ANNEX 9

WORKSHOP ON BIOREGIONALISATION OF THE SOUTHERN OCEAN

(Brussels, Belgium, 13 to 17 August 2007)

Executive Summary

Report of the Workshop

EXECUTIVE SUMMARY

(This summary is not a document adopted by the Workshop participants.
It has been prepared by the Co-conveners, Drs P. Penhale and S. Grant.)

CONTENTS

EXECUTIVE SUMMARY*

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

INTRODUCTION

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

2. The agenda was prepared based on the Workshop terms of reference as agreed by the Scientific Committee (SC-CAMLR-XXIV, paragraph 3.66) (Appendix A). The Workshop itself was organised around two subgroups considering the benthic and pelagic systems respectively.

3. The Workshop report deals with Data, Methods and Results, focusing separately on benthic and pelagic discussions within each section. It was adopted in full and constitutes advice to the Scientific Committee. This paper summarises the major Workshop outcomes and advice.

WORKSHOP BACKGROUND

4. Paragraphs 7 to 14 of the Workshop Report provide a summary of its background. Particular note should be taken of the Scientific Committee's agreement in 2006 (SC-CAMLR-XXV, paragraph 3.33) that the following components of work should be undertaken in developing a system of MPAs for the Convention Area:

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

5. 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; Workshop Report, paragraphs 10 and 11). It essentially focused on component (i) in paragraph 4 above.

6. The importance of ongoing cooperation between CEP and CCAMLR has also been highlighted (Workshop Report, paragraphs 12 and 13) as important in the context of elaborating a 'systematic environmental geographic framework', environmental monitoring and identification of sensitive or vulnerable areas.

7. In planning its work, the Workshop drew on the report of an Experts Workshop on Bioregionalisation of the Southern Ocean conducted in September 2006 in Hobart, Australia,

* This summary is not a document adopted by the Workshop participants. It has been prepared by the Co-conveners, Drs P. Penhale and S. Grant.

by WWF-Australia and ACE CRC (2006 Hobart Workshop) (Grant et al., 2006). The 2006 Hobart Workshop was aimed at developing a 'proof of concept' for a broad-scale bioregionalisation of the Southern Ocean, using remotely-sensed physical environmental data as the primary inputs.

8. 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.

9. 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 (Workshop Report, paragraph 17).

10. It was agreed that the benthic and pelagic systems should be considered separately, since current knowledge of benthic-pelagic coupling is not sufficient to allow a combined benthic-pelagic bioregionalisation to be produced at this stage (Workshop Report, paragraph 18).

11. 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 (Workshop Report, paragraph 19). It is important that actual heterogeneity of ecosystem processes and biodiversity patterns is still represented at relevant scales.

12. Temporal scales were also seen as important. The Workshop agreed that temporal scales are different in the pelagic compared to the benthic environment, with temporal variability needing to be reflected within an appropriately sized spatial region.

EXISTING CLASSIFICATIONS AND APPROACHES TO BIOREGIONALISATION

13. Several presentations described existing classification systems and approaches to bioregionalisation (Workshop Report, paragraphs 21 to 38). The Workshop agreed to endorse the outcomes of the 2006 Hobart Workshop, and to adopt its primary classification (Workshop Report, paragraph 26).

DATA

Pelagic data

14. Several presentations provided information on the types of data that might be used in a pelagic bioregionalisation analysis (Workshop Report, paragraphs 39 to 61).

15. The Workshop considered available bathymetric, physical oceanographic and biological data 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 (Workshop Report, paragraph 39).

16. Key discussions (Workshop Report, paragraphs 39 to 64) were on the use of available data for a pelagic bioregionalisation, including the generation of derived datasets, the reflection of key determinants of ecosystem structure and function or specific processes related to biota of interest, and the utility of generating process layers (Workshop Report, paragraphs 157 to 164) for comparison with bioregionalisation outcomes.

17. It was noted that, for most physical datasets, some future work to consider mean state, seasonal variation and interannual variation would be desirable (Workshop Report, paragraph 44).

18. Biological datasets indicating spatial attributes of different areas were considered (Workshop Report, paragraphs 50 to 64). It was determined that some of these datasets might be most appropriately used at the regional scale.

19. 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 (Workshop Report, paragraph 59).

20. The Workshop noted that CPR survey data are likely to be valuable for Southern Ocean bioregionalisation, since methods are standardised across a wide geographical area (Workshop Report, paragraph 62). Other biological data considerations are outlined in the Workshop Report, paragraph 63.

21. The SCAR-MarBIN network allows users to search, display and extract taxonomy and distribution information for many Southern Ocean species. The Workshop welcomed the continuing development of SCAR-MarBIN and recognised that it is of great present and potential value to bioregionalisation (Workshop Report, paragraph 38).

Benthic data

22. WS-BSO-07/10 described recent analyses of biogeographic patterns of benthic invertebrate megafauna on shelf areas of the Southern Ocean Atlantic sector. 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. Future work of this nature was encouraged, and it was suggested that it may be possible to use water mass features to gain insight into benthic biogeography for other regions where little data is available (Workshop Report, paragraphs 65 to 68).

23. The Workshop considered which datasets would be most useful for a benthic bioregionalisation, the robustness and quality of these datasets, and use of other datasets that could potentially be useful. The Workshop agreed that bathymetric data, sea-floor temperature and current data, geomorphology data, sediment data and sea-ice concentration data are important (Workshop Report, paragraphs 69 to 71).

24. 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 (Workshop Report, paragraphs 72 to 73).

25. Given such limitations, the Workshop agreed that biological data to be considered for inclusion for analysis could include data on molluscs, data from SCAR-MarBIN, fine-scale data on invertebrate abundance and composition along the Antarctic Peninsula and presence/absence data for demersal finfish (Workshop Report, paragraph 74).

26. 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 (Workshop Report, paragraph 78). It is anticipated that an Antarctic-wide geomorphic map will be available soon.

27. A number of biological datasets used for validation of the benthic bioregional classification are described in the Workshop Report, paragraph 79. The majority of biological data used for validation were extracted from SCAR-MarBIN.

METHODS

Pelagic methods

28. The 2006 Hobart Workshop adopted a mixed non-hierarchical and hierarchical pelagic classification method. The methods, datasets and statistical routines are explained and provided in Grant et al. (2006).

29. The Workshop recognised that there are large amounts of biological data from the Southern Ocean, which are currently available, or are likely to become available in the near future. These data are potentially very useful for bioregionalisation, although each dataset needs to be considered in detail.

30. The Workshop recommended a hierarchical, two-level approach to bioregionalisation of the pelagic domain (Workshop Report, paragraph 89):

(i) broad-scale circumpolar bioregionalisation which provides delineation of approximately 20 regions;

(ii) fine-scale bioregionalisation of each broad-scale region separately.

31. Various other Workshop discussions on the data and analyses involved in a pelagic realm bioregionalisation can be found in the Workshop Report, paragraphs 90 to 93. Key conclusions are that:

(i) circumpolar, spatially-extensive data layers are required to determine broad-scale bioregionalisation;

(ii) biological data are likely to be particularly valuable at the fine scale (Workshop Report, paragraph 91);

(iii) spatial and temporal heterogeneity occurs at a broad range of scales, and fine-scale bioregions should be aimed at scales appropriate to management (Workshop Report, paragraph 92);

(iv) static maps can be used to identify meaningful bioregions in the Southern Ocean that reflect consistent differences between ecological patterns and processes in different areas (Workshop Report, paragraph 93).

32. The Workshop endorsed the general methodology used to provide a broad-scale regionalisation of the Southern Ocean from the 2006 Hobart Workshop. It also agreed that, at the broad scale, the primary bioregionalisation from the 2006 Hobart Workshop was a good working product that could be used to inform spatial management of the Convention Area (Workshop Report, paragraphs 94 and 95).

33. 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. mixed layer depth (MLD), primary production: see Workshop Report, paragraph 49);

(iv) use of biological data to transform and combine environmental data layers;

(v) consideration of spatial variability in data layer quality.

34. Five methods of how biological data could be used to enhance bioregionalisation of the Southern Ocean were discussed (Workshop Report, paragraphs 97 to 121). These included the BRT method for modelling single response variables using several predictors.

35. The Workshop applied biological data and the BRT method to investigate whether the bioregionalisation result from the 2006 Hobart Workshop could be enhanced by the use of spatially extensive biological data layers (Workshop Report, paragraphs 102 to 104). It noted that the use of layers representing the spatial distributions of certain zooplankton species in the Southern Ocean could help to delineate broad-scale bioregions (Workshop Report, paragraph 103).

36. The Workshop was concerned that extrapolation outside the range of the data, both in geographic and environmental space, was potentially unreliable (Workshop Report, paragraph 106). 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. This assumption was investigated in relation to CPR zooplankton-derived groupings, and the data were extrapolated through the Southern Ocean by the BRT method (Workshop Report, paragraphs 106 to 108 and Figures 1 and 2).

37. 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 methods and results are described in the Workshop Report, paragraphs 109 to 111 and 132 to 144.

38. The Workshop noted that Species Habitat Modelling may also be a valuable tool for capturing heterogeneity, particularly at finer scales (Workshop Report, paragraphs 114 to 121).

39. The Workshop noted that fine-scale bioregionalisation of the clusters produced from the broad-scale bioregionalisation should use appropriate information on environment, biology and process. Considerable amounts and a variety of data were identified for potential use in the fine-scale bioregionalisation. (See Workshop Report, paragraphs 39 to 64 and paragraphs 157 to 164 for details of data that could be used.) Since the data used in fine-scale bioregionalisation do 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.

Benthic methods

40. The approach to a benthic bioregionalisation consisted of a three-step process, by which physical regions (Workshop Report, paragraph 77) were first defined using the process employed by the 2006 Hobart Workshop (Workshop Report, paragraph 14). The biological data were then overlaid, and the classification evaluated (Workshop Report, paragraph 79).

41. Further work on this classification was undertaken after the Workshop, under the guidance of the Workshop conveners, using the methods described above (SC-CAMLR-XXVI/BG/23).

42. An additional evaluation was undertaken for the western Antarctic Peninsula by overlaying biological data in this region with the geomorphological provinces map. A range of analyses were undertaken to investigate species richness and numbers of sampling stations per geomorphic polygon. The results are described in the Workshop Report, paragraphs 147 and 148.

RESULTS

Pelagic results

43. The results of the broad-scale primary regionalisation from the 2006 Hobart Workshop were fully reported in Grant et al. (2006). The resulting map is shown in Figure 3 of the Workshop Report, and contains 14 regions summarised in Table 1 of the report . This broad-scale bioregionalisation differentiates between coastal Antarctica (including embayments), the sea-ice zone and 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.

44. The 2006 Hobart Workshop had included ice and remotely sensed near-surface chl-*a* concentration in a 'secondary' classification displayed with 40 groups (Grant et al., 2006, Figures 21, 23 and 25). It could not achieve consensus regarding plausibility of the spatial patterns shown in this secondary regionalisation.

45. The Workshop endorsed the broad-scale 'primary' regionalisation produced by the 2006 Hobart Workshop. This uses clustering based on four environmental variables (log10 depth, SST, silicate concentration, nitrate concentration) with an agreed display resolution of 14 groups (Workshop Report, Figure 3). The Workshop felt that this classification was a good first-stage bioregionalisation and a potentially valuable tool at the broad circumpolar scale.

46. The Workshop re-displayed the 'secondary' classification from the 2006 Hobart Workshop to show 20 groups (Workshop Report, Figure 4) to be consistent with the chosen display resolution of the classification obtained using biological data layers (Workshop Report, paragraph 143 and Figures 5 and 6).

47. 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 to the Scientific Committee as working papers. The Workshop also noted there were many approaches to using biological data in a broad-scale bioregionalisation of the Southern Ocean that warrant further investigation.

48. The Workshop agreed that the statistical method (BRT) it had employed for the production of continuous biological species distributions and abundances should be considered for wider use in the future (Workshop Report, paragraph 139).

