ANNEX 5

REPORT OF THE FIRST MEETING OF THE WORKING GROUP ON KRILL

(Southwest Fisheries Centre, La Jolla, California, USA, 14 to 20 June 1989)

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INTRODUCTION

The meeting of the Working Group was held at the Southwest Fisheries Centre of the National Marine Fisheries Service, La Jolla, California, USA, from 14 to 20 June 1989. The Convener, (Mr D.G.M. Miller), chaired the meeting.

2. A provisional agenda, distributed before the meeting was amended to include two new subitems under 'Other Business'. One to consider a request from the Convener of the Commission's Working Group for the Development of Approaches to Conservation of Antarctic Marine Living Resources (WG-DAC), and another to include an item suggested by the US Delegation at SC-CAMLR-VII on strategic planning in the context of the Working Group's terms of reference. The subitem of the provisional agenda, 'Evaluation of impact of fishing on krill stocks', was included in item 4 under a new title 'Krill fisheries and the impact of fishing'.

3. The amended agenda was adopted (Appendix 1). A list of participants (Appendix 2) and a list of meeting documents and references (Appendix 3) are attached.

4. Responsibility for the preparation of the Working Group's report was assigned to the following rapporteurs: Drs I. Everson, E.J. Murphy, D.L. Powell and J.L. Watkins.

5. The Convener outlined the broad objectives (WG-KRILL-89/3) for the Working Group's First Meeting based on its terms of reference (SC-CAMLR-VII, paragraph 2.26). The Working Group agreed that at this, the first meeting, it was important to take full account of Article II in developing approaches and procedures for management and conservation of krill. It was acknowledged that there was a risk of giving too much attention to the assessment of fishing on the krill stocks and not enough to the impact on dependent and related species.

6. It was agreed that because of the complexity of the task and the current state of knowledge, it would be necessary to break the task into tractable parts, while remaining conscious of the total problem. That is to say, focusing on a single species (i.e. krill) initially with a view to extending the task to include dependent and related species as information

becomes available. It was agreed that when tendering advice which was based on a single species approach, it should be clearly stated that interactions with dependent and related species had not been taken into account.

7. The Working Group agreed that the terms of reference were clear in requiring advice leading to decisions on the management of the krill fishery. There was some discussion on the need for a management 'strategy' or 'procedure' for krill. The Working Group concluded that at the present stage in its work it was premature to develop a formal management procedure for krill. The recommendations of this meeting taken together therefore constitute a structured approach to the management task. The process will be refined as the Working Group's work progresses.

METHODS FOR ESTIMATING KRILL DISTRIBUTION AND ABUNDANCE

8. The Working Group recognised that considerable data on krill abundance and distribution have been collected to date, both through national and international programs. In addition, the commercial krill fishery provides data on krill abundance and distribution.

9. Dr John Beddington, Convener of the Workshop on the Krill CPUE Simulation Study (WS-KCPUE), summarised the proceedings of the Workshop. The Working Group agreed that a number of questions arising from the Workshop were pertinent to the terms of reference of the Working Group on Krill.

10. In particular, the Working Group noted that the combination of data from the Japanese and Soviet fishery provides information that allows the calculation of a Composite Index of Krill Abundance. This index is based on measuring certain parameters of swarms and concentrations (Appendix 4). The Working Group decided to focus its discussion on the Composite Index of abundance as a way of addressing the problems associated with krill abundance estimation.

Acoustics

11. Acoustic techniques can be used to provide information on all the parameters of the Composite Index. The information obtainable with different types of acoustic equipment is summarised in Table 1. The Working Group emphasised that collection of additional

information on krill aggregations was essential. In this respect, it was agreed that information on the depth of swarms from the surface, the vertical thickness of swarms and the interswarm distances were important.

12. The Working Group attached considerable importance to the estimation of krill abundance and spatial patterns by acoustic techniques. The practical and operational considerations associated with acoustic estimation of krill consequently are reported in detail.

13. Acoustic data can be used to estimate both the relative and absolute density of krill. Reasonable estimates of relative density are directly derivable from echo-integrator outputs. Absolute density estimates can also be derived through echo-integration, but a representative mean backscattering cross section ($\bar{\sigma}$) or scaling factor must be used to convert relative estimates to absolute estimates of number density (number-per-unit volume or number-per-unit area) or biomass density (mass-per-unit volume or mass-per-unit area), respectively. The mean backscattering cross section and scaling factor may each vary with the size, distribution, behaviour (e.g. orientation) and physiological condition (e.g. nutritional, reproductive state) of krill detected and insonified. These quantities will also generally vary with the frequency of sound. Controlled measurements on *Euphausia superba* need to be conducted to ensure accurate absolute density estimates.

14. Absolute estimates of number density require knowledge of the mean backscattering cross section (see Appendix 5 for definition of $\bar{\sigma}$). As stated above, backscattering cross section is likely to be a function of krill size, behaviour and physiological condition. Previous studies with zooplankton suggest that size is the most important of these factors (i.e. explains the greatest proportion of the variance associated with acoustic detection of krill abundance). Hence, the Working Group recognised the need for controlled measurements to develop a functional relationship between the mean backscattering cross section and krill size.

15. With this relationship, net catch data on the distribution of krill sizes can be converted to a representative distribution of backscattering cross sections. From this distribution, the mean backscattering cross section can be derived and an absolute estimate of krill number density computed. Furthermore, this absolute number density estimate can be apportioned to different size classes, thus providing estimates of the absolute number density for each size class of krill.

16. In addition to the above procedure for estimating absolute number density by size class, an entirely acoustically based method of determination may also be feasible. In this case, rather than relying on net catch data, the mean and distribution of the backscattering cross sections are derived by *in situ* target strength (TS) estimation techniques (see Appendix 5 for definition of **TS**). These techniques include both 'dual-beam' and 'split-beam' methods. The key to using either of these techniques in studies of krill is to deploy the acoustic transducers sufficiently close to the animals to resolve individual scatterers. Surface deployment on ship's hulls or towed bodies are inadequate and other methods of deployment should be explored (on nets, deep-towed bodies or remotely operated vehicles). Information on the use of acoustic instrumentation on fisheries trawls, published within ICES was noted (Council Meeting Reports and Journal du Conseil).

17. Absolute estimates of biomass density require accurate estimation of a scaling factor to relate volume backscattering strength to biomass. As with backscattering cross section, this scaling factor is generally a function of krill size, behaviour and physiological condition. There is some evidence from other acoustic studies on crustacean zooplankton that treating this factor as a constant may be a reasonable first approximation. Controlled measurements, combined with sensitivity analyses, are necessary to justify this approximation. If the errors introduced by this approximation are negligible (i.e. small relative to other errors), then estimates of absolute biomass density could be made in the field using only acoustic methods. Information on the size distribution and absolute number density would require the additional procedures described in paragraphs 15 and 16.

18. The Working Group recognised a number of potential problems in the acoustic measurement of krill density. These include non-detection of animals below the acoustic threshold, the occurrence of animals out of range of the sounder either near the sea surface or under ice, inadequate determination of target strength, inadequate calibration of acoustic instrumentation and limited identification of acoustic targets.

