APPENDIX D

CEMP REVIEW WORKSHOP
(Cambridge, UK, 18 to 22 August 2003)

CONTENTS

REPORT OF THE CEMP REVIEW WORKSHOP
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INTRODUCTION

Background

In 2001 the Scientific Committee agreed, as part of its scheduled plan of work, to commence a review of the CCAMLR Ecosystem Monitoring Program (CEMP) at the 2003 meeting of WG-EMM. The Scientific Committee established the following terms of reference for this review (SC-CAMLR-XX, Annex 4, paragraphs 5.16 and 5.17):

(i) Are the nature and use of the existing CEMP data still appropriate for addressing the original objectives[1]?

(ii) Do these objectives remain appropriate and/or sufficient?

(iii) Are additional data available which should be incorporated in CEMP or be used in conjunction with CEMP data?

(iv) Can useful management advice be derived from CEMP or be used in conjunction with CEMP data?

2. An interim steering committee, convened by Prof. J. Croxall (UK), met during the WG-EMM 2002 meeting and prepared a report and plan of intersessional work that was subsequently adopted by WG-EMM and the Scientific Committee (SC-CAMLR-XXI, Annex 4, Appendix E; SC-CAMLR-XXI, paragraphs 6.1 to 6.16).

3. The Scientific Committee agreed that the inauguration of CEMP (in 1987) and its subsequent development and implementation represented an outstanding achievement of CCAMLR. It noted that major new programs of monitoring and directed research in support of CEMP had been initiated by Australia, Japan, South Africa, UK and the USA, together with significant additional contributions by Argentina, Chile, Germany, New Zealand and the former USSR. The value of these programs and of the time series of data collected in consistent fashion as part of CEMP was recognised worldwide.

4. Nonetheless, it endorsed the timeliness of reviewing CEMP, especially to assess the strengths and weaknesses of the existing program and the limitations these might impose for meeting the original objectives, and potential additions and improvements to the existing program.

5. The Steering Committee for the Review of CEMP (members indicated on the list of participants (Attachment 1)) was co-convened by Prof. Croxall and Dr C. Southwell (Australia). Meetings were held to discuss and further develop the implementation of the

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[1] The original objectives of CEMP (SC-CAMLR-IV, paragraph 7.2) were to:
(i) detect and record significant changes in critical components of the ecosystem to serve as a basis for the conservation of Antarctic marine living resources;
(ii) distinguish between changes due to the harvesting of commercial species and changes due to environmental variability, both physical and biological.

intersessional work plan (SC-CAMLR-XXI, Annex 4, Appendix E, Attachment 4) on 3 August 2002 at Big Sky, Montana, USA (Interim Steering Committee), and on 24 October 2002 at Hobart, Australia. Various subgroups were established to coordinate and undertake intersessional work.

6. The reports of the above meetings, details of the revised intersessional work plan, the coordinators of the subgroups on data analysis, krill and environmental data, and references to appropriate background literature were all made available on the CCAMLR website from early December 2002.

Opening of the Meeting

7. The Co-conveners welcomed participants (Attachment 1) and thanked the UK hosts and the local organising committee for their assistance with the arrangements for the meeting, and the CCAMLR Secretariat for support during intersessional planning and at the meeting itself.

8. The Preliminary Agenda was adopted with minor changes (Attachment 2).

9. The report was prepared by Prof. Croxall, Drs M. Goebel (USA), R. Hewitt (USA), G. Kirkwood (UK), E. Murphy (UK), S. Nicol (Australia), D. Ramm (Secretariat), K. Reid (UK), Southwell, P. Trathan (UK), W. Trivelpiece (USA) and G. Watters (USA).

GENERAL REVIEW OF DATA, SUPPORTING PAPERS AND OTHER MATERIALS AVAILABLE

10. CEMP data available to the workshop are listed in detail in WG-EMM-03/24 and are summarised in terms of sites (for locations see Figure 1) and the number of years for which data for each parameter of each species are available (Table 1).

11. In preparing the CEMP data for the workshop, a process of validation and logic testing was prescribed by the Steering Committee and carried out by the CCAMLR Data Manager and his staff. Data were checked logically using database queries; data owners were contacted where appropriate to clarify or resubmit any data which failed these tests. It was noted that CEMP data submission for some sites was limited to the essential data defined in the CEMP standard methods.

12. These data had been analysed in terms of anomalies and trends (WG-EMM-03/24) as well as for their power to detect change (WG-EMM-03/26 and 03/27; see paragraphs 22, 23, 31, 85 and 109).

13. The Steering Committee had emphasised the importance of acquiring and analysing non-CEMP time-series data which had been collected in a standardised fashion as an adjunct to the time series of CEMP data. The Secretariat noted, however, that despite requests for such sets of non-CEMP data, only one had been submitted prior to the workshop and was therefore the only one available for analysis during the meeting. However, a number of papers submitted to the meeting contained summaries of non-CEMP data (Table 2).

14. The workshop noted that there were notable time series of non-CEMP data, particularly for physical variables over a wide geographic range. These data included information on: DPOI (WG-EMM-03/46), satellite imagery of sea-ice, sea-surface temperature (e.g. WG-EMM-03/20) and meteorological data. There was also information available from other scientific programs such as SO GLOBEC and the Italian Antarctic Program. These datasets could be used to augment data from the CEMP database and can be used to set up future analyses.

15. The Steering Committee had indicated the kinds of non-CEMP data that would be relevant and desirable for its analyses (Table 3). Notable absences of non-CEMP data available to the workshop included time series of krill abundance and distribution from areas other than Elephant Island, time series for pelagic predators (whales and crabeater seals) and time series of fisheries information from sources other than the former USSR.

UPDATE ON INTERSESSIONAL WORK

Data Availability and Validation

16. Validation and logic testing on all CEMP data were undertaken by the Secretariat during the intersessional period and is now completed for data submitted to June 2003. This validation process is ongoing and will continue to be applied to all data submissions.

17. Validations were carried out with special attention paid to the tasks set by the Interim Steering Committee (SC-CAMLR-XXI, Annex 4, paragraph 6.12 and Appendix E, Attachment 4). Data were checked logically using database queries; data owners were contacted where appropriate to clarify or resubmit any data which failed these tests.

18. CEMP data available at the workshop were reported in WG-EMM-03/24 and 03/25 (see data matrix) and summarised in Table 1. CCAMLR fishery data available at the workshop were reported in WG-EMM-03/28.

19. Non-CEMP data available at the workshop were reported in Table 2. Only one set of data had been submitted in advance of the workshop and was therefore available for analysis.

SENSITIVITY ANALYSES

20. The Interim Steering Committee for the CEMP Review established a correspondence group that was tasked with undertaking preliminary intersessional discussion and analyses on the sensitivity and power to detect trends in CEMP indices. The correspondence group consisted of Drs Hewitt, Watters and Southwell.

21. The correspondence group reviewed available power analysis software programs at the commencement of their work and, after some consideration of various programs' respective strengths and weaknesses, suggested the DOS program MONITOR for exploratory analyses (see also paragraph 24). During the course of intersessional work, several limitations and constraints became evident in this software. Nevertheless, the process of intersessional

discussion and analysis using MONITOR was valuable in exploring concepts, assessing the magnitude of variability both temporally and spatially where possible, and exploring the implications of this variability on power to detect trends.

22. The correspondence group completed a number of exploratory analyses during the intersessional period, and these analyses were presented to the workshop in WG-EMM-03/26, 03/27, 03/47 to 03/49 and 03/52. The analyses considered sources and estimates of spatial and temporal variability and their consequences on power to detect trends of varying magnitude, in relation to monitoring program parameters such as duration of monitoring, number of sites monitored, Type I error levels and one- or two-sided tests.

23. Serial correlation in CEMP indices, which may affect predictions of power, was examined by the Secretariat during the intersessional period. Results of this work were presented as WG-EMM-03/27. Autocorrelation functions were estimated for 157 of the 198 biological time series and 64 of the 80 environmental and fishery time series in the CEMP database. The remaining time series could not be analysed due to insufficient or invariant data. Serial correlation occurred in 4, 10 and 33% of the biological time series at alpha levels of 0.05, 0.10 and 0.20 respectively (i.e. not more frequently than would be expected by chance alone). Generally, serial correlation was more prevalent in time series of population size, CEMP Indices A3 and B1a. Serial correlation occurred in 23, 38 and 55% of the environmental and fishery time series at alpha levels of 0.05, 0.10 and 0.20 respectively. Generally, serial correlation appeared more prevalent in time series of CEMP Indices H3b and F2c.

24. The documents submitted by members of the correspondence group (archived at the Secretariat and available on request) contained a variety of related results, and the workshop decided to review these results by deliberating on three topic areas:

(i) outlining issues and problems identified during the work of the correspondence group (paragraphs 25 to 30);

(ii) providing a synopsis of the analytical results prepared by the correspondence group (paragraphs 31 to 39);

(iii) discussing alternative approaches to power analysis (paragraphs 40 to 43).

Issues and Problems Identified by the Correspondence Group

25. The workshop acknowledged that only some of the CEMP parameters might be expected to show a sustained, gradual change in relation to changing krill availability and hence be suitable for trend analysis as undertaken by MONITOR, and that alternative methods of detecting change would be required for parameters that exhibited a sudden change. The nature of expected change would reflect the shape of the predator response relationship with krill availability, which was being investigated in parallel prior to and at the workshop by separate correspondence group and subgroup.

26. The workshop recognised that it was important to identify appropriate sources of variability for input to power analyses. There was some intersessional discussion regarding process and measurement error, and the workshop paid particular attention to this issue during the CEMP review (paragraphs 33 to 39).

27. The workshop discussed the issue of one- and two-tailed tests in the context of a traditional hypothesis-testing approach and alternative approaches such as Bayesian methods. With regard to hypothesis-testing approaches, three alternatives were discussed: (i) a one-tailed test initially at pre-impact when only a uni-directional change was required to be detected, then subsequently a two-tailed test after detection of a detrimental effect to determine whether the effect has been reversed or not; (ii) use of a two-tailed test at all stages of monitoring; and (iii) the use of 'asymmetrical' one-tailed tests as a compromise between (i) and (ii). The appropriate choice from these and possibly other options would need to be considered in relation to specific management objectives and decision rules yet to be established.

28. The workshop noted that in undertaking power analyses it was critical to specify the effect size that is required to be detected. This would also need to be considered in conjunction with the establishment of specific management objectives and decision rules, and may need to take account of the demographic characteristics of the species.

29. Two types of error may be expected when trying to detect an environmental impact. A Type I error is the probability of falsely concluding an effect has occurred, and a Type II error the probability of failing to detect a real effect. Power is the inverse of a Type II error, or the probability of successfully detecting a real effect. The traditional hypothesis-testing approach has tended to consider only Type I errors and by convention has used Type I error levels of 0.05. Use of this error level in management would mean that management action would be taken unnecessarily one in 20 times. Since the probability of one type of error occurring varies inversely with the other, this approach places a low priority on Type II errors and leads to reduced power. However, in assessing environmental impacts it may be preferable to take a precautionary approach by giving higher priority to Type II errors, since the cost of management action in response to occasional false reports of change may be considered an acceptable trade-off to waiting for definitive change, at which time there may be fewer management options. Consequently in undertaking preliminary power analyses, the correspondence group considered a range of Type I error levels from the traditional level of 0.05 to higher levels of 0.10 and 0.20.

30. The workshop discussed the need to consider power analysis within the context of the management framework within which a monitoring program is operating. There is a need to distinguish between power in a statistical context and power in a management context. In a management context for CCAMLR, power would need to take into consideration the time lag due to delayed effects of demographics as well as the time lag for statistical detection, such that detection and recovery would be possible within two to three decades of an impact occurring.

Synopsis of the Analytical Results prepared by the Correspondence Group

31. In attempting to summarise the analytical results presented in WG-EMM-03/26, 03/47 to 03/49 and 03/52, the workshop noted both the exploratory nature of the analyses (paragraphs 21 and 22) that were conducted and the variety of difficulties that the correspondence group had with identifying appropriate inputs to the power analysis software (paragraphs 25 to 30). In view of these points, the workshop agreed that the objectives of the CEMP review might best be accomplished by gaining an improved understanding of the nature of variation in the CEMP indices rather than by studying specific results from these documents.

32. Identifying the source of variability in CEMP indices is useful for at least two reasons. First, it would be useful to separate measurement variance (uncertainty arising from the observation of a phenomenon and summarising observations in the form of an index) from process variance (uncertainty arising from environmental forcing, variability in demographic parameters etc.). Such separation would facilitate identification of those indices for which increased sample size or alternative observation protocols could reduce uncertainty. Ultimately, reductions in uncertainty may increase power to detect trends. The workshop recognised, however, that first it is not always feasible to increase precision in a CEMP index because of fiscal and logistic constraints, and, second, that reducing measurement uncertainty will not guarantee an increase in power to detect trends if the total amount of variation in the index remains large.

33. A second, useful reason to identify the source of variability in CEMP indices relates to the level at which data are summarised in the development of such indices. It is possible that summarised data contain too many levels of variation to be useful indices. For example, foraging trip duration is dependent on the immediate energetic requirements of an individual animal. If individual variability in foraging trip duration is not preserved, it is possible that an index which is developed from combined data would have limited utility for detecting trends. This could occur if the between-individual variability is greater than the interannual variability in foraging trip duration. In general, identifying the sources of variability in CEMP indices can illustrate whether improvements can be made by alternative levels of data aggregation.