49. 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, the Workshop suggested that the method be written up and submitted for technical review by WG-SAM (Workshop Report, paragraphs 140 and 141).

50. 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.

51. Two outputs (Workshop Report, Figures 5 and 6) were produced for a trial pelagic bioregionalisation using additional biological layers at the circumpolar scale.

52. The Workshop agreed that the approach using physical and biological layers in bioregionalisation is promising and that, subject to addressing the issues in paragraphs 49 and 50, results from this approach will be useful in the future.

Benthic results

53. 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 (Workshop Report, paragraph 145).

54. The Workshop was satisfied that the methods outlined in the Workshop Report, 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.

55. The results of further work on this benthic classification are presented in SC-CAMLR-XXVI/BG/23.

56. The geomorphic map of the East Antarctic margin (Workshop Report, Figure 10) 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.

57. The identified geomorphic provinces were used to select and classify the biological point data. These data were then analysed by applying the techniques outlined in the Workshop Report, paragraphs 129 to 131 and Figures 11, 12 and 13.

58. These figures demonstrate that there is variation in known species numbers between similar geomorphic provinces. Species distribution is therefore affected by factors additional to geomorphology, such as sampling effort or ice cover. Observed differences in patterns of species distribution and sampling effort show that potential biodiversity hotspots are not necessarily related to sampling effort. These methods could be further applied to validate the benthic physical classification.

Ecological processes

59. The Workshop noted that in providing a framework for understanding spatial structure and function of ecosystems, it is important to consider biodiversity pattern information as well as 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.

60. Biodiversity patterns are the spatial representation of the distribution of species or habitats at a defined scale, 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). Ecological processes can be either flexible in time and space (e.g. oceanic fronts) or fixed (e.g. related to a geomorphic feature).

61. Whilst the Workshop's 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 mapping of spatially defined processes.

62. 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).

63. The Workshop considered available ecological process data as well as other information that could easily be acquired. It 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 shown in Table 2 of the Workshop Report.

64. Whilst ecological process information should be used at the circumpolar scale considered at this Workshop, it was noted that these data will become more important at a finer-scale regional level. The reasons for this are: (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 follows that the best areas to develop further fine-scale bioregionalisation are mostly likely those geographical areas where most information and expert knowledge exists.

65. Some of the spatially defined ecosystem processes considered to be important are shown in Figures 14 to 17 of the Workshop Report.

FUTURE WORK

66. The Workshop agreed that:

(i) the primary pelagic regionalisation described in the Workshop Report, paragraphs 132 and 133 can be regarded as useful for application by CCAMLR and CEP;

(ii) initial regionalisation of the benthic environment should be reviewed and optimised for use by CCAMLR and CEP. The overall Workshop results and data show that there will be a greater heterogeneity in biodiversity and ecosystem structure and function at finer scales;

(iii) refinements of 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 using existing data;

(iv) future work could include efforts to delineate fine-scale provinces, where possible;

(v) workshop participants should submit papers to the Scientific Committee on approaches to fine-scale regionalisation, including on statistical methods and potential data sources;

(vi) WG-SAM should be requested to consider the statistical methods presented in the Workshop Report, paragraphs 140 and 141;

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

Geomorphology

67. 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 CAMLR Convention Area would be valuable. Updated sea-floor sediment maps would also be useful for benthic bioregionalisation.

Fine-scale bioregionalisation data availability

68. The Workshop recognised that biological data existed in some smaller-scale regional areas which might be utilised to further delineate broad-scale bioregionalisation. These would include long-term datasets from the Southern Scotia Sea, Ross Sea, East Antarctic Sea as well as other areas.

69. Specific data sources of potential relevance are described in the Workshop Report, paragraphs 171 to 176. They include finfish data from research surveys, benthic data from scientific bottom trawl surveys and museum collections, krill biomass and distribution data, and fine-scale physical oceanographic data from national research efforts.

70. 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 are thus very difficult to access.

71. The Workshop recognised that CCAMLR’s efforts to define SSMUs may be useful in fine-scale bioregionalisation efforts because this work investigates 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 to those employed to define SSMUs.

72. The Workshop considered gaps in the current sets of data, and identified future efforts that are likely to improve data coverage and quality (Workshop Report, paragraphs 178 and 179).

Development of fact sheets

73. 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 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 during meetings and intersessionally, as well as for the public at large to understand how work in CCAMLR is undertaken.

74. A bioregionalisation atlas could follow the approach illustrated in WS-BSO-07/9, where a hierarchy of sheets are presented showing regional features, and where more detailed features, bioregions and provinces are depicted on finer-scale sections of the Southern Ocean in subsidiary sheets. Fact sheets could include maps of 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.

75. 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.

76. 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 ecological process layers and other data layers considered in this report.

Further work on the development of a system of MPAs

77. 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 the Workshop 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.

REPORT OF THE WORKSHOP

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). 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 the Commission (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 concentration and nitrate concentration. These highlighted the different environmental characteristics of large regions including the continental shelf and slope, frontal features (SAF, Polar Front (PF) and 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 compiled 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 Center 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., 1994; Levitus and Boyer, 1994) and the Southern Ocean Atlas (Orsi and Whitworth, 2004). It was noted that the Southern Ocean Atlas data have 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 MLD 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. Dr Kahru noted that the mean surface chl-*a* for the October to March period of 1996 to 1997 was created with a new algorithm (SPGANT) based on Southern Ocean data (Mitchell, 1999) 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 Orthogonal 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 a 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, CPR sampling, penguin foraging areas, seabird foraging tracking data, and East Antarctic pack-ice seal surveys. 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 the 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 extend 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 have 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 towards regionalisation. However, if this information is not available, the effects of these currents 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 is 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 were 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 (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 areas shallower 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 are 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 seabirds. 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 that it:

(i) accommodates continuous and factor predictors
(ii) automatically fits interactions
(iii) is 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 subset 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 involved a method exactly analogous to the method employed 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 it 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 realised 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 indicate 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 onto 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 were 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 was 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 the 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 concentration, nitrate concentration); 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 'Benthic methods' 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 'Benthic methods' 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 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 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 a steep upper slope and a lower slope. The steep upper slope 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 'Benthic methods' 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 the 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 Ocean, 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 shown 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 most 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 shown 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 CAMLR 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 and 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 bioregionalisation 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 bioregionalisation 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 Sea, 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 contributions 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 Raymond, who made an invaluable contribution to the Workshop by undertaking analyses remotely in Hobart throughout the week, undeterred by the eight-hour time difference.

190. The Workshop on Bioregionalisation of the Southern Ocean was closed.

REFERENCES

Arrigo, K.R., G.L. van Dijken, D.G. Ainley, M.A. Fahnestock and T. Markus. 2002. The impact of the B-15 iceberg on productivity and penguin breeding success in the Ross Sea, Antarctica. *Geophys. Res. Lett.*, 29: 10.1029/2001glo14160.

Atkinson, A., V. Siegel, E. Pakhomov and P. Rothery. 2004. Long-term decline in krill stock and increase in salps within the Southern Ocean. *Nature*, 432: 100–103.

Balmford, A., G. Mace and J.R. Ginsberg. 1998. The challenges to conservation in a changing world: putting processes on the map. In: Mace, G., A. Balmford and J.R. Ginsberg (Eds). *Conservation in a Changing World*. Cambridge University Press, Cambridge: 1–28.

Barry, J.P., J. Grebmeier, J. Smith and R.B. Dunbar. 2003. Bathymetric versus oceanographic control of benthic megafaunal patterns in the Ross Sea, Antarctica. *Ant. Res. Ser.*, 78: 327–354.

BirdLife International. 2004. *Threatened Birds of the World 2004*. CD-ROM. BirdLife International: Cambridge, UK.

Carton, J.A., G. Chepurin, X. Cao and B.S. Giese. 2000a. A simple ocean data assimilation analysis of the global upper ocean 1950–95, Part I: methodology. *J. Phys. Oceanogr.*, 30 (2): 294–309.

Carton, J.A., G. Chepurin and X. Cao. 2000b. A Simple Ocean Data Assimilation analysis of the global upper ocean 1950–1995, Part 2: results. *J. Phys. Oceanogr.*, 30: 311–326.

CEP. 2007. Report of the Committee for Environmental Protection (CEP X). http://cep.ats.aq/cep/MediaItems/atcm30_att084_rev1_e.pdf.

Comiso, J.C. 2004. Sea ice algorithm for AMSR-E. *Rivista Italiana di Telerilevamento*, 30/31: 119–130.

Comiso, J.C., D.J. Cavalieri and T. Markus. 2003. Sea ice concentration, ice temperature, and snow depth using AMSR-E data. *IEEE TGRS*, 41 (2): 243–252.

Cowling, R.M., R.L. Pressey, M. Rouget and A.T. Lombard. 2003. A conservation plan for a global biodiversity hotspot—the Cape Floristic Region, South Africa. *Biol. Cons.*, 112: 191–216.

De'ath, G. 2007. Boosted trees for ecological modeling and prediction. *Ecology*, 88 (1): 243–251.

Dinniman, M.S., J.M. Klinck and W.O. Smith Jr. 2007. Influence of sea ice cover and icebergs on circulation and water mass formation in a numerical circulation model of the Ross Sea, Antarctica. *J. Geophys. Res*., 112 10.1029/2006JC004036.

Ferrier, S., G. Manion, J. Elith and K. Richardson. 2007. Using generalised dissimilarity modelling to analyse and predict patterns of beta diversity in regional biodiversity assessment. *Diversity and Distributions*, 13: 252–264.

Friedman, J.H. 2001. Greedy function approximation: a gradient boosting machine. *Annals of Statistics*, 29: 1189–1232.

Grant, S., A. Constable, B. Raymond and S. Doust. 2006. Bioregionalisation of the Southern Ocean: Report of Experts Workshop (Hobart, September 2006). WWF-Australia and ACE CRC, Sydney: 44 pp. (www.wwf.org.au/publications/bioregionalization-southern-ocean/).

Hastie, T. and R. Tibshirani. 1990. *Generalized Additive Models*. Chapman and Hall, London.

Hastie, T., R. Tibshirani and J. Friedman. 2001. *The Elements of Statistical Learning: Data mining, Inference and Prediction*. Springer, New York.

Hofmann, E.E. and Y.S. Husrevoglu. 2003. A circumpolar modeling study of habitat control of Antarctic krill (*Euphausia superba*) reproductive success. *Deep-Sea Res*., II, 50: 3121–3142, doi:10.1016/j.dsr2.2003.07.012.

Hunt, B.P.V. and G.W. Hosie. 2006a. Seasonal zooplankton community succession in the Southern Ocean south of Australia, Part I: the Seasonal Ice Zone. *Deep-Sea Res*., I, 53: 1182–1202.

Hunt, B.P.V. and G.W. Hosie. 2006b. Seasonal zooplankton community succession in the Southern Ocean south of Australia, Part II: the sub-Antarctic to Polar Frontal Zones. *Deep-Sea Res*., I, 53: 1203–1223.

Hutchinson, G.E. 1957. Concluding remarks. *Cold Spring Harb. Symp. Quant. Biol.*, 22: 415–427.

Kahru, M., B.G. Mitchell, S.T. Gille, C.D. Hewes and O. Holm-Hansen. 2007. Eddies enhance biological production in the Weddell-Scotia Confluence of the Southern Ocean. *Geophys. Res. Lett*., 34 (14): L14603, doi:10.1029/2007GL030430.

Kaschner, K. 2004. Modelling and mapping resource overlap between marine mammals and fisheries on a global scale. PhD thesis. The University of British Columbia.

Kitchingman, A. and S. Lai. 2004. Inferences on potential seamount locations from mid-resolution bathymetric data. In: Morato, T. and D. Pauly (Eds). *Seamounts: Biodiversity and Fisheries*: 7–12.