19. Problems associated with the determination of krill target strength were addressed in a presentation by Dr K.G. Foote. The results of recent experiments conducted in austral summer 1987/88 with I. Everson, J.L. Watkins and D.G. Bone, to determine the target strength of Antarctic krill were presented (see also WG-KRILL-89/4). Caged aggregations of krill were insonified over periods ranging from 15 to 65 hours. The values of the target strength obtained at 120 kHz were at least 10 db lower than those previously reported and used for the analysis of krill acoustic data. Values measured at 38 kHz were approximately 20 db lower than those previously reported and used at 50 kHz. Independent measurements of sound velocity and density were also used to calculate the target strength based on a

scattering model (Greenlaw, 1979). Results obtained from this approach were consistent with those from the experiments on caged aggregations and this work is being published.

20. The Working Group noted that a 10 db reduction in individual target strength at 120 kHz would involve a tenfold increase in estimated biomass. The 20 db at 38 kHz would result in a hundredfold increase.

21. The Working Group recognised that as a result of this most recent work, the target strength of krill has been much more rigorously defined, although work to define the dependence of target strength on length, orientation and animal condition is still necessary. It was also emphasised that with the technology currently available for work in the Southern Ocean, the estimation of number density still requires net samples in order to determine the size distribution of animals in the population being studied.

22. Developments in echo-sounders were discussed. The next generation of echo-sounders and integrators being developed in Norway was described by Dr Foote. Several other members of the Working Group provided information on equipment being used or developed elsewhere. Details are provided in Appendix 6.

23. While a new generation of echo-sounders and integrators will significantly increase the acoustic capabilities of research vessels, the Working Group recognised that for the foreseeable future a large number of vessels will continue to utilise the present generation of equipment.

24. A simple outline of procedures which could be adopted by research and survey vessels to collect and process acoustic data was drawn up (see paragraph 79 and Appendix 7). This would provide potentially useful information for the Working Group. The approach outlined is based on that used by Dr M. Macaulay (WG-KRILL-89/10).

25. The Working Group also recognised the need to archive the original records of raw data on as fine a scale as possible and in such a way that they cannot be changed. It would also be advantageous to standardise units, formats and media on which data are stored in order to facilitate the exchange of data and analysis software between researchers involved in acoustic surveys on krill.

26. In conclusion the Working Group emphasised the potential of acoustics to provide crucial information:

(a) in areas where there is no krill fishery; and
(b) for the Composite Index in fishery areas (Appendix 4).

Nets

27. The Working Group recognised that net hauls are essential for the verification of acoustic data on krill (i.e. for target identification and to obtain representative length frequency distributions) and that catch data can also provide essential information for independent estimates of abundance.

28. When using nets for acoustic target verification, the Working Group emphasised that it is important to establish the underlying size selectivity characteristics of the equipment being used. Discussion highlighted the need for considerable additional work to be done on size selectivity factors for various nets currently being used. For instance, a comparison of a Japanese commercial fish trawl (560 m^2) with a (KYMT) research trawl (9 m^2) showed no detectable difference in mean body length of krill in catches taken with either. In contrast, a comparison of a German pelagic trawl with RMT8 catches indicated that for krill larger than 45 mm the trawl collected more krill than the RMT while the opposite occurred for krill smaller than 45 mm in length.

29. It is therefore unlikely that a single net will sample all size classes of krill representatively and it would be premature to recommend a single net for such studies. A summary of the known characteristics and problems associated with the nets most commonly used in the Antarctic is given in Table 2.

30. There is little information on inter-net comparisons for Antarctic krill and such studies would be valuable. In addition the design of new nets to overcome or reduce the problems associated with net selectivity should be encouraged.

31. The Working Group also recognised that when using nets to estimate abundance, net avoidance and integration of areas containing no krill as well as catch selectivity effects, are all potential sources of errors.

32. The Working Group recognised that even large nets may be subject to avoidance problems and the unqualified use of nets for krill abundance estimates is not encouraged for the reasons set out in paragraph 31.

Other Direct Methods

33. Methods using cameras or remotely operated vehicles to directly observe krill were discussed. It was felt that at present although such techniques may be useful for calibration of other methods (e.g. catch data from nets), they generally operate over too restricted a spatial scale to be of widespread use.

Indirect Methods

34. The Working Group agreed that the Krill CPUE Simulation Study (WS-KCPUE-89) has demonstrated that commercial catch and effort data may have some utility in relative abundance estimates.

35. Other indirect methods such as surveys of egg numbers, larvae or cast exoskeletons (exuviae) were discussed. The Working Group highlighted a number of potential problems with these techniques. These include the large vertical distribution of eggs, the effect of variation in fecundity and the number of spawning episodes in any one season, and the infrequency of catches containing exuviae. However, the Working Group concluded that such indirect methods could be potentially valuable and may provide a relatively untapped source of information on krill. Their continued development was encouraged.

36. Attempting to estimate total krill abundance indirectly based on multiplying estimated predators consumption by a calculated production/biomass ratio assumes knowledge of the age structure of the krill population. Recent research has indicated that krill live longer than previously thought and this in turn would decrease the production/biomass ratio thereby increasing the estimate of abundance.

SPATIAL AND TEMPORAL PATTERNS IN KRILL DISTRIBUTION AND ABUNDANCE

37. Over the past decade various attempts have been made to classify krill abundance and distribution in terms of fundamental characteristics and scales of occurrence. These classifications have been of major importance in refining our knowledge of krill biology and were fundamental in the development of the Krill CPUE Simulation Study.

38. Depending on the spatial and temporal scales being considered, the estimation of abundance and distribution must take account of a number of different factors. To a great extent the important factors introducing variance into the estimation of abundance depend on the scale of operation. It is possible to consider the techniques available in terms of their applicability to investigating processes operating over different scales.

39. Taking account of the various techniques discussed in the previous section (paragraphs 8 to 36), the Working Group discussed the various methods of monitoring krill abundance and distribution over different spatial scales identified at the second meeting of the Working Group for CCAMLR Ecosystem Monitoring Program (WG-CEMP) (Table 3). This discussion highlighted how various techniques may be used to monitor prey abundance and distribution over different spatial scales.

40. Using the definitions of spatial scale in Table 3, the Working Group considered krill distribution and abundance over each scale. On the global scale (> 1 000 km), it was recognised that ideally distribution and abundance should be ascertained and that this would be useful in gaining an understanding of krill population dynamics. The Working Group felt that it was impractical to attempt to estimate total krill abundance directly. The same problems generally apply to the macro scale (100–1 000 km).

41. It was agreed that the meso (1–100 km) and micro (0.01–1 km) scales are the scales most readily investigated with current methods. The Working Group also agreed that the processes operating on these scales form the basis for the Krill CPUE Simulation Study. Furthermore, all the scales from the micro to macro, are important in terms of key predator-krill interactions.

42. The Working Group was also of the opinion that available information on large scale (i.e. global-macro) krill distribution is currently limited (paragraph 40).

