, with the submission of relevant papers to either the Scientific Committee or its working groups. The Scientific Committee anticipated that further work towards the development of methods for the selection and designation of MPAs will be progressed by the Scientific Committee.

12. At CEP X (New Delhi, India, 2007), CCAMLR introduced an information paper which updated progress towards the CCAMLR Bioregionalisation Workshop. CCAMLR encouraged CEP participation in this Workshop, and noted the relevance of this work to the Committee, particularly with regard to the elaboration of the ‘systematic environmental geographic framework’, environmental monitoring and identification of sensitive or vulnerable areas. The importance of this work in relation to ongoing cooperation between CEP and CCAMLR was also highlighted.

13. CEP encouraged its Members to work together with their CCAMLR colleagues on this initiative and looked forward to the outcomes of the Workshop (CEP 2007, paragraph 194).

14. In planning its work on the abovementioned objective, the Workshop noted the report of the Experts Workshop on Bioregionalisation of the Southern Ocean conducted in September 2006 in Hobart, Australia, by WWF-Australia and ACE CRC (2006 Hobart Workshop) (Grant et al., 2006; www.wwf.org.au/publications/bioregionalization-southern-ocean/). The aim of this workshop was to develop a ‘proof of concept’ for a broad-scale bioregionalisation of the Southern Ocean, using remotely-sensed physical environmental data as the primary inputs.

15. Dr Grant introduced WS-BSO-07/11 on key questions and considerations for bioregionalisation analysis. The paper highlighted the need to establish a conceptual framework in which the analysis can be undertaken, with clear principles and objectives, focused at appropriate and relevant spatial scales.

16. The Workshop noted that the primary end-use of bioregionalisation analysis would be to assist in achieving the conservation of marine biodiversity, which can include the development of representative MPAs.

17. Bioregionalisation may also inform other end-uses, including, *inter alia*, ecological modelling, ecosystem monitoring, a framework for assessing risk and directing further research. Bioregionalisation outputs form one component of systematic conservation planning, which includes consideration of biodiversity patterns and processes, and the definition of conservation targets within a framework of rational use.

18. It was agreed that the benthic and pelagic systems should be considered separately. Prof. A. Clarke (UK) noted that, although there are some links between the benthic and pelagic systems, current knowledge of benthic–pelagic coupling is not sufficient to allow a combined benthic–pelagic bioregionalisation to be produced at this stage.

19. A range of scales for bioregionalisation can be considered according to available input data and end-user requirements. The Workshop agreed that, ideally, the definition of appropriate scales should be data-driven, but that often this will need to be supplemented with expert advice. It is important that actual heterogeneity of ecosystem processes and biodiversity patterns is still represented at relevant scales.

20. It is also important to consider temporal scales. The Workshop agreed that temporal scales are different in the pelagic environment compared to the benthic environment. It is important to ensure that this variability is captured within an appropriately sized spatial region.

EXISTING CLASSIFICATIONS AND APPROACHES TO BIOREGIONALISATION

21. Dr A. Constable (Australia) presented the results of the 2006 Hobart Workshop, which were presented to, and considered by, the Scientific Committee (SC-CAMLR-XXV, paragraphs 3.44 to 3.52) and CCAMLR (CCAMLR-XXV, paragraphs 6.1 to 6.6).

22. In introducing the 2006 Hobart Workshop, Dr Constable noted that:

(i) the broad aims of the Workshop were –

(a) to consider important relationships between taxa, ecological processes and physical characteristics;

(b) to determine appropriate data for use in the classification (physical data, data transformations, indicator species);

(c) to group points using synoptic data that are relatively homogenous and different from a neighbouring group, taking account of uncertainties;

(ii) bioregionalisation with perfect and complete data could identify –

(a) the relationships within and between assemblages of species;

(b) the realised niches (physical and biological environment) of species;

(c) biogeographic differences in species and assemblages, including the nature and uncertainty of transition boundaries arising from spatial clustering;

(iii) conservation of marine biodiversity will need to give consideration to the ranges of organisms and processes in the region, including consideration of the global distribution (relative to circum-Antarctic) and local abundances (relative to fine-scale areas, e.g. a seamount) of species. In that case, the importance of an area to a species might be judged in a relative sense in the following schema for taxa –

(a) globally common (found in most places), locally abundant (when found is often in high abundance): an individual area would be less important to the conservation of the population or species;

(b) globally common (found in most places), locally rare (when found is most often in low abundance): an individual area to these taxa would be considered more important than for those taxa above, but would be less important than the following;

(c) globally rare (found in one or only a few places), locally abundant (when found is often in high abundance): endemic taxa where an individual area would be important to the conservation of the population or species, but the species may be relatively robust compared to the following;

(d) globally rare (found in one or only a few places), locally rare (when found is most often in low abundance): an individual area would be critical to the conservation of the population or species.

23. Dr Constable indicated that the 2006 Hobart Workshop participants had concluded, and the report showed, that a bioregionalisation is possible with sparse data. He noted that a bioregionalisation, for the purposes of conservation of marine biodiversity, with sparse data needs to:

(i) avoid giving undue weight to globally common, locally common species as drivers in the analysis;

(ii) avoid the homogenising effect of temporal variability, e.g. a combined dataset indicates greater spatial coverage of organisms when those organisms are actually associated with specific environmental features that vary over time (e.g. coincidence of organisms with ocean fronts);

(iii) ensure spatial data are unbiased with respect to bioregionalisation classification;

(iv) match scales of data with scales of interest – Southern Ocean data tends to be on large scales (few smaller-scale replicates) and therefore difficult to use for finer-scale subdivisions;

(v) for parameters used in correlations, relate to the same location and same time; if not extrapolation/interpolation errors need to be accounted for in making correlations;

(vi) adopt a process that accounts for statistical Type II errors as well as Type I errors, i.e. avoid concluding there is no heterogeneity when heterogeneity exists, which, in this context, means using available data to identify whether heterogeneity at smaller scales is plausible and to what extent might there be important heterogeneity to account for when using the bioregionalisation.

24. Dr Constable concluded his presentation by noting that, at the 2006 Hobart Workshop:

(i) a statistically rigorous approach had been adopted and used in the physical classification;

(ii) experts verified that outcomes were plausible;

(iii) natural latitudinal and longitudinal differences are evident in results, including spatial subdivision of banks and the continental shelf.

25. Participants noted that in the course of the 2006 Hobart Workshop:

(i) Issues examined included the choice of data and extraction of relevant parameters to best capture ecological properties. The final method involved the use of a clustering procedure to classify individual sites into groups that are similar to one another within a group, and reasonably dissimilar from one group to the next.

(ii) The primary datasets retained by the agreed primary classification and used in the analysis were depth, SST, silicate and nitrate. These highlighted the different environmental characteristics of large regions including the continental shelf and slope, frontal features (Sub-Antarctic Front (SAF), Polar Front (PF), Southern Antarctic Circumpolar Current Front (SACCF)), the deep ocean, banks and basins, island groups and gyre systems.

(iii) A secondary analysis added ice concentration and annual mean chlorophyll-*a* (chl-*a*) values. The addition of these datasets suggested smaller-scale spatial heterogeneity within the regions, particularly in the continental shelf and slope areas, and the seasonal ice zone.

(iv) The final stages of the analysis included discussion on how well the defined regions corresponded to our present knowledge of the Southern Ocean. Experts provided information on expected patterns and features according to current observations and understanding, and these largely concurred with the outcomes of the analysis.

26. The Workshop agreed to endorse the outcomes of the 2006 Hobart Workshop, and to adopt the primary classification.

27. Prof. Clarke gave a presentation on the use of biological data in bioregionalisation analysis. He noted that one of the 14 regions identified at the 2006 Hobart Workshop was the Antarctic shelf region, and described the extent to which this region could be subdivided based on biological data, using the distribution and abundance of molluscs (gastropods and bivalves) from the Southern Ocean Molluscan Database (SOMBASE).

28. A map of the distribution of samples shows that although molluscs have been collected from most areas of the Southern Ocean, three areas have received particular attention. These are the western Antarctic Peninsula and Scotia Sea, the eastern Weddell Sea and the Ross Sea. Areas that have been particularly poorly sampled are the continental slope and the deep sea (though this is being addressed by the Antarctic Benthic Deep-sea Biodiversity (ANDEEP) Program, the Amundsen and Bellingshausen Seas and parts of East Antarctica. Rarefaction analysis suggested that a significant number of species remain to be discovered; recent experience suggested that these will likely prove to be small species, or species identified by molecular methods.

29. Analysis of the SOMBASE data indicated that most Antarctic molluscs are uncommon or rare (or at least rarely sampled), and relatively few have circumpolar distributions. As a result, relatively few areas of the Southern Ocean have a high recorded species richness. An attempt can be made to correct for the effects of this spatial variability in sampling effort by using the residuals around a regression line fitted to the species richness/sampling intensity relationship. However, a map of such corrected data still showed highest diversities in the most-studied regions, indicating that correction for sampling error has been only partially successful.

30. Cluster analysis of presence/absence data can be used to divide the Antarctic Shelf region into a series of biogeographic provinces. These largely match provinces established previously, and suggest that there are important variations in molluscan diversity and assemblage composition around Antarctica that may be used to add a biological layer to the preliminary physical regionalisation established previously.

31. Dr Vierros gave a presentation on approaches to biogeographic classification of the world's oceans. International policy developments of importance to bioregionalisation include targets established by the World Summit on Sustainable Development and the Convention on Biological Diversity. The presentation noted international expert groups and bodies dealing with bioregionalisation, and global datasets that are available as a result of this work, which might be of interest to similar efforts in the Southern Ocean.

32. Selected global biogeographic classification systems were reviewed, concentrating in particular on two recent efforts developed to support international conservation and management of marine biodiversity. These were the Marine Ecoregions of the World (MEOW) and the deep- and open-ocean biogeographic criteria under development as a result of a recent international workshop hosted by Mexico.

33. The presentation then provided an overview of some common issues encountered in biogeographic classification of marine systems. These included the need for clear objectives for the bioregionalisation, which serve to inform the selection of data, the scale of data and

the weighting of data. Additionally, the presentation discussed the types of data (biological, ecological and mixed) commonly used, the methods applied (qualitative, quantitative), scale considerations and classification systems (hierarchical, non-hierarchical). The presentation concluded by highlighting the need for periodic review of bioregion boundaries as a result of new sampling efforts, improved technology, and effects of climate change.

34. Dr B. Sharp (New Zealand) introduced WS-BSO-07/6 which undertook to:

(i) diagram and explain the underlying conceptual premises of the bioregionalisation process. It is important to distinguish environmental space (the environmental and oceanographic conditions at different places), biological space (biological organisms and processes at different places), and geographic space (the location). Bioregionalisation aims to map biological space into geographic space and then simplify it in a meaningful way. The need to determine the relationship between environmental space and biological space arises due to the patchiness of biological data, hence the need for a proxy to inform interpolation and extrapolation.

(ii) review a number of marine environment classifications that have been produced by New Zealand using a variety of methods, and highlight methodological and practical lessons of particular relevance to the CCAMLR bioregionalisation process.

35. Several methods have been used for bioregionalisation in New Zealand (WS-BSO-07/6). The particular strengths and weaknesses of the following three classifications used in New Zealand were presented:

(i) an environmental classification that was optimised to represent a wide variety of both benthic and pelagic taxa;

(ii) an environmental classification that was optimised in particular to represent demersal fish communities;

(iii) a biological classification that used a new hierarchical multiple regression modelling package called Boosted Regression Trees (BRT: see paragraph 99) to generate spatially comprehensive distribution layers for individual species of demersal fish, and then created a spatial classification using these biological layers directly.

36. Dr Sharp noted that CCAMLR could benefit from the following lessons arising from the New Zealand experience (WS-BSO-07/6):

(i) use biological data in bioregionalisation;

(ii) model species individually;

(iii) generate a classification based on abundance, not presence-absence;

(iv) use the most powerful statistical methods available, such as BRT and Generalised Dissimilarity Modelling (GDM);

(v) use a hierarchical clustering algorithm;

(vi) focus on an environment or community of particular interest;

(vii) include information representing uncertainty.

37. He also noted that dynamic aspects of functionally important ecosystem processes will often need to be captured using a separate parallel process.

38. Dr Danis presented information on the ongoing development of the SCAR-MarBIN network. The web-based SCAR-MarBIN system allows users to search, display and extract taxonomy and distribution information for many Southern Ocean species. Access to metadata for interpretation and searching of data is also available. The Workshop welcomed the continuing development of SCAR-MarBIN and recognised that it is of great present and potential value to bioregionalisation.

DATA

Pelagic data

39. The Workshop considered bathymetric, physical oceanographic and biological data available for the pelagic bioregionalisation. It noted that the datasets used in the 2006 Hobart Workshop were a useful starting point for any further analyses on the pelagic realm. The following paragraphs provide important considerations when using available data for a pelagic bioregionalisation.

40. GEBCO data provide a common foundation for bathymetry data layers.

41. Physical oceanographic data for the Southern Ocean are available from a number of sources, including satellites, ocean (WOCE) transects and other CTD and at-sea observations, and model interpolation and outputs:

(i) SST and sea-surface height can be typically obtained and interpolated from satellite data.

(ii) Nutrient data are derived from discrete ocean sampling and contoured as a function of time. A variety of data sources are publicly available, including the WOCE dataset, the Southern Ocean Atlas (Orsi and Whitworth, 2005 complied at Texas A&M University, USA), and historical data from the US National Ocean Data Center. Certain regions, such as the Antarctic Peninsula, Weddell Sea and Ross Sea, have high-resolution data (in both space and time) and can be obtained for use (e.g. from the Alfred Wegener Institute, Bremerhaven, Germany, and the Centre for Coastal Physical Oceanography, Old Dominion University, USA). Also available are model outputs, which can be compared to the observed distributions in space (e.g. output from OCCAM/FRAM).

(iii) Mixed-layer depth (MLD) derived from temperature and salinity data and a preferred mixed-layer definition. Two versions of datasets for MLD based on this approach are the World Ocean Atlas (Levitus et al., 1994a, 1994b) and the Southern Ocean Atlas (Orsi and Whitworth, 2005). It was noted that the Southern Ocean Atlas data has been subjected to a fair degree of scrutiny and quality control. Simulated datasets that provide MLD are the OCCAM/FRAM Southern Ocean simulations (available from Southampton via www.noc.soton.ac.uk/JRD/OCCAM/) and regional models such as the Ross Sea and West Antarctic Peninsula circulation models (Hoffman, pers. comm.) and a regional model for the Weddell Sea (Alfred-Wegener Institute). Blended model-data products include the Simple Ocean Data Assimilation reanalysis products (Carton et al., 2000a, 2000b; www.atmos.umd.edu/~ocean/). This provides temperature and salinity from which mixed layer depth can be calculated.

42. Additional ocean information is included in some charts, such as the widely used mean front locations by Orsi et al. (1995). The Workshop noted that, rather than using these specifically in a spatial realisation, it would be useful to plot these as a process layer (paragraphs 157 to 164) for comparison with the outcomes of the bioregionalisation.

43. Sea-ice concentration and extent are available from satellite datasets. Ice concentrations and associated parameters (e.g. ice extent and area) are derived using data from the Special Sensor Microwave Imager (SSM/I) on the Defense Meteorological Satellite Program (DMSP) and mapped on a polar stereographic grid at a 25 × 25 km resolution. Ice concentrations are generally derived from satellite passive microwave data using the enhanced bootstrap algorithm used for the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) data and adapted for SSM/I data (e.g. Comiso et al., 2003; Comiso, 2004). The Workshop noted that these or some derivative dataset, such as average over time, rates of retreat or some transformed dataset, could be used in the bioregionalisation. However, it was also noted that the type of dataset to be used will need to be determined by whether it was to reflect key determinants of ecosystem structure and function or to reflect specific processes related to biota of interest. Care would need to be taken to ensure that some parameters did not become over-represented in the analyses.

44. The Workshop noted that, for most physical datasets, some consideration of mean state, seasonal variation and interannual variation would be desirable in this work in the future.

45. Dr Kahru presented WS-BSO-07/5 on spatial patterns of temporal relationships in the Southern Ocean. He noted that phytoplankton production during the austral summer in the Southern Ocean is known to be limited by iron and light. Distributions of satellite-detected chl-*a* show very complex and time-variable patterns that are hard to explain. Analyses of covariance between several satellite-detected and modelled variables showed that this covariance in time between the MLD, SST and chl-*a* can be used to map areas where different factors control phytoplankton production. Statistically significant spatial patterns in the covariance between MLD, SST and chl-*a* show that the physical factors controlling phytoplankton production in the Southern Ocean change in a predictable manner. Areas where phytoplankton is light-limited in the summer due to insufficient stratification were defined along with other areas where phytoplankton is clearly limited by nutrients (probably iron). The boundary between light limitation and nutrient limitation can be sharp and is sometimes, but not always, associated with the main hydrographic fronts (e.g. SAF). The correlation coefficient between MLD and chl-*a* has a characteristic banded structure.

46. Dr Kahru also showed that similar but opposite banded structure is visible in the correlation structure between SST and chl-*a*. The latter correlation is more reliable as an indicator, as both are actually measured variables (the MLD is based on a model). In the sub-tropics the correlation between MLD and chl-*a* is clearly positive which means that higher chl-*a* is associated with deep MLD and lower chl-*a* is associated with shallow MLD. This is indicative of a regime where nutrients are limiting for phytoplankton growth and the limiting nutrients are provided by vertical mixing. More stratification (with shallow MLD) means less nutrient input from below and therefore lower chl-*a*. South of about 40°S in the Atlantic and Indian Oceans and about 50°S in the Pacific Ocean is a band of negative correlation between MLD and chl-*a* (positive correlation between SST and chl-*a*) where increased chl-*a* is associated with more stratified conditions. This is the regime where phytoplankton is not generally limited by nutrients but by light due to deep mixing and insufficient vertical stratification. The southern edge of this band coincides often with the mean position of the SAF. Further to the south the banded structure breaks down and the correlation patterns show not only zonal but also more meridional variability. The other major fronts (PF, SACCF and the southern boundary of the ACC (SBDY)) show some relationship with the correlation patterns but the similarity is rather local. For example, around South Georgia the PF and SACCF delineate the area where light limitation (insufficient stratification) is evident. Along the Antarctic Peninsula the nutrient limitation state (between PF and SACCF) changes abruptly to light-limited state near the coast (south of SACCF and SBDY).

47. He noted that the mean surface chl-*a* for the October to March period of 1996 to 2007 was created with a new algorithm (SPGANT) based on Southern Ocean data (B.G. Mitchell) using combined Ocean Colour and Temperature Scanner (OCTS) (1996–1997) and SeaWiFS (1997–2007) data. Some of the high chl-*a* areas are related to the main hydrographic fronts. For example, the high chl-*a* areas of the Scotia Sea and South Georgia area are centred on the SACCF (between the PF to the north and the SBDY to the south) and are supported by eddy mixing through SACCF (Kahru et al., 2007). Mean concentrations in the extreme southern part of the Southern Ocean have to be treated with caution as they are based on only a few measurements. The maximum number of valid monthly measurements using OCTS (October 1996 to March 1997) and SeaWiFS (November 1997 to March 2007) is currently 65. Extensive cloud cover significantly reduces the number of available satellite data. In the Weddell Sea and in some other areas, ice cover during most years reduces the number of available months to only 1 or 2 (dark purple colour in WS-BSO-07/5, Figure 2) during the 11 years of measurements.

