KRILL BIOMASS IN AREA 48 AND AREA 58: RECALCULATIONS OF FIBEX DATA

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Abstract

FIBEX acoustic and length frequency data held in the BIOMASS database were used to provide estimates of mean density and biomass for the Indian Ocean sector and the West Atlantic sector as well as for FAO Statistical Area 41, and CCAMLR Subareas 48.1, 48.2, 48.3, 48.6 and Division 58.4.2. Density estimates were calculated using the target strength relationships used at the original FIBEX acoustic workshop. Estimates for the different areas were also calculated using the target strength relationships of Green *et al.* (1990). The new estimates were on average 4.76 times larger than the old estimates for those cruises (seven out of the nine considered) that used an echosounder frequency of 120 kHz.

Résumé

Les données acoustiques et de fréquence des longueurs provenant de la FIBEX et stockées à la banque des données BIOMASS ont fourni les estimations de densité et de biomasse moyennes pour les secteurs de l'océan Indien et de l'Atlantique ouest, de même que pour la zone statistique 41 de la FAO et les sous-zones 48.1, 48.2, 48.3, 48.6 et la division 58.4.2 de la CCAMLR. Les estimations de densité ont été calculées au moyen des rapports de réponse acoustique utilisés lors du premier atelier acoustique FIBEX. Pour les diverses zones, les estimations ont également été calculées à l'aide des rapports de réponse acoustique de Green *et al.* (1990). Les nouvelles estimations étaient en moyenne de 4,76 fois plus élevées que les anciennes estimations des campagnes (sept sur les neuf examinées) qui utilisaient une fréquence d'échosondeur de 120 kHz.

Резюме

Акустические данные и данные по размерному составу криля, полученные в период FIBEX и хранящиеся в базе данных БИОМАСС, были использованы с целью получения оценок средней плотности и биомассы в индоокеанском и западноатлантическом секторах, а также Статистическом районе ФАО 41 и подрайонах 48.1, 48.2, 48.3, 48.6 и Участке 58.4.2 АНТКОМа. Оценки плотности были вычислены используя величины отношения силы цели к длине криля, принятые на первоначальном рабочем семинаре FIBEX по акустике. Оценки по этим районам также были вычислены с

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использованием величин отношений силы цели, приведенных в работе Грина и др. (Green *et al*, 1990). В среднем новые оценки были в 4,76 раза больше старых оценок, полученных в результате рейсов (семь из девяти), в ходе которых использовалась частота эхолота 120кГц.

Resumen

Se utilizaron los datos acústicos y de frecuencia de tallas de FIBEX archivados en la base de datos BIOMASS para obtener valores de la densidad media y biomasa en los sectores del océano Indico y del Atlántico occidental, así como para el Area estadística 41 de la FAO y las Subáreas 48.1, 48.2, 48.3, 48.6 y la División 58.4.2 de la CCRVMA. Los valores de densidad fueron estimados a partir de las relaciones de potencia del blanco utilizadas en el primer taller de acústica de FIBEX. También se calcularon valores para las distintas zonas mediante las relaciones de potencia del blanco de Green *et al.* (1990). Los nuevos valores fueron, en promedio, 4.76 veces superiores a los antiguos valores para aquellas campañas (siete de las nueve consideradas) que emplearon una frecuencia de sonido de 120 kHz.

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1. INTRODUCTION

In 1991 the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) set precautionary catch limits for krill in Statistical Area 48 (Conservation Measure 32/X). These limits were based on calculations undertaken by the Scientific Committee's Working Group on Krill (WG-Krill) (SC-CAMLR, 1991a) using estimates of krill biomass established from results of the First International BIOMASS Experiment (FIBEX) (Anon., 1986).

An important parameter in the estimation of krill abundance from acoustic survey data is acoustic target strength (TS) (*cf.* Miller and Hampton, 1989). Krill TS has recently been re-assessed (Foote *et al.*, 1990) and there is now a general consensus that the TS values used during the FIBEX analysis (reported in Anon., 1986) were too high, thereby resulting in unrealistically low biomass estimates (Everson *et al.*, 1990). WG-Krill has recommended that a revised TS/length relationship should now be used (SC-CAMLR, 1991b) for analysing acoustic survey data.