Koubbi, P., G. Duhamel, X. Harlay, P. Eastwood, I. Durand and Y.-H. Park. 2003. Distribution of larval *Krefftichthys anderssoni* (Myctophidae, Pisces) at the Kerguelen archipelago (Southern Indian Ocean) modelled using GIS and habitat suitability. In: Huiskes, A.H.L., W.W.C. Gieskes, J. Rozema, R.M.K. Schorno, S.M. van der Vies and W.J. Wolf (Eds). *Antarctic Biology in a Global Context.* Backhyus Publisher, Leiden, NL: 215–223.

Koubbi, P., C. Loots, G. Cotonnec, X. Harlay, A. Grioche, S. Vaz, C. Martin, M. Walkey and A. Carpentier. 2006. Spatial patterns and GIS habitat modelling of *Solea solea, Pleuronectes flesus* and *Limanda limanda* fish larvae in the eastern English Channel during the spring. In: Olivar, M.P. and J.J. Govoni (Eds). Recent advances in the study of fish eggs and larvae. *Sci. Mar*., 70S2: 147–157.

Kwok, R. and J.C. Comiso. 2002. Spatial patterns of variability in Antarctic surface temperature: Connections to the Southern Hemisphere Annular Mode and the Southern Oscillation. *Geophys. Res. Lett*., 29: 10.1029/2002GL015415.

Leathwick, J.R., J. Elith, M.P. Francis, T. Hastie and P. Taylor. 2006. Variation in demersal fish species richness in the oceans surrounding New Zealand: an analysis using boosted regression trees. *Mar. Ecol. Prog. Ser.*, 321: 267–281.

Levitus, S. and T.P. Boyer. 1994. *World Ocean Atlas 1994*, Vol. 4: Temperature. NOAA Atlas NESDIS 4. US Department of Commerce, Washington DC.

Levitus, S., R. Burgett and T.P. Boyer. 1994. *World Ocean Atlas 1994*, Vol. 3: Salinity. NOAA Atlas NESDIS 3. US Department of Commerce, Washington DC.

Loots, C., P. Koubbi and G. Duhamel. 2007. Habitat modelling of *Electrona antarctica* (Myctophidae, Pisces) in Kerguelen by generalized additive models and geographic information systems. *Polar Biol*., 30 (8): 951–959, DOI 10.1007/s00300-007-0253-7.

Lynnes, A.S., K. Reid, J.P. Croxall and P.N. Trathan. 2002. Conflict or coexistence? Foraging distribution and competition for prey between Adélie and chinstrap penguins. *Mar. Biol*., 141: 1165–1174.

McCullagh, P. and J.A. Nelder. 1989. *Generalised Linear Models, Monographs on Statistics and Applied Probability,* 37, 2nd Edn. Chapman and Hall, London.

Mitchell, B.G., M. Kahru, R.A. Reynolds, J.D. Wieland and D. Stramski. 1999. Satellite estimation of seasonal variations in organic carbon to chlorophyll-*a* ratios in the Southern Ocean and interpretation of carbon flux dynamics. EOS, Transactions, American Geophysical Union, 80 (49): 27.

Moore, J.K., M.R. Abbott and J.G. Richman. 1997. Variability in the location of the Antarctic Polar Front (90°–20°W) from satellite sea surface temperature data. *J. Geophys. Res*., 102: 27825–27833.

Orsi, A.H. and T. Whitworth III. 2004. *Hydrographic Atlas of the World Ocean Circulation Experiment (WOCE),* Vol. 1: Southern Ocean. Sparrow, M., P. Chapman and J. Gould (Eds). International WOCE Project Office, Southampton, UK.

Orsi, A.H., T. Whitworth and W.D. Nowlin. 1995. On the meridional extent and fronts of the Antarctic circumpolar current. *Deep-Sea Res*., I, 42 (5): 641–673.

Peloquin, J.A. and W.O. Smith Jr. 2007. Phytoplankton blooms in the Ross Sea, Antarctica: interannual variability in magnitude, temporal patterns, and composition. *J. Geophys. Res.*, 112: 10.1029/2006JC003816.

R Development Core Team. 2007. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Ridgeway, G. 2006. *Generalised Boosted Models: a Guide to the GBM Package*. GBM Library for R.

Smith, W.O. Jr. and J.C. Comiso. (Submitted). The influence of sea ice on primary production in the Southern Ocean: a satellite perspective. *J. Geophys. Res*.

Smith, W.O. Jr., M.S. Dinniman, J.M. Klinck and E. Hofmann. 2003. Biogeochemical climatologies in the Ross Sea, Antarctica: seasonal patterns of nutrients and biomass. *Deep-Sea Res*., II, 50: 3083–3101.

Smith, W.O. Jr., D.G. Ainley and R. Cattaneo-Vietti. 2007. Trophic interactions within the Ross Sea continental shelf ecosystem. *Phil. Trans. Roy. Soc., B*, 362: 95–111.

Southwell, C., C.G.M. Paxton, D. Borchers, P. Boveng and W. de la Mare. 2007. Taking account of dependent species in management of the Southern Ocean krill fishery: estimating crabeater seal abundance off East Antarctica. *J. Appl. Ecol*.: 10.1111/j.1365-2664.2007.01399.x.

Takahashi, K., S. Kawaguchi, M. Kobayashi, G.W. Hosie, M. Fukuchi and T. Toda. 2002. Zooplankton distribution patterns in relation to the Antarctic Polar Front Zones recorded by Continuous Plankton Recorder (CPR) during 1999/2000 *Kaiyo Maru* cruise. *Polar Bioscience*, 15: 97–107.

Umeda, H., G.W. Hosie, T. Odate, C. Hamada and M. Fukuchi. 2002. Surface zooplankton communities in the Indian Ocean Sector of the Antarctic Ocean in early summer 1999/2000 observed with a Continuous Plankton Recorder. *Ant. Rec*., 46 (2): 287–299.

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	–4 119.952	821.342	8.681	1.854	7.998	2.402	20.919	1.616
Sub-Antarctic Front	40 180	–3 917.738	921.884	5.840	0.791	15.231	2.582	25.158	1.052
Polar Front	83 006	–4 134.095	732.582	3.539	0.999	28.382	6.492	29.236	1.815
Southern ACC Front	108 053	–4 109.261	818.366	0.945	0.872	56.089	9.814	32.370	1.503
Antarctic Open Ocean	136 360	–3 612.533	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	–1 455.466	389.636	–1.227	0.434	79.961	2.946	33.599	1.343
Campbell Plateau, Patagonian Shelf, Africana Rise	7 451	–1 034.451	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	–1 270.202	734.782	3.360	0.818	25.846	4.024	29.279	1.318
Subtropical Front	94 234	–4 461.472	788.887	11.804	1.511	4.607	1.235	15.257	2.062
Northern Temperate	9 946	–4 163.621	951.003	15.496	0.774	4.336	0.727	10.154	1.667
Weddell Gyre and Ross Sea banks	52 905	–4 466.641	762.290	–0.680	0.333	98.163	5.615	31.965	0.553
Chatham Rise	3 025	–1 568.439	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)	

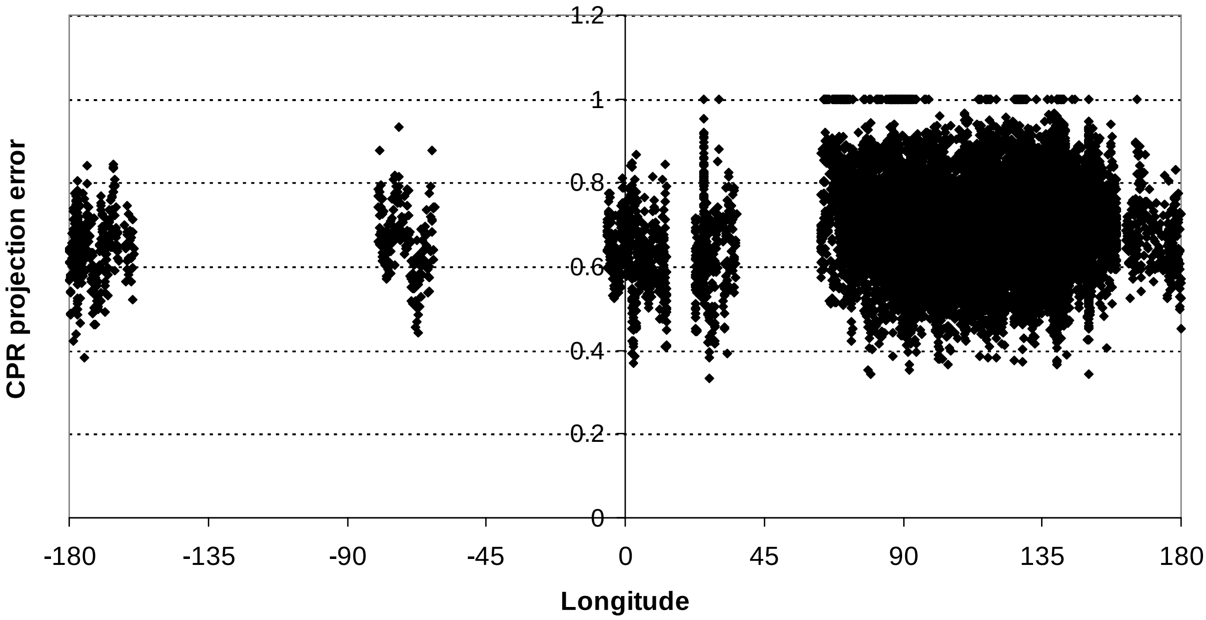

Figure 1: Error in the predicted CPR zooplankton distributions predicted using BRT with longitude. Most of the training data are in East Antarctica (longitude 60–158°E), but there are also CPR data in the Scotia Arc, between New Zealand and the Ross Sea, and in the southern Indian Ocean. This comparison shows that there is no significant difference in model predictive power with region.

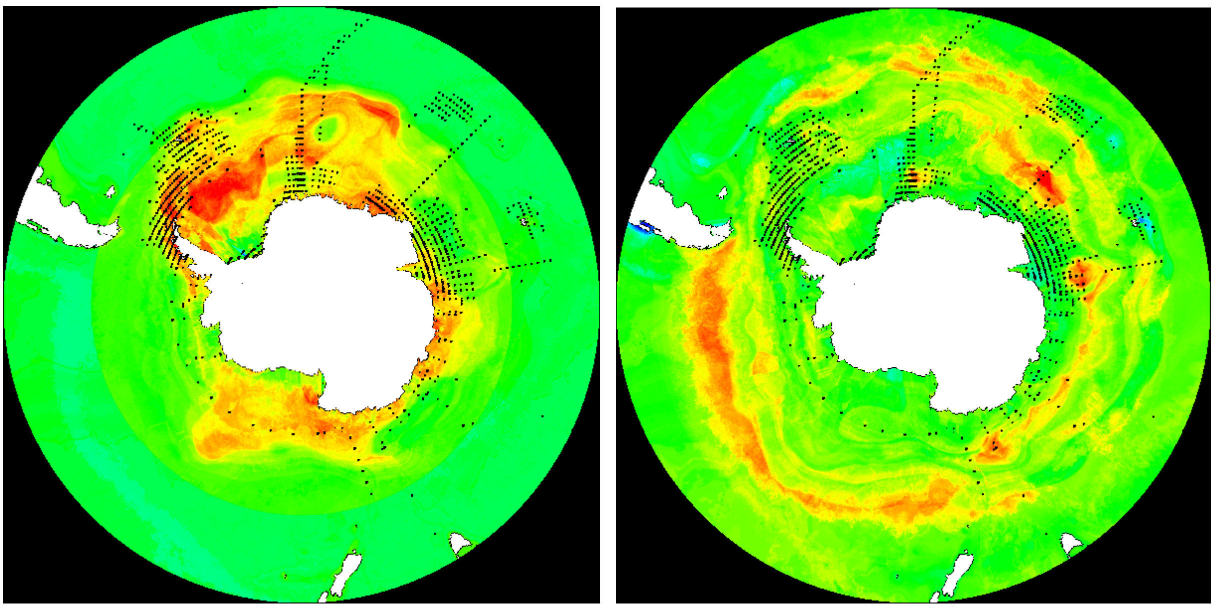

Figure 2*: Predicted krill (left) and salp (right) abundances using a BRT regression based on net-haul measurements. Red indicates higher abundance; blue indicates lower abundance. Black symbols show the location of net haul measurements.