48. The Workshop noted that:

(i) the predictability of the mean patterns in satellite-detected chl-*a* is important and useful as it also corresponds to the distribution patterns of zooplankton;

(ii) satellite-derived chl-*a* could be biased in the Weddell Sea due to a lower number of observations and a shorter season than other areas in the time-averaged period. These could bias a regionalisation if the potential for under-sampling is not addressed;

(iii) the use of Empirical Orthological Function/Principal Component (EOF/PC) analysis could be difficult because the chl-*a* distributions are very complex and even using EOF/PC analysis does not provide much insight as the EOFs are hard to explain and there are many EOFs. For example, in an analysis of chl-*a* distribution of the Fram Strait/Scotia Sea area, the first three EOFs describe only 26.5% of the total variability;

(iv) chl-*a* patterns can be affected by eddies (Kahru et al., 2007). They are easily detected by satellite altimetry. Most intense eddies are in the PF area but these eddies have relatively weak influence on chl-*a* distribution as nutrient concentrations change little across PF. The relatively weak eddies in the SACCF have a strong influence on the chl-*a* distribution as described in the cited paper.

49. Primary productivity is significantly correlated with the distribution of sea-surface chl-*a* as measured from satellites, although it was noted that care was needed in defining the time period over which a measure of mean chl-*a* might be derived so as not to inadvertently bias the data from incomplete or poor sampling in some areas, i.e. average over a month was less likely to cause bias than averaging over a six-month period. Other factors that could be important determinants of primary production could be the insolation of an area, the amount of cloud cover, SST and MLD. Photosynthetically active radiation (PAR) may also be important. It was noted that different derivative spatial datasets could be used, such as total production over a season, average seasonal production, length of period in which most production occurs, interannual variability in production, and difference between lowest and highest over the monitoring period.

50. Biological datasets indicating spatial attributes of different areas were considered. These included data from krill net sampling, krill acoustic surveys, Continuous Plankton Recorder (CPR) sampling, penguin foraging areas, seabird foraging tracking data, and East Antarctic pack-ice seals. It was determined that some of these datasets might be most appropriately used at the regional scale.

51. A multidecadal-scale krill and salp dataset compiled by Atkinson et al. (2004) was considered. This database was assembled from net sampling data from multiple sources at a circumpolar scale. Concerns were raised about data standardisation across methods. Some of these data have been collected using different methods and at different times during the year as well as at varying spatial coverage and locations over the period of sampling. Dr V. Siegel (Germany) offered advice to improve data standardisation.

52. Krill acoustic survey data are available for Subareas 48.1, 48.2, 48.3 and 48.4 and Divisions 58.4.1 and 58.4.2. These data, although collected for estimating biomass of krill, could be used to help with finer-scale regionalisation.

53. Dr P. Trathan (UK) described the process by which WG-EMM had previously delineated the SSMUs for the krill fishery in the southwest Atlantic. He suggested that many of the issues considered by WG-EMM in 2002 had great relevance to the bioregionalisation of the Southern Ocean.

54. Dr Trathan emphasised that the delineation of SSMUs and a bioregionalisation of the Southern Ocean were both complex processes that involved subdivision of geographic, environmental and biological structure in the ecosystem. Environmental structure spanned a broad range of spatial and temporal scales while numerous species and communities were also highly variable in space and/or time.

55. Such a subdivision of the ecosystem would require data-driven analyses, however, not all such analyses could rely on equally comprehensive and robust data. Furthermore, some ecological processes were difficult to delineate in space and time. Consequently, expert opinion was of crucial importance in judging where appropriate boundaries could be developed.

56. Dr K. Shust (Russia) described the role of specific hydrographic features in the Southern Ocean and the impact of bottom topography which influenced the circumpolar distribution of marine organisms to the south of the PF. Such factors led to the creation of localised highly productive areas within gyres and eddies close to continental shelf areas surrounding the sub-Antarctic islands and over submarine banks.

57. Dr Shust identified that of the sub-Antarctic islands, the highest productivity was observed in Subarea 48.3 around South Georgia. This area had supported a high level of commercial harvesting in the past. At present it supports sustainable fisheries for Patagonian toothfish, mackerel icefish and Antarctic krill. Dr Shust suggested that a similar situation occurred in the Ross Sea where productivity was high and where there was a fishery for Antarctic toothfish. In contrast, Dr Shust suggested that in the waters surrounding the Kerguelen Archipelago, productivity was lower and that this was mainly due to the absence of hydrological conditions that would support the formation of large krill concentrations. Consequently, the biomass of local populations of Patagonian toothfish and mackerel icefish were lower than in the South Georgia area. In addition, Dr Shust indicated that toothfish length was also reduced, possibly because of the absence of krill that were likely to be important to toothfish at early stages of development.

58. Dr Shust suggested that these examples demonstrated that the Southern Ocean was spatially heterogenous and that the bioregionalisation should take into account levels of productivity, especially in local areas, as well as associated indicator species. Furthermore, the regionalisation should take into account those environmental conditions that are responsible for maintaining productivity.

59. The Workshop reaffirmed its understanding that productivity and factors affecting production levels should be taken into account when considering the results of data-driven bioregionalisation, and that this was best carried out by means of expert evaluation.

60. Dr W. Smith (USA) presented a summary of the oceanography of the Ross Sea continental shelf, including physical, chemical and biological oceanography. The region has been a focus of study for over a century due to the proximity to the continent's major research and logistics base, McMurdo Station. Because of the extensive investigations, a large dataset is available that may allow the area to be used to test some of the ideas about fine-scale bioregionalisation. Dr Smith noted the following:

(i) The continental shelf break is a delimiter of distributions and processes. A current flows along the shelf break and induces intrusions onto the shelf, which are a source of heat and micronutrients.

(ii) Ice concentrations and distributions are controlled by polynya processes, which result in an ice-free region near the Ross Sea ice shelf that seasonally expands to the north. Substantial interannual variability in ice occurs, and recent iceberg groundings have accentuated this variability (Arrigo et al., 2002; Dinniman et al., 2007).

(iii) Chemical and biological climatologies (long-term means) have been generated for the region (Smith et al., 2003). The seasonal uncoupling of nitrate and silicic acid is clear, as is the dominance in spring by the haptophyte *Phaeocystis antarctica*. Climatologies of pigments confirm these spatial patterns. However, significant interannual variations in the distribution of pigments and chemical substances occur (Peloquin and Smith, 2007), in a manner similar to those of ice.

(iv) The food web of the Ross Sea ice shelf is relatively well known and is dominated by ice and seasonal production (Smith et al., 2007). However, notable gaps occur in our knowledge, especially with regard to the middle trophic levels (*Euphausia crystallorophias*, *Pleuragramma antarcticum*) and the large, mobile and migratory species (whales, squid). This food web is in stark contrast to the 'typical' Antarctic krill-based food web that occurs elsewhere.

(v) Away from the coast, the distribution of benthic fauna is largely controlled by sea-floor habitats rather than surface productivity patterns (Barry et al., 2003).

(vi) Significant increases in the ice cover in the Ross Sea have occurred since 1979, nearly balancing the decreases observed in the Amundsen-Bellingshausen sector (Kwok and Comiso, 2002). Based on a bio-optical model, a significant increase in productivity of the entire Southern Ocean has been detected, but this increase cannot be attributed to a change in any one particular region (Smith and Comiso, submitted).

(vii) A list of data sources for the Ross Sea that may be used in addition to those large-scale datasets was compiled and presented.

61. Dr Hosie presented the outcomes and datasets from the Southern Ocean CPR (SO-CPR) Survey collections since 1991. The details of this survey work are clearly provided in WS-BSO-07/P4, 07/P5 and 07/P6. The purpose of this work was to map the biodiversity of zooplankton, variation in biodiversity patterns, and to monitor the health of the region by using the sensitivity of plankton to environmental change as early warning indicators. The survey involves Australia, Germany, Japan, New Zealand and the UK, and is a SCAR program supported by the Action Group on CPR Research. In particular, Dr Hosie noted that:

(i) spatial, seasonal, annual and long-term variability in plankton patterns has been monitored primarily in eastern Antarctica between 60° and 160°E and south of 48°S with some transects in other parts of the Southern Ocean;

(ii) the CPR is towed behind the ships at a depth of about 10 m, sampling in the ship's wash which mixes the top 20 m. Each tow produces approximately 450 n miles (833 km) of continuous plankton data. The SO-CPR dataset comprises abundance data (counts) of zooplankton for 5 n mile sections. Zooplankton species are identified to species or the lowest possible taxon. Developmental stages of euphausiids are included;

(iii) published papers describe the fine-scale distributions of species and assemblages in relation to the frontal and sub-branches, including season variation (Takahashi et al., 2002; Umeda et al., 2002; Hunt and Hosie, 2006a, 2006b; WS-BSO-07/P4, 07/P5, 07/P6).

(iv) the CPR has been used for rapidly and repeatedly surveying plankton on ocean basin scales, including helping define bioregions and substantial changes in plankton composition in the North Sea and North Atlantic Ocean;

(v) a zooplankton atlas for the Southern Ocean is being prepared, noting that there is evidence of small and longer temporal variation in spatial composition in the plankton of eastern Antarctica;

(vi) the characteristics of this method are:

- the CPR is towed horizontally so diurnal migration effects need to be considered – higher zooplankton abundances usually occur at night at the surface;

- small aperture of 12.5 x 12.5 mm is suited more for sampling mesozooplankton, although it does catch adult Antarctic krill;

- soft gelatinous zooplankton are poorly sampled, although high numbers of larvaceans are caught;

- some species are difficult to identify, often due to damage in being trapped on the silk mesh, or have not been properly described – some zooplankton are grouped as families or orders;

- the best spatial cover is between 60° and 160°E although other tows have been done east to the Ross Sea and further west between Drake Passage and south of Africa;

- most of the data have been collected from September to April and most since 1997, although some data extends back to 1991 and some winter tows have been conducted.

62. The Workshop noted that due to standardisation of methods across a wide geographical distribution, these data are likely to be valuable for bioregionalisation.

63. For other biological datasets, the Workshop noted that:

(i) fish survey data could be used in some areas, although pelagic survey data are very limited geographically. Typically, commercial species can be mapped by topographic features. Other species might be more locally distributed and habitat dependent;

(ii) considerable data exist on Antarctic pack-ice seal distribution and abundance in East Antarctica taken with a rigorous methodology (Southwell et al., 2007);

(iii) with respect to whaling records and fisheries data, such data are confounded by both biological and commercial factors influencing where activities occurred. While data for some species have been standardised, this has not been done for many species, particularly by-catch. For these reasons, it was considered that these data were not able to be used by the Workshop;

(iv) the predicted marine mammal distributions (University of British Columbia) were derived using expert knowledge combined with physical parameters to infer distributions globally. As yet, these distributions have not been validated;

(v) seabird sightings-at-sea data have the potential for inconsistency in the implementation of the methods between observers and therefore make these data difficult to use for the purposes of the bioregionalisation.

64. The Workshop noted that a spatial dataset should preferably comprise data using a standard methodology. This is most important for analyses within regions but may not be as necessary between regions if the within-region classification is most important. However, if there is reason to have a between-region comparison of the classification on the same scales, then data would need to be sampled in a consistent way across regions.

Benthic data

Background

65. WS-BSO-07/10 was introduced by Dr C. Jones (USA). In this study, benthic invertebrate megafaunal communities of five shelf habitats within the Atlantic sector of the Southern Ocean from scientific survey trawl catches were quantitatively analysed in order to identify and characterise such communities for comparative purposes at a fine spatial scale. The region for which the greatest complexity of data was available, the northern Antarctic Peninsula and the South Shetland Islands, revealed a two-layered pattern based on standardised invertebrate biomass density data and the composition of phyla that contributed to that biomass. Relative to biomass, the shelf area adjacent to the northern Antarctic Peninsula is comprised of regions with extremely high levels of invertebrate biomass (particularly hexactinellid sponge dominated communities) compared to the relatively sparse South Shetland Island shelf. The situation is reversed at each region's easternmost shelves. In terms of composition, the demarcation occurs where the sponge dominated communities most frequently encountered on both shelf systems rather abruptly decline westwards on the shelf north of the South Shetland Islands off western King George Island. By referencing average sea-bottom temperatures for the region, the influence of the ACC and Weddell water masses was shown to capture the pattern of shelf faunal zonation.

66. The benthic invertebrate communities on the northern shelves of the South Shetland Islands and the northern Antarctic Peninsula can apparently be separated into two zoogeographic zones based on the physical properties of the ACC and the Weddell water masses that meet and mix in this region. Superimposed on this geographic pattern are the effects of disturbance regimes, whether by iceberg scouring or commercial bottom trawling, which work at smaller spatial scales.

67. Patterns of benthic invertebrate biomass are also described for the South Orkney Islands, as well as general patterns of composition at the level of phyla for South Georgia, the South Sandwich Islands and Bouvet Island. These latter regions are generally echinoderm dominated, relative to the hexactinellid sponge dominated northern Antarctic Peninsula region.

68. The Workshop welcomed this work, and agreed that this sort of high-resolution benthic data provides insight into benthic biogeographic patterns. The Workshop noted that this work highlights the importance of physical features, such as bottom temperature and water mass features, in influencing patterns of benthic communities. Mr H. Griffiths (UK) noted that recent collections around the Shag Rocks region has demonstrated a higher level of benthic diversity than that described in WS-BSO-07/10, and that the area is very patchy. Dr M. Pinkerton (New Zealand) indicated that there are statistical approaches that can be taken that could quantify relationships between position of water mass features and structure of benthic communities. The Workshop encouraged future work of this nature, and suggested that it could be possible to use water mass features to gain insight into benthic biogeography of other regions where little data is available.

Overview of various data sources available for benthic bioregionalisation

69. The Workshop addressed key areas that would lead to the most appropriate benthic bioregionalisation, including which datasets would be most useful, the robustness and quality of these datasets, and use of other datasets that could potentially be useful.

70. The Workshop agreed that optimal benthic bioregionalisation should include both physical and biological datasets.

71. The Workshop agreed that the following physical datasets could be considered for inclusion in the analysis:

(i) Bathymetric data – including information on the position of seamounts, trenches and canyons. The Workshop underscored the importance of identifying known seamounts in the Southern Ocean, as these regions are either known to have, or likely include, unique benthic fauna.

(ii) Sea-floor temperature data – the Workshop recognised the likely influence of sea-floor temperature on benthic biogeographic patterns.

(iii) Geomorphology data interpreted from bathymetry data and seismic reflection data in the SCAR Seismic Data Library System (see WS-BSO-07/8).

(iv) Sediment data – the Workshop noted that the available sediment map dates from 1991 and so should be viewed with caution. The degree to which sediment samples represent the sea floor varies with the horizontal variability of the sea-floor environment. The available map reliably represents the sediment distribution in the deep ocean with its uniformity. The continental shelf and slope, however, will be less reliably represented by the present widely spaced data points because of the complexity of the sea-floor in those regions.

(v) Sea-ice concentration – can provide clues as to food availability for benthos.

(vi) Southern Ocean bottom currents – the Workshop agreed that this information could provide useful information toward regionalisation. However, if this information is not available, their effects can be observed indirectly through geomorphology data.

72. Regarding biological datasets available for benthic bioregionalisation, the Workshop noted that for the most part, biological data are primarily restricted to shelf areas. Although these data are largely patchy, they are considerably better known than data from slope and deep ocean regions.

73. The Workshop noted that extremely little information is available on benthic fauna from the region between the Antarctic Peninsula and the Ross Sea in the vicinity of the Bellingshausen and Amundsen Seas, as well as the eastern Antarctic Peninsula region/western Weddell Sea.

74. Given these limitations, the Workshop agreed that the following biological datasets could be considered for inclusion in the analysis:

(i) mollusca dataset (SOMBASE);

(ii) data available from SCAR-MarBIN network;

(iii) fine-scale data on abundance and composition of invertebrates along the Antarctic Peninsula (WS-BSO-07/10);

(iv) demersal finfish data. With respect to demersal fish, the Workshop agreed it would be useful to examine data sources from SCAR-MarBIN, FishBase, as well as both scientific survey and fine-scale commercial catch data that are currently available in the CCAMLR database. The latter potentially provides additional insight into species distribution, as well as spatial patterns of finfish diversity and species richness, which the Workshop felt would potentially add to the benthic bioregionalisation effort. This data would not be examined in terms of abundance or catch rates, but in the form of presence/absence only.

75. The Workshop felt that it was important to not restrict the bioregions to any one group of taxa, since no one group are currently known to represent any others well.

76. The Workshop considered the importance of scale with respect to variability, since broad-scale patterns inevitably have some unrepresented small-scale variability. Within this context, the Workshop agreed that the question of consistency between large-scale and smaller-scale patterns should be addressed. The Workshop felt it would further be advantageous to produce maps that describe regions of benthic uncertainty.

Data used in the benthic bioregional classification

Physical data

77. A benthic bioregional classification was undertaken with physical data that was considered to be robust and to have a strong relationship with the distribution of species. All datasets used for the broad-scale classification covered the entire Southern Ocean. The following datasets were used for the initial, broad classification:

- bathymetry (gridded (1 min) bathymetry from GEBCO)
- slope (degrees of incline derived from GEBCO)
- sea-floor temperature
- sea-floor sediment types.

Short descriptions of each dataset are available in Appendix D.

78. In addition, it was agreed that a finer-scale geomorphic dataset of the East Antarctic margin and adjacent ocean basins from 55°S to the coast and 38°E to 164°E (Geoscience Australia) would be included as soon as feasible. This dataset consists of a GIS of geomorphic features mapped at a scale of 1 to 1 million. In some shelf areas, the relationships are known between geomorphology, sea-floor processes, seabed type and biological communities. The geomorphic mapping integrates knowledge about physical process and their interaction with the seabed. In particular, it identifies areas likely to be scoured by icebergs and/or currents and identifies features likely to have unusual substrates of significance for biological communities such as seamounts and canyons. The incorporation of these data into statistical analyses has yet to be developed so the geomorphic map is used as a layer for comparison with the other analyses. It is anticipated that an Antarctic-wide geomorphic map will be available soon.

Biological data

79. A number of biological datasets were used for validation of the benthic bioregional classification. These included eight taxonomic groups, 33 000 records, 7 600 stations and 3 000 taxa (species). The data were selected for their robustness, for their quantitative nature and for their good spatial coverage. Combined, these data provided circumpolar coverage, although this was not the case for every individual dataset. The datasets included in the analysis were:

- Antarctic Echinoids
- SOMBASE
- Southern Ocean Sea Stars Biogeography
- Ant’phipoda (a database of amphipods)
- FishBase (benthic fish)
- Hexacorallia
- ZIN Brittlestars
- CCAMLR scientific survey and commercial finfish database (demersal fish – presence/absence only).