34. The workshop attempted to identify sources of variation (process variation and measurement variation) in CEMP Indices A3 (breeding population size), A5a (mean foraging trip duration) and A6c (breeding success) for Adélie penguins at a number of CEMP sites. An upper limit for measurement variance in Index A3 was assumed to be determined by the guidelines specified in the standard method for that index (i.e. that replicate counts should be made until such time as those counts are within 10% of each other). Measurement variance in Index A5a was estimated by computing the standard error of the index from numbers of foraging trips recorded in the CEMP database. Measurement variance in Index A6c was estimated from the properties of the binomial distribution. Empirical estimates of process variation in all three indices were developed directly from the time-series data in the CEMP database.

35. Measurement variance in Indices A3 and A6a for Adélie penguins may be relatively small (Tables 4 and 5 respectively). This result has two possible implications: (i) sample sizes for these indices have likely been sufficient; (ii) uncertainty in these indices may not have stemmed from the ways in which these data were collected and summarised in the

CEMP database. The workshop noted, however, that it is possible that assuming replicate counts are within 10% of each other may both overestimate the level of measurement variance in Index A3 for small colonies and underestimate this level for large colonies. It was recognised that the only way to resolve this issue would be to analyse the replicate counts used to develop Index A3 at two or three of the largest and smallest colonies. The workshop agreed that these counts should be compiled and analysed as part of its future work.

36. The workshop also noted that Standard Method A3a may predispose Members to monitor relatively small colonies. This could lead to bias because animals in large colonies may respond to changes in krill availability differently than animals in small colonies. It was noted that Standard Method A3b does describe methods for counting animals from aerial photographs, and these are appropriate for use on large colonies.

37. Finally, with respect to Index A3, the workshop recalled the generally high degree of serial correlation in indices of population size and noted that such serial correlation is likely an important component of the process variation in these indices. Thus, in the future, it might be desirable to compute the power of non-linear models to detect trend in Index A3.

38. In contrast to Indices A3 and A6c, measurement variance in Index A5a for Adélie penguins appears to be relatively large (Table 6). This suggests that it may be possible to reduce uncertainty in this index by either collecting additional data or summarising the foraging trip data in an alternative way. The workshop noted that variation in foraging trip duration is determined by individually and temporally specific energetic requirements (paragraph 33), and agreed that a first attempt to reduce uncertainty in Index A5a should be to account for this variability in the index. Such an approach might lead to a revised standard method or to the submission of additional data. The workshop further emphasised that Index A5a is a potentially valuable index for evaluating changes in krill availability, and, given the complexity of variation in foraging trip duration, work on this index should be a priority.

39. The workshop agreed that the exploratory analysis of variation in the CEMP indices for Adélie penguins was informative, and future work to extend this analysis to include other CEMP indices, species and sites may lead to improvements in CEMP. Such work might best be accomplished by convening a small subgroup comprising individuals familiar with the collection and summarisation of CEMP data and with statistical knowledge.

Alternative Approaches to Power Analysis

40. The subgroup considered that any future consideration of power should be undertaken within the framework of a monitoring program designed to meet explicit and specific management objectives. Therefore, explicit and specific statements of management objectives are a priority.

41. Bayesian or maximum likelihood approaches, in which different candidate models are fitted to data in an attempt to better understand those that best explain the observed patterns, were recommended as possible alternatives to the traditional hypothesis-testing approach. Simulation and data-assimilative approaches could also be used to investigate optimal designs for proposed monitoring programs within the context of fixed sampling constraints.

Data-assimilative models minimise the degree of misfit between data and observations, thereby giving simulations that are accurate to the level allowed by the dynamical model and the input datasets. Data-assimilative models allow exploration of the type and frequency of data that are needed, the structure of the dynamical model, and the degree of accuracy that is needed in the observations that are input to the model. The CEMP time series, which extend for more than 20 years for some sites, would be more than adequate for development and testing of data-assimilative models. This approach has been used in the development of meteorological monitoring networks for weather prediction, the implementation of oceanographic sampling programs, and for analyses of historical multi-disciplinary oceanographic datasets.

42. The workshop recognised that a monitoring program that aimed to detect an effect at scales appropriate to management may require a different design to a monitoring program that aims to attribute causality, given fixed sampling constraints. Such contrasting designs may need to be applied within differing spatial contexts and measure different sets of parameters.

43. In a later plenary session, it was suggested that another alternative was to test for the absence of an undesirable change, as opposed to the usual test for the absence of any change (paragraphs 122 and 123).

PREDATOR PARAMETERS AS INDICATORS OF KRILL AVAILABILITY

44. A subgroup was convened to consider the relationship between the response of krill-dependent predators to krill abundance. The Terms of the Reference for that group were to:

(i) update the intersessional comparisons of the response of krill-dependent predators to krill in Subareas 48.1 and 48.3;

(ii) examine different functional response models and to identify sources of data with which to investigate models;

(iii) investigate the options for predicting krill abundance based on the functional response of krill predators.

Update of the Intersessional Comparisons of the Response of Krill-dependent Predators to Krill in Subareas 48.1 and 48.3

45. The subgroup recognised that whereas there are no CEMP data on prey abundance, there are long time series of krill abundance estimates from Subareas 48.1 (WG-EMM-03/06, 03/54, 03/61) and 48.3 (WG-EMM-03/43) and that these are the areas from which there are the longest time series of predator performance parameter; hence these regions formed the focus of the data analysis conducted in the intersessional period and during the workshop.

46. Using indices of predator performance from four species of krill-eating predator together with independent ship-based acoustic estimates of krill abundance from South Georgia (Subarea 48.3), WG-EMM-03/43 examined the relationship between a range of

indices of predator performance and krill abundance. Predator parameters that reflected processes occurring during the summer showed the closest relationship with krill abundance, especially those for species with foraging ranges similar to the spatial scales at which krill surveys were undertaken. Using combinations of indices that reflect processes at the same temporal scale to produce CSIs, showed an increased fit to the krill abundance data compared to any of the individual parameters. Population size parameters showed no such functional response relationship with annual krill abundance estimates.

47. This analysis emphasised the importance of identifying the spatial, and especially the temporal scales, over which indices of krill-dependent species operate (Figure 2) and the importance of this in identifying those indices, either individually or combined, that show the closest relationship with krill abundance.

48. WG-EMM-03/61 presented analyses of a suite of CEMP and non-CEMP predator performance indices collected at Admiralty Bay and Cape Shirreff, South Shetland Islands (Subarea 48.1), to assess the characteristics of the individual parameters and their relationships to krill abundance indices. The analysis of these parameters indicated that body mass and egg size/mass measurements have low overall CVs (<10%), whereas breeding success, population change and foraging trip duration have relative high (25–50%) CVs. The results of linear regression analyses of individual predator indices and krill biomass density for the South Shetland Islands indicated that Adélie penguin incubation shift durations, gentoo penguin population size changes, and gentoo penguin egg masses were significantly correlated with krill biomass density.

49. The analysis presented in WG-EMM-03/43 suggests that combining variables into standardised indices has the advantage of not only reducing the dimensionality of the data to a form in which it is readily interpretable but also, by encapsulating the variability inherent in the suite of parameters, provides a better fit of the functional response of predators to changes in krill abundance. Following this approach, CSIs were calculated using those parameters that reflect 'summer' variables for Adélie, chinstrap and gentoo penguins from Admiralty Bay and Cape Shirreff (WG-EMM-03/61) and from Antarctic fur seals at Cape Shirreff (WG-EMM-03/54) in order to investigate the form of the relationship with the krill data presented in WG-EMM-03/36 for the Elephant Island region.

50. It was noted that the apparent relationships between predator performance and krill biomass density from data collected in the vicinity of the South Shetland Islands was not of the same form as that from data collected at South Georgia (Figure 3). In considering potential reasons why the predator–prey functional relationships at Admiralty Bay and Cape Shirreff did not appear to follow the same Holling Type II relationships that were found for predators at South Georgia, the subgroup discussed the following:

(i) The krill biomass data used in the South Shetland Islands analyses were derived from a series of surveys conducted on a survey grid centred on Elephant Island (WG-EMM-03/6), whereas estimates of krill biomass derived for monitored predator foraging areas near Admiralty Bay and Cape Shirreff may be more appropriate. Accordingly, a times series of krill biomass densities for these areas was generated by: (a) noting the strong correlation between density estimates in the Elephant Island stratum and the South stratum (encompassing the foraging area of predators monitored at Admiralty Bay) and the West stratum (encompassing the foraging area of predators monitored at Cape Shirreff) of recent US AMLR Program surveys (r^2 = 0.91, n = 5, and r^2 = 0.89, n = 6 respectively); and (b) generating a longer times series for the South and West strata based on results from the Elephant Island strata. However, the spatial refinement of the krill biomass density estimates did not substantially change the relationships between krill and CSIs of predator performance.

(ii) The difference in length of data time series at different sites is considerable and this may be a particularly important consideration for Cape Shirreff where most data exist only from 1998.

(iii) The South Georgia time series includes two years, 1991 and 1994, when predator performance and krill density estimates were exceptionally low. Although lower krill densities than those measured for South Georgia have been recorded in the South Shetland Islands, these have not been associated with the same level of reduced reproductive performance in predators.

(iv) The amplitude of variability of krill biomass densities may be greater at South Georgia than at the South Shetland Islands, arising from differences in krill demographic parameters (WG-EMM-02/16), thereby producing a greater range of predator response values.

(v) Krill biomass densities, although apparently suitable for defining functional relationships for predators foraging from South Georgia, may not be the best parameter for defining functional relationships for predators in general or at other sites. In past working group deliberations other parameters have been considered, for example, mean distance of prey from predator colonies, mean depth of prey, persistence of prey over time (Hewitt et al., 1997). These, as well as other potential parameters (e.g. intensity, density and/or size of patches) may warrant further exploration. In essence, this highlights the need to better understand the relationship between the measures of the abundance of krill and the availability of that krill to predators.

51. Whilst the CSI approach is able to accommodate missing values, the subgroup recognised that, where there were systematic biases in the reasons for the absence of data, this posed a particular problem in reflecting krill abundance.

52. In particular, the subgroup considered the importance of identifying those indices that may not be available for measurement under certain conditions, e.g. during situations of complete breeding failure where it is not possible to measure indices such as foraging trip duration when none of the study birds return to the colony. Where such methodological biases exist these monitoring parameters may be of limited utility to CEMP.

53. WG-EMM-03/44 described the relationship between krill availability and predator performance in the Mawson region of East Antarctica. Shipboard acoustic surveys of krill indicated that more than three times as much krill was present during the survey period in 2001 than in 2003 and this was reflected in the reproductive performance of Adélie penguins at Béchervaise Island. Penguins travelled further to forage in 2003 than 2001, remained at sea for longer, brought back smaller meals and achieved lower breeding success. Fish (mostly *Pleuragramma antarcticum*) contributed significantly to the diet in 2003 but was only a minor component in 2001.

54. In welcoming this integrated analysis of predator performance and prey availability, the workshop noted that WG-EMM-03/59 reported a similar contrast in the reproductive performance for Adélie penguins between 2001 and 2003 at Edmonson Point in the Ross Sea, however, the reasons for the latter had been attributed to unusual sea-ice and weather conditions during critical periods of the breeding season.

55. Dr Nicol informed the workshop that meteorological data from Béchervaise Island from both 2001 and 2003 did not indicate any anomalous events that might have contributed to the differences in breeding success.

56. Dr S. Olmastroni (Italy) informed the workshop that there were no measurements of krill abundance in the vicinity of the Edmonson Point colony. In considering the potential for such confounding problems in the interpretation of CEMP data, the subgroup recognised the importance of collecting data for a suite of parameters of predator performance and environmental conditions.

Indicator Species

57. The workshop recognised that the extent to which predators are dependent on krill may have a large influence on their potential utility as indicator species. This level of dependence should be reflected in the proportion of krill (by mass) in the diet. An analysis of the diet parameters (A8) in the CEMP database indicates that there are considerable intra-specific regional differences with the dietary dominance of krill being greatest in Area 48 in all species, especially for chinstrap penguins (Figure 4). The variability in dietary dominance of krill may reflect differences in alternative prey resources as well as the extent to which species are obligate krill feeders in different locations.

58. However, the workshop noted that although krill comprised 50% of the diet of gentoo penguins in Subarea 48.3, this species had the best fit to the functional response between predator-specific CSI and krill abundance of the range of CEMP species at South Georgia (r^2 = 0.6; WG-EMM-03/43).

Sources of Available Data with which to Examine Functional Responses

59. Drs K. Shust and V. Sushin (Russia) reminded the workshop that it was difficult to assess the distribution, density, aggregation structure and biomass of krill from small-scale surveys that have been undertaken in locally restricted areas and within relatively restricted time periods. When oceanographic flux and advection of krill are taken into account, there are potential impacts both on the assessment of the stock and the amount of krill available to predators.

60. They suggested that information from the commercial fishery could therefore be extremely useful in augmenting predator–prey analyses as they may reflect the distribution and density of krill concentrations. They further suggested that CPUE indices derived from the commercial fishing fleet could provide useful information that could be included in analyses of CEMP indices, krill distribution, predator consumption and the potential impact on predators of catches made by the fishing fleet.

61. The workshop considered the utility of using fishery-based indices as a proxy for krill density when examining the functional response of predators to availability of their prey (krill). It noted that such proxies could be extremely valuable in a variety of contexts; thus, they could help inform those studies where information on predators and krill have been collected on an annual basis for some years (e.g. South Georgia and South Shetland Islands), as well as other areas where regular krill surveys have not been conducted annually (e.g. South Orkney Islands).

62. Dr Sushin reminded the workshop that there was an index of the krill fishery performance in the CEMP database (CEMP Index H1) although there were no analyses of these indices presented at this workshop. The workshop agreed that in order to fully evaluate these indices of fishery performance, these data should be subjected to the same evaluation procedures as other CEMP indices. The workshop recommended that such an analysis of the sensitivity and power to detect trends in indices of krill fisheries performance and the evaluation of functional responses of dependent species to those indices should follow the procedures and recommendations arising from this workshop.