In order to refine the krill biomass and subsequent yield estimates used to set the precautionary catch limits, SC-CAMLR has requested that the FIBEX data should be re-analysed using the most recent TS estimates (SC-CAMLR, 1991b) (Task 1). This re-analysis should not only calculate krill biomass by statistical subareas within Area 48 (West Atlantic) but should also be extended to other statistical areas, subareas or divisions wherever possible (Task 2). This paper presents the results of these analyses.

2. MATERIALS AND METHODS

The original FIBEX analysis was carried out by the BIOMASS Acoustic Working Group in September 1984. The report of that workshop (Anon., 1986) and other archived material (listed in Anon., 1986 - Appendix I) were used extensively for primary reference. The analysis reported here was undertaken at the BIOMASS Data Centre, British Antarctic Survey, Cambridge, UK.

2.1 Data Availability

A list of areas surveyed by the 11 vessels concerned is given in Table 1. Survey areas in relation to statistical subarea divisions are depicted in Figures 1 and 2.

2.1.1 Length Data

Length frequency data were available from net hauls for all cruises except *Kaiyo Maru* and *Nella Dan*. A single mean length was available for the *Kaiyo Maru* (41.4 mm) (Anon., 1986 - p. 46), but no information was available for the *Nella Dan*.

2.1.2 Acoustic Data

Data were available as the acoustic parameter Mean Volume Backscattering Strength (MVBS) for all cruises except *Odissey* and *Dr Eduardo L. Holmberg*, where krill densities were expressed in tonnes • n mile^2. To ensure that all data were available in equivalent units prior to analysis, MVBS values for these two cruises were calculated following the procedures outlined in Appendix I of this paper. Correspondence with Dr K. Yudanov and Dr W. Tesler (USSR) indicated that the methods described in archived material from Anon. (1986) were appropriate for *Odissey*. Correspondence with Lic. E. Marschoff (Argentina) and a subsequent visit to Argentina by Dr I. Everson (UK) established that the original data from *Dr Eduardo L. Holmberg* could not be used. The original FIBEX acoustic echocharts were therefore examined by Dr A. Madirolas (Argentina) and Dr Everson and the deflection in millimetres determined. These deflections were subsequently converted to MVBS following the approach outlined in Appendix I of this paper.

The *Umitaka Maru* and *Melville* cruises comprised only single transects. These data sets could be used to provide a mean but not a variance and therefore were not included in the calculations of total biomass reported in Anon. (1986). They were not considered further in the present analyses.

The final analyses were based upon a total transect length of 22 131 km, surveyed by nine vessels during the period 16 January to 12 March, 1981.

2.2 Data Analyses Carried Out

Every attempt was made to ensure that the current analyses were comparable with those of Anon. (1986). Wherever possible, the original analysis methodologies and area definitions were used. As a check, the FIBEX results were recreated using original TS values and strata prior to undertaking any analysis with new TS values and area definitions. The analyses themselves were carried out as follows so as to address the two tasks outlined above.

2.2.1 Task (1) - Recalculation of FIBEX Results

Phase 1: Krill densities by individual cruise were calculated and Table VIII in Anon. (1986) was recreated. The TS relationships used by Anon. (1986) and the new relationships specified by WG-Krill (SC-CAMLR, 1991b) were incorporated into separate calculations. This allowed for comparison between the original FIBEX results in Anon. (1986), recalculated results using the original FIBEX TS values and results derived from the new TS values.

Phase 2: Krill densities within strata (where strata were based upon geographic area and were originally defined in Table IX of Anon., 1986) were calculated using the new TS values. Estimates for the overall biomass in the Indian Ocean sector and in the West Atlantic sector were calculated.

2.2.2 Task (2) - Extension of New TS Analysis to Statistical Subareas

Most cruise survey transects ran meridionally and therefore could be allocated to new strata on the basis of longitude (with the exception of *Walther Herwig* where further division on the basis of latitude was necessary). These new strata were assigned to statistical areas or subareas and densities and biomass estimates by area or subarea were calculated.

2.3 Analysis Details

Analyses followed those described in Anon. (1986) (for a full description of their statistical basis see also Jolly and Hampton, 1990).