80. The majority of biological data used for validation were extracted from SCAR-MarBIN (SCAR Marine Biodiversity Information Network – www.scarmarbin.be). SCAR-MarBIN contains a total of 47 distribution datasets and 490 000 records. It establishes and supports a distributed system of interoperable databases, forming the Antarctic Regional Ocean Biogeographic Information System (OBIS) Node, under the aegis of SCAR. SCAR-MarBIN gives free and open access to raw data on Antarctic Marine Biodiversity. The majority of the datasets used in the framework of this exercise were directly downloaded from the SCAR-MarBIN webportal. A short description (metadata) of the datasets is given in Appendix D. The complete metadata record is available either from the SCAR-MarBIN webportal or from the Global Change Master Directory (GCMD) website.

METHODS

Pelagic methods

Summary of methods developed at the 2006 Hobart Workshop

81. The classification method adopted during the 2006 Hobart Workshop was a mixed non-hierarchical and hierarchical approach. Consideration of the methods, datasets and statistical routines are explained and provided in Grant et al. (2006). The classifications were performed on a 1/8th degree grid, covering the marine area from 80° to 40°S. The full set of 720 835 grid cells was subjected to a non-hierarchical clustering to produce 200 clusters. Hierarchical classification was then performed on these 200 clusters to produce a dendrogram and the final clustering at 14 and 40 levels.

82. Sites with missing data were excluded from the analyses. These were principally sites shallower than 200 m depth, for which the chosen nutrient data did not apply. These excluded sites are shown in the maps as white. Future work will need to fill in these missing cells.

83. The broad-scale (primary) regionalisation from the 2006 Hobart Workshop with 14 clusters or regions was derived from the following four environmental data layers:

(i) bathymetry (log10 transformed)
(ii) SST
(iii) nitrate (NOx) concentration
(iv) silicate (Si) concentration.

Descriptions of each of these datasets are provided in Appendix IV of Grant et al. (2006).

84. The ocean water masses combined with topography of the ocean floor were considered likely to define the primary features of the Southern Ocean and coastal Antarctic systems. SST was included as a proxy for the different water masses of the Southern Ocean. Topography (captured by bathymetric data) was included because of the ecological differentiation between shelf, slope and abyssal regions as well as the effect of bathymetry on upwelling, eddying and as a potential source of iron. Bathymetry was transformed (log10) to give increased weight to the shallower areas less than 2 500 m. Silicate and nitrate concentrations were included to provide information on nutrient characteristics. Silicate concentration is related to phytoplankton production in some areas of the Southern Ocean. The silicate layer differentiated water masses in deeper water and along the various fronts,

which may reflect differences in plankton communities. The nitrate and silicate climatologies at the 200 m depth layer were used as this is likely to be an indicator of broad-scale long-term (annual) nutrient availability. Surface nutrients are likely to be seasonally depleted in areas of nutrient-limited productivity. However, the use of the 200 m depth layer resulted in missing data in the shelf areas of less than 200 m depth.

85. Two components of a fine-scale (secondary) regionalisation were explored at the 2006 Hobart Workshop. Descriptions of each of these two extra datasets are provided in Appendix IV of Grant et al. (2006), and summarised below.

86. Sea-ice is known to influence the distribution of biology in the Southern Ocean, including affecting, *inter alia*, primary production, marine mammals and birds. The impact of sea-ice on the environment was explored using a data layer comprising the long-term (more than 10 years) average number of days an area was covered by at least 15% concentration of sea-ice.

87. The concentration of satellite-observed sea-surface chl-*a* was explored using a data layer comprising log transformed chl-*a* densities from ocean colour satellite sensors. The chl-*a* distribution was truncated at 10 mg m^{-3} (where all values greater than 10 were made equal to 10). Near-surface chl-*a* concentration observed by satellite sensors is closely related to rates of primary production in the water column, and was considered to be a suitable proxy for the purposes of exploring spatial heterogeneity in primary production at the large scale.

Pelagic bioregionalisation methods considered at the 2007 Brussels Workshop

88. The Workshop recognised that there are large amounts of biological data of the Southern Ocean, which are currently available, or are likely to become available in the near future. These biological data are potentially very useful for bioregionalisation, although each dataset needs to be considered in detail.

89. The Workshop recommended a hierarchical, two-level approach to bioregionalisation of the pelagic domain:

(i) broad-scale circumpolar bioregionalisation which provides delineation of approximately 20 regions;

(ii) fine-scale bioregionalisation of each broad-scale region separately.

90. Circumpolar, spatially extensive data layers are required to determine broad-scale bioregionalisation. There are a limited number of circumpolar data applicable. The Workshop considered how environmental, oceanographic, remotely sensed data and biological data layers can be used within this process (paragraphs 39 to 64), and noted that non-hierarchical clustering methods using these broad-scale data layers should not be used for fine-scale bioregionalisation.

91. The Workshop agreed that each of the broad-scale regions could be divided into fine-scale bioregions using all appropriate data on pattern and process within that broad-scale

region. A greater quantity and variety of data will be applicable for fine-scale bioregionalisation than is available for broad-scale bioregionalisation. Biological data is likely to be particularly valuable at the fine scale.

92. The Workshop recognised that spatial and temporal heterogeneity occurs at a broad range of scales and further noted that the fine-scale bioregions should be aimed at scales appropriate to management.

93. Although there are inherent limitations in the use of static maps to represent spatially and temporally dynamic ecosystems, the Workshop agreed that it is possible to identify meaningful bioregions in the Southern Ocean that reflect consistent differences between ecological patterns and processes in different areas.

Broad-scale bioregionalisation method

94. The Workshop endorsed the general methodology used to provide a broad-scale regionalisation of the Southern Ocean from the 2006 Hobart Workshop.

95. The Workshop agreed that, at the broad scale, the primary bioregionalisation result from the 2006 Hobart Workshop was a good working product that could be used to inform spatial management of the Convention Area. This product has 14 bioregions or clusters.

96. The Workshop agreed that the broad-scale bioregionalisation from the 2006 Hobart Workshop could potentially be enhanced by considering, *inter alia*:

(i) additional data layers representing seasonal variation in environmental conditions;

(ii) additional data layers representing interannual variation in environmental conditions;

(iii) new environmental parameters (e.g. MLD, primary production: see paragraph 49);

(iv) use of biological data to transform and combine environmental data layers;

(v) consideration of spatial variability in data layer quality.

97. Five methods of how biological data could be used to enhance bioregionalisation of the Southern Ocean were discussed:

(i) cluster using environmental data layers, and use point biological data retrospectively to test how well the clusters distinguish between different biological properties;

(ii) extrapolate point biological data to the circumpolar domain using the fitted dependence on environmental properties, and use these modelled biological layers in the clustering to produce the bioregionalisation. The BRT approach can be used for this process;

(iii) use GDM to determine how differences in biology between locations depend on environmental variables. Then use circumpolar environmental data to map biological dissimilarity in geographic space and determine bioregions;

(iv) use expert opinion to determine the dependence of selected species on environmental variables (e.g. for marine mammals using the relative environmental suitability approach (Kaschner, 2004));

(v) use Species Habitat Modelling to consider realised ecological niches.

Extrapolation of biological data using environmental data

98. Dr Pinkerton noted that biological datasets, in general, are not circumpolar. Spatially extensive, circumpolar biological data layers can however be estimated by extrapolating point biological data to the whole domain using the relationship to environmental data layers as a proxy for spatially continuous biological coverage. One statistical method that may be used for this purpose is BRT analysis.

99. BRT is a relatively recent statistical method for modelling single-response variables using several predictors (Friedman, 2001; Hastie et al., 2001; Leathwick et al., 2006; Ridgeway, 2006; De'ath, 2007). BRT developed from machine-learning techniques, where the dependence of the response variable on each predictor, and interactions between predictors, are modelled hierarchically. BRT is an ensemble method, meaning that predictions are made not on the basis of a single model, but rather combines an ensemble of several (often thousands) models. At the Workshop, BRTs were applied using the software package R (R Development Core Team, 2007), using the Generalised Boosted Model (GBM) library (Ridgeway, 2006) and scripts developed by Leathwick et al. (2006). Ten-fold cross-validation of the models (Hastie et al., 2001; Leathwick et al., 2006) was used to optimise the trade-off between bias and variance and minimise the risk of over- or under-fitting. The particular advantages of BRT over other regression methods include:

(i) accommodates continuous and factor predictors
(ii) automatically fits interactions
(iii) insensitive to monotone transforms of predictors
(iv) allows missing values in predictors
(v) ignores extraneous predictors.

100. The Workshop noted that it was important to determine how the reliability of the extrapolation could be assessed, and that this would need to be considered in the application of any biological dataset in this process.

101. Dr Pinkerton noted that at the first stage, expert opinion was recognised as being important to assess the quality of the biological point data themselves, and whether the biological data were likely to be representative of, or sensitive to, the biological environmental space. Second, experts considered whether the extrapolated distribution was sensible: did the extrapolated distribution match what is known about the occurrence of the biology, including using knowledge of the biological distribution not included in the training set? These expert-knowledge-based methods of evaluation are necessary but not sufficient for the Workshop to have confidence in the extrapolated biological data layers. More formal

methods to investigate the extrapolation reliability are required. Results are less reliable where the method predicts values outside the range of the (environmental) training set than when the environment space for the predictions is well represented in the training data. These formal methods of assessing reliability in extrapolated biological data layers were not available at the Workshop.

102. The Workshop recognised that biological data and the BRT method were available to the Workshop, and applying this method during the Workshop could be used to investigate whether the bioregionalisation result from the 2006 Hobart Workshop could be enhanced by the use of spatially extensive biological data layers.

103. The Workshop noted that biological data available during the Workshop that was most appropriate to investigate the potential utility of biological layers in bioregionalisation was krill and salp distributions derived from net hauls (Atkinson et al., 2004) and zooplankton distributions from SO-CPR surveys (G. Hosie, AAD). The Workshop noted that the use of layers representing the spatial distributions of these zooplankton species in the Southern Ocean could help to delineate broad-scale bioregions.

104. Ten circumpolar environmental variables were used in the spatial extrapolation by BRT. Nine of these were provided by the 2006 Hobart Workshop (bathy, par, logChl, ssh, sst, nox, si, po4, ice), and an extra clear skies insolation data layer (paragraph 49) was also used.

105. Most of the SO-CPR data presented to the Workshop (WS-BSO-07/7) were from the East Antarctica region, although a few transects were available from the Scotia Arc, the area between New Zealand and the Ross Sea, and the southern Indian Ocean. The data consisted of counts of abundance of 220 taxonomic groups of zooplankton from which 11 groups of zooplankton were produced for consideration by the Workshop. Data for these groups are available at nearly 20 000 locations in the Southern Ocean. For the purposes of bioregionalisation, the Workshop considered that the BRT results for two zooplankton groups were most plausible: pteropods and copepods.

106. The Workshop was concerned that extrapolation to outside the range of the data, both in geographic and environmental space, was potentially unreliable. Note that this is different from extrapolation in environmental space discussed in paragraph 34 above. Extrapolation in biological space relies on the assumption that the relationship between biology and environment represented in the training data is consistent across geographic space. Such an assumption underpins the use of environmental data layers in bioregionalisation. During the Workshop this assumption for the CPR zooplankton groups was investigated (Figure 1). Even though most of the CPR data are in East Antarctica, there was no significant difference in the predictive power of the model between this region and the Scotia Arc, between New Zealand and the Ross Sea, and in the southern Indian Ocean.

107. A sub-set of the circumpolar net haul krill (*E. superba*) and salp (mainly *Salpa thompsoni*) data from Atkinson et al. (2004) was available at the Workshop. After consideration of data characteristics, data taken before 1980 were excluded. A correction for net sampling as suggested by Atkinson et al. (2004) was applied to the krill abundances. These data were extrapolated through the Southern Ocean by the BRT method (Figure 2).

108. Krill experts at the Workshop noted that the patterns of krill abundance predicted by this preliminary extrapolation were broadly consistent with their understanding of krill distribution in the Southern Ocean. It was noted that the extrapolation suggested relatively high abundances of krill off Cape Adare in the Ross Sea, an area measured as having elevated abundances of *E. superba* at some times (e.g. WG-EMM-07/7) but from which the model had no net haul data to inform the prediction.

109. Spatially continuous modelled distributions for four taxa (krill, salps, pteropods and copepods) were added to the broad-scale bioregionalisation from the 2006 Hobart Workshop. The layers were added to the existing four environment variables (bathymetry, SST, nitrate, silicate) in various combinations:

(i) four primary physical variables + krill
(ii) four primary physical variables + krill + salps
(iii) four primary physical variables + krill + salps + copepods
(iv) four primary physical variables + krill + salps + pteropods
(v) four primary physical variables + krill + salps + copepods + pteropods.

110. The process by which different combinations of input variables were used to generate alternate bioregionalisations was using a method exactly analogous to the method used at the 2006 Hobart Workshop.

111. For each combination of variables the clustering algorithm from the 2006 Hobart Workshop was used to generate 200 spatial clusters. These clusters were then hierarchically re-aggregated to generate a hierarchically nested dendrogram viewable at any user-defined level of resolution from 1 to 200 groups. The Workshop chose to display the classification at the 20-group level (results are described in paragraphs 132 to 144).

Generalised Dissimilarity Modelling

112. Generalised dissimilarity Modelling is a statistical method which determines how environmental information explains differences in biological communities between locations. It is perhaps the best option for environmental classification where biological data is presence-only rather than presence/absence (see Ferrier et al., 2007). However, the method retains the following disadvantages:

(i) it is designed to assess biological communities in terms of species presence rather than abundance (which may be the more ecologically relevant measure);

(ii) it models the aggregate relationship between community composition and environment, rather than modelling the distributions and abundances of particular species;

(iii) it is not widely available within the statistical community at present, although may become so in the next few months.

Relative Environmental Suitability

113. Recent work at the University of British Columbia (Kaschner, 2004) has developed a quasi-objective approach to map global geographic ranges of marine mammals using the Relative Environmental Suitability (RES) model for marine mammal species.

Species Habitat Modelling

114. Dr P. Koubbi (France) outlined the principles of Species Habitat Modelling, which provides a means of dealing with information gaps in studied areas. Sampling stations are scattered in space and time, meaning that mapping of raw abundances can be insufficient for an understanding of species distribution, especially for biogeographic and conservation issues. Each survey is a snapshot of the relation between species and environmental factors because of temporal and spatial variability, but also linked to complex interactions with other species. When combining data from different surveys, one has to be careful of how to deal with information that was obtained with different sampling strategies, spatial or temporal scales, gears or sampling efforts.

115. A species habitat is the manifestation of the real ecological niche of the species as defined by Hutchinson (1957). This is influenced not only by correlations with the physical environment, but also by species interactions (competition, predation etc.). The species habitat is the combination of environmental factors that explains the distribution of a species. In a specific area, the presence of some individuals is due to suitable conditions for survival. For that reason, habitats can be divided into three components:

(i) the potential habitat where the environmental conditions of the species' presence can be found;

(ii) the realised habitat that can be observed. Some patches of habitats may or may not be occupied permanently by the species according to metapopulation theories because of fragmentation, connectivity etc. Populations can occupy patches of potential or optimal habitat, moving from one to another either by migration or advection processes sometimes without success of recruitment;

(iii) the successful habitat where the species will find the best conditions for its growth and recruitment.

116. Species habitat can be mapped using GIS, based on survey data as a way of assessing the realised niche of the species. Different methods are available for modelling habitats, including habitat suitability index and quantile regressions. Statistical methods such as GAMs (Hastie and Tibshirani, 1990) or GLMs (McCullagh and Nelder, 1989) have also been used. These are more suitable for modelling realised habitat and abundances rather than optimal habitat.

117. Habitat modelling deals with complex species' response to multiple interacting factors. In representing these responses, there is a danger of generating simple models that cannot deal with the complexity of species–habitat relationship. Habitat mapping can be used to model environmental scenarios in unknown areas (Koubbi et al., 2003) or to study spatio–temporal changes (Loots et al., 2007). Among problems, there are some differences in habitat of each

developmental stage – spawning grounds, areas of larval development, nurseries and trophic grounds – which indicates that the species–environment relationship changes during the life-cycle (Koubbi et al., 2006). In some cases and for some species, these areas can be geographically separated.

118. However, provided that limitations of the datasets are taken into account, these methods are robust and coherent. A major advantage is that they are data-driven rather than model driven, and the results of modelling can be improved with new datasets, especially when using GAMs.

119. Dr Koubbi noted that these models should only be applied to the environmental ranges that were used to create them. Extrapolation outside environmental ranges is not ecologically reasonable, except when validated by expert knowledge based on ecological or ecophysiological studies that were not considered to do the models.

120. Habitat modelling can also be used to test environmental scenarios in species, habitats and as a tool for modelling species distribution in unknown areas where environmental factors are known. The resolution of habitat maps will depend on the resolution of environmental factors, as spatial variability is better modelled for abiotic factors than for species abundances because of patchiness and sampling errors.

121. The Workshop noted that Species Habitat Modelling may be a valuable tool for capturing heterogeneity, particularly at finer scales.

Fine-scale pelagic bioregionalisation method

122. Fine-scale bioregionalisation of each of the clusters produced from the broad-scale bioregionalisation should use appropriate information on environment, biology and process. The Workshop noted the availability of considerable amounts and variety of data that could be used in the fine-scale bioregionalisation. See 'Pelagic data' (paragraphs 39 to 64) and 'Ecological processes' (paragraphs 157 to 164) for details of data that could be used. Because data used in fine-scale bioregionalisation does not have to be circumpolar, nor be measured consistently between broad-scale bioregions, much more information can be used for fine-scale bioregionalisation than can be used for broad-scale (circumpolar) bioregionalisation.

123. Fine-scale bioregionalisation of the pelagic environment was not conducted at the Workshop due to time constraints.

Benthic methods

124. The approach to a benthic bioregionalisation consisted of a three-step process, by which physical regions (paragraph 77) were first defined using the process employed by the 2006 Hobart Workshop (paragraph 14). The biological data were then overlaid, and the classification evaluated (paragraph 79).

Physical benthic classification

125. Dr B. Raymond (Australia) undertook the analysis of the benthic data to provide physical bioregionalisation maps for the benthic environment. The methods he used were identical to those used in the 2006 Hobart Workshop.

126. Benthic data were mapped on to a 0.5° grid because insufficient time was available to do a finer-scale resolution.

127. The following data were used:

- Bathymetry: standard data were used ($\log_{10}(x + 1)$ transform).
- Sea-floor temperature: this was provided on a global 0.125° grid with a linear interpolation from that grid to the 0.5° grid used here.
- Slope was provided as raster data in polar orthographic projection. This was inverse-projected (to get the latitude and longitude coordinates of each pixel in the raster). The data was too large to interpolate directly due to technical constraints, so they were randomly subsampled from one in four pixels and then a linear interpolation was used to convert these data to the 0.5° grid. Note that this data had areas of missing values that were filled in by the interpolation.
- Sediment data was difficult to use in the time available. Most detail from this data layer are applicable to the ocean basin areas. It was agreed that comparisons of the regionalisation for the ocean basin areas with the sediment map would show the expected heterogeneity of the benthic environment in the ocean basin areas.