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

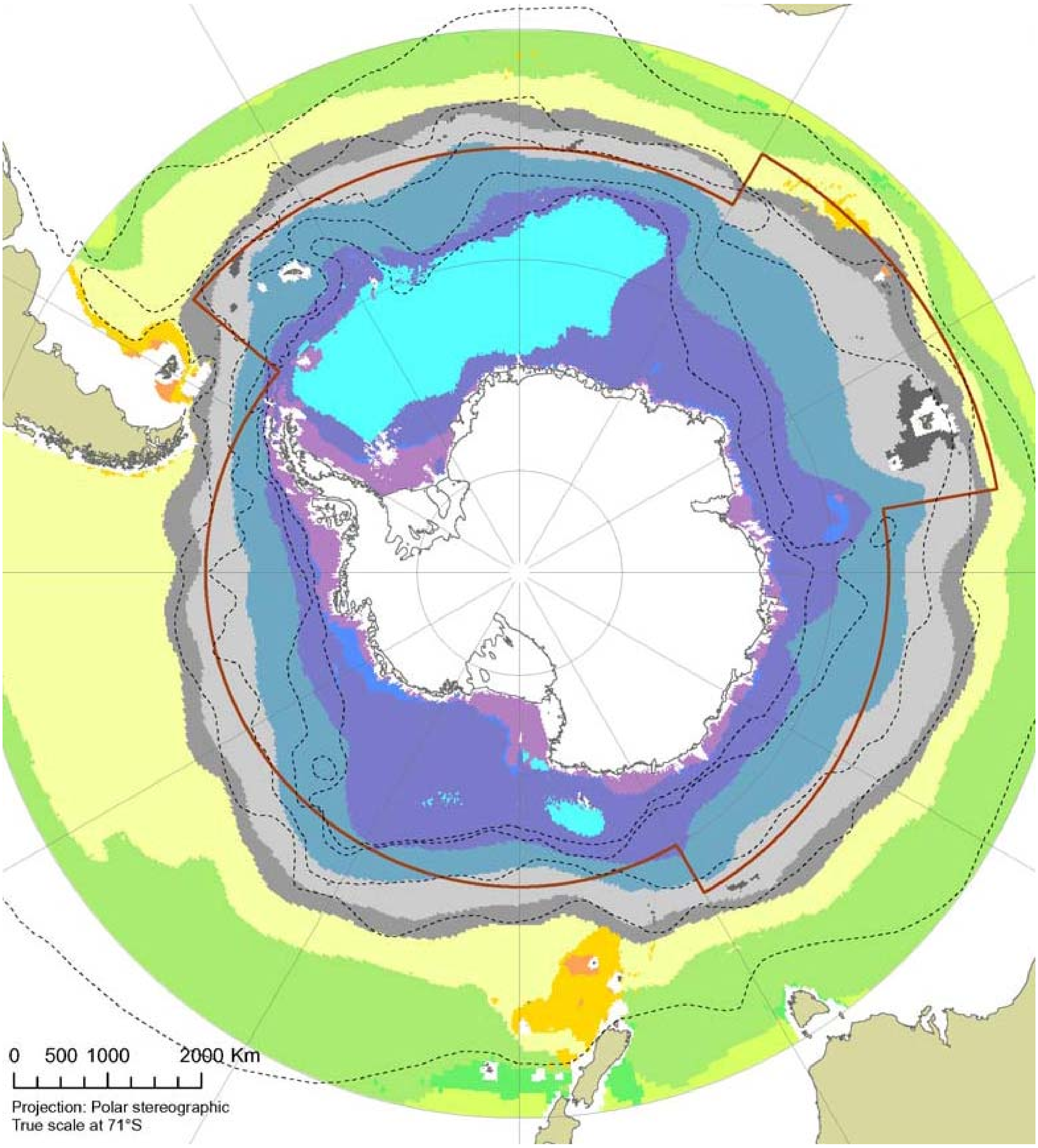

Figure 3*: The primary regionalisation from the 2006 Hobart Workshop. The regionalisation uses four physical environment layers (depth, SST, silicate concentration, nitrate concentration).

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

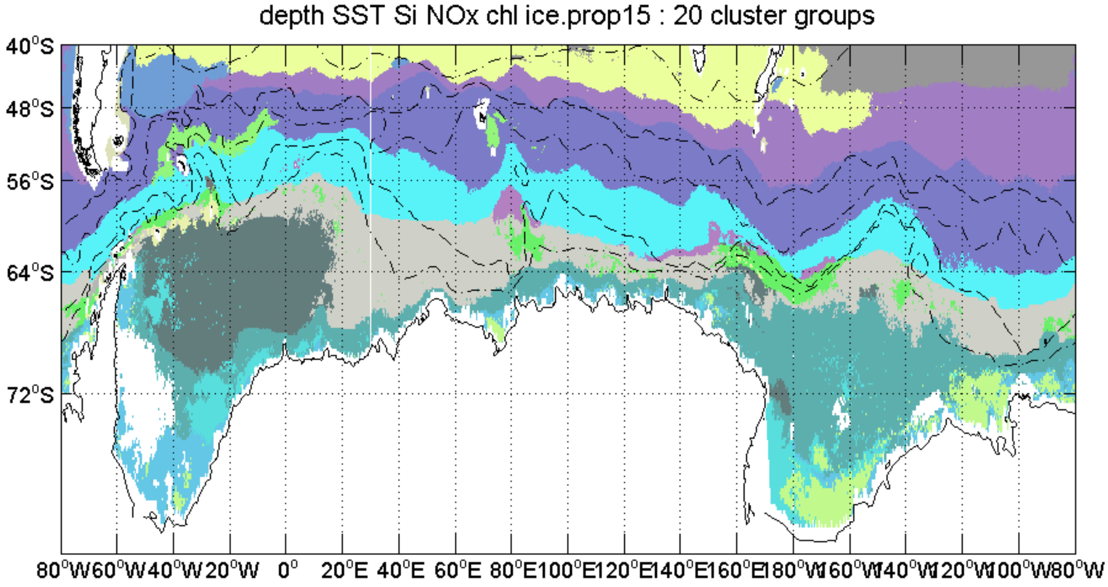

Figure 4*: The secondary regionalisation from the 2006 Hobart Workshop achieved by adding layers representing chl-*a* and ice to the agreed primary regionalisation. That workshop agreed that these two variables were related to heterogeneity at fine scales not captured by the primary classification, and 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.

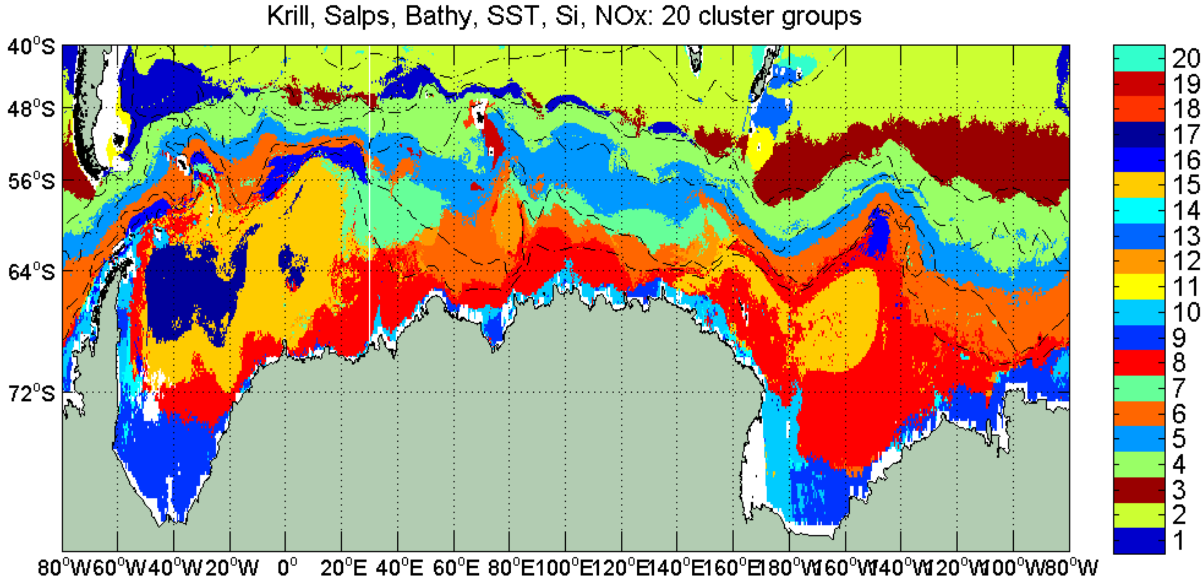

Figure 5*: Bioregionalisation using four primary physical environment layers (depth, SST, nitrate concentration, silicate concentration) plus modelled circumpolar distributions for krill and salps, displayed at the 20-group level.

---

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

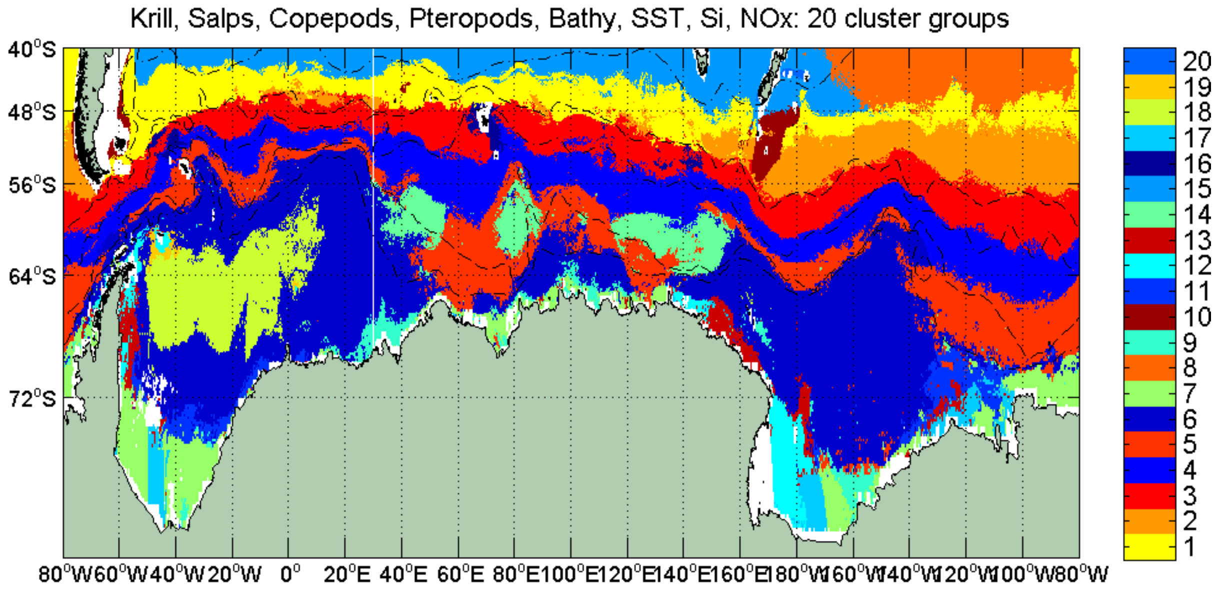

Figure 6*: Bioregionalisation using four primary physical environment layers (depth, SST, nitrate concentration, silicate concentration) plus modelled circumpolar distributions for krill, salps, copepods, and pteropods, displayed at the 20-group level.

