ANNEX 5

REPORT OF THE WORKING GROUP ON KRILL

(Yalta, USSR, 22 to 30 July 1991)

REPORT OF THE THIRD MEETING
OF THE WORKING GROUP ON KRILL
(Yalta, USSR, 22 to 30 July 1991)

INTRODUCTION

1.1 The Third Meeting of the Working Group on Krill (WG-Krill) was held at the Oreanda Hotel, Yalta, USSR, from 22 to 30 July 1991. The meeting was chaired by the Convener, Mr D.G.M. Miller (South Africa).

1.2 The Working Group was welcomed to Yalta by the Deputy Mayor of Yalta and Director of the Yalta Fish Factory, Mr A.A. Vorobyov.

REVIEW OF THE MEETING OBJECTIVES AND ADOPTION OF THE AGENDA

2.1 The Convener opened the meeting and described the meeting objectives. These were set out in paragraphs 2.59 to 2.61 of the Scientific Committee's report of 1990 (SC-CAMLR-IX) and were primarily the review of fishing activities, refinement of estimates of potential yield and biomass. In addition, the Scientific Committee and WG-Krill have been specifically requested to provide best estimates for precautionary catch limits on krill in various statistical subareas and to identify various options on which such limits could be based (CCAMLR-IX, paragraphs 8.1 to 8.14). The Working Group noted that the USSR, Japan and Korea had considered that there was no need for such precautionary measures as the fishery has remained at approximately the same level since 1986 (CCAMLR-IX, paragraph 8.9) and fishing countries have indicated that they have no intention of dramatically increasing their effort.

2.2 In light of the tasks identified above, the Working Group agreed that all topics should be considered in the the context of improving management advice on krill and continued development of approaches to krill management (SC-CAMLR-IX, paragraph 2.60).

2.3 A Preliminary Agenda had been circulated prior to the meeting. Two additions were suggested, under Item 3 and Item 6. With these additions the Agenda was adopted.

2.4 The Agenda is given in Appendix A, the List of Participants in Appendix B, and the List of Documents submitted to the meeting in Appendix C.

2.5 The report was prepared, in agenda item order, by Drs D.J. Agnew (Secretariat), I. Everson (UK), R. Hewitt (USA), M. Basson (UK), E. Murphy (UK), V. Siegel (Germany/EEC), S. Nicol (Australia) and D. Butterworth (South Africa).

REVIEW OF FISHERIES ACTIVITIES

3.1 Document WG-Krill-91/9 described in detail the fine-scale distribution of catches in the years 1988 to 1990. These data showed a highly consistent pattern of fishing in Subarea 48.1, concentrated around Elephant and Livingston Islands. The distribution of fishing in Subarea 48.2 was much more variable and could not be predicted from year to year.

3.2 The two papers WG-Krill-91/36 and 39, together with comments from Members, established the following preliminary catch figures for krill in the 1990/91 season.

Nationality	Months	Subarea/Catch (tonnes)		
		48.1	48.2	48.3
USSR	June - September			80 000
	May			30 000
	June			?
	October - December	4 000	21 000	
	January - May		120 000	
Poland	July - May			3 336.2
	December - April		5 998	
	December - January	315.3		
Chile	February - March	3 679		
	Totals	7 994	146 998	113 336

3.3 In addition to these catches there were reports that the Soviet Union had fished in the South Georgia region in July 1991, and in the Pacific Ocean sector (Statistical Area 88) from January to April 1991; Japan had fished in Statistical Area 48 at about the same level as in previous years and Korea had carried out fishing in the Scotia Sea taking 431 tonnes.

3.4 It was reported that at the moment the USSR and Poland have no plans for increasing the level of fishing for krill in the near future, the level of Japanese and Korean fishing may well fall, depending on market forces and Chile is likely to increase fishing effort slightly.

3.5 Dr Nicol reported that an application by an Australian company to harvest 80 000 tonnes of krill annually is currently under consideration. Australia is developing an interim management plan pending the development of a krill management procedure by CCAMLR in line with its precautionary approach to management. Mr O. Østvedt (Norway) reported that there was some interest in harvesting krill by Norwegian companies but that this may not develop in the near future.

3.6 Dr Everson noted that the indications of future fishing activity contained in Reports of Members' Activities, while being very helpful, did not contain all the information necessary for the Working Group to determine the likely level of fishing effort. He suggested that the number of fishing vessels expected to be operational during the season should be provided along with their catching capacity. This suggestion was endorsed by the Working Group.

3.7 Paper WG-Krill-91/39 described haul-by-haul data from the Chilean fishery north of the South Shetland Islands. These data enabled a detailed analysis of the distribution of catches and the behaviour of the fishery to be made. Analysis of catch-per-unit-effort (CPUE) where effort is measured in hours fished, showed a drop in CPUE in the years 1989 and 1990 and a return to high levels in 1991. A second paper, WG-Krill-91/37, also analysed CPUE values from haul-by-haul data, and it was emphasised that these sorts of calculations are preferable to analyses of catch rates alone because the processing capacity of fishing vessels usually sets a limit on daily catch rates.

3.8 The Working Group considered this an extremely useful analysis and recalled and endorsed paragraph 2.63 of SC-CAMLR-IX which encouraged the reporting of haul-by-haul data on the krill fishery within 10 km of land-based predator colonies. It was emphasised that depth of fishing and bottom depth should be included in these reports since the relation of krill catch depth to the sea floor will be important (e.g. in assessing by-catches of fish) for CEMP and in analysing the distribution of the fishery in relation to hydrological features.

3.9 Document WG-Krill-91/12 provided information collected by a scientific observer based on board a Soviet commercial fishing vessel. It was emphasised that biological and other data from the fishery were extremely important to the work of the Working Group, and therefore further reports of this type should be encouraged.

3.10 The Scientific Committee in 1990 called for an investigation of the by-catch of young and larval fish in the krill fishery in order to assess the potential impact of such by-catch on fish stocks (SC-CAMLR-IX, paragraph 3.16). A list of nine by-catch species of fish caught by one commercial Chilean vessel was presented in WG-Krill-91/39. An analysis of research vessel data from South Georgia presented in WG-Krill-91/25 showed that adult *Champsocephalus gunnari* was the fish most commonly caught, that it was more likely to be caught when krill catches were low, and that there was by-catch only when fishing was conducted over the shelf. The high risk area for this species was off Clerke Rocks, South East South Georgia. No data are yet available on the larval fish by-catch in the krill fishery.

3.11 The Working Group noted the concern that there may be a substantial mortality of krill not retained in the nets. Paper WG-Krill-91/6 suggested that only 5 to 10% of krill encountering a net are caught in the codend, and that 37 to 74% of those not caught may die as a result of the contact with the net. The Working Group regretted that the data contributing to this paper were not available. Dr V. Sushin (USSR) expressed doubts on the reliability of figures presented in WG-Krill-91/6 and indicated that neither the method nor the data for these estimates were ever published. Moreover, in order to determine the extent of such mortality, these 1975 studies were carried out by means of vertical tows of nets of a different type to those used today. Papers WG-Krill-91/18 and 22 presented a theoretical approach to the estimation of krill damage by midwater trawls.

3.12 The Working Group encouraged work of this nature to determine mortality of krill not retained in krill trawls as this information is extremely important for determining the impact of the krill fishery. If such mortality is high, fishing gear that minimises this mortality should be developed. For example, wings could be removed from nets or replaced by screens of compressed air that serve to herd krill into the net (the latter is included in an Italian Patent reported in *Fishing News International*).

3.13 In considering whether the 1990/91 season had been a poor fishing year for krill in all areas, the Working Group noted the information contained in papers WG-Krill-91/22, 39 and WG-CEMP-91/11 that krill were scarce to the north of the South Shetland Islands until early February 1991; this represented a delay in the arrival of krill of at least two weeks.

3.14 Dr Everson reported results from a fish stock assessment survey around South Georgia (to be presented to the next meeting of the Working Group on Fish Stock Assessment, WG-FSA) which found that only 20% of *C. gunnari* stomachs contained krill, in comparison to an average of 60% from earlier years. This implied a scarcity of krill in the South Georgia region in January 1991. The timing and duration of these periods of krill scarcity have important implications for the fishery and for predators.

INFORMATION NECESSARY FOR MANAGEMENT

Survey Methods and Biomass Estimation

Review of Subgroup on Survey Design's Work

4.1 The Convener of the Subgroup on Survey Design, Dr I Everson (UK), presented the report of the meeting which had been held in Yalta at the Hotel Oreanda from 18 to 20 July 1991.

4.2 The report of the Subgroup is attached in Appendix D.

4.3 In reviewing the report, the Working Group thanked the Convener and participants for all their hard work. A large number of papers tabled for WG-Krill had been considered by the Subgroup. A list of these documents is given in Attachment 3 of Appendix D.

4.4 The Working Group endorsed the report of the Subgroup and in receiving the report, used its findings as a basis for discussion under this agenda item.

4.5 To avoid unnecessary duplication, the Subgroup report is summarised here by section, designated by paragraph number. Where sections of the Subgroup report were accepted with only minor or no comment, this report refers to the relevant paragraphs in the Subgroup report. This section should therefore be read in conjunction with that report.

4.6 Analyses undertaken prior to the meeting and the discussion of the papers are described in Appendix D, paragraphs 7 to 23. Discussion arising from the working papers provided information on specific analytical techniques: standing stock estimation, variance of the standing stock estimate, distribution of patches, geostatistical techniques and aggregation shape (Appendix D, paragraphs 24 to 47).

4.7 The value of simulation studies was emphasised by the Working Group and it was noted that they would have particular application in the development of designs involving analysis by geostatistical techniques. Simulation would also provide indication of the robustness of the various estimators. Further work in these fields was encouraged.

4.8 The analytical techniques discussed by the Subgroup (Appendix D, paragraphs 48 and 56) were then applied to specific cases; monitoring prey to relate to data from CEMP predator monitoring and at three scales, meso (10s to 100s of km), micro (a few to 10s km) and macro (100s to 1 000s km) as used in WG-Krill-91/10.

Prey Surveys for CEMP

4.9 In considering prey surveys for CEMP, the Subgroup discussed, as an example, a design to provide prey information to relate to Predator Parameter A5 (Penguin Foraging Trip Duration) in the Antarctic Peninsula Integrated Study Region of CEMP. This example survey is set out in Survey Design 1 (Appendix D, Attachment 4).

4.10 The design proposed by the Subgroup involves a series of randomly spaced parallel transects. This layout of transects is different to the guidelines adopted last year (SC-CAMLR-IX, Annex 4, paragraph 100). The Working Group agreed that the design provided by the Subgroup offered significant advantages in terms of estimation of standing stock and determining the distribution of krill within a given area.

4.11 Random spacing of transects ensures unbiased estimates of variance, but it was felt that this requirement offered little advantage over a design involving the same number of regularly spaced transects. Regularly spaced transects have the advantage that they are more effective in providing information on krill distribution within the survey area. For this reason the Working Group favoured the use of regularly spaced transects for the survey design.

4.12 It was agreed that this example survey design should be submitted to WG-CEMP in this revised form.

4.13 The design described in Survey Design 1 is aimed at providing a time series of standing stock estimates throughout the CEMP integration period for parameter A5. The Working Group noted that much additional information on the distribution of patches and their composition is available from acoustic datasets and that this might be of value to WG-CEMP.

4.14 The Working Group therefore asks WG-CEMP to indicate the types of information on krill distribution and aggregation that are likely to be most useful in understanding predator/prey interactions. The following types of information might be derived from acoustic datasets collected according to an appropriate design:

standing stock
areal coverage of krill
estimated number of patches
distribution of patches
aggregation parameters:
    depth
    area
    density
    location
    spacing.

4.15 The Working Group, noting that the proposed design was quite specific in considering one predator parameter at one site, agreed that different designs will be required for the other parameters and at the other sites.

Surveys for Direct Abundance Estimation

4.16 The Subgroup had considered the proposals for studies in the south-west Atlantic sector in document WG-Krill-91/10 and had provided guidance on conducting surveys on micro-, meso- and macro-scales (Appendix D, Attachment 4, Survey Designs 2, 3 and 4).

4.17 The meso-scale survey (Survey Design 3) would form the central part of the investigation by providing a standing stock estimate of direct interest for krill studies and also for CEMP. Such a survey could be undertaken in two phases: a rapid mapping phase aimed at identifying gross environmental features and krill patches followed by more detailed local surveys in areas of particular interest.

4.18 In this form the meso-scale survey is broadly equivalent to, but on a slightly smaller scale than, that required for complete subareas. Survey Design 3 describes some of the general principles for the development of meso-scale survey design. These are of application in any situation where standing stock and distribution are of interest.

4.19 The macro-scale survey (Survey Design 4) would be aimed at determining broad-scale krill distribution and the location of specific features such as oceanic fronts. These might be further investigated by the use of drifting buoys.

4.20 The micro-scale surveys (Survey Design 2) would be at sites identified during the meso-scale survey as containing krill aggregations. The Working Group noted that the replication of these micro-scale surveys would need to be made within a short period: days rather than weeks.

Future Work

4.21 It was felt that further work should be directed at describing the general principles and specific details to be used in designing surveys. The following is a list of topics that the Working Group considered required further investigation:

Specific Topics

- Develop survey designs for specific CEMP predator parameters.

- Develop survey designs for determining krill distribution and standing stock at the meso-scale level within CEMP Integrated Study Regions.

General Topics

- Determine the likely variance for meso- and macro-scale surveys of krill standing stock as a function of survey intensity.

- Undertake simulation studies in order to determine the robustness of the parameter estimates under different designs and assumptions about krill distribution.

- Investigate the application of geostatistics to the analysis of acoustic survey data.

Submissions on these topics were encouraged for discussion at the next WG-Krill meeting.

4.22 The Soviet Delegation proposed the construction of a model for the conduct of simulation studies using real acoustic survey data for the development of survey designs and analysis procedures. The Working Group agreed that this was a useful proposal and urged the Soviet Delegation to submit full details to the Scientific Committee's next meeting.

4.23 Dr V. Tesler (USSR) reminded the Working Group that acoustic surveys were only one of several field observation techniques aimed at a better understanding of the distribution of krill. Much could be gained by the use of multi-purpose surveys. He noted that planning for such surveys would need coordination through a small international steering group for each region. He offered to provide the Working Group with a plan for the implementation of such a design for consideration at its next meeting. This offer was gratefully accepted.

Biomass Estimation

Acoustic Target Strength

4.24 A task group, convened by Dr R. Hewitt (USA) met to discuss working papers and informal communications regarding krill target strength. This value is critical to the estimation of krill biomass using calibrated echo sounders.

4.25 Three methods of defining krill target strength were recognised. These are:

(i) single animal measurements, either under controlled conditions or *in situ*;

(ii) aggregation measurements of a known quantity of animals, either caged or *in situ* and subsequently captured by trawl or photographed; and

(iii) theoretical modelling considering animal size, shape, orientation, and physical properties.

4.26 The task group discussed the measurements presented to them with the following comments:

(i) Dr Hewitt presented a distribution of *in situ* measurements of individual krill target strengths (WG-Krill-91/13). The distribution was broader than that expected considering the size frequency of the krill sampled at the same time using an Isaacs-Kidd Midwater Trawl (IKMT) net. The spread is likely to be due to two causes: firstly, variations in animal orientation and shape; and secondly, multiple targets being erroneously identified as single animals;

(ii) Dr S. Kasatkina (USSR) presented a paper describing measurements of encaged aggregations and direct trawl observations (WG-Krill-91/29). The dependence of target strength on biological condition and maturity state of krill was also described. The encaged experiments were undertaken at operating frequencies of 136 and 20 kHz. For aggregations of individuals with a mean length of 45 to 50 mm, target strength values in the range -68 to -69 dB were obtained. At 20 kHz, a series of experiments using krill from 43 to 47 mm total length gave target strength values ranging from -71 to -77 dB;

(iii) the trawl observations presented by Dr Kasatkina in WG-Krill-91/29, involved observation of krill aggregations using a transducer mounted either in front of the net, or on the headline or in the body of the net. The operating frequency of the system was 20 kHz. Catchability of the trawl was described in WG-Krill-91/32. There was a slight increase in the estimated mean target strength as krill entered the net; this was attributed to an artefact induced by aggregation. For krill of mean length 47 to 50 mm, target strength varied from -71 to -77 dB, while for krill in the range 41 to 47 mm the target strength varied from -76 to -81 dB;

(iv) Dr J. Watkins (UK) presented estimates of krill target strength based on underwater photographs on ensonified volumes of krill (WG-Krill-91/40). The results are preliminary and analyses of additional photographs will be presented in a later report. The study will also investigate target strength with respect to the variation of animal orientation;

(v) Dr Everson informally presented a series of target strength measurements made by J. Penrose and T. Pauly in Australia. These measurements were made on free-swimming individual krill in a 3 m deep tank using a 120 kHz system. A formal report is anticipated for the next meeting of the Working Group;

(vi) results from SC-CAMLR-VII/BG/30 and SC-CAMLR-VIII/BG/30 were also available to the meeting;

(vii) a paper by Greene *et al*. (1991) (*Nature 349*: 110), which had been tabled in draft form the previous year as WG-Krill-90/29 was discussed. This paper described measurements of target strength of a variety of zooplankton at 420 kHz and predictions of the likely values at other operating frequencies;

(viii) no working papers on theoretical models of target strength were presented, although the task group was aware of recent models described by Stanton (1988)

(*J. Acoust. Soc. Am. 86*: 1499-1510), and verified by Weibe *et al*. (1990) (*J. Acoust Soc. Am. 88*: 2346-2360), which include parameters for animal size, shape, orientation and physical properties; and

(ix) the task group also considered a communication from Dr K. Foote (Norway) (WG-Krill-91/41) regarding methods for the measurement of krill target strength and recommendations for future work. The task group endorsed the recommendations in the paper. Dr Foote also indicated in his paper that he would present a more formal review of the status of work on the definition of krill target strength at the 1991 Meeting of the Scientific Committee in Hobart.