128. The final clustering analysis was undertaken according to the methods from the 2006 Hobart Workshop. The three layers were collated in a single matrix. Non-hierarchical clustering (the CLARA routine in R) was used to reduce the full set of grid cells down to 200, and then hierarchical clustering (unweighted pair group method with arithmetic mean – UPGMA) was used from there to obtain 40 and 20 groups. A Gower metric was used in the clustering (equivalent to a Manhattan distance with equal weights on the three input variables). (Results are described in paragraphs 145 and 146.)

Evaluation using biological data

129. The biological data were displayed as a gridded 2° by 2° longitude layer for a broad-scale overview. Similar hotspots for sampling locations and for taxa were found. These were generally in shallow areas and in a group of regions consisting of the Antarctic Peninsula, Scotia Arc, sub-Antarctic islands, eastern Weddell Sea and Ross Sea. It should be noted that there were gaps in the data due to the patchiness of sampling.

130. A number of analyses were then performed. Among these, an analysis of relative rarity, which included counting the number of grid squares where species were found. Most of the species were found in less than 10 squares, meaning that most species were rare and found in a small number of areas. Only few were widely distributed. Most species were restricted to one box, indicating that most species would be endemic on this scale. Because

this would lead us to expect major differences between small geographic regions, it will not be possible to use assemblage difference as an indicator of biological processes. However, it is possible to concentrate on large-scale patterns of relative species richness and relative endemism.

131. An additional evaluation was undertaken for the western Antarctic Peninsula by overlaying biological data in this region with the geomorphological provinces map. The data were extracted based on where they were located spatially on the geomorphic classification. A species list per class was extracted. A range of analyses were undertaken to look at species richness and numbers of stations per polygon. (Results are described in paragraphs 147 and 148.)

RESULTS

Pelagic results

Summary of results from the 2006 Hobart Workshop

Primary regionalisation

132. The results of the broad-scale primary regionalisation from the 2006 Hobart Workshop are given in full in Grant et al. (2006). The resulting map is shown in Figure 3, which contains 14 regions as summarised in Table 1. This regionalisation differentiates on the broad scale between coastal Antarctica (including embayments), the sea-ice zone and the northern open ocean waters. The analysis highlights the different environmental characteristics of large regions including the continental shelf and slope, frontal features (SAF, PF, SACCF), the deep ocean, banks and basins, island groups and gyre systems.

133. A limited analysis at the 2006 Hobart Workshop was undertaken to investigate the uncertainty associated with the primary clustering (see Grant et al., 2006). Uncertainty was computed by first calculating the difference between the environmental characteristics of a grid cell and the average environmental characteristics of the cluster to which it was assigned. A second difference was then computed, this time between the environmental characteristics of a grid cell and the average environmental characteristics of the next-most similar cluster. The first difference value was then divided by the second. Thus, high uncertainty values indicate that a grid cell lies on the environmental boundary between two different clusters, and so its allocation to one or the other is less certain than for a grid cell that is strongly typical of the cluster to which is has been allocated. This uncertainty analysis considers only a specific subset of the possible sources of uncertainty in the regionalisation (specifically, to do with the allocation of grid cells to particular clusters).

Secondary regionalisation

134. The Workshop noted that the 2006 Hobart Workshop had included ice and remotely sensed near-surface chl-*a* concentrations in a ‘secondary’ classification displayed with 40 groups. The results are shown and discussed in Grant et al. (2006 – Figures 21, 23

and 25). The secondary regionalisation at the level of 40 groups showed spatial patterns on which the experts at 2006 Hobart Workshop could not achieve consensus regarding plausibility.

Results from the 2007 Brussels Workshop: pelagic – broad scale

135. The Workshop endorsed the broad-scale ‘primary’ regionalisation produced by the 2006 Hobart Workshop. This bioregionalisation used clustering based on four environmental variables (log10 depth, SST, silicate, nitrate); the agreed display resolution has 14 groups (see Figure 3). The Workshop felt that this classification was a good first stage bioregionalisation and a potentially valuable tool at the broad circumpolar scale.

136. The Workshop re-displayed the ‘secondary’ classification from the 2006 Hobart Workshop with 20 groups (Figure 4) to be consistent with the chosen display resolution of the classification obtained below (paragraph 143, Figures 5 and 6), which uses biological data layers.

137. The Workshop agreed that the BRT method for generating biological data layers is a valuable development and that biological layers could be used to enhance the 2006 Hobart Workshop bioregionalisation of the Southern Ocean at the circumpolar scale. The Workshop encouraged further work also at the species level to be submitted as a working paper to the Scientific Committee.

138. The Workshop noted that there were many approaches to using biological data in a broad-scale bioregionalisation of the Southern Ocean that warrant further investigation.

139. The Workshop agreed that the statistical method employed at the Workshop for the production of continuous biological species distributions and abundances, known as BRT, be considered for wider use in the future.

140. The Workshop was supportive of the potential for the BRT method to produce biological data layers for broad-scale and fine-scale bioregionalisation. Some Workshop participants noted particular enthusiasm for the krill abundance data layer derived from the data of Atkinson et al. (2004). However, many of the participants did not fully understand the statistical details of the method or felt that some uncertainties remained about the scope for its future application. The Workshop suggested that the method be written up and submitted for technical review by WG-SAM.

141. Dr Constable noted that it would be useful if WG-SAM could consider the degree to which distributions of biota can be extrapolated outside the environmental and geographic spaces of the data, the degree to which sampling error can be accounted for in the BRT method and in how uncertainty in predictions from the BRT method can be incorporated in the final classification. In so doing, it will be useful if WG-FSA and WG-EMM could review the degree to which extrapolation might mask changes in the distribution of taxa with similar characteristics, particularly taxa that are not found within the sampling area.

142. The Workshop noted that WG-EMM and WG-FSA might be asked to review the appropriateness of the datasets to be included as response variables (biological data) and those for inclusion as environmental layers which relate to processes giving rise to the data in the biological datasets.

143. The Workshop reviewed outputs from a trial bioregionalisation using additional biological layers at the circumpolar scale:

(i) four environmental data layers + krill + salps (Figure 5)
(ii) four environmental data layers + krill + salps + copepods + pteropods (Figure 6).

144. The Workshop agreed that the approach using physical and biological layers in bioregionalisation is promising and that, subject to addressing the issues in paragraphs 141 and 142, results from this approach will be useful in the future.

Benthic results

Physical benthic bioregional classification

145. Initial maps of a physical regionalisation of the benthic environment in the Southern Ocean were developed using the same approach as the 2006 Hobart Workshop to generate a primary regionalisation of the pelagic environment. These maps were the result of a cluster analysis undertaken using three data layers: bathymetry, slope and sea-floor temperature at the level of 20 and 40 bioregional classes. The sediment data was left out due to time constraints.

146. The Workshop was satisfied that the methods outlined in the 'Methods – Benthic' section (paragraphs 125 to 128) were consistent with the 2006 Hobart Workshop, and that they could be used as a basis for an initial benthic physical classification. In particular, inclusion of the sediment data will likely improve the bioregionalisation due to the relationship between sediment type and biota. The initial map using 20 physical classes is displayed in Figure 7. The Workshop noted that the degree of heterogeneity that would arise when the sediment data is included would likely be greatest in the continental slope and near-shore zones. It also noted that increasing the number of classes above 20 would result in greater diversity of physical habitats, particularly in the coastal region.

Evaluation using biological data

147. The map in Figure 8 represents the raw biological data used for evaluation of the benthic physical classification. As detailed in the 'Methods – benthic' section (paragraphs 129 to 131), the data incorporates eight taxonomic groups, and approximately 33 000 records, 7 600 stations and 3 000 taxa (species).

148. Figure 9 below shows the relative species richness divided into 2° by 2° grid cells. The map shows that the greatest concentrations of known species are found within the 1 000 m contour.

Geomorphology

149. The geomorphic map of the East Antarctic margin (Figure 10) has some key features relevant to benthic bioregionalisation. The features that make up most of the shelf are the shelf banks which are less than 550 m deep. These banks are the main environment that experiences iceberg scouring and, in places, are subject to energetic current activity. Substrates are likely to be hard sediment although mobile sands may be present. Banks are most likely to be colonised by filter feeder communities.

150. Shelf depressions are sheltered from most iceberg scouring and commonly act as sediment traps for sediment mobilised from the banks and for phytodetritus from the water column. It is expected that most depressions to have low current activity, however some experience fairly energetic flows where bottom water forms. Depressions are the geomorphic features most favoured to accumulate biogenic ooze and so support deposit feeding communities and abundant infauna. Anoxic sediments may be present in some deep depressions.

151. The continental slope is divided into the steep upper slope which experiences ice keel scouring at the shelf break and strong flows of the Antarctic Coastal Current. The steep gradients make sediment accumulation less likely, favouring hard-bottom communities. Where bottom water forms, the slope is affected by cascading plumes of dense cold water. The lower slope has a gentler gradient but may still experience strong bottom water flows and episodic turbidity current activity. The lower slope features well defined canyons and, in places, sediment mounds. The canyons tend to have eroding walls and thus hard bottoms. Inactive canyons and sediment mounds have soft sediment beds. Canyons that cut the shelf edge are features of importance for marine communities around other continents. Such canyons are rare around the Antarctic because of the effects of glaciation on the margin. One of the few such canyons is the Oates Canyon at 158°56'36"E 68°44'6"S. Whether it has similar significance to fish and benthos as similar canyons at low latitudes is unknown.

152. True seamounts are found in the eastern part of the study area associated with the rugged, relatively young ocean crust and fracture zones between the Ross Sea and Tasmania and with the Hjort Trench and Macquarie Ridge. Another group of seamounts occurs at around 100°56'E 58°54'38"S. Ridges and seamounts that stand in the order of 500 m above the surrounding ocean floor were also recognised. They are commonly ridges associated with fracture zones but also occur nearer the continent. All seamounts will have hard substrates, however, the seamount ridges that protrude hundreds rather than thousands of metres above the ocean floor may affect the overlying ocean differently to the taller true seamounts, thus affecting their habitat characteristics.

153. The abyssal plain is a broad area of sediment extending north from the margin. It is likely floored by clay and ooze. It thins onto a younger oceanic crust which has been mapped as rough ocean floor. The rough ocean floor is likely to have patches of hard, rocky sea floor but may support pockets of soft sediment. The deepest sea floor in the region is the 6 000 m plus Hjort Trench. Its great depth is likely to influence the habitats within.

154. The identified geomorphological provinces were used to select and classify the biological point data. These data were then analysed by applying the techniques outlined in the 'Methods – benthic' section (validation using biological data) (paragraphs 129 to 131).

Figure 11 shows the geomorphological provinces of the northern Antarctic Peninsula. Figure 12 shows the number of species per province. Figure 13 shows sampling effort per province (number of stations).

155. The figures demonstrate that there is variation in known species numbers between similar geomorphological provinces. Species distribution is therefore affected by factors additional to geomorphology, such as sampling effort or ice cover. Differences in patterns of species distribution and sampling effort show that potential biodiversity hotspots are not necessarily related to sampling effort.

156. These methods could be further applied to validate the benthic physical classification.

Ecological processes

157. The Workshop noted that in providing a framework for understanding spatial structure and function of ecosystems it is important to consider both biodiversity pattern information and spatially defined ecological processes (Balmford et al., 1998; Cowling et al., 2003). This can be of assistance to a spatial decision-making framework, which was used in developing the conservation plan for the Prince Edward Islands (WS-BSO-07/P1). The Workshop endorsed the approach to develop maps representing ecological processes and other features that cannot easily be incorporated into an analysis of spatial pattern.

158. Biodiversity patterns are the spatial representation of the distribution of species or habitats at a defined scale (e.g. habitats or species distributions), whilst ecological processes are actions or events that shape biodiversity patterns and ecological interactions at different scales (e.g. upwelling events, spawning areas or foraging areas).

159. Ecological processes can be either flexible in time and space (e.g. oceanic fronts) or fixed (e.g. related to a geomorphic feature).

160. Whilst the bioregionalisation analysis was successful in capturing the physical and biological patterns of the Southern Oceans, the Workshop felt that this needs to be complemented by the mapping of spatially defined processes.

161. The Workshop noted that ecological processes can be mapped spatially in two ways:

(i) flexible processes can be mapped using spatial probability data (e.g. Kernels)
(ii) fixed processes can be mapped using fixed features that define the process (e.g. geomorphic features).

162. The Workshop considered ecological process data that were available to this Workshop as well as other information that could easily be acquired. The Workshop also noted that some of these datasets can be incorporated within a bioregionalisation analysis, whilst others are best depicted as separate spatial overlays. The results of this discussion are depicted in Table 2.

163. The Workshop noted that whilst ecological process information should be used at the circumpolar scale considered at this Workshop, these data will become more important at a finer-scale regional level. The reasons for this are two-fold: (i) many process datasets are

regional in scale (e.g. tracking data for top predators); (ii) expert knowledge of spatially defined ecosystem processes can be more easily incorporated at a regional scale. It therefore followed that the best areas to develop further fine-scale bioregionalisation are mostly likely to be those geographical areas where most information and expert knowledge exists.

164. Some of the spatially defined ecosystem processes that were considered to be important are depicted in Figures 14 to 17.

FUTURE WORK

165. The Workshop agreed that the primary regionalisation for the pelagic environment contained in the 'Results' section (paragraphs 132 and 133) can be regarded as useful for application by CCAMLR and CEP. It was agreed that the initial regionalisation for the benthic environment should be reviewed and optimised for use by CCAMLR and CEP. The Workshop noted that the overall results and data considered at the Workshop show that there will be a greater heterogeneity in biodiversity and ecosystem structure and function at finer scales.

166. The Workshop agreed that refinements to this bioregionalisation could be made in the future as methods are improved and data acquired and analysed. Further finer-scale bioregionalisation work could be undertaken in a number of areas based on existing data.

167. The Workshop agreed that future work could include efforts to delineate fine-scale provinces, where possible. It was recommended that participants should submit papers to the Scientific Committee on approaches to fine-scale regionalisation, including on statistical methods and potential data sources. It was further recommended that WG-SAM should be requested to consider the statistical methods presented in paragraphs 140 and 141.

168. The inclusion of process and species information could also be considered further, particularly in the context of systematic conservation planning, and in developing a spatial decision-making framework (paragraph 157). This may be particularly applicable at finer scales.

Geomorphology

169. The Workshop recognised that the work carried out so far suggests that mapping of sea-floor geomorphology provides additional information that integrates physical data into the bioregionalisation process. Extension of this work to cover the whole CCAMLR Convention Area would be valuable. Updated sea-floor sediment maps would also be useful for benthic bioregionalisation.

Fine-scale bioregionalisation data availability

170. The Workshop recognised that biological data existed in some smaller-scale regional areas which might be utilised to further delineate broad-scale bioregionalisation efforts. These would include long-term data collections in the Southern Scotia Sea, Ross Sea, East Antarctic Sea as well as other areas.

171. The Workshop suggested that substantial finfish data from research bottom trawl surveys may be available from several national programs. In addition, other finfish data may be available from scientific collection efforts, not currently available to Workshop participants. Data pertaining to rare species may be obtained from museum collections and catalogues.

172. Although several national efforts have collected benthos data during scientific bottom trawling surveys, much of it is not presently available in electronic format. Museum collections may also be a valuable source for defining areas where rare or infrequently caught benthos species have been found.

173. It was noted that with increasing data entry into the SCAR-MarBIN network and with additional data expected from the CAML-IPY joint research effort, this network will become of great importance for future data access. Currently, many of these data are dispersed widely and stored by individual scientists or institutes and thus are very difficult to access.

174. The Workshop recognised that krill biomass and distribution data collected using both nets and acoustic methodology may be useful in these efforts. Some of these data, such as the CCAMLR-2000, BROKE East and BROKE West data, already reside with CCAMLR. The main purpose of these surveys was to gather data on krill abundance for catch limit estimates. The krill, zooplankton and associated protists and oceanographic data can be used for further bioregionalisation. Other data reside with national programs.

175. The Workshop recognised that CCAMLR's efforts to define SSMUs may be useful in fine-scale bioregionalism efforts because these efforts investigated relationships among finfish, krill, predator and prey species. The Workshop noted it may be possible to include data on other components of the ecosystem and use similar techniques such as those employed to define SSMUs.

176. The Workshop agreed that substantial bottom temperature, salinity, chl-*a*, zooplankton and phytoplankton data exist from many research efforts by national programs in several fine-scale areas. Fine-scale resolution of bathymetry data may also exist. These would be valuable to enhance fine-scale bioregionalism efforts.

177. The Workshop considered gaps in the current datasets. The SO-CPR Survey has delivered a relatively high density of zooplankton data between 60° and 160°E, with 5 n mile sampling resolution. This dataset can provide sufficient detail of zooplankton patterns for finer bioregionalisation analysis. However, there have been fewer CPR tows outside this region to date, but this is expected to increase during the IPY and afterwards as the survey continues to develop.

178. There is also a substantial gap between the southern tow limits of the CPR and the coast, predominantly over the continental shelf because of the inability to tow the CPR in

pack-ice. CPR tows are only conducted over the shelf during ice-free periods, e.g. January and February. This gap is best covered by surveys using traditional plankton nets, although the resolution between sampling sites is usually much coarser than the CPR, especially in the eastern Antarctic sector between the Weddell and Ross Seas. A number of surveys have been conducted in this area before, during and after the BIOMASS Survey. Various nets were used. Surveys were also intermittent and sporadic. More consistency in sampling has occurred since BIOMASS with the RMT1+8 being a common net system.

179. Sampling of demersal and pelagic fish assemblages, as well as the sampling of benthos, has been less extensive in the eastern Antarctic region. Again, most sampling has been sporadic. There was a more concentrated sampling in the Prydz Bay during the 1990s and there was an attempt to classify the benthic communities in the Mertz Glacier area during a geoscience survey in 2001 using grab samples and multi-beam mapping. A more comprehensive fine-scale fish and benthos survey will be conducted in this region during 2007/08, in a three-ship survey of the plankton, fish, benthos and oceanography for CAML. Other CAML surveys will be conducted around Antarctica, notably in the Ross Sea, Antarctic Peninsula, Scotia Arc and Lazarev Seas, that will provide additional data for fine-scale bioregionalisation. CAML is also gathering historical benthic data that will contribute to the bioregionalisation. SCAR-MarBIN will be the primary portal to access those data.

Development of fact sheets

180. The Workshop agreed that the development of a bioregionalisation atlas of fact sheets would be a valuable resource for CCAMLR and CEP. This would provide a standardised approach to reporting and archiving of results of bioregionalisation work for the Southern Ocean in the same manner that fishery reports are developed for each fishery in CCAMLR. Since their inception, fishery reports have been found to be a useful way to present detailed information for use by CCAMLR in its deliberations, both during meetings and intersessionally, and for the public at large to understand how work in CCAMLR is undertaken.

181. A bioregionalisation atlas could follow the approach illustrated in WS-BSO-07/9, where a hierarchy of sheets is presented showing regional features in overarching sheets and then, where available, more detailed features of bioregions and provinces on finer-scale sections of the Southern Ocean in subsidiary sheets. Fact sheets could include maps of the relevant bioregions and provinces as well as maps showing locations of important processes, colonies or aggregations of biota and other summarised details considered important for managing bioregions.

182. This format also provides a means for easily reviewing, refining and updating bioregional information and classification in specific areas without needing to revise the classification for the entire Southern Ocean.