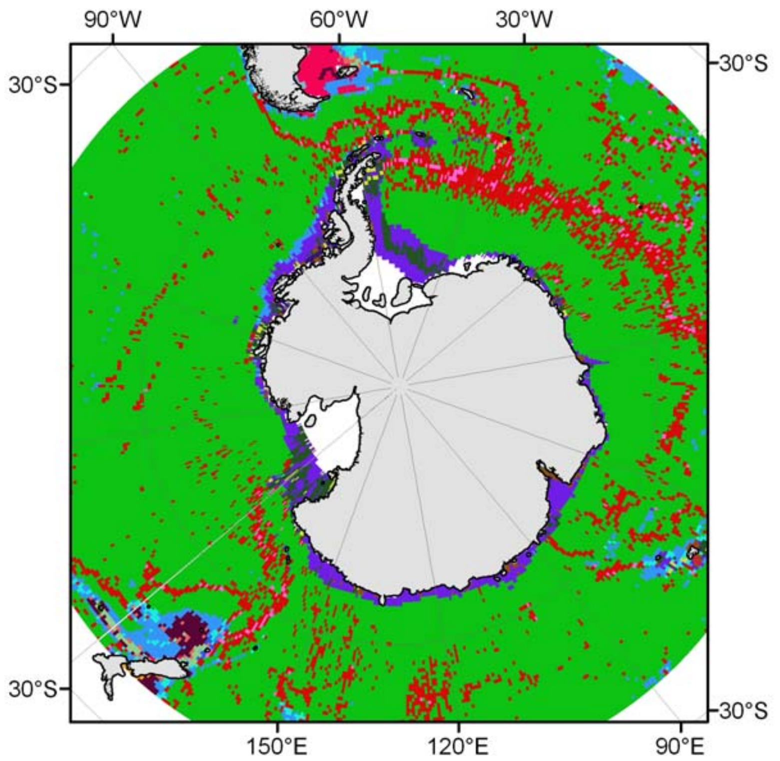

Figure 7*: Initial benthic physical classification using three data layers: bathymetry, slope and sea-floor temperature at the level of 20 bioregional classes.

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

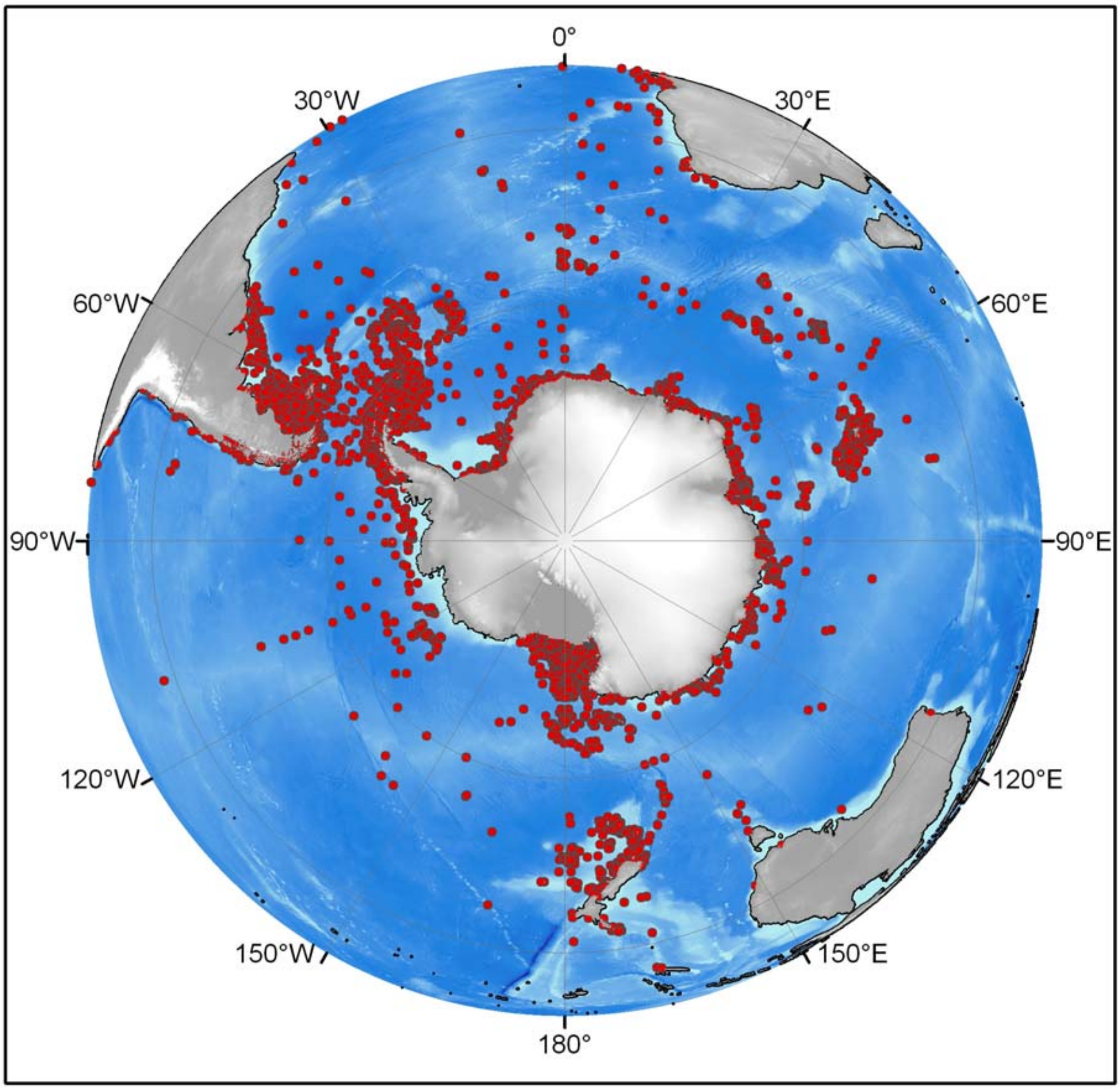

Figure 8*: Map of Southern Ocean showing the distribution of benthic samples for selected taxa.

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

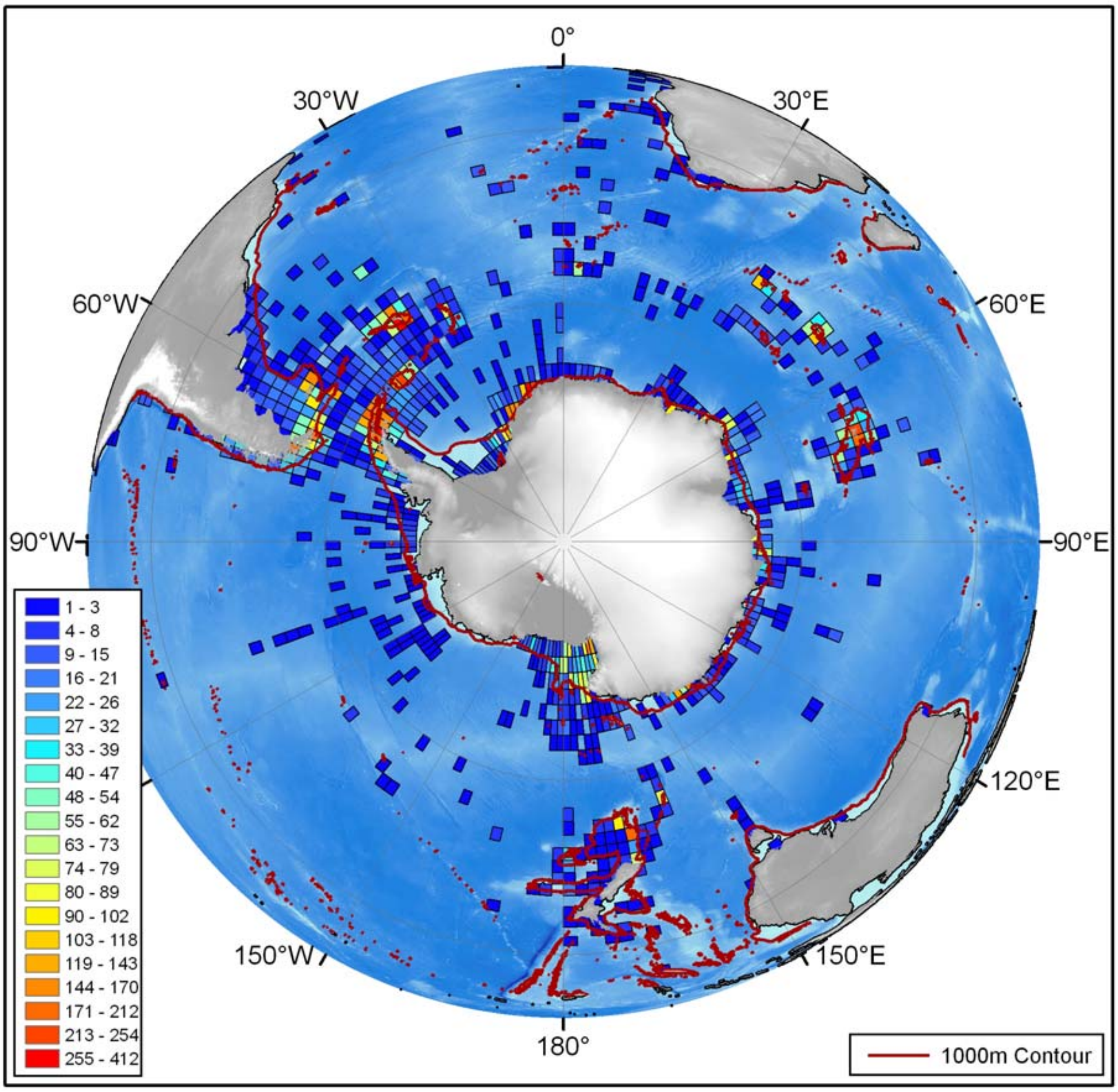

Figure 9*: A 2° x 2° grid showing the total number of species per grid cell.

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

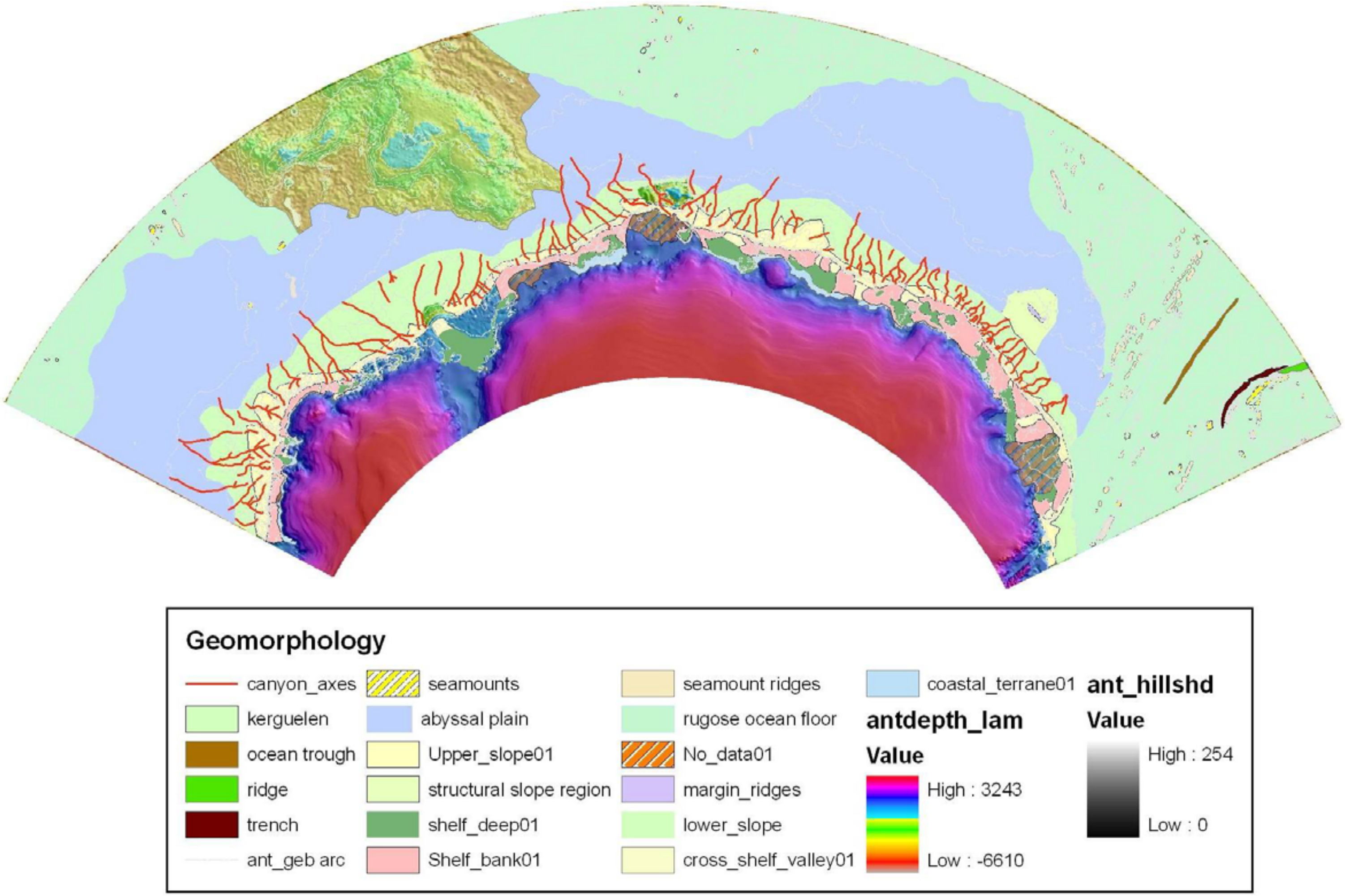

Figure 10*: Geomorphic map of the East Antarctic margin.