4.27 The task group decided that it would be instructive to plot the various measurements at 120 and 136 kHz discussed in paragraphs 4.26(i) to 4.26(v) on a graph of krill target strength against animal length (Figure 1). Also included in Figure 1 is the description of target strength as a function of length at 120 kHz given in *BIOMASS Report No. 40* (1986) and the prediction published by Greene *et al*. (1991).

4.28 Using the same data and applying the frequency- and size-dependent functions described by Greene *et al*. (1991), Dr Tesler estimated target strength at 120 kHz values for 40 mm krill. These estimated values are compared with the BIOMASS value for a krill of the same size in the table below.

Target Strength for 40 mm Krill at 120 kHz	Data Source
-71.6 dB	Greene *et al.*
-71.6	WG-Krill-91/13
-71.4	WG-Krill-91/29
-72.7	WG-Krill-91/40
-72.9	SC-CAMLR-VII-BG/30
-71.5	SC-CAMLR-VIII-BG/30
-63.8	*Biomass Report No. 40*

4.29 The task group concluded that a growing body of evidence suggests that the BIOMASS definition of krill target strength as a function of length at 120 kHz consistently overestimates target strength. Furthermore, measurements over a range of animal lengths implies a stronger dependence of target strength on length than that predicted by the BIOMASS definition. These observations agree with theoretical models of scattering from elongated cylinders which predict that target strength is a function of animal volume rather than cross-sectional area.

4.30 The task group recommended that:

(i) the BIOMASS definition of krill target strength at 120 kHz should not be used when converting measurements of volume backscattering strength to biomass. Pending a more formal review of krill target strength, the task group recommends that the following definition, derived from Greene *et al*., be used:

$$TS\ (dB) = -127.45 + 34.85 \times \log_{10}\ (\text{length in mm});$$

(ii) additional measurements of krill target strength be made, in accordance with suggestions by Dr Foote (WG-Krill-91/41), and reported to WG-Krill and published in referred journals. These suggestions include:

(a) cage and *in situ* measurements of krill aggregations should be made over a range of acoustical frequencies and animal lengths and physiological condition. Because of difficulties in estimating trawl avoidance, a minimum of two frequencies should be used with *in situ* experiments so that the dependence of target strength on frequency can be measured without the need for quantitative estimates of the number of krill. Alternately, the numerical density of krill may be calculated with a second high resolution echosounder or from underwater photographs;

(b) *in situ* measurements of individual krill target strength should be made using dual- or split-beam echosounders. Because the target strength of an individual krill often approaches the detection threshold of the instruments used, particular attention should be paid to potential bias toward high measurements;

(c) the shape, orientation, and physical properties (including biological condition and maturity state) of krill should be measured whenever possible to determine the range of variation in these parameters under conditions when the animals would be surveyed; and

(d) the above measurements should be put into theoretical models so as to predict the distribution of individual target strengths that would be expected from a natural aggregation of animals.

Other Methods of Biomass Estimation

4.31 Working paper WG-Krill-91/32 was discussed. The catchability of commercial fishing trawls and small scientific trawls is strongly influenced by krill distribution characteristics. The precision of biomass assessment made with fishing trawls is considerably higher than that of an IKMT. The size distribution of krill obtained with an IKMT is also biased when compared to that obtained with a fishing trawl. Fishing trawls are thus considered to be more reliable than small scientific trawls for quantitative estimates of krill biomass.

Estimation of Yield and Production

4.32 At the 1990 Meeting of WG-Krill, it was requested that calculations of the numerical factor (λ) relating yield to initial, unexploited, biomass and natural mortality, be performed to take into account the seasonal growth of krill (SC-CAMLR-IX, Annex 4, paragraph 68). Results of these calculations are given in document WG-Krill-91/24.

4.33 The results indicate that the main factors affecting the parameter λ are the values of natural mortality and recruitment variability. Results are less sensitive to the values of age-at-first-capture, age-at-maturity and the degree of uncertainty in the survey estimate of biomass.

4.34 Results also seem to suggest that the effect of seasonality is not very strong.

4.35 The paper drew attention to two major caveats. Firstly, the calculations ignored any correlation between estimates of growth rate and natural mortality; these two factors ought to be considered together.

4.36 Secondly, the calculations assume that an estimate of the entire unexploited stock is known. It is, however, known that krill moves through some areas and that surveys may only provide estimates of some proportion of the stock.

4.37 Members agreed that the estimation of total unexploited biomass from estimates of part of the stock was very important and could be incorporated into the model.

4.38 It was pointed out that the model makes the implicit assumption that the krill population would respond to fishing in a compensatory fashion.

4.39 It was also noted that the model assumes that the fishing mortality was imposed homogeneously on the population and that localised effects (and their implications for krill predators, for example) are not considered.

4.40 This matter is difficult to deal with in the framework of the current model but attention was drawn to paragraph 69 of the 1990 Report of WG-Krill (SC-CAMLR-IX, Annex 4) where it was recognised that the resultant value for λ would need to be reduced by some amount to take account of the requirements of krill predators.

4.41 It was also pointed out that the model assumes three months fishing coinciding with the growth period whereas the USSR fishing fleet sometimes fishes in Statistical Area 48 throughout the year. It was explained that the choice of the current analysis was made, primarily, for simplicity and because it reflected an extreme situation. A large proportion of the catch was usually taken during the summer months in Subareas 48.1 and 48.2. Dr Butterworth indicated that alternative scenarios can be considered but it was felt that the duration and timing of fishing should not seriously affect results.

4.42 It was felt that further work was necessary to investigate the sensitivity of λ to the criterion used for the calculations. The results presented in paper WG-Krill-91/24 were obtained using that in the original paper by Beddington and Cooke (1983), as requested by the meeting. This criterion ensures that the probability of the krill spawning biomass falling below 20% of its average pre-exploitation level over a 20-year period of harvesting does not exceed 10%.

4.43 Members felt that because of the nature of the fishery, age-at-first-capture was not something that could be regulated or changed but information from commercial length frequencies should be used to refine the estimate of this parameter.

4.44 The Secretariat indicated that although a data collection scheme had been initiated at the WG-Krill meeting in La Jolla (1989), no biological data or length frequency data from commercial catches of krill had been submitted. The urgent need for such data was re-emphasised.

4.45 Dr Agnew drew attention to a report of a biologist-observer on a commercial trawler (WG-Krill-91/12). This report contains some graphs of length frequencies from the catches and could be used to give some preliminary guidance. Similar data on length distribution were provided from the Polish commercial fishery in WG-Krill-91/37. These data have yet to be submitted to the CCAMLR Secretariat.

4.46 It was felt that the current approach to the estimation of potential yield of krill was in general very useful and that it was now possible to focus on the input parameters, particularly natural mortality (**M**) and recruitment variability, to try to narrow the range of likely values.

4.47 The Working Group agreed that there were still many problems associated with calculation of $\mathbf{B_o}$, the initial biomass. The main problem was felt to be that of estimating immigration and emigration rates of krill between subareas.

4.48 The Working Group agreed that further calculations would be done for the next meeting of WG-Krill. These calculations would attempt to take most of the comments and suggestions into account. Details of these further calculations are given in Appendix E.

4.49 Paper WG-Krill-91/15 presents results from net sampling surveys in the Antarctic Peninsula region in December 1989 and January 1990. Comparisons are made between results from an identical survey done in 1987/88.

4.50 Results indicate that the seasonal variability in abundance is much higher than the interannual variability. The greatest effect on interannual variability was the near absence of juveniles of age group 1^+.

4.51 Production was estimated and ratios of production to biomass of 0.94 (1987/88) and 0.83 (1989/90) were found for the two surveys. These results are similar to those from other studies.

Distribution

4.52 Paper WG-Krill-91/11 presents results for 20 years of study in Subarea 48.2 in the region of the South Orkney Islands. Length frequency data are used to study the spatial distributions of size classes. Distributions varied from year to year and the distributions in the Antarctic Circumpolar Current waters were less complex that those in the Weddell Sea waters.

4.53 The long-term studies at the South Orkney Islands (WG-Krill-91/11), as well as the work on the Antarctic Peninsula (WG-Krill-91/15), note spatial separation of adolescent and adult krill. These observations suggest that the adolescent krill may have been spawned outside the respective survey areas.

4.54 It was felt that the differences in size compositions at different localities together with information on currents could be used to consider stock separation for management purposes.

4.55 Results from a general zooplankton survey in the Bransfield Strait during 1989/90 are presented in paper WG-Krill-91/14. During the survey period (December 1989 to January 1990), the proportion of krill in samples was only 1.3% in number.

4.56 Dr S. Kim (Korea) pointed out that the percentage of salps was very high and that these species tend to clog the type of nets used in the survey. This may have affected the sampling process.

4.57 Net avoidance is another possible factor that could have affected the percentage of krill in samples. Members indicated that krill avoidance, particularly in the case of Bongo nets, is well known.

4.58 Survey results of krill distribution north of the South Shetland Islands in the 1990/91 austral summer are presented in paper WG-Krill-91/22. The main aims of this study were to estimate the biomass of krill acoustically and to investigate mechanisms for the formation of krill concentrations.

4.59 Two different surveys were conducted and a 3.4-fold increase in krill abundance was observed over a 40-day period.

4.60 It was pointed out that the surveys covered very different areas and were therefore not directly comparable. It was also felt that information on strata used to estimate biomass, as well as confidence limits of biomass estimates, should be presented.

Movement

4.61 It was emphasised that the 1990 Meeting of WG-Krill had indicated that movement of krill between subareas may effect the estimation of yield (SC-CAMLR-IX, Annex 4, paragraph 34). This topic was considered to be sufficiently important to highlight the need for further information. A number of papers were presented to the Working Group and these were used as a basis for discussion.

4.62 The Working Group reiterated that localised estimates of instantaneous standing stock will not give an estimate of the effective total stock where krill fluxes (i.e., movement of krill) are significant. This has important implications for the calculation of potential yield from fisheries data. To obtain an estimate of effective total stock, large-scale instantaneous surveys may be required. An alternative is to investigate fluxes directly. This requires knowledge of input, export and residence times for krill in a particular area or region.

4.63 Dr Siegel reported (WG-Krill-91/15) on drifter buoy (FGGE[1]) releases in the Antarctic Peninsula region which produced an estimate of average current velocity of 0.2 m s^{-1} for the near-surface layer. On this basis, the calculated residence time of a specific body of water in the region was approximately three months. During a complete summer season the resident krill stock would therefore be changed approximately twice. Adding the local production, this would result in four to five times the biomass passing through the region during one season.

4.64 Dr V. Marín (Chile) told the Working Group that drift rates calculated using haul-by-haul data from the Chilean fishery (WG-Krill-91/39) were consistent with the results reported by Dr Siegel. Assuming that the fishing fleet located the same krill patch twice over a 17-day period on the northern shelf of King George Is., the estimated drift speed for the patch was 0.05 m s^{-1}.

4.65 Dr Marín also mentioned data obtained from an Argos drifter buoy released in this area as part of the RACER[2] program (USA). These produced an estimate of maximum current speed of 0.19 m s^{-1}.

4.66 Dr P. Fedulov (USSR) described an experiment carried out on the cruise of the RV *Atlantida* in June 1991 in the South Georgia area. This cruise was aimed at estimating the krill biomass transported to South Georgia and at comparing two methods of acoustic biomass estimation: one based on echo-integration and the other on information from each encountered swarm. An area of 8x6 miles, close to the area of operation of the commercial fishery was covered eight times. Preliminary results indicated that this approach can be used for the estimation of krill flux into an area as well as its influence on the resident standing stock.

4.67 The Working Group noted that this particular approach was likely to be extremely useful in studying krill flux through a region and WG-Krill looked forward to formal presentation of the results of this particular survey.

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1 First GARP (Global Atmospheric Research Program) Global Experiment

2 Rates and Processes in Antarctic Coastal Ecosystem Research

4.68 Preliminary results of estimates of krill drift over the shelf around South Georgia undertaken by Dr V. Popkov (VNIRO, USSR) were presented by Dr Shust. A mean value of 10 cm s^{-1} drift was obtained under conditions when there were no well-defined gyres over the shelf resulting in an estimated input of $2x10^5$ tonnes of krill to the shelf area in a 35- to 37-day period.

4.69 Dr M. Naganobu (Japan) informed the Working Group of Japanese Argos drifter buoy studies carried out during the 1990/91 season (WG-Krill-91/22). Four buoys were released on the northern side of the South Shetland Islands and were tracked. One buoy travelled north-east reaching South Georgia five and a half months after deployment. Other buoys showed complex tracks and a tendency to become entrained in topographical eddies generated in shelf waters.

4.70 Additional discussion focused on the extent to which krill could be considered as passive tracers of specific water masses. The Working Group acknowledged that there was little information on the capacity of krill to move against the prevailing current.

4.71 The Working Group was informed by Dr Murphy of the development of a project by IOS (UK) in which krill-like tracers are tracked in the Fine Resolution Antarctic Model (FRAM). This will provide further information on the potential large-scale movement of krill in the Southern Ocean.

4.72 Dr Marín indicated that the Chilean Antarctic Program in collaboration with the US RACER Program will undertake further studies with drifter buoys in the Gerlache Strait during the 1991/92 season.

4.73 The importance of horizontal fluxes of krill between particular regions was considered. Members agreed that such fluxes were likely to be significant within the Scotia Sea region.

4.74 In considering krill fluxes in the Scotia Sea (i.e., Subareas 48.1, 48.2 and 48.3) it was suggested that the Working Group should focus on three hypotheses, namely that:

(i) each subarea is a self-contained krill stock;

(ii) the whole of Statistical Area 48 contains a single stock consisting of interlinked populations; and

(iii) the major region of production is in the Antarctic Peninsula area, all other regions are then supplied by upstream fluxes of krill from this area.

The Working Group acknowledged that a fourth option existed involving much more complex processes.

4.75 A diagram was produced showing a schematic representation of the potential fluxes between subareas in the Scotia Sea (Figure 2). Regions of major fishing impact and containing predator colonies were used to restrict the areas of interest within each subarea. A simplified functional diagram of the flux system was also presented (Figure 3) and this identified the potential fluxes of krill within and between regions. The diagram was also used to illustrate the three hypotheses outlined in paragraph 4.74.

4.76 Members agreed that this series of diagrams provided a useful framework for developing further analyses of the operational dynamics of this complex system.

4.77 The quantitative and qualitative information available to the Working Group concerning water movement in the three subareas was summarised and is shown in Table 1. This table indicates the existence and the potential magnitude of some key fluxes. It is clear that very little of the required information was available to the Working Group. Members considered such information crucial to the further assessment of potential krill yield in the subareas concerned.

4.78 It was also acknowledged that considerably more information may be available in the wider scientific community and members saw that the synthesis of this type of information into a form useful to the Working Group is an important task.

4.79 The Working Group recommended that submissions on this topic be made to the next meeting of the WG-Krill. These should concentrate on estimating the fluxes in the form laid out in Table 1.

4.80 The Working Group formulated two questions for consideration in this regard:

(i) what existing quantitative information can members provide on water movements in the Convention Area for the depth range 0 to 200 m, in terms of velocity fields or integrated mass flows across statistical subarea boundaries?

(ii) what plans are in progress or under consideration for further research on water movements with respect to krill?

The Convener will convey these questions to SCOR and IOC for their consideration.

4.81 Members noted that submissions involving current measurements should also include information on the methodology involved to collect such data, the relevant water depths and details of the analyses undertaken.

4.82 The Working Group acknowledged that methods for considering the relationships between krill fluxes and oceanographic fluxes were required. It was noted that as well as large-scale work of the form described in paragraph 4.71, more localised work would be required. In particular, attention should be given to relating the flux of krill and the retention time in an area. This involves interaction between oceanographic and biological processes.

Demographic Parameters

4.83 Paper WG-Krill-91/15 presents estimates of total mortality (**Z**) from catch curves based on survey data from the Antarctic Peninsula region. Estimates are 0.88 (1989/90) and 0.96 (1987/88).

4.84 Some reservations were expressed regarding the appropriateness of pooling length frequencies where there is a possibility that individuals could be from different populations, where there is spatial succession or where haul-by-haul data are not homogeneous with respect to the population structure.

4.85 It was pointed out that four clusters of stations were identified on the basis of the length frequency distributions. The individual length frequency distributions were appropriately weighted by density strata before pooling within clusters and combining the four clusters.

4.86 Dr Agnew drew attention to results in paper WG-CEMP-91/25 which compares krill catches to estimates of predator consumption. These results suggest that, in certain regions, the fishing mortality could be quite a large proportion of total mortality.

4.87 Some members felt that a value of **Z** close to 1 may be too high if it is assumed that fishing mortality is relatively low and that the life span of krill is about seven years.

4.88 Dr Siegel agreed that longevity is closely related to natural mortality and, using the theoretical approach of Alagaraja (1984) (*Indian J. Fish 31*: 177-208), the expected values of **M** would range from 0.66 to 0.92 for a 7- and 5-year life span respectively (WG-Krill-91/15).

4.89 Three other factors that could lead to biased estimates of total mortality were noted:

(i) net avoidance (particularly of larger animals);

(ii) immigration and/or emigration; and

(iii) consumption by predators.

It was pointed out that it is well known that there are problems of net avoidance in krill, particularly in the case of smaller nets, but that it is very difficult to quantify this effect.

4.90 The surveys presented in WG-Krill-91/15 covered the whole distribution range of all age classes of krill along the Peninsula and the continuous drift of the stock through the area takes considerably longer than the survey. This occurs for all age groups so that immigration/emigration of single age groups which might affect the slope of the catch curve data is of minor importance to the estimate of **M** in Subarea 48.1, presented in this paper.

4.91 Dr L. Maklygin (USSR) reported preliminary results of mortality estimates from RV *Discovery* samples (1926 and 1928) and more recent samples (up to 1985). Estimates of **M** range between 0.75 and 1.13 and values from the *Discovery* and recent samples are very close.

4.92 Three tables of published demographic parameters were prepared. The tables contain growth parameters of the von Bertalanffy equation (Table 2), daily growth rates (Table 3) and estimates of total mortality (Table 4).

4.93 It was noted that the Working Group did not have the time to examine the estimates given in the tables or the methods used to obtain them and that this would need to be done in future. It was also noted that the evaluation of estimates have been done, to some extent, in paper WG-Krill-91/15 and Miller and Hampton (1989) *(BIOMASS Scientific Series No. 9*).