183. The Workshop agreed that such an atlas could be developed based on the results of the primary regionalisation agreed at this Workshop, preliminary results on how finer-scale heterogeneity might exist within those regions and supplementary information from the process and other data layers considered in this report.

Further work on the development of a system of MPAs

184. The Workshop noted that bioregionalisation could serve as one component of work to be undertaken towards the development of a system of MPAs for the Convention Area (SC-CAMLR-XXV, paragraph 3.33). Further work on the consideration of methods for the selection and designation of MPAs is required, and it was noted that this work could include the further development of ecological process information, including spatial information on human activities. Intersessional work focusing on systematic conservation planning, possibly for finer-scale areas, could be an important contribution to achieving this goal.

ADVICE TO THE SCIENTIFIC COMMITTEE

185. A summary report will be submitted by the Co-conveners to the Scientific Committee.

ADOPTION OF THE REPORT AND CLOSE OF THE MEETING

186. The Report of the Workshop on Bioregionalisation of the Southern Ocean was adopted.

187. In closing the meeting, Dr Grant thanked the participants for their contribution to the successful conclusion of the Workshop, and thanked Mr de Lichtervelde for hosting the meeting and providing outstanding support. She extended special thanks to the rapporteurs, and to those who had provided their data for analysis during the Workshop.

188. The participants joined Ms G. Slocum (Australia) in thanking Drs Grant and Penhale for organising and chairing the meeting, and in thanking the CCAMLR Secretariat for their excellent support.

189. The participants also recorded their particular thanks to Dr B. Raymond (Australia), who made an invaluable contribution to the Workshop by undertaking analysis remotely in Hobart throughout the week, undeterred by the eight-hour time difference.

190. The Workshop on Bioregionalisation of the Southern Ocean was closed.

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Table 1: Physical properties (mean and standard deviation of data values) of regions shown in Figure 3 (14 cluster groups based on primary datasets).

Region name	Number of grid cells	Depth mean (m)	Depth SD	SST mean (°C)	SST SD	Si mean (µmol/kg)	Si SD	NOx mean (µmol/kg)	NOx SD
Southern Temperate	110 567	–4119.952	821.342	8.681	1.854	7.998	2.402	20.919	1.616
SACCF	40 180	–3917.738	921.884	5.840	0.791	15.231	2.582	25.158	1.052
Polar Front	83 006	–4134.095	732.582	3.539	0.999	28.382	6.492	29.236	1.815
Southern ACC Front	108 053	–4109.261	818.366	0.945	0.872	56.089	9.814	32.370	1.503
Antarctic Open Ocean	136 360	–3612.533	897.680	–0.682	0.535	79.593	5.804	33.169	1.374
Antarctic Shelves	30 767	–520.048	213.352	–1.149	0.380	82.044	9.211	32.356	1.821
Antarctic Shelf Slope, BANZARE Bank	6 508	–1455.466	389.636	–1.227	0.434	79.961	2.946	33.599	1.343
Campbell Plateau, Patagonian Shelf, Africana Rise	7 451	–1034.451	427.437	8.453	1.129	7.876	2.582	20.898	1.735
Inner Patagonian Shelf, Campbell and Crozet Islands	913	–343.482	109.436	7.742	0.827	8.084	2.233	20.857	1.427
Kerguelen, Heard and McDonald Islands	2 294	–1270.202	734.782	3.360	0.818	25.846	4.024	29.279	1.318
Subtropical Front	94 234	–4461.472	788.887	11.804	1.511	4.607	1.235	15.257	2.062
Northern Temperate	9 946	–4163.621	951.003	15.496	0.774	4.336	0.727	10.154	1.667
Weddell Gyre and Ross Sea banks	52 905	–4466.641	762.290	–0.680	0.333	98.163	5.615	31.965	0.553
Chatham Rise	3 025	–1568.439	858.953	14.361	0.802	4.112	0.610	12.061	1.453

Table 2: A list of spatially defined ecological processes for which datasets are available and which could be incorporated into a spatial decision-making framework.

Type of process	Effects of processes	Datasets considered for this workshop	Available datasets for future analyses
Physical			
Flexible processes			
Position of oceanic fronts	Enhanced local productivity and other effects	Orsi et al. (1995)	Moore et al. (1997) Probability of position of the APF
Eddies and current variability	Enhanced local productivity and other effects	Average sea-surface height anomaly (Figure 1)	
Iceberg scouring	Benthic disturbance		Probability model to be developed
Fixed Processes			
Sub-Antarctic Island effects	Nutrient trapping, upwelling and vertical mixing	SeaWiFS	
Continental shelf effects	Nutrient trapping, upwelling and vertical mixing, ice melts	SeaWiFS, ice extent	
Canyons and other bathymetric irregularities in the shelf break	Deep water upwelling onto the continental shelf	Developed by Geoscience Australia (Figure 15)	Dinniman et al. (2003). Other regional and large-scale physical models
Seamounts	Taylor columns	Kitchingman and Lai (2004)	
Polynyas	Upwelling and mixing	Arrigo and van Dijken (2003)	
Biological			
Flexible processes			
Procellariform breeding foraging areas	Areas of high dependence and productivity	Birdlife (2004) probability kernel maps (Figure 16)	
Elephant seal data	Areas of high dependence and productivity		International elephant seal collaboration
Krill recruitment areas	Areas of high dependence for key species		Probability data Hoffman and Husrevoglu (2003)
Cetacean foraging areas	Areas of high dependence and productivity		IWC sightings data
Fixed processes			
Penguin foraging buffers	Areas of high dependence	Adélie, gentoo, macaroni, chinstrap (Figure 17)	

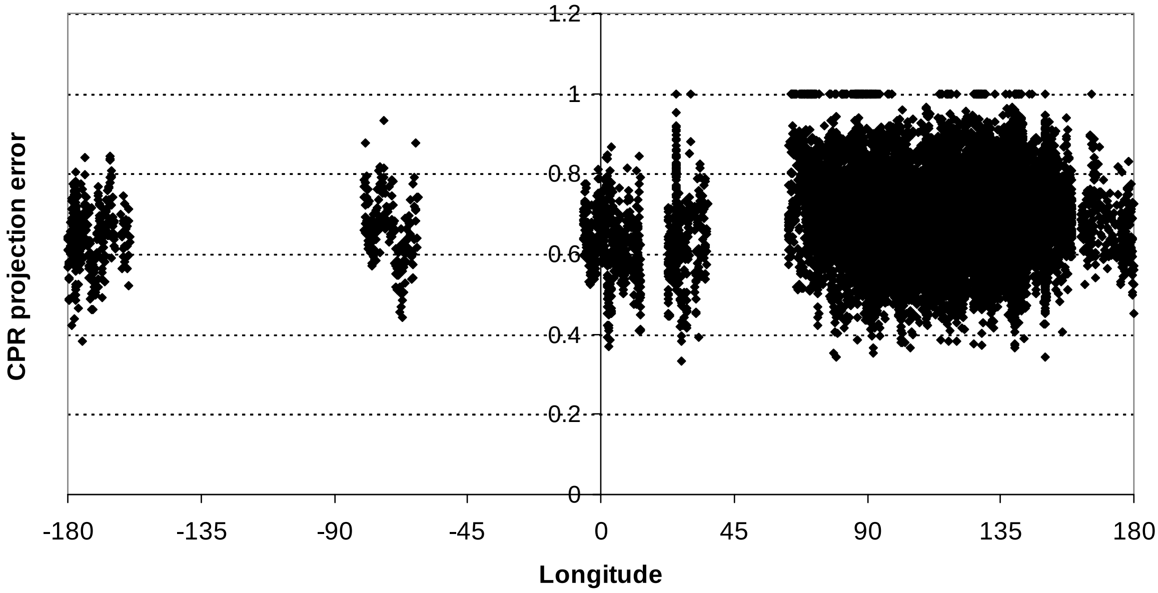

Figure 1: Error in the predicted CPR zooplankton distributions predicted using BRT with longitude. Most of the training data are in East Antarctica (longitude 60–158°E), but there are also CPR data in the Scotia Arc, between New Zealand and the Ross Sea, and in the southern Indian Ocean. This comparison shows that there is no significant difference in model predictive power with region.

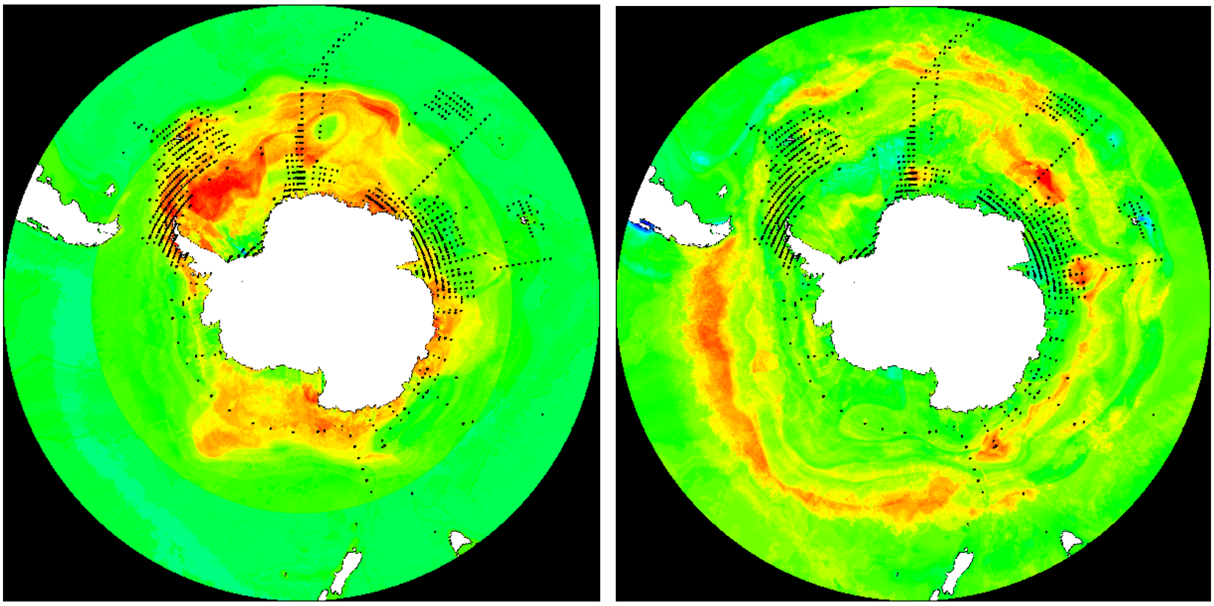

Figure 2: Predicted krill (left) and salp (right) abundances using a BRT regression based on net-haul measurements. Red indicates higher abundance; blue indicates lower abundance. Black symbols show the location of net haul measurements.

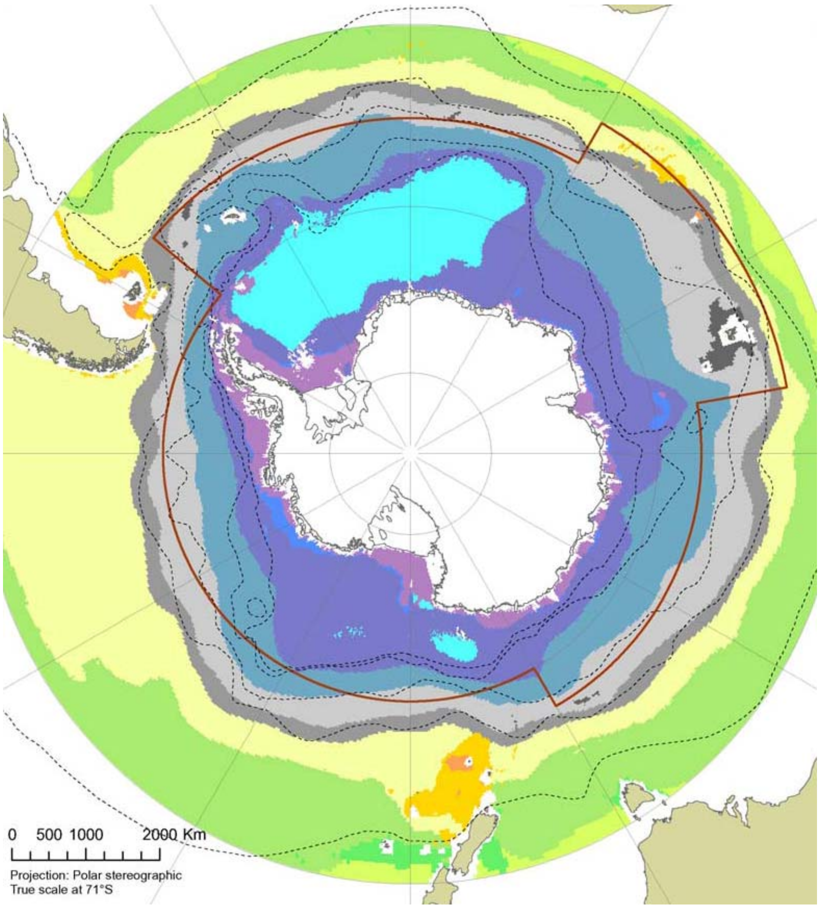

Figure 3: The primary regionalisation from the 2006 Hobart Workshop. The regionalisation uses four physical environment layers (depth, SST, silicate concentration, nitrate concentration).

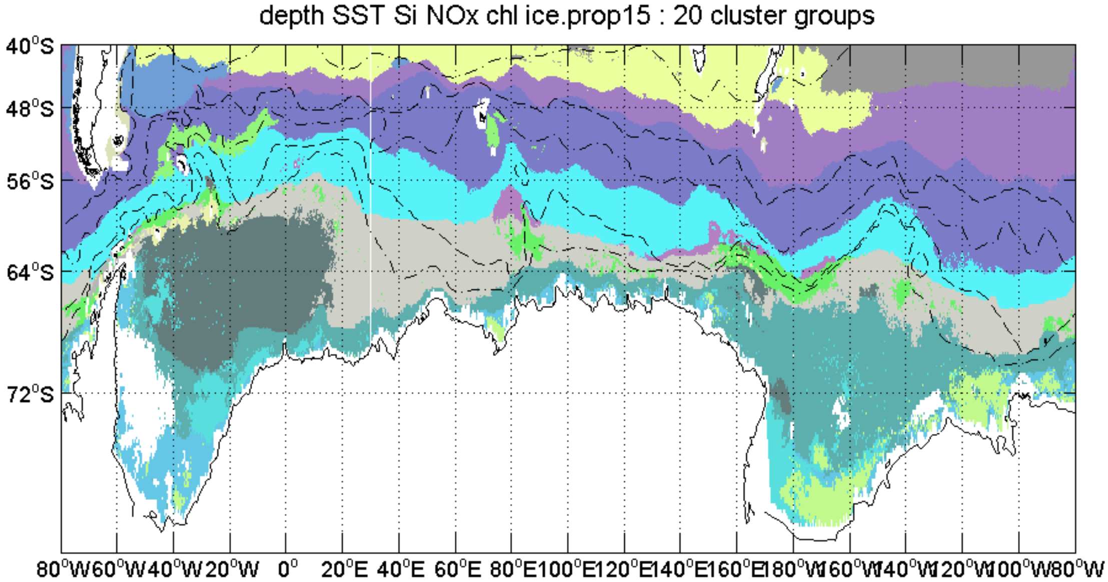

Figure 4: The secondary regionalisation from the 2006 Hobart Workshop, achieved by adding layers representing chl-*a* and ice to the agreed primary regionalisation. That workshop agreed that these two variables were related to heterogeneity at fine scales not captured by the primary classification, and produced the secondary classification at the 40-group level; however the workshop did not achieve consensus as to whether the resulting patterns were plausible. The secondary regionalisation has thus been re-aggregated to 20 groups for comparison with the results of the mixed environment–biological regionalisation, below.

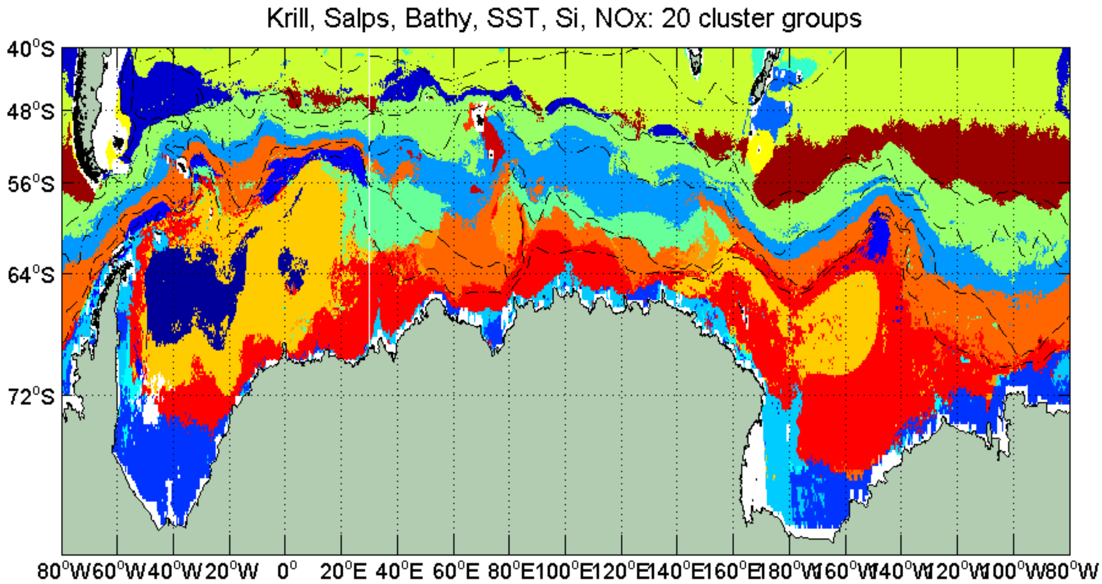

Figure 5: Bioregionalisation using four primary physical environment layers (depth, SST, nitrate, silicate) plus modelled circumpolar distributions for krill and salps, displayed at the 20-group level.