---

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

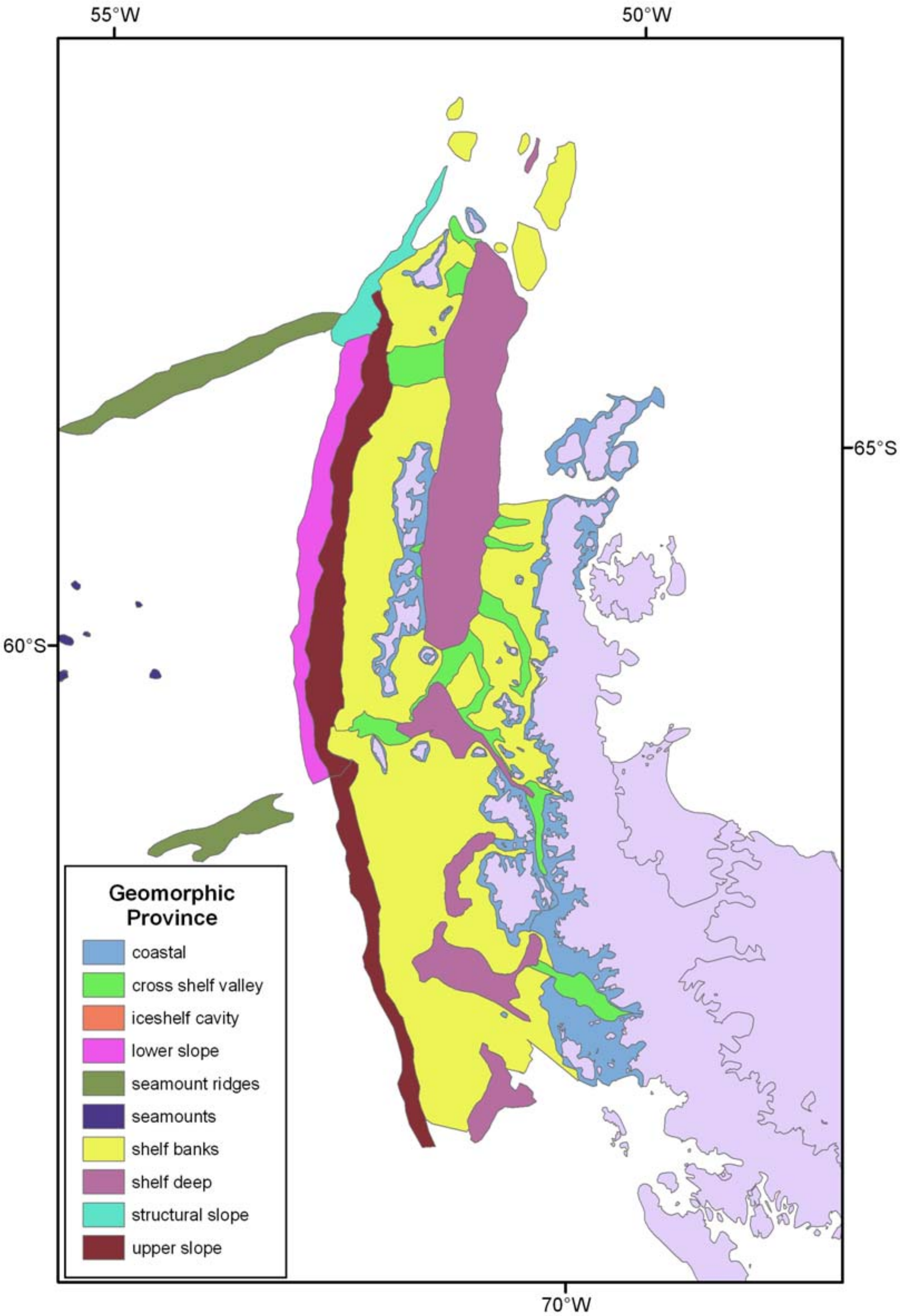

Figure 11*: Geomorphic provinces of the northern Antarctic Peninsula.

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

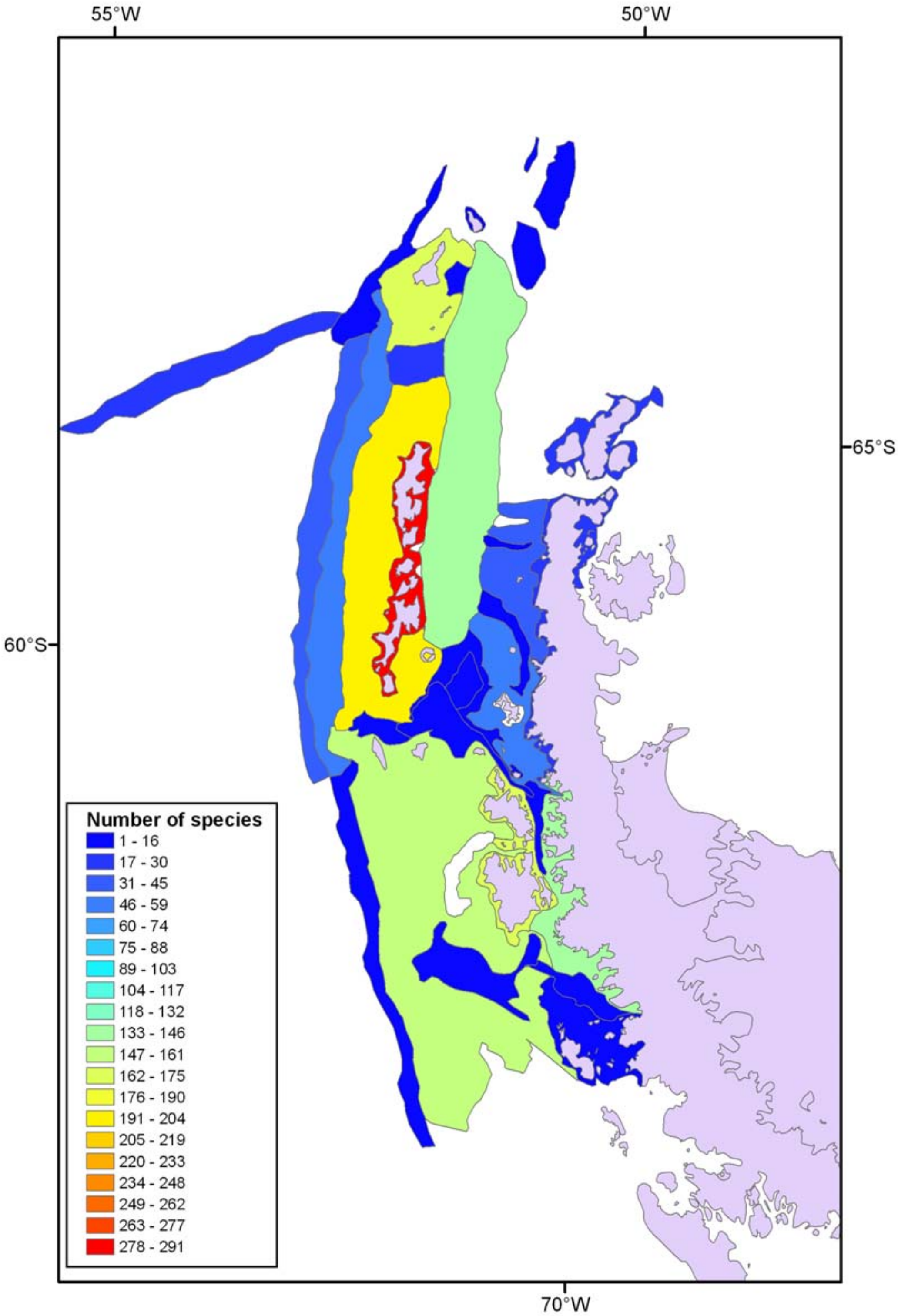

Figure 12*: Number of known species sampled in different geomorphic provinces.

---

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

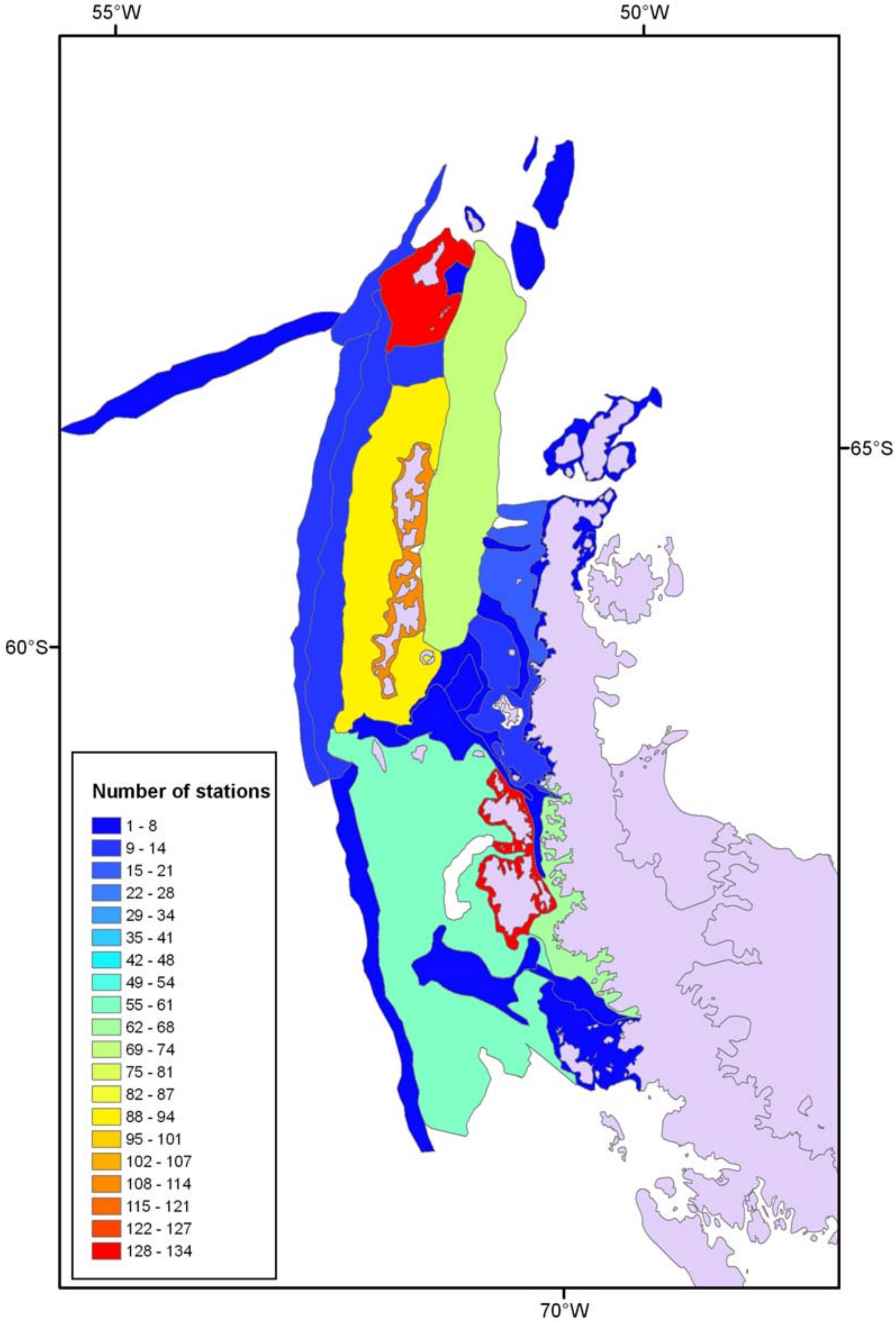

Figure 13*: Concentration of sampling locations in different geomorphic provinces.