4.94 Members who have further information on demographic parameters were urged to submit these to the next meeting of WG-Krill.

ADVICE TO WG-CEMP

5.1 The Working Group considered several issues of direct relevance to WG-CEMP, in particular: (i) development of survey designs for prey monitoring, and (ii) estimation of the amount of krill consumed by predators. Papers considered relevant under this agenda item were: Report of the Subgroup on Survey Design (Appendix D), WG-CEMP-91/4 and 25.

Survey Design for Prey Monitoring

5.2 The specific results of the Subgroup on Survey Design's deliberations were discussed in detail under Agenda Item 4 (see paragraphs 4.1 to 4.20). Some of these results were further considered in light of their applicability to the work of WG-CEMP.

5.3 The Convener of WG-CEMP, Dr J. Bengtson (USA), said that he found the report of the Subgroup on Survey Design to be useful and that the Subgroup had made good progress in specifying survey guidelines for prey monitoring. In initiating its work, the Subgroup chose one Standard Method as an example (A5 - Penguin Foraging Trip Duration) and developed survey guidelines for prey monitoring specifically related to this parameter. He noted that it would be helpful if the Working Group could build on this successful start by developing survey guidelines for prey monitoring associated with the other Standard Methods as well.

5.4 The question was raised concerning whether WG-CEMP would be most interested in survey designs which assessed krill standing stock within particular predator foraging areas or the local distribution of krill aggregations. It was emphasised that obtaining these two types of data may require different survey designs. Because of the current uncertainties concerning the degree to which each of these two factors (abundance versus aggregation patterns) affect relative krill availability to predators, resolving this issue is expected to be a topic of directed research and discussion within WG-CEMP for a number of years. Until this matter is clarified, Dr Bengtson requested that WG-Krill further specify survey designs to be used in each of these cases as well as guidelines for surveys to provide both sorts of information simultaneously.

5.5 In reply, the Convener of WG-Krill drew the Working Group's attention to earlier discussions under Agenda Item 4 (paragraphs 4.9 to 4.15). Nevertheless, there was general agreement that the development of improved survey designs, specifically to address the problem of accurately assessing both aggregation patterns and overall biomass within an area of interest, will undoubtedly be facilitated by additional simulation studies aimed at considering the problems involved.

5.6 Furthermore, it was recognised that it may not be possible to provide a single generalised design for prey monitoring surveys for all areas since the criteria for stratification in one area may not necessarily apply to other areas.

5.7 It was emphasised that krill surveys do not necessarily need to be designed for each predator parameter individually since certain types of surveys would provide reliable information for several predator parameters simultaneously. Still, it would be helpful for various survey designs to be developed so that they may be implemented in conjunction with directed research on specific predator parameters. Such an approach would facilitate the study of specific aspects of interactions between prey availability and predator parameters monitored by Standard Methods.

5.8 It was noted that the general principles for the design of meso-scale standing stock surveys described in Survey Design 3 (Appendix D, Attachment 4) would be used in the development of survey designs for standing stock estimation in the vicinity of CEMP sites.

5.9 The Working Group agreed that more work was needed on the development designs for meso- and macro-scale surveys. Furthermore, the logistic constraints under which such surveys must operate will require additional evaluation. To assist WG-Krill in its work (see paragraph 4.21) during the forthcoming year, WG-CEMP is requested to consider the following questions at its 1991 Meeting:

(i) Is the approach outlined in the Subgroup's report (i.e., the survey design for prey monitoring related to Standard Method A5) appropriate from WG-CEMP's perspective?

(ii) Would it be helpful for WG-Krill to develop survey designs for additional Standard Methods (if so, specify which Methods are priorities for developing associated survey designs, which Methods can be grouped for this purpose and which temporal and spatial scales are appropriate to this task)?

(iii) Is it possible to state at this time whether surveys should be designed to emphasise preferentially either krill abundance or the distribution of aggregations, or both?

(iv) To what extent are the survey designs outlined in Subgroup Survey Designs 2, 3 and 4 relevant to prey monitoring for CEMP?

(v) Which methods of presenting acoustic data (as outlined in SC-CAMLR-IX, Annex 4, paragraph 102) would be most relevant for CEMP prey monitoring?

Krill Consumption by Predators

5.10 The Working Group expressed its continued interest in obtaining estimates from WG-CEMP on the amount of krill eaten by predators in various geographic areas. Such data are important both for estimating the potential yield of krill stocks and for calculating required krill escapement from the fishery. It was noted that in response to a request from the Commission (CCAMLR-IX, paragraph 4.36), WG-CEMP is currently addressing this matter and is considering holding a workshop to formulate the requested estimates. The Working Group endorsed WG-CEMP's efforts and encouraged it to proceed with the development of these estimates as soon as possible.

5.11 It was noted that relevant information required to formulate such estimates is presently more available for land-breeding predators such as fur seals and penguins than for other species. However, because of the importance of pelagic predators such as whales and ice-breeding seals, the Working Group recommends that WG-CEMP include these species in their deliberations on predator requirements (see paragraphs 8.4 and 8.5).

5.12 Dr Marín pointed out that there may be problems of scale when considering catches only at the subarea level and drew attention to the instruction from the Scientific Committee that krill harvesting should not disproportionally affect land-based predators when compared to pelagic predators (SC-CAMLR-IX, paragraph 2.19).

5.13 As the fine-scale data have shown (WG-Krill-91/7), the fisheries catch may be highly localised in areas where predators are foraging at times when krill availability is critical (e.g. predators' breeding season). Although the krill catch on a subarea basis may not appear great, it may be highly significant in terms of the impact that it has on local predator populations.

5.14 Dr Agnew had prepared a paper evaluating the fine-scale catch data in conjunction with important land-based colonies of penguins and fur seals (WG-CEMP-91/25). This paper indicated that a very high percentage of the commercial krill catch occurred close to some colonies during the breeding season, which highlighted the need for closer evaluation of the potential impact of highly localised commercial catches on land-breeding predators.

5.15 The interannual variation in krill consumption by predators may affect the extent to which the fisheries catch may potentially impact on predators. It was noted that there was certainly an upper limit to consumption by a predator population of a given size, although, in years when prey were relatively scarce, krill consumption by predators would probably fall below this upper limit. At present, the variability in the ratio between krill consumption by predators and the commercial catch level is unknown, but this ratio should be taken into account when assessing the interactions between fisheries and other krill consumers.

DEVELOPMENT OHF APPROACHES TO MANAGING THE FISHERY

Operational Definitions of Article II

6.1 At its previous meeting, the Working Group had suggested four concepts on which to base operational definitions of Article II (SC-CAMLR-IX, Annex 4, paragraph 61):

‘(i) aim to keep the krill biomass at a level higher than might be the case if only single-species harvesting considerations were of concern;

(ii) given that krill dynamics have a stochastic component, focus on the lowest biomass that might occur over a future period, rather than the mean biomass at the end of that period as might be the case in a single-species context;

(iii) ensure that any reduction of food to predators which may arise because of krill harvesting is not such that land-breeding predators with restricted foraging ranges are disproportionately affected in comparison with predators present in pelagic habitats; and

(iv) examine what level of krill escapement would be sufficient to meet the reasonable requirements of krill predators. It was agreed that WG-CEMP be asked to consider this aspect.’

6.2 The Scientific Committee and Commission (SC-CAMLR-IX, paragraph 2.19 and CCAMLR-IX, paragraph 4.17) had endorsed these suggestions as a useful basis on which to develop a management policy for krill, and the Working Group's request that members provide operational definitions to its next meeting. However, no such suggested definitions had been forthcoming.

6.3 The Working Group agreed that this matter required further attention. However, it noted that the matter needed to be considered in the context of a particular management procedure(s) and its associated mechanisms for monitoring the krill resource.

Possible Approaches to Managing the Fishery and their Development

6.4 The Working Group decided to base its discussions on the categories listed in paper WG-Krill-90/14, namely:

- reactive management;
- predictive management (modelling);
- open and closed areas;
- indicator species;
- pulse fishing; and
- feedback management.

Reactive Management

6.5 Reactive management is the practice of implementing conservation measures only after the need for them has become apparent.

6.6 The Working Group identified three questions pertinent to consideration of reactive management:

(i) What criteria would be used to decide when some form of regulation would be necessary?

(ii) What information about the status of the stocks would be needed to apply the criteria?

(iii) What confidence could there be that the regulations would be introduced in time and be sufficient to prevent failure or to achieve the conservation objectives of the Convention?

6.7 The Working Group was unable to provide any suggestions for (i) and (ii) above. With respect to (iii), the Working Group noted that reactive management has been the default approach in many fisheries, and that it entailed a very high risk of failure often resulting in the collapse of the fisheries. Accordingly, the Working Group agreed that reactive management was not a viable long-term strategy for the management of the krill fishery.

6.8 The Working Group agreed that a case could be made for a modified reactive strategy in which regulations had no effect on the conduct of the fishery until the fishery itself had attained certain characteristics; e.g. it had reached a certain annual catch. This is the type of approach that the Commission discussed at its Ninth Meeting (CCAMLR-IX, paragraph 8.6) in terms of a precautionary catch limit and a controlled rate of expansion of the fishery after it had reached that level.

6.9 Such precautionary limits would obviously have to be much less than the point estimate of the level of fishing which would maximise production from the stock. Calculations of a range of values for such precautionary limits are given below in paragraphs 6.31 to 6.59.

6.10 Once the precautionary limit has been reached, the Commission should be prepared to implement the next phase of its management strategy, which would be based on some combination of the approaches discussed below.

Predictive Management

6.11 Predictive management involves predicting the level of catch that the resource can sustain from available information, and is usually based on some form of model of the system. The formula $Y = \lambda M B_o$ discussed in paragraphs 6.42 to 6.55 below is an example of such a predictive model.

6.12 Predictive management should not be based on the 'best' estimates of parameters only. Plausible ranges for these parameters have to be considered to make allowance for uncertainty.

6.13 Positive aspects of predictive management are that it provides information on appropriate criteria for determining when conservation measures may need to be enacted and what data will be required to evaluate such criteria.

6.14 Negative aspects are that predictive management alone cannot be adequate in the long-term because of the need to correct, over time, for inexact estimates and imperfect models.

6.15 Simple compensatory single-species models (such as the model which leads to the $Y = \lambda MB_o$ equation) are usually used for predictive purposes. Concerns expressed in this regard were:

(i) the need for some additional adjustment factor to take account of multi-species aspects;

(ii) the justification for the assumption of compensatory behaviour; and

(iii) whether the additional mortality imposed by fishing would indeed be equally felt by all members of the population as is usually assumed by such models.

Open and Closed Areas

6.16 Closing certain areas, whose size would typically be much smaller than statistical areas or subareas, for part or all of the season could provide a mechanism to:

(i) reduce the by-catch of juvenile fish;
(ii) reduce any impact on the food resources of land-based predators; and
(iii) guarantee a certain escapement of krill from the fishery.

6.17 Positive aspects of such measures are that they may be implemented both cheaply and in the near future.

6.18 The negative aspect is the difficulty in defining the areas appropriately. Further, care would have to be taken that areas remaining open would still guarantee a ready availability of krill to the fishery.

6.19 Given present knowledge, closed area specifications could not be determined with sufficient confidence to guarantee adequate escapement of krill for conservation of the resource, so that such an approach would be inadequate in isolation, but might be used in conjunction with other approaches.

Indicator Species (and Other Indirect Methods)

6.20 The concept underlying this approach is to detect deleterious effects of krill fishing by monitoring condition factors of a small range of predators.

6.21 A positive aspect of this approach is its direct appeal to Article II, in terms of which predators must be monitored in any case. Further, it captures the effects of the location of fishing, which may adversely affect land-breeding predators while not compromising conservation of the krill resource itself.

6.22 Difficulties are calibration of non-linearities in the predator index versus krill abundance relationship, and the possibilities of time-lags in this relationship which could mean that it fails to provide timely warning of a threat to the krill resource. Further, distinguishing the effects of natural events from those of the fishery can be problematic.

6.23 As with closed areas, this approach would not be adequate on its own, but might form part of a suite of management tools.

6.24 Monitoring certain factors, such as environmental variables, might provide an indication of where krill is likely to be found, but this approach provides information on the krill habitat only, and not on resource status which is essential from a management perspective.

Pulse Fishing

6.25 Pulse fishing is intense fishing in a number of areas in sequence, so that the stock in a given area has recovered by the time that fishing recommences there.

6.26 No advantages were seen in such a system. Stock size and productivity would still have to be estimated (as for predictive management), continuous movement of the area of operation would probably be unattractive for the fishing operations, and heavy exploitation in a localised area would be likely to conflict with concerns for land-breeding predators.

Feedback Management

6.27 Feedback management involves successive adjustments to control measures (such as catch limits) as more information about the resource becomes available, so that management objectives are better achieved. Any management approach eventually requires adjustment in this feedback manner. An example of a possible feedback management approach for krill is given in SC-CAMLR-VIII/BG/17.

6.28 Feedback management procedures are developed by simulation testing and can be designed to be relatively robust to a number of the uncertainties about a stock's dynamics. Such trials also provide information on the relative value of different kinds of information about the stock; this information may be under consideration for collection.

6.29 Feedback management may require costly monitoring, and so may not be justified in the initial phase of a developing fishery. However, the development period should be used to test and select from a number of candidate feedback procedures, as well as to collect base-line information, so that such a procedure can be put into operation immediately the fishery reaches the appropriate size.

6.30 The Working Group agreed that developing a feedback management procedure for krill should be a long-term aim. In the meantime, the other approaches discussed would have to provide the basis for formulating the advice on precautionary measures for the krill fishery that had been requested by the Commission.

Precautionary Limits on Krill Catches

6.31 The preceding meeting of the Commission had asked for an indication of the best estimate of a precautionary limit for krill in the various statistical areas and an identification of the various options for the basis on which such a precautionary limit could be established (CCAMLR-IX, paragraph 8.5).

6.32 At that meeting 'The USSR, Japan and Korea stated their view that they were not in principle opposed to the idea of a precautionary limit on krill fishing, but that the quantitative basis for such a precautionary limit on fishing should have scientific justification based on assessments performed by the Scientific Committee' (CCAMLR-IX, paragraph 8.7).

6.33 The Working Group decided to concentrate its efforts on providing estimates for precautionary limits in the form of annual catches. However, it recognised that such limits could be formulated in different terms to achieve similar aims. For example, a limit might be set in terms of fishing effort, expressed, for instance, in vessel-months. Nevertheless, the level of effort selected would probably have to be derived from a prior calculation of an appropriate catch limit.

6.34 The Working Group noted that the rationale underlying the consideration of precautionary measures is the prevention of unregulated expansion of the fishery at a time when the information available for predicting potential yield is very limited. It stressed that such measures were short-term and would need regular review. Further, they were of an interim nature and should be superseded as soon as the information for an improved basis for management becomes available.

6.35 The Working Group recognised that it is possible to devise precautionary measures based on whole statistical areas or on individual subareas, and that each approach has different consequences.

6.36 The whole-area approach has the advantage that it is less sensitive to spatial and temporal variability, and allows a higher degree of flexibility to the fishery. The disadvantages of this approach are that the krill and predator populations may not enjoy the same degree of protection as they would under a scheme utilising the subarea approach.

6.37 Two alternative bases for specifying precautionary catch limits were considered for Statistical Area 48. The first sets these limits in relation to historical catches in the area. The second utilises the $Y = \lambda MB_o$ formula (see paragraphs 6.42 to 6.55 below) to specify a level of catch below which no management action would be necessary.

Historical Catch Basis

6.38 Table 5 provides precautionary limits based on historical catches in Statistical Area 48. The approach is to set the limit equal to the maximum annual catch that has been taken.

6.39 Two options are shown. The first is a whole-area approach which sets the limit for Statistical Area 48 to the sum of the maximum catch taken from each of the subareas over the history of the fishery, which is 619 500 tonnes.

6.40 The second option limits the catch in each subarea to the maximum ever taken in that subarea, but also 'caps' the catch in the whole area by the maximum catch ever taken in the whole area in one year, which is 425 900 tonnes. The reason for such a 'cap' is that there may be only one stock in the area, with variations in distribution from year to year, so that the calculation of the first option would overestimate an appropriate limit.

6.41 There are a number of objections to this general approach as the basis for setting precautionary limits:

(i) there is little scientific basis or relation to assessment of the stock;

(ii) the limits could be unnecessarily restrictive if the stock is capable of yielding much greater amounts than have been taken historically; and

(iii) it takes no account of changes in fishing effort due to economic and other factors.

' $Y = \lambda MB_o$ '

6.42 The formula $Y = \lambda MB_o$ provides an estimate of the potential yield from a resource. The resultant figure would be higher than would be appropriate for a precautionary limit for krill catches because:

(i) a precautionary limit should be <u>below</u> the possible ultimate level for the fishery, since the later stages of the growth of the fishery to such a level should take place under an improved management procedure (e.g. feedback control); and

(ii) allowance needs to be made for uncertainty in the estimates of the parameters used for the $Y = \lambda MB_o$ calculation.

6.43 A 'discount' factor **d** is introduced into the formula for these reasons. This factor has to be selected somewhat arbitrarily at this time, but common sense suggests that it should be neither too close to 1 nor too small. A value of 0.5 or 0.67 might therefore be appropriate; the calculations in Table 6 have used **d** = 0.67.

6.44 Values of λ were only available for the combination of choices for recruitment variability ($\sigma_{\mathbf{R}}$) and natural mortality (**M**) reported in Table 2 of WG-Krill-91/24. A selection had therefore to be made from amongst these combinations.

6.45 It was decided to base calculations on the choice $\sigma_{\mathbf{R}}$ = 0.4. The parameter $\sigma_{\mathbf{R}}$ measures the standard deviation in the natural logarithm of krill year-class strength. No information is as yet available from which to estimate σ_R for krill in Statistical Area 48, but 0.4 is a typical value for stocks of other pelagic prey species.

6.46 For $\sigma_{\mathbf{R}}$ = 0.4, the product λ **M** is relatively insensitive to whether **M** = 0.3 or 0.6 yr^{-1}. Further, there is no indication of a value of **M** as low as 0.3 in Table 4. Thus it was decided not to consider results for **M** = 0.3 further.