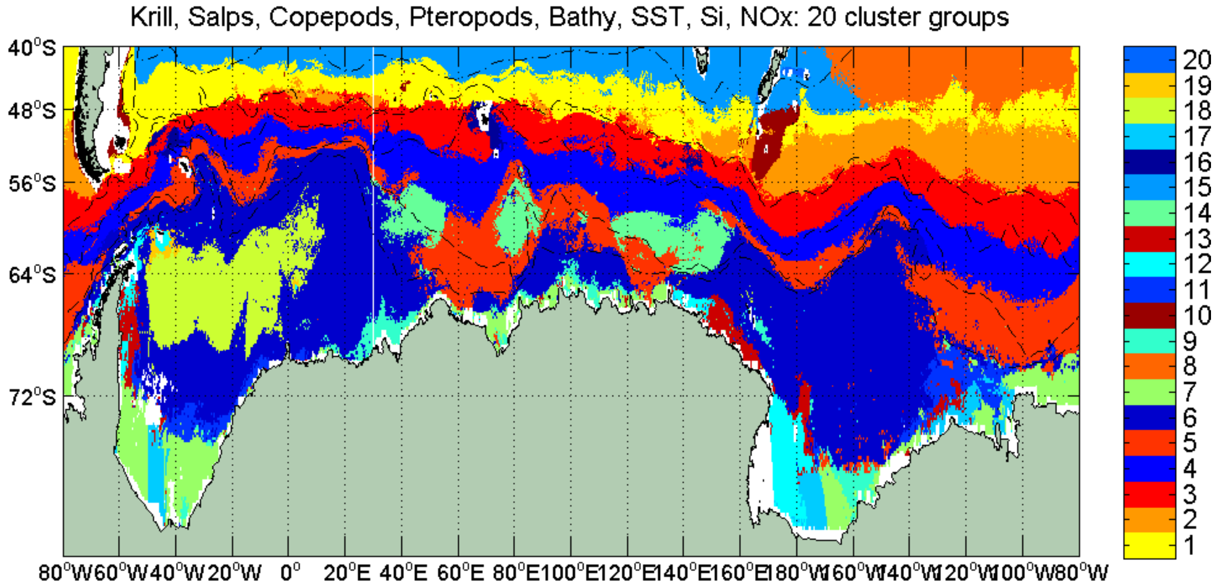

Figure 6: Bioregionalisation using four primary physical environment layers (depth, SST, nitrate, silicate) plus modelled circumpolar distributions for krill, salps, copepods, and pteropods, displayed at the 20-group level.

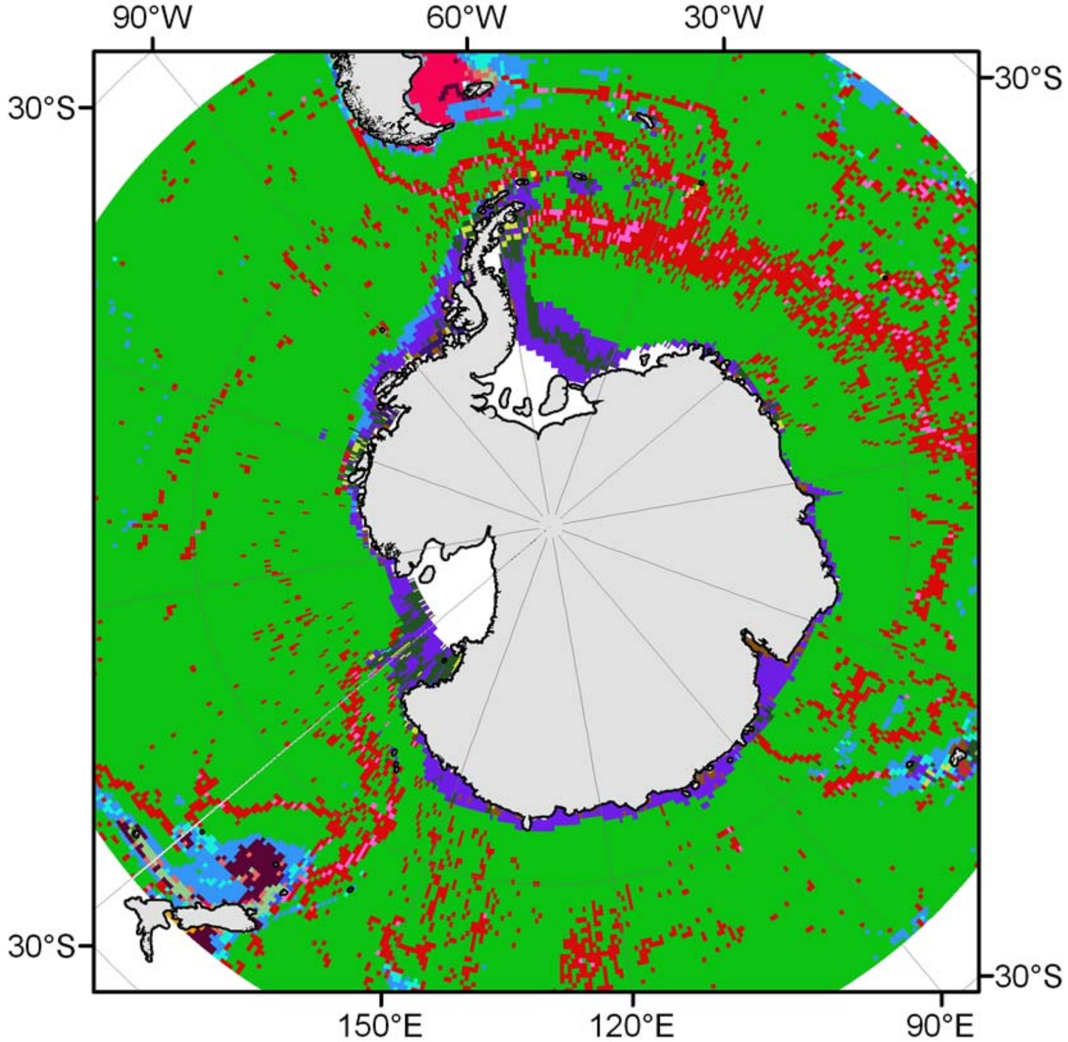

Figure 7: Initial benthic physical classification using three data layers: bathymetry, slope and sea-floor temperature at the level of 20 bioregional classes.

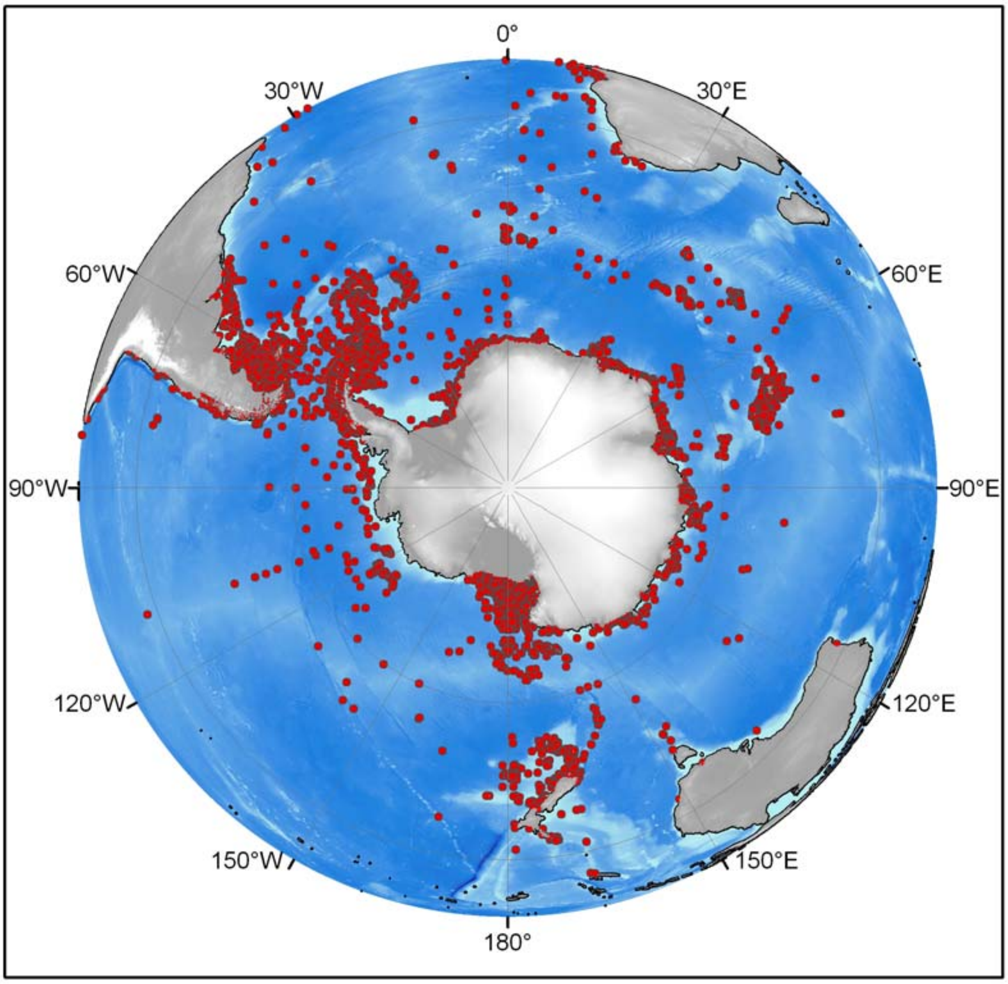

Figure 8: Map of Southern Ocean showing the distribution of benthic samples for selected taxa.

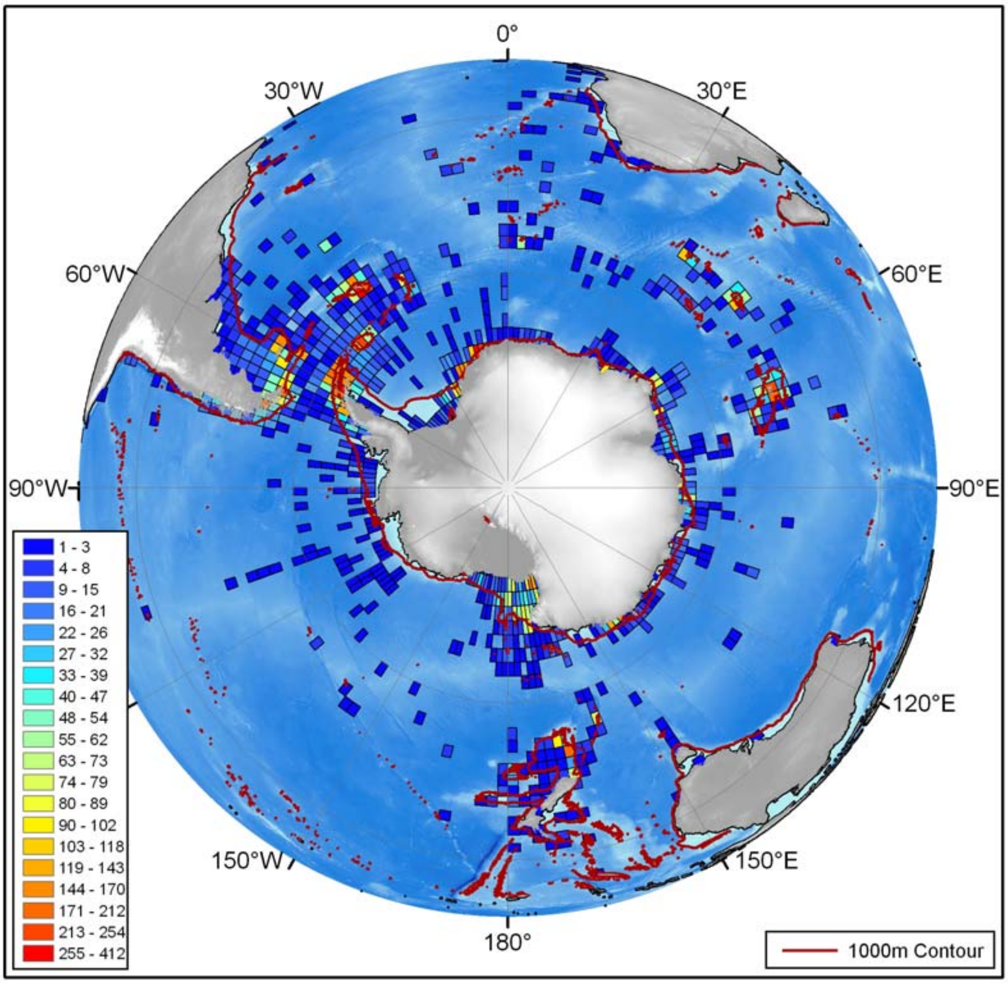

Figure 9: A 2° x 2° grid showing the total number of species per grid cell.

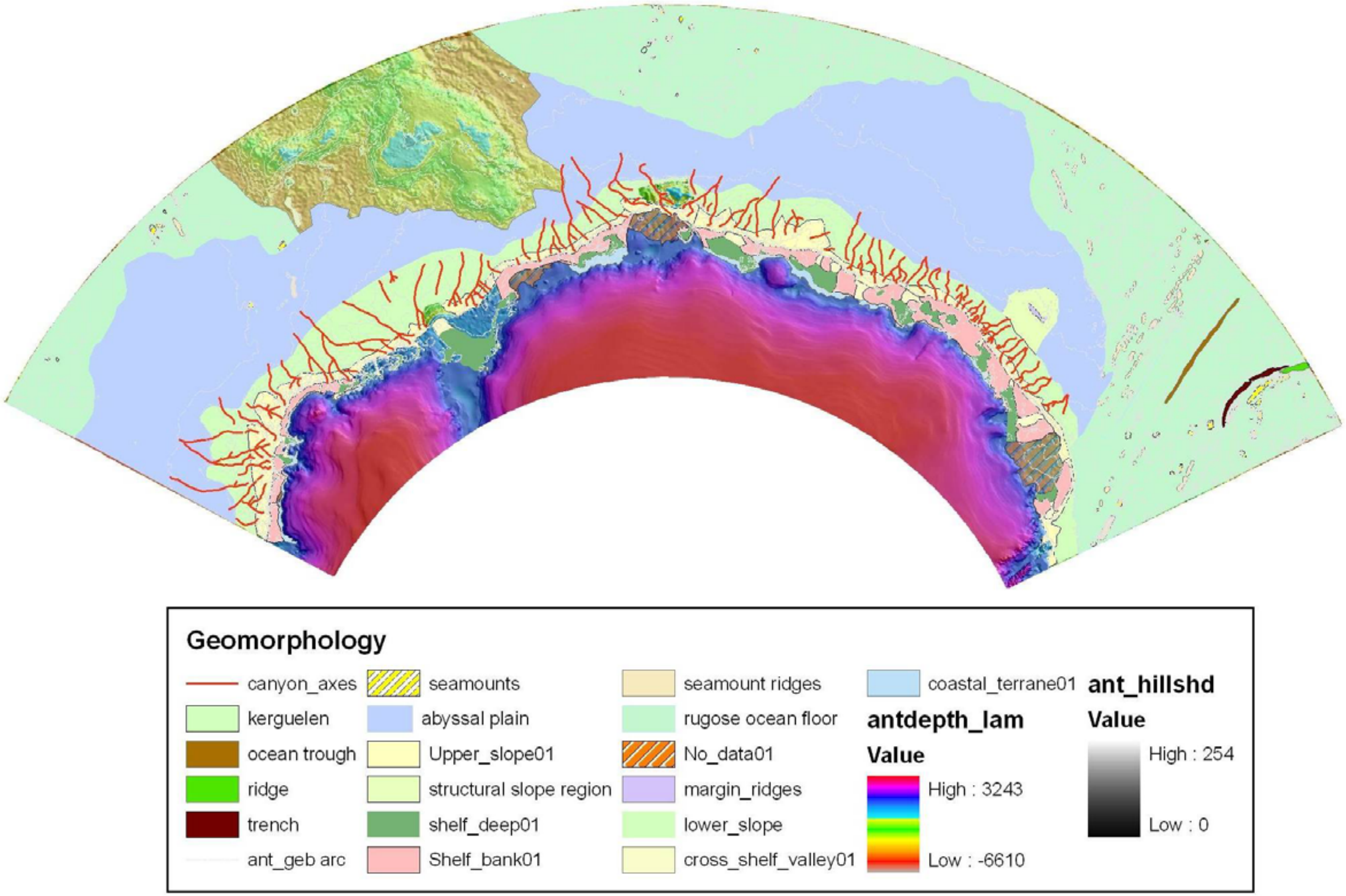

Figure 10: Geomorphic map of the East Antarctic margin.

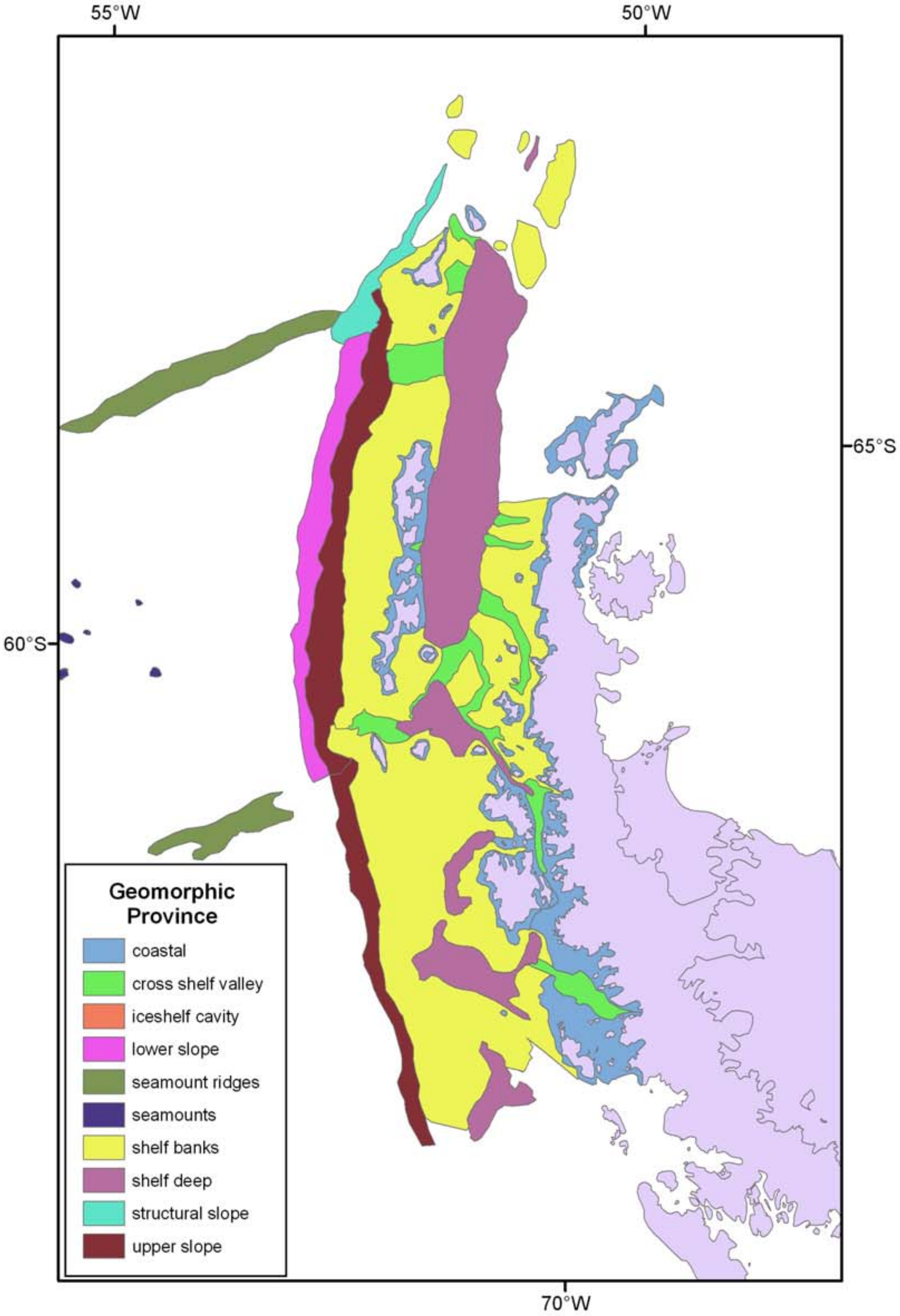

Figure 11: Geomorphic provinces of the western Antarctic Peninsula.