63. The workshop established a subgroup (comprising Drs Hewitt (Convener), M. Naganobu (Japan), Nicol, Reid and Sushin) on the evaluation of fisheries-derived CEMP indices with respect to functional relationships of krill-dependent species with the following terms of reference:

(i) to define analytical procedures
(ii) to define the data required
(iii) to specify protocols for the submission, curation and use of the data.

This subgroup was asked to submit their recommendations to WG-EMM-03 under Agenda Item 3.2.

Predicting Krill Abundance Based on the Functional Response of Krill Predators

64. Drs A. Constable (Australia) and Murphy investigated approaches to predicting krill abundance based on the functional response of krill predators. This involved the development of a simulation framework to evaluate the influence of the choice of functional response model and the CV associated with the estimates of predator performance. The inclusion of the error associated with the estimation of krill density estimates will have a large impact on the utility of predator response functions to predict krill abundance (details are presented in Attachment 3).

65. Dr R. Crawford (South Africa) indicated that it was important to recognise the importance of these predator response functions both in terms of predicting krill abundance and in their intrinsic value in understanding the potential consequences of changes in krill abundance on krill dependent predators.

66. The workshop recognised that the ability to relate concurrent indicators of predator performance to changes in krill when measured at appropriate scale was an important

advance. However, it further recognised that the ability to relate these indices to the long-term demographics of predator populations and how these might respond to long-term trends in the krill resource is critical to future work on this topic.

ENVIRONMENTAL PARAMETERS

Relevance of Non-CEMP Data to the CEMP Review

67. WG-EMM-03/20 reported that VNIRO have been monitoring sea-surface temperature in Subarea 48.3 (around South Georgia) since December 1989. The monthly SST maps (with resolution of 1° latitude by 1° longitude) have been constructed from GOES-E and Meteosat-7 daily satellite data that have incorporated real-time data from vessels and buoys. The workshop recognised the utility of such data and the potential to extract indices that could be included in analyses of CEMP data, other predator data and fishery data.

68. WG-EMM-03/46 reported on recent work to update the DPOI described by Naganobu et al. (1999). The index is now available from January 1952 to May 2003 and describes sea-level pressure differences across the Drake Passage between Rio Gallegos (51°32'S 69°17'W), Argentina, and Base Esperanza (63°24'S 56°59'W), at the tip of the Antarctic Peninsula. The workshop recognised the potential utility of the DPOI to the work of CEMP.

Relevance of Southern Ocean GLOBEC

69. Prof. E. Hofmann (Invited Expert) informed the workshop about the success of the recent field studies carried out by the SO GLOBEC multinational science program. The primary objective of SO GLOBEC is to understand the physical and biological processes that control the abundance, distribution and population variability of Antarctic krill (*Euphausia superba*). Addressing this objective requires concurrent studies of the habitat, predators and competitors of Antarctic krill. The SO GLOBEC program is focused on understanding winter processes, especially those that contribute to overwinter survival of Antarctic krill.

70. The west Antarctic Peninsula was chosen as one of the regions for SO GLOBEC field programs because this area is known to include large populations of Antarctic krill and predators, such as Adélie penguins and seals, and dependable winter sea-ice. The region of the west Antarctic Peninsula studied during the SO GLOBEC field effort was centred around Marguerite Bay and extended across the continental shelf to the seaward side of the southern boundary of the ACC. The US and German Antarctic programs undertook large SO GLOBEC field efforts in the west Antarctic Peninsula region.

71. The US SO GLOBEC field effort consisted of four process cruises, four survey cruises and three current meter mooring deployment and/or recovery cruises which took place during the austral autumn and winter of 2001 and 2002. Data collected during these cruises consisted of measurements of hydrographic distributions, sea-ice properties and distribution, hydroacoustic and net-derived zooplankton distributions, phytoplankton pigment distributions and rates of primary production, ecology and physiology of Antarctic krill and zooplankton, fish abundance and distribution, seabird abundance and distribution, penguin abundance and distribution and diet sampling, seal abundance and distribution and physiology, penguin and

seal tagging and cetacean abundance and distribution. These data are now undergoing analyses and some of these results are presented in a special issue of *Deep-Sea Research* devoted to SO GLOBEC, which will be published in early 2004.

72. One of the results emerging from analyses of the US SO GLOBEC datasets is the importance of CDW to the physical and biological processes on the west Antarctic Peninsula continental shelf. CDW is a large water mass that is transported by the ACC and is identified by its relatively warm (1.5°C to 2.0°C) and salty (34.65‰ to 34.72‰) characteristics. This water mass also contains high concentrations of macronutrients and also micronutrients, such as iron. Along the west Antarctic Peninsula the ACC is located along the outer continental shelf edge, which puts CDW at depths of 200 to 500 m. In regions of topographic variability, CDW intrudes onto the continental shelf and floods the shelf below 150 m. Areas where CDW intrudes onto the west Antarctic Peninsula continental shelf are characterised by variable topography and deep trenches that extend from the outer to inner shelf. In particular, the Marguerite Trough provides a conduit for the movement of CDW from the outer shelf to the innermost part of Marguerite Bay. Thus, the regions of CDW intrusion and upwelling are persistent over time.

73. Once on the continental shelf, CDW upwells via a range of processes that introduce heat, salt and nutrients into the upper water column. The introduction of heat to the upper ocean affects sea-ice thickness and concentration as shelf surface waters remain above freezing in winter, producing reduced sea-ice thickness and concentration. Thus, CDW is an integral part of the heat and sea-ice budgets developed for west Antarctic Peninsula continental shelf waters.

74. Diatom-dominated phytoplankton blooms characterise the areas where CDW upwells. This is believed to result from the high silica and possibly iron concentrations associated with CDW. These upwelling areas provide a dependable supply of food for grazers, such as Antarctic krill. As such, these regions may represent preferred sites for biological production along the west Antarctic Peninsula continental shelf. Dr P. Wilson (New Zealand) reported that in the Ross Sea an analogous scenario seems to be operating in relation to increased primary productivity and penetration of CDW. Thus, where diatom-dominated blooms occur, penetration of CDW also occurs. Prof. Hofmann confirmed that where blooms of *Phaeocystis* occur, penetration of CDW is likely to be minimal or absent. Dr Nicol noted that the deep waters around Heard Island are not iron rich; Prof. Hofmann suggested that there existed a shelf-slope front around the island and that this potentially prevented the iron-rich CDW from flooding the shelf.

75. Prof. Hofmann reported how the emerging results from SO GLOBEC could be of use to CEMP. Firstly, she indicated that the results showed that the physical and biological structure of Antarctic continental shelf waters are largely controlled by one particular water mass, CDW. Secondly, that the distribution of this water results in regions of consistent and dependable enhanced biological production, which is reflected in the overall food web. Thus, the effects of this physical and biological structure may influence CEMP indices, especially those indices collected from predator colonies that are in close proximity to areas where CDW upwells. Knowledge of where these areas occur may therefore be an important part of analyses for some of the CEMP data.

76. Prof. Hofmann reported how it may be possible to include information about CDW distribution in the predator-based measurements that are being made by CEMP. Recent work,

undertaken by Dr D. Costa (University of California, Santa Cruz, USA) as part of SO GLOBEC, showed the feasibility of instrumenting crabeater seals with PTTs that also contain temperature and salinity sensors. Preliminary analyses of the temperature and salinity data from these tags show that it is possible to use these data to characterise the thermohaline properties of the portion of the water column sampled by the seals. In many instances, the depth to which the seals dive is sufficient to encounter CDW. Thus, incorporation of this technology into CEMP measurements would allow sampling of the oceanographic conditions within the predator foraging area. The inclusion of temperature and salinity sensors in predator tags is becoming a proven technology and the experiences from SO GLOBEC provide a basis from which additional uses and analyses of these data can be developed.

General Conclusions

77. Following Prof. Hofmann's presentation about SO GLOBEC, the workshop considered various issues related to the krill fishery in the light of the information presented.

78. Prof. Hofmann suggested that the strongest correlations between krill and hydrography occurred with modified CDW rather than with CDW *per se*; indeed recently upwelled or recently modified CDW often show poor relationships with krill. In Marguerite Bay, relationships between secondary production and modified CDW are strong, thus the workshop expressed some surprise that the krill fishery had not developed in this area. Dr Naganobu agreed and further emphasised that variability in Antarctic Surface Water was also important for the krill fishing fleet.

79. Dr Naganobu noted that there was considerable variability in water mass structure in the fishing grounds to the north of the South Shetland Islands. Prof. Hofmann suggested that in this region the ACC did not always occur in close proximity to either the shelf or the land boundaries. This large-scale movement of the ACC potentially has a number of consequences at both small and medium scales. For example, when the ACC moved offshore from the land, waters from Bransfield Strait and from the Weddell Sea can move into the region. Prof. Hofmann indicated that understanding such movement of the ACC was critical to understanding the ecosystem. She suggested that the role of atmospheric forcing may be crucial in this process at a local scale.

80. The workshop recognised that our understanding about large-scale environmental affects and their impact on small- and medium-scale processes continued to increase with the advent of new and sophisticated modelling studies. Indeed, the confidence in modern global circulation models (GCMs) is such that they now potentially offer valuable insights into how the physical environment can be monitored in a way that provides useful information for management. Studies about the levels of spatial and temporal variability present in such GCMs could help identify the necessary scales for a field-based, or satellite-based, environmental monitoring program.

81. Such an approach could potentially lead to the collation of new and relevant environmental data (at a range of scales) that may eventually prove to be of value as covariates when examining predator–prey functional response relationships. Such data would also help identify the degree to which sites were likely to be representative of their local and/or regional area.

82. The workshop recognised that a number of environmental parameters are potentially important covariates in analyses of predator–prey interactions. It therefore considered that it would be valuable to produce a matrix of environmental parameters that potentially confound the analysis of predator–prey functional response relationships. The workshop acknowledged that producing such a matrix was beyond the scope of the current CEMP Review Workshop, but recommended that work continue intersessionally to develop such a matrix. Table 1 outlines a pro-forma layout that the workshop considered appropriate; it recognised that for some species for some areas the content of the matrix would be sparse.

RESPONSES TO THE TERMS OF REFERENCE FOR THE CEMP REVIEW

83. The workshop noted that the review of CEMP is a key element in the work plan of WG-EMM, being closely linked to its main workshop activities planned for 2004/05, (SC-CAMLR-XXI, Table 1) viz:

(i) selection of appropriate predator–prey–fishery–environment models (2004);

(ii) evaluation of management procedures, including objectives, decision rules and performance measures (2005).

84. The workshop also noted that the present meeting represents only the commencement of a review of CEMP. Therefore replies to the questions posed by means of the terms of reference should be seen, in many cases, as interim responses based on work in progress.

Are the Nature and Use of the Existing CEMP Data still Appropriate for Addressing the Original Objectives?

85. Previous discussions (SC-CAMLR-XXI, Annex 4, Appendix E, paragraph 11) by the Interim Steering Committee had concluded that CEMP data were likely to be appropriate for detecting and recording significant change in some critical components of the ecosystem. The workshop endorsed this conclusion, but also emphasised that critical evaluation of the nature, magnitude and statistical significance of changes indicated by CEMP data was necessary. The work on power analysis and sensitivity undertaken by the workshop (see also WG-EMM-03/26, 03/27, 03/47 to 03/49 and 03/52) was crucial in this respect for identifying the sources and magnitude of variation in CEMP data.

86. During previous discussions (SC-CAMLR-XXI, Annex 4, Appendix E, paragraph 12), the Interim Steering Committee had considered that the design of CEMP should be evaluated in order to determine whether the construction of the monitoring program was adequate to assess changes before and after potential environmental perturbation at the scales appropriate to management decisions. However, in considering this issue, the workshop now recognised that CEMP had not been designed *per se*, rather it had been formed by the incorporation or development of research within national programs. It remains important therefore, to determine how representative these sites are of their local areas and regions.

87. The workshop further recalled (SC-CAMLR-XXI, Annex 4, Appendix E, paragraph 13) that at current harvesting levels it was unlikely that the existing design of

CEMP, with the data available to it, would be sufficient to distinguish between ecosystem changes due to harvesting of commercial species and changes due to environmental variability, whether physical or biological. The workshop reiterated this conclusion and further noted that with the existing design of CEMP it may never be possible to distinguish between these different and potentially confounding causal factors. As a result, the workshop felt that the Scientific Committee should seek advice from the Commission on the extent to which further work should be directed towards this topic.

88. Within any ecosystem monitoring program, there will always remain a level of uncertainty when assessing predator–prey interactions; a direct consequence of this is that there will always be associated levels of uncertainty in management advice. Without a real ability to separate the confounding effects of harvesting and environmental variation and in the context of uncertainty, the workshop felt that the Scientific Committee should seek advice from the Commission about the policy of how management should proceed when a significant change was detected, but no causal factor could be attributed.

89. The workshop considered that one possible method that could potentially lead to a separation between the confounding effects of harvesting and environmental variation was to initiate a structured fishing experiment that concentrated fishing effort in the vicinity of specifically selected predator colonies. If the Commission determined that it was desirable to initiate such an experiment with the power to distinguish between these confounding effects, an appropriate structured monitoring program would also be required. This would be necessary as it is unlikely that the existing design of CEMP would be sufficient.

90. Dr Sushin suggested that a structured fishing experiment may have economic consequences for the commercial fishery. Prof. Croxall agreed but noted that:

(i) the nature of these consequences, if any, would depend on the design and location of the experiment;

(ii) until the concept and detail of any such experiment was approved, consideration of fishery economics might be premature.