6.47 The preponderance of values for **M** in Table 4 is nearer to **M** = 1.0 than **M** = 0.6. However, the values in this table all assume **Z** = **M**, i.e. that fishing mortality is zero, so that they will be positively biased to some extent. Further, estimates of **M** are correlated with the growth rate used for krill; since a slowish growth rate was assumed for the calculations of WG-Krill-91/24, it would be inappropriate to use the results of that paper for a very large estimate for **M**.

6.48 Taking these facts into account, and appreciating that considerable uncertainty about an appropriate choice for **M** still remained, the Working Group decided that results should be reported both for **M** = 0.6 and **M** = 1.0.

6.49 The two values of **d**λ**M** are 0.093 and 0.14. The calculations based on these values are presented in Table 6.

6.50 The biomass estimates selected under Option 1 in Table 6 for the various subareas of Statistical Area 48, correspond to the most recent and extensive surveys in these regions. There are further recent estimates available (e.g. that given in WG-Krill-91/22 for Subarea 48.1), but substitution of such estimates would not substantially alter the results given.

6.51 Nevertheless, these estimates are for localised surveys within each subarea, and therefore provide negatively biased estimates of krill biomass in these regions, and fail to allow for immigration and emigration of krill transported by currents.

6.52 Accordingly, the biomass estimates shown should be multiplied upwards by a 'flux' factor (**f**), before being taken to correspond to the $\mathbf{B_o}$ value required for the formula. The precautionary limits shown corresponding to Option 1 (which assume **f** = 1) are therefore considerably smaller than is realistic.

6.53 Values for **f** in the range 2 to 4 may be appropriate. Option 2 in Table 6 gives results for a specific estimate of **f** in Subarea 48.1. However, there are possible problems in applying an **f** factor to every subarea because, unless these subareas contain effectively isolated stocks of krill, some multiple-counting may arise.

6.54 The Working Group's preferred basis for calculation is therefore Option 3 of Table 6. This uses the FIBEX estimate of biomass which is calculated from the results of simultaneous sampling of krill by a number of vessels at various localities throughout Statistical Area 48, and thus provides a direct estimate of $\mathbf{B_o}$ with little need for adjustment by some **f** factor.

6.55 The resultant estimate for a precautionary limit for the krill catch in Statistical Area 48 on this basis therefore lies in the range 1.4 to 2.1 million tonnes. These values are compatible with those for Options 1 and 2 in Table 6, if allowance is made for flux factors.

Other Information

6.56 The Working Group agreed that it was desirable to have more than one approach to calculating a precautionary limit, as more confidence could be placed in the result if different approaches provided similar answers.

6.57 Table 7 shows the results of an approach by Yamanaka (1983) based on a model of krill, natural krill predators and the fishery, which suggests that an appropriate level of fishing mortality would be 10%. This leads to a precautionary limit of 1.5 million tonnes for Statistical Area 48 (also using the biomass estimate from the FIBEX survey).

6.58 SC-CAMLR-VIII/BG/17 investigated a feedback control management procedure for krill in Statistical Area 48. Its calculations suggested that a precautionary catch limit (below which no restrictions would be placed on the rate of expansion of the fishery) should lie in the range 1 to 2 million tonnes.

6.59 The values suggested by these two different approaches in paragraphs 6.57 and 6.58 are therefore similar to those obtained from the $Y = \lambda MB_o$ approach and listed in paragraph 6.55 above.

Conclusions

6.60 The Working Group agreed that its best estimate of a precautionary catch limit for krill in Statistical Area 48 is 1.5 million tonnes. Shortage of time prevented consideration of similar calculations for other areas and the Working Group recommended that these calculations be performed as soon as practicable.

6.61 The Working Group also agreed that this estimate for Statistical Area 48 should be divided on a subarea basis, to allow for the possibility that these subareas contain separate stocks. However, the calculations required to do this could not be performed, because the basic FIBEX data divided by subareas were not available at the meeting. The Working Group recommended that these calculations be carried out as a priority.

6.62 It was further noted that these calculations should ideally include immigration and emigration rates between subareas as discussed in paragraphs 4.61 to 4.82 and 6.52 to 6.55.

6.63 Dr Shust stated that the Soviet Delegation wished to re-emphasise the concerns they had raised earlier in the report about the various methods suggested for calculating a precautionary catch limit. These particular concerns are reflected in paragraphs 6.41 and 6.50 to 6.54. In the light of their concerns they considered that the best estimate arrived at in paragraph 6.60 was not necessarily an adequate basis for a recommendation for a precautionary limit.

6.64 In response, other members wished it noted that they too shared the concerns indicated above and had raised questions reflected in paragraphs 6.50 to 6.54. These concerns did not detract from the situation that the present calculations were the best that could be made at this time.

6.65 Dr Naganobu stated that Japan has been concerned that placing precautionary limits on the krill fishery would be premature. This is because:

(i) krill catches remain small compared, for example, to the krill consumed by baleen whales before their removal from the Antarctic ecosystem (the so-called 'krill surplus');

(ii) the available scientific information on which to base any precautionary limits is still subject to considerable uncertainty; and

(iii) there should not be unnecessary limitations on countries making rational use of renewable marine resources.

6.66 Dr Naganobu added that this should not be understood to imply that Japan was not concerned about the need for appropriate regulation of krill catches, and stated that he felt the approach advocated by the Working Group to formulate a precautionary limit might have potential. However, he needed more time to consider the details of this approach in consultation with his scientific colleagues in Japan, and accordingly wished to reserve Japan's position in respect of the Working Group's conclusions in paragraphs 6.60 and 6.61.

ADVICE TO THE SCIENTIFIC COMMITTEE ON THE STATUS OF STOCKS

The Status of Krill Stocks

7.1 The Working Group had sufficient time to review only the krill resource in Statistical Area 48. It considered the estimate of 15.1 million tonnes from FIBEX (now adjusted for a revised acoustic target strength relationship, see paragraph 4.30) to be the best available for the biomass of krill in the area (see paragraphs 6.60 to 6.61).

7.2 Calculations based on the formula $Y = \lambda M B_o$ suggest that current catches in Statistical Area 48 are well within the likely limits of productivity of the resource, if the harvest is viewed as a single-species fishery (compare Tables 5 and 6; see also paragraphs 6.42 to 6.55).

7.3 Nevertheless, much of the catch is taken in close proximity to colonies of land-breeding predators. Available evidence does not allow a determination of whether the fishery is having a marked effect on these colonies.

7.4 The Working Group agreed that its best estimate of a precautionary catch limit for krill in Statistical Area 48 is 1.5 million tonnes. This should be divided on a subarea basis as indicated in paragraph 6.61.

New and Developing Fisheries

7.5 At the 1990 Meeting of the Commission, the Executive Secretary had been asked to prepare a working document relating to appropriate definitions of 'new and developing fisheries'. Underlying this request was the concern that fishery development should not proceed faster than development of the data base necessary to assess the effects of harvesting on target, dependent and associated species.

7.6 Dr D. Powell (Secretariat) introduced document CCAMLR-X/6 which he had prepared towards this end, and sought comments from the perspective of WG-Krill on the ideas it contained, particularly in regard to the suggested definition of a 'New Fishery':

> 'A NEW FISHERY is a fishery on a species using a particular fishing method in a statistical subarea, for which catch and effort data never have been submitted to CCAMLR; or, a fishery on a species using a particular fishing method in a statistical subarea, for which catch and effort data have not been submitted to CCAMLR for at least the past two years.'

7.7 Comments made included:

(i) the definition did not adequately capture the sense of the information requirement, particularly as survey biomass estimates rather than effort data might be of more pertinence to krill;

(ii) there should be room for flexibility on common sense grounds;

(iii) the matter of differences between data submitted and data requested needed to be addressed; and

(iv) comments already made by WG-FSA were relevant from the krill fishery viewpoint as well.

7.8 Some views were expressed that 'definitions' *per se* might be problematic to develop, and that listing criteria might be more useful.

7.9 In summary, it was seen as important that the definition suggested be expanded to reflect the types of information needed for assessment purposes.

CCAMLR Scheme of International Scientific Observation

7.10 The Working Group noted that the Commission at its 1991 Meeting, will discuss the details of an international scientific observation scheme. A paper (CCAMLR-X/7) has been prepared by the Secretariat to assist in the discussions. Each of the Working Groups of the Scientific Committee have been asked to provide an input to the discussions in the form of tasks to be undertaken and methods to be used by scientific observers on board fishing vessels.

7.11 At its 1990 Meeting the Working Group had discussed a form used by Soviet observers to report biological information from commercial krill catches. This form was modified and expanded as a result of these discussions and distributed by the Secretariat in January, 1991 as SC-CIRC 91/1.

7.12 After some further modification it was agreed that these forms should be submitted to the Scientific Committee for inclusion in its advice to the Commission on the CCAMLR Scientific Observer Scheme.

7.13 The Working Group also noted that to use the above forms effectively, it will be necessary to provide some form of detailed handbook to ensure that Standard Methods are used. Consequently the Working Group welcomed an offer from the Soviet Delegation to provide the handbook accompanying their report of observation form and a colour identification chart of krill to the Secretariat. The Secretariat was requested to circulate a translated version of the handbook to Members during the intersessional period.

Future Work of WG-Krill

7.14 Table 8 provides a list of data and research requirements previously identified by the Working Group. The list is annotated to indicate progress to date, and also to indicate the Working Group’s comments on further action necessary.

7.15 Although a number of the topics identified by WG-Krill at its last meeting remained on the Working Group’s agenda, there was strong agreement that its work had progressed well. In particular, refinement of estimates of potential yield including the investigation of krill fluxes between areas in Statistical Area 48, the estimation of precautionary limits and discussions on the development of various approaches to management were seen as important.

7.16 The Working Group agreed that of the topics identified elsewhere in the report (see for example Table 8) which require further work during the forthcoming year, the following should be given the highest priority:

- investigations of flux in Statistical Area 48 and other areas;

- estimation of total effective biomass in Statistical Area 48 and other areas; and

- refinement of calculations of potential yield including further evaluation of the pertinent population models and demographic parameters used in such calculations.

7.17 Subject to these priorities, the Working Group recognised that its ongoing work should also continue to address problems associated with survey design, development of management approaches and the continued liaison with WG-CEMP on matters of common concern.

7.18 In regard to the continued collection of data from the commercial fishery the Working Group emphasised that:

(i) length frequency data from the fine-scale reporting areas should be submitted to the Secretariat. The Working Group acknowledged that the collection of this data would, to a large extent, only be possible by specially trained personnel; and

(ii) haul-by-haul data should be collected and submitted to the Secretariat. The Working Group recognised that the collection and submission of such data may on occasion be problematical.

7.19 The Working Group further agreed that the priority tasks referred to in paragraph 7.16 above should form the basis of the agenda for the Working Group's next meeting. It was noted that the Scientific Committee at its 1991 Meeting, will almost certainly raise matters for inclusion on this agenda. It was agreed that the favoured timing for the meeting of WG-Krill in 1992 would be July/August.

OTHER BUSINESS

8.1 The Convener advised that he had made formal contact with SCOR as he had been previously requested to do (SC-CAMLR-IX, Annex 4, paragraph 129), and had been forwarded several documents related to water circulation studies. Copies of these would be available through the Secretariat, and SCOR would be thanked for their response.

8.2 The Convener also made reference to a letter received last year from the Soviet Academy of Sciences concerning the potential impact of the krill fishery. A number of the papers submitted to the current meeting expressed views of members of the Academy (WG-Krill-91/4, 5 and 6) and these had been taken into account by the Working Group in its deliberations. It was agreed that this matter had now received appropriate consideration.

8.3 Dr Butterworth had written to the Convener pointing out that perceptions that there was the potential for a very large sustainable catch from the krill resource were based primarily on calculations of the so-called ‘krill surplus’ (the annual consumption of krill by major predators which have been subsequently removed from the Antarctic ecosystem). However, such calculations were now more than 10 years old, and many of the data and perceptions on which they were based had subsequently been revised. Dr Marín drew attention to further comments made on this matter in WG-Krill-91/4.

8.4 Dr Butterworth suggested that the time was appropriate for a review of the ‘krill surplus’ concept and a re-estimation of its magnitude, and that these might be effected by an expansion of the terms of reference of the planned joint IWC/CCAMLR Workshop on the Feeding Ecology of Southern Baleen Whales.

8.5 The Working Group agreed that a review of this matter was timely, and would provide information useful to WG-Krill. It noted that effective evaluation of the surplus would require consideration of predators other than baleen whales alone, and that WG-CEMP had plans for work along related lines (see paragraph 5.11). The Working Group believed that the Scientific Committee would be best placed to consider the most effective way to pursue the matter further.

ADOPTION OF THE REPORT

9.1 The report of the Third Meeting of the Working Group on Krill was adopted.

CLOSE OF THE MEETING

10.1 In closing the meeting, the Convener thanked the Convener of the Subgroup on Survey Design and the various task group conveners, the Secretariat and all the rapporteurs for their support and assistance in ensuring the meeting's smooth running. He also thanked the participants for the input and indicated that in his opinion the good spirit prevailing during the meeting was to a large measure the reason for the wide ranging discussions held and the comprehensive report that was a result. Finally, he thanked the meeting hosts, Southern Basin Joint Fishery Enterprise 'Yugryba' and the Oreanda Hotel for their hospitality and organisational support.

Table 1: Estimates of flow between areas in Figure 2.

Flux	Speed/Transport Time	Method	Proportion of Krill Standing Stock Exported	Reference and Comment
1. Inputs				
PA	Flux exists			
	Mean 0.20 m s^{-1}	Drift buoys		Capella, Ross, Quetin and Hoffmann (in press)
	~ 0.10 m s^{-1}	Geostrophic and current meters below 200 m		Referenced in WG-Krill-91/15
	Replacement of water mass off Peninsula ~ twice within 150 days ~ 3 months residence time	Production and fishing data		WG-Krill-91/15 and WG-Krill-91/36
			~ 100% imported from south-west 100% exported to east and north-east. Minor flow back to south-west with coastal current.	Siegel (1988)
	0.26 - 0.64 ms^{-1}		General flux of patches with the current within the Antarctic Peninsula region.	Everson and Murphy (1985)
2. Upstream Fluxes These fluxes exist and are probably significant but variable from year to year.				
AB	0.05 - 0.10 m s^{-1} 0.19 m s^{-1}			Flux from Peninsula goes to South Georgia and South Orkneys WG-Krill-91/39 Nieler, P. (Racer unpublished, MS)
BC	Probably exists			
AC	5.5 months 0.3 - 0.4 m s^{-1}			WG-Krill-91/22 Foster (1984) General for ACC

Table 1 (continued)

Flux	Speed/Transport Time	Method	Proportion of Krill Standing Stock Exported	Reference and Comment
3. Exports Losses probably exist but are uncertain and variable.				
AL	Rates similar to PA		100% export to east and north-east. Minor part back to south-west with coastal current.	
BL CL	Rates similar to AB, BC, AC classes		Loss is 100% to the east	General flow through areas Siegel (1986) Biomass - FIBEX Results of first Biomass Workshop *Biomass Rep. Ser. (22)*
4. Reverse Flows				
BA	Unknown/impossible			Unrealistic
CA	Possible	Months/years	Low	
CB	Possible		Possible via Weddell gyre but takes more than a year - probably longer	Maslennikov (1980) *Oceanology 2*: 192-195
			Number very low	Siegel (1986)

Key to flux codes:

PA Pacific to Antarctic Peninsula
AB Antarctic Peninsula to South Orkneys
BC South Orkneys to South Georgia
AC Antarctic Peninsula to South Georgia (direct)

AL Antarctic Peninsula loss
BL South Orkney loss
CL South Georgia loss

BA South Orkneys to Antarctic Peninsula return
CA South Georgia to Antarctic Peninsula return
CB South Georgia to South Orkneys return

Table 2: Von Bertalanffy growth function (VBGF) for krill.

Yearly growth Parameter **K**	L_∞	Method	Reference
0.445 / 0.429	62.4 / 62.5	Ford-Walford Plot	Siegel (1986)
0.445 / 0.4018	61.8 / 63.8	Non-linear regression VBGF	Siegel (1986)
0.4728	61.0	Modified VBGF (Pauly and Gaschütz, 1979)	Siegel (1986)
(0.27) 0.43 - 0.47	60.0	VBGF (seasonal growth)	Rosenberg *et al.* (1986)
0.478 / 0.354	63.3 / 61.3	Non-linear regression VBGF	Siegel (1987)
0.8		ELEFAN*	McClatchie (1988)

* Length-frequency analysis program

Table 3: Daily growth rates of Antarctic krill.

Daily Growth Rate (mm/day)	Comments	Reference
0.0354	Laboratory experiments	Murano *et al.* (1979)
0.07	Laboratory experiments (22 to 44 mm length)	Ikeda *et al.* (1985)
0.024 - 0.044	Laboratory experiments	Poleck and Denys (1982)
0.047	Laboratory experiments juvenile krill	Ikeda and Thomas (1987)
0.13	Theoretical approach, using a 90-day growth period for the year	Mauchline (1980b)
≡ 0.032	Mean annual growth rate	
0.141	In summer for 30 mm length class	Rosenberg *et al.* (1986)
0.083 - 0.156	Laboratory experiments for 32 mm length class	Buchholz (1988)
0.033	Mean annual growth rate for all age groups	Siegel (1986)
0.12	Juvenile age group 1+ in summer	
0.07	Sub-adult age group 2+ in summer	
0.13	0 age group in summer	McClatchie (1988)
0.025	Adult ≥ 3+ age group in summer	
0.01 - 0.048	In winter	

Table 4: Estimates of krill natural mortality.