43. The Working Group agreed that results from the WS-KCPUE (see paragraph 2 and Figure 1, Appendix 5 of WS-KCPUE-89) indicate that concentrations of krill are consistently targetted by the commercial fishery. There is some congruence of such regions within and between seasons. The Working Group noted that at this scale prevailing hydrography and bathymetry would be important in the formation and maintenance of such concentrations.

44. In discussion of the distributions of krill concentrations the Working Group acknowledged that research vessel surveys are not able to provide a sufficiently broad areal coverage. The Working Group felt that, to determine the underlying mechanisms associated with the formation and maintenance of observed patterns in krill distribution, analysis of data from the fishery currently offers the most promise.

45. The Working Group noted that areas other than those in which the fishery operates, may be of crucial ecological importance. Furthermore, some major fishing areas are also known to be important to krill predator populations. The Working Group agreed that such areas probably cannot be considered as containing discrete populations, but they have been identified as being potentially useful for management purposes.

46. In this context, recent attempts to delineate separate stocks of krill (e.g. through genetically based analysis as in WG-KRILL-89/9) were noted and the need to develop knowledge of the spatial and temporal scales of crucial ecological processes to allow a more constructive approach to the development of management strategies was acknowledged by the Working Group.

47. Therefore, the Working Group emphasised that areas identified as being important in terms of krill's broader scale distribution, should be further investigated using other data sources than those forthcoming from the fishery. Information from as many sources as possible (including historical data such as found in the *Discovery*, BIOMASS and national data sets) should be drawn together and analysed for this purpose.

48. Taking account of the above and the fact that the WS-KCPUE had provided an operational definition of three types of krill concentrations (Table 4), the Working Group considered the proposed definitions to be workable and sensible.

49. It was acknowledged that more general definitions of krill aggregation are of greater utility than the rigid categorisation of aggregation types.

50. Similarly, the Working Group agreed that it would be useful to carry out analyses of both past and present acoustic data (e.g. echo-charts from fisheries survey vessels) to verify the defined concentration/aggregation types and to investigate the underlying ecological processes involved in their formation and maintenance.

51. It was recommended that such analyses should be undertaken as soon as possible and the results presented to the Working Group's next meeting. The Working Group also agreed that there would be considerable merit in ensuring that the echo-charts of both fisheries survey and research vessels are suitably annotated in order to provide information on krill aggregation types and their distribution.

52. An outline for the minimum level of echo-chart annotation was produced (Appendix 8), but the Working Group stressed that the effectiveness of such annotation should be considered further at the Working Group's next meeting.

53. Echo-charts should be examined in order to collect data on concentration parameters (WS-KCPUE-89) and aggregation types. The Working Group recommended that such examinations should be undertaken as soon as possible (either nationally or cooperatively) and that submissions on how these data should be accessed and analysed are to be reported to the next meeting.

54. The Working Group also considered that investigations of possible within- and between-season patterns in the distribution of fishing activity from historical data will be a valuable exercise and will facilitate identification of the requirements for possible future data collection and analyses. The Working Group also recommended that the necessary analyses should be carried out (either nationally or cooperatively) as soon as possible.

55. STATLANT and fine-scale data (1° longitude x 0.5° latitude x 10 day periods over the last three years) from the fishery are currently available within the CCAMLR database. Fine-scale data are from Subarea 48.2 and the Integrated Study Regions identified by the CCAMLR Ecosystem Monitoring Program. The Working Group concluded that available data should be analysed to investigate the spatial distribution of fishing activity during 10 day periods within each season. The Working Group recommended that the above analyses be carried out by the Secretariat as soon as possible. The available fine-scale data are still relatively coarse, the Commission has requested that haul-by-haul data be collected (CCAMLR-VII, paragraph 59) but they are not yet required for submission to CCAMLR.

56. It was agreed that given the structure of concentrations, analyses of haul-by-haul data are required for at least some of the regions in which the fishery operates (see paragraphs 28(iii) and (iv) of WS-KCPUE-89). Such analyses have potential utility in clarifying within-season variation in the location of fishing operations alluded to above.

57. The Working Group recognised that finer scale analyses of areas of krill concentration should be carried out using methods independent of the commercial fishery. These should include directed surveys using acoustics and nets as well as indirect methods such as predator based studies (various methods for studying different aspects of krill distribution and abundance have been outlined).

58. Such surveys and studies should be carried out in areas where commercial fishing occurs as well as in areas remote from the fishing operations. Results of finer scale analyses could also provide information relevant to the Krill CPUE Simulation Study.

59. The methods considered most useful for investigating particular temporal and spatial scales and their relevance to estimating the parameters required for the CPUE Composite Index (Appendix 4) have been given in Table 1.

60. The Working Group again emphasised that every effort should be made to relate fisheries to research data directly. It was noted that such a cooperative survey has already been carried out by Japanese scientists (WS-KCPUE-89/7 and WS-KCPUE-89/8) and the Working Group agreed that such information would be extremely useful.

61. The Working Group concluded that the understanding of large scale krill distribution may be enhanced from satellite imagery of sea surface temperature. This would allow the sea surface hydrodynamics to be related to the position of fishable krill concentrations. Although there are known problems in the available satellite data (e.g. excessive cloud cover) the Working Group recommended that currently available information should be accessed and analysed.

KRILL FISHERIES AND THE IMPACT OF FISHING

Commercial Fishing Activities

62. The current status of the krill fishery had been discussed during SC-CAMLR-VII (paragraphs 2.1 to 2.7) and it was noted that the total catch during the past three seasons

(1986–1988) had been 445 673, 376 456 and 370 663 tonnes respectively. The greatest proportion of these catches came from the Atlantic Sector in each season. The Working Group noted that at this level the Antarctic krill fishery is probably the largest single species crustacean fishery in the world.

63. Dr Endo reported that the preliminary figure for the Japanese krill catch for 1988/89 to be around 79 000 tonnes. The precise figure is not currently available as the STATLANT forms are not due to be submitted until 30 September. Dr Endo indicated that the level of the Japanese krill fishery was likely to be similar to that in the past two or three years.

64. The Working Group noted that krill catches had remained at more or less the same level over the past few years and that advice from fishing countries (SC-CAMLR-VII, paragraph 2.9) indicated that this level would continue or be increased only slightly in the foreseeable future.

65. The Working Group acknowledged that assessment of the abundance and distribution of krill in the whole of the Convention Area was extremely difficult. Historically, however, as about 90% of the catch has been taken from particular locations in Statistical Area 48, the task can be brought down to manageable proportions by focusing, at least initially, on the areas fished.

66. It was agreed that the current total catch was unlikely to be having much impact on the circumpolar krill population. However, the Working Group was unable to say whether or not the present level of krill catch was having an adverse impact on local predators. The Working Group recommended that the fishery should not greatly exceed the current level until assessment methods are developed further and until more is known about predator requirements and local krill availability. The development of suitable assessment methods is important and is encouraged.