91. The workshop recognised that the number of indices that describe harvested components remains small. It therefore welcomed the suggestion of Dr Shust that future analyses should take into account fishery-derived information describing the distribution and biomass of krill. Dr Shust emphasised that the marine ecosystem is dynamic and that the potential overlap between dependent species and the commercial fishery probably varies. Given the dynamic nature of the system, the workshop agreed that further details from the commercial fleet were essential.

92. The workshop recommended the prompt evaluation and production of appropriate indices. However, it was recognised as critical to have the involvement of experienced ecologists and fisheries scientists in order to establish which indices would adequately describe the relevant operations of the fishery. The workshop proposed that intersessional work be undertaken to develop suitable indices based on fisheries data.

93. The workshop recognised that Antarctic krill and those species that were dependent on it were central to CEMP. Other data describing the krill-centric system were also available, but were not a component of CEMP. Further data were also available that described the

non-krill-centric system (see Tables 1 to 3). Most CEMP data originate from the west Antarctic Peninsula and the Scotia Sea, though considerable data holdings are also available from the East Antarctic. Data holdings from the Ross Sea and the Indian Ocean are still relatively sparse. Incorporating data from other locations will be important as it is now recognised that the Southern Ocean contains a number of regional components that may differ from each other in important ways.

94. The workshop recognised that the existing CEMP has many strengths. Thus, the program has provided an extremely valuable description of the Southern Ocean that was not previously available; it has provided exceptional time series of data relating to key components in the ecosystem; and it has documented a number of events where environmental variability has been positively attributed as the reason for decreases in predator breeding performance. Such events include extensive sea-ice around colonies or colonies blocked by icebergs; other such events have occurred in localities where no fishery has been operating. The workshop agreed that the existing CEMP continues to have considerable management utility.

Do these Objectives remain Appropriate and Sufficient?

95. Previous discussions (SC-CAMLR-XXI, Annex 4, Appendix E, paragraph 15) by the Interim Steering Committee had concluded that the existing objectives of CEMP remain appropriate. The workshop reiterated this conclusion, and agreed that an additional objective was now necessary. This was, that 'Appropriate management advice should be developed from CEMP and related data'.

Are Additional Data Available which should be Incorporated in CEMP or be Used in Conjunction with CEMP Data?

96. The workshop has found valuable a number of datasets that are not part of the standard CEMP, particularly those that have been collected for a number of years using standardised procedures. Given the wide variety of non-CEMP datasets that have been of use to this workshop and the potential number that could be of use to the 2004 Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management, the workshop recognised that it would be inappropriate to incorporate all these data into the CEMP databases. Therefore, it recommended that:

(i) the Secretariat should maintain a register of non-CEMP time-series data of potential utility for the work program of WG-EMM and its subgroups and workshops;

(ii) conveners of WG-EMM workshops and subgroups should, in relation to their terms of reference and objectives, determine which of these data (and other appropriate data) would be useful for their work, especially in relation to the development of management advice.

97. Details about two time series of non-CEMP data were presented: WG-EMM-03/42 and 03/05. The first of these described potential monitoring information from mackerel icefish, the second from Antarctic shags.

98. Dr I. Everson (UK) explained that icefish are potentially a very useful species for monitoring krill, being an important predator of krill over the shelf at a number of Antarctic and sub-Antarctic islands. Dr Shust agreed and reminded the workshop that icefish diet had a greater proportion of other euphausiids as well as *Themisto* at some locations, particularly in the Indian Ocean.

99. WG-EMM-03/42 described several possible indices that may have application to the work of CEMP. Dr Everson emphasised that these were not currently proposed as standard CEMP indices, rather these indices reflected the data currently available. He considered that three indices, in particular standing stock, condition and diet, may have some utility to CEMP; the others (cohort strength and recruitment, natural mortality, gonad maturation and size of age 1 and age 2 fish), may be useful in the future, pending further study.

100. The workshop recommended that the data owners/originators carry out any necessary work to refine these icefish indices. They should then subject the indices to the same analyses as undertaken for CEMP indices. This should include comparison with other CEMP and non-CEMP indices from similar locations and reflect krill availability over similar temporal and spatial scales.

101. Prof. Croxall introduced WG-EMM-03/05, reporting research on Antarctic shags carried out by Argentinean colleagues over a number of years, including the results of a five-year evaluation of the methods and results of a pilot study. WG-EMM-03/05 described the way in which the standardised analysis of pellets can be used for estimating qualitatively and quantitatively the diet of shags and how this can reflect differences in fish availability between seasons and areas. The workshop thanked its Argentinean colleagues for their careful work.

102. Dr Hewitt reminded the workshop that it had previously agreed that a detailed analysis of the non-krill-centric component of the ecosystem would be beyond the scope of the current CEMP Review Workshop (SC-CAMLR-XXI, Annex 4, Appendix E, paragraph 17). However, the workshop recognised that this work on shags had potential utility to both WG-EMM and WG-FSA as it provided information about potentially important ecosystem interactions. The workshop agreed that WG-EMM-03/05 demonstrated that an appropriate method now existed for monitoring aspects of the abundance of young life-history stages of coastal fish species, including those of commercial importance which were subject to CCAMLR conservation measures. It requested WG-FSA to evaluate ways in which such data could be useful to its stock assessment and management procedures.

103. The workshop noted that the papers for the WG-EMM meeting included a wealth of material on the status and trends of seabird and seal populations for the southwest Indian Ocean (WG-EMM-03/8 to 03/19, 03/22 and 03/53). These papers would be more fully discussed in WG-EMM Agenda Item 4.1.5, but the content of several papers contained matters of relevance to the CEMP Review Workshop.

104. First, many papers summarised time-series data on dependent species (WG-EMM-03/8, 03/10, 03/11, 03/15 to 03/18, 03/32 and 03/53), in many cases substantially

updating data and interpretations most recently reviewed by Woehler et al. (2001) and considered by WG-EMM at its 2000 meeting. In addition, several of the species reported on are CEMP indicator species (WG-EMM-03/8, 03/15, 03/16, 03/18 and 03/53). It was recognised that such data from a region where krill is not the main prey of any of the species involved, form a valuable resource for comparison with CEMP data for the same species in areas where krill is the main diet.

105. Second, several of the papers made convincing cases that some trends in dependent species populations may relate to causes other than changes in prey availability (e.g. by-catch mortality in longline fisheries; WG-EMM-03/8, 03/11 and 03/14) or local disease effects (WG-EMM-03/32).

106. Third, several papers described effects likely due to changes in prey availability at different spatial and temporal scales, ranging from the temporary acute effects on breeding performance due to ENSO-type effects (WG-EMM-03/13 and 03/17) to potential shifts in climatic and oceanographic regimes in the sub-Antarctic Southern Ocean (WG-EMM-03/17 and 03/53). In addition, some papers suggested that interactions between different dependent species may be influencing population trajectories and reproductive performance (WG-EMM-03/17 and 03/18).

107. The workshop recognised that the valuable information and ideas contained in these papers complemented earlier reviews of analogous processes of krill-centric systems, particularly in the Atlantic sector (e.g. Area 48 Workshop (SC-CAMLR-XVII, Annex 4, Appendix D)).

108. Many features of the long-term data on population trends and dynamics, arising from studies by South African and French scientists in the Indian Ocean are of considerable relevance to the work of CCAMLR, including CEMP, and it was hoped that the data in these papers (and updates thereof) could continue to be made available for work related to the review of CEMP.

Can Useful Management Advice be Derived from CEMP or be Used in Conjunction with CEMP Data?

109. Previous discussions (SC-CAMLR-XXI, Annex 4, Appendix E, paragraphs 22 to 24) by the Interim Steering Committee had concluded that intersessional work to develop models that would contribute to appropriate management advice was necessary. It recognised that valuable progress had been made (and will continue to be made), particularly work relating to the development of CSIs and functional responses (WG-EMM-03/43), and work relating to power analyses and sensitivity (WG-EMM-03/26, 03/27, 03/47, 03/49 and 03/52). The workshop recognised that such work had the potential to contribute to appropriate management advice.

110. The workshop further considered two different modelling approaches. The first approach (WG-EMM-03/33 and 03/34) allows the consideration of a spatial, dynamic ecological interaction between predators and their prey using a life-history perspective. The

second method relates indices of upper-trophic level species to indices of independent ship-based acoustic estimates of krill abundance through functional responses (WG-EMM-03/43).

Behavioural Models

111. Dr Hewitt informed the workshop that the behavioural models developed by the authors of WG-EMM-03/33 and 03/34 had considered the vertical movement of krill, aspects of penguin foraging behaviour and interactions with the krill fishery. These papers suggest that changes in species' abundance and distribution caused by human disturbances can have indirect effects on other species in a community. However, a fuller understanding of how individual behaviour determines interactions within and between species is required if such effects are to be incorporated into ecosystem approaches to management. The behavioural model predicts that increased fishing pressure offshore will lead to behavioural responses of krill and reduced penguin food intake. Given the documented links between krill and penguins, this also leads to a prediction of decreased penguin survival and reproduction. Krill behaviour is predicted to cause stronger effects from krill fisheries than those explained solely by the percentage of biomass removed. Environmental conditions that decrease krill growth rates or cause krill to spend time in deeper water are also predicted to increase the magnitude of the effect of fishing on penguin reproductive success. The authors show that changes in penguin foraging behaviour can be used to assess the impact of local fisheries on penguin reproductive success.

112. Results from WG-EMM-03/33 and 03/34 demonstrate that an understanding of predator–prey interactions, indirect effects between species, and individual behaviour, is important to our ability to manage populations, particularly if, as suggested by WG-EMM-03/34, the population dynamics of these species may respond to changes in the abundance of their prey at time scales that are too long to be used in a management context. The workshop asked Dr Hewitt to convey its thanks to Drs S. Alonzo and P. Switzer (USA) and Prof. M. Mangel (USA) for their useful contribution.

113. Dr Southwell reported that concurrent predator–prey studies at Béchervaise Island have indicated that foraging trip duration may be a sensitive indicator of krill availability (see paragraph 33). Further field studies and modelling work targeting the interactions between foraging behaviour and krill diel vertical migration may therefore prove useful for the future WG-EMM Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management.

114. Dr Sushin noted that WG-EMM-03/34 described a theoretical modelling scenario, and that as a consequence the potential utility of the model to provide advice was untested. It was agreed that the parameterisation of such models was critical and that careful validation with field observations was important.

115. The workshop therefore suggested that individuals with relevant expertise consider the model carefully with a view to providing advice, given the likely incorporation of such approaches into the WG-EMM workshop activities planned for 2004 and 2005.

Functional Responses

116. The workshop agreed that there had been significant developments in work on functional responses during the intersessional period, as described in WG-EMM-03/43 and 03/61. It was noted that a range of factors could affect the ability to fit such functions to the available krill and predator data. These included: spatial and temporal scale mismatches in the predator and prey datasets, and the fact that predators may not be obligate krill feeders and therefore the relationships may be affected by prey switching. The workshop discussion highlighted that such effects may require changes in the mathematical functions used to characterise the relationships.

117. The question of whether it is possible to estimate changes in krill abundance using predator performance indices was raised. It was noted that there is considerably more information available about predator performance than there are direct measures of local krill availability. If so, it may be possible to use the information from the predator indices to predict krill availability.

118. The workshop noted that a more explicit examination of the assumptions on which the response curve fitting is undertaken would be valuable. It was noted that it would be possible to simulate some of the effects of including estimated error distributions in the estimates of krill abundance and predator performance. It should then be possible to examine the implications for fitting predator response curves and the ability to detect changes in krill abundance.

119. Preliminary simulation studies undertaken by workshop members are reported in Attachment 3. The simulations indicated that the nature of the variability observed had significant implications for our capacity to characterise and quantify underlying predator response curves. The initial results highlighted that the current methods for determining anomalies could be improved by taking account of the nature of the variability of the krill abundance and predator performance estimates. These preliminary studies indicate that there would also be implications for how the analyses of data on krill abundance might be developed to improve the capacity to detect anomalies.

120. The workshop considered that an important aspect of the approach was that it could provide the potential for determining unusual events based on biologically significant criteria rather than just statistical significance.

121. The workshop noted that the time for developing and considering the simulations reported in Attachment 3 was severely constrained. The information presented in the appendix, although very provisional, did indicate the approach should be further developed and reported in detail. This should include further simulation work to determine the robustness of the approaches for detecting anomalies and changes in krill abundance. The workshop considered that this development was an important and novel outcome from the meeting and requested the workshop members involved (Drs Constable and Murphy) to develop the simulation studies and present a detailed account for the forthcoming Scientific Committee meeting.

Burden of Proof

122. Given the goal of precautionary management, Dr T. Gerrodette (Invited Expert) suggested that the CEMP indices could be interpreted in a different way to that currently adopted. At present, an anomalous value of an index is one that is outside the normal range, as identified by a test of statistical or biological significance. This is equivalent to testing the null hypothesis of no change. A more appropriate test in the context of precautionary management may be of the null hypothesis that an undesirable change, as identified by the management objectives, has not occurred. This alteration in the 'burden of proof' is a common component of other precautionary management regimes.

123. The workshop considered this to be a useful suggestion and recommended that it be considered further at the Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management.

OTHER MATTERS

Relationships between ISRs and SSMUs

124. Last year WG-EMM requested that the review of CEMP consider the utility of ISRs and whether the proposed SSMUs might provide a suitable alternative structure for future work on the relationships between krill, predators and fisheries (SC-CAMLR-XXI, Annex 4, paragraph 5.31).

125. It was recollected that the original formulation of CEMP distinguished two categories of operations: ISRs and network sites. The former were delimited regions (in Subarea 48.3 (South Georgia), Subarea 48.1 (Antarctic Peninsula) and Division 58.4.2 (Prydz Bay)), within which a wide range of monitoring studies, together with associated directed research, would be undertaken in order to provide insights into the nature and dynamics of prey–krill–environment interactions, including those in relation to fisheries.