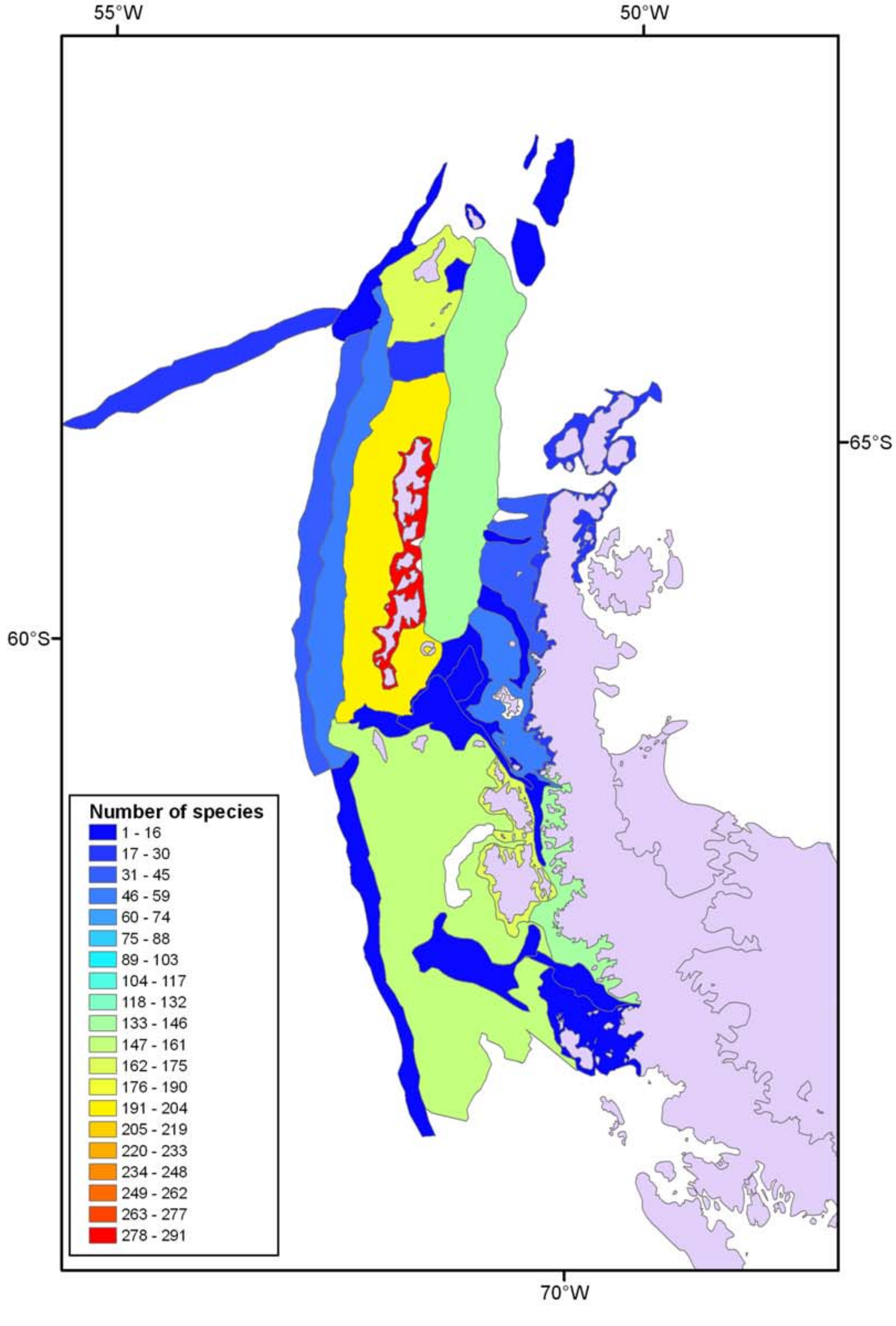

Figure 12: Number of known species sampled in different geomorphic provinces.

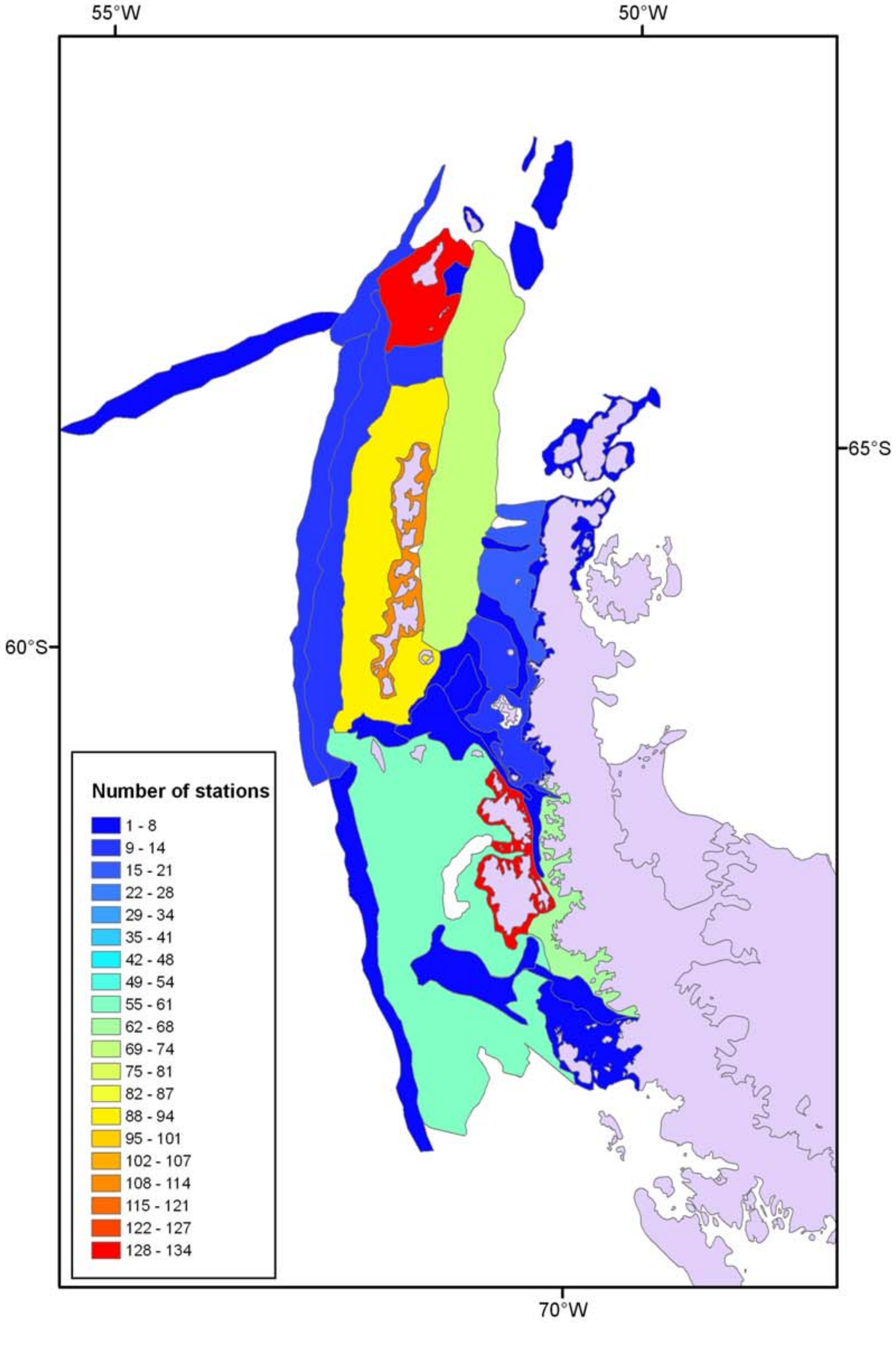

Figure 13: Concentration of sampling locations in different geomorphic provinces.

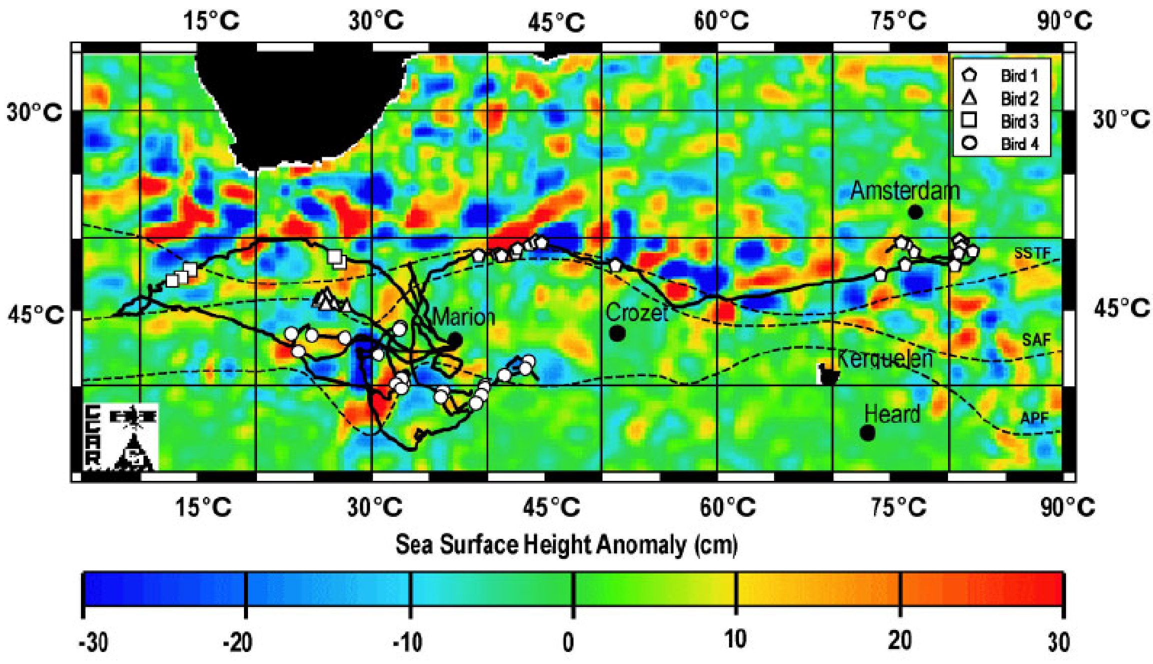

Figure 14: Position of mesoscale eddies in the southern Indian Ocean as depicted by sea-surface height anomaly data. This figure also depicts the foraging tracks of grey-headed albatrosses which exploit these features. Symbols, indicate birds moving at <10 km/h during daytime, probably foraging.

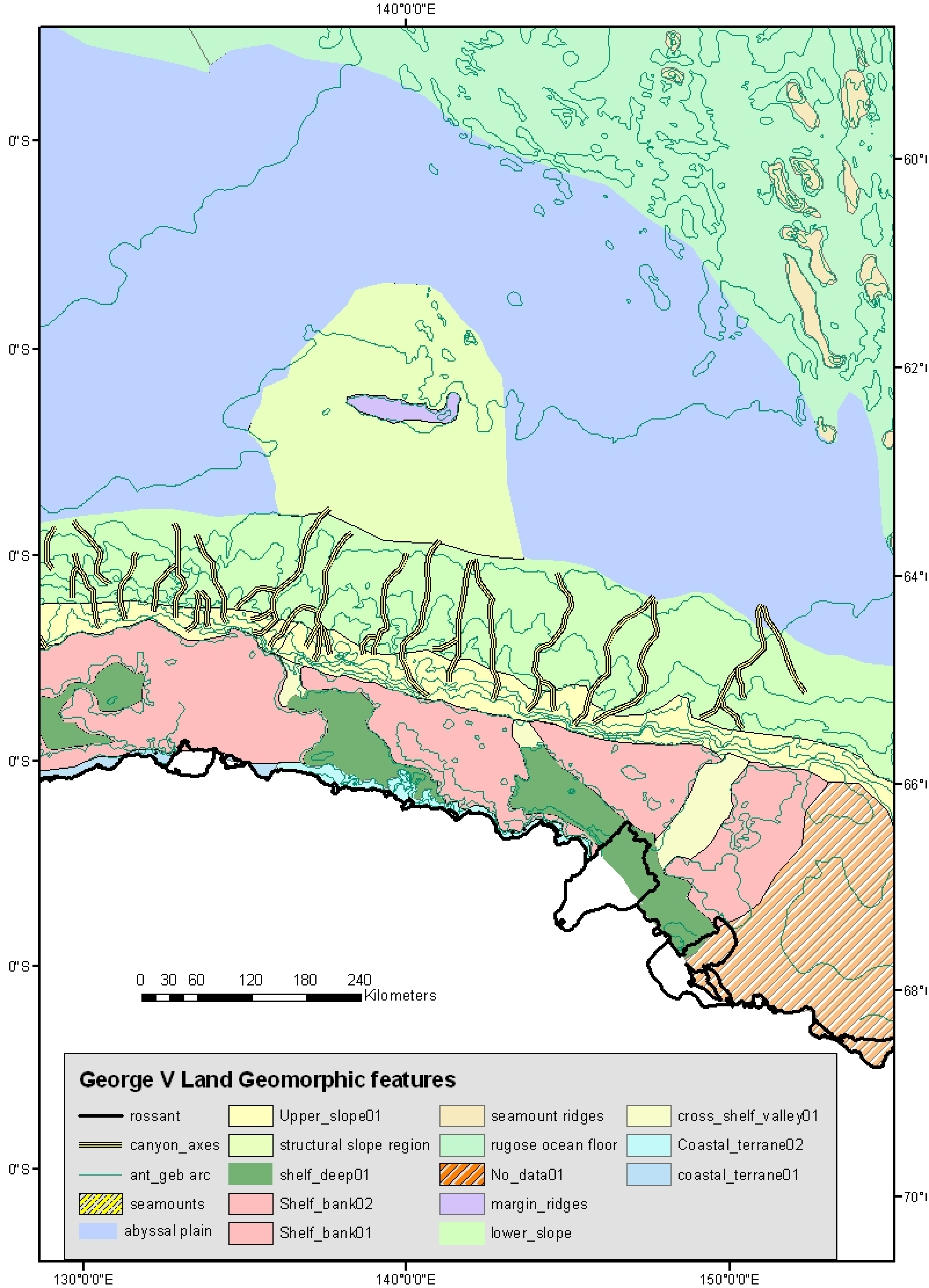

Figure 15: Position of submarine canyons in the eastern Antarctic region.

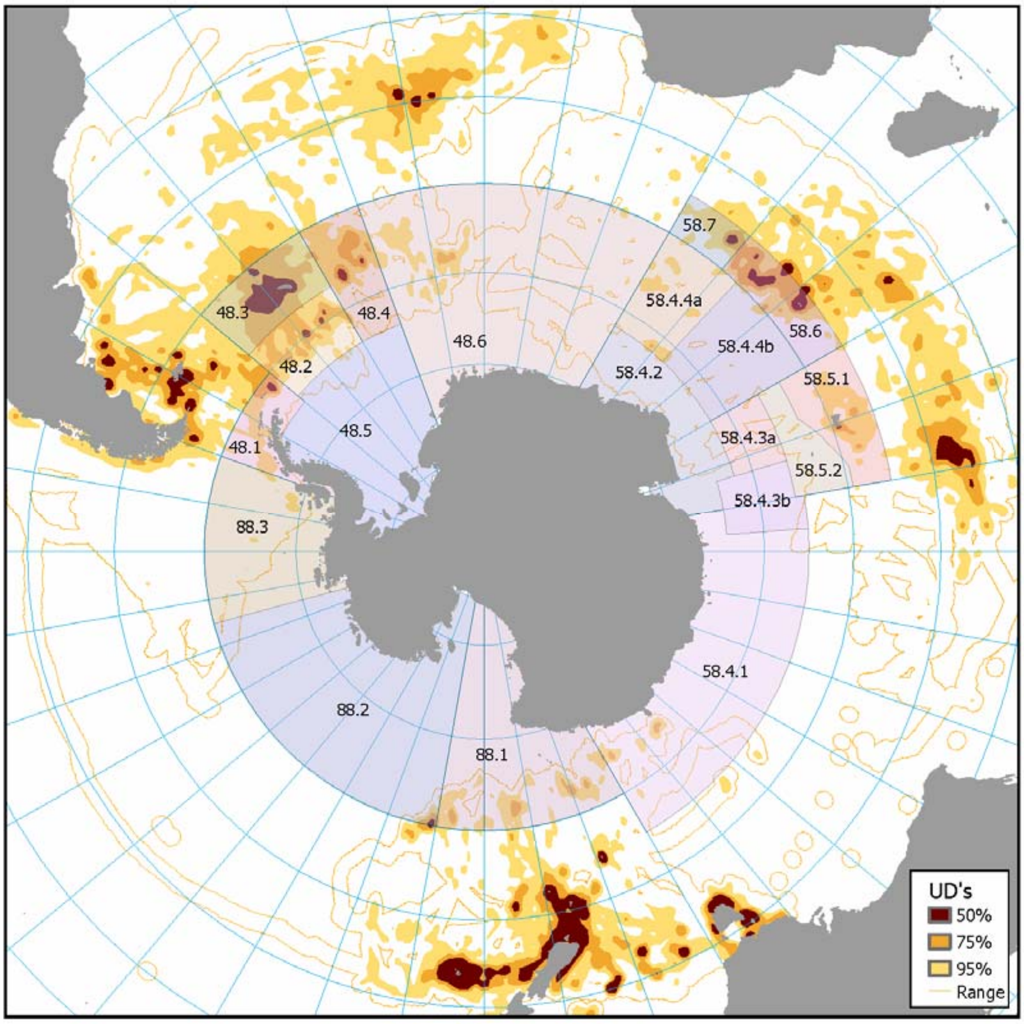

Figure 16: Combined utilisation distribution map for the breeding distribution of 18 albatross, giant petrel and petrel species represented in the BirdLife International Global Procellariiform Tracking Database. Each species has been given equal weighting.