M = **Z**	Method	Area	Reference
5.5	Edmondson's method		Kawakami and Doi (1979)
	Abundance data of length groups	Scotia sea	
2.31	Larval to sub-adults, 1-2 years old		Brinton and Townsend (1984)
0.51	2-3 years old		
0.78 - 1.17	Linearized catch curve data	Ant. Peninsula	Siegel (1986)
0.88 - 0.96	Linearized catch curve data		Siegel (1991)
0.94 - 0.99	Pauly (1980) formula on VBGF and **M** relationship		Siegel (1986)
0.8 - 1.35	**M** = 2 times **K** of VBGF	Scotia Sea	Priddle *et al.* (1988)
0.5	1-cumulative length frequency	RV *Discovery* data	Basson and Beddington (1989)
0.45 - 0.65	Length dependent predation curve		

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Table 5: Precautionary limits for Statistical Area 48 based on historical catch data.

Option	Subarea	Method of Calculation	Precautionary Limit 10^3 tonnes
1	Total of 48.1, 48.2 and 48.3	Sum of the maximum catches from each subarea over all years	619.5
2	48.1 48.2 48.3	Maximum catch over all years in subarea	105.6 257.7 256.2
	Total of 48.1, 48.2 and 48.3	Maximum of combined catch from three subareas over all years	425.9

Table 6: Precautionary levels based on the **dλMB$_0$** formula. Biomass estimates are from several sources. The calculations have assumed a discount factor **d** = 0.67, **M** = 0.6 and 1.0, and corresponding values of λ from Table 2 of WG-Krill-91/24 (the corresponding values of **dλM** were 0.093 and 0.14 respectively). The biomass estimates for Options 1 and 3 are unadjusted for flux (paragraphs 6.52 to 6.55); for Option 2 the biomass for Subarea 48.1 only is adjusted following the flux calculations presented in WG-Krill-91/15.

Option	Subarea	Data Source	Reasons for Choice	Year	Method	Area Covered (n. miles^2 x10^3)	Biomass (10^6 tonnes)	Precautionary Limit (10^3 tonnes) **dλM** = 0.093	Precautionary Limit (10^3 tonnes) **dλM** = 0.14
1	48.1	WG-Krill-91/15	Most extensive	Dec/Jan 1989/90	Net	92.8	1.16	107	162
	48.2	SC-CAMLR-VIII/BG/10	Only survey	Jan 1985	Acoustic	2.0	2.85[1]	264	399
	48.3	WG-Krill-91/30	Most extensive	Nov/Dec	Acoustic	45.5	1.83	169	256
	Total of 48.1, 48.2, 48.3						<u>5.84</u>	<u>540</u>	<u>817</u>
2	48.1	WG-Krill-91/15 estimates of production and flux over the summer months for Subarea 48.1 only.					4.3	398	602
	Total of 48.1, 48.2, 48.3	Total flux calculation for Subarea 48.1 only (from WG-Krill-91/15), plus Subareas 48.2 and 48.3 as above.					<u>8.98</u>	830	1 257
3	Total	Miller and Hampton (1989)	Combined FIBEX results	1981	Acoustic		15.1[1]	1 404	2 114

[1] This figure was calculated from the original FIBEX estimate multiplied by 5.7 to take into account the difference between the target strength values used during FIBEX and the most recent estimates of TS - see Figure 1 and Appendix F.

Table 7: Precautionary limit based on Yamanaka's calculations. A coefficient of 0.1 (Yamanaka, 1983) is applied to the estimate of biomass.

Subarea	Data Source	Reasons for Choice	Year	Method	Biomass 10^6 tonnes	Precautionary Limit 10^3 tonnes
Whole area	Miller and Hampton (1989)	Combined FIBEX results	1981	Acoustic	15.1[1]	1 500

[1] This figure was calculated from the original FIBEX estimate multiplied by 5.7 to take into account the difference between the target strength values used during FIBEX and the most recent estimates of TS - see Figure 1 and Appendix F.

Table 8: Data requirements.

Data Required	Reference	Data Submitted	Comments/Discussion at WG-Krill-III
Operational definitions of Article II	SC-CAMLR-IX, paragraph 2.19	No definitions submitted	These definitions probably need to be developed in conjunction with proposed management procedures (see paragraph 6.3).
Estimation of total effective biomass	SC-CAMLR-IX, paragraph 2.33	Papers WG-Krill-91/15, 22 and 30 provide estimates of recent surveys for Subareas 48.1 and 48.3	Further work should be done to estimate total biomass from all Subareas of Statistical Area 48, including re-working of FIBEX data. All estimates provided should be accompanied by a c.v. together with a description of the survey design and basis for strata selection (see also SC-CAMLR-IX, Annex 5, Appendix F).
Suggestions of methods to take account of predator needs	SC-CAMLR-IX, paragraph 2.40	WG-CEMP-91/25, estimates relative rates of catch and consumption	A 'discount' factor was used in calculation (Table 5); continued requirement, which the WG-CEMP will be addressing.
Estimates of potential yield should be obtained for areas other Subarea 48.3	SC-CAMLR-IX, paragraph 2.41	WG-Krill-91/24	Results shown in Table 5 for all subareas of Statistical Area 48. Statistical Areas 58 and 88 still to be addressed. Specification of further calculations required for the $Y = \lambda MB_0$ formula are given in Appendix E.
Review of demographic parameters	SC-CAMLR-IX, Annex 4, paragraphs 46 to 47	Siegel (in press): reproduced in Tables 2 to 4	Continued requirement (paragraph 4.94). The estimates in Tables 2 to 4 need to be reviewed by Working Group members.
Acoustic target strength	SC-CAMLR-IX, paragraph 2.31	WG-Krill-91/13, 29 and 40	Continued requirement (paragraph 4.30(i)).
Acoustic survey designs	SC-CAMLR-IX, paragraph 2.31	Appendix D and referenced papers	Continued requirement (paragraph 4.14, 4.16 to 4.20
Krill movement	SC-CAMLR-IX, paragraph 2.37	Table 1	Continued requirement (paragraph 4.80).
Analysis of fine-scale fisheries data	SC-CAMLR-IX, paragraph 2.65	WG-Krill-91/9, and 39 WG-CEMP-91/25	Continued requirement.
Observer reports from commercial fishery	SC-CAMLR-IX, Annex 4, paragraph 121	WG-Krill-91/12	Continued requirement (paragraph 3.9).
Investigation of sampling regimes for krill length-frequency data	SC-CAMLR-IX, paragraph 2.68	No investigations submitted	Continued requirement to assess optimum sample size and sampling regime.

Table 8 (continued)

Data Required	Reference	Data Submitted	Comments/Discussion at WG-Krill-III
Observer reports from commercial fishery	SC-CAMLR-IX, Annex 4, paragraph 121	WG-Krill-91/12	Continued requirement (paragraph 3.9).
Investigation of sampling regimes for krill length-frequency data	SC-CAMLR-IX, paragraph 2.68	No investigations submitted	Continued requirement to assess optimum sample size and sampling regime.
Length-frequency data	SC-CAMLR-IX, paragraph 2.68	WG-Krill-91/12 was only data submitted	Continued requirement (paragraph 7.18(i)). These data should be submitted to the Secretariat.
Haul-by-haul data	SC-CAMLR-IX, paragraph 2.63	WG-Krill-91/39	These data should be collected and submitted to the Secretariat (paragraph 7.18(ii)). (1) Collection should be irrespective of proximity to CEMP sites. (2) Collection by observers may be necessary although WG-Krill-91/39 shows that for some fleets collection by commercial personnel is possible. (3) If full fleet collection is not possible, collection by a subset of fleet is desirable. (4) All haul-by-haul data should be submitted to the Secretariat. Duplicate submissions of these data in fine-scale format should not be made as they will be compiled by the Secretariat
Biological data from the fishery	This report, paragraph 7.13		Observer forms and translations of USSR methodologies will be circulated, together with instructions on data submission to the Secretariat.
Analysis of acoustic and bridge log data from the commercial fishery	SC-CAMLR-IX, Annex 4, paragraph 120		Continued requirement.
Number and capacity of fishing vessels	This report, paragraph 3.6		Should be provided in Members' Activities Reports.

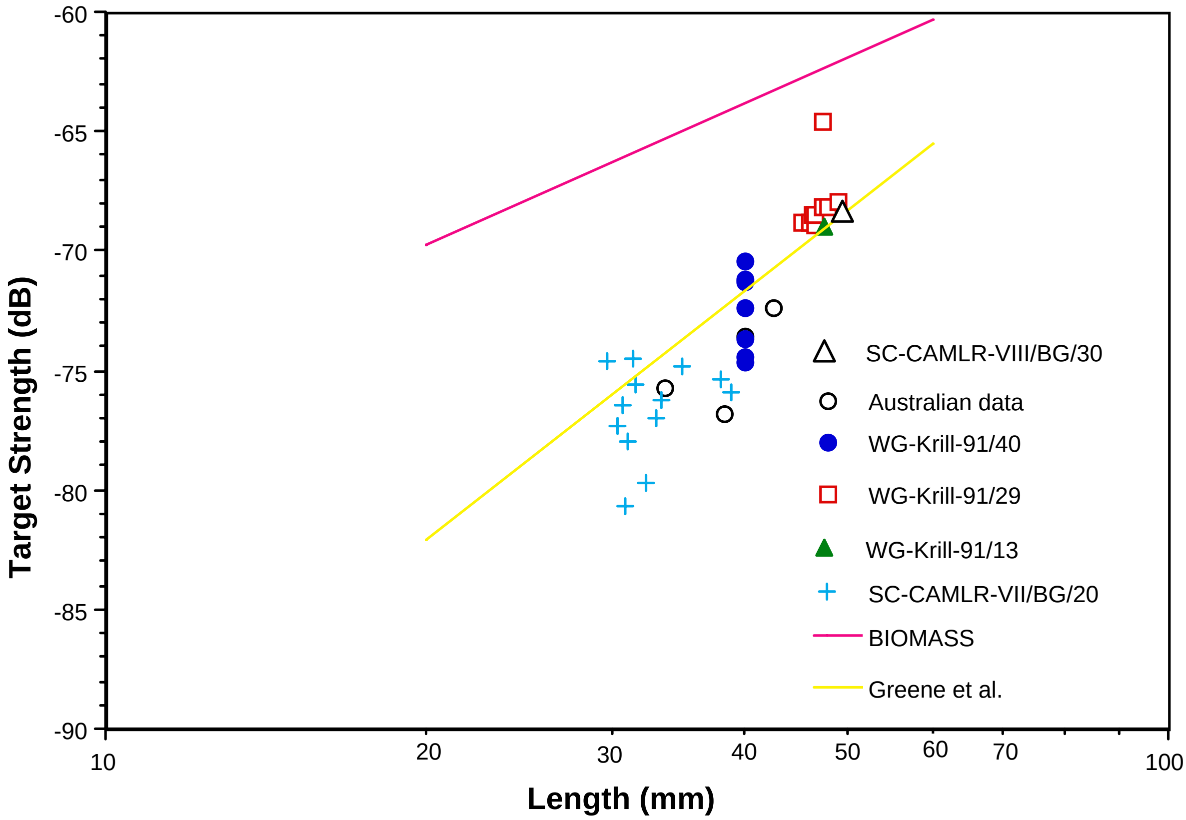


Figure 1: Target strength estimates from various sources.

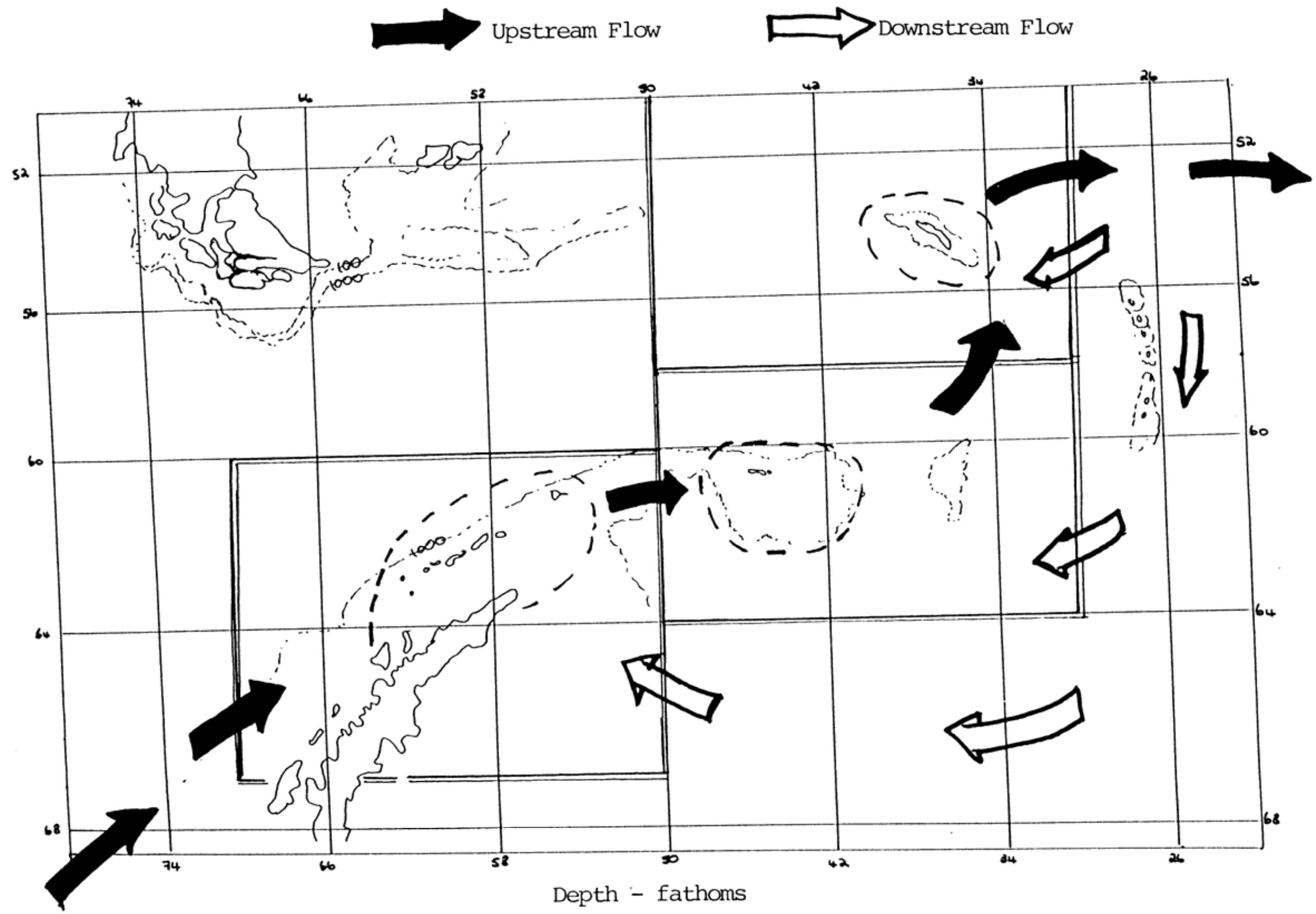
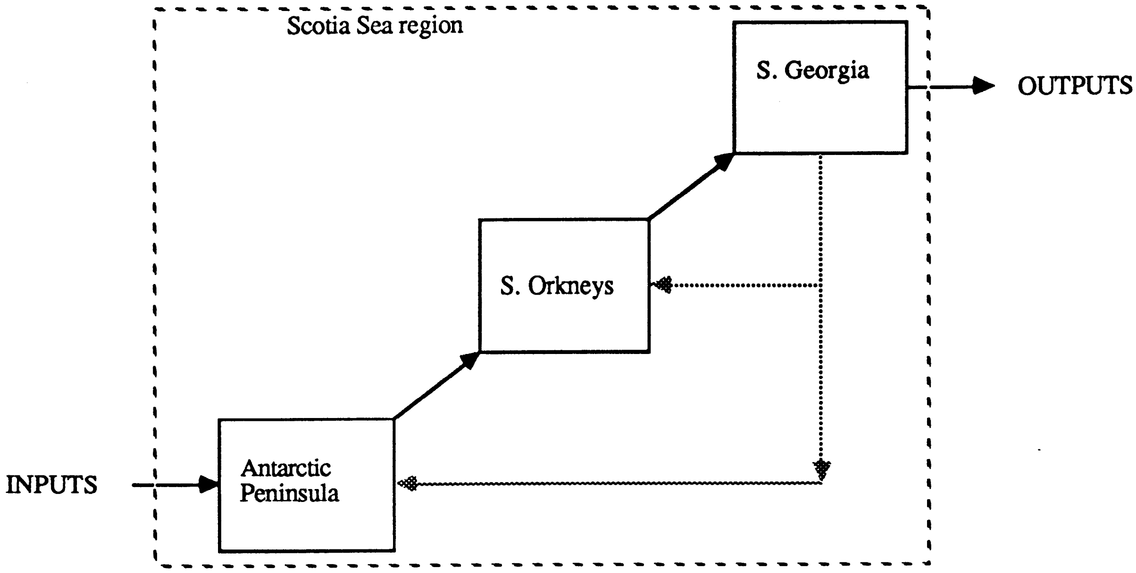


Figure 2: Schematic representation of movement of krill in the Scotia Sea. (Depth: fathoms)



Detail of flux for a single compartment of the above model

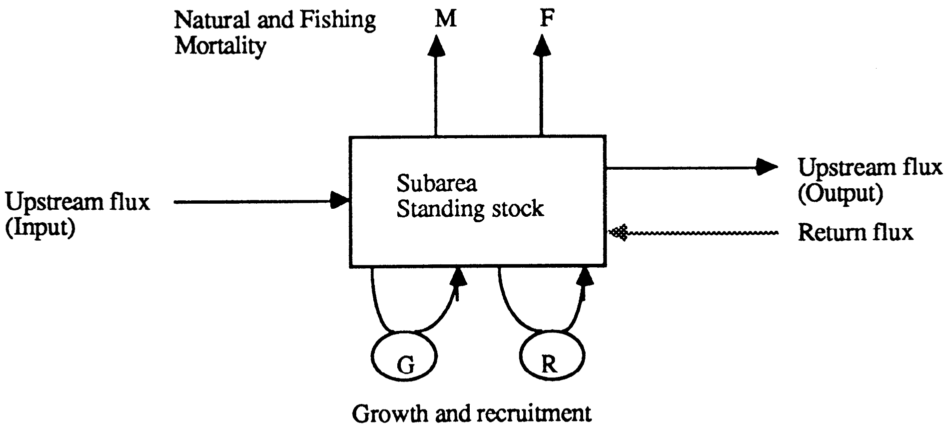


Figure 3: Functional subarea flows for one connected stock.