2.3.1 Length (l) to Weight (w) Relationship

The following length-weight relationship (Anon., 1986 - equation 15) was used to calculate mean weight from length frequency data:

$w = 0.000925 l^{3.55}$ (w in mg, l in mm).

2.3.2 Target Strength (TS) to Length (l) Relationship

The following TS/length relationships were used in the calculation of mean weight density (gm^{-2}) from available MVBS values for the original FIBEX analysis reported in Anon. (1986) and were also used in this report in the recalculations carried out for comparison with the original results. Some of these TS/length relationships are shown in Figure 3.

120 kHz
$TS = 19.9 \log l - 95.7$ (Anon., 1986 - equation 11)

50 kHz
$TS = 19.9 \log l - 90.5$ (Anon., 1986 - p. 46)

200 kHz
The *Kaiyo Maru* mean weight densities reported in Anon. (1986) were derived using a TS value of -68.10 dB for a mean animal length of 41.4 mm for the cruise. Since no length frequency data were available for *Kaiyo Maru*, this TS value was based on information collected during the Second International BIOMASS Experiment (SIBEX). These same values were used to recalculate density estimates for comparison with the original results reported in Anon. (1986).

The new TS/length relationship recommended by WG-Krill (SC-CAMLR, 1991b) is that of Greene *et al.* (1990). This new relationship was used to calculate new mean weight density estimates (gm^{-2}). This TS/length relationship is shown in Figure 3.

120 kHz
$TS = 34.85 \log l - 127.45$ (Greene *et al.*, 1990)

50 kHz

In the absence of new information on krill TS at 50 kHz the method of Greene *et al.* (1990) was used to estimate an adjustment factor (-10 • log(120/50) = -3.80) to provide the following revised TS/length equation at 50 kHz.

$$TS = 34.85 \log l - 131.25$$

The TS/length relationship at 50 kHz given in Klindt and Zwack (1984), which corresponds to a TS of -63.86 dB for a 40 mm krill, was also used for comparative purposes.

$$TS = 0.21l - 72.26 \qquad \text{(Klindt and Zwack, 1984)}$$

200 kHz

No new information was available from experimental studies at 200 kHz. The method of Greene *et al.* (1990) was therefore applied to estimate the appropriate adjustment factor (that is -10 • log(120/200) = + 2.22). This provides a new TS/length relationship at 200 kHz.

$$TS = 34.85 \log l - 125.23$$

For the *Kaiyo Maru*, with a mean animal length of 41.4 mm, this gives a TS of -68.85 dB. This new TS is very close to that used for *Kaiyo Maru* in Anon. (1986).

2.4 Areas and Strata

The area estimates for strata were obtained from Table VIII in Anon. (1986) and with the exception of *Walther Herwig* values were not recalculated (see Table 5 and the discussion below).

In accordance with the procedure outlined in Anon. (1986), strata were defined by cruise unless the areas overlapped. Areas of overlap identified in Anon. (1986) were present in the Drake Passage (*Itzumi* and *Professor Siedlecki* cruises) and the Bransfield Strait (again *Itzumi* and *Professor Siedlecki*).

Stratification of the Bransfield Strait caused few problems. The area covered by each stratum was taken from Table VIII of Anon. (1986). Survey strata were allocated to the "Central Bransfield" area (*Itzumi* Transects 1-16: Area = 24 900 km^2, *Professor Siedlecki* Transects 12-21: Area = 29 100 km^2) and to the "East Bransfield" area (*Itzumi* Transects 17-24: Area = 8 600 km^2).

The definition of strata reported in Anon. (1986) for the Drake Passage was more complex and required the division of individual transects surveyed by the *Professor Siedlecki*, however, the criteria for this division were not recorded. However, the mean density for the three Drake Passage strata calculated from both the *Professor Siedlecki* and the *Itzumi* was 0.39 gm^{-2} (Anon. 1986 - Table IX) compared to 0.39 gm^{-2} for the *Professor Siedlecki* stratum alone (Anon., 1986 - Table VIII). Given this similarity, and the difficulty of objectively dividing the *Professor Siedlecki* transects, the mean density from the *Professor Siedlecki* data was taken as representative of the Drake Passage stratum as a whole. Therefore, *Itzumi* transects falling within the Drake Passage stratum were not included in the area estimation of biomass (see Table 3 below) although they were included in the estimation of biomass by cruise (see Table 2 below).