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

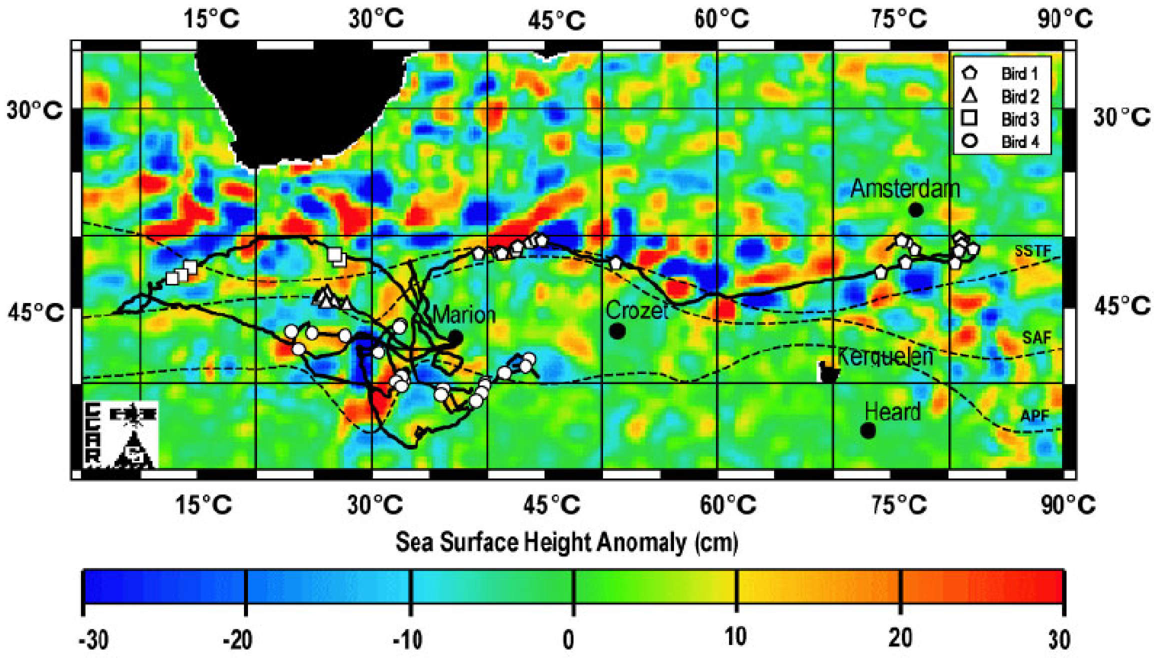

Figure 14*: Position of mesoscale eddies in the southern Indian Ocean as depicted by sea-surface height anomaly data. This figure also depicts the foraging tracks of grey-headed albatrosses which exploit these features. Symbols indicate birds moving at <10 km/h during daytime, probably foraging.

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

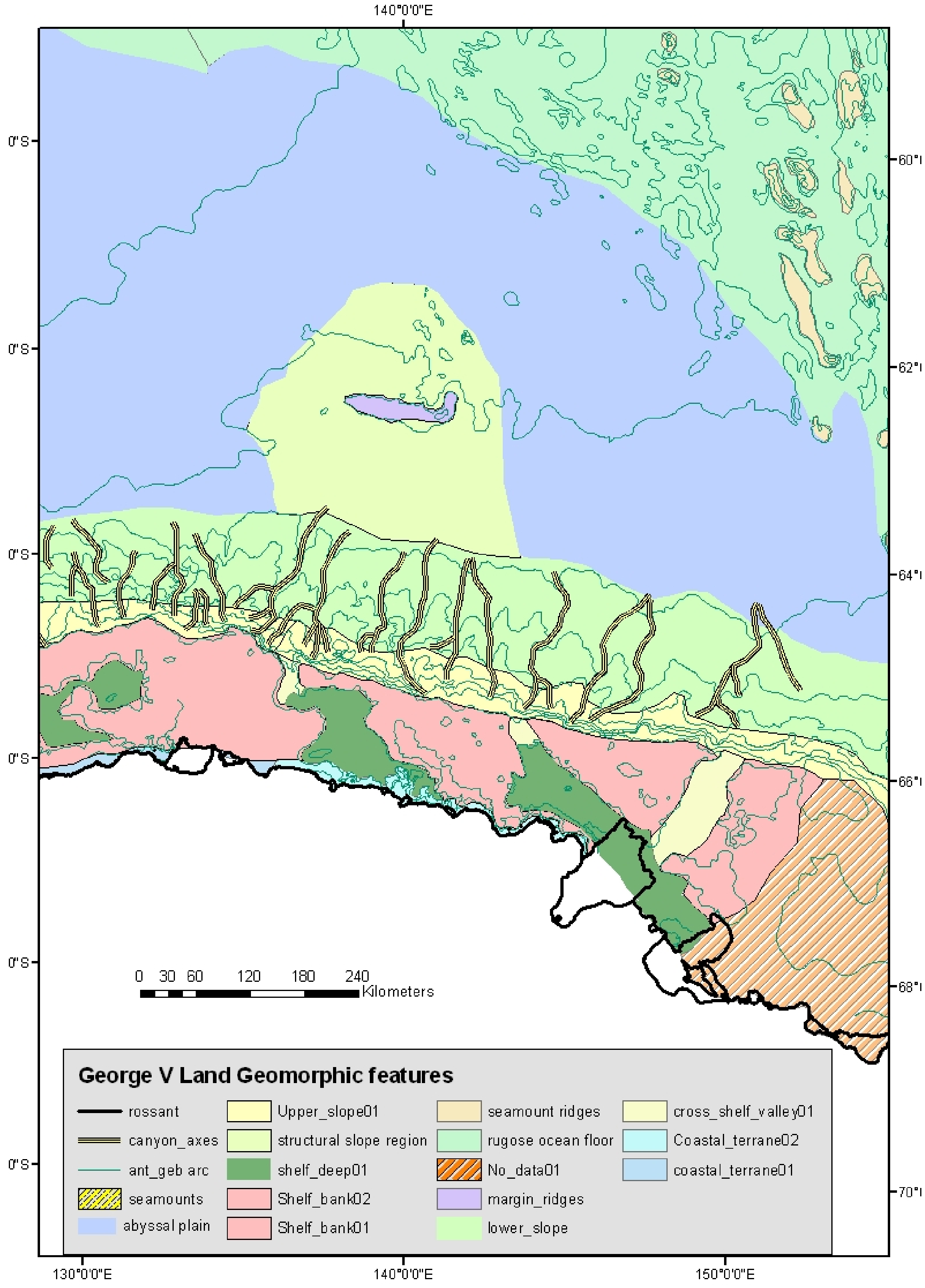

Figure 15*: Position of submarine canyons in the eastern Antarctic region.

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

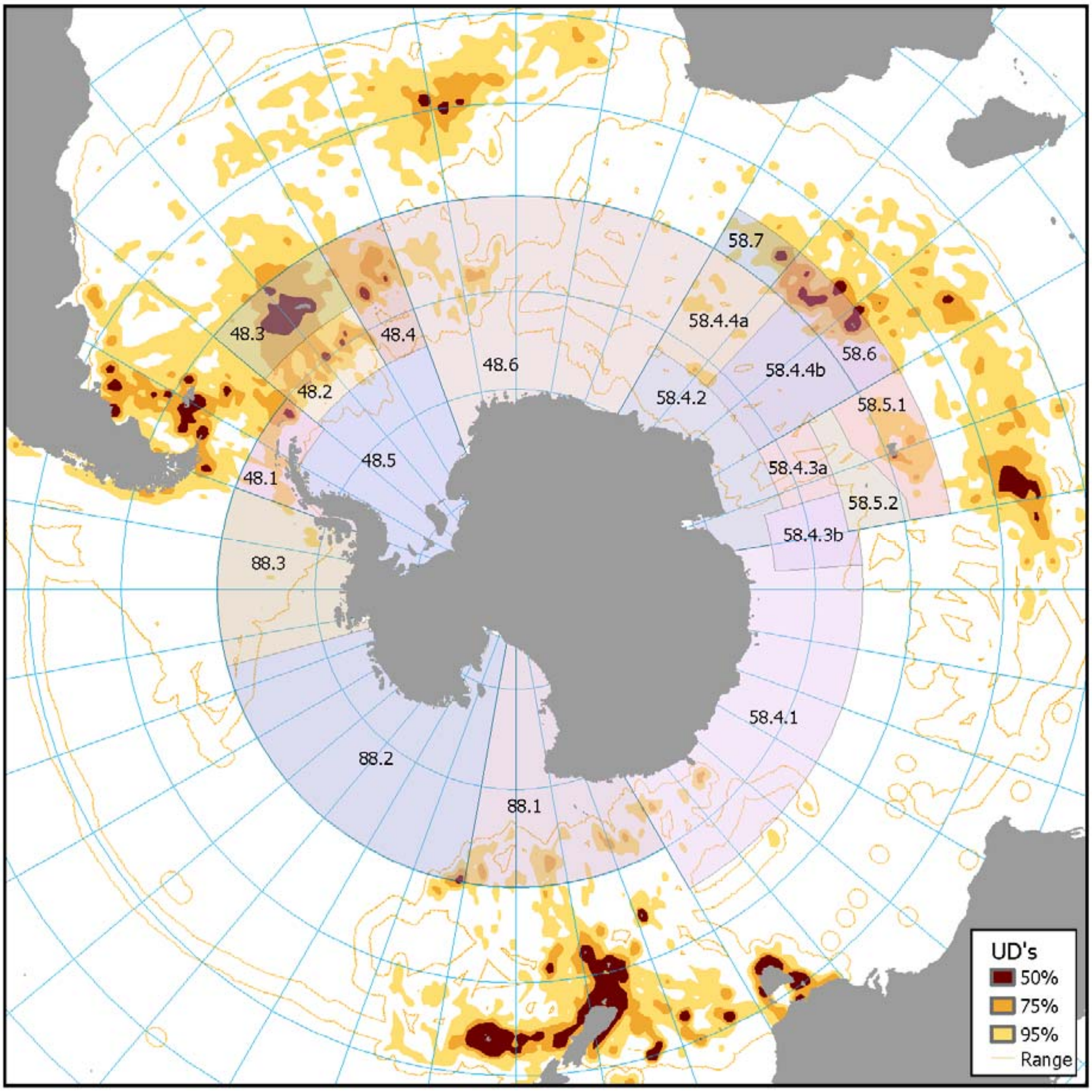

Figure 16*: Combined utilisation distribution map for the breeding distribution of 18 albatross, giant petrel and petrel species represented in the BirdLife International Global Procellariiform Tracking Database. Each species has been given equal weighting.

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

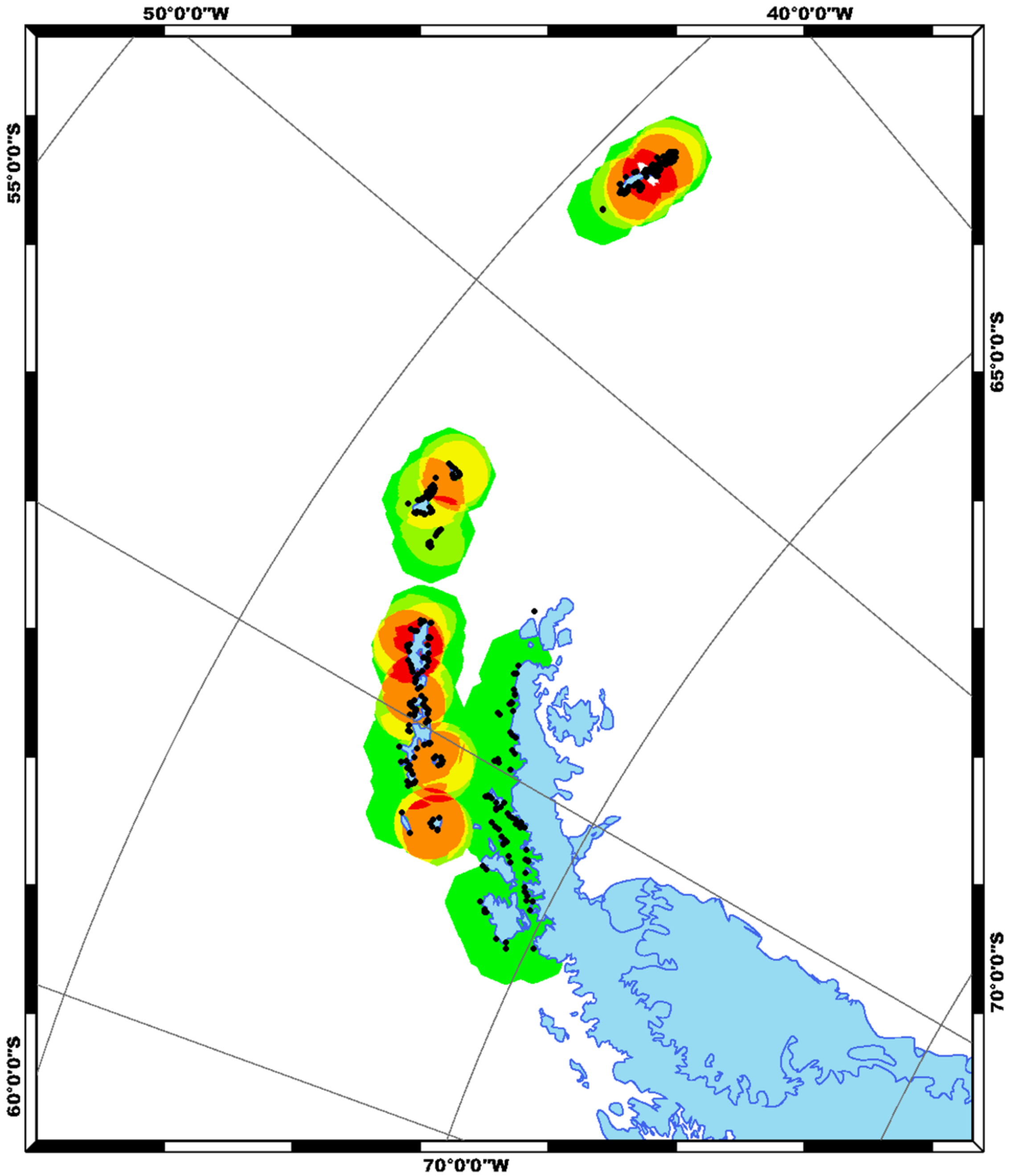

Figure 17*: Relative foraging effort of chinstrap penguin colonies in the west Antarctic Peninsula; foraging effort is scaled to colony size; foraging range is taken from Lynnes et al. (2002).

* This figure is available in colour on the 'Publications' page of the CCAMLR website www.ccamlr.org/pu/e/e_pubs/sr/07/toc.htm.

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)

ALDER, Viviana (Dr)	Instituto Antártico Argentino Departmento Ciencias Biológicas Cerrito 1248 C1010AAZ Buenos Aires Argentina viviana@ege.fcen.uba.ar viviana_alder@yahoo.com
BAIVIER, Bertrand (Mr) (Host, local organiser)	Public Health, Food Chain Security and Environment International Affairs (DG5) Place Victor Horta 40, Box 10 1060 Brussels Belgium bertrand.baivier@health.fgov.be
CLARKE, Andrew (Prof.)	British Antarctic Survey High Cross Madingley Road Cambridge CB3 0ET United Kingdom accl@bas.ac.uk
CONSTABLE, Andrew (Dr) (Co-convener, WG-SAM)	Antarctic Climate and Ecosystems Cooperative Research Centre Australian Antarctic Division Department of the Environment and Water Resources 203 Channel Highway Kingston Tasmania 7050 Australia andrew.constable@aad.gov.au
DANIS, Bruno (Dr) (Invited expert)	Royal Belgian Institute of Natural Sciences rue Vautier 29 1000 Brussels Belgium bruno.danis@naturalsciences.be bruno.danis@scarmarbin.be

DE BROYER, Claude (Dr) — Royal Belgian Institute of Natural Sciences
rue Vautier 29
1000 Brussels
Belgium
claude.debroyer@naturalsciences.be

DE LICHTERVELDE, Alexandre (Mr) (Host, local organiser) — Public Health, Food Chain Security and Environment
International Affairs (DG5)
Place Victor Horta 40, Box 10
1060 Brussels
Belgium
alexandre.delichtervelde@health.fgov.be

FERNHOLM, Bo (Prof.) — Swedish Museum of Natural History
Box 50007
SE-104 05
Stockholm
Sweden
bo.fernholm@nrm.se

GOFFART, Anne (Dr) — Laboratoire d'Océanologie – MARE Center
University of Liège
Allée de la Chimie, 3 Bâtiment B6c
4000 Liège Sart-Tilman
Belgium
a.goffart@ulg.ac.be

GRANT, Susie (Dr) (Co-convener) — British Antarctic Survey
High Cross
Madingley Road
Cambridge CB3 0ET
United Kingdom
suan@bas.ac.uk

GRIFFITHS, Huw (Mr) — British Antarctic Survey
High Cross
Madingley Road
Cambridge CB3 0ET
United Kingdom
hjg@bas.ac.uk

HOLT, Rennie (Dr) — US AMLR Program
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, CA 92037
USA
rennie.holt@noaa.gov

HOSIE, Graham (Dr) (Invited expert)	Australian Antarctic Division Department of the Environment and Water Resources 203 Channel Highway Kingston Tasmania 7050 Australia graham.hosie@aad.gov.au
JONES, Christopher (Dr) (Co-convener, WG-SAM)	US AMLR Program Southwest Fisheries Science Center 8604 La Jolla Shores Drive La Jolla, CA 92037 USA chris.d.jones@noaa.gov
KAHRU, Mati (Dr) (Invited Expert)	Scripps Institute of Oceanography 8604 La Jolla Shores Drive La Jolla, CA 92037-1508 USA mkahru@ucsd.edu
KELLY, Emily (Ms)	National Science Foundation Office of Polar Programs 4201 Wilson Blvd Arlington, VA 22230 USA emkelly@nsf.gov
KOUBBI, Philippe (Dr)	Laboratoire d’Océanographie de Villefranche – UMR 7093 Observatoire Océanologique Université Pierre et Marie Curie – Paris VI BP 28 06234Villefranche-sur-mer France koubbi@obs-vlfr.fr
LOMBARD, Mandy (Dr)	C/- WWF South Africa Millennia Park Private Bag X2 Die Boord 7613 South Africa gemsbok@mweb.co.za

MARSCHOFF, Enrique (Dr)	Instituto Antártico Argentino Cerrito 1248 C1010AAZ Buenos Aires Argentina marschoff@dna.gov.ar
MARTIN-SMITH, Keith (Dr)	Australian Antarctic Division Department of the Environment and Water Resources 203 Channel Highway Kingston Tasmania 7050 Australia keith.martin-smith@aad.gov.au
MEMOLLI, Mariano (Dr)	Dirección Nacional del Antártico Cerrito 1248 C1010AAZ Buenos Aires Argentina drmemolli@gmail.com
NEL, Deon (Dr)	WWF South Africa Millennia Park Private Bag X2 Die Boord 7613 South Africa dnel@wwf.org.za
O'BRIEN, Phil (Dr)	Geoscience Australia GPO Box 378 Canberra ACT 2601 Australia phil.obrien@ga.gov.au
PENHALE, Polly (Dr) (Co-convener)	National Science Foundation Office of Polar Programs 4201 Wilson Blvd Arlington, VA 22230 USA ppenhale@nsf.gov
PINKERTON, Matt (Dr)	National Institute of Water and Atmospheric Research Private Bag 14-901 Kilbirnie Wellington New Zealand m.pinkerton@niwa.co.nz

RAYMOND, Ben (Dr)
(participated remotely from AAD, Australia)
Antarctic Climate and Ecosystems Cooperative Research Centre
Australian Antarctic Division
Department of the Environment and Water Resources
203 Channel Highway
Kingston Tasmania 7050
Australia
ben.raymond@aad.gov.au

SAKAMOTO, Takaaki (Mr)
Fisheries Agency of Japan
1-2-1, Kasumigaseki, Chiyda-ku
Tokyo 100-8907
Japan
takaaki_sakamoto@nm.maff.go.jp

SHARP, Ben (Dr)
Ministry of Fisheries
PO Box 1020
Level 4, GBL House
256 Lambton Quay
Wellington
New Zealand
ben.sharp@vanuatu.com.vu

SHUST, Konstantin (Dr)
VNIRO
17a V. Krasnoselskaya
Moscow 107140
Russia
antarctica@vniro.ru

SIEGEL, Volker (Dr)
Institut für Seefischerei
Bundesforschungsanstalt für Fischerei
Palmaille 9
22767 Hamburg
Germany
volker.siegel@ish.bfa-fisch.de

SLOCUM, Gillian (Ms)
Australian Antarctic Division
Department of the Environment and Water Resources
203 Channel Highway
Kingston Tasmania 7050
Australia
gill.slocum@aad.gov.au

SMITH, Walker (Dr)	Virginia Institute of Marine Science College of William and Mary PO Box 1346 Gloucester Point, VA 23062-1346 USA wos@vims.edu
TRATHAN, Phil (Dr)	British Antarctic Survey High Cross Madingley Road Cambridge CB3 0ET United Kingdom pnt@bas.ac.uk
VAN DE PUTTE, Anton (Mr)	Laboratory of Animal Diversity and Systematics Katholieke Universiteit Leuven (KUL) Charles Deberiotstraat 32 3000 Leuven Belgium anton.vandeputte@bio.kuleuven.be
VIERROS, Marjo (Dr) (Invited Expert)	United Nations University Institute of Advanced Studies 6F International Organizations Center Pacifico-Yokohama 1-1-1 Minato Mirai, Nishi-ku Yokohama 220-8502 Japan vierros@ias.unu.edu

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) (*CCAMLR Science*, submitted)
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) *Progr. Oceanogr.*, 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 Res.*, 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 – 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 one-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://data.aad.gov.au/aadc/metadata/metadata_redirect.cfm?md=AMD/AU/geb.
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.noaa.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 81 echinoid 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.nasa.gov/records/01-FishBase-99.html
Dataset creators: R. Froese, Institute of Marine Research, Kiel, Germany; D. 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 Research (Zoological Institute of the Russian Academy of Sciences) has set up a series of databases on Antarctic 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.