126. Network sites were envisaged as locations providing as wide as possible geographic distribution of monitoring activities, albeit with a restricted range of variables being monitored at each site.

127. Although the nature of activities within SSMUs is still under discussion, it was felt unlikely that the extensive monitoring and research programs developed within ISRs would be necessary for each SSMU.

128. However, the envisaged subdivision of precautionary catch limits into SSMUs might need to be accompanied by monitoring of appropriate indicators to assess the efficacy of the management process and objectives. Initial ideas on the scope and nature of such monitoring should be sought once the nature of the precautionary catch limits and associated management operations and objectives were clarified.

129. The nature of existing CEMP monitoring within each ISR, SSMU and subarea/ division is summarised in Table 8.

ADVICE TO WG-EMM

Preparatory Work

130. CEMP data were comprehensively validated prior to the workshop. Summaries of available CEMP data and fishery data were prepared by the Secretariat (paragraphs 10, 11, 16 to 18). Although only one non-CEMP dataset was submitted to the Secretariat prior to the workshop, many such datasets were made available in background documents (paragraphs 13 and 14). Notable absences of non-CEMP data included information on krill abundance and distribution from areas other than Elephant Island and South Georgia, and fisheries information from sources other than the former USSR (paragraph 15). Analyses undertaken related to: (i) serial correlation and power of the CEMP predator indices; and (ii) functional responses between these indices and measures of krill availability.

Results of Analyses

131. With regard to analyses of serial correlation and power, the workshop concluded that:

(i) in general, the amount of serial correlation in the biological indices was not greater than what might be expected by chance alone, but there was more serial correlation in the environmental and fisheries indices (paragraph 23);

(ii) it would be useful to obtain an improved understanding of the sources of variation in the CEMP indices, including spatial and temporal variability and the consequences of such variability on power to detect trends of varying magnitude, over varying lengths of time, at different numbers of monitoring sites, and under various levels of risk. An example of the type of work necessary to achieve this understanding was developed for indices on Adélie penguins (paragraphs 34 to 38);

(iii) extending the analysis of the sources of variation to the full suite of CEMP indices may lead to improvements in CEMP. It is recommended that such work should be conducted in the near future (paragraph 39).

132. With regard to functional responses between indices of predator performance and measures of krill availability, the workshop concluded that:

(i) predator performance appears to be related to krill availability both at South Georgia and at the South Shetland Islands (WG-EMM-03/61) (paragraphs 46 to 48), but the form of the relationship differs between these two areas (paragraph 50);

(ii) at South Georgia, the relationship between predator performance and krill density was improved when multiple indices of predator performance were combined, but this was not the case for predators at the South Shetland Islands. The workshop identified a number of possible explanations for the different patterns of response by predators at these two locations (paragraphs 49 and 50);

(iii) differences in predator performance during 2001 and 2003 were also observed in the Mawson region of East Antarctica and at Edmonson Point in the Ross Sea (paragraphs 53 to 56). In the former case, this difference was attributed to differences in krill biomass, and in the latter case it was attributed to environmental conditions;

(iv) the data requirements and analytical procedures required to evaluate the indices of krill availability derived from fisheries data should be defined. A subgroup was formed to do this and to report its recommendations to WG-EMM-03 (paragraphs 60 to 63);

(v) it may be possible to use the relationships between predator performance and krill availability for predicting krill availability and for developing a biological basis for the identification of years in which predator performance was anomalous (paragraphs 64 to 66 and Attachment 3);

(vi) the ability to relate CEMP indices (both singularly and combined) to the long-term demographics of predator populations and how these might respond to long-term trends in the krill resource are critical to future work (paragraph 66).

Responses to Terms of Reference

133. With regard to the first term of reference (Are the nature and use of the existing CEMP data still appropriate for addressing the original objectives?), the workshop concluded that:

(i) the CEMP data were appropriate for detecting and recording significant change in some critical components of the ecosystem, but also emphasised that critical evaluation of the nature, magnitude and statistical significance of changes indicated by the data were necessary (paragraph 85);

(ii) it was not possible to distinguish between ecosystem changes due to harvesting of commercial species and changes due to environmental variability. It was recommended that the Scientific Committee seek advice from the Commission about the policy of how management should proceed when a significant change was detected but no causal factor could be attributed (paragraphs 87 and 88);

(iii) one possible method that may assist in the separation of confounding effects of harvesting and environmental variation would be the establishment of an experimental fishing regime whereby fishing would be concentrated in local areas in conjunction with an appropriate predator monitoring program (paragraphs 89 and 90);

(iv) useful indices of krill availability to land-based krill predators could be derived from fishery-dependent data. Intersessional work was established to address this (paragraphs 91 and 92).

134. With regard to the second term of reference (Do these objectives remain appropriate and/or sufficient?), the workshop concluded that the original objectives of CEMP remained appropriate. However, a third objective should be added 'To develop management advice from CEMP and related data' (paragraph 95).

135. With regard to the third term of reference (Are additional data available which should be incorporated in CEMP or be used in conjunction with CEMP data?), the workshop concluded that:

(i) the Secretariat should maintain a register of the wide range of non-CEMP time-series data that were of use to this workshop and of potential utility to future workshops in support of the work of WG-EMM, including datasets derived from South African and French seabird and pinniped monitoring programs in the southern Indian Ocean (paragraphs 96 and 108);

(ii) indices derived from mackerel icefish data may be of value in monitoring krill in certain regions; these indices should be subjected to the same analyses undertaken for CEMP data (paragraphs 98 to 100);

(iii) indices derived from pellets regurgitated by Antarctic shags may be of value in monitoring the early life-history stages of coastal fish species, including several of commercial importance. It was recommended that WG-FSA consider how such indices may be useful to its stock assessment and management procedures (paragraphs 101 and 102).

136. With regard to the fourth term of reference (Can useful management advice be derived from CEMP?), the workshop concluded that:

(i) behavioural models based on interactions between the aspects of the environment, krill, krill predators and a krill fishery may be of utility in a management context, although correct parameterisation and validation of such models was critical to their use (paragraphs 111 to 115);

(ii) functional responses linking predators to their prey field may also be of utility in a management context, although several confounding factors were identified requiring further work (paragraphs 116 to 119);

(iii) simulation studies conducted during the workshop indicated that accounting for the nature of the variability of estimates of krill availability and predator performance could result in improved ability to detect anomalies (paragraphs 119 to 121 and Attachment 3);

(iv) further consideration of 'burden of proof' issues might be timely (paragraphs 122 and 123);

(v) all the above topics might appropriately be considered at the WG-EMM Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management.

137. The workshop considered the relationship between ISRs and SSMUs, and concluded that it would be unlikely that the extensive monitoring and research programs developed

within ISRs would be necessary for SSMUs (paragraph 127). Nevertheless, monitoring within SSMUs might need to be extensive and the workshop summarised the nature of existing CEMP monitoring within each SSMU (paragraphs 128 and 129 and Table 8).

Future Work

138. A program of future work was defined and is summarised in Table 9.

ADOPTION OF REPORT AND CLOSE OF WORKSHOP

139. The report, with figures, tables and attachment, was adopted.

140. The Convener of WG-EMM, Dr Hewitt, thanked the Co-conveners for their hard work in coordinating and organising the workshop and their guidance throughout in ensuring its success.

141. The Co-conveners thanked all the participants, particularly the members of the CEMP Review Steering Committee and of the intersessional and workshop subgroups. They thanked the invited experts for their valuable contributions, all the owners and originators of submitted data, without which the review could not have taken place, and the Secretariat for their unfailing support both intersessionally and at the workshop.

142. The workshop closed on 22 August 2003.

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Woehler, E., J. Cooper, J.P. Croxall, W.R. Fraser, G.L. Kooyman, G.D. Miller, D.C. Nel, D.L. Patterson, H.-U. Peter, C.A. Ribic, K. Salwicka, W.Z. Trivelpiece and H. Weimerskirch. 2001. *A Statistical Assessment of the Status and Trends of Antarctic and SubAntarctic Seabirds*. SCAR, Cambridge.

Table 1: Summary data matrix for CEMP biological indices currently held in the CEMP database. Number of years for which data are available. A1: weight of adult penguin on arrival; A2: duration of penguin incubation shift; A3: penguin breeding population size; A5a: duration of penguin foraging; A6: penguin breeding success (a: chicks fledged per egg laid; b: % potential chicks; c: chicks fledged per chicks hatched); A7: penguin chick weight at fledging; A8: weight of stomach contents of adult penguins; A8: diet composition of adult penguin (b: proportion; c: occurrence); B1a: albatross breeding population size; B1b: albatross breeding success; B5c: petrel breeding population size; C1: duration of fur seal cow foraging; C2b: growth rate of fur seal pups.

Species	Site	Biological Index														
		A1	A2	A3	A5a	A6a	A6c	A7	A8	A8b	A8c	B1a	B1b	B5c	C1	C2b
Arctocephalus gazella (SEA)	Bird Island (BIG)														14	14
	Bouvetoya (Bouvet Island) (BOI)														2	2
	Cape Shirreff (CSS)														6	10
	Seal Island (SES)														7	8
Diomedea melanophrys (DIM)	Bird Island (BIG)											28	28			
Eudyptes chrysolophus (EUC)	Bird Island (BIG)	15		28		27		15	15	15	15					
	Bouvetoya (Bouvet Island) (BOI)			2	2	2			2	2	2					
	Elephant Island (Stinker Point) (EIS)			1		1		1	2	2	2					
	Marion Island (MAR)	9		9			9	9	9	9	9					
	Seal Island (SES)				1		7	1								
Pygoscelis adeliae (PYD)	Admiralty Bay (ADB)		21	26		3		18	18	18	18					
	Anvers Island (Antarctic Peninsula) (AIP)			8	10		10	10	10	10	10					
	Béchervaise Island (BEE)	12	13	13	11	12	12	12	11	11	11					
	Edmonson Point (EDP)	2	5	9	1	7	6	3	5	5	5					
	Esperanza Station (Hope Bay) (ESP)	6	8	9		9		8								
	Laurie Island (LAO)	3		8		7			6	6	6					
	Magnetic Island (Prydz Bay) (MAD)		1	1			1	1								
	Ross Island (ROS)			21												
	Shirley Island (Casey Station) (SHI)			1	1	1	1		1	1	1					
	Signy Island (SIO)			13		13		7	7	7	7					
	Stranger Point (King George Island) (SPS)	2		9		8			2	2	2					
	Syowa Station (SYO)			22												
	Verner Island (Mawson Station) (VIM)	1		6												

(continued)

Table 1 (continued)

Species	Site	Biological Index														
		A1	A2	A3	A5a	A6a	A6c	A7	A8	A8b	A8c	B1a	B1b	B5c	C1	C2b
Pygoscelis antarctica (PYN)	Admiralty Bay (ADB)		13	25		2		8	18	18	18					
	Bouvetoya (Bouvet Island) (BOI)			2	2	2			2	2	2					
	Cape Shirreff (CSS)			6		4		7	6	6	6					
	Elephant Island (Stinker Point) (EIS)			1		1		2	2	2	2					
	Laurie Island (LAO)								6	6	6					
	Seal Island (SES)				7		8	10	7	7	7					
	Signy Island (SIO)	6		13		13		7	7	7	7					
Pygoscelis papua (PYP)	Admiralty Bay (ADB)			25		2		6	16	16	16					
	Bird Island (BIG)			27		26		14	15	15	15					
	Cape Shirreff (CSS)			6				4	6	6	6					
	Marion Island (MAR)			9		6	3	9	3	3	3					
	Signy Island (SIO)			13		13			5	5	5					
Thalassoica antarctica (TAA)	Svarthamaren (SVA)													6		

Table 2: Non-CEMP data available at the workshop.

Type of Data	Years	Availability
BIOLOGICAL DATA		
Antarctic and sub-Antarctic seabirds and seals		
Status and trends of seabirds	Various times, areas	Woehler et al., 2001
Predators at South Georgia		
Black-browed albatross peak mass	1989–2003	Submitted to Secretariat
Fur seal median pupping date	1984–2003	Submitted to Secretariat
Fur seal pup production	1979–2003	Submitted to Secretariat
Fur seal birth mass	1984–2003	Submitted to Secretariat
Fur seal frequency of fish in diet	1999–2003	Submitted to Secretariat
Fur seal pup survival	1979–2003	Submitted to Secretariat
Fur seal growth deviate	1989–2003	Submitted to Secretariat
Predators at South Shetland Islands		
Predator parameters	1978–2003	WG-EMM-03/61
Penguin population parameters	1981–2000	WG-EMM-03/29
Fur seal performance indices	1987–2003	WG-EMM-03/54
Predators in Indian Ocean		
Seabird population parameters	2001–2002	WG-EMM-03/9
Seabird population parameters, diet	1980s, 1994–2003	WG-EMM-03/8, 10, 11, 13, 15, 16, 17
Seabird population parameters	1950s–2000	WG-EMM-03/53
Fur seal population parameters	2001	WG-EMM-03/18
Predators in Eastern Antarctica		
Penguin population parameters	2000–2003	WG-EMM-03/59
Penguin foraging and breeding	2001–2003	WG-EMM-03/44
Icefish		
Standing stock	Various times, areas	WG-EMM-03/42
Cohort strength, recruitment	Various times, areas	WG-EMM-03/42
Natural mortality	Various times, areas	WG-EMM-03/42
Length at age 1+ and 2+ years	Various times, areas	WG-EMM-03/42
Condition	Various times, areas	WG-EMM-03/42
Gonad maturity	Various times, areas	WG-EMM-03/42
Diet	Various times, areas	WG-EMM-03/42
Size and age	1987–2002	WG-EMM-03/7
Age and growth	Various times	WG-EMM-03/60
Species profile	Various times	WG-FSA-03/4
Coastal fish populations		
Shag diet	Various years	WG-EMM-03/5
Krill		
CPUE	1977–1992	WG-EMM-03/35
Krill at South Georgia		
Length index	1991–2003	Submitted to Secretariat
Density	1981–2003	Submitted to Secretariat
Biomass and density	2002	WG-EMM-03/30
Size	1988	WG-EMM-03/40
Krill at South Shetland Islands		
Biomass and density	1991–2002	WG-EMM-03/6
Abundance	1978–2003	WG-EMM-03/61
Krill in Eastern Antarctica		
Biomass and density	2001–2003	WG-EMM-03/44
SO GLOBEC		
Plankton, krill and predators	2001–2002	globec.whoi.edu/globec

(continued)

Table 2 (continued)

Type of Data	Years	Availability
ENVIRONMENTAL DATA		
DPOI	1952–2003	WG-EMM-03/46
SST adjacent to South Georgia	1989–2003	WG-EMM-03/20
Air temperature Indian Ocean	1950s–2000	WG-EMM-03/53
Sea-ice at South Shetland Islands	1978–2003	WG-EMM-03/61
SO GLOBEC Southwest Atlantic		
Hydrography, sea-ice, currents, bathymetry, meteorology	2001–2002	globec.whoi.edu/globec
Ross Sea		
Automatic weather stations	1987–1999	meteo.pnra.it
Air temperature data	1984–2003	meteo.pnra.it
Synoptic data	1994–2003	meteo.pnra.it
Satellite images	1998–2003	meteo.pnra.it

Table 3: Types of data of known or potential utility in relation to CEMP (SC-CAMLR-XXI, Annex 4, Appendix E, Table 1).