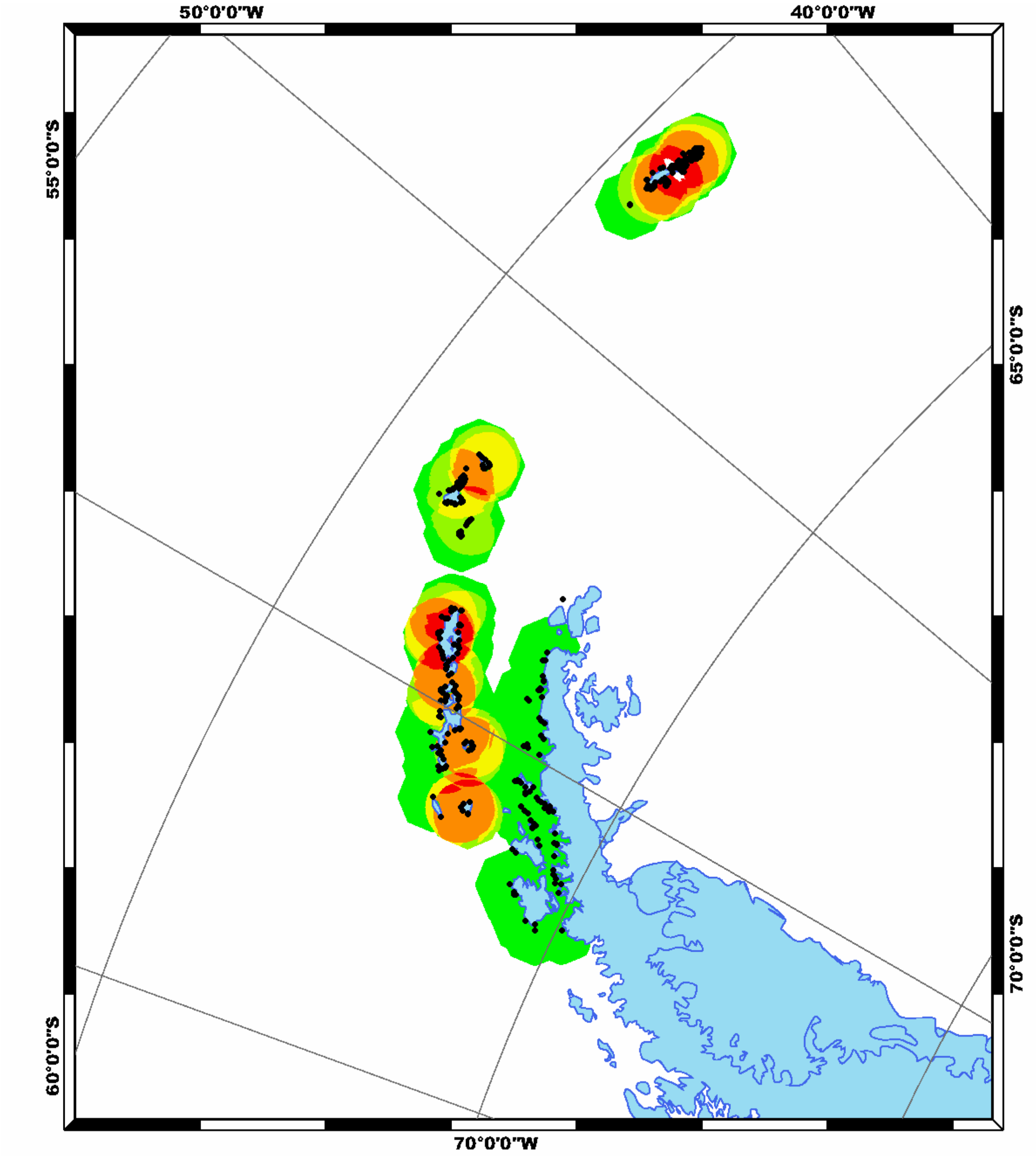

Figure 17: Relative foraging effort of chinstrap penguin colonies in the west Antarctic Peninsula; foraging effort is scaled to colony size; foraging range is taken from Lynnes et al. (2002).

APPENDIX A

AGENDA

Workshop on Bioregionalisation of the Southern Ocean
(Brussels, Belgium, 13 to 17 August 2007)

Introduction

Adoption of agenda

Workshop objectives:

- To advise on a bioregionalisation of the Southern Ocean, including, where possible, advice on fine-scale subdivision of biogeographic provinces.

Introductory presentations

Terms of reference for the Steering Committee
(annotated with key points to be addressed by the Workshop)

(i) Collate existing data on coastal and oceanic provinces, including benthic and pelagic features:

- review collated datasets on coastal and oceanic provinces, including benthic and pelagic features, and physical and biological data;

- consider which datasets would be most useful for (i) broad-scale bioregionalisation analysis, and (ii) fine-scale delineation of provinces.

(ii) Determine the statistical analyses required to facilitate a bioregionalisation, including the use of empirical, model and expert data:

- review approaches to bioregionalisation (including outcomes from 2006 Hobart Workshop and other intersessional work);

- undertake practical (computer-based) analysis to investigate statistical issues and refine methods;

- establish agreed methods for use in (i) broad-scale bioregionalisation analysis, and (ii) fine-scale delineation of provinces.

(iii) Develop a broad-scale bioregionalisation based on existing datasets and other datasets possibly available prior to the workshop.

(iv) Delineate fine-scale provinces within regions, where possible:

- review results from intersessional work (including 2006 Hobart Workshop)

- undertake (i) broad-scale bioregionalisation analysis, and (ii) fine-scale delineation of provinces, using agreed methods and datasets.

(v) Establish a procedure for identifying areas for protection to further the conservation objectives of CCAMLR:

- Preliminary discussion on procedures that might be utilised (with a view to undertaking further work during the next stages of the work program).

Recommendations for future work

Advice to SC-CAMLR

Adoption of workshop report.

APPENDIX B

LIST OF PARTICIPANTS

Workshop on Bioregionalisation of the Southern Ocean
(Brussels, Belgium, 13 to 17 August 2007)

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Secretariat:

Denzil MILLER (Executive Secretary) Eugene SABOURENKOV (Science/Compliance Officer) Genevieve TANNER (Communications Officer)	CCAMLR PO Box 213 Tasmania Australia ccamlr@ccamlr.org

APPENDIX C

LIST OF DOCUMENTS

Workshop on Bioregionalisation of the Southern Ocean
(Brussels, Belgium, 13 to 17 August 2007)

WS-BSO-07/1	Draft Agenda
WS-BSO-07/2	List of Participants
WS-BSO-07/3	List of Documents
WS-BSO-07/4	Southern Ocean continuous plankton recorder survey: spatial and temporal patterns of variation in zooplankton abundance, distribution and diversity G.W. Hosie (Australia)
WS-BSO-07/5	Spatial patterns of temporal relationships in the Southern Ocean M. Kahru and B.G. Mitchell (USA)
WS-BSO-07/6	Marine classification: lessons from the New Zealand experience B. Sharp, M. Pinkerton and J. Leathwick (New Zealand)
WS-BSO-07/7	Use of biological data to inform bioregionalisation of the Southern Ocean M. Pinkerton, B. Sharp and J. Leathwick (New Zealand)
WS-BSO-07/8	A scheme for mapping Antarctic seafloor geomorphology to aid benthic bioregionalisation P. O'Brien (Australia)
WS-BSO-07/9	Summary fact sheets for bioregionalisation of the Southern Ocean – examples from the Indian Ocean sector (Area 58) K. Martin-Smith, P. O'Brien, B. Raymond and A. Constable (Australia)
WS-BSO-07/10	On biogeographic patterns of benthic invertebrate mega fauna on shelf areas of the Southern Ocean Atlantic sector S.J. Lockhart and C.D. Jones (USA)
WS-BSO-07/11	Bioregionalisation: some key questions and considerations S. Grant, A. Clarke, P.N. Trathan and H.J. Griffiths (UK)

WS-BSO-07/12	Spatial disposition of euphausiid larvae in relation with the Weddell-Scotia Confluence E. Marschoff, D. Gallotti, G. Donnini and N. Alescio (Argentina)

Other Documents

WS-BSO-07/P1	Conserving pattern and process in the Southern Ocean: designing a Marine Protected Area for the Prince Edward Islands (Lombard, A.T., B. Reyers, L.Y. Schonegevel, J. Cooper, L.B. Smith-Adao, D.C. Nel, P.W. Froneman, I.J. Ansorge, M.N. Bester, C.A. Tosh, T. Strauss, T. Akkers, O. Gon, R.W. Leslie and S.L. Chown (2007) *Ant. Sci.*, 19 (1): 39–54)
WS-BSO-07/P2	Vacant
WS-BSO-07/P3	A new approach to selecting Marine Protected Areas (MPAs) in the Southern Ocean (Harris, J., M. Haward, J. Jabour and E.J. Woehler (2007) *Ant. Sci.*, 19 (2): 189–194, doi: 10.1017/S0954102007000260)
WS-BSO-07/P4	Development of the Southern Ocean Continuous Plankton Recorder survey (Hosie, G., M. Fukuchi and S. Kawaguchi (2003) *Progress in Oceanography*, 58: 263–283)
WS-BSO-07/P5	The Continuous Plankton Recorder in the Southern Ocean: a comparative analysis of zooplankton communities sampled by the CPR and vertical net hauls along 140°E (Hunt, B.P.V and G. Hosie (2003) *J. Plankton Res.*, 25 (12): 1561–1579)
WS-BSO-07/P6	Zonal structure of zooplankton communities in the Southern Ocean south of Australia: results from a 2150 km continuous plankton recorder transect (Hunt, B.P.V. and G. Hosie (2005) *Deep-Sea Research,* I, 52 (7): 1241–1271)
WG-EMM-07/7	Interactions between oceanography, krill and baleen whales in the Ross Sea and Adjacent Waters in 2004/05 M. Naganobu, S. Nishiwaki, H. Yasuma, R. Matsukura, Y. Takao, K. Taki, T. Hayashi, Y. Watanabe, T. Yabuki, Y. Yoda, Y. Noiri, M. Kuga, K. Yoshikawa, N. Kokubun, H. Murase, K. Matsuoka and K. Ito (Japan)
SC-CAMLR-XXV/BG/18	To the question for bioregionalisation of the Antarctic waters with ecosystem approach Delegation of Russia

APPENDIX D

DESCRIPTIONS OF THE DATASETS USED IN BENTHIC BIOREGIONAL CLASSIFICATION

1. Physical data

Bathymetry – T Depth data were obtained from the GEBCO digital atlas (IOC, IHO and BODC, 2003). These data give water depth in metres and are provided on a 1-minute global grid. Centenary Edition of the GEBCO Digital Atlas, published on CD-ROM on behalf of the Intergovernmental Oceanographic Commission and the International Hydrographic Organization (IHO) as part of the General Bathymetric Chart of the Oceans, British Oceanographic Data Centre, Liverpool, UK.
See www.gebco.net and www.bodc.ac.uk/projects/international/gebco.
A metadata record for the bathymetry polygons can be obtained from: http://aadcmaps.aad.gov.au/aadc/metadata/metadata_redirect.cfm?md=AMD/AU/gebco_bathy_polygons.
In addition to the GEBCO bathymetry, geomorphic mapping used the ETOPO2 topography grid (www.ngdc.noaa.gov/mgg/fliers/01mgg04.html) which includes satellite derived bathymetry. These data are particularly useful for identifying seamounts.

Slope – Slope (degrees of incline) are derived from the GEBCO bathymetry dataset (see above for details) using the 'slope' function in ArcGIS (version 9) Spatial Analyst.

Sea-floor sediment type – A map of surficial sediment distributions was digitised from McCoy (1991). This map is a compilation of published and unpublished data, including historical records such as from the Challenger and Discovery cruises, and more recent drilling projects. All information was compared to a regional framework of sediment data from core analyses. The map depicts unconsolidated sediments recovered primarily by coring, but also by grab samplers, dredges, and other types of sediment samplers.
McCoy, FW. (1991). Southern Ocean Sediments: circum-Antarctic to 30°S. In: Hayes, D.E. (Ed.). Marine Geological and Geophysical Atlas of the Circum-Antarctic to 30°S. *Ant. Res. Ser.*, 34.

Sea-floor temperature – Mean sea temperature by depth sourced from the US National Oceanic and Atmospheric Administration (NOAA – www.nodc.nooa.gov). Created by H. Griffiths (British Antarctic Survey, UK).

Geomorphology – Geomorphology was mapped by visual inspection of the combined bathymetry datasets and polygons digitised directly into ACRGIS. The different geomorphic features were mapped using criteria set out in WS-BSO-07/8. In addition, seismic lines from the SCAR Seismic Data Library System were used to give a profile view of the sea floor and give insight into the likely character of the sea floor (hard versus soft).

2. Biological data

Antarctic Echinoids
Metadata page:
http://gcmd.gsfc.nasa.gov/KeywordSearch/Metadata.do?Portal=scarmarbin&KeywordPath=Locations%7COCEAN%7CSOUTHERN+OCEAN&OrigMetadataNode=GCMD&EntryId=Ant_Echinoids_SCARMarBIN&MetadataView=Brief&MetadataType=0&lbnode=gcmd3
Dataset creators: B. David, University of Burgundy, France; C. De Ridder, Free University of Brussels, Belgium
Short description: 'Antarctic Echinoids' is an interactive database synthesising the results of more than 100 years of Antarctic expeditions. It comprises information about 81echinoid species present south of the Antarctic convergence. It includes illustrated keys for the determination of the species, and information about their morphology and ecology (text, illustrations and glossary), their distribution (maps and histograms of bathymetrical distribution); the sources of the information (bibliography, collections and expeditions) are also provided. Antarctic Echinoids is part of the Belgian BIANZO consortium, which constitutes the kernel of SCAR-MarBIN.

Southern Ocean Mollusc Database (SOMBASE)
Metadata
http://gcmd.gsfc.nasa.gov/KeywordSearch/Metadata.do?Portal=scarmarbin&KeywordPath=Locations%7COCEAN%7CSOUTHERN+OCEAN&OrigMetadataNode=GCMD&EntryId=scarmarbin_SOMBASE&MetadataView=Brief&MetadataType=0&lbnode=gcmd3
Dataset creators: A. Clarke and H. Griffiths, British Antarctic Survey, UK
Short description: SOMBASE contains comprehensive distribution records of Antarctic, Magellanic, and sub-Antarctic gastropods and bivalves as well as records for many other species from the southern hemisphere. Based on published records and British Antarctic Survey data these distribution maps form part of a biogeographic database, which also includes taxonomic, ecological and habitat data. The database contains information on over 1 400 species from more than 3 350 locations.

Southern Ocean Sea Stars Biogeography
Metadata page (not complete):
http://gcmd.gsfc.nasa.gov/KeywordSearch/Metadata.do?Portal=scarmarbin&KeywordPath=Locations%7COCEAN%7CSOUTHERN+OCEAN&OrigMetadataNode=GCMD&EntryId=scarmarbin_Asteroids_stampanato&MetadataView=Brief&MetadataType=0&lbnode=gcmd3
Dataset creator: B. Danis, Free University of Brussels, Belgium
Short description: This dataset is an extension of the 'Antarctic and Sub-Antarctic Asteroid Zoogeography [SCAR-MarBIN]' datasets, which is available on SCAR-MarBIN. The version of the datasets used in the framework of the present workshop includes data from six expeditions, including 7 308 records, belonging to 147 sea star species, from 331 stations. The complete dataset will soon be made available on SCAR-MarBIN, when primary analysis is completed.

Ant'Phipoda
Metadata page:
http://gcmd.gsfc.nasa.gov/KeywordSearch/Metadata.do?Portal=scarmarbin&KeywordPath=Locations%7COCEAN%7CSOUTHERN+OCEAN&OrigMetadataNode=GCMD&EntryId=scarmarbin_AntPhipoda&MetadataView=Brief&MetadataType=0&lbnode=gcmd3
Dataset creator: C. De Broyer, Royal Belgian Institute of Natural Sciences, Brussels, Belgium
Short description: Ant'phipoda is a specialised database that records and organises the widely scattered information on taxonomy, geographic and bathymetric distribution, ecology and bibliography available on Southern Ocean amphipods. Ant'phipoda is part of the Belgian BIANZO consortium, which constitutes the kernel of SCAR-MarBIN.

FishBase
Metadata page:
http://gcmd.gsfc.nasa.gov/KeywordSearch/Metadata.do?Portal=scarmarbin&KeywordPath=Locations%7COCEAN%7CSOUTHERN+OCEAN&OrigMetadataNode=GCMD&EntryId=scarmarbin_Fishbase&MetadataView=Brief&MetadataType=0&lbnode=gcmd3
Dataset creators: Rainer Froese, Institute of Marine Research, Kiel, Germany; Daniel Pauly, Fisheries Centre, University of British Columbia, Canada
Short description: A subset of the data described here (7 775 records from Southern Ocean locations) is served by SCAR-MarBIN. FishBase is a global information system covering all aspects of fish biology, ecology, population dynamics, life history and usage by humans. The information is provided in monthly updates at www.fishbase.org. Occurrence data stem mostly from museum collections, less from surveys and the scientific literature; in addition, about 1 000 observation records were reported by the public (fish watchers). Fish were collected with varying gear and deposit of specimens; also trawl surveys and a few individual observations, e.g. by anglers or divers. Habitat coverage includes, marine, brackish, and freshwater. All classes of fish are represented, Myxini (hagfish), Cephalaspidomorphi (lampreys), Holocephali (chimaeras), Elasmobranchii (sharks and rays), Sarcopterygii (lobe-finned fish) and Actinopterygii (ray-finned fish), with altogether 29 200 of 30 000 estimated species. In the framework of this Workshop, SCAR-MarBIN was queried only for benthic fish species.

Hexacorallia
Metadata page:
http://gcmd.gsfc.nasa.gov/KeywordSearch/Metadata.do?Portal=scarmarbin&KeywordPath=Locations%7COCEAN%7CSOUTHERN+OCEAN&OrigMetadataNode=GCMD&EntryId=scarmarbin_HEXACORALLIA&MetadataView=Brief&MetadataType=0&lbnode=gcmd3
Dataset creator: D. Fautin, University of Kansas, USA
Short description: A subset of the data described here (1 428 Southern Ocean records) is served by SCAR-MarBIN. Hexacorallia is a compilation of publications concerning taxonomy, nomenclature and geographic distribution of extant hexacorallians – members of cnidarian orders Actiniaria (sea anemones in the strict sense), Antipatharia (black corals), Ceriantharia (tube anemones), Corallimorpharia (sea anemones in the loose sense), Ptychodactiaria (sea anemones in the loose sense), Scleractinia (hard or stony corals) and Zoanthidea (sea anemones in the loose sense). More information on the collections and temporal coverage of the data included can be obtained at:
http://hercules.kgs.ku.edu/hexacoral/ anemone2/ index.cfm

ZIN Brittlestars
Metadata page:
http://gcmd.gsfc.nasa.gov/KeywordSearch/Metadata.do?Portal=scarmarbin&KeywordPath=Locations%7COCEAN%7CSOUTHERN+OCEAN&OrigMetadataNode=GCMD&EntryId=scarmarbin_MANFA&MetadataView=Brief&MetadataType=0&lbnode=gcmd3
Dataset creator: I. Smirnov, Zoological Institute of St Petersburg, Russia
Short description: The Laboratory of Marine Resarch (Zoological Institute of the Russian Academy of Sciences) has set up a series of databases on Antartic marine biodiversity. The databases focus on taxonomy, biogeography, phylogeny and ecology of Antarctic marine invertebrates. The collections deposited in the laboratory are the largest in Russia. They contain more than 15 000 species and about 1 700 000 items. The Marine Antarctic Fauna (MANFA) Database is part of CAML which investigates the distribution and abundance of Antarctica's vast biodiversity to develop a benchmark for assessing effects of climate change. MANFA data will be made accessible through SCAR-MarBIN.

CCAMLR Scientific Survey and Commercial Fishery database (not available online)
In order to complete the information available via SCAR-MarBIN, the subgroup on benthos requested a distribution database for benthic fish. The list of taxa making up the data request include: Artedidraconidae, Bathydraconidae, Channichthyidae, Harpagiferidae, Nototheniidae (*Dissostichus, Gobionotothen, Lepidonotothen, Notothenia*, *Nototheniops, Paranotothenia, Trematomus*), Tripterygiidae and Zoarcidae.