Data Analyses

67. The Convener reported on analyses of STATLANT catch and effort data for the period 1973–1988 that he had prepared for the CCAMLR/IWC Workshop on the Feeding Ecology of Southern Baleen Whales (WG-KRILL-89/5). The results confirmed that the Atlantic Sector (i.e. Statistical Area 48) was the main area fished and has provided the bulk of the accumulated krill catch over the past fifteen years.

68. Examination of the monthly catches for Subarea 48.3 over several years indicate that the bulk of the fishing effort there took place during the months April–August (winter). In other Subareas (particularly 48.1 and 48.2) the greatest catches were taken during January–April (summer).

69. The greatest fishing effort (hours fished) by the USSR fleet was confined to winter in Subarea 48.3 and summer in Subarea 48.2. This suggests that the fleet moves northwards as ice encroaches into Subarea 48.2 during winter.

70. These results indicate that USSR krill fishery can take place year round and that the notion of a krill fishing 'season' may be misleading. The Working Group suggested that this should be borne in mind in making management decisions about the krill fishery.

71. It was agreed that the STATLANT data provide a good general picture of the fishery but they are not sufficiently detailed to determine the status of, or patterns in, the fishery with adequate precision.

72. As previously discussed, the WS-KCPUE had made use of haul-by-haul data from the Japanese krill fishery and had demonstrated that such data could be used to provide indices of abundance within krill concentrations.

73. The Krill CPUE Simulation Study had also shown that data from the USSR survey vessels can be used to estimate the numbers of concentrations in an area.

74. In terms of improving understanding of krill fishing operations, the Working Group welcomed this development and having endorsed the recommendations of the Workshop on the Krill CPUE Simulation Study (WS-KCPUE-89), noted that additional analyses of data from the fishery should be considered.

75. Dr Endo and Mr Ichii (WS-KCPUE-89/8) reported a survey of krill in an area north of Livingston Island (Subarea 48.1) in 1987/88 undertaken at the same time that the area was being intensively fished. Catches from both commercial and research vessels were sampled for length frequency distribution. Using an acoustic estimate of abundance for the surveyed area the authors estimated the impact of fishing on the krill stock in the area.

Planned Future Analyses

76. Fine-scale catch and effort data have been submitted to the CCAMLR Secretariat for Subarea 48.2 and the Integrated Study Regions identified by CEMP. These data are grouped by geographical areas of 0.5° latitude x 1° longitude and summed over 10 day periods. (Also see discussion in paragraph 87.)

77. It was agreed that fine-scale data might provide some information on the location of krill concentrations, particularly as defined by the Krill CPUE Simulation Study (see paragraphs 43 to 56 and Table 4). Furthermore, given a sufficient series of data it might also be possible to determine to what extent such concentrations appear in successive years. It was agreed that the Secretariat should provide plots of these data for examination at the next meeting of the Working Group (see paragraph 55).

78. It was also agreed that analyses of haul-by-haul data and searching vessel data, as outlined in the Report of the Workshop on the Krill CPUE Simulation Study (WS-KCPUE-89) should commence as soon as possible.

79. The collection of acoustic data, by both survey vessels accompanying the fishing fleet and by independent research/resupply vessels to define more clearly the extent and location of concentrations, is important. A data collection procedure was agreed and a data collection format is shown in Appendix 7. These data will provide information on size of concentrations, distance between concentrations and the number of swarms within a concentration. It was agreed that collection and analyses of such data should be undertaken.

80. Despite the problems associated with net selectivity already discussed (paragraphs 30 and 31), analyses of size frequency distributions from scientific net hauls had provided further information on krill growth rates. It was emphasised that in such analyses of length frequency data for assessment purposes, seasonal effects are important and should be taken into account. It was noted that analyses of length frequency distributions from commercial catches in conjunction with those from research net-based population estimates could provide valuable information on population dynamics.

81. It was stressed that such an approach requires fishery independent survey information on krill abundance in addition to length frequency data from both the fishery and the overall natural population. It was also noted that, for completeness, such analyses should consider data from predators.

82. The Working Group stressed that although all fishing fleets appear to be using the same type of nets it does not necessarily follow that these have the same selection factors. Therefore, to be effective an approach based on commercial catch information requires length frequency distribution data from all fishing fleets.

83. Some concern was expressed that, due to the small area of operation of the fleets relative to the total Southern Ocean, such analyses might not be sufficiently sensitive to detect important changes in krill demography. It was, however, noted that the analyses envisaged were only part of a broad suite of studies that might focus on abundance estimation from fishery data, water circulation patterns, identification of stocks and local predator dependence on krill. Together such studies could be used to develop advice for management. A possible schema is shown in Appendix 9.

84. The Working Group considered further possible approaches to estimating the local impact of fishing on krill stocks. It was suggested that an attempt be made to extend the analyses reported by Dr Endo and Mr Ichii (see paragraph 75) to the whole of Statistical Area 48 using the length frequency distributions from the scientific sampling and the commercial catches together with the fine-scale catch data available in the CCAMLR database. The Working Group noted, however, potential problems associated with seasonal effects in size frequency data (see paragraph 80). Nevertheless, it was agreed that such an analysis would provide a useful preliminary estimate of the potential impact of the fishery on available krill in Statistical Area 48. This would also help in identifying important deficiencies in data and methods.

85. The Working Group encouraged Members to develop methods of analysing catch length frequency distributions to infer the local impact of fishing on krill stocks.

Data Requirements

86. In order to undertake the analyses identified by the WS-KCPUE, the Working Group recommended that the following data be collected (see paragraphs 28(i), (iii) and (v) of WS-KCPUE-89):

(a) bridge log data;

(b) haul-by-haul data from commercial fishing vessels; and

(c) acoustic data for determination of concentration characteristics (paragraph 77 above).

87. To provide a longer time base with which to examine trends in fishing activity within and between seasons the Working Group recommended that fine-scale catch data should continue to be reported for Subarea 48.2 and the three CEMP Integrated Study Regions (paragraph 59, CCAMLR-VII).

88. There was considerable discussion on the type and quantity of length frequency data to be collected by the fishery. Recent evidence indicates that there are significant differences in size distribution and sex ratio of even closely adjacent swarms (Watkins et al., 1986). Similar evidence has also been obtained from layers of a size similar to those fished by commercial operations (WG-KRILL-89/6). The Working Group recommended the development of sampling procedures which take account of how many samples and how frequently samples of krill length distributions in commercial catches should be taken.

89. It is current practice in the Japanese fishery for each fishing vessel to measure a sample of 50 krill from one haul per day spent fishing. The Working Group recommended that as an interim measure sampling of at least that level be undertaken by all other commercial fleets.

90. The Japanese data are based on the krill length measurement from tip of rostrum to tip of telson measured to the nearest millimetre below. This standard is, in practice, virtually identical to the other widely used standard: front of eye to tip of telson. It was recommended that the latter standard be adopted (see Appendix 10).

OTHER BUSINESS

Liaison with CCAMLR Ecosystem Monitoring Program (CEMP)

91. At its last meeting the Scientific Committee decided that (SC-CAMLR-VII, paragraph 5.40):

(a) The WG-CEMP should identify the characteristics of predators that need to be taken into account in prey survey design;

(b) Simulation studies are likely to be particularly useful in generating advice on survey design, frequency and distribution. Work including modelling krill distribution and behaviour is being undertaken within the Krill CPUE Simulation Study. The WG-CEMP should consult with the Working Group on Krill to develop this, and other relevant studies, to provide appropriate advice; and

(c) The WG-Krill should arrange the production of standard method sheets for the technical aspects of prey surveys.

92. As a result of this decision the Convener of the WG-CEMP wrote to the Convener of the WG-Krill pointing out that as the WG-CEMP was not scheduled to meet until August 1989, there had been no opportunity since the last meeting of the Scientific Committee for the WG-CEMP to specify the characteristics of predators necessary for the design of prey surveys referred to in SC-CAMLR-VII, (paragraph 5.40 (i)). In this situation he thought it would be useful for the Working Group on Krill to consider:

(a) the nature of the CEMP and the reasons for requiring prey surveys and the development of standard methods;

(b) the requirement for prey monitoring as set out in the table taken from a CEMP Report (Table 5, Annex 4, SC-CAMLR-VI);

(c) information and advice that may help the WG-CEMP to formulate specific requests to the WG-Krill for specific methods and survey design.

93. The Working Group agreed that little progress could be made on the specification of surveys for monitoring prey until the 'important characteristics of predators' were specified by WG-CEMP. The Working Group also agreed that the most important characteristics (for each of the krill predator species identified by CEMP) are the foraging range, foraging frequency, the time of day that foraging is undertaken and the normal depth range over which feeding takes place (SC-CAMLR-VII/5 and SC-CAMLR-VII/BG/8).

94. With respect to point 92(a) above, the attention of WG-CEMP was drawn to several references in this report to the importance of studying predator/krill interactions in the context of estimating changes in krill abundance and distribution. Although the Working Group was not able at this stage to draw up a manual of standard methods for surveys of krill as such, most of the recommendations of the Working Group are directly relevant to the

conduct of such surveys. In particular the CEMP Integrated Study Regions were selected for the application of CPUE to estimate changes in krill abundance and the tables in the relevant sections of this report provide guidance on the implementation of acoustic surveys, of fishery independent net surveys and for sampling catches from commercial vessels in those areas.

95. The table referred to in 92(b) was modified (Table 3) and is referred to WG-CEMP for consideration.

96. It was suggested that the simulation models used in the Krill CPUE Simulation Study might be adapted for use in identifying important parameters to study predator/krill interactions in the context of CEMP.

STRATEGIC PLANNING

97. At the last meeting of the Scientific Committee, the US Delegation reported on a procedure in use at the Southwest Fisheries Centre for the planning of research programs which also takes account of various management objectives. It was suggested that the method be evaluated for possible application by the various CCAMLR working groups. A paper describing the procedure and a detailed report on the application of the method were distributed to members of the Working Group before the meeting. In addition, an outline of the process was given by the US participants. Some participants of the Working Group had taken part in the application of the method in the planning of the US Antarctic Marine Living Resources (AMLR) Program.

98. The Working Group agreed that the process is most applicable to situations for which the future direction is rather unclear, the choice of several options is possible or widely divergent views are held by potentially opposing factions. At present, none of these situations can be considered to apply to matters being addressed by the WG-Krill. It was, nevertheless, suggested that the procedure may have some application in the work of the WG-DAC.

CONSIDERATION OF A REQUEST FROM THE CONVENER OF THE WORKING GROUP FOR THE DEVELOPMENT OF APPROACHES TO CONSERVATION OF ANTARCTIC MARINE LIVING RESOURCES

99. The Convener of the WG-DAC had drawn attention to two matters on which the Commission had sought the advice of the Scientific Committee. These are:

(a) the development of operational definitions for depletion and for target levels of recovery of depleted populations; and

(b) the ability of the CCAMLR Ecosystem Monitoring Program to detect changes in ecological relationships and to recognise the effects of simple dependencies between species, including distinguishing between natural fluctuations and those induced by fisheries.

100. The Working Group agreed that at this stage it had no contribution to make to the preparation of the advice of the Scientific Committee on these issues. It was acknowledged, however, that at some stage it may be able to assist the WG-CEMP in the provision of its advice on krill predators.

CLOSE OF THE MEETING

101. Before the close of the meeting, the Convener drew attention to the ongoing responsibilities of the Working Group set down in the terms of reference (SC-CAMLR-VII, paragraph 2.26). At this meeting, the Working Group had prepared advice to the Scientific Committee concerning the current level of fishing, identified data requirements and described analyses to be undertaken. These analyses are aimed at determining the value of further data collection necessary for the management of the krill fishery. It was recommended that in order to maintain the momentum begun at this meeting, the Working Group should meet again in 1990. The Convener, in consultation with the Secretariat, will prepare and distribute a list of topics to form the basis of the agenda of the Working Group’s next meeting before the 1989 meeting of the Scientific Committee.

102. The Convener thanked the Working Group participants, particularly the rapporteurs, for their cooperation and support. He also thanked Drs R. Holt and R. Hewitt and Mrs G. Horner for their assistance in the organisation and conduct of the meeting. Finally, he thanked the Director of the Southwest Fisheries Centre, Dr I. Barrett for hosting the meeting.

APPENDIX 1

AGENDA FOR THE FIRST MEETING

Working Group on Krill
(Southwest Fisheries Centre, La Jolla, California, USA, 14 to 20 June 1989)

1. Opening of the meeting
   (i) Review Working Group's terms of reference
   (ii) Review objectives of meeting
   (iii) Adoption of agenda

2. Methods for estimating krill distribution and abundance
   (i) Review available information
   (ii) Evaluate available information with respect to:
      (a) Methods of determination, and
      (b) Relative value of various methods, their applicability, accuracy and precision
   (iii) Recommendations

3. Spatial and temporal patterns in krill distribution and abundance
   (i) Review available information
   (ii) Evaluate available information with respect to:
      (a) Scale of variability
      (b) Value of information at different scales, and
      (c) Potential relevance of information to CCAMLR
   (iii) Recommendations

4. Krill fisheries
   (i) Review available information
   (ii) Evaluate available information with respect to:
      (a) Detail information available
      (b) Trends in the fishery, and
      (c) Potential relevance of information to CCAMLR
   (iii) Krill fisheries and impact of fishing
   (iv) Recommendations

5. Other Business
   (i) Liaison with CCAMLR Ecosystem Monitoring Program
   (ii) Consideration of a request from the Convener of the Working Group for the Development of Approaches to Conservation of Antarctic Marine Living Resources
   (iii) Strategic Planning

6. Adoption of report

7. Close of the meeting.

APPENDIX 2

LIST OF PARTICIPANTS

Working Group on Krill
(Southwest Fisheries Centre, La Jolla, California, USA 14 to 20 June 1989)

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APPENDIX 3

LIST OF DOCUMENTS

Working Group on Krill
(Southwest Fisheries Centre, La Jolla, California, USA, 14 to 20 June 1989)

Meeting Documents

WG-KRILL-89/1	Agenda for the First Meeting of the CCAMLR Working Group on Krill
WG-KRILL-89/2	Annotated Agenda for the First Meeting of the CCAMLR Working Group on Krill
WG-KRILL-89/3	Main Objectives of the First Meeting of the CCAMLR Working Group on Krill
WG-KRILL-89/4	Table of Krill Target Strengths from Everson et al., SC-CAMLR-VII/BG/30
WG-KRILL-89/5	Commercial Krill Fisheries in the Antarctic, 1973–1988 (D.G.M. Miller)
WG-KRILL-89/6	Size and Density of Krill Layers Fished by a Japanese Trawler in the Waters North of Livingston Island in January 1988 (Y. Endo and Y. Shimadzu)
WG-KRILL-89/7	Correspondence between the Convener of the Working Group for the Development of Approaches to Conservation of Antarctic Marine Living Resources and the Chairman of the Scientific Committee
WG-KRILL-89/8	Correspondence from the Convener of the Working Group for the CCAMLR Ecosystem Monitoring Program
WG-KRILL-89/9	Preliminary Study on Chromosomes of Antarctic Krill, *Euphausia superba* (P.V. Ngan et al.)
WG-KRILL-89/10	AMLR Hydroacoustic Survey System Description of Methods, A Case Study (M.C. Macaulay)

WS-KCPUE-89 Report of the Workshop on the Krill CPUE Simulation Study

WS-KCPUE-89/8 CPUE's, Body Length and Greenness of Antarctic Krill During 1987/88 Season on the Fishing Ground North of Livingston Island
(Y. Endo and T. Ichii)

References

1. CCAMLR-VII. Report of the Seventh Meeting of the Commission

2. SC-CAMLR-VII. Report of the Seventh Meeting of the Scientific Committee

3. SC-CAMLR-VI, Annex 4. Report of the Working Group for the CCAMLR Ecosystem Monitoring Program

4. SC-CAMLR-VII/BG/30. Target Strength of Antarctic Krill (*Euphausia superba*). I. Everson et al. (UK)

5. On the Biology of Krill, *Euphausia superba*, Proceedings of the Seminar and Report of the Krill Ecology Group. Schnack, S.B. (Ed.). Bremerhaven 12–16 May 1983, Ber. Polarforsch. Sond. (4) 1983.

6. Scales of Interaction Between Antarctic Krill and the Environment. E.J. Murphy et al. In: Antarctic Ocean and Resources Variability. Sahrhage, D. (Ed.), 1988. pp 120-130. Springer-Verlag, Berlin, Heidelberg.

7. Watkins, J.L., D.J. Morris, C. Ricketts and J. Priddle. 1986. Differences Between Swarms of Antarctic Krill and Some Implications for Sampling Krill Populations. Marine Biology Vol. 93, pp 137-146.

8. Greenlaw, C.F. 1979. Acoustic Estimation of Zooplankton Populations. Limnology and Oceanography 24, pp 226-242.

DEFINITION OF COMPOSITE INDEX OF KRILL BIOMASS

At the Workshop on the Krill CPUE Simulation Study (WS-KCPUE-89) the Composite Index was developed to monitor the abundance of krill in areas where the krill fishery is operating. The index utilises a number of measurements based on spatial dimensions of krill concentrations and krill swarms. It also utilises an estimate of density based on catch per fishing time or acoustic data. For more details see Appendix 7 of WS-KCPUE-89.

The Composite Index is defined as:

$$CI = N_c L_c^2 D_c r^2 \delta$$

where
- CI = Composite Index
- N_c = number of concentrations in the area of interest
- L_c = characteristic radius of concentrations
- D_c = number of swarms per unit area in a concentration
- r = characteristic radius of swarms in concentrations
- δ = areal density of krill within swarms

APPENDIX 5

DEFINITIONS OF ACOUSTIC TERMS

The acoustic backscattering cross section **σ** of a finite-size target ensonified by a uniform plane wave at a single frequency is defined as follows:

$$\sigma = \lim_{r \to \Box} 4\pi r^2 \frac{\& P_{bsc} \&^2}{\& p_o \&^2}$$

where **r** is the range at which the backscattering pressure amplitude $\mathbf{p_{bsc}}$ is measured, and $\mathbf{p_o}$ is the pressure amplitude of the incident wave. Because this quantity often varies enormously due to changes in acoustic frequency, scatterer size, or scatterer orientation, it is convenient to use a logarithmic expression. This is done through the so-called target strength **TS**:

$$\overline{TS} = 10 \log \frac{\bar{\sigma}}{4\pi}$$

where **SI** units are used for **σ**.

2. Many surveying applications require averaging of the backscattering cross section. This is typically performed with respect to a distribution of krill sizes or orientations, for example. If the result of any averaging procedure is denoted $\bar{\sigma}$, then the corresponding mean or average target strength $\overline{\mathbf{TS}}$ is defined according to that of an individual datum, namely

$$\overline{TS} = 10 \log \frac{\bar{\sigma}}{4\pi}$$

3. An alternative quantity, denoted $\boldsymbol{\sigma_{bs}}$, is sometimes used. This is related to the above **σ** by the relation

$$\sigma_{bs} = \frac{\sigma}{4\pi}$$

In this case, **TS** is expressed by the equation

$$TS = 10 \log \sigma_{bs}$$

Caveat 1: Whether σ or σ_{bs} is used in any particular application, it is always necessary, in documenting work, to state which quantity is used.

Caveat 2: Averaging of the backscattering cross section σ must always be performed in the σ - or equivalent intensity domain. Average or mean target strengths are derived from $\bar{\sigma}$.

A. NEXT-GENERATION ECHO-SOUNDER AND INTEGRATOR UNDER DEVELOPMENT IN NORWAY

(K. Foote)

The newest echo-sounder, the SIMRAD EK500 scientific echo-sounding system, will operate as many as three different split- or single-beam transducers simultaneously. Use of logarithmic amplifiers achieves a dynamic range of 160 dB. Time-varied gain is applied digitally. For each operator-specified depth channel and sailed-distance interval, the result of echo-processing is the echo-integral together with a histogram of resolved single-target target strengths. These numbers are tabulated for each depth channel and for each frequency on the hard-copy colour echo-gram.

The new postprocessing system, developed at the Institute of Marine Research, Bergen, the 'Bergen Echo Integrator', consists of a set of computer programs written in C. These are intended to be machine independent insofar as the operating system is UNIX and such other internationally accepted standard software as X-WINDOWS, GKS, and INGRES, for example, are available. Echo survey data can be stored with maximal or submaximal resolution, and presented and processed at will during or after the cruise. Interpretation of the echo-gram displayed on the screen is facilitated by operator-drawing of integration limits of arbitrary shape. Operator control of the coloration of displayed echo-gram by means of a joystick aids discernment of internal structure in scatterer concentrations.

References to the described echo-sounder and postprocessing system are the following:

Bodholt, H., Nes, H. and Solli, H. 1988. A new echo-sounder system for fish abundance estimation and fishery research. Coun. Meet. Int. Coun. Explor. Sea B: 11. Copenhagen.

Bodholt, H., Nes, H. and Solli, H. 1989. A new echo-sounder system. Proc. Inst. Acoust. 11(3): 123-130.

Knudsen, H.P. 1989. Computer network for fishery research vessels. Proc. Inst. Acoust. 11(3): 115-122.

More recent information may be obtained from the following:

H. Bodholt, SIMRAD Subsea A/S, PO Box 111, 3191 Horten, Norway.

H.P. Knudsen, Institute of Marine Research, PO Box 1870, Nordnes, 5024 Bergen, Norway

B. SOME DETAILS OF PROTOTYPE DUAL-BEAM ACOUSTIC SYSTEMS

(C.H. Greene)

Prototype dual-beam acoustic systems are presently used for krill research in other oceanic environments. These systems can be used to estimate the absolute number density, absolute biomass density and size distribution of krill. Information on these systems is presented in the following papers.

Greene, C.H., Wiebe, P.H., Burczynski, J. and Youngbluth, M.J. 1988. Acoustical detection of high density demersal krill layers in the submarine canyons off Georges Bank. Science 241: 359-361.

Greene, C.H., Wiebe, P.H. and Burczynski, J. 1989. Analysing zooplankton size distributions using high frequency sound. Limnol. Oceanogr. 34: 129-139.

Greene, C.H., Wiebe, P.H. and Burczynski, J. 1989. Analysing distributions of zooplankton and micronekton using high-frequency, dual-beam acoustics. Prog. Fish. Acoust. 11: 44-53.

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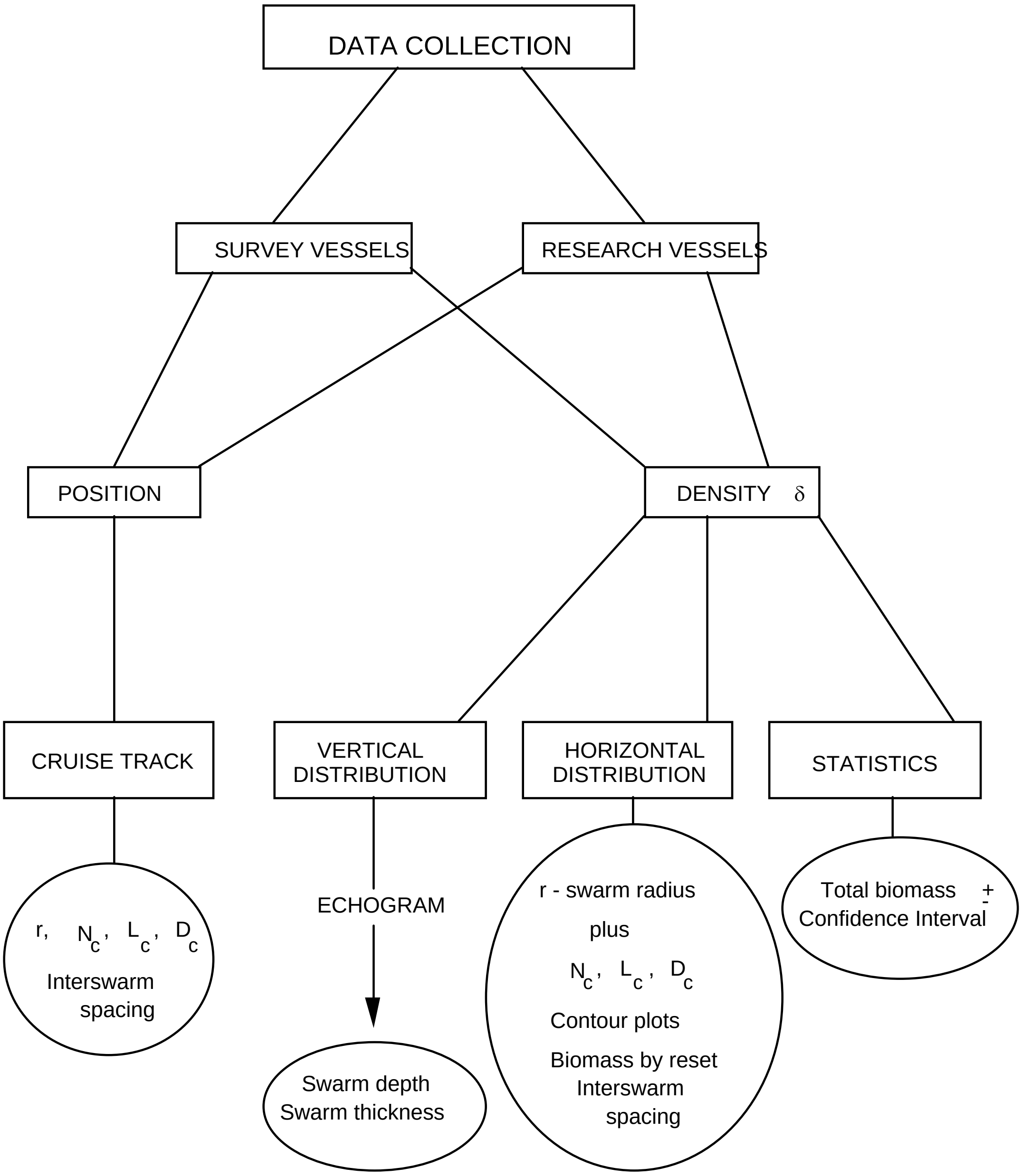
SCHEMA FOR ACOUSTIC DATA COLLECTION AND ANALYSES

(See Appendix 4 for definitions)



APPENDIX 8

MINIMUM ANNOTATION STANDARD OF ECHO CHARTS FROM SURVEY AND RESEARCH VESSELS

Header for Each EchoChart

Vessel Name:

System Type: Hull mounted
Towed
(Manufacturer and Model?)

Operating Frequency:

Echosounder Settings

(Settings that can change during run)

Paper Speed:

Recorder Gain:

Depth Range:

Set Time Annotation

(30 minute intervals)

Time:

Position:

LOCAL

[resident population abundance]
- local reproduction
- depletion by natural sources (e.g. predation) and fishery

GLOBAL

replenishment of resident population by advective transport ⇒ [LOCAL] ⇒ losses from resident population by advective transport

GLOBAL

[global population abundance]

Assessment Strategy

- Monitor [resident population abundance] (fishery independent) density and size structure of concentrations

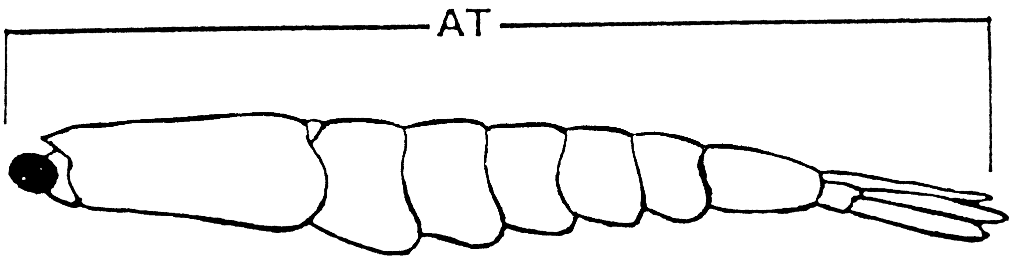
- Use stock assessment approach on resident population to examine its utility (recognizing problem of open system)

- Monitor fishery removal (amount and selectivity)

- Monitor natural sources of mortality (amount and selectivity)

- Can we measure advective transport inputs and outputs?

APPENDIX 10



Suggested body length measurement (AT) for krill caught during commercial fishing operations (BIOMASS Handbook No. 4, Measurement of body length of *Euphausia superba* Dana)

Table 1: Acoustical analysis of krill concentrations

System Type	Types of Vessels[1]	Data Output	Methods of Data Analysis and Presentation	Parameters Estimated from Acoustical Data[2]: N_c	L_c	D_c	r	δ	Other spatial statistics[3]	Comments and Caveats
1. Echo-sounder	F,FS,SR R	Echo-gram	Record start and end of concentrations, number and size of swarms	√	√	√	√		√	Problems associated with • nondetection: - surface krill - minimum levels of detection • misidentification - other scattering sources - TVG problems
2. Echo-sounder with Integrator	SR	Echo-gram	Same as 1.	√	√	√	√		√	• Same as 1.
	(FS,R)	Relative Biomass Density	Mean volume backscattering strength from integrator					(√)		• Variability in scaling factor
		Absolute Biomass Density	Calculate biomass density from integrator output and scaling factor relating mean volume backscattering strength to biomass (from calibration experiments)					(√)		
		Absolute Number Density	Calculate number density from integrator output and mean backscattering cross section (from calibration experiments and simultaneous trawl data)					(√)		• Variability in mean backscattering cross section • Errors from trawl sampling • Reduced flexibility in post-processing
3. Echo-sounder with Integrator and ping by ping data storage	Same as 2.	Same as 2.	Same as 2., but added capability for improved post-processing	√	√	√	√	√	√	• Greater data storage requirements than 2. • Greater expense than 2.
4. Echo-sounder with Integrator ping by ping data storage, and dual- or split-beam capability	SR	Same as 2., but absolute number density and size distribution can be estimated entirely by acoustic methods	Same as 2., but mean backscattering cross section and size distribution are estimated by dual- or split-beam procedures of *in situ* target strength determination on acoustically resolvable krill	√	√	√	√	√	√	• Same as 3., but more data storage requirements and more expensive • Biases of dual- and split-beam techniques must be examined • Dual- and split-beam transducers must be deployed to resolve individual targets

Table 1 (continued)

5. Sonar (single beam and sector seaming with ping by ping data storage	FS,SR	Echo-gram	Same as 1., but also including indication of swarm conformation (i.e. shape and size)	√	√	√	√	(√)	√	• Expensive and requires specialist interpretation/ analyses

[1] Types of Vessels
F - Fishing vessel
FS - Fishing Survey vessel
SR - Scientific Research vessel
R - Resupply vessel

[2] See Appendix 4 for definitions

[3] Other swarm parameters include: depth layer/swarm thickness, interswarm distances (see paragraph 11)

( ) indicates additional research required

Table 2: Scientific nets used in the Southern Ocean for krill research

Gear	Advantage	Limitations
Polish } German } Krill trawls	- large sample size - little to zero net avoidance - deployed on a large number of trawlers = large data set	- net deployment restricted to larger research vessels - net selection for krill > 40 - 45 mm depending on trawl mesh size
RMT 1	(a) relatively simple to handle on most research vessels (b) electronic device enables to have real time net data on e.g. depth of net, filtered water volume (c) opening and closing device for vertical profiles, multiple version of the net available (d) effective on krill larvae sampling	- strong net avoidance of krill - especially unefffective for krill > 35 mm
RMT 8	(e) see (a) to (c) of RMT 1 (f) effective on relative abundance of krill (> 20 mm) for length and development stage compositions (g) working with conducting cable	- net selection for krill > 20 mm - net avoidance in daylight, factor unknown - difficult to handle when no A-frame available on the ship
Bongo	- see (a) and (d) under RMT 1 - two replicate samples at a time	- see RMT 1 - no real time information on depth of net - no opening/closing device
Neuston	- easy to handle on most ships - effective for late krill larvae during certain periods of the season	- impossible to handle during bad weather - restricted to surface sampling
MOCNESS* 1 10	- see RMT 1 (b) to (d) - see RMT 8 - working with conducting cables	- see RMT 1 - see RMT 8 - fixed net frame, difficult to handle on smaller vessels, requires large A-frame for deployment

Table 2 (continued)

IKMT 6' 12'	- simple to handle on most research vessels -	(a) unknown net avoidance and size selectivity (b) requires large A-frame for deployment - see IKMT 6' under (a)
Discovery net **	-	- see Bongo ?
Kaiyu Maru Midwater Trawl KYMT	- see RMT 8 (f)	- see RMT 8 - no opening/closing device
Netmot - * JKMT 5 m^2 (MIK trawl)	- capable of high speed tows (≅ 4 Kt)	- unknown net avoidance and selectivity - requires large A-frame for deployment
BIONESS (1m^2) *	- see MOCNESS 1	- see MOCNESS 1
ORI net (1.6 m^2)	- opening/closing device - easy to handle on research vessels	- no real time information on depth of net - see RMT 1

* not used frequently but may have potential or is under development
** out of use except for comparative studies

Table 3: Methods which could be utilized in monitoring rates of change in abundance and dristribution of krill.

Species	Krill, *Euphausia superba*			
Scales (1) Parameters	Global	Macro	Meso	Micro
Abundance Changes				
Absolute	A* N* (S)	A* N* (S)	A* N*	A* N*
Relative		C Pr	C Pr M	P M
Emigration/ Immigration		A N H	A N H	
Aggregation patterns		A* N* H	A* N* H V	A* N* H P V
Demography				
Sex		N*	N*	N*
Size/Age		B	B	B
Reproductive/ Development Stage				
Community structure				

Key:

A - Acoustics
B - Biochemical/genetic tracers
C - Fisheries catch dependent methods
H - Hydrographic measurements
M - Moored systems
N - Net sampling
P - Photography
Pr - Predator dependent methods
(S) - Satellite Imagery (future development)
V - Visual observations

* Techniques are developed but require further research on sampling design prior to implementation

(1) Definition of scales:

Global: 1 000 km
Macro: 100 - 1 000 km
Meso: 1 - 100 km
Micro: 0.01 - 1.00 km

Table 4: Definitions of krill concentrations produced by the Krill CPUE Simulation Study (7 to 13 June 1989, USA)

Type	Name	Qualitative Description	Inter-Aggregation Distance	Aggregation Diameter	Comment
1	Poor	Swarms widely spaced Diffuse aggregations	Several to 10’s km	Several to 10’s m	
2	Good Layer	Dense continuous layer	0	Few to 10’s km	Both horizontal and vertical separation is possible
3	Good aggregation	Close groups of dense swarms	10’s m	10 - 100’s m	