APPENDIX A

AGENDA FOR THE THIRD MEETING

Working Group on Krill
(Yalta, USSR, 22 to 30 July 1991)

1. Welcome

2. Introduction
   (i) Review of the Meeting Objectives
   (ii) Adoption of the Agenda

3. Review of Fisheries Activities and Other Information in 1990/91
   (i) Fisheries Information
      (a) Catch Levels
      (b) Location of Catches
      (c) Reports of Observers
   (ii) Other Information
      (a) Krill Distribution and Abundance
   (iii) Possible Future Trends

4. Information Necessary for Management
   (i) Survey Methods and Biomass Estimation
      (a) Review of the Subgroup on Survey Design's Work
      • Prey Monitoring Surveys
      • Surveys to Estimate Subarea Krill Biomass
      (b) Biomass Estimation
      • Acoustic Target Strength
      • Abundance Indicies
   (ii) Estimation of Yield and Production
      (a) Distribution
      • Stock Separation
      • Statistical Areas
      (b) Movement
      • Immigration/Emigration Rates
      • Residence Times

- Hydrographic Influences

(c) Demographic Parameters

- Natural Mortality (**M**)
- Other Essential Demographic Parameters (e.g. growth and longevity)

5. Advice to WG-CEMP
   (i) Review of Subgroup on Survey Design's Work
   (ii) Guidelines for Krill Monitoring Surveys
   (iii) Other Matters

6. Development of Approaches to Managing the Fishery
   (i) Operational Definitions of Article II
   (ii) Precautionary Limits on Krill Catches
      (a) Established and Current Fisheries
      (b) New and Developing Fisheries
   (iii) Other Possible Approaches and Their Development

7. Advice to the Scientific Committee on the Status of Stocks
   (i) The Status of Krill Stocks
   (ii) CCAMLR Scheme of International Scientific Observation
   (iii) Future Work of WG-Krill

8. Other Business

9. Adoption of the Report

10. Close of the Meeting.

APPENDIX B

LIST OF PARTICIPANTS

Working Group on Krill
(Yalta, USSR, 22 to 30 July 1991)

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APPENDIX C

LIST OF DOCUMENTS

Working Group on Krill
(Yalta, USSR, 22 to 30 July 1991)

Meeting Documents:

WG-KRILL-91/1	REVISED PROVISIONAL AGENDA
WG-KRILL-91/1 Rev.1	AGENDA
WG-KRILL-91/2	LIST OF PARTICIPANTS
WG-KRILL-91/3	LIST OF DOCUMENTS
WG-KRILL-91/4	ANTHROPOGENIC EVOLUTION OF ANTARCTICA'S PELAGIC COMMUNITIES N.M. Voronina (USSR)
WG-KRILL-91/5	ON THE CONSEQUENCES OF LARGE-SCALE HARVESTING OF MESOPELAGIC FISH AND ANTARCTIC KRILL N.I. Kashkin (USSR)
WG-KRILL-91/6	RESOLUTION OF THE ALL-UNION SYMPOSIUM "ECOSYSTEMS OF THE PELAGIC WATERS OF THE SOUTHERN OCEAN" (USSR)
WG-KRILL-91/7	CHARACTERISTICS OF KRILL SWARMS FROM PRYDZ BAY D.J. Agnew (Secretariat) and I.R. Higginbottom (Australia)
WG-KRILL-91/8	DEFINITION OF THE PROBLEM OF ESTIMATING FISH ABUNDANCE OVER AN AREA FROM ACOUSTIC LINE-TRANSECT MEASUREMENTS OF DENSITY Kenneth G. Foote and Gunnar Stefánsson (Norway)
WG-KRILL-91/9	FINE-SCALE CATCHES OF KRILL REPORTED TO CCAMLR 1988-1990 Secretariat

WG-KRILL-91/10 ON CONSTRUCTION OF MULTIDISCIPLINARY AND STOCK ASSESSMENT SURVEYS AS WELL AS ON COLLECTION OF MATERIAL ON *EUPHAUSIA SUPERBA* AND ENVIRONMENTAL CONDITIONS IN THE FISHING AREAS AND ADJACENT WATERS
R.R. Makarov and V.V. Maslennikov (USSR)

WG-KRILL-91/11 PECULIARITIES OF *EUPHAUSIA SUPERBA* SIZE COMPOSITION IN STATISTICAL SUBAREA 48.2 (SOUTH ORKNEY ISLANDS)
V.I. Latogursky and R.R. Makarov (USSR)

WG-KRILL-91/12 REPORT OF THE BIOLOGIST-OBSERVER FROM THE COMMERCIAL TRAWLER *GRIGORY KOVTUN*, SEASON 1989/90
A.V. Vagin (USSR)

WG-KRILL-91/13 TARGET STRENGTH OF ANTARCTIC KRILL
Roger P. Hewitt and David A. Demer (USA)

WG-KRILL-91/14 OCEANIC CONDITION AND ZOOPLANKTON DISTRIBUTION/ ABUNDANCE IN BRANSFIELD STRAIT DURING AUSTRAL SUMMER 1989/1990
S. Kim and M.S. Suk (Korea)

WG-KRILL-91/15 ESTIMATION OF KRILL (*EUPHAUSIA SUPERBA*) MORTALITY AND PRODUCTION RATE IN THE ANTARCTIC PENINSULA REGION
Delegation of Germany

WG-KRILL-91/16 ESTIMATION OF DISTRIBUTION CHARACTERISTICS OF THE FISHING OBJECTS FROM SHOAL LINEAR CROSS-SECTIONS (METHODICAL DIRECTIONS)
Y.V. Kadilnikov (USSR)

WG-KRILL-91/17 AUTOMATED DATA COLLECTION AND PROCESSING SYSTEM RELEVANT TO FISHING OBJECT DISTRIBUTION
Y.V. Kadilnikov, O.M. Khandros and Y.A. Starovoyt (USSR)

WG-KRILL-91/18 BRIEF PROGRAM AND METHODS OF INVESTIGATIONS ON KRILL DAMAGE BY MIDWATER TRAWL SECTIONS
Y.V. Zimarev (USSR)

WG-KRILL-91/19 SMALL SCALE KRILL SURVEYS: SIMULATIONS BASED ON OBSERVED EUPHAUSIID DISTRIBUTIONS
D.J. Agnew (Secretariat) and S. Nicol (Australia)

WG-KRILL-91/20 NOTE ON ESTIMATING ABUNDANCE FROM ACOUSTIC DATA ON INDIVIDUAL KRILL AGGREGATIONS
I. Hampton and D.G.M. Miller (South Africa)

WG-KRILL-91/21 SOME COMMENTS ON THE PROCEDURE FOR TESTING ESTIMATORS OF KRILL ABUNDANCE WHICH UTILISE SURVEY DATA
D.S. Butterworth, D.L. Borchers and D.G.M. Miller (South Africa)

WG-KRILL-91/22 KRILL (*EUPHAUSIA SUPERBA*) DISTRIBUTION IN RELATION TO WATER MOVEMENT AND PHYTOPLANKTON DISTRIBUTION OFF THE NORTHERN SOUTH SHETLAND ISLANDS
Delegation of Japan

WG-KRILL-91/23 BRIEF REPORT OF THE SIXTH ANTARCTIC SURVEY CRUISE OF JFA R/V *KAIYO MARU*
Mikio Naganobu, Taro Ichii and Haruto Ishii (Japan)

WG-KRILL-91/24 A SIMPLE APPROACH FOR CALCULATING THE POTENTIAL YIELD OF KRILL FROM BIOMASS SURVEY RESULTS
D.S. Butterworth (South Africa) and M. Basson (UK)

WG-KRILL-91/25 BY-CATCH OF FISH IN THE KRILL FISHERY
Inigo Everson (UK), Alexei Neyelov and Yuri Permitin (USSR)

WG-KRILL-91/26 WHEN WILL THE INFORMATION REQUIRED FOR RATIONAL MANAGEMENT OF THE KRILL FISHERY BECOME AVAILABLE AND WHAT SHOULD CCAMLR DO IN THE MEANTIME?
Stephen Nicol and Andrew Constable (Australia)

WG-KRILL-91/27 KRILL AGGREGATION CHARACTERISTICS IN SOUTH ORKNEY ISLAND AREA IN APRIL 1990
P.P. Fedulov *et al.* (USSR)

WG-KRILL-91/28 POSSIBLE APPROACH TO KRILL MOVEMENT ESTIMATION BY HYDROACOUSTIC OBSERVATIONS
P.P. Fedulov (USSR)

WG-KRILL-91/29 TARGET STRENGTHS OF KRILL AT 136 AND 20 KHZ
S.M. Kasatkina (USSR)

WG-KRILL-91/30 ANALYSES OF ACOUSTIC LINE-TRANSECT DATA FROM THE WATERS AROUND SOUTH GEORGIA: ESTIMATION OF KRILL (*EUPHAUSIA SUPERBA* DANA) BIOMASS
E. Murphy, I. Everson and A. Murray (UK)

WG-KRILL-91/31 KRILL AGGREGATION CHARACTERISTICS: SPATIAL DISTRIBUTION PATTERNS FROM HYDROACOUSTIC OBSERVATIONS
D.G.M. Miller and I. Hampton (South Africa)

WG-KRILL-91/32	MIDWATER TRAWL CATCHABILITY REGARDING QUANTITATIVE ESTIMATION OF KRILL BIOMASS USING THE METHOD OF TRAWLING SURVEYS ON ABUNDANCE S.M. Kasatkina (USSR)
WG-KRILL-91/33	SOME STATISTICAL PROPERTIES OF KRILL ACOUSTICAL DATA FROM SIBEX AND ICE EDGE ZONE SURVEYS M. Godlewska (Poland)
WG-KRILL-91/34	KRILL DISTRIBUTIONS AND THEIR DIURNAL CHANGES M. Godlewska and Z. Klusek (Poland)
WG-KRILL-91/35	REPORT OF THE WORKING GROUP ON KRILL SUBGROUP ON SURVEY DESIGN (Yalta, USSR, 18 to 20 July 1991)
WG-KRILL-91/36	PRELIMINARY RESULTS OF THE POLISH COMMERCIAL KRILL FISHERY IN THE ANTARCTIC DURING 1990/91 SEASON I. Wójcik and R. Zaporowski (Poland)
WG-KRILL-91/37	CPUES AND BODY LENGTH OF ANTARCTIC KRILL WITHIN COMMERCIAL HAULS OF POLISH TRAWLER FV *LEPUS* IN THE FISHING GROUND OFF SOUTH ORKNEYS IN JANUARY AND FEBRUARY 1991 I. Wójcik and R. Zaporowski (Poland)
WG-KRILL-91/38	VOLUMETRIC ANALYSES OF ANTARCTIC MARINE ECOSYSTEM DATA Delegation of the USA
WG-KRILL-91/39	CHILEAN KRILL FISHERY: ANALYSIS OF THE 1991 SEASON Victor H. Marín *et. al.*
WG-KRILL-91/40	KRILL TARGET STRENGH ESTIMATED BY UNDERWATER PHOTOGRAPHY AND ACOUSTICS J.L. Watkins (UK)
WG-KRILL-91/41	REPORT ON DISCUSSIONS ON KRILL TARGET STRENGTH Kenneth G. Foote *et. al.*
WG-KRILL-91/42	A PROPOSAL FOR STOCK BIOMASS ESTIMATE OF *EUPHAUSIA SUPERBA* DANA BY THE ENVIRONMENTAL INDEX Q_{200} IN COMPARISON WITH HAMPTON’S METHOD (EXTENDED ABSTRACT) Mikio Naganobu (Japan)

WG-KRILL-91/43	HYDROMETEOROLOGICAL BASIS FOR FORECASTING BIOMASS AND SOME FISHERY INDICES OF ANTARCTIC KRILL IN THE SODRUZHESTVA SEA V.A. Bryantsev (USSR)

Other Documents:

CCAMLR-X/6	NEW AND DEVELOPING FISHERIES Executive Secretary
CCAMLR-X/7	CCAMLR SCHEME OF INTERNATIONAL SCIENTIFIC OBSERVATION Executive Secretary
WG-CEMP-91/4	TEMPORAL AND SPATIAL SCALES FOR MONITORING CEMP PREDATOR PARAMETERS (WG-CEMP)
WG-CEMP-91/11	AMLR 1990/91 FIELD SEASON REPORT Delegation of the USA
WG-CEMP-91/25	KRILL CATCHES AND CONSUMPTION BY LAND-BASED PREDATORS IN RELATION TO DISTANCE FROM COLONIES OF PENGUINS AND SEALS IN THE SOUTH SHETLANDS AND SOUTH ORKNEYS, 1987-1990 D.J. Agnew (Secretariat)

APPENDIX D

REPORT OF THE WORKING GROUP ON KRILL SUBGROUP ON SURVEY DESIGN
(YALTA, USSR, 18 TO 20 JULY 1991)

INTRODUCTION

The First Meeting of the Subgroup on Survey Design of the Working Group on Krill met in Yalta, USSR, from 18 to 20 July 1991. The meeting was chaired by the Convener, Dr I. Everson (UK).

2. The Convener welcomed the Subgroup and introduced the Proposed Agenda. This was adopted with some minor changes. The Agenda is appended as Attachment 1, and a List of Participants as Attachment 2.

3. The report was prepared by Drs D.J. Agnew (Secretariat) and P.P. Fedulov (USSR).

BACKGROUND TO THE GROUP

4. The Convener outlined the Subgroup’s terms of reference which were set out in paragraph 97 of the 1990 WG-Krill Report (SC-CAMLR-IX, Annex 4):

‘Noting similar work being carried out within ICES, and on the basis of the *ad hoc* group’s discussions, it is recommended that a small subgroup be charged to do the following:

(i) examine the problem of estimating krill biomass from acoustic measurements of density along line transects;

(ii) describe specific statistical techniques that can be used to derive estimates of biomass and associated variance;

(iii) describe how such estimates can be applied to various krill distributions, both assumed and observed;

(iv) meet for three days immediately prior to the next WG-Krill meeting in order to discuss and evaluate items (i) to (iii); and

(v) prepare a report to WG-Krill for consideration along with recommendation of specific standard techniques to be used by Members to describe krill distribution and estimate biomass from acoustic surveys.'

5. The Convener also noted that the Working Group for the CCAMLR Ecosystem Monitoring Program (WG-CEMP) had endorsed the decision of WG-Krill to set the Subgroup up and that the members of WG-CEMP had been invited to participate in the Subgroup's work during the intersessional period, in addition to the members of WG-Krill (SC-CAMLR-IX, Annex 6, paragraphs 99 to 103).

6. A number of working papers submitted for the consideration of WG-Krill were considered by the Subgroup on Survey Design. These are shown in Attachment 3.

ANALYSES UNDERTAKEN

7. Three sets of data were available to the Subgroup on Survey Design:

- data derived from a transect in Prydz Bay in December 1990 completed by Australian RV *Aurora Australis*;
- South African data from a survey in the south west Indian Ocean during FIBEX collected by MV *S.A. Agulhas* in February/March 1981; and
- data from Germany collected during the FIBEX cruise on RV *Walter Herwig* during January to February 1981, from transects around 55°W.

These datasets were circulated to all members of the Subgroup and all members of WG-Krill and WG-CEMP were notified of their existence. Requests for the data were received from Dr V. Marín (Chile) and Dr V. Tesler (USSR).

8. Two documents presented to the Subgroup, WG-Krill-91/7 (Australia) and WG-Krill-91/31 (South Africa) described analyses based on the abovementioned datasets. The following distributional features and physical characteristics of *Euphausia superba* (WG-Krill-91/31) and *Euphausia crystallorophias* (WG-Krill-91/7) were calculated: length,

depth, thickness, between-swarm distance and biomass. An additional document (WG-Krill-91/21) used some of these data and is further described in paragraph 14. Dr E. Murphy (UK) informed the Subgroup that some swarm characteristics derived from these data had been used in some preliminary simulation studies.

9. Document WG-Krill-91/27 (USSR) presented krill aggregation characteristics derived from a survey in the South Orkney area by RV *AtlantNIRO* in April 1990. These data were not available to the Secretariat.

10. Summary statistics based on the available datasets and on information presented in tabled papers are compiled in Table 1. In general, the swarm characteristics calculated from various datasets and different subareas are in reasonable agreement.

11. The results presented in WG-Krill-91/27 emphasised that using different spatial resolution for the methods of swarm identification can lead to discrepancies in swarm dimension estimates, and that problems of this kind may be overcome by using methods with the highest resolution. Document WG-Krill-91/17 describes an automated acoustic data collection and processing system that may be employed as a standard method for collecting this type of information. The Subgroup felt that standardisation in this type of survey was important for making comparisons, but even in cases of the highest resolution possible there would probably be remaining problems, such as the operation of Doppler effects at these scales. It was also felt that because these data are often not normally distributed, provision of the raw data is important.

12. There was some discussion about the effects of target strength on survey estimates of biomass, and a number of papers concerned with target strength were tabled for consideration by WG-Krill. However, it was decided that whilst target strength has an important effect on absolute biomass estimates, the relative effect of this is the same irrespective of survey design, and target strength should more properly be addressed by WG-Krill than the Subgroup.

13. The Subgroup found WG-Krill-91/8 very useful as an introduction to the general problems and methodologies used for estimating biomass from acoustic transects. The general conclusion of this paper is that it is essential to be specific in the requirements of a survey in order to choose the methodology best suited to that survey.

14. WG-Krill-91/21 used South African data and introduced a two-level model of krill distribution which achieved overall spatial correlations similar to observed correlations,

derived by placing krill swarms at random within larger aggregations. Nevertheless, evidence of model mis-specification remains, and the ability of this kind of model and of more complex models to provide improved correlation with data needs to be investigated. This should be done before these kinds of model are used to provide simulated krill distributions to test alternative survey strategies and estimators of krill standing stock.

15. WG-Krill-91/19 examined the behaviour of two survey designs using known distributions and shapes of euphausiid swarms. It showed that parallel survey designs with transects travelling at right angles to the orientation of krill swarms have lower variances than either parallel designs with transects aligned with swarm orientation or radial designs. The relationship between the coefficient of variance and the number of transects can be used with power analysis to estimate the number of transects required to reliably detect changes in mean biomass.

16. The Subgroup recognised the importance of simulation studies to investigate various aspects of survey design in relation to krill standing stock estimates and distribution.

17. The Subgroup drew attention to the fact that there are two approaches to biomass estimation: one based on echo-integration and the other based on information from each encountered swarm. The theoretical principles and practical considerations of the last method were described in documents WG-Krill-91/16 and 17. In document WG-Krill-91/20 these approaches were compared; for the purposes of straightforward abundance estimation it was concluded that the echo-integration method has some advantages, since it is easier to apply and does not involve assumptions concerning aggregation distribution or form.

18. However, it was suggested that both methods were important in providing different information (on abundance, or on aggregation distribution) and that the appropriate design should be chosen for the task being considered.

19. The use of data from a large-scale acoustic survey around South Georgia in the estimation of total krill biomass was described by WG-Krill-91/30. Data were analysed using various definitions of strata. The Subgroup agreed that the use of strata for biomass estimation should improve biomass estimates. The paper briefly discusses other methods of survey analysis, and in particular cautions against the uncritical application of bilinear interpolation techniques.

20. A simulation model produced by Dr Murphy was discussed. The model is hierarchical and capable of introducing variation at different scales. It is of high resolution,

producing metre-by-metre transect data, and the effects of current and swarm movement are included. The model is being used to investigate survey design (for standing stock estimation) and the techniques for the analysis of swarm distribution.

21. A general approach to survey design proposed in WG-Krill-91/10 may provide the opportunity to obtain the information necessary for an abundance estimate as well as for a broad spectrum of additional problems (krill transport, distribution patterns, aggregation formation) in the larger area of the whole Scotia Sea. The approach is based on the combination of surveys of three different scales - micro, meso and macro. It was pointed out that this approach, whilst it would require the organisation of and cooperation between several vessels, would contribute significantly to the establishment of a baseline biomass estimate ($\mathbf{B_o}$) for the area in addition to contributing to the question of migration. Dr Murphy suggested that simulations, including the use of oceanic models of the form of the IOS[*] Fine Resolution Antarctic Model (FRAM), would contribute to investigation of the factors determining the large-scale distribution of krill.

22. Two papers described data from surveys completed in the current year (WG-Krill-91/7 and 22) and this was appreciated by the Subgroup. WG-Krill-91/22 described a survey off the South Shetlands by Japan which showed a relationship between krill distribution and water movements. Mr D. Miller (South Africa) informed the Subgroup that principal components analysis on some German data had shown that 60% of the variance in krill aggregation characteristics could be attributed to hydrographic variability and that this would have importance in the definition of strata for surveys.

23. WG-Krill-91/28 described a study on krill movement with respect to water current. This involved a repeated series of rectangular box surveys.

ANALYTICAL TECHNIQUES

24. The development of a survey design is dependent on scales of the processes being investigated. The various aspects in the development of acoustic survey designs for fish populations have been extensively studied. Particular reference was made to the ICES FAST (Fisheries Acoustic Science and Technology) Working Group. Key elements of any survey design are:

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[*] Institute of Oceanographic Sciences, UK

(i) definition of survey area;

(ii) stratification of the area;

(iii) track design, e.g.:
- predetermined;
- adaptive;

(iv) data analyses. Key techniques of relevance to krill:

(a) strata-based analyses: to produce area-weighted estimates of density;

(b) object-based analyses: swarm characteristics and spatial distribution.

Geostatistics may have some relevance to krill but this requires further study.

25. There are likely to be key elements which should be emphasised in the analyses of krill distributions. For example:

(i) scales of aggregation - extreme patchiness at of the distribution of krill at different scales;

(ii) scale effects - e.g. the large-scale stability of strata during the survey period; and

(iii) migration effects - both passive and active - such as the large-scale movement of krill in current systems and behavioural movement such as diurnal vertical migration.

26. The Subgroup identified five types of analytical techniques that could be used for krill surveys.

Standing Stock Estimation

27. The echo-integration survey design generally involves a series of parallel transects with regular or random spacing, run over the area of interest. Mean densities of krill are calculated for each transect, and then weighted values of the transect means are used to calculate total biomass. The design and analysis is usually subject to stratification which may be very important in the final determination of mean biomass.

28. Prior information is essential for the definition of strata and can be:

- fisheries data (identifying regions of high biomass);

- oceanographic and bathymetric information/other surveys.

Adaptive survey techniques, in which an initial rapid survey is performed, may also be used to identify regions for stratification.

29. Survey tracks other than parallel transects have been suggested (radial - e.g. WG-Krill-91/19; zig-zag; concentric ring paths). All will give estimates of the standing stock but problems are encountered with estimation of mean and variance.

Variance Estimation

30. The standard method of estimating variance follows from the generalised method for estimating standing stock described above, and uses weighted transect values of variance (*c.f.* Jolly and Hampton, 1990; in: *Can. J. Fish. Aquat. Sci. 47*: 1282-1291).

31. Dr Murphy pointed out that the variance usually increases with the mean. Where surveys are stratified by krill density more transects should be run over the high density strata.

32. In regard to other survey designs, Dr Tesler briefly described some of the work of the ICES FAST Working Group. In general, this work shows that whilst the use of parallel transects yields statistically robust results, this may not be the case for zig-zag designs. This arises because of the inequality of coverage of the survey area (areas close to the turning points have a higher density of transect paths) and resultant serial correlations.

33. Several members suggested that set against these potential difficulties, there may be logistic advantages with non-parallel transects. Mr Miller drew the attention of the Subgroup to a paper by Jolly and Hampton (*Rapp. P.-v Réun. cons. int. Explor. Mer*, *189*, in press) which shows that zig-zag transects provide a poorer distribution of sampling effort than parallel transects.

34. The Subgroup felt that whilst radial and zig-zag designs may offer some benefits for surveys, the robustness of these methods was less well established than for parallel transect designs and more work on the analytical statistics was required before they should be used.

Distribution of Patches

35. The Subgroup agreed that the definition of aggregation scale in any studies of krill distribution is essential and used Figure 30 of Miller and Hampton (1989: *Biomass Series*) to define the following scales:

	Spatial Scale (length)	Temporal Scale
Patch	10 to 100 km	days to months
Cohesive aggregations		
Superswarms	several km	hours to days
Swarms	several to 10s m	
Dispersed aggregations		
Layers and scattered swarms	many km	
Irregular forms	10s m	

36. The methods for determining vertical characteristics of aggregations from acoustic data are well established (one such method being comprehensively described in WG-Krill-91/16 and 17) and were used to produce the datasets available to the Subgroup.

37. Two problems remain. The first is the interpretation of aggregation data (e.g. swarm radius, thickness and spacing) in relation to patch characteristics (i.e. size and spacing). The second is the problem of using along transect inter-aggregation spacing to derive distributional relationships between aggregations (and ultimately patches) in the horizontal dimension.

38. WG-Krill-91/27 indicated that different spatial resolution of echosounders and different methods used to process acoustic data, may provide systematic bias of mean patch characteristics (such as intercepted swarm length, thickness and interswarm distance).

39. Mr Miller drew attention to the statistical procedures outlined in Hampton (1981) (*Fish. Bull. S. Afr. 15:* 99-108) which can be used to estimate krill standing stock from information on swarm parameters. Information on intercepted length and the number of aggregations-per-unit-area can be used to estimate fractional cover and its variance. Fractional cover in turn is used to estimate standing stock in a survey area if mean aggregation thickness and packing density can also be estimated. The estimator of fractional cover is an unbiased estimate of aggregation intercepted length irrespective of the shape or distribution of aggregation.

40. Furthermore, information on swarm spacing can be used to estimate the mean and variance of the distance between one aggregation and its nearest neighbour in the horizontal dimension. However, certain fundamental assumptions concerning swarm shape are necessary in order to derive this estimator and in addition it is assumed that swarms are randomly distributed.

41. This approach was similar to that outlined in WG-Krill-91/16.

Geostatistical Techniques

42. Geostatistical techniques are means of treating data that take account of spatial correlation within the data. They may be used for the investigation of variance and mapping of spatially distributed data, or for fitting a surface to the data. The volume under the surface may be used to calculate standing stock. WG-Krill-91/8 describes a number of approaches to surface fitting, one of which (Krigeing) is being used by several investigators for analysing acoustic data.

43. Dr Murphy noted that geostatistical methods may need further development for use with acoustic surveys. In general, they are good at mapping conservative data, but acoustically derived mean krill densities are extremely variable and fitting with these techniques is more complex. Mr Miller added that the techniques have been developed for static, geological systems and their application to dynamic systems is not simple. In addition, Dr Murphy described some simulation work that showed that simplistic application of parallel transects when used with Krigeing techniques may distort the resultant surfaces.

44. In the light of the developmental nature of much of this work, the Subgroup could give no advice on different types of approaches to geostatistical techniques, but thought that any work on these lines would be of interest.

Aggregation Shape

45. The Subgroup agreed that information on the shape and relative orientation of aggregations will be important for the successful interpretation of surveys directed at the distribution of patches. It is also important for the development of simulations of survey behaviour (WG-Krill-91/19).

46. Dr S. Nicol (Australia) outlined the difficulties and assumptions involved in the application of techniques for determination of aggregation shape. Aerial photography can cover large areas of water, and the determination of shapes, distribution, spatial relationships and movement is simple, however, it can only be used for surface aggregations (<10 m depth) and the behaviour of these aggregations may be different from deeper aggregations. Sidescan sonar can be used at depth and produces images of aggregation shapes, orientation and relation to each other but is more limited in the area that can be surveyed instantaneously.

47. It was agreed that information on the areal shape and distribution of patches was important for the interpretation of other surveys and simulations, but that these surveys were not routine and the Subgroup could not comment in detail on desired methodologies.

APPLICATION OF TECHNIQUES

48. The Subgroup considered the application of various survey designs to particular tasks under the general headings of (i) application to CEMP predator parameters, and (ii) application to the three scales (macro, meso and micro) (WG-Krill-91/10), with particular reference to the meso-scale estimation of standing stock. Each survey design was defined by descriptions of the Aims and Constraints of the task, the Design Specification of the survey (including logistic considerations) and the Analytical Procedures required for the results.

49. It was emphasised that each of the designs suggested would require rigorous testing before use in the field. The assumptions under Aims and Constraints would need to be examined in detail for their applicability to a specific task, and the suggested survey designs tested (e.g. using simulation studies) to examine the robustness of the results to changes in

krill characteristics. Simulations may also indicate the parameters for which particular designs are not as good.

50. The Subgroup split into two groups chaired by Drs Everson and Murphy, to prepare the survey designs.

51. The suggested Survey Designs are given in Attachment 4. Survey Design 1 addressed the CEMP Parameter A5 (Penguin Foraging Trip Duration) for Adélie and chinstrap penguins. Survey Designs 2, 3 and 4 address the three spatial scales suggested by WG-Krill-91/10.

52. The Subgroup emphasised that the transect spacings suggested in Survey Design 1, Figure 1 were chosen with the assumption that the gradient of krill density runs offshore from the CEMP site, perpendicular to the shelf edge, and the design should therefore minimise the variance between transects.

53. Dr Tesler pointed out that the aspects of survey design addressed by the Subgroup formed only a small part of the overall planning work required for a survey. He suggested that in the light of the comments made by the Subgroup concerning standardisation (paragraph 11) it may be useful to have a combined approach to standardisation of surveys. This would include recommendations for standard methodologies of:

- survey design;
- survey equipment - types and operation;
- processing; and
- analysis.

Some of these recommendations could hold for all areas and methodologies, and some would be more specific.

54. The Subgroup agreed that such a proposal would be valuable and recommended that it be referred to WG-Krill for their consideration.

55. Dr M. Naganobu (Japan) drew attention to his paper (1986) (*Mem. Natl. Inst. Polar Res. Spec. Issue 40*: 194-196) which describes a method that uses survey data on krill biomass, together with temperature integrated over 0-200 m depth to extrapolate the expected krill densities over the whole of the species' range. This method relies on the strong

relationship between krill density and temperature structure which is a result of oceanographic structure (water mass, currents and fronts).

56. The Subgroup recommended that this approach, being a post survey treatment of the data, should be addressed by WG-Krill.

ADOPTION OF THE REPORT

57. The report of the meeting was adopted.

CLOSE OF THE MEETING

58. The Convener thanked the organisers Yugryba (Southern Basin Joint Fishery Enterprise), and the Oreanda Hotel for making facilities available to the Subgroup. He also thanked the rapporteurs and the Secretariat for the speedy preparation of the report.

Table 1: Swarm characteristics described in papers submitted to the meeting of the Subgroup on Survey Design. WG-Krill-91/31 describes the South African data, WG-Krill-91/7 is the Australian data available to the Subgroup, WG-Krill-91/27 is a survey by the USSR.

Year	Area	Mean (Metres)	Range (Metres)	Standard Error	No. of swarms	Reference
Intercepted length						
1981	SW Indian Ocean	17.1	276[4]	0.48	1 567	WG-Krill-91/31
1991	S. Orkneys	10.4		1.14	437	WG-Krill-91/27
1990	Prydz Bay	24.1[1]	3.3 - 642.3	0.045[2]	475	WG-Krill-91/7
1981	S. Atlantic	92.36	20.4-2 915.2	7.82	682	Calculated at the meeting from the dataset provided by FRG
Distance between swarm encounters						
1981	SW Indian Ocean	4 168.5	340 590	473.4	1 567	WG-Krill-91/31
1991	S. Orkneys	2 200.0			437	WG-Krill-91/27
1990	Prydz Bay	82.8[1]	15.7 - 1 279.2	0.040[3]	475	WG-Krill-91/7
1981	S. Atlantic	937.6	1 - 72 366.1	161.02	682	Calculated at the meeting from the dataset provided by FRG
Swarm thickness						
1981	SW Indian Ocean	6.53	36	0.12	1 567	WG-Krill-91/31
1991	S. Orkneys	2.5	-	0.12	437	WG-Krill-91/27
1990	Prydz Bay	28.62	25 - 75	0.346	475	WG-Krill-91/7
1981	S. Atlantic	3.4	1 - 20	0.18	682	Calculated at the meeting from the dataset provided by FRG
Depth of swarm						
1981	SW Indian Ocean	54.08	91	0.52	1 567	WG-Krill-91/31
1991	S. Orkneys	53.5	-	1.24		WG-Krill-91/27
1990	Prydz Bay	57.68	25 - 200	1.75	475	WG-Krill-91/7
1981	S. Atlantic	35.33	10 - 99	1.68	682	Calculated at the meeting from the dataset provided by FRG

1 Derived from log-transformed data
2 Standard error of log-transformed data with mean 3.184
3 Standard error of log-transformed data with mean 4.417
4 Absolute range value

ATTACHMENT 1

AGENDA

Working Group on Krill
Subgroup on Survey Design
(Yalta, USSR, 18 to 20 July 1991)

1. Introduction

   1.1 Welcome followed by Domestic Arrangements
   1.2 Adoption of the Agenda and Appointment of Rapporteur

2. Background to the Subgroup

   2.1 Aims of the Subgroup
   2.2 Description of Datasets Offered for Analysis

3. Analyses Undertaken

   3.1 Using the Distributed Datasets
   3.2 Other Analyses

4. Review of Specific Analytical Techniques

5. Application of Techniques

   5.1 Application to CEMP
   5.2 Direct Abundance Estimation
   5.3 Other Methods of Abundance Estimation

6. Other Business

7. Adoption of the Report

8. Close of the Meeting.

ATTACHMENT 2

LIST OF PARTICIPANTS

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Subgroup on Survey Design
(Yalta, USSR, 18 to 20 July 1991)

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ATTACHMENT 3

LIST OF DOCUMENTS

Working Group on Krill
Subgroup on Survey Design
(Yalta, USSR, 18 to 20 July 1991)

Meeting Documents:

WG-KRILL-91/7	CHARACTERISTICS OF KRILL SWARMS FROM PRYDZ BAY D.J. Agnew and I.R. Higginbottom (Australia)
WG-KRILL-91/8	DEFINITION OF THE PROBLEM OF ESTIMATING FISH ABUNDANCE OVER AN AREA FROM ACOUSTIC LINE-TRANSECT MEASUREMENTS OF DENSITY Kenneth G. Foote and Gunnar Stefánsson (Norway)
WG-KRILL-91/10	ON CONSTRUCTION OF MULTIDISCIPLINARY AND STOCK ASSESSMENT SURVEYS AS WELL AS ON COLLECTION OF MATERIAL ON *EUPHAUSIA SUPERBA* AND ENVIRONMENTAL CONDITIONS IN THE FISHING AREAS AND ADJACENT WATERS R.R. Makarov and V.V. Maslennikov (USSR)
WG-KRILL-91/12	REPORT OF THE BIOLOGIST-OBSERVER FROM THE COMMERCIAL TRAWLER *GRIGORY KOVTUN*, SEASON 1989/90 A.V. Vagin (USSR)
WG-KRILL-91/16	ESTIMATION OF DISTRIBUTION CHARACTERISTICS OF THE FISHING OBJECTS FROM SHOAL LINEAR CROSS-SECTIONS (METHODICAL DIRECTIONS) Y.V. Kadilnikov (USSR)
WG-KRILL-91/17	AUTOMATED DATA COLLECTION AND PROCESSING SYSTEM RELEVANT TO FISHING OBJECT DISTRIBUTION Y.V. Kadilnikov, O.M. Khandros and Y.A. Starovoyt (USSR)
WG-KRILL-91/19	SMALL SCALE KRILL SURVEYS: SIMULATIONS BASED ON OBSERVED EUPHAUSIID DISTRIBUTIONS D.J. Agnew (Secretariat) and S. Nicol (Australia)

WG-KRILL-91/20	NOTE ON ESTIMATING ABUNDANCE FROM ACOUSTIC DATA ON INDIVIDUAL KRILL AGGREGATIONS I. Hampton and D.G.M. Miller (South Africa)
WG-KRILL-91/21	SOME COMMENTS ON THE PROCEDURE FOR TESTING ESTIMATORS OF KRILL ABUNDANCE WHICH UTILISE SURVEY DATA D.S. Butterworth, D.L. Borchers and D.G.M. Miller (South Africa)
WG-KRILL-91/27	KRILL AGGREGATION CHARACTERISTICS IN SOUTH ORKNEY ISLAND AREA IN APRIL 1990 P.P. Fedulov *et al.* (USSR)
WG-KRILL-91/26	WHEN WILL THE INFORMATION REQUIRED FOR RATIONAL MANAGEMENT OF THE KRILL FISHERY BECOME AVAILABLE AND WHAT SHOULD CCAMLR DO IN THE MEANTIME? Stephen Nicol and Andrew Constable (Australia)
WG-KRILL-91/28	POSSIBLE APPROACH TO KRILL MOVEMENT ESTIMATION BY HYDROACOUSTIC OBSERVATIONS P.P. Fedulov (USSR)
WG-KRILL-91/29	TARGET STRENGTHS OF KRILL AT 136 AND 20 KHZ S.M. Kasatkina (USSR)
WG-KRILL-91/30	ANALYSES OF ACOUSTIC LINE-TRANSECT DATA FROM THE WATERS AROUND SOUTH GEORGIA: ESTIMATION OF KRILL (*EUPHAUSIA SUPERBA* DANA) BIOMASS E. Murphy, I. Everson and A. Murray (UK)
WG-KRILL-91/31	KRILL AGGREGATION CHARACTERISTICS: SPATIAL DISTRIBUTION PATTERNS FROM HYDROACOUSTIC OBSERVATIONS D.G.M. Miller and I. Hampton (South Africa)

Other Documents:

WG-CEMP-91/4	TEMPORAL AND SPATIAL SCALES FOR MONITORING CEMP PREDATOR PARAMETERS (WG-CEMP)

ATTACHMENT 4

SELECTED SURVEY DESIGNS

SURVEY DESIGN 1

1. Aims

1.1 Objective:

Determine availability of krill within foraging range of Adélie and chinstrap penguins in the Antarctic Peninsula Integrated Study Region of CEMP and to relate it to Predator Parameter A5 (Foraging Trip duration).

1.2 Primary type of information required:

Time series of standing stock estimates

2. Constraints

2.1 Time and space scales:

Rectangle extending 50 km offshore and 50 km either side of study colony (the area is therefore 50 x 100 km) for Adélie penguin and 25 km offshore and 25 km either side for chinstrap penguin.

It is assumed that the study colony is situated in the centre of an approximately straight coast.

Time series of surveys to be made within the two-month period 15 December to 15 February.

2.2 Type of survey:

Replicated survey with approximately ten replicates.

2.3 Is stratification advised Y/N: Yes

If Yes indicate basis for stratification:

Stratification is based on distance from the colony. Two strata are suggested, a rectangle for higher intensity sampling based on the chinstrap penguin foraging range (25 km) and a lower intensity stratum based on the Adélie penguin foraging range (50 km). It is assumed that the 50 km range stratum includes all of the 25 km range stratum.

3. Design

3.1 Transects:

Series of randomly spaced parallel transects running offshore. A suggested general scheme is shown in Figure 1.

The transects to be sampled in order against the local current direction.

During replicate surveys the same or a different random set may be surveyed.

Each replicate survey to begin in the same part of the polygon.

3.2 Logistics:

The total distance steamed for one acoustic survey is estimated to be <u>800 km</u> = 450 n. miles.

Estimated time budget:

A. Acoustic Survey

Vessel Speed	Time	Vessel Days[1]
8 knots	56 hrs	3.5
7 knots	64 hrs	4
6 knots	75 hrs	4.7

B. Net Hauls (?) 10 hrs 0.5

C. Weather and other contingency (20%)

Total period for one survey varies from 5 to 6.5 days depending on vessel survey speed.

Ten surveys could be undertaken according to this regime during the course of one season.

4. Analytical procedures

5. Comments

A. The area is not well charted, particularly close inshore. This will pose problems for operating the vessel close inshore. It will also mean that the amount of krill available to predators will be underestimated.

B. It is advisable that the survey be integrated into broader-scale surveys.

C. Pack ice may be a problem in some years particularly early in the season.

D. The same survey design, but using regularly spaced transects, may also be appropriate for investigation of the distribution of krill aggregations.

1 Survey confined to period 8 hours either side of noon (SC-CAMLR-IX, Annex 6, paragraph 103)

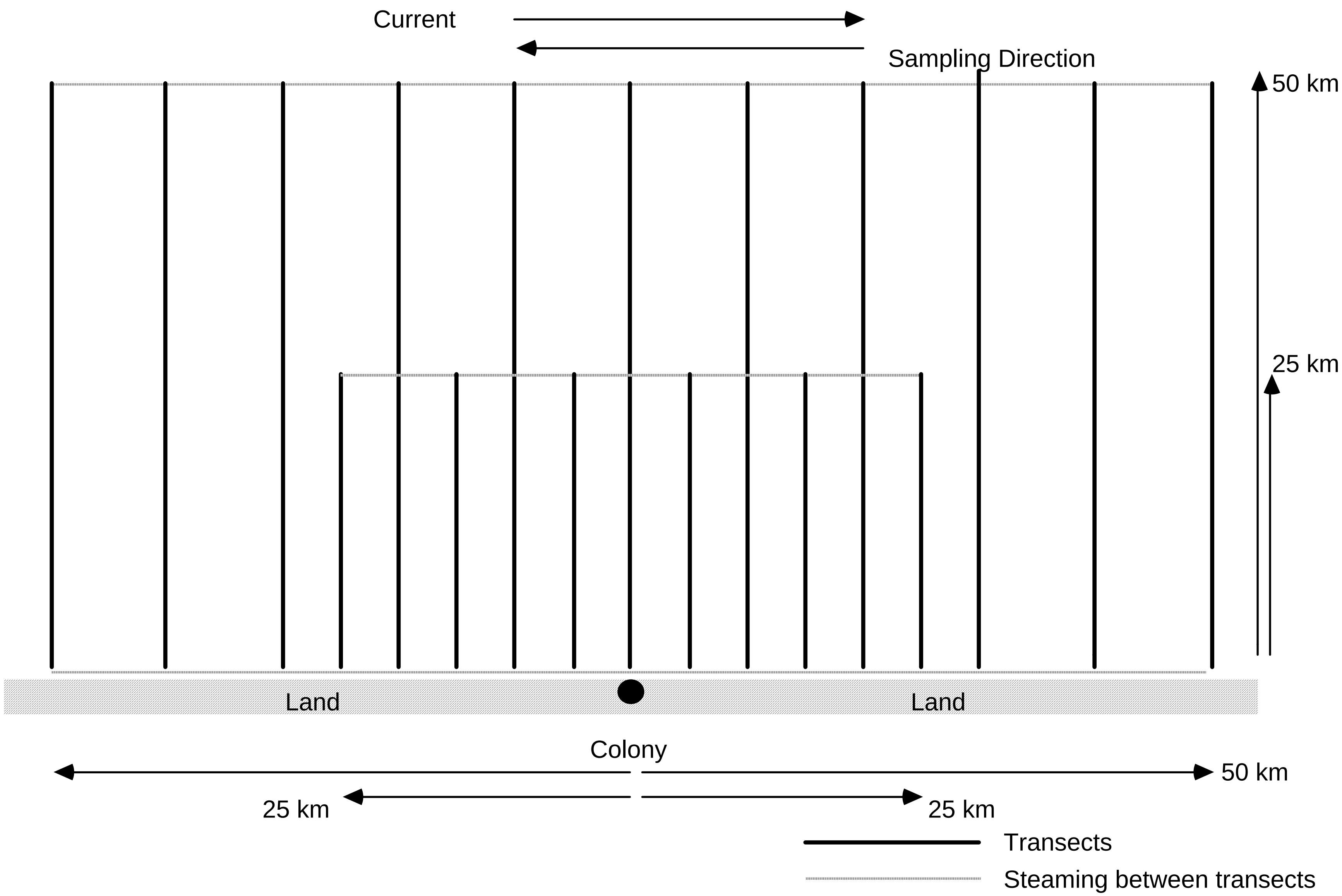

Figure 1: Sampling design to monitor krill biomass in relation to a land-based colony of penguins (CEMP Standard Method A5). In practice sampling grid at the spacing frequency illustrated would be composed of randomly spaced transects.

SURVEY DESIGN 2: Micro-survey

1. Aims

1.1 Objectives:

- characterise spatial distribution of krill aggregations;
- investigate aggregation dynamics of krill;
- estimate parameters for fishery/predator search patterns.

1.2 Primary type of information required:

- swarm dimensions;
- spacing, shape;
- depth distribution;
- diurnal changes.

2. Constraints

2.1 Time and space scales:

- a few to 10s km and hours to days;
- need for continuous sampling over a 24-hour period.

2.2 Survey information (available at planning stage):

On the basis of larger scale surveys at the mesoscale a restricted region would have been identified.

2.3 Type of survey:

Repeated regular grid survey. Time stations - to look at diurnal changes. Shape of swarms obtained by off transect sampling. Where patch drifting is involved then off transect sampling is likely to be most appropriate.

3. Design

Dependent on scales of aggregations would require:

- nets for demographic analyses and target ID;
- CTD - vertical profiles,
  - oceanographic data;
- ADCP[1] - data on currents;
- underwater photography/television/remotely operated vehicle;
- *in situ* TS measurements.

4. Analytical procedures:

- swarm dimensions and spacing statistics;
- mapping;
- biological characteristics of swarms;
- TS data in relation to orientation;
- time series data;
- image processing of shape.

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1 Acoustic Doppler Current Profiler

SURVEY DESIGN 3: Meso-survey

1. Aims

1.1 Objective:

Determine the standing stock of krill at the mesoscale (10s to 100s km). For example in the vicinity of South Georgia.

1.2 Primary type of information required:

Standing stock estimate.

2. Constraints

2.1 Time and space scales:

- survey to be completed within 15 to 30 days;
- the survey to cover shelf area and some distance further offshore, 50 to 100 miles.

2.2 Survey information (available at planning stage):

- historical datasets available for survey area;
- information on locations of high fishing activity;
- bottom topography;
- other information, e.g. water mass frontal zones, satellite sea surface temperature in real time.

2.3 Type of survey:

Adaptive stratified single acoustic survey in a season.

First Phase: to determine location of krill aggregations and temperature regime. Requires underway on board monitoring of sea temperature and other parameters, e.g. fluorescence and bottom topography and SiO_2.

Second Phase: might be stratified using the following:

- standing stock - increased effort in and around regions of high krill biomass;
- increased effort in particular bathymetric regions;
- temperature - increased effort in region of water colder than zero degrees;
- increased effort in areas of 'traditional' krill fishing grounds;
- routine monitoring should include net sampling for acoustic target identification and demographic biological characteristics of krill and also hydrography to characterise water masses and investigate other features of importance in determining krill distribution.

3. Design

3.1 Transects:

First phase

Regular spaced parallel transects to give even coverage of sampling. Transects perpendicular to the contours of krill density. In the South Georgia region this probably involves running on-shelf to off-shelf transects.

Probable 5- to 10-day time period allocated to this phase. Allowing approximately 600 n miles of transects.

Second phase

Parallel transects randomly or regularly spaced within strata.

Highest intensity of sampling in high density strata identified from phase one.

3.2 Logistics:

Problems could include presence of ice, weather. Five to ten days during the first phase; 20 to 25 days during the second phase.

4. Analytical procedures:

- analyses of demographic parameters, for TS calculations;

- mapping of distribution;

- area weighted estimates of standing stock.

SURVEY DESIGN 4: Macro-survey

1. Aims

1.1 Objective:

Improve understanding of krill movement and macro-scale, distribution - (100 to 1 000 km).

1.2 Primary type of information required:

- hydrographic investigations. Water mass specification - confluence position;

- krill demography and biomass;

- plankton community structure and seasonal state

2. Constraints

2.1 Time and space scales:

40 days per survey repeated two- to four-times to investigate seasonal variation. To cover area influenced by major circulatory features. (100s to 1 000s km).

2.2 Survey information (available at planning stage):

- satellite information;

- topography;

- historical information from survey data for region - e.g. water masses characterisation;

- historical krill data - from surveys and the fishery.

2.3 Type of survey:

- transects irregularly spaced across the confluence region or major circulatory feature;

- probably 100 to 300 n miles transects - against the flow.

Other data could include:

- net samples for plankton and target I.D.;

- acoustics when under-way;

- vertical and horizontal water mass sampling;

- hydro-chemistry;

- biological data on krill;

- primary production.

3. Design

3.1 Transects:

- 12 to 14 transects;
- length 120 to 300 n miles;
- spacing 150 to 250 n miles.

3.2 Logistics:

- weather / ice could cause problems;
- real time satellite information would be a major component;
- stability of large scale feature over time-scale of survey is important and may require adaptive transect layout.

3.3 Analysis could include:

- vertical profiles of all parameters along transect;
- large scale gross feature map;
- multivariate analyses of water mass and biological parameters;
- major pathways of krill movement;
- geostrophic measurements and analyses.

Comments: It would be useful to obtain estimates of flow rates from moored ships or through the deployment of drifting buoys.

APPENDIX E

SPECIFICATION OF FURTHER CALCULATIONS OF FACTORS RELATING YIELD TO SURVEY BIOMASS ESTIMATES

APPROACH

There is considerable uncertainty about values for a number of the parameters needed for these calculations. Rather than give the results for different combinations of possible values, these results will be 'integrated' over the ranges considered to incorporate the uncertainty about each parameter (termed the 'prior' distribution for each parameter). Such computations yield a 'posterior' distribution for the quantity of interest - in this case the ratio of the yield to the biomass estimate.

SPECIFICATIONS

$Y = \lambda M B_o$
$B_o = f\ B_s$

where **f** is a factor that adjusts the survey assuming that it does not cover the complete distribution of the biomass of the stock;
B_s is biomass from survey.

Posterior distributions are required for two quantities:

(i) $\gamma = \lambda\ M$ i.e. $Y = \gamma\ B_o$
(ii) $\delta = \lambda\ Mf$ i.e. $Y = \delta\ B_s$

Prior distribution and assumption parameters are as follows:

(i) Growth curve:
Fixed - as specified by Rosenberg, Beddington and Basson (1986) (*Nature 324*: 152-154);
Growth - over three months (November to January).

(ii) Fishing season:

Three options: (a) 3 months: December to February (e.g. Japanese fishery);
(b) 6 months: April to September (e.g. Soviet fishery in Subarea 48.3);
(c) uniform throughout the year.

(iii) Natural mortality:

Uniform throughout the year

M = *U* [0.4,1.0]

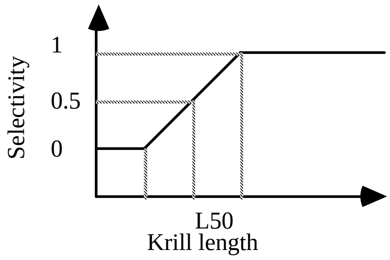
where ***U*** indicates a uniform distribution over the range shown.

(iv) Age-at-first capture:

Express in terms of length and convert these to age using the growth equation.

'width' = 10 mm

Length at 50% vulnerability, $l_r^{50} = U[38,42 \text{ mm}]$



The values for 'width' and for the centre point of the $\boldsymbol{l_r^{50}}$ range were determined from inspection of Figure 2 of WG-Krill-91/12.

(v) Age at maturity:

Similar for to (iv) above: 'width' = 12 mm

$l_m^{50} = U[34,40 \text{ mm}]$

The values for 'width' and the centre point of the $\boldsymbol{l_m^{50}}$ range were determined from data in Siegel (1986) (*Mitt. Inst. Seefisch. 38*: 1-244. Hamburg).

(vi) Biomass survey:
Ages surveyed: $a_+ = 1^+$ (fixed)
Survey c.v.: $\sigma_S = 0.3$ (fixed)

(vii) Recruitment variability:
Recruitment c.v.: $\sigma_R = U[0.4,0.6]$

(viii) Incomplete survey coverage:
$f = U[1,4]$

OUTPUT

Posterior distributions for γ and δ corresponding to a 10% probability over a 20-year period that $\mathbf{B_{sp}/K}$ drops below $\mathbf{D_{crit}}$ are required, where:

$D_{crit} = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6$

The corresponding distributions for this probability in the absence of any fishing are also to be evaluated. Distributions are to be shown in tabular form (values at each integral 10% point), and as plotted probability distribution functions.

$\mathbf{B_{sp}}$ is the average spawning biomass over the December to March period in the presence of a constant annual catch of krill; **K** is the corresponding value for zero catch, i.e. the average spawning prior the exploitation of the resource. Calculations are to be carried out on a discrete basis at half-monthly intervals.

APPENDIX F

CALCULATION OF THE 'THRESHOLD LEVEL' IN STATISTICAL AREA 48

(Delegation of the USSR)

1. Calculations were made using the following formula:

$$Y_t = yB_s \tag{1}$$

where **Y_t** = 'threshold level';
B_s = krill biomass in Statistical Area 48;
y = proportion of **B_s** exploitable without negative impact on krill population and dependent species.

2. Parameter evaluations

2.1 $$B_s = k\, B^0_s \tag{2}$$

where **B_s** = biomass assessment from hydroacoustic surveys during FIBEX in the Statistical Area 48 taken to be 2.65 million tonnes (Miller and Hampton, 1989);
k = correction coefficient introduced as the result of a review of the target strength of krill within the length range 35 to 55 mm. In accordance with calculations of Tesler and Kasatkina based on results of Subgroup discussions on the matter, **k** = 5.7.

2.2 Coefficient y = 0.1 (Yamanaka, 1983*)

Note: the value of this coefficient is apparently heavily underestimated because feeding area of predators does not completely overlap krill fishing areas (WG-CEMP-91/25).

3. Results

B_s = 15.1 million tonnes; Y_t = 1.5 million tonnes.

4. Result evaluations

There is a good chance that the obtained **Y_t** is heavily underestimated (possibly several times).

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* Yamanaka, I. 1983. Interaction among krill, whales and other animals in the Antarctic ecosystem. *Mem. Natl. Inst. Polar Res.*, Spec. Issue No. 27: 220 - 232