KRILL	METEOROLOGY AT CEMP SITE
Abundance	Precipitation
Distribution	Air temperature
Demographics	
Condition	PREDATOR PARAMETERS (non-CEMP)
Fisheries performance	Demographics
	Diet composition
PELAGIC PREDATORS	
Whales	DATA FROM OTHER BODIES/PROGRAMS
Crabeater seals	IWC
Icefish	SCAR
	France
BIOLOGICAL ENVIRONMENT	LTER
Primary productivity	
Other prey species	DATA FROM ‘NON-KRILL’ FISHERIES
Salps	IMAF
	Icefish
PHYSICAL ENVIRONMENT	Squid
Sea-ice	Myctophids
Frontal positions	
ENSO	
DPOI	
SST	
Surface-layer temperature	

Table 4: Sources of variation in CEMP index A3 (breeding population size) for Adélie penguins at a variety of CEMP sites. Proportions represent the proportion of the total variation in a time series from the CEMP database.

CEMP Site	Proportion Representing Process Variation	Proportion Representing Measurement Variation
Admiralty Bay (ADB)	0.9880	0.0120
Béchervaise Island (BEE)	0.9355	0.0645
Ross Island (ROS)	0.9983	0.0017
Anvers Island (AIP)	0.9238	0.0762
Edmonson Point (EDP)	0.9937	0.0063
Esperanza Station (ESP)	0.9879	0.0121
Laurie Island (LAO)	0.8068	0.1932
Signy Island (SIO)	0.9587	0.0413
Stranger Point (SPS)	0.9599	0.0401
Syowa Station (SYO)	0.9925	0.0075
Verner Island (VIM*)	–2.6463	3.6463

* The estimate of measurement variation at this site was greater than the total amount of variation empirically estimated from the CEMP database, suggesting that the assumption used to develop an estimate of the measurement error was positively biased in this case.

Table 5: Sources of variation in CEMP index A5a (mean foraging trip duration) for Adélie penguins at three CEMP sites. Proportions represent the proportion of the total variation in a time series from the CEMP database.

CEMP Site	Proportion Representing Process Variation	Proportion Representing Measurement Variation
Admiralty Bay (ADB*)	–0.3470	1.3470
Béchervaise Island (BEE)	0.3389	0.6611
Anvers Island (AIP)	0.6758	0.3242

* The estimate of measurement variation at this site was greater than the total amount of variation empirically estimated from the CEMP database, suggesting that variation in foraging-trip duration among individuals and among trips is a large source of variation that data in the CEMP database cannot account for.

Table 6: Sources of variation in CEMP index A6c (breeding success) for Adélie penguins at three CEMP sites. Proportions represent the proportion of the total variation in a time series from the CEMP database.

CEMP Site	Proportion Representing Process Variation	Proportion Representing Measurement Variation
Admiralty Bay (ADB)	0.9957	0.0043
Béchervaise Island (BEE)	0.9911	0.0089

Table 7: Examples of environmental covariates, potentially important in relationships between krill predators and their prey. Numbers indicate the relative ranking between regions (1 = minimal influence, 2 = moderate influence, 3 = major influence).

	Sea-Ice	Fast-ice and Icebergs	Total Sum of Ranking
Scotia Sea			
South Georgia	1	1	2
South Orkney Islands	3	2	5
South Shetland Islands	3	2	5
Ross Sea	3	3	6
East Antarctica	3	3	6

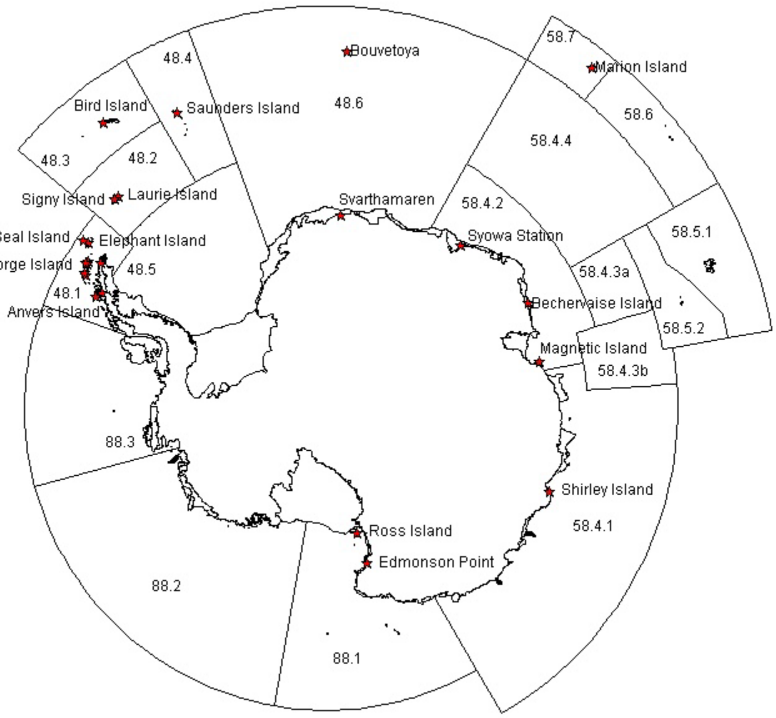
Table 8: Summary of CEMP data (number of annual index values) by ISR and SSMU. Details of the specific parameters measured at each site can be found in WG-EMM-03/24, Table 4. AP: Antarctic Peninsula (BSE Bransfield Strait East; DPW: Drake Passage West; EI: Elephant Island; W: Western); SO: South Orkney Islands (NE: North East); SG: South Georgia (W: West); *: in part.

Subarea/ Division	ISR	SSMU	CEMP Site/Area	CEMP Indices								
				Penguins				Fur Seal	Black-browed Albatross	Antarctic Petrel	Krill Fishery	Sea-ice and SST
				Macaroni	Adélie	Chinstrap	Gentoo					
48.1	AP	APBSE	Admiralty Bay (ADB)		175	131	106					
	AP	APW	Anvers Island (AIP)		96							67
	AP	APDPW	Cape Shirreff (CSS)			46	39	26				21
	AP	APEI	Elephant Island (EIS)									21
	AP	APBSE	Esperanza Station (ESP)		44							21
	AP	APEI	Seal Island (SES)	7		65		23				67
	AP	APBSE	Stranger Point (SPS)		25							67
	AP*	AP*	Subarea 48.1								188	24
48.2	-	SONE	Laurie Island (LAO)		45	30						21
	-	SONE	Signy Island (SIO)		66	76	48					67
		SO*	Subarea 48.2								134	24
48.3	SG	SGW	Bird Island (BIG)	173			139	42	84			21
	SG*	SG*	Subarea 48.3								158	24
48.6	-	-	Svarthamaren (SVA)							4		
58.4.1	-	-	Division 58.4.1								34	
58.4.2	Prydz Bay	-	Magnetic Island (MAD)									21
	Prydz Bay	-	Béchervaise Island (BEE)		199							52
	Prydz Bay	-	Verner Island (VIM)		5							
	Prydz Bay	-	Prydz Bay									24
	Prydz Bay*	-	Division 58.4.2								31	
	-	-	Syowa Station (SYO)		21							21
58.4.4	-	-	Division 58.4.4								6	
58.7	-	-	Marion Island (MAR)	89			39					
88.1	-	-	Subarea 88.1								20	
	-	-	Edmonson Point (EDP)		64							21
	-	-	Ross Island (ROS)		14							
88.3	AP*	-	Subarea 88.3								8	

Table 9: Future work for the 2003/04 intersessional period.

	Task/Topic	Paragraphs of Report	Responsibility	Comments
1.	Further examine the sources and magnitudes of variability in predator response parameters.	39	Data Manager, UK, USA, Southwell	Hold an analysis meeting during the 2003/04 intersessional period.
2.	Further work on defining the relationship between estimates of krill abundance and availability to dependent species.	50(v)	UK, USA	
3.	Within the CSI approach, identify indices where systematic biases might be inherent in missing data.	51 and 52	UK, Australia	
4.	Investigate the utility of haul-by-haul CPUE data as a proxy for direct measures of krill availability, with a view to further analyses of functional relationships for research purposes.	59 to 63	Hewitt, Naganobu, Nicol, Reid, Sushin	Terms of Reference are in paragraph 63. Interim report to 2003 meeting of WG-EMM.
5.	Investigate alternate methods for determining anomalies by using predator response curves for a predator parameter or composite index.	64 to 66, 119 to 121 and Attachment 3	Constable, Murphy	Interim report to the 2003 meeting of the Scientific Committee.
6.	Develop a matrix of environmental parameters that are potentially important covariates in the analyses of predator–prey interactions.	82 and Table 7	Trathan, Wilson, Southwell	
7.	Maintain a register of non-CEMP time-series data of potential utility for future CEMP work.	96	Secretariat	Commence with data listed in Table 2. Review and incorporate other datasets/sources after discussion with members of the CEMP Review Steering Committee and/or conveners of Scientific Committee working groups.

(a)



(b)

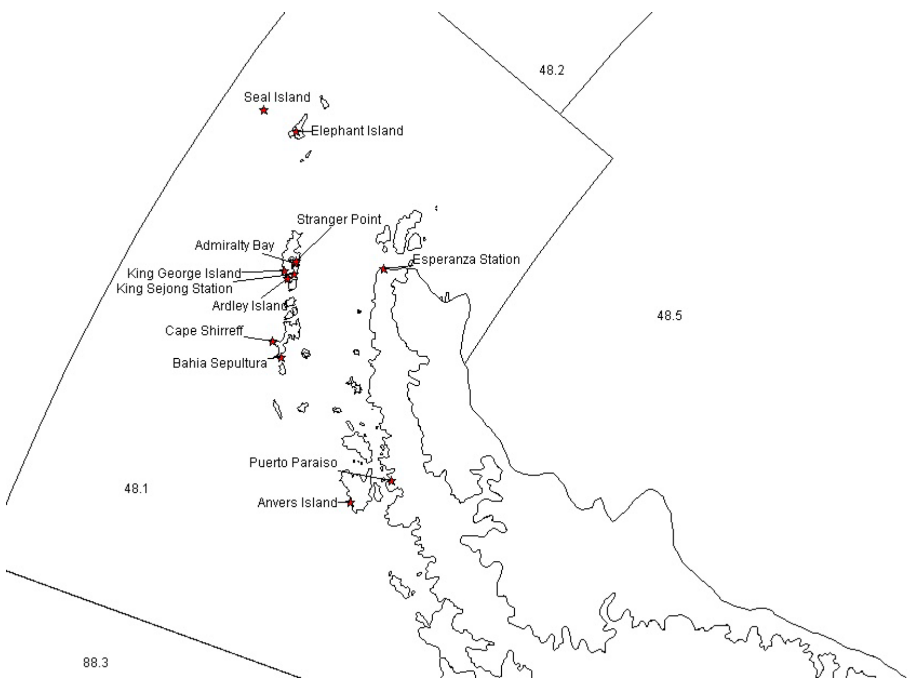


Figure 1: Location of CEMP sites (star). General view (a) and Antarctic Peninsula (b).

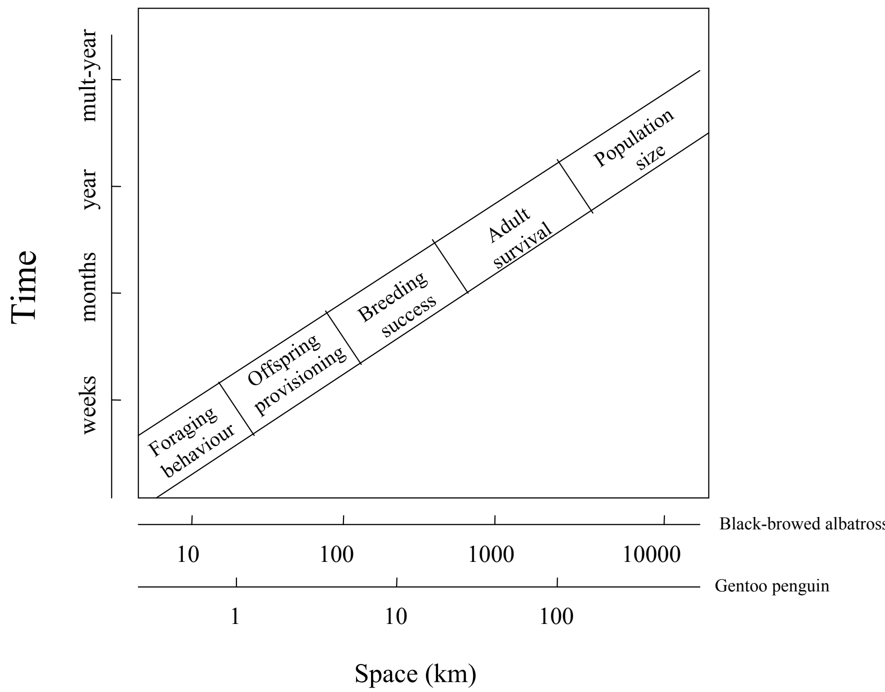


Figure 2: The spatial and temporal scales over which indices of predator performance reflect ecosystem processes. The x-axes scales reflect the two extremes within the group of predators in the CEMP database (from WG-EMM-03/43).

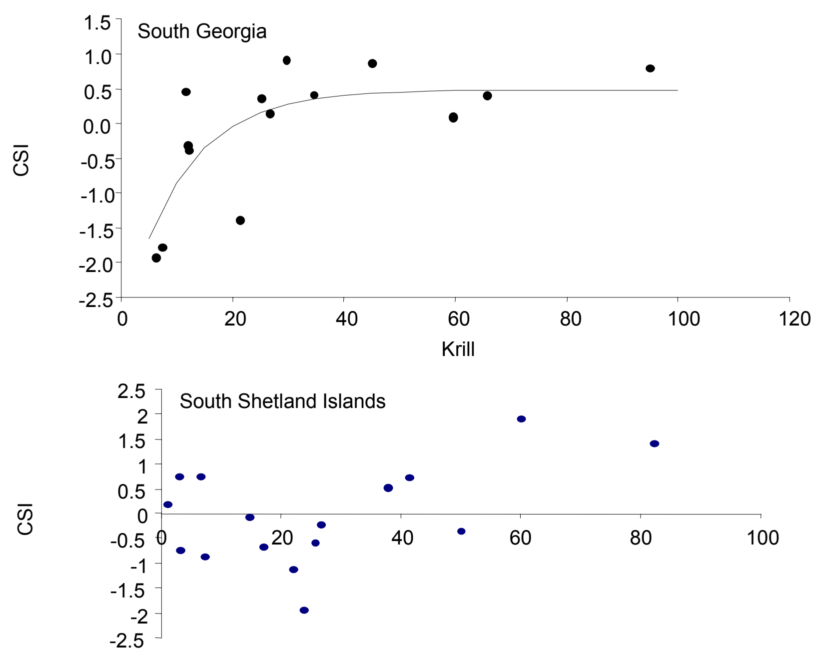


Figure 3: The relationship between krill density (g m^{-2}) and CSI of predator performance at South Georgia and South Shetland Islands.

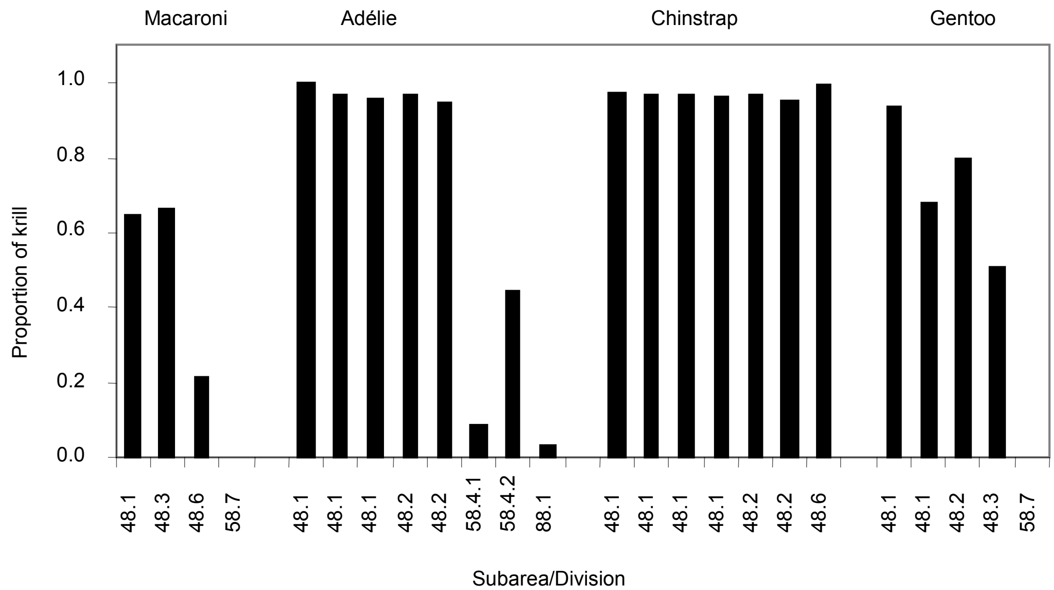


Figure 4: The mean proportion by mass of krill (*Euphausia superba*) in the diet of penguins. Data from the CEMP database.

ATTACHMENT 1

LIST OF PARTICIPANTS

CEMP Review Workshop
(Cambridge, UK, 18 to 22 August 2003)

* Members of the CEMP Review Steering Committee

ANTONIO, Celio (Mr)	Subsecretário para Desenvolvimento de Pesca e Aquicultura Secretaria Especial de Aquicultura e Pesca da Presidência da República Esplanada dos Ministérios Bloco D, 9º Brasilia, DF 70043-900 Brazil celioan@agricultura.gov.br
AKKERS, Theressa (Ms)	Research Support and Administration Research and Development Marine and Coastal Management Private Bag X2 Rogge Bay 8012 South Africa takkers@mcm.wcape.gov.za
BERGSTRÖM, Bo (Dr)	Kristineberg Marine Research Station S-450 34 Fiskebäckskil Sweden b.bergstrom@kmf.gu.se
CONSTABLE, Andrew (Dr)	Australian Antarctic Division Environment Australia Channel Highway Kingston Tasmania 7050 Australia andrew.constable@aad.gov.au
CORSOLINI, Simonetta (Dr)	Dipartimento di Scienze Ambientali Università di Siena Via P.A. Mattioli, 4 53100 Siena Italy corsolini@unisi.it

CRAWFORD, Robert (Dr)	Marine and Coastal Management Private Bag X2 Roggebaai 8012 South Africa crawford@mcm.wcape.gov.za
CROXALL, John (Prof.)*	British Antarctic Survey High Cross, Madingley Road Cambridge CB3 0ET United Kingdom j.croxall@bas.ac.uk
DAVIES, Campbell (Dr)	Australian Antarctic Division Environment Australia Channel Highway Kingston Tasmania 7050 Australia campbell.davies@aad.gov.au
FANTA, Edith (Dr)	Departamento Biologia Celular Universidade Federal do Paraná Caixa Postal 19031 81531-970 Curitiba, PR Brazil e.fanta@terra.com.br
FORCADA, Jaume (Dr)	British Antarctic Survey High Cross, Madingley Road Cambridge CB3 0ET United Kingdom jfor@bas.ac.uk
GERRODETTE, Tim (Dr)	Southwest Fisheries Center 8604 La Jolla Shores Drive La Jolla, CA 92037 USA tim.gerrodette@noaa.gov
GOEBEL, Michael (Dr)*	US AMLR Program Southwest Fisheries Science Center 8604 La Jolla Shores Drive La Jolla, CA 92037 USA mike.goebel@noaa.gov

HEWITT, Roger (Dr)*	US AMLR Program Southwest Fisheries Science Center 8604 La Jolla Shores Drive La Jolla, CA 92037 USA roger.hewitt@noaa.gov
HILL, Simeon (Dr)	British Antarctic Survey High Cross, Madingley Road Cambridge CB3 0ET United Kingdom sih@bas.ac.uk
HOFMANN, Eileen (Prof.)	Center for Coastal Physical Oceanography Crittenton Hall Old Dominion University 768 52nd Street Norfolk, VA 23529 USA hofmann@ccpo.odu.edu
HOLT, Rennie (Dr)	Chair, Scientific Committee US AMLR Program Southwest Fisheries Science Center 8604 La Jolla Shores Drive La Jolla, CA 92037 USA rennie.holt@noaa.gov
KIRKWOOD, Geoff (Dr)	Renewable Resources Assessment Group Imperial College RSM Building Prince Consort Road London SW7 2BP United Kingdom g.kirkwood@ic.ac.uk
KOUZNETSOVA, Elena (Dr)	VNIRO 17a V. Krasnoselskaya Moscow 107140 Russia vozrast@vniro.ru
MURPHY, Eugene (Dr)	British Antarctic Survey High Cross, Madingley Road Cambridge CB3 0ET United Kingdom e.murphy@bas.ac.uk

NAGANOBU, Mikio (Dr)*	National Research Institute of Far Seas Fisheries 5-7-1, Shimizu Orido Shizuoka 424-8633 Japan naganobu@affrc.go.jp
NICOL, Steve (Dr)*	Australian Antarctic Division Environment Australia Channel Highway Kingston Tasmania 7050 Australia steve.nicol@aad.gov.au
OLMASTRONI, Silvia (Dr)	Dipartimento di Scienze Ambientali Università di Siena Via P.A. Mattioli, 4 53100 Siena Italy olmastroni@unisi.it
REID, Keith (Dr)*	British Antarctic Survey High Cross, Madingley Road Cambridge CB3 0ET United Kingdom k.reid@bas.ac.uk
SHUST, Konstantin (Dr)	VNIRO 17a V. Krasnoselskaya Moscow 107140 Russia antarctica@vniro.ru
SOUTHWELL, Colin (Dr)*	Australian Antarctic Division Environment Australia Channel Highway Kingston Tasmania 7050 Australia colin.southwell@aad.gov.au
SULLIVAN, Kevin (Dr)	Ministry of Fisheries PO Box 1020 Wellington New Zealand sullivak@fish.govt.New Zealand

SUSHIN, Vyacheslav (Dr)	AtlantNIRO 5 Dmitry Donskoy Str. Kaliningrad 236000 Russia sushin@atlant.baltnet.ru
TRATHAN, Philip (Dr)*	British Antarctic Survey High Cross, Madingley Road Cambridge CB3 0ET United Kingdom p.trathan@bas.ac.uk
TRIVELPIECE, Sue (Ms)	US AMLR Program Antarctic Ecosystem Research Division PO Box 1486 19878 Hwy 78 Ramona, CA 92065 USA sueskua@aol.com
TRIVELPIECE, Wayne (Dr)	US AMLR Program Southwest Fisheries Science Center 8604 La Jolla Shores Drive La Jolla, CA 92037 USA wayne.trivelpiece@noaa.gov
VANYUSHIN, George (Dr)	VNIRO 17a V. Krasnoselskaya Moscow 107140 Russia sst.ocean@g23.relcom.ru
WATTERS, George (Dr)	Southwest Fisheries Science Center Pacific Fisheries Environmental Laboratory 1352 Lighthouse Avenue Pacific Grove, CA 93950-2097 USA george.watters@noaa.gov
WILSON, Peter (Dr)	Manaaki Whenua – Landcare Research Private Bag 6 Nelson New Zealand wilsonpr@landcareresearch.co.nz

Secretariat:

Denzil MILLER (Executive Secretary)	CCAMLR
Eugene SABOURENKOV (Science Officer)	PO Box 213
David RAMM* (Data Manager)	North Hobart 7002
Rosalie MARAZAS (Website and Information Services Officer)	Tasmania Australia
Genevieve TANNER (Communications Officer)	ccamlr@ccamlr.org

ATTACHMENT 2

AGENDA

CEMP Review Workshop
(Cambridge, UK, 18 to 22 August 2003)

1. Introduction

   1.1 Adoption of agenda and work plan
   1.2 Operational issues and appointment of rapporteurs

2. General review of planning and preparatory work

3. General review of data, supporting papers and other materials available

4. CEMP Review Workshop

   4.1 Defining those indices which, either singly or in combination, are the most informative biologically

      4.1.1 Update on intersessional work
         (i) Data availability and validation
            (a) CEMP data: spatial and temporal availability, by species and parameter (data matrices)
            (b) Non-CEMP data: spatial and temporal availability, by species and parameter (data matrices)
         (ii) Sensitivity analyses
            (a) Spatial and temporal correlation issues and solutions
            (b) Type I and type II error level considerations
            (c) Effect size and form of change considerations
            (d) Progress on analysis of western Antarctic data
            (e) Progress on analysis of eastern Antarctic data
         (iii) Issues related to predator parameters as indicators of krill availability

      4.1.2 Predator parameters as indicators of krill availability
         (i) Prey parameters
            (a) Availability of predator/krill data
            (b) Proxies to krill data
         (ii) Functional relationships
            (a) Availability of predator/krill or proxy data
            (b) Modelling relationships

(iii) Composite indices
(iv) Indicator species
(v) Responsiveness

4.1.3 Environmental parameters

4.1.4 Sensitivity analyses
(i) Time required to detect a trend
(ii) Frequency of monitoring
(iii) Number of monitoring sites
(iv) Interactions and trade-offs between monitoring progam parameters

4.1.5 Appropriateness of parameters to monitoring at different scales and for different purposes

4.2 Implementation considerations

4.3 Management advice considerations

4.4 Further work on the workshop theme program

5. Responses to the Terms of Reference for the CEMP Review

5.1 Are the nature and use of the existing CEMP data still appropriate for addressing the original objectives?

5.2 Do these objectives remain appropriate and/or sufficient?

5.3 Are additional data available which should be incorporated in CEMP or be used in conjunction with CEMP data?

5.4 Can useful management advice be derived from CEMP or be used in conjunction with CEMP data?

6. Other matters

6.1 Potential links between ISRs and SSMUs

7. Further work

8. Advice to WG-EMM.

USING PREDATOR RESPONSE CURVES TO DECIDE ON THE STATUS OF KRILL AVAILABILITY: UPDATING THE DEFINITION OF ANOMALIES IN PREDATOR CONDITION – PRELIMINARY ANALYSES

By A. Constable[1] and E. Murphy[2]
[1] Australian Antarctic Division
[2] British Antarctic Survey

A number of predator parameters monitored in CEMP have been shown, using non-linear regression, to be correlated to krill availability. These relationships will be termed 'predator response' curves in this note. The aim of this note is to consider the use of predator response curves in helping make decisions about the status of krill availability in a given year, based on the magnitude of the predator parameter or composite index for that year. In doing so, the note will consider the types of data available, the uncertainties associated with the analysis and consideration about how decisions on krill availability might be made.

BACKGROUND

2. Currently, the determination of extreme years for predators is through a two-tailed test of anomalies. This test determines whether the value of a predator parameter or a composite index is outside the generally observed norm, i.e. less than the lower 2.5 percentile or above the 97.5 percentile of the baseline series. This identifies very good or very poor years, whichever sign they may be assigned.

3. Over the last five years, data have been used for estimating predator response curves, using non-linear regression techniques. These data comprise:

(i) individual predator parameters estimated for a year
(ii) relative estimates of krill abundance for a given year.

4. The predator parameters may be combined into CSIs, first presented to WG-EMM in 1997 (de la Mare, 1997) and later elaborated in de la Mare and Constable (2000) and Boyd and Murray (2001).

5. Difficulties arise with these datasets when data may not be available for some years (de la Mare and Constable, 2000). This is critical if they are more likely to be the low krill years.

COMPARING PREDATOR RESPONSE CURVES TO FUNCTIONAL FEEDING RELATIONSHIPS

6. Functional relationships are often considered in the form of functional feeding relationships which relate the consumption rate of a predator to prey (krill) abundance. In this

case, the relationship will begin at the origin and increase in some form, usually to an asymptote. Two types of relationship are usually considered – Holling Type II and Holling Type III. These are illustrated in Figure 1.

7. The formulation of the relationship is

$$f\left(k_d, k_{0.5}, q\right) = \frac{k^{q+1}}{k_{0.5} + k^{q+1}} \tag{1}$$

where k_d is krill density, $k_{0.5}$ is the krill density when the function equals half the range and q is a shape parameter such that the function is a Holling Type II when $q = 0$ and Holling Type III when $q > 0$.

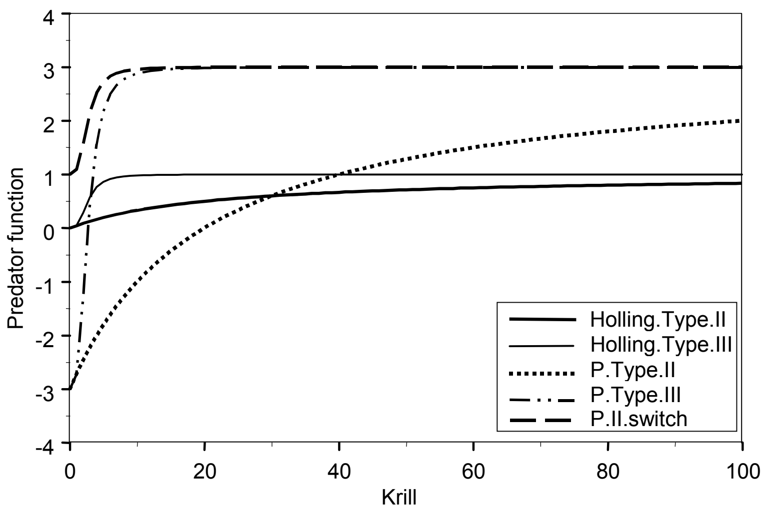


Figure 1: Predator functions in response to hypothetical levels of krill availability. The Holling Type II and Type III functions are functional feeding relationships. The P.Type II and Type III functions are predator response curves based on the respective functional feeding relationships but not restricted to the origin. The P.II.switch curve illustrates the potential effect of prey switching on the predator response, such that the predator remains relatively unaffected when krill are absent.

8. The predator response curves considered by WG-EMM differ from the feeding relationships in four main ways:

(i) estimate a response (parameter/s) of predator performance relative to availability of the prey (krill) species;

(ii) prey switching or other factors may result in relationship not beginning at the origin;

(iii) the shape function may be influenced by many factors other than the prey;

(iv) combined indices potentially range from $-\infty$ to $+\infty$.

9. The formulation of the predator response curve is based on the equation above, such that

$$P\left(P_{range}, k_d, k_{0.5}, q\right) = P_{range}\left[\frac{k^{q+1}}{k_{0.5} + k^{q+1}}\right] + P_0 \qquad (2)$$

where P_{range} is the range of the predator response from P_0, which is the value of the predator response when krill availability is zero, and the upper asymptote.

10. Examples of predator responses based on the Holling Type II and III formulations as well as the effect of prey switching are shown in Figure 1.

UTILITY OF PREDATOR RESPONSE CURVES

11. Predator response curves have been proposed to be used to facilitate decisions on when krill abundance is seriously affecting predators (Boyd, 2002). Alternatively, in the absence of estimates of krill availability, these curves might be used to help estimate from predator parameters what the status of the krill availability is for a given year. A question is whether such an approach might also be useful for areas where predator parameters may be monitored but little information is available on krill availability.

12. A number of uncertainties may influence the utility of this approach.

(i) The correlation between the predator response variable and krill availability may be poor and may not appropriately match the spatial and temporal scales or locations of the krill time series.

(ii) Predators may not be obligate krill feeders and therefore the relationship may be influenced by prey switching or other factors.

(iii) The abundance of krill is highly variable, approximating a lognormal distribution, which means that the chances of sampling at the lower end of krill availability will be low and potentially problematic in short time series of data, such that the ability to estimate the curvature in the relationship may be poor.

(iv) The probability of sampling at the lower end may also be reduced further by autocorrelation in the time series of krill abundance, which could also lead to autocorrelation in the predator response.

(v) The estimates of krill availability have uncertainty as well with errors considered to be lognormally distributed.

(vi) Uncertainties in the underlying model of predator response to krill availability, e.g. difference between Type II and Type III approaches.

(vii) The error function for the predator response may not be correctly modelled with a Gaussian or lognormal.

13. The results of some of these uncertainties are illustrated in Figure 2 which shows a predator response curve that then is sampled according to error functions on both krill availability and the predator response. This set of samples is then used to illustrate the issues below.

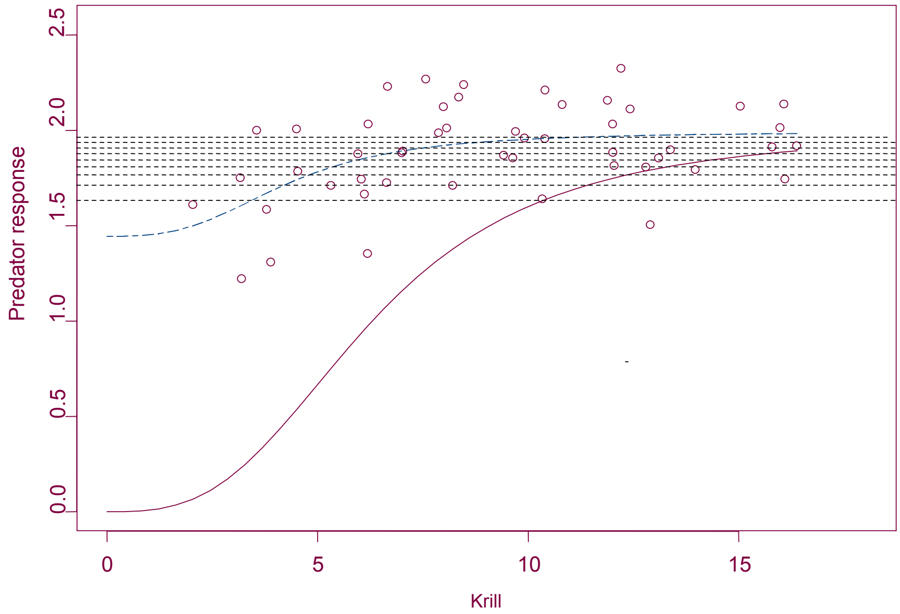


Figure 2: Predator response related to theoretical krill availability. Points are estimates of the predator response to estimates of krill abundance. The solid line shows the Type III relationship. The dashed line shows the fitted relationship using non-linear regression estimating P_{range}, P_0 and $K_{0.5}$. Horizontal dashed lines show the 0.05 percentile intervals starting at the lower 0.05 percentile and increasing to the 0.5 percentile. The shift of the points to the left of the true predator response curve is because of the lognormal error function in the krill estimates (based on the range of CVs observed at the Antarctic Peninsula).

14. The parameters in equation 2 (except for q in this simulation) were estimated using a non-linear regression (see Figure 2). The percentiles for the asymptote were estimated based on the residuals of the fit and the estimate of P_{range} plus P_0.

DECIDING ON STATUS OF KRILL AVAILABILITY

15. In order to decide on the status of krill availability based on the estimate of predator response, the relationship needs to be viewed as krill availability as predicted by a function of predator response. Figure 2 has been replotted in Figure 3 to reflect this change of view.

16. Figure 3 illustrates how there is little or no information above the lower 0.05 percentile of the predator response for estimating the availability of krill. Therefore, the first step is to determine an appropriate percentile of predator response, above which the data would be excluded from an assessment of krill availability under the assumption that the krill availability is likely to be sufficient for predators. The area of interest would then be below that percentile.

17. Figure 3 also provides the current approach to estimating anomalies where the lower 0.025 percentile and upper 0.975 percentile are shown. It also shows a one-tailed test of anomalies such as the lower 0.1 percentile illustrated.

18. In this example, it would appear that the estimation of the predator response asymptote and its variance provides an opportunity to revise the view of anomaly such that an anomaly would be any value of the predator response falling below the critical percentile.

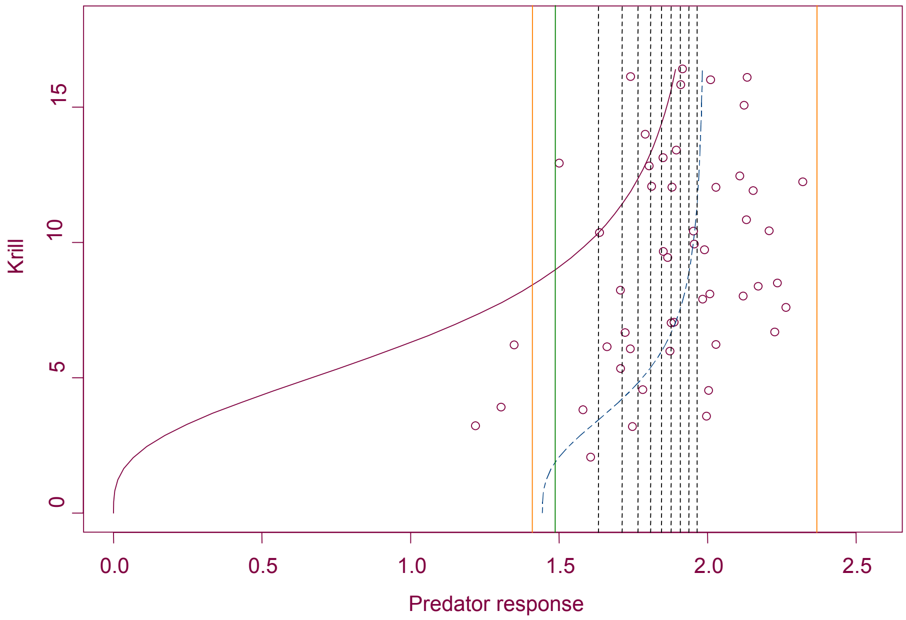


Figure 3: The inverted predator response curve to consider the estimation of krill availability from the predator response. Lines are as indicated in Figure 2. The vertical solid lines indicate from left to right – lower 0.025 anomaly, lower 0.1 anomaly and upper 0.975 anomaly as formulated for the predator response by WG-EMM in 1997.

CONCLUSIONS

19. This short note provides some possibilities for the future work of WG-EMM:

(i) it is apparent that the current method for determining anomalies could be improved for some parameters based on appropriate predator response estimates;

(ii) the ability to decide on krill availability will be contingent on the CV of the predator response in the upper part of the range of krill availability;

(iii) it seems most likely that the asymptote of the predator response curve will be reasonably estimated while the lower tail may be difficult to estimate in short time series. This would favour an approach based on anomalies rather than estimation of krill availability;

(iv) the lognormal errors in the krill estimates will cause some problems with this procedure and will need to be incorporated explicitly in the approach in the future.

20. Given the uncertainties surrounding these responses and the importance of identifying a critical level below which the predator response is likely to be reduced, it would seem reasonable to conclude that the lower percentile anomaly test should be a one-tailed test and probably at a higher percentile than the current 0.025.

21. The use of predator response curves provides an opportunity to base the anomaly criterion on biological rather than statistical parameters. It is a way of screening out the lower tail of predator responses in defining a more biologically oriented criterion.

22. Further simulation work is needed to determine the robustness of the method to the uncertainties in the approach described above. In that respect, simulations to identify the length of time series required to undertake this assessment would be very helpful.

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