REPORT OF THE SIXTH MEETING OF THE WORKING GROUP ON KRILL

(Cape Town, South Africa, 25 July to 3 August 1994)

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INTRODUCTION

1.1 The Sixth Meeting of the Working Group on Krill (WG-Krill) was held at the Breakwater Lodge, Cape Town, South Africa, from 25 July to 3 August 1994. The meeting was chaired by the Convener, Mr D.G.M. Miller (South Africa).

1.2 The Working Group was welcomed to Cape Town by Mr G. de Villiers, the Director of Sea Fisheries Administration in South Africa.

REVIEW OF THE MEETING OBJECTIVES AND ADOPTION OF THE AGENDA

2.1 The Convener briefly outlined the major objectives of the meeting which had been set out in detail and circulated prior to the meeting in SC CIRC 94/6.

2.2 A Provisional Agenda had also been circulated prior to the meeting. There were no additions or amendments and the Agenda was adopted.

2.3 The Agenda is included in this report as Appendix A, the List of Participants as Appendix B and the List of Documents submitted to the meeting as Appendix C.

2.4 The report was prepared by Drs D. Agnew (Secretariat) and M. Basson (UK), Prof. D. Butterworth (South Africa), Drs W. de la Mare (Australia), I. Everson (UK), R. Hewitt (USA), E. Murphy (Invited Expert), S. Nicol (Australia) and J. Watkins (UK).

Fisheries Information

Data Submission

3.1 An analysis by the Secretariat of fine-scale krill catch data from the 1992/93 season (WG-Krill-94/6) revealed that some Polish catches were made to the north of the Convention Area in Division 41.3.2. The proportion of the total catch from outside the Convention Area was, however, small:

Subarea/ Division	1992/93 Total Catch (tonnes)	%
41.3.2	2 506	2.8
48.1	37 716	42.5
48.2	12 670	14.3
48.3	30 040	33.8
48.4	50	0.06
48.6	33	0.04
58.4.1	57 62	6.5

Paper WG-Krill-94/6 also included maps of fine-scale catches taken from Division 58.4.1 in 1992/93.

3.2 A full set of fine-scale krill catch data from 1974 to 1994 and krill catch data on a scale of 10 x 10 n miles from 1992/93 has now been supplied to the Secretariat by Japan. The Working Group noted this submission and acknowledged the utility of this data set.

3.3 A sample of commercial krill catch data from 1978 from the former Soviet Union was presented in WG-Krill-94/10. Only YugNIRO (Ukraine) has historic catch data from Subarea 58.4 (from 1978 to 1984 and 1988). The high cost of preparing the data precluded the submission of a complete data set. The Working Group urged Members with available resources to aid with the analysis of fisheries data from the former Soviet Union (Russia and Ukraine) and recalled the initiative by the US to obtain funds to assist with these analyses (SC-CAMLR-XII, Annex 4, paragraph 3.20).

3.4 The Working Group noted that monthly catch data are being submitted in accordance with Conservation Measure 32/X. Data have arrived from Japan, Poland and Ukraine. In addition, Chile has submitted a full set of haul-by-haul data.

Presentation of Data by CCAMLR

3.5 The CCAMLR Secretariat had reported to Members in January on krill catch levels and will continue to do so every six months.

3.6 The Working Group recommended that the *Statistical Bulletin* include details of effort on the same temporal and spatial scales as catch data and noted that the Secretariat was preparing a paper on this subject for the Scientific Committee.

1993/94 Catches

3.7 Japan has submitted monthly reports from July 1993 to June 1994 which give a total krill catch for this period of 62 315 tonnes. Poland fished from July to June and reported a total catch of 7 915 tonnes; Ukraine fished from March to May and reported a catch of 8 205 tonnes. Chile fished in Subarea 48.1 during March and April and reported a catch of 3 834 tonnes. There was no indication that Russia fished for krill in the Convention Area during 1993/94. The total reported krill catch for 1993/94 was 82 269 tonnes.

3.8 The Japanese 1993/94 fishery deployed six vessels and the catch was mainly taken in Subareas 48.1 and 48.3. In the summer, the catch came mainly from Subarea 48.1 and later in the season from Subarea 48.3. The Japanese catch was taken between January and May, and followed the general trend towards a later-season fishery in Subarea 48.1 over recent years.

3.9 One thousand tonnes of the Japanese catch was taken off Wilkes Land (Division 58.4.1) by one vessel. This vessel usually fishes for other species near New Zealand and targets krill stocks in Division 58.4.1 because of their operational proximity.

3.10 The Polish catch for 1991/92 and 1992/93 was reported by subarea in WG-Krill-94/9 although this paper gives no indication of catches which were reported to have been taken outside the Convention Area (WG-Krill-94/6). The Working Group seeks clarification from Poland on this omission.

3.11 Ukraine reported that from March to July 1994 two vessels landed a total catch of 9 618 tonnes in Subareas 48.2 and 48.3 (WG-Krill-94/33). This fishery will continue until August 1994 and further results will be submitted to CCAMLR as soon as they are available.

Reports of Observers

By-catch of Young Fish

3.12 The incidental catch of fish in the Japanese commercial krill catch in summer 1994 from Subarea 48.1 was reported in WG-Krill-94/25. A total of 77 specimens of 13 species were documented from 25 trawl catches. This level of by-catch is an order of magnitude less than the by-catch reported by Ukraine last year (WG-FSA-93/8).

3.13 Fish appeared more rarely in hauls from high density krill swarms, those targeted preferentially by the fishery. There were, however, only two samples where there were relatively high fish catches, so the data were suggestive rather than conclusive on this point.

3.14 The Working Group welcomed this data set on by-catch and considered the results very useful. The absence of *Champsocephalus gunnari* in the catches was noted despite its prevalence in the area. The Working Group encouraged other fishing nations to obtain comparable data sets from different areas and seasons and noted that some data may become available from Ukrainian, Polish and possibly Russian observers.

3.15 However, the method reported in WG-Krill-94/25 only used a subsample of 25 kg of the catch. The methodology for analysing the commercial krill catch for fish by-catch given in the *Scientific Observers Manual* recommends that standard samples of 40 to 50 kg of krill be taken from all sampled hauls. The Working Group therefore recommended that the standard method in the *Scientific Observers Manual* be followed in future studies.

Length Frequency and Haul-by-haul Data

3.16 A study of the length frequency of krill sampled from the Japanese commercial catch in 1993 (WG-Krill-94/28) failed to note a change as the fishing season progressed, although in most seasons there has usually been a shift to smaller krill later in the season. Body lengths of krill from this area (Subarea 48.1) are generally greater further offshore.

3.17 The same study (WG-Krill-94/28) found that the Japanese fishing fleet operating off the South Shetlands moved from offshore in January closer to shore in April. Catch/tow and catch/trawling time in the same area both increased to mid-summer then declined again.

3.18 The Working Group encouraged the continued submission of length frequency and haul-by-haul information. These data are useful for assessing the overlap between the predators and the fishery and length at selection to the fishery.

Fishing Escapement Loss/Mortality

3.19 The Working Group noted that the Secretariat has not been sent, for validation purposes, the model of krill escapement from WG-Krill-93/34. The Working Group repeated the request for the submission of the model for validation.

3.20 The Working Group noted that there were two aspects to the study of escapement of krill from commercial trawls - experimental studies and modelling exercises. The Working Group, recognising the potential seriousness of escapement, encouraged the development of both approaches.

Development of CPUE Indices

3.21 Paper WG-Krill-94/14 presented an attempt to derive a composite index (SC-CAMLR-VII) of krill abundance using a combination of acoustic and fisheries data collected off Elephant Island. Three points arose from the study:

- the large changes in abundance and distribution of krill observed between the four acoustic surveys in this study have implications for future near-synoptic surveys;

- the frequency distributions of catch-per-fishing-time and krill density (measured acoustically) showed similar forms, although it was noted that the non-random movement of the fishing vessel may obscure this comparison; and

- search time could not be used to estimate other aspects of krill distribution because fishing operations were limited by processing efficiency rather than by availability of krill.

3.22 The Working Group noted that conclusions on search time from one area may not be generalised for other areas. For example, the composite index, including search time, was developed for the fishery off Wilkes Land (Division 58.4.1) and therefore may not be applicable to other areas such as the Peninsula (Subarea 48.1).

3.23 As the krill fishery develops, krill availability may change and search time may become a useful index. Feedback management will require some estimate of krill abundance. Acoustic surveys are too costly to be carried out frequently enough to regularly assess abundance for management purposes, so it is necessary to investigate other options for assessing availability of krill to the fishery through an index such as search time.

3.24 The Working Group noted that it had not received any information on whether it is practical to collect search time information from fishing vessels using techniques such as gathering information on ships' activities at random intervals (SC-CAMLR-XII, Annex 4, paragraph 5.31). The Working Group encouraged the development of a pilot study on the collection of such data, possibly on the fishery off Wilkes Land (Division 58.4.1) (see paragraph 3.30).

3.25 Dr T. Ichii (Japan) reported that he had examined the collection of search time information on a Japanese commercial fishing vessel off Wilkes Land. He drew similar conclusions to those made in respect of fishing off the Peninsula - i.e., search time was difficult to measure directly.

Scientific Observers Manual

3.26 There were no reports of the *Scientific Observers Manual* having been used.

3.27 The Working Group examined the list of research activities concerning krill outlined on pages 5 and 6 of the *Scientific Observers Manual* and considered that the activities listed under 4, 'Fishery for *Euphausia superba*', could be split into those which involved general observations of fishing operations (items (i), (ii) and (vii)) and those which involved specific tasks using samples from the commercial catch (items (iii), (iv), (vi) and (v)). The Working Group agreed that the latter tasks could be prioritised in the order specified above.

3.28 There appeared to be some contradiction between the priorities for observers' activities listed on pages 5 and 6 and those specified on page 7 of the manual. The Working Group sought direction from the Scientific Committee as to whether the listing on page 7 was in some form of priority order, and if not, whether the Scientific Committee might want to prioritise these activities.

3.29 Scientists with experience of fisheries activities reported that the workload suggested in the manual was very great and that observers would have to be selective in the tasks that they performed. It was suggested that a time management report from experienced observers might aid in the interpretation of the results from observations and would assist in the use of the manual.

3.30 It was further suggested that information on the ship's activities should be collected by the observer at 20 randomly selected intervals. A list of standard activities carried out on board ship could be assembled for the observer to record against each time interval, including: fishing, processing, hove to, trans shipping, relocating and searching. An example of a timesheet for collection of random samples over a month is attached (Table 1).

3.31 The Working Group urged Members to assess whether the measurements suggested for krill in the manual were appropriate and to report to future meetings of the Working Group any suggested changes, particularly in the light of any new prioritisation established by the Scientific Committee.

Future Plans

3.32 Scientists from the fishing nations present (Japan, Ukraine and Chile) reported that their nations' fishing plans for 1994/95 were similar in magnitude, season and area to the 1993/94 season. The Japanese fishery will continue at the same level due to limited market demand.

3.33 An Australian company is still interested in fishing for krill with one to four ships catching up to 80 000 tonnes, but it is uncertain whether this venture will proceed in the next year.

3.34 There is still no further information on India's interest in entering the krill fishery, which was reported at last year's meeting (SC-CAMLR-XII, Annex 3, paragraph 3.12), and the Working Group expressed interest in knowing India's plans.

3.35 Members expressed continuing interest in knowing the future plans of nations, particularly with regard to potential catch levels and areas.

ESTIMATION OF KRILL YIELD

Estimation of Krill Biomass

Krill Flux in Statistical Area 48 and Other Areas

4.1 Dr de la Mare presented the report of the Workshop on Evaluating Krill Flux Factors (Appendix D) held at the Sea Fisheries Research Institute, Cape Town, South Africa, from the 21 to 23 July 1994.

4.2 Although much of the data required for the workshop were available prior to the meeting, this data did not have sufficiently wide coverage to calculate all the fluxes set out in the terms of reference. Consequently, the workshop needed to identify areas for which it could carry out calculations. The computations required more time than anticipated. Therefore, the workshop report covers the calculations carried out but does not go into detail about their interpretation.

4.3 The oceanographic data provided to the workshop included CTD data from Mr M. Stein (Invited Expert) and Dr M. Naganobu (Japan) which were used to calculate geostrophic current velocities. Dr Murphy provided a set of current vectors based on the average values over the top 250 m for a single instant of time from the FRAM (Fine Resolution Antarctic Model, IOS, NERC, UK). Further limited data sets on buoy and iceberg tracks and local surface currents were also available.

4.4 The krill data used were from the FIBEX, SIBEX 1 and SIBEX 2 surveys. Dr Agnew provided interpolation software to allow the oceanographic and acoustic data to be combined.

4.5 After initial consideration of the problem in the workshop, it became clear that the calculation of fluxes over the CCAMLR subareas would not be possible or particularly useful. A number of small boxes were defined within the subareas, based on such criteria as data coverage, natural boundaries of oceanographic features and krill distribution. Krill and water fluxes were calculated across the boundaries of these boxes, allowing water and krill residence times to be estimated. Integrated values over areas covering a number of contiguous boxes were also generated.

4.6 The analyses provide a range of values which can be used to examine krill flux in relation to fishery and predator requirements in particular regions.

4.7 There is a lack of good quality acoustic and oceanographic data collected simultaneously over the same areas, and the geographical coverage of the data is generally poor. Furthermore, the data used for the complex calculations of krill flux were originally collected for other purposes.

4.8 The calculations were based on the assumption that krill are passive tracers in the water stream. The calculations were made by multiplying the current profile along a boundary by the krill density profile along the same boundary. Residence times (as defined in Appendix D) for krill greater than those for water would suggest that krill are actively maintaining their position (i.e., not passive tracers). Although comparable residence times for krill and water would not necessarily demonstrate that krill can be considered as passive tracers, comparability over a range of geographic scales would suggest that krill are behaving as passive tracers.

4.9 The results from the workshop tended to show comparable residence times for water and krill over a range of geographic scales, implying that krill may be behaving as passive tracers. However, care must be taken in interpretation of the data, as the main water flows may be separated from areas of high krill densities. This may be a particular problem in shelf and island regions.

4.10 Dr Naganobu noted that there may be considerable aggregations of krill close to the sea bottom on the slope to the north of the South Shetland Islands, a supposition based on several reports in the literature (WG-Krill-93/15). Krill rise to the surface during summer, indicating a 'seasonal vertical flux'. This would suggest that not only horizontal, but also vertical migration may constitute an important factor in the movement and concentration of krill. Consequently, more data on vertical flux should be collected.

4.11 Nonetheless, the results from the workshop do indicate that the horizontal transport of krill is an important factor in the overall stock distribution, and aspects of krill flux do need to be considered in the development of management procedures and in the advice given.

4.12 The impact of these results on the current views of the potential yield from the fishery needs to be assessed, and consideration needs to be given to whether the current catch limits require revision (see paragraph 5.2).

4.13 The development of further analytical methods was discussed. Mr Stein indicated that there were other CTD data that should be used, and inclusion of the wind-field and Ekman drift effects could be investigated. Mr Stein indicated that he would attempt to prepare a paper on this for the next meeting. Dr Murphy said that a second FRAM data set was available which was the mean of the last six years of the model run. This data set might more realistically take account of the fine-scale eddy field. This data set could be provided to CCAMLR to repeat the calculations carried out in the workshop.

4.14 The differences between the FRAM model output and geostrophic flows result from a range of effects such as the lack of wind-induced surface currents in the geostrophic analyses, the topographic resolution of the FRAM data and the variability evident in the CTD-based estimates.

4.15 There are also a number of other oceanographic data sets on which the Working Group would encourage further submissions. In particular, there is a large body of drifter and buoy data, mainly US data (e.g., FGGE data), which would be useful. Analyses of the data to determine regions of rapid water transport with little eddy activity and areas of high eddy activity and drifter retention would be extremely useful.

4.16 Dr E. Hofmann (USA) suggested that a suite of models should be developed. At one end of the scale are the detailed regional circulation models coupling biology and oceanography. These more complex models can be developed alongside less complex, more management orientated approaches. In this way questions can be asked at a range of levels to investigate particular aspects of the more complex models, and their outputs can be used as inputs to management. As an example of the type of coupled models that could be developed, reference was made to Capella *et al*. (1992)[1] and Hofmann *et al*. (1992)[2].

4.17 The Working Group considered that restricted regional surveys, including direct current measurements, were needed in key areas, such as shelf and shelf-break regions, where the oceanographic regime is not well described by geostrophic calculations.

4.18 The Working Group agreed that restricted spatial scale repeat surveys of particular regions, of the AMLR or LTER type, which include both oceanography and biology, were particularly useful.

4.19 The Working Group noted the distinction between more applied and more basic research questions. The development of large-scale coupled biological-oceanographic circulation models was considered to be an important area of longer term research which the Working Group should monitor.

4.20 The flux analyses carried out indicate that small-scale isolated surveys are likely to give a misleading index of krill availability to restricted predator colonies. Near-synoptic surveys were still considered to have advantages for calculating catch levels, but large-scale flux patterns need to be considered in their design.

New Work on Acoustic Methods

4.21 Three papers were tabled dealing with aspects of krill target strength (TS) estimation, WG-Krill-94/12, 13 and 35.

4.22 Paper WG-Krill-94/13 reported measurements of zooplankton TS obtained at different frequencies. Two theoretical models were examined, a high-pass bent-cylinder model that indicated TS was dependent on animal volume and a ray bent-cylinder model in which TS is dependent on the

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1 Capella, J.E., L.B. Quetin, E. Hofmann and R.M. Ross. 1992. Models of the early life history of *Euphausia superba* - Part II. Lagrangian calculations. *Deep-Sea Research*, 39 (7/8): 1201-1220.

2 Hofmann, E.E., J.E. Capella, R.M. Ross and L.B. Quetin. 1992. Models of the early life history of *Euphausia superba* - Part I. Time and temperature dependence during the descent-ascent cycle. *Deep-Sea Research*, 39 (7/8): 1177-1200.

cross sectional area. Neither of these models incorporates orientation which is a confounding factor of sufficient complexity that while both models provide descriptions of the observed effects, neither provides a comprehensive explanation. The authors concluded that linear regressions of TS on the log of animal length or weight can be misleading.

4.23 The Working Group agreed that approaches using more than one frequency provided a more realistic approach to target identification. This had been examined in WG-Krill-94/12, where theoretical estimates of target strength were used in conjunction with field sampling to determine whether it was possible to distinguish between salps and krill. Although having similar acoustic properties, these two scatterers could be distinguished with reasonable success by the technique.

4.24 Paper WG-Krill-94/35, previously published in the *Journal of the Marine Acoustics Society of Japan*, discussed the conditions that are necessary for precise measurement of *in situ* TS. It was concluded that the conditions for detection of individual targets were unlikely to be met by numerical densities of krill greater than about one per resolution volume.

Review of Issues on Survey Design

4.25 Four papers, WG-Krill-94/14, 18, 20, 27, and the report of the Subgroup on Survey Design (SC-CAMLR-X, Annex 5, Appendix D) were discussed.

4.26 Paper WG-Krill-94/14 described a series of acoustic surveys in a limited area near Elephant Island which had been used to investigate spatial variability prior to the commencement of commercial krill fishing during the 1992 season. There was some concordance between the first three surveys, but the last survey indicated a major reduction in krill abundance. Commercial fishing soon after the last survey was characterised by high catch rates. This implied that the abundance of krill in the Elephant Island area can change rapidly, and when krill do come into the area, they are most often found at the same location.

4.27 Plans for an acoustic survey in Division 58.4.1 were discussed (WG-Krill-94/18). The primary aim of the survey will be to provide an estimate of standing stock which could be used as the basis for setting a precautionary catch limit for the area. Some information is available on the distribution of commercial catches in the region but little additional information is available. Planning the survey has highlighted the constraints imposed by incorporating regular series of CTD casts and net hauls into a study based mainly on acoustic observations.

4.28 Alternative strategies were discussed, such as undertaking intensive surveys in three smaller localities with broader scale surveys in between and then extrapolating to the overall area. No ideal alternative strategy was identified and the Working Group felt that if the survey were undertaken according to the submitted design the results would be suitable for providing a standing stock estimate to use as the basis for a precautionary catch limit. It was recognised that most of the krill in Division 58.4.1 were likely to be found south of 63°S.

4.29 Plans for a Japanese survey in Subarea 48.1 were discussed (WG-Krill-94/27). This study aims to investigate krill flux in the South Shetland Islands region, estimate the grazing impact of krill on other planktonic species and to study krill-predator interactions. Krill close to the bottom would be investigated using a deep echosounder and closing nets. It was reported that an acoustic doppler current profiler would be used for the study but could not be used in conjunction with the echosounder due to interference between the two instruments. This problem has been noticed by other researchers. The study would be undertaken in three phases during the period December 1994 to March 1995. The Working Group welcomed this initiative.

4.30 Guidelines for the design of surveys were summarised in WG-Krill-94/20 following the results of the meeting of the Subgroup on Survey Design (SC-CAMLR-X, Annex 5, Appendix D), and responses to a request for information were circulated by the Working Group Convener. The Working Group recognised the need to obtain unbiased estimates of biomass and variance from acoustic surveys. Because spatial data are rarely independent, it might be assumed that a strategy which gives an even coverage of the area would be the more effective. However, according to classical sampling theory this design would lead to a biased estimate of variance because samples would not be independent of each other unless the resource is assumed to be randomly distributed. As the latter is not likely to be true, an unbiased estimate of variance would only be possible using classical sampling theory with a random sampling design (with or without stratification).

4.31 The geostatistical approach exploits the existence of spatial correlation. Independence of samples is not a requirement under this approach. Variance is estimated in accordance with a model fitted to the covariance function or variogram.

4.32 When the inter-transect distance is greater than the range of spatial correlation, the variance estimated by both approaches is very similar.

4.33 The Working Group recognised that these approaches warrant further consideration and encouraged continued discussion to enable the group to recommend specific approaches to survey design and data analysis.

Methodology Used on Recent Surveys

4.34 Four papers were discussed on this subject, WG-Krill-94/21, 32, 34 and WG-Joint-94/9.

4.35 Paper WG-Krill-94/21 reported recent surveys in the Prydz Bay region. The Working Group noted that the three-dimensional plots of the results indicated that there might be some spatial structure present along the transects, particularly close to the shelf break, which might warrant further investigation.

4.36 Paper WG-Krill-94/32 included results from two surveys using a 38 kHz system in the marginal ice zone. Noise margin levels were set by inspecting signal levels on an oscilloscope whilst operating in clear water; this resulted in different values being used for the two legs of the study. The survey design was of parallel transects, 20 minutes of longitude apart.

4.37 A 120 kHz system was available for this study but the results were considered by the authors to be unreliable due to low signal levels and an unexplained, approximately 20 log R, increase in mean volume backscattering strength with depth.

4.38 Paper WG-Krill-94/34 summarised biomass estimates from a variety of surveys from 1977 to 1992. Estimates based on net surveys were all at least an order of magnitude lower than the acoustic estimates, suggesting that avoidance is a significant problem with the former method. Without details of the individual surveys, the Working Group was unable to comment further.

4.39 Paper WG-Joint-94/9 included information on a series of four sequential surveys undertaken in the vicinity of Elephant Island during January and February 1994 as part of the AMLR Program. Two designs were used for the surveys, the first and last of which covered a large area with parallel transects spaced at 15 n mile intervals while the other two surveys covered a smaller area with transects spaced at 5 n mile intervals. It was accepted that these designs represented a compromise between the requirements for estimating abundance and its variance by the traditional methods and determining spatial structure.

4.40 Comparisons were made between biomass estimates calculated assuming that all zooplankton sound scatterers were krill, and those calculated by assuming that only distinct swarms contained krill. Biomass estimates differed by only 6 to 8%.

4.41 The Working Group agreed that reports of surveys should include not only the results of calibrations, but also the instrument settings used during the survey. It was noted that when calibrations were undertaken away from the survey area, the sound speed and absorption coefficient volumes might not be appropriate for polar regions. During surveys, values of these parameters appropriate to the conditions should be used. There remains some uncertainty regarding how to compensate for noise.

Modelling the Distribution of Krill Aggregations

4.42 Two papers were discussed, WG-Krill-94/7 Rev. 1 and WG-Krill-94/31.

4.43 Paper WG-Krill-94/7 Rev. 1 described an approach to modelling the distribution of krill aggregations based on observations in the Southern Indian Ocean sector. The presence of krill in the surface 3 to 8 m during daylight early in the austral summer was noted by the authors. Such an occurrence can introduce bias into acoustic estimates of krill density, and hence abundance. At larger scales the distribution of aggregations was reasonably well described by an exponential function, but this was not the case at smaller scales. The Working Group noted these developments and encouraged further examination of the data, particularly since they were obtained in an area from which little information had been available in the past.

4.44 Paper WG-Krill-94/31 described the fitting of random-process models to the distribution of the centre-to-centre distances of krill aggregations detected on surveys undertaken aboard FFS *Walther Herwig* and FSV *Agulhas*. A total of twelve models were investigated, including both simple distributions and binary mixtures of these. The authors concluded that the best fit was obtained using a two-component Weibull mixture model or a log-transformed extreme value approach. It was agreed that one of the reasons that the models had been poor descriptors of the distributions was that at least two processes were being described: random diffusion and active aggregation.

Biomass Estimates from the Integrated Study Regions
(see also Annex 7, paragraphs 3.8 to 3.18)

4.45 No new surveys for Statistical Area 48 suitable for use in revising the precautionary catch limit were reported.

4.46 Surveys were reported for parts of the CEMP Integrated Study Regions (ISRs) and the results are set out below.

4.47 Results from three surveys in the region of Prydz Bay are presented in WG-Krill-94/21. These cover areas which are part of the ISR. Biomass estimates are summarised below:

	Weight Density (g/m²)	Biomass (10^6 tonnes) over 150 000 km²	CV (%)
1985	20.2	3.02	16
1991	16.6	2.47	17.6
1992	10.25	1.53	34.8
1993	7.7	1.15	23.7

4.48 A review of results of Ukrainian krill surveys in the vicinity of Prydz Bay are presented in WG-Krill-94/34. The results from acoustic surveys are summarised below:

Period	Area (km²)	Mean Biomass (g/m²)	Total Biomass (million tonnes)
February-March 1977	133 200	187.7	25.0
December 1977-January 1978	129 260	50.7	6.56
February-March 1978	129 000	65.8	8.49
February 1979	107 600	60.7	6.53
January 1980	133 000	20.5	2.72
January-March 1981	112 400	20.0	2.25
December 1981-January 1982	168 000	22.6	3.80
December 1982-January 1983	126 800	21.3	2.70
December 1983-January 1984	124 000	71.0	8.81
January-February 1984	345 000	17.5	6.04
February 1985	123 000	41.1	5.1
February 1986	94 000	36.6	3.44
February 1987	105 000	18.3	1.92
February-March 1988	42 000	48.0	2.0
February 1989	37 800	92.0	3.5
February-March 1990	53 800	167.0	9.0
January-February 1991			5.37
February-March 1992			2.58

4.49 Results of a series of acoustic surveys in early 1994 from within the Elephant Island region of the Antarctic Peninsula ISR were presented in WG-Joint-94/9 and are summarised below:

	Weight Density (g/m²)	Variance	Area (10^6 m²)	Biomass (10^3 tonnes)	CV (%)
17 to 28 January	9.63	1.06	41 673	401	11
29 January to 2 February	12.02	1.12	7 203	86	9
17 to 19 February	13.46	8.66	7 203	97	22
25 February to 9 March	8.61	3.71	41 673	359	22

4.50 The biomass from these four surveys was substantially lower than that from surveys in previous years. Mean values of density from previous years are summarised in the table below. It was noted that the high value in 1993 may in part be due to difficulties in differentiating between echo signals from salps and krill.

	Average Krill Density (g/m^2)
1990	58.6
1991	26.3
1992	45.4
1993	111.4
1994	8.8

Krill Yield Calculations

Evaluation of Population Models

4.51 A number of papers were presented describing further work on the krill yield model of Butterworth *et al*. (1993). This model, which has been developed and used within the Working Group to relate krill yield to a pre-exploitation survey estimate of krill biomass (see paragraph 4.92), has been further developed according to specifications outlined in SC-CAMLR-XII, Annex 4, Appendix E.

4.52 Paper WG-Krill-94/5 reported that the computer code for the krill yield model had been updated to incorporate the recruitment module as developed in WG-Krill-93/13. Checking of the computer code was carried out intersessionally and at the meeting and it was concluded that the program was now correct.

4.53 Paper WG-Krill-94/23 detailed preliminary computations carried out for the krill yield model. This involved modifying the input distributions for the lengths at recruitment and maturity (according to the results of WG-Krill-94/4), natural mortality (M) and the extent of recruitment variability. Sensitivity tests were carried out to assess the consequences of avoidance of gravid females by the fishery and higher natural mortality for younger ages of krill.

4.54 Results of the sensitivity tests indicate that partial avoidance of gravid females leads to greater depletion of males, but lesser depletion of females, than for the comparative base case where gravid females are not avoided. This effect increases for large values of γ, the proportion of the unexploited biomass that can be taken as catch[3].

4.55 The reproductive behaviour of krill is such that a single male produces sufficient spermatophores to fertilise more than one female. It is therefore unlikely that the heavier depletion of

3 γ is a value (corresponding to a decision criterion) which is computed by means of the krill yield model and used in the formula $Y = \gamma B_0$ to obtain the yield, or catch, (Y) from an estimate of the pre-exploitation krill biomass, B_0.

males would adversely affect reproduction of the krill population at the levels of γ that have previously been considered appropriate by WG-Krill ($\gamma \sim 0.1 - 0.165$; see paragraph 4.94).

4.56 Results of sensitivity tests (WG-Krill-94/42) also indicate that higher values of M for younger ages result in a krill population which is less resilient to higher harvesting intensities, i.e., higher values of γ. The assumption used in the tests was that M for ages 0, 1 and 2 is double that for older ages. The realism of this assumption was questioned, and the Working Group referred this question to the Joint Meeting of WG-Krill and WG-CEMP (WG-Joint). This discussion is presented in Annex 7, paragraphs 4.34 and 4.35).

Evaluation of Demographic Parameters

Estimation of Krill Recruitment Variability

4.57 At the WG-Krill meeting in 1993, a method for estimating the proportion of recruits in the population from data on length density distributions was presented (WG-Krill-93/12). This proportion is estimated by fitting a mixture distribution to a length density distribution. The proportion of 1-year-old recruitment is estimated as the ratio of 1-year-olds to all older animals, and the proportion of 2-year-old recruits similarly.

4.58 The average proportion of recruits and the variability about this average are estimated from a number of data sets. These two statistics are then used as inputs to the krill yield model to generate time series of (fluctuating) recruitment. One of the assumptions of the estimation method is that the length density distributions are representative of the length structure of a self-sustaining krill population for the range of age classes considered.

4.59 Results, in terms of the average and variance of the proportion of recruits, had been calculated in WG-Krill-93/12 from a subset of the data sets considered in the analysis. Estimates (of the recruitment proportion) that were close to zero were excluded.

4.60 At this meeting, an attempt was made to develop criteria for the exclusion of data sets from the estimation of recruitment proportion and variability. There were no obvious reasons for exclusion of any of the original data sets used in WG-Krill-93/12. Two modifications to the data sets were, however, suggested.

4.61 The *Walther Herwig* FIBEX survey included a number of samples made in the Weddell Sea, just to the southeast of the Antarctic Peninsula, and it was suggested that data from this area should be excluded. The main reason for this exclusion is the different mean length of the krill age group 1+

compared to the krill from the Peninsula area, suggesting an origin from different populations. Inclusion of these data is thought to violate the assumption of representativeness of a single population.

4.62 The second suggestion was to exclude all data for sizes below 20 mm because of possible net selectivity problems. Only data obtained from RMT8 nets were considered, and this type of gear is likely to select animals greater than 20 mm in length. Selectivity at the upper end of the size distribution is unlikely to have a serious effect on estimates, whereas selectivity at the lower end of the size distribution is far more likely to do so.

4.63 Further data sets for use in the estimation of recruitment variability were requested in SC-CAMLR-XII, Annex 5, Appendix E, and nine more data sets were submitted. At the present meeting, these new data sets were analysed together with a re-analysis of the original data sets, incorporating the suggestions noted above (paragraphs 4.61 and 4.62).

4.64 Estimates of recruitment proportion were obtained for 1-year-olds (18 data sets) and for 2-year-olds (17 data sets)[4]. These values were combined into three estimates of the average and variance of recruitment proportion, based on: (i) 1-year-old recruitment; (ii) 2-year-old recruitment; and (iii) 1- and 2-year-old recruitment combined (see below). Full details of the results are given in Appendix F.

	1-year R	2-year R	Combined
Number of estimates	18	17	35
Mean R estimate	0.404	0.557	0.415
Standard deviation	0.456	0.126	0.442
CV of distribution	1.128	0.226	1.067

Note: combined statistics reflect inverse variance weighting.

4.65 The mean recruitment proportions are similar, but the standard deviations (SDs), and, hence, coefficients of variation (CVs), are much higher for 1-year-old recruitment than for 2-year-old recruitment. The combined results are dominated by estimates for 1-year-old recruitment, because values are combined by inverse variance weighting.

4.66 The high CVs for the 1-year-old recruitment proportion and for the combined sets of estimates imply that these distributions are U-shaped with high probabilities of observing values close to zero and values close to 1. These distributions are more variable than a uniform distribution,

4 Results are for all data sets analysed in WG-Krill-93/12 and all nine new data sets (paragraph 4.63); see Appendix F.

which has a CV of about 0.3. On the other hand, a CV less than 0.3 would imply a bell-shaped distribution, and this would be the case for the results based on 2-year-old recruitment.

4.67 Although it is possible that the recruitment proportion distribution for krill is U-shaped rather than bell-shaped, it is unlikely that it would be as extreme as suggested by the results. If mortality is in a range compatible with the expected life-span of krill, then one would not expect frequent occurrences of recruitment much larger than the numbers in several older age classes, and one would therefore not expect a high probability of a recruitment proportion close to 1. There is a high probability that recruitment proportions will be close to zero.

4.68 There is, however, an apparent contradiction in that the results for 1-year-old recruitment suggest a U-shaped distribution, whereas results for 2-year-old recruitment suggest a bell-shaped distribution. There are two possible explanations for this.

4.69 First, the basic assumptions of the recruitment method may be violated, which would lead to unreliable results. The assumptions are that:

(i) length density distributions are representative of the length structure of a self-sustaining population;

(ii) the length structure can be described by a mixture distribution with increasing age, leading to a monotonic increase in mean length-at-age; and

(iii) krill do not shrink naturally.

At least one set (1+ year-olds or 2+ year-olds) may, for example, not be representative of the length structure of a self-sustaining population.

4.70 In this regard, it was noted that there were possible reasons for excluding some of the data from two of the surveys included in the new analysis (the German surveys in 1982 and 1983, code-named GER1982 and GER1983). These data sets gave estimates of 1-year-old recruitment proportion close to 1, which was thought to be due to over-sampling of small krill in the Bransfield Strait, or from the shelf area. The spatial segregation of krill of different age/size classes is well-documented for this area (e.g., WG-Krill-94/22), and could lead to non-representative length density distributions. This concern may also be expressed for some other surveys and should be considered before future discussion of matters mentioned in paragraphs 4.64 and 4.66 to 4.68.

4.71 Paper WG-Krill-94/22 presents estimates of recruitment proportion using distribution mixture analysis for the same two surveys, but including data from the vicinity of Elephant Island only. The surveys in this area are thought to cover the distribution range of all krill life stages and size groups.

4.72 Due to limited time, the recruitment variability analysis could not be repeated at the meeting excluding all, or some, of the data from the German surveys in 1982 and 1983. These surveys are not included in the estimates of 2-year-old recruitment.

4.73 The second possible explanation for the different shapes of recruitment distribution suggested by the 1-year and 2-year-old recruitment proportions, is that natural mortality for krill between ages 1 and 2 may differ from that at greater ages, reflecting also large variability, possibly as a result of density dependence. If this is the case, then it would be reasonable to use estimates based on 2-year-old recruitment in the yield model, since the fishery does not take 1-year-olds.

4.74 The krill yield model was run with the new estimates of average recruitment proportion and variability. Both sets of results, those based on 1- and 2-year-old recruitment combined, and those based only on 2-year-old recruitment were used. Results are discussed in paragraph 4.101 below.

4.75 The algorithm that generates krill recruitment in the yield model, using the estimates of average recruitment proportion and variability, is based on the assumption that the distribution of recruitment proportion is bell-shaped. A bootstrap re-sampling procedure was therefore applied instead to provide results for analyses including the 1-year-old recruitment proportions.

4.76 Paper WG-Krill-94/15 raised two points regarding the method of estimating recruitment variability and its implementation. First, concern was expressed whether net samples were likely to provide representative samples. Criteria for the exclusion of data (paragraphs 4.61 and 4.62) were discussed; only data from RMT8 nets, which are likely to fully select for animals above 20 mm, were considered, and data on size classes below 20 mm were excluded.

4.77 The second concern was that, at high recruitment proportions (around 0.7 and above), the simulated variance is higher than the 'true' variance. In response, it was noted that currently the average values of recruitment proportion are around 0.5 and most values are below 0.7, so this problem is unlikely to have a great effect on results.

4.78 It would, however, be possible to try to modify the algorithm to improve its performance at high levels of recruitment. The Working Group agreed that this could not be done during the meeting, but should be given attention before its next meeting.

Krill Natural Mortality and Growth

4.79 Paper WG-Krill-94/16 presented growth and mortality estimates for krill from the Prydz Bay area. Results are consistent with previous estimates. It was noted that although growth estimates were obtained by fitting mixture distributions to length frequency data, these data could not be used directly for the estimation of recruitment proportion because this requires length density distributions. The data are, however, recorded in sufficient detail to construct length density distributions.

4.80 The author noted that there is some evidence of spatial segregation by age in the samples. To the north of the Antarctic divergence, mainly 4+ animals are found, whereas all age classes are represented south of the divergence. This should be considered if the data are to be used for the estimation of recruitment proportion in the future.

4.81 The data described in this paper are not in the CCAMLR database, and Prof. V. Yakovlev (Ukraine) indicated that the main problem in submitting the data to CCAMLR is lack of finance for extracting and preparing the data. The Working Group emphasised that the data would be very valuable to the work of WG-Krill.

4.82 In general discussion of the estimation of von Bertalanffy growth parameters, the negative correlation between κ and L_{inf} was noted[5]. If the curvature in the mean size-at-age plot is not evident, then it is easier to determine the product ($\kappa.L_{inf}$) than either parameter on its own.

4.83 Paper WG-Krill-94/17 presents results of a study investigating whether krill shrink in the wild. If krill do shrink, then current estimates of growth rate may be positively biased. Estimates of recruitment variability, and hence mortality, may also be affected. The study considers the number of crystal cones in the eyes as a possible index of age. The crystalline cone count may not decline with shrinkage, and may therefore give a more reliable index of age than that provided by length.

4.84 Preliminary results indicate some evidence for shrinkage in the wild, though further experiments are under way to validate basic assumptions and hypotheses. The method and study were brought to WG-Krill's attention at this early stage, because of their potential importance.

4.85 Dr V. Siegel (Germany) suggested that changes in crystal cone counts during maturation should also be examined, since changes in eye shape have been observed in spawning males. The eye shape returned to a pre-spawning shape after spawning.

5 κ = kappa, growth rate; for instance in the von Bertalanffy equation Length = $L_{inf}(1\text{-}e^{\kappa(a+t_o)})$

M/κ Distribution

4.86 At last year's meeting a request was made for a comparative analysis of ratios of natural mortality to von Bertalanffy growth rate for species other than krill (SC-CAMLR-XII, Annex 4, Appendix E). The main reason for this request was to enable the correlation between M and κ to be incorporated into the krill yield model. Prior to the development outlined in paragraph 4.52, the model used a fixed value of κ (0.45) with a range of values of M.

4.87 Paper WG-Krill-94/11 presented results of a wide range of M/κ ratios for crustaceans, including euphausiids. These estimates had to be extracted directly from the literature, and most estimates are therefore for tropical exploited species. A major problem associated with euphausiids is the lack of estimates of natural mortality. The range of values for M/κ is very wide and would lead to unrealistic values of κ for krill if used with the current range of mortality values generated in the length density distribution analyses.

4.88 The main conclusion from this paper was that M/κ cannot be obtained reliably from a comparative analysis. The Working Group agreed that the way forward would be to look at the properties of the yield model with regard to correlation between M and κ. Two options should be considered. First, the current ratio of (average) M over κ should be used to generate a κ-value for each M in the simulation. This would imply that each κ-value is simply some constant multiplied by the realised M.

4.89 The second option is to add some 'noise' or variability around this linear dependence. In each case, the effect of the correlation between M and κ on the results from the model needs to be investigated.

Maturity and Recruitment to the Fishery by Length

4.90 Paper WG-Krill-94/4 presented revised estimates for size at 50% maturity (l_{m50}) and size at 50% recruitment (l_{r50}) to the fishery. Results indicate that the krill yield model should sample from uniform distributions with the following parameters:

l_{r50} = U[30, 39] with a width of 9 mm
l_{m50} = U[32, 37] with a width of 6 mm

where U[ ] indicates uniform distribution with upper and lower bounds.

4.91 The Working Group agreed that estimates of the range for l_{m50} were likely to be reliable, since they are derived directly from biological information on maturity. Estimates of the range for l_{r50}, on the other hand, were subject to the combined effects of gear selectivity and fishing operations. The Working Group therefore suggested that sensitivity tests with regard to l_{r50} be conducted at this meeting using the updated estimates of recruitment variability (see paragraphs 4.108 and 4.109).

Criteria for Selecting an Appropriate Value for γ

4.92 Over the past several years, the Working Group has been developing the krill yield model. This is used to provide values for the proportion of a survey estimate of the pre-exploitation krill biomass that can be harvested under a given set of criteria. The proportionality coefficient is called γ, and catch limits are calculated as the product of γ and an estimate of the pre-exploitation krill biomass, B_0 (see footnote to paragraph 4.54).

4.93 Last year the Working Group had one decision rule for selecting a value of γ: choose γ so that the probability of the spawning biomass dropping below 20% of its pre-exploitation median level over a 20-year harvesting period is 10%. This decision rule was aimed at protecting the krill stock by not allowing the spawning biomass to drop to very low levels at which the chance for successful recruitment may be impaired. Although the probability of 10% is somewhat arbitrary, it is consistent with values used in managing other fisheries.

4.94 This decision rule, however, derives from a single-species approach. The Working Group had some initial discussions in 1993 aimed at establishing decision rules that would accord some protection to krill predators as required under Article II. Further discussions were held at this year's meeting, both in WG-Krill and the joint meeting with CEMP (Annex 7, paragraph 5.31).

4.95 In terms of predators, it is appropriate to devise a decision rule on the basis of the median level of krill escapement, defined as the ratio of median krill biomass under exploitation to the corresponding median pre-exploitation level. In a single-species management context, an escapement level of about 50% is usually considered to be appropriate. The highest level of escapement (i.e., 100% - the best situation for the predators) is achieved when there is no harvest. Given that a final decision has yet to be reached in CEMP regarding appropriate levels of escapement for predators, the Working Group suggested that a value halfway between these two bounds (i.e., at 75%) should be used as a preliminary target level, as also agreed at WG-Joint (Annex 7, paragraphs 4.33 and 4.34).

4.96 The second decision rule, aimed at protecting predator requirements, is therefore: choose γ so that the median krill escapement at the end of a 20-year period is 75%.

4.97 Each decision rule would lead to the selection of a value of γ, and these values are likely to be different. The third rule for deciding between these two values of γ is to select the lower, more conservative value. This means that the γ-value associated with the 'limiting factor' in the system would be selected.

4.98 The following decision rules were therefore defined:

(i) choose γ_1, so that the probability of the spawning biomass dropping below 20% of its pre-exploitation median level over a 20-year harvesting period is 10%;

(ii) choose γ_2, so that the median krill escapement over a 20-year period is 75%;

(iii) select the lower of γ_1, and γ_2 as the level of γ for calculation of krill yield.

Yield Estimates

4.99 Results from the krill yield model with the updated estimates of average recruitment proportion and its variability are presented below. Three sets of results are summarised: last year's results (last); results for 1- and 2-year-old recruitment combined (1-2+); and results for 2-year-old recruitment only (2+). Results are given for the two values of γ that were used at last year's meeting (SC-CAMLR-XII, Annex 4, paragraph 6.3).

Parameter		$\gamma = 0.1$			$\gamma = 0.165$		
		Last	1-2+	2+	Last	1-2+	2+
Probability spawning biomass falls below 0.2 K_{sp} over 20-year period	(Prob)	0.02	0.89	0.02	0.10	0.93	0.14
Median spawning biomass after 20 years	(Med)	0.78	0.10	0.78	0.62	0.03	0.64
Lower 5%-ile spawning biomass after 20 years (Low)		0.41	0	0.43	0.24	0	0.20

4.100 Results for the recruitment parameters derived from 1- and 2-year-old recruitment combined (1-2+) are very different from the other two sets of results because of the much higher CV and U-shaped nature of the recruitment distribution.

4.101 The values of Prob, Med and Low at different levels of γ for the updated recruitment parameters are given below.

γ	This year 1+ and 2+			This year 2+ only		
	Prob	Med	Low	Prob	Med	Low
0	0.66	1	0.07	0	1	0.68
0.016	0.76	0.61	0.003	0	0.97	0.65
0.032	0.80	0.43	0.0002	0	0.94	0.62
0.048	0.84	0.30	0	0.001	0.89	0.58
0.064	0.86	0.22	0	0.002	0.87	0.55
0.080	0.87	0.16	0	0.008	0.83	0.48
0.096	0.88	0.12	0	0.017	0.79	0.43
0.112	0.90	0.07	0	0.04	0.76	0.39
0.128	0.91	0.06	0	0.06	0.72	0.33
0.144	0.92	0.05	0	0.09	0.68	0.26
0.160	0.93	0.04	0	0.13	0.65	0.22
0.176				0.17	0.61	0.17
0.192				0.22	0.57	0.13

4.102 Given the reservations expressed with regard to the combined results for 1- and 2-year-old recruitment, and in particular the inclusion of the two German data sets for 1982 and 1983 which are thought to be unrepresentative, and the apparent inconsistencies (see paragraph 4.64) in results for 1- and 2-year-old recruitment, the Working Group agreed that at this stage it is most appropriate to consider yield calculations based on 2-year-old recruitment only.

4.103 The first decision rule resulted in $\gamma_1 = 0.149$ and the second decision rule $\gamma_2 = 0.116$. Full results (using 2-year-old recruitment) for both γ values are given below:

Statistic		First Decision Rule P = 0.10 $\gamma_1 = 0.149$	Second Decision Rule M = 0.75 $\gamma_2 = 0.116$
Probability of spawning biomass falling below 0.2 over 20-year harvest period	(Prob)	0.10	0.04
Median spawning biomass level at the end of 20 years	(Med)	0.68	0.75
Lower 5%-ile spawning biomass	(Low)	0.25	0.38

4.104 It was noted that these two values of γ lie between the values of 0.1 and 0.165 used previously.

4.105 The third decision rule, which indicates that the lower of the two γ-values should be chosen, implies that a γ-value of 0.116 should be used in calculations of catch levels.

4.106 The sensitivity of results to the distribution of size at 50% recruitment to the fishery was investigated. Calculations for the 2+ estimates of M and recruitment variability from this meeting have been repeated for 5 mm upward and downward variations in the distribution assumed for length at 50% recruitment (l_{r50}), which is currently taken from a distribution U[30,39] mm.

4.107 The values of γ corresponding to the two criteria identified as a basis for management recommendations are given below.

l_{r50}	γ		
	U[25, 34] mm	U[30, 39] mm	U[35, 44] mm
Prob = 0.10	0.131	0.149	0.214
Med = 0.75	0.109	0.116	0.128

4.108 Paragraph 4.107 shows that most changes in γ are not too substantial (~10%) for the changes in l_{r50} used. The Working Group agreed that there was a need to determine whether the ranges of distributions used in the sensitivity tests were likely to reflect the real situation.

4.109 Dr Agnew said that, having analysed the data, he felt that the real situation was indeed covered by the sensitivity analyses. He indicated that it would be possible to quantify the likely bounds on estimates of l_{r50} to determine whether the 95% confidence interval from the estimates falls within the ranges tested above. This would be facilitated by more length frequency samples from the fishery, particularly from Ukrainian and Chilean fishing vessels, becoming available.

4.110 The analyses presented in WG-Krill-94/4 were based on samples from the Japanese and former Soviet fisheries which used 15 to 17 mm and 12 mm mesh sizes respectively. Precise information on the mesh size used by the Ukrainian fishery was requested.

Review of Precautionary Catch Limits

4.111 Discussion under this item is reflected in Section 5 and Table 2.

ADVICE ON KRILL FISHERY MANAGEMENT

Precautionary Limits on Krill Catches in Various Areas

Estimates of Potential Yield

5.1 The meeting agreed that, as in the past, calculations of precautionary limits on catches should be made using the formula $Y = \gamma B_0$, where B_0 is an estimate of the pre-exploitation krill biomass, and γ is a value (corresponding to certain decision criteria) which is computed by means of the krill yield model. In terms of the decision rules agreed above (see paragraph 4.98), the current best estimate for γ is 0.116.

5.2 There was considerable discussion on whether survey estimates of B_0 (in Subareas 48.1, 48.2 and 48.3, for example) should be adjusted upward to allow for krill flux through these subareas. Details of this discussion, and its implications for management, are reported in Appendix E.

5.3 The outcome of these discussions was that making no 'flux adjustment' to survey estimates for B_0 constituted a sufficient and conservative basis for management, provided that the regions for which precautionary limits were set did not contain more than one self-sustaining stock. This approach would allow catch limits to be set for all subareas or divisions in the Antarctic for which biomass estimates are available.

5.4 An alternative approach of making adjustments for flux for certain subareas would necessitate zero catch limits being set in other subareas - particularly those upstream of the subareas concerned, for example. This option could not be implemented immediately and further analyses would be necessary if it is to be pursued.

5.5 The meeting accordingly applied the approach of paragraph 5.3 to calculate precautionary catch limits. The results are given in Table 2.

5.6 Conservation Measure 46/XI specifies subarea maxima that currently apply in addition to the present overall precautionary catch limit of 1.5 million tonnes of krill in Statistical Area 48 (Conservation Measure 32/X). A number of views were put forward as to how the revised calculation of a limit of 4.1 million tonnes for Statistical Area 48 (see Table 2) should be subdivided.

5.7 The first view was that the revised precautionary limit of 4.1 million tonnes should replace the existing 1.5 million tonnes figure, and be subdivided as reflected by column A in Table 2. This approach follows from the rationale given in Appendix E, which implies that the limits for subareas should be based solely on biomass estimates for those subareas (so that, *inter alia*, zero limits apply in subareas where there has as yet been no survey). Advocates of this approach queried the use of historic catch data as a guide towards subdivision, arguing that this was not a sound approach in the longer term, as the fact that a particular level of catch has been maintained over a limited period constitutes no guarantee that it is sustainable.

5.8 One reservation expressed concerning this approach was that it was unreasonable to reduce the existing limits for Subareas 48.4 and 48.5 from 75 000 tonnes to zero. Another was that the resultant decrease for Subarea 48.3 from 360 000 to 180 000 tonnes was inappropriate, as it was an artefact of the low coverage of this subarea achieved in the FIBEX survey used to provide the B_0 estimate.

5.9 In response to these concerns, proponents of the approach in paragraph 5.7 argued that:

(i) these low values provided an appropriate incentive to organise surveys of these subareas (for the first time, or on a more extensive basis than previously);

(ii) the approach, consistently applied, obviated the need for restriction of consideration to the results from near-synoptic surveys in setting precautionary catch limits - hence other surveys in, for example, Subarea 48.3 in addition to FIBEX could be considered in refining the estimate of B_0 for that subarea;

(iii) the situation for subareas with zero limits (because of the absence of a prior survey) might be reconsidered in the context of limited allowances for exploratory fisheries;

(iv) further flux studies might provide evidence of a sufficiently large transfer of krill between, say, Subareas 48.2 and 48.3 to negate an hypothesis that these subareas contained effectively separate self-sustaining stocks, thus allowing them to be combined for the purpose of setting precautionary catch limits.

(The meeting did not have sufficient time to pursue analyses which might have allowed options (ii), (iii) or (iv) to be further examined.)

5.10 The second view concurred with the revision of the overall precautionary catch limit to 4.1 million tonnes. However, according to this view the matter of subdivision had already been discussed at length at previous meetings, and the sub-division proportions for each subarea then agreed (SC-CAMLR-XII, Annex 4, Table 5) should be applied pending further detailed consideration of this matter (since little time had been available to study the rationale advanced in Appendix E at this meeting). These percentages are based on taking the average of the proportion of FIBEX survey estimates and the proportion of the historic catch in a subarea of Statistical Area 48 and adding 5%. The results of such a subdivision, and the percentages upon which it is based, are shown under column B in Table 2.

5.11 A reservation concerning this second view was that the percentages adopted for subdivision had been agreed in the context of an overall limit of 1.5 million tonnes for Statistical Area 48. It was argued that this agreement had not been intended to extend to a higher figure for this limit, as was now under consideration.

5.12 A third view was that the likely levels of fishing for the next season were considerably less than the 'subdivision trigger' level of 0.62 million tonnes in Conservation Measure 46/XI. Accordingly, there was no immediate need to revise either the trigger level or the 1.5 million tonnes overall limit of Conservation Measure 32/X for Statistical Area 48.

5.13 The Working Group had insufficient time to discuss these views further.

5.14 Concern has previously been expressed that krill fishing has occurred in Division 58.4.1, but that a survey of the krill biomass in that region has yet to take place. The meeting was therefore pleased to hear (WG-Krill-94/18) of plans by the Australian Antarctic Division for a survey of this division during the 1995/96 summer season.

5.15 Comments on the detailed proposals of WG-Krill-94/18 are recorded in paragraph 4.27. The meeting endorsed the overall proposal which would provide key information.

5.16 Drs de la Mare and Nicol stated that they would welcome the participation of vessels from other countries in the survey, as this would improve survey intensity and synopticity. Dr Naganobu advised that Japan was giving consideration to this possibility. The CCAMLR Secretariat could facilitate the coordination necessary if a multi-national survey becomes likely. In the meantime Dr Nicol would be the contact person for information.

5.17 The Scientific Committee had accorded a high priority to the refinement of the biomass estimate for Division 58.4.2 (SC-CAMLR-XII, paragraph 2.83). Two papers, WG-Krill-94/21 and 34, presented estimates of krill biomass for areas within Division 58.4.2. Due to differences in coverage, estimates could not easily be related to the biomass in the whole of Division 58.4.2 and it is also not easy to relate these estimates to the original FIBEX estimate previously used by WG-Krill.

5.18 The Working Group had insufficient time to discuss this matter further.

Possible Ecological Effects on Catch Limits

5.19 The Working Group noted the precautionary catch limits using the new estimate of $\gamma = 0.116$, obtained from the three decision rules agreed upon at this meeting. The estimates of biomass for Subareas 48.1, 48.2, 48.3 and 48.6 have not been changed, since no new information has been received.

5.20 WG-CEMP (SC-CAMLR-XII, Annex 6, paragraph 5.33) had addressed certain questions to WG-Krill. These were considered by WG-Joint (Annex 7, paragraphs 4.7 to 4.16).

Refining Operational Definitions of Article II

5.21 The Working Group agreed that substantial progress had been made in the refinement of operational definitions, in particular on the three decision rules for the selection of γ (paragraph 4.98).

5.22 The Working Group recognised the need for operational definitions that considered the needs of predators as well as prey, and in this regard welcomed the adoption of a value of krill escapement of 75% (Annex 7, paragraphs 4.32 and 4.33). The Working Group recommended that such operational definitions should be developed.

5.23 The Working Group recommended that the interim decision rules for the selection of an exploitation rate in calculating precautionary catch limits be considered for adoption by the Scientific Committee. The Working Group noted that the krill yield model has been refined and that the key parameters in that model were now based on analyses of data. The Working Group also noted that the revised precautionary catch limit for Statistical Area 48 has been calculated using agreed data and methods. The major problem facing the Working Group is in providing advice on the allocation of a precautionary limit to subareas within Statistical Area 48 (see paragraphs 5.7 to 5.13). The two basic approaches to allocation each result in some anomalies. The Working Group recommended that the Scientific Committee consider this matter further with a view to clarifying the basic approach to be followed and possible means of resolving the anomalies in the selected approaches.

Data Requirements

5.24 Standard data requirements of the Working Group are given in Table 3. Two additional items were discussed.

5.25 The Working Group received an offer from Chile to present data on trawl start times and duration. The Working Group agreed that this data would be useful. Analyses such as catch/towing hour could show seasonal trends. In addition, the data would be of use in fishery behaviour models. The Working Group therefore recommended that such data should be presented to the next meeting.

5.26 As requested by CCAMLR-XII (paragraph 6.10), the Working Group discussed the implications of a 50-tonne research catch as a trigger level for Conservation Measure 64/XII. Experience from a German research cruise utilising commercial krill trawls indicated possible catches of up to 400 tonnes of krill. The Working Group recommended that other researchers using commercial types of trawl submit similar information, which would then enable WG-Krill to review the situation at its next meeting.

Access to and Use of Data within CCAMLR

5.27 The Convener outlined briefly the principles of access to data and use of data within CCAMLR (WG-Krill-94/19).

5.28 Some concern was expressed where collaborative analyses, to be carried out during the intersessional period, were sanctioned by the Working Group during its meeting.

5.29 The Working Group reiterated that:

(i) analyses presented as Working Group documents are not considered to be public documents; and

(ii) if the final aim of the analysis is formal publication, then the onus is on the person(s) undertaking the analysis to obtain the necessary permission from the originators of the data at the outset of any collaborative undertaking.

5.30 The Working Group agreed that it is highly desirable that in cases outlined in paragraph 5.29 that this permission be obtained during the relevant Working Group or subgroup meeting.

Future Work and Organisation of WG-Krill

Review of Terms of Reference

5.31 A discussion of this item is given in the Report of the Joint Meeting of WG-Krill and WG-CEMP (Annex 7, Section 6).

Future Organisation of Work

5.32 The report of the Joint Meeting of WG-Krill and WG-CEMP identified three areas of further work which have implications for WG-Krill:

(i) the determination of krill flux;

(ii) the determination of options for decision rules for calculating appropriate levels of krill harvesting; and

(iii) the functional relationships between predators and prey.

5.33 In addition, ongoing activities of WG-Krill that need to continue through the intersessional period are listed in Table 4.

OTHER BUSINESS

6.1 The Working Group noted that in recent years the catch of *E. superba* in the Convention Area has been smaller than that of *Euphausia pacifica* off the west coast of Japan. The catch of *E. pacifica* will reportedly fall to 90 000 tonnes this year, with management of this fishery being based on market demand rather than on biomass estimates. Mr Ichii agreed to contact those involved with the management of the *E. pacifica* fishery to investigate whether there were matters of common interest to scientists involved in the management of these krill fisheries.

ADOPTION OF THE REPORT

7.1 The report of the Sixth Meeting of WG-Krill was adopted.

CLOSE OF THE MEETING

8.1 In closing the meeting the Convener, Mr Miller, thanked participants, rapporteurs and the Secretariat for ensuring a successful and productive meeting. In particular he thanked Dr V. Shannon, Director of the Sea Fisheries Research Institute for his assistance and support in organising the whole suite of Flux, Krill, CEMP and joint meetings, and all his staff who had worked tirelessly to effect its success. He stated that holding these meetings in South Africa was of great personal satisfaction to him.

8.2 Mr Miller then informed the meeting that it was his intention to step down from the position of Convener at the close of the 1994 Scientific Committee meeting. He thanked all participants, past and present chairmen of the Scientific Committee and other Working Groups, and all staff of the Secretariat for making his years as Convener, from 1989 to 1994, productive, pleasurable and satisfying. He particularly congratulated the Working Group on the direction which it was taking and the progress it had made towards responsible scientific support of the Commission and the Convention.

8.3 Dr Shannon congratulated Mr Miller on successfully concluding the meeting, and thanked all participants for their support in its deliberations in South Africa. The Executive Secretary also extended thanks and congratulations to Mr Miller on behalf of CCAMLR.

8.4 Dr Everson then delivered a vote of thanks to the Convener from the Working Group and presented him with an engraved avian statuette.

8.5 The Convener then closed the meeting.

Table 1: CCAMLR Observer Program. Random times of day to be used when recording fishing vessel activity. Activity type should be recorded in the boxes provided.

Activity codes:

F = Fishing (haul in progress)
S = Vessel searching/steaming
P = Vessel stopped while processing of previous catch is completed
A = Vessel stationary either at anchor or hove to
T = Transhipping catch
R = Vessel repositioning in preparation for next haul

day 1	2	3	4	5	6	7	8	9	10
date:	date:	date:	date:	date:	date:	date:	date:	date:	date:
0:51	0:49	0:23	0:17	0:18	0:57	1:51	0:51	1:07	0:02
1:12	2:37	1:13	0:28	0:26	1:55	2:01	3:33	2:36	2:36
2:18	2:46	4:40	1:36	2:08	2:49	2:49	4:24	3:06	3:15
3:17	4:23	6:41	3:45	2:12	3:17	3:08	5:50	3:18	3:29
3:59	6:23	7:15	6:02	4:32	4:13	4:02	6:10	3:39	4:12
6:09	6:25	7:27	6:44	4:49	4:15	4:25	12:06	5:30	5:27
6:44	6:48	7:59	7:49	5:40	7:36	4:54	14:50	5:41	10:04
8:17	8:41	8:02	8:24	7:41	8:38	5:13	14:59	6:45	10:28
10:36	8:57	8:39	10:25	8:17	8:49	7:13	15:55	7:13	10:29
10:40	9:30	9:04	10:28	9:47	13:22	8:35	16:10	7:36	11:16
11:35	10:43	10:46	11:38	10:53	14:02	8:58	17:26	7:39	11:19
11:47	10:54	13:21	15:12	15:16	14:49	9:06	17:50	11:00	11:35
12:43	11:42	13:33	16:03	16:25	14:58	9:46	18:58	14:42	11:51
13:09	12:10	14:20	16:48	17:01	15:11	12:13	19:53	16:20	14:32
13:23	15:32	15:53	17:37	17:19	18:47	15:31	19:56	16:48	17:12
16:22	15:51	17:55	20:02	18:05	22:17	17:41	20:14	17:35	18:09
18:14	16:22	19:14	21:47	18:47	22:59	18:56	21:02	17:46	18:50
19:10	18:26	20:27	22:11	19:43	23:07	18:57	21:27	17:56	20:48
20:09	19:20	23:22	22:14	20:16	23:35	19:02	21:30	19:07	21:50
21:34	20:12	23:56	23:12	20:57	23:56	23:20	23:38	21:12	23:15

Table 1 (continued)

day 11		12		13		14		15		16		17		18		19		20	
date:		date:		date:		date:		date:		date:		date:		date:		date:		date:	
0:18		0:09		0:21		0:23		1:03		1:07		0:38		0:18		1:41		1:26	
2:39		0:17		0:29		1:40		1:07		1:42		1:01		2:27		2:18		3:45	
3:34		0:44		0:49		2:51		2:11		2:46		1:33		5:38		3:22		4:02	
3:41		3:02		3:55		3:15		2:37		2:56		3:07		10:12		4:36		4:22	
5:28		3:58		4:03		3:41		3:02		6:22		3:08		13:34		4:40		5:02	
6:44		5:27		4:03		4:04		3:14		8:36		8:41		15:32		4:51		5:28	
6:49		7:18		5:25		4:19		4:46		8:55		9:12		15:45		5:18		5:39	
7:42		10:42		7:27		4:42		7:01		9:39		10:04		16:18		8:26		12:34	
9:30		10:45		8:08		4:58		7:52		11:34		10:58		16:43		9:08		13:19	
10:29		12:37		9:44		6:34		9:21		11:46		11:30		18:26		9:22		13:32	
10:42		13:10		11:07		8:12		9:36		15:16		12:34		19:06		9:53		14:04	
11:26		13:54		12:45		10:59		11:03		15:23		12:48		20:32		11:29		14:14	
14:22		16:31		14:19		13:54		12:25		16:22		13:23		20:44		12:48		14:44	
14:48		16:50		15:02		14:04		12:47		16:55		15:02		21:10		12:51		15:21	
17:55		19:35		16:50		16:09		14:17		17:11		16:34		21:26		14:33		15:23	
18:11		20:37		16:50		16:21		17:03		17:44		18:47		21:48		17:18		17:19	
18:34		20:49		18:25		18:07		18:15		20:17		20:58		22:38		17:24		18:15	
19:44		22:09		22:01		18:32		18:24		21:29		22:36		23:04		19:58		20:56	
21:09		23:12		22:33		21:07		20:29		23:03		22:50		23:27		23:15		21:42	
22:06		23:32		23:31		23:54		21:18		23:17		23:18		23:34		23:50		22:03	

Table 1 (continued)

day 21 date:	22 date:	23 date:	24 date:	25 date:	26 date:	27 date:	28 date:	29 date:	30 date:	31 date:
0:58	0:19	1:08	0:05	0:48	1:57	0:04	1:55	0:27	0:32	0:32
1:24	1:57	1:47	2:10	0:54	5:34	0:45	3:09	0:30	0:54	2:38
1:34	3:06	2:23	2:56	0:54	5:55	2:48	3:59	2:56	1:31	2:39
2:41	5:56	4:47	3:58	2:15	6:45	5:25	5:21	3:07	2:08	2:40
4:23	6:34	6:00	4:43	2:28	7:34	8:26	7:37	3:27	2:21	3:26
6:26	6:58	6:21	5:33	6:14	8:46	9:19	9:19	3:57	4:15	3:31
8:13	7:27	7:22	5:40	8:50	10:20	14:02	9:34	4:52	9:19	4:15
11:16	7:43	8:30	7:11	10:38	11:00	14:31	10:55	6:55	9:59	4:54
11:40	8:28	9:35	7:36	10:48	13:26	14:38	12:13	7:03	10:16	6: 0
15:05	8:55	10:21	7:39	13:17	14:19	14:49	13:43	8:41	11:42	6:39
15:18	10:08	11:36	7:55	13:18	14:26	15:19	14:52	10:37	12:06	8: 0
16:10	11:51	12:16	9:13	14:24	16:10	16:22	15:35	16:53	13:37	10: 1
16:20	12:58	14:15	15:02	14:41	17:03	16:36	16:21	16:55	14:48	12:18
17:00	14:10	15:51	18:25	16:44	17:59	16:46	17:27	17:50	17:09	12:38
17:45	14:25	16:23	19:40	18:23	19:55	17:16	18:05	19:42	17:47	13:14
19:18	16:25	18:13	19:51	18:33	20:17	19:22	19:42	20:22	19:19	15:43
19:51	19:09	18:23	20:21	18:44	20:55	20:54	20:21	22:48	20:26	16:34
20:21	21:09	21:52	21:14	19:51	21:06	20:55	21:57	23:08	20:34	22:41
21:24	23:02	23:17	21:49	19:55	22:18	21:07	22:31	23:10	20:48	23:19
23:28	23:32	23:38	21:56	20:48	22:39	23:17	23:53	23:14	21:39	23:58

Table 2: Precautionary limits on krill catches in various areas, based on the formula $Y = \gamma B_0$, where $\gamma = 0.116$ (see paragraph 4.105). Units are 10^6 tonnes. Two methods of calculation of catch limits by subarea are given: (A) allocation proportional to biomass estimate for subarea; and (B) allocation on basis of previous recommendation (see SC-CAMLR-XII, Annex 4, Table 5). B_0 values are taken from SC-CAMLR-XII, Annex 4, Table 4.

Subarea/ Division	B_0		$Y = \gamma B_0$	Catch Limit by Subarea A	B		1993/94 Catch
48.1	13.6}			1.58	1.39	(34%)	0.045
48.2	15.6}	30.8	3.57	1.81	2.01	(49%)	0.019
48.3	1.5}			0.18	1.07	(26%)	0.019
48.4	-			0	0.21	(5%)	0
48.5	-			0	0.21	(5%)	0
48.6	4.6		0.53	0.53	0.49	(12%)	0
Total 48		35.4	4.10				0.083
58.4.2	3.9		0.45				

Table 3: Data requirements. This table lists the requests of WG-Krill-93 and additional requests of the Sixth Meeting of the Working Group.

Data Requested by WG-Krill-93	Data/Work Submitted	Data Requested by WG-Krill-94
Examination of the precision of estimates of krill length/weight relationships	Not done	Continued requirement
Demograhic data, especially as parameters for the yield model	WG-Krill-94/4, 11, 16, 17	-
Krill flux data	See WS-Flux report (Appendix D)	Additional data for continued work on flux required (paragraphs 4.13 to 4.15)
Length frequency data submission	Length frequency data from Japanese fishery	Continuing requirement, especially from Chile and Ukraine, that data be submitted to the CCAMLR Database (paragraphs 4.81 and 4.109)
Haul-by-haul data	Chile only	Continued requirement from other fleets
Finer scale data submission	Japanese 10 n mile x 10 n mile data reporting	-
Estimates of biomass for ISRs	WG-Krill-94/21, WG-Joint-94/9	Continued requirement
Monthly catch reporting	Proceeding	-
Data on amount and viability of krill passing through a net	Model in WG-Krill-93/34 had not been sent to Secretariat	Validation of assumptions of WG-Krill-93/34 recommended (SC-CAMLR-XII, Annex 4, paragraphs 3.36 and 3.38) - continued requirement (paragraph 3.19)
Historical fine-scale catches	Information provided by Ukraine WG-Krill-94/10	Progress and assistance for submission of historical fine-scale data encouraged (paragraph 3.3)
Minimum data requirements from acoustic surveys required (SC-CAMLR-XI, Annex 4, Appendix H)	Compliance	-
Net haul density data should be submitted for calculation of recruitment	German and Japanese data submitted (paragraph 4.63)	-
Data on by-catch of fish in krill trawls	WG-Krill-94/25	Continued requirement - see future work Trawl start times and duration; from Chile (paragraph 5.25) Information on catch quantities in research surveys (paragraph 5.26)

Table 4: Future work requirements. This table lists the requests of WG-Krill-93 and additional requests of the Sixth Meeting of the Working Group.

Work Requested by WG-Krill-93	Data/Work Submitted	Future Work Requested by WG-Krill-94
Operational definitions of Article II particulary decision rules	Paragraph 4.98	Specific intersessional work requested on determining options for decision rules (WG-Joint report and paragraphs 5.22 and 5.32)
Refinement of parameters and model of functional relationships	See WG-Joint report (SC-CAMLR-XIII/5)	Continued requirement (paragraph 5.32)
Further validation of R/M model and input parameters (Appendix E)	WG-Krill-94/6	-
Further work on acoustic methodologies, especially on upward-looking and multi-frequency transducers encouraged (paragraphs 4.17 and 4.20)	Number of papers (paragraphs 4.21 to 4.24)	Continued requirement
Survey designs	WG-Krill-94/20; also paragraphs 4.25 to 4.33	Future work should take into account considerations in paragraph 4.33
Further detailed quantitative analysis of overlap of predators and fishery in all CCAMLR areas requested	This topic was addressed by the joint meeting	-
Further consideration of the *Scientific Observers Manual*	Japanese data (WG-Krill-94/25)	Suggested use of random time table 1 to examine ship activities (paragraph 3.33)
Evaluate CPUE index	WG-Krill-94/14	Further work encouraged
Yield model	WG-Krill-94/4, 5, 11, 23, 42	Modify algorithm for estimates of recruitment proportion (paragraph 4.26) and various sensitivity analyses (paragraphs 4.89 and 4.91)
Liaison between fishermen, biologists and managers	None	Continued requirement
Investigations of the scale and frequency of surveys applicable to feedback management approaches	None	Continued requirement

Table 4 (continued)

Work Requested by WG-Krill-93	Data/Work Submitted	Future Work Requested by WG-Krill-94
Subdivision of results from existing surveys in line with WG-Krill-92 (SC-CAMLR-XI, Annex 4, Appendix D)	-	Continued requirement
Modelling to evaluate feedback control management options and spatial effects related to localised predator aggregations	-	Continued requirement
A workshop on krill flux should be held in 1994 (paragraph 4.10)	Flux workshop held	Additional work on hydrographic data (paragraphs 4.13 and 4.15) and krill flux (paragraph 5.32)
-	-	New work on tables for *Statistical Bulletin* (paragraph 3.6)
-	-	Information on mesh size on Ukrainian vessels (paragraph 4.110)

APPENDIX A

AGENDA

Working Group on Krill
(Cape Town, South Africa, 25 July to 3 August 1994)

1. Welcome

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

3. *Review of Fisheries Activities
   (i) Fisheries Information
      (a) Data Submission
      (b) Catch Levels
      (c) Location of Catches
      (d) Reports of Observers
         (i) By-catch of Young Fish
         (ii) Length Frequency/Haul-by-haul Data
         (iii) Use of Draft Observer Manual
   (ii) Other Information
      (a) Fishing Escapement Loss/Mortality
      (b) Development of CPUE Indices
      (c) Future Fishing Plans

4. Estimation of Krill Yield
   *(i) Krill Flux in Statistical Area 48 and Other Areas
      (a) Results of Flux Workshop
      (b) Immigration/Emigration Rates
      (c) Residence Times
      (d) Influence of Hydrography
      (e) Effects on Estimates of Yield
   (ii) Estimation of Effective Biomass
      (a) Techniques
      (b) Statistical Area 48

(c) Other Areas
(d) Future Near-synoptic Survey(s) in Statistical Area 48
(i) Results from *Ad Hoc* Correspondence Group
(iii) Refinement of Yield Estimate Calculations
(a) Evaluation of Population Models
(b) Evaluation of Demographic Parameters
(i) Estimation of Recruitment Variability
(ii) Criteria for Selecting γ
(iv) Review of Precautionary Catch Limits
(a) Statistical Area 48
(b) Other Statistical Areas

5. Advice on Krill Fishery Management
(i) Precautionary Limits on Krill Catches in Various Areas
(a) Estimates of Potential Yield
(b) Possible Ecological Effects on Catch Limits
(ii) Refining Operational Definitions of Article II
(iii) Other Possible Approaches and Their Development
(iv) Data Requirements
*(v) Future Work and Organisation of WG-Krill
(a) Review of Terms of Reference
(b) Future Organisation of Work

6. Other Business

7. Adoption of Report

8. Close of Meeting.

[* To be considered as far as possible prior to joint meeting with WG-CEMP]

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(Cape Town, South Africa, 25 July to 3 August 1994)

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LIST OF DOCUMENTS

Working Group on Krill
(Cape Town, South Africa, 25 July to 3 August 1994)

WG-Krill-94/1	AGENDA
WG-Krill-94/2	LIST OF PARTICIPANTS
WG-Krill-94/3	LIST OF DOCUMENTS
WG-Krill-94/4	PARAMETERS FOR THE STOCHASTIC KRILL DYNAMICS MODEL (SKDM): SELECTIVITY AND MATURITY D.J. Agnew (Secretariat)
WG-Krill-94/5	INCORPORATION OF A MODEL OF KRILL RECRUITMENT INTO THE BUTTERWORTH *ET AL.* STOCHASTIC KRILL DYNAMICS MODEL (SKDM) D.J. Agnew (Secretariat)
WG-Krill-94/6	FINE-SCALE CATCHES OF KRILL IN AREA 48 REPORTED TO CCAMLR FOR THE 1992/93 FISHING SEASON Secretariat
WG-Krill-94/7 Rev. 1	TO THE PROBLEM OF ASSESSMENT OF PROBABILITY OF FINDING ANTARCTIC KRILL CONCENTRATIONS IN DIVISION 58.4.2 V.N. Yakovlev, V.A. Bibik and L.M. Kokoz (Ukraine)
WG-Krill-94/8	VACANT
WG-Krill-94/9	POLISH KRILL FISHERY IN THE 1991/92 AND 1992/93 SEASONS RESULTS OF CATCHES AND BIOLOGICAL INVESTIGATIONS Jósef Sosinski and Zdzislaw Cielniaszek (Poland)
WG-Krill-94/10 Rev. 1	ANALYSIS OF KRILL FISHING BY SOVIET FISHING VESSELS IN THE COOPERATION SEA (DIVISION 58.4.2) IN 1978 BY FINE-SCALE DATA V. Yakovlev and V.A. Bibik (Ukraine)
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WG-Krill-94/19	ACCESS TO AND USE OF DATA WITHIN CCAMLR (Prepared by the Convener, WG-Krill)
WG-Krill-94/20	SUGGESTED OUTLINE FOR THE DESIGN AND IMPLEMENTATION OF FUTURE NEAR-SYNOPTIC KRILL SURVEYS Submitted by Denzil G.M. Miller (Convener WG-Krill)
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WG-Krill-94/25 FISHES CAUGHT ALONG WITH THE ANTARCTIC KRILL IN THE VICINITY OF THE SOUTH SHETLAND ISLANDS DURING THE AUSTRAL SUMMER MONTHS OF 1994
Tetsuo Iwami (Japan)

WG-Krill-94/26 NUMERICAL MODEL OF ECOSYSTEM INCLUDING *EUPHAUSIA SUPERBA* DANA AS A KEY SPECIES IN CIRCUMPOLAR REGION
Michio J. Kishi and Mikio Naganobu (Japan)

WG-Krill-94/27 THE PLAN FOR THE 7TH ANTARCTIC RESEARCH CRUISE BY THE RV *KAIYO MARU* OF THE JAPANESE FISHERIES AGENCY IN 1994/95
M. Naganobu, T. Ichii, S. Kawaguchi, T. Ogishima and Y. Takao (Japan)

WG-Krill-94/28 CPUES AND BODY LENGTH OF ANTARCTIC KRILL DURING 1992/93 SEASON IN THE FISHING GROUNDS NORTH OF LIVINGSTON ISLAND
S. Kawaguchi, T. Ichii and M. Naganobu (Japan)

WG-Krill-94/29 HYDROGRAPHIC FLUX IN STATISTICAL AREA 88 OF CCAMLR IN THE PACIFIC SECTOR OF THE SOUTHERN OCEAN
Mikio Naganobu (Japan)

WG-Krill-94/30 CHANGE OF SEX RATIO OF KRILL (*EUPHAUSIA SUPERBA*) FROM AUSTRAL EARLY SUMMER TO MIDSUMMER IN 1983/84 IN THE VICINITY OF PRYDZ BAY, ANTARCTICA
M. Naganobu and S. Kawaguchi (Japan)

WG-Krill-94/31 MODELLING THE SPATIAL DISTRIBUTION OF ANTARCTIC KRILL (*EUPHAUSIA SUPERBA* DANA)
A.W.A. Murray (UK) and D.G.M. Miller (South Africa)

WG-Krill-94/32 BIOLOGICAL ACOUSTIC SURVEY IN THE MARGINAL ICE EDGE ZONE OF THE BELLINGSHAUSEN SEA
Alistair W.A. Murray, Jonathan L. Watkins and Douglas G. Bone (UK)

WG-Krill-94/33 OPERATION RESULTS OF UKRAINIAN VESSELS AT ANTARCTIC KRILL FISHERY IN SUBAREAS 48.2 AND 48.3 IN MARCH-JUNE 1994. KRILL SIZE COMPOSITION
V.A. Bibik and V.N. Yakovlev (Ukraine)

WG-Krill-94/34 A REVIEW OF THE ANTARCTIC KRILL (*EUPHAUSIA SUPERBA* DANA) BIOMASS IN THE COOPERATION SEA (= PRYDZ BAY REGION, DIVISION 58.4.2)
E.A. Pakhomov (Ukraine)

WG-Krill-94/35	CONDITIONS FOR THE PRECISE MEASUREMENT OF FISH TARGET STRENGTH *IN SITU* Kouichi Sawada and Masahiko Furusawa (Japan), Neal J. Williamson (USA)
WG-Krill-94/36	REPORT OF THE WORKSHOP ON EVALUATING KRILL FLUX FACTORS (Cape Town, South Africa, 21 to 23 July 1994)

OTHER DOCUMENTS

WG-CEMP-94/10	SPATIAL STRUCTURE OF THE SOUTHERN OCEAN ECOSYSTEM: PREDATOR-PREY LINKAGES IN SOUTHERN OCEAN FOOD WEBS E.J. Murphy (UK)
WG-Krill-93/12	ESTIMATING KRILL RECRUITMENT AND ITS VARIABILITY W.K. de la Mare (Australia)
WG-Krill-93/13	MODELLING KRILL RECRUITMENT W.K. de la Mare (Australia)
WG-Krill-93/42	FURTHER COMPUTATIONS OF THE CONSEQUENCES OF SETTING THE ANNUAL KRILL CATCH LIMIT TO A FIXED FRACTION OF THE ESTIMATE OF KRILL BIOMASS FROM A SURVEY D.S. Butterworth, G.R. Gluckman, R.B. Thomson and S. Chalis (South Africa), K. Hiramatsu (Japan) and D.J. Agnew (Secretariat)
WG-Krill-93/43	POSSIBLE EFFECTS OF DIFFERENT LEVELS OF KRILL FISHING ON PREDATORS - SOME INITIAL MODELLING ATTEMPTS D.S. Butterworth and R.B. Thomson (South Africa)
SC-CAMLR-X APPENDIX D	REPORT OF THE WORKING GROUP ON KRILL - SUBGROUP ON SURVEY DESIGN (Yalta, USSR, 18 to 20 July 1991)

REPORT OF THE WORKSHOP ON EVALUATING KRILL FLUX FACTORS

(Cape Town, South Africa, 21 to 23 July 1994)

REPORT OF THE WORKSHOP ON
EVALUATING KRILL FLUX FACTORS
(Cape Town, South Africa, 21 to 23 July 1994)

The Workshop on Evaluating Krill Flux Factors was held from 21 to 23 July 1994 in the Sea Fisheries Research Institute, Cape Town, South Africa. Dr Vere Shannon, Director of the Institute, welcomed participants.

2. A Preliminary Agenda, circulated prior to the meeting, was adopted. Dr W. de la Mare (Australia) was elected Chairman for the meeting. Terms of reference for the workshop were given in SC-CAMLR-XII, paragraph 2.29. Further specification of the data and analyses required were given in SC-CAMLR-XII, Annex 4, Appendix D.

3. The Agenda, lists of participants and papers submitted to the workshop are given as Attachments A, B and C. The report was prepared by Drs D. Agnew (Secretariat), M. Basson (UK), W. de la Mare (Australia), R. Hewitt and E. Hoffman (USA) and E. Murphy and Mr M. Stein (Invited Experts).

DATA AVAILABILITY AND PREPARATION

4. The data required for the workshop to proceed were outlined in SC-CAMLR-XII, paragraph 2.30. This section describes the available data and their preparation for the meeting.

5. Krill acoustic survey data were available from the BIOMASS experiments which covered the following areas:

FIBEX: *Odissey* - small area north of South Georgia, and another to the east of Subarea 48.2.
Dr Eduardo L. Holmberg - western Subarea 48.2, including areas to the west and north of the South Orkneys.
Walther Herwig - large area overlapping Subareas 48.1, 48.2 and Division 41.3.2 north of the Convention Area.
Itzu Mi - Drake Passage and Bransfield Strait.

FIBEX cruises took place from January to March 1981.

SIBEX 1: *Polarstern* - area surrounding Elephant Island; October to November 1983.
Professor Siedlecki - Drake Passage and Bransfield Strait south to Anvers Island; December to January 1983/84.

SIBEX 2: *John Biscoe* - Drake Passage and Bransfield Strait south to Anvers Island; January to February 1985.
Capitan Alcazar - Bransfield Strait; January to February 1985.
Walther Herwig - Peninsula south to 68°S; March to April 1985.
Polarstern - around Elephant Island; November to December 1984.

6. These data were prepared prior to the meeting by the Data Manager using the same techniques as have been used in previous analyses (WS-Flux-94/4) (see also Trathan *et al*. (1992))[1]. The data available to the workshop were therefore latitude, longitude, krill density, integration interval distance, top and bottom integration depths and a day/night flag for each integration interval stored in the database. Most data sets had integration depths of 150 to 200 m.

7. Data on current velocity were available from two sources:

- a single time slice (FR2191) of the FRAM (Fine Resolution Antarctic Model) was provided at a resolution of 0.5° longitude x 0.25° latitude for Subareas 48.1, 48.2 and 48.3 south to 64.5°S by Dr Murphy. Data available were latitude, longitude, speed (cm/sec) in northerly and easterly directions. Prior to use by the workshop, they were converted to the standard latitude, longitude, direction and speed, averaged over the top 250 m; and

- geostrophic current velocities derived from CTD samples were provided by Mr Stein and Dr M. Naganobu (Japan). These data covered three years of sampling by Germany off the Antarctic Peninsula (1986, 1987 and 1990), a number of samples from Subarea 48.2 and two years sampling by Japan and Germany in the vicinity of the Subarea 48.1/48.2 boundary (1988 and 1992). All data were provided in the standard format of latitude, longitude, direction and speed, and averaged over the upper 200 m. Maximum reference depth for the calculations was 800 m. Interpolated flow vectors for the German data were presented in WS-Flux-94/6.

[1] Trathan, P.N., D.J. Agnew, D.G.M. Miller, J.L. Watkins, I. Everson, M.R. Thorley, E. Murphy, A.W.A. Murray and C. Goss. 1992. Krill biomass in Area 48 and Area 58: recalculations of FIBEX data. In: *Selected Scientific Papers (SC-CAMLR-SSP/9). CCAMLR*, Hobart, Australia: 157-181.

8. Figure 1 shows the extent of all these data sets together with krill catch distribution by fine-scale area.

ANCILLARY DATA

9. A number of additional data sources were available to the group, including passive tracer streamlines derived using the FRAM (WS-Flux-94/9), ship displacement trajectories (WS-Flux-94/10), buoy paths (WS-Flux-94/8) and iceberg drift paths (WS-Flux-94/6).

10. Latitude, longitude and date of buoy positions were extracted from Figure 8 of WS-Flux-94/8, and average speeds between consecutive positions were calculated. A comparison of these data with hydrodynamic data is presented in Table 1.

11. Iceberg drift speeds in WS-Flux-94/6 did not contain any information on direction. Average speed across boundaries of subareas (see paragraph 13) was nonetheless calculated for comparison with other data. On the basis of Figure 1 in WS-Flux-94/6, a general direction of 30° was assumed. Results are given in Table 3.

ESTIMATION OF KRILL AND WATER TURNOVER AND RESIDENCE TIMES

General Methodology

12. Krill flux and residence times were calculated following the methods detailed in Appendix D of SC-CAMLR-XII, Annex 4, and applied and developed in WG-Flux-94/15.

13. Inward flows into an area were termed as positive and outward flows as negative. The flux of krill V_D across a boundary of an area was expressed as the product of the profile of krill density along a boundary and the profile of water transport across that boundary.

$$V_D = \sum_{j=1}^{n} d_j f_j \qquad (1)$$

where n = number of intervals along a boundary

δ_j = density of krill in each interval (t km^{-3})

f_j = water transport across each interval (km^3 hr^{-1})

The krill influx was given by adding together the values for the inflow boundaries

$$V_I = \sum_{V_m > 0}^{b} V_m \tag{2}$$

where b is the number of boundaries, and the total efflux

$$V_o = \sum_{V_m < 0}^{b} V_m \tag{3}$$

Residence times (days) based on the inflow or outflow were calculated by dividing the krill biomass in the area by the relevant flux.

Inflow-based residence time

$$R_I = \frac{B}{V_I} \tag{4}$$

Outflow-based residence time

$$R_o = \frac{B}{V_o} \tag{5}$$

where B = krill biomass (tonnes).

14. Similar formulae were used to calculate water replacement times using water flows and water volume in the area in place of krill flux and biomass.

Calculation of Flux Rates and Residence Times in Subareas 48.1, 48.2 and 48.3

15. A number of small boxes were defined within subareas, using criteria such as data coverage and natural boundaries of oceanographic features and krill distribution (Figure 2).

16. Krill and water flux across each of the boundaries of the boxes defined in Figure 2 was calculated using programs developed by the Secretariat (WS-Flux-94/4). Krill density along each boundary and water speed normal to that boundary (i.e., directly across the boundaries) were calculated at interpolation points at intervals of 5 n miles along the boundary by weighted averaging of nearest data using the computer program described in WS-Flux-94/4. Weighting was by inverse distance and, for acoustic data, integration interval distance. For krill density calculations, all data

within a 30 n mile radius of an interpolation point were used, whereas for water flow the nearest nine data points were used.

17. This procedure was used for all acoustic data, the FRAM data and some of the CTD data. Some water flow vectors, however, were calculated directly from lines of CTD stations using linear interpolation because boundary effects rendered the inverse distance procedure unsuitable. Only those acoustic integration intervals taken during daylight hours were used for krill density calculations.

18. Krill density boundary vectors were calculated for FIBEX, SIBEX 1 and SIBEX 2 data separately. Water flow vectors were calculated for the FRAM data set and for the separate years of available geostrophic flow data. Figure 3 shows an example of krill density and flow vectors along a boundary (boundary 8, between boxes D and F). Krill and water flux across the boundary were calculated simply as the product of these vectors (t hr^{-1} and km^3 hr^{-1}).

19. Table 3 gives water flow rates across each of the boundaries in Figure 2, calculated using a number of data sets. The results of calculations of flux, using all the available combinations of acoustic data and hydrographic data are given in Table 4.

20. In order to calculate krill residence times, an estimate of the total biomass of krill in a box was required (paragraph 12). Similarly, for calculation of water residence times, total effective volume of water in a box was required.

- For krill, mean krill density (g m^{-2}) in each box was calculated using a simple mean of all acoustic density data in that box, weighting by integration distance (Table 5). For this reason, biomass estimates in Table 5 are slightly higher than those calculated by Trathan *et al*. (1992) using a transect-based method.

- For water, the relevant depth of the water column was taken to be 200 m for CTD derived data and 250 m for FRAM data.

21. Equations for calculation of residence times from a combination of boxes were developed (Attachment D) and used to calculate residence times for both water and krill for individual boxes (Table 6) and groups of boxes (Table 7).

Results

22. Generally, water flux values derived from the FRAM model were up to four times larger than those obtained from direct observations. This might reflect the incorporation of wind-induced surface currents to the model. The flux rates derived from observed data represent only the geostrophic component of the current field, based upon the given vertical density field. Additional analyses of the actual windfield data, as collected during the CTD measurements, should be undertaken to estimate the amount of wind-driven surface currents.

23. There was some seasonal variability in the estimates of water flow from the CTD data which was not resolved by the single time slice from FRAM. A further discrepancy was that the southwestward flowing Antarctic Coastal Current was not apparent in the FRAM data.

24. The only area of consistency between FRAM and observational data seems to be in the Bransfield Strait. Data derived from direct observations indicate that the inflow and outflow were balanced for this area. However, inflow and outflow were not balanced in the FRAM data. This might reflect the fact that water mass transport in the region is mostly confined to the upper hundreds of metres since the deep parts of the Bransfield Strait are blocked by ridges. These topographic features prevent deep reaching, consistent flow to the northeast and are not well described in the FRAM model.

25. Concerning inflow and outflow of individual boxes calculated from the FRAM data, boxes A, D, F and H might serve as examples where for the upper 200 m the influx of water masses is fairly consistent with the outflow.

RECOMMENDATIONS AND FUTURE WORK

26. Discussion of the significance of these results, recommendations to the Scientific Committee and suggestions for future work was left to the WG-Krill meeting.

CONCLUSION

27. The Chairman thanked all participants for a hard-working and successful workshop.

Table 1: Ancillary data on buoy speeds (derived from WS-Flux-94/8).

Section	Direction	Buoy Speed (cm/s)	FRAM Average Speed (cm/s)	Sub-section Coordinates
3	151.6°	-13.0	8.3	61 - 61.5 W
3	151.6°	11.4	12.1	59.9 - 61W
6	90°	20.3	7.9	61.05 - 61.2 S
7	0°	4.6	3.5	53.9 - 54.2 W
7	0°	-12.9	2.5	53 - 53.9 W
14	0°	10.3	0.9	51 - 51.2 W
14	0°	6.4	-2.2	49.9 - 51 W

Table 2: Areas and boundaries for the regions shown in Figure 4.

Region	Boundary Sections	Area (km^2)
A	0, 2, 3b, 3	39 466
B	1, 2, 4	31 106
C	4, 5, 10	30 465
K	3a, 3b, 5, 6	45 739
D	6, 7, 8, 9	40 759
E	9, 10, 11, 12	22 206
F	8, 12, 15, 13, 14	56 448
G	t1, t2, t3	30 343
H	t3, 22, 24, 25, 23, 21	70 852
I	24, 26, 28, 27	50 149
J	31, 32, 33, 34	34 452

Table 3: Water flow rates (cm sec^{-1}) across boundaries shown in Figure 2, from the FRAM data set, a number of hydrographic datasets (CTD samples) and iceberg track data. Negative flows are in a direction diametrically opposite to that shown.

Section	Distance (n miles)	Flow Direction	FRAM	CTD 1986	CTD 1987	CTD 1988	CTD 1990	CTD 1992	Iceberg
0	80	64.0	8.1	1.7	0.1		5.2		
1	50	64.0	3.9	-1.1	-0.1		-0.2		
2	140	59.3	0.2				0.2		
3	150	151.9	0.3						
3a	185	61.3	1.4						
3b	75	68.7	8.8						
4	80	70.9	7.7		6.8		7.3		
5	35	0	5.6				2.6		
6	120	90	8.6	3.8	4.4		4.8		
7	100	0	3.8						5.5
8	120	90	11.3	2.3			0.4		3.1
9	95	0	6.8				0.1		9.9
10	50	90	3.1	6.0			7.1		
11	55	0	5.2						7.0
12	70	90	0.3				1.3		3.3
13	190	90	7.2						4.3
14	90	0	1.6						5.7
15	80	0	1.6						7.3
t1	190	0	2.8						5.7
t2	215	65.4	-1.2						
t3	90	90	3.2			5.0			5.6
21	120	90	8.9						2.8
22	100	0	-2.6						9.5
23	90	0	0.4						13.0
24	110	90	9.7			3.2		1.6	3.4
25	95	90	4.9					1.9	5.3
26	130	0	6.7						8.3
27	120	0	3.2						5.0
28	110	90	5.9			3.1			3.5
31	40	90	-2.8						
32	125	0	3.9						9.1
33	95	90	-5.9						5.5
34	55	180	-2.8						

Table 4: Apparent krill flux and water flow rates across sections for various combinations of krill survey and oceanographic data sets. Negative fluxes are in a direction diametrically opposite to that shown.

Section	Data Set	Direction (°)	Krill Flux (tonnes h^{-1})	Water Flux (km^3h^{-1})
0	SIBEX 2*FRAM	64.0	80.8	8.7
	SIBEX 2*G86		17.4	1.8
	SIBEX 2*G87		1.0	0.2
	SIBEX 2*G90		52.7	5.5
1	SIBEX 2*FRAM	64.0	30.6	2.6
	SIBEX 2*G86		-10.7	-0.7
	SIBEX 2*G87		-3.0	-0.1
	SIBEX 2*G90		-4.5	-0.1
2	SIBEX 1*FRAM	329.3	43.2	-0.4
	SIBEX 1*G90		-8.9	-0.4
	SIBEX 2*FRAM		-7.5	-0.4
	SIBEX 2*G90		-15.4	-0.4
3	FIBEX*FRAM	331.9	1.3	-0.5
	SIBEX 2*FRAM		16.7	-0.5
3a	FIBEX*FRAM	331.3	83.1	-3.3
	SIBEX 1*FRAM		-39.1	-3.3
	SIBEX 2*FRAM		-28.5	-3.3
3b	FIBEX*FRAM	68.7	664.1	8.8
	SIBEX 1*FRAM		861.1	8.8
	SIBEX 2*FRAM		195.1	8.8
4	FIBEX*FRAM	70.9	6005.4	8.2
	FIBEX*G87		3787.6	7.3
	FIBEX*G90		4833.9	7.8
	SIBEX 1*FRAM		206.7	8.2
	SIBEX 1*G87		230.5	7.3
	SIBEX 1*G90		234.1	7.8
	SIBEX 2*FRAM		530.5	8.2
	SIBEX 1*G87		324.5	7.3
	SIBEX 2*G90		378.8	7.8
5	FIBEX*FRAM	0	511.4	2.6
	FIBEX*G90		151.3	1.2
	SIBEX 1*FRAM		18.0	2.6
	SIBEX 1*G90		12.9	1.2
	SIBEX 2*FRAM		168.5	2.6
	SIBEX 2*G90		94.2	1.2
6	FIBEX*FRAM	90.0	619.7	13.8
	FIBEX*G86		980.2	6.0
	FIBEX*G87		1309.2	7.1
	FIBEX*G90		1438.0	7.6
	SIBEX 1*FRAM		93.0	13.8
	SIBEX 1*G86		32.4	6.0

Table 4 (continued)

Section	Data Set	Direction (°)	Krill Flux (tonnes h^{-1})	Water Flux ($km^3 h^{-1}$)
	SIBEX 1*G87		38.9	7.1
	SIBEX 1*G90		38.2	7.6
	SIBEX 2*FRAM		312.0	13.8
	SIBEX 2*G86		166.3	6.0
	SIBEX 2*G87		213.2	7.1
	SIBEX 2*G90		215.5	7.6
7	FIBEX*FRAM	0	1007.6	5.1
	SIBEX 1*FRAM		50.8	5.1
	SIBEX 2*FRAM		58.7	5.1
8	FIBEX*FRAM	90.0	3556.1	18.1
	FIBEX*G86		741.8	3.7
	FIBEX*G90		153.0	0.6
	SIBEX 1*FRAM		0	18.1
	SIBEX 1*G86		0	3.7
	SIBEX 1*G90		0	0.6
	SIBEX 2*FRAM		0	18.1
	SIBEX 2*G86		0	3.7
	SIBEX 2*G90		0	0.6
9	FIBEX*FRAM	0	3826.3	8.7
	FIBEX*G90		43.1	0.1
	SIBEX 1*FRAM		26.3	8.7
	SIBEX 1*G90		0.4	0.1
	SIBEX 2*FRAM		251.4	8.7
	SIBEX 2*G90		2.2	0.1
10	FIBEX*FRAM	90.0	1462.1	2.1
	FIBEX*G87		3790.5	5.6
	FIBEX*G90		4932.9	6.7
	SIBEX 1*FRAM		8.4	2.1
	SIBEX 1*G87		28.7	5.6
	SIBEX 1*G90		34.8	6.7
	SIBEX 2*FRAM		82.4	2.1
	SIBEX 2*G87		210.6	5.6
	SIBEX 2*G90		258.0	6.7
11	FIBEX*FRAM	0	2538.3	3.8
	SIBEX 1*FRAM		33.8	3.8
	SIBEX 2*FRAM		153.1	3.8
12	FIBEX*FRAM	90.0	172.2	0.3
	FIBEX*G90		652.0	1.3
13	FIBEX*FRAM	90.0	2566.2	18.3
14	FIBEX*FRAM	0	204.4	1.9
15	FIBEX*FRAM	0	78.2	1.7

Table 4 (continued)

Section	Data Set	Direction (°)	Krill Flux (tonnes h^{-1})	Water Flux (km^3h^{-1})
t1	FIBEX*FRAM	0	449.8	7.1
t2	FIBEX*FRAM	335.8	1458.0	3.4
t3	FIBEX*FRAM	90.0	2546.7	3.9
	FIBEX*G88		3969.1	5.6
21	FIBEX*FRAM	90	1712.8	14.3
	FIBEX*G88		354.6	2.7
22	FIBEX*FRAM	180.0	2554.9	3.5
23	FIBEX*FRAM	0	6596.9	0.5
24	FIBEX*FRAM	90.0	13308.7	14.2
	FIBEX*G88		3052.0	4.7
	FIBEX*G92		2074.6	2.4
25	FIBEX*FRAM	90.0	11406.3	6.2
	FIBEX*G92		5295.9	2.4
26	FIBEX*FRAM	0	1564.3	11.7
27	FIBEX*FRAM	0	3116.9	5.2
28	FIBEX*FRAM	90.0	1898.2	8.6
	FIBEX*G88		1322.9	4.6
31	FIBEX*FRAM	270.0	179.6	1.5
32	FIBEX*FRAM	0	1002.3	6.6
33	FIBEX*FRAM	270.0	1889.1	7.5
34	FIBEX*FRAM	0	1553.8	2.1

Table 5: Biomass estimates for the regions in Figure 2 from the various surveys.

Region	Biomass from Survey (000s tonnes)		
	FIBEX	SIBEX 1	SIBEX 2
A	54	722	116
B	3 502	262	187
C	2 178	226	525
K	1 924	155	229
D	7 848	107	274
E	2 531	50	162
F	1 907	-	-
G	1 764	-	-
H	10 265	-	-
I	2 495	-	-
J	1 725	-	-

Table 6: Apparent krill and water retention times in the regions based on both influx and efflux rates, for various combinations of survey and oceanographic data sets.

Region	Data Set	Water Retention Time (days)		Krill Retention Time (days)	
		Influx	Efflux	Influx	Efflux
A	SIBEX 2*FRAM	44.7	44.8	60.0	22.1
B	SIBEX 2*FRAM	108.2	39.7	205.3	14.7
C	FIBEX*FRAM	38.8	67.1	15.1	46.0
	SIBEX 1*FRAM			45.6	355.7
	SIBEX 2*FRAM			41.3	87.2
	FIBEX*G90	32.4	32.2	18.8	17.9
	SIBEX 1*G90			40.2	197.3
	SIBEX 2*G90			57.8	62.1
K	FIBEX*FRAM	32.3	34.5	68.2	114.1
	SIBEX 1*FRAM			7.0	69.5
	SIBEX 2*FRAM			24.4	30.6
E	FIBEX*FRAM	39.2	25.8	26.4	26.4
	SIBEX 1*FRAM			49.7	---
	SIBEX 2*FRAM			28.7	---
	FIBEX*G90	---	170.6	---	151.8
D	FIBEX*FRAM	18.9	18.3	73.6	71.7
	SIBEX 1*FRAM			37.4	87.8*
	SIBEX 2*FRAM			20.3	195.1*
	FIBEX*G90	44.0	---	220.8	---
	SIBEX 1*G90			115.5	---
	SIBEX 2*G90			52.6	---
F	FIBEX*FRAM	29.2	29.1	20.9	28.7
G	FIBEX*FRAM	44.6	43.7	163.4	18.4
H	FIBEX*FRAM	33.3	36.1	31.9	17.3
I	FIBEX*FRAM	26.9	25.8	6.3	30.0
J	FIBEX*FRAM	37.7	44.2	20.9	60.8

* No krill density estimates were available on section 8 for SIBEX 1 and 2 (see second page of Table 4, column 4). Therefore these retention times are probably biased upwards.

Table 7: Apparent krill and water retention times in combined regions based on both influx and efflux rates, for various combinations of survey and oceanographic data sets.

Combined Regions	Data Set	Water Retention Time (days)		Krill Retention Time (days)	
		Influx	Efflux	Influx	Efflux
ABKCDE	SIBEX 2*FRAM	115.5	93.0	212.7	---
KDCEF	FIBEX*FRAM	79.0	80.4	73.6	176.9
KCDE	FIBEX*FRAM	60.2	61.7	65.5	125.2
	SIBEX 1*FRAM			19.7	---
	SIBEX 2*FRAM			54.7	---
HI	FIBEX*FRAM	46.1	47.6	32.2	35.8

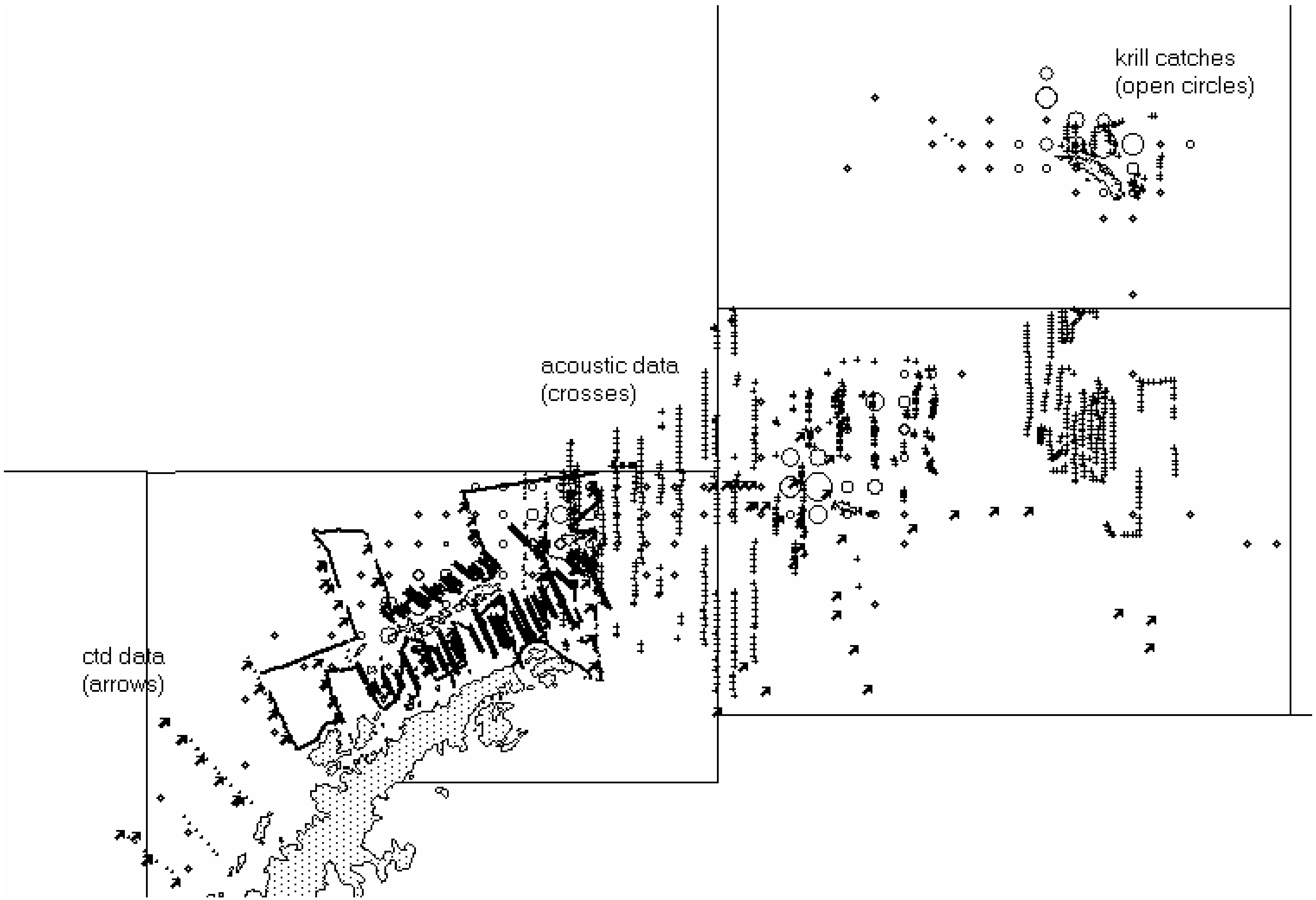

Figure 1: Acoustic CTD data available to the workshop overlaid with the distribution of krill catches over the last 10 years.

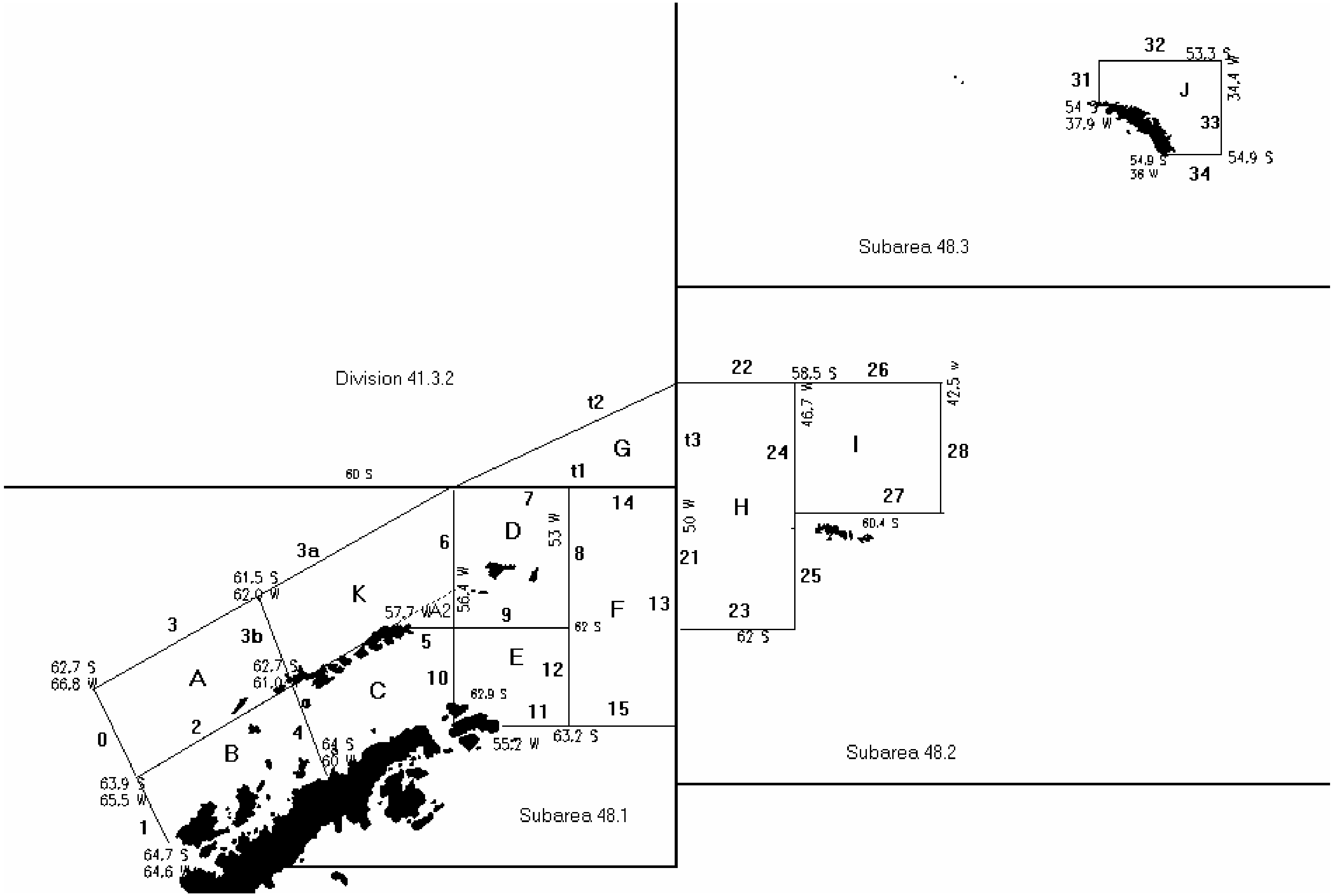

Figure 2: Boxes and boundaries (bold) defined for krill and water flux calculations. Boundary positions are marked.

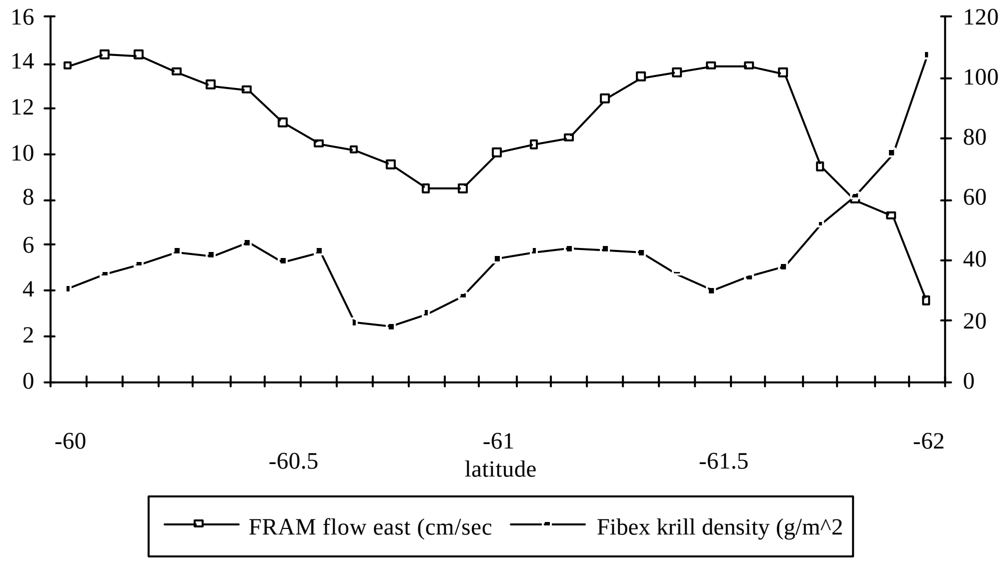

Figure 3: Example of water flow and krill density calculated along a boundary (boundary 8). These data were combined to yield a total flux for that boundary. Left hand y-axis is cm/sec.

ATTACHMENT A

AGENDA

Workshop on Evaluating Krill Flux Factors
(Cape Town, South Africa, 21 July to 23 July 1994)

1. Introduction
   (i) Appointment of Chairman
   (ii) Appointment of Rapporteurs
   (iii) Adoption of the Agenda

2. Review of Data and Analyses
   (i) Krill Acoustic Data Specified in Appendix D (SC-CAMLR-XII, Annex 4)
   (ii) FRAM Oceanographic Data Specified in Appendix D (SC-CAMLR-XII, Annex 4)
   (iii) Primary Oceanographic Data
   (iv) Additional Data and Analyses

3. Composite Flux Analysis
   (i) Subarea 48.1
   (ii) Subarea 48.2
   (iii) Subarea 48.3

4. Implications and Recommendations to WG-Krill

5. Close of Meeting.

ATTACHMENT B

LIST OF PARTICIPANTS

Workshop on Evaluating Krill Flux Factors
(Cape Town, South Africa, 21 July to 23 July 1994)

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LIST OF DOCUMENTS

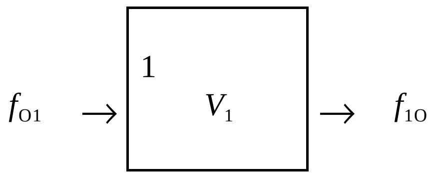
Workshop on Evaluating Krill Flux Factors
(Cape Town, South Africa, 21 July to 23 July 1994)

WS-Flux-94/1	AGENDA
WS-Flux-94/2	LIST OF PARTICIPANTS
WS-Flux-94/3	LIST OF DOCUMENTS
WS-Flux-94/4	ACOUSTIC DATA FOR THE 1994 KRILL FLUX WORKSHOP Secretariat
WS-Flux-94/5	USE OF CURRENT VELOCITY DATA FROM FRAM TO INVESTIGATE THE LARGE SCALE TRANSPORT OF KRILL IN THE SCOTIA SEA E.J. Murphy (UK)
WS-Flux-94/6	LARGE SCALE CIRCULATION IN THE SOUTH ATLANTIC: ESTIMATES FROM GIANT ICEBERG DRIFT RATES P.N. Trathan and C. Symon (UK)
WS-Flux-94/7	COMPARISON OF GEOSTROPHIC VELOCITIES FROM SUBAREA 48.1 William K. de la Mare (Australia)
WS-Flux-94/8	REFERENCE MATERIALS ON STATISTICAL AREA 48 FOR KRILL FLUX WORKSHOP Mikio Naganobu (Japan)
WS-Flux-94/9	STREAM LINES IN THE FRAM VELOCITY FIELD: SPEEDS AND DIRECTIONS FROM PASSIVE TRACERS E.J. Murphy (UK)
WS-Flux-94/10	TRACER TRAJECTORIES FROM THE WESTERN SHELF OF SOUTH GEORGIA: SHIP DISPLACEMENT DATA E.J. Murphy, I. Everson and C. Goss (UK)

ATTACHMENT D

RETENTION/RESIDENCE TIMES

1-BOX SYSTEM - Example



V_1 = volume (e.g., water volume) in box 1 (e.g., km^3)

f_{O1} = input from 'outside' into box 1 (e.g., in km^3/day)

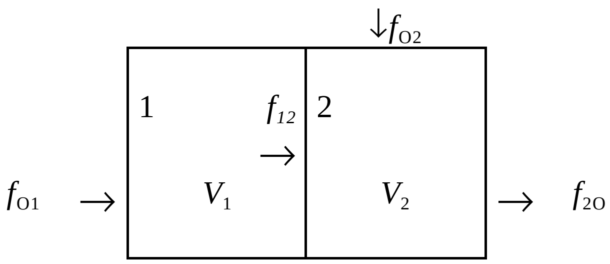
f_{1O} = outflow from box 1 to the 'outside' (e.g., in km^3/day)

The subscript 'O' refers to 'outside'

T_1 = turnover for box 1 = $\dfrac{f_{O1}}{V_1}$

r_1 = residence time in box 1 = $\dfrac{V_1}{f_{O1}}$ (e.g., in days)

2-BOX SYSTEM - Example



*V*s and *f*s as above: all *f*s > 0 (if $f_{ij} < 0 \Rightarrow f_{ji} = -f_{ij}$ to get a positive flow)

r_1 = residence time in box 1 = $\dfrac{V_1}{f_{O1}}$

r_2 = residence time in box 2 = $\dfrac{V_2}{f_{12} + f_{O2}}$

If we ignore the subdivision then the overall R (residence time) is:

$$R = \frac{(V_1 + V_2)}{f_{O1} + f_{O2}} = \frac{V_1}{f_{O1} + f_{O2}} + \frac{V_2}{f_{O1} + f_{O2}}$$

Can we write R in terms of r_1 and r_2?

Yes,

$$R = \frac{V_1}{f_{O1} + f_{O2}} \cdot \left(\frac{f_{O1}}{f_{O1}} \right) + \frac{V_2}{f_{O1} + f_{O2}} \cdot \left(\frac{f_{12} + f_{O2}}{f_{12} + f_{O2}} \right)$$

which can be re-organised as:

$$\begin{aligned} R &= \frac{V_1}{f_{O1}} \cdot \left(\frac{f_{O1}}{f_{O1} + f_{O2}} \right) + \frac{V_2}{f_{12} + f_{O2}} \cdot \left(\frac{f_{12} + f_{O2}}{f_{O1} + f_{O2}} \right) \\ &= r_1 \underbrace{\left(\frac{f_{O1}}{f_{O1} + f_{O2}} \right)}_{\text{call this } w_1} + r_2 \underbrace{\left(\frac{f_{12} + f_{O2}}{f_{O1} + f_{O2}} \right)}_{\text{call this } w_2} \\ &= r_1 \cdot w_1 + r_2 \cdot w_2 \end{aligned}$$

where the w_1, w_2 are called pooling weights.

Note:

(i) any weight can be less than or greater than 1 (e.g., if $f_{12} > f_{O1}$ then w_2 will be > 1);

(ii) $R = r_1 + r_2$ only if $w_1 = 1$ and $w_2 = 1$; i.e. residence times in the boxes can only be added directly, that is unweighted, when $f_{O2} = 0$ and $f_{12} = f_{O1}$.

N-BOX SYSTEM: GENERAL CASE

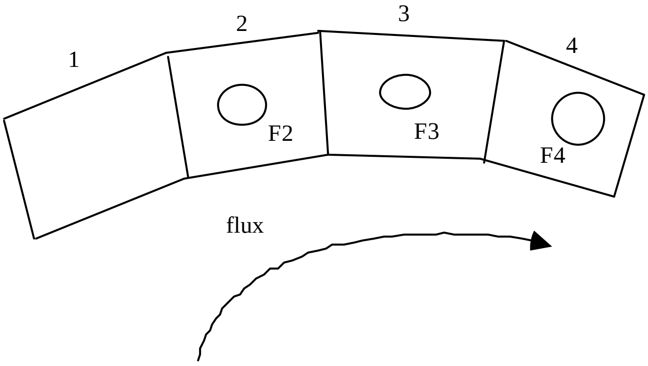
$$R = \sum_{i=1}^{N} r_i \cdot w_i$$

where each $r_i = V_i \Big/ \sum_{j=0}^{N} f_{ji}$

and $w_i = \sum_{j=0}^{N} f_{ji} \Big/ \sum_{j=1}^{N} f_{Oj} = \dfrac{\text{all inputs to box } i \text{ (from 'anywhere')}}{\text{all inputs to the system from OUTSIDE (N boxes)}}$

INITIAL CONSIDERATION OF METHODS TO INCORPORATE KRILL FLUX INTO THE CALCULATION OF CATCH LIMITS

Consider a connected set of n management areas as shown in the figure below, with a net clockwise flux of krill at constant rate f. We wish to find a way of allocating catch limits such that $\sum y_i \leq g \sum_{i=1}^{n} B_i$ where y_i is the limit set in each area and B_i is the unexploited biomass in area i. To illustrate the factors to be considered, let us suppose that areas 2, 3 and 4 each contain one fishing ground at F_2, F_3 and F_4 respectively. Let $\tau_{i,\, i+1}$ be the average time taken for krill to travel from F_I to F_i+1. Let the length of the fishing season be t.



If there is no fishing immediately upstream of F_2 and ignoring production which occurs during the fishing season, the potential yield which can be taken on this ground is given by

$$Y_2 = \gamma f t \qquad (1)$$

By definition the average residence time in area i is

$$T_i = \frac{S_i}{f} \qquad (2)$$

where S_i = stock biomass in area i, and hence

$$Y_2 = \frac{g\, S_2\, t}{T_2} \qquad (3)$$

The estimate can be inflated in the ratio t/T_2. This means, however, that the potential yield from at least part of one or more areas upstream has been allocated to area 2. Therefore upstream areas cannot be fished until upstream of the point where

$$g\sum S_i \geq Y_1 \quad i \subset \{\text{contiguous areas upstream of } 2\} \tag{4}$$

If it is assumed that Y_2 is all taken in fishing ground F_2, then the limit in area 3 is that part of this stock not fished in the span between F_2 and F_3; given by

$$Y_3 = \gamma f \delta_{2,3}$$

where

$$\delta_{2,3} = \tau_{2,3} \quad ; \quad \tau_{2,3} < t$$
$$\delta_{2,3} = t \quad ; \quad \tau_{2,3} = t$$

Similarly

$$Y_4 = \gamma f \delta_{3,4}$$

and so on until the area is reached from which fishing must be excluded in accordance with (4) above. Therefore

$$\sum_{i=1,n} Y_i = gf\sum \delta_{i,i+1} \tag{5}$$

The total yield which we allow to be taken is

$$Y = g\sum B_i \tag{6}$$

which can be written as

$$Y = gf\sum T_i$$

Clearly

$$\sum \delta_{i,i+1} \quad \text{is} \quad \leq \quad \sum T_i$$

and hence

$$\sum y_i \leq Y,$$

which meets the basic requirement.

Now consider what happens if we ignore the effects of flux. Clearly the total yield is still given by equation (6). The yield in area *i* is given by:

$$Y_i = \gamma \cdot S_i \tag{7}$$

For areas 2, 3 and 4, the total yield taking flux into account is

$$Y_{2,3,4} = gf\left(t + \sum_{i=2}^{3} \delta_{i,i+1}\right)$$

C learly if

$$t + \sum_{i=2}^{3} d_{i,i+1} \approx \sum_{i=2}^{4} T_i \qquad \text{(which requires that } T_i < t\text{),} \tag{8}$$

then

$$Y_{2,3,4} \approx gf \sum_{i=2}^{4} T_i \approx g \sum_{i=2}^{4} fT_i$$

and, substituting equation 2,

$$Y_{2,3,4} \approx g \sum_{i=2}^{4} s_i$$

which is the yield calculated if the flux factor is ignored (equation 7). The only component of potential yield missed is due to the difference between the biomass not incorporated from the upstream side and any biomass surveyed downstream of the fishing ground in area 4. This is the approach currently taken for Statistical Area 48 where the approximation given in (8) is assumed to hold.

In summary, if the unmodified rule, i.e. ignoring flux, is used globally, the total precautionary catch limit is correct. If the flux factor is taken into account, some areas may have the catch from upstream areas added into them, with the proviso that no other catches can be taken from those upstream areas. The allowable catch in downstream fishing grounds depends on the average time taken for krill to be transported from the upstream ground to the downstream ground, and whether there is some 'unused' catch from the upstream ground available for catching at the downstream ground. However, given that reliable data on the average time taken for krill to move between fishing grounds is not yet available, and noting that for a series of contiguous areas the overall results from not taking flux into account may not dffer by relatively much, it should be sufficient, but conservative overall, to proceed by making no corrections for krill flux. This is because in contiguous areas, the flux-modified limits may result in changed allocation between areas, but within a total which is only modified by addition from the flux into the one area at the upstream end.

FULL RESULTS FROM THE RE-ANALYSIS OF RECRUITMENT PROPORTION

(paragraph 4.64)

Table F.1: Proportions of recruits for a range of net surveys obtained by fitting mixture distributions (using method of de la Mare, 1994[1]). *R*(1) is the proportion of recruits to the population age 1+.

1-Year-Old Recruitment			
Survey	*R*(1)	Std. Error	CV of Length-at-age
HEFX	0.142	0.0347	0.122
NDFX	0.167	0.0468	0.096
SIFX	0.370	0.0422	0.153
NDS2	0.528	0.0475	0.117
ADBEX1	0.001	0.0010	0.117
ADBEX2	0.016	0.0273	0.087
AAMBER	0.025	0.0174	0.085
AA2	0.314	0.0113	0.150
KROCK	0.064	0.0269	0.103
GER1978	0.043	0.0653	0.074
GER1982	0.936	0.0025	0.100
GER1983	0.937	0.0156	0.105
GER1984	0.114	0.0463	0.114
GER1985	0.027	0.0441	0.095
GER1986	0.317	0.0217	0.113
GER1987	0.863	0.0417	0.152
GER1989	0.057	0.0390	0.095
KMS1	0.001	0.0031	0.100

2-Year-Old Recruitment			
Survey	*R*(2)	Std. Error	CV of Length-at-age
MDFX	0.286	0.0645	0.071
HEFX	0.360	0.1183	0.096
NDFX	0.096	0.0592	0.091
SIS1	0.968	0.0540	0.169
NDS2	0.320	0.0560	0.157
NDS2	0.431	0.0877	0.119
ADBEX1	0.561	0.0851	0.110
ADBEX2	0.557	0.2715	0.084
AAMBER	0.231	0.1300	0.084
AA2	0.556	0.0063	0.083
KROCK	0.020	0.1307	0.095
GER78	0.109	0.1130	0.106
GER84	0.827	0.0557	0.114
GER85	0.099	0.0572	0.064
GER86	0.982	0.0323	0.194
GER89	0.465	0.0370	0.065
KMS1	0.211	0.283	0.106

Table F.2: Summary statistics.

	1+	2+	Combined
Number of estimates	18	17	35
Mean *R* estimate	0.404	0.557	0.415
Standard error	0.012	0.010	0.006
Standard deviation	0.456	0.126	0.442
CV of distribution	1.128	0.226	1.067

Figures demonstrating goodness of fit for each data set are held at the Secretariat.

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1 de la Mare. 1994. Estimating krill recruitment and its variability. *CCAMLR Science*, Vol. 1: 55-69.