Only data collected during the daytime were used in analyses by strata. Transect length was calculated by summing the lengths of the relevant echo-integrator[1] intervals. This is in keeping with the original FIBEX approach (Anon., 1986).

2.5 Calculation of Biomass

The mean weight density for each echo-integrator interval was calculated using equation 1 in Appendix II (this report). In the original FIBEX analysis (Anon., 1986) length frequency data from individual net hauls were assigned to specific echo-integrator resets. Since the criteria for such assignments were not archived it was impossible to recreate exactly the results reported in Anon. (1986). To avoid some of the sampling problems highlighted by Watkins *et al.* (1990), the present analyses utilised acoustic data from each stratum together with the combined length frequency distribution from all net hauls (excluding neuston net catches) taken in a cruise. Integrator interval densities were combined for each transect and weighted by echo-integrator reset length using equation 2 in Appendix II (this paper) (Anon., 1986 - equation 3) to provide an estimate for transect density (ρ_k). The mean density by stratum (ρ_A) weighted by transect length, was then calculated using equation 3 in Appendix II (this report), and biomass derived through multiplication by stratum area. The within-stratum density variance was estimated using equation 4 in Appendix II of this paper (Anon., 1986 - equation 4).

As described above, the Central Bransfield Strait was the only stratum in the current analysis where two survey sections overlapped. A single stratum value for (ρ_A) was obtained by combining the individual survey section densities, having weighted these by the inverse of their variance using equations 5 and 6 in Appendix II of this paper.

3. RESULTS AND DISCUSSION

3.1 Task (1) - Recalculation of FIBEX Results

Phase 1: The first task assigned by SC-CAMLR was the recalculation of density and biomass by cruise and region (SC-CAMLR, 1991b). Table 2 shows density by cruise taken from Table VIII of Anon. (1986) compared with results recalculated using the TS/length relationships from Anon. (1986) and the new TS/length relationships recommended by WG-Krill (SC-CAMLR, 1991b). The recalculated densities using the old TS/length relationships were mostly close ($\pm$10.0%) to those reported in Table VIII of Anon. (1986) with the exception of *Itzumi* in the Drake Passage, *Odissey* around South Georgia and *Dr Eduardo L. Holmberg* in the Scotia Sea.

Since the allocation of transects for *Itzumi* and *Odissey* were recreated exactly, it is impossible to determine the exact cause of the large differences observed. It is assumed that only small differences would have been brought about by variations in the krill length frequency distributions within individual nets allocated to particular echo-integrator resets in the analysis reported in Anon. (1986).

For the *Dr Eduardo L. Holmberg* the very large difference may be attributed to the very different methods used for providing density estimates. The original estimate, the derivation of which is described in Anon. (1986) Appendix G, was based upon a conversion factor determined from targeted net hauls. Examination of the details of the method, together with the

[1] The amount of acoustic energy returned from krill for an interval (set either on the basis of time or on distance steamed) of ship's track was measured by analogue or digital echo-integration. MVBS values were then stored in the BIOMASS database for individual Echo-Sounder Distance Units (ESDU) corresponding to specific echo-integrator resets by time or distance.

difficulties of reproducing the calculations, suggested that the method described in Appendix I (this paper), was more reliable and that the associated estimate was probably a better assessment of the biomass in the strata.

By contrast, a much wider range of differences between density estimates using the old TS values and the new TS values are apparent; these varied from 0.98 times for *Kaiyo Maru* to 40.92 times in the case of *Walther Herwig*. For the *Kaiyo Maru*, the similarity can be accounted for by the minor difference between the 200 kHz TS value used in Anon. (1986) and the value derived from Greene *et al.* (1990). For the *Walther Herwig*, the large increase can be accounted for by the major difference between the TS value used in Anon. (1986) and the new value. For a 40 mm krill this reflects a change in TS value at 50 kHz from -58.62 dB to -75.35 dB. The density estimated using the 50 kHz TS value given in Klindt and Zwack (1984) (see above) was somewhere between that from using the TS value given in Anon. (1986) and that from using the value derived from Greene *et al.* (1990), but somewhat closer to the former (see Figure 3). Reservations have been expressed that extrapolating individual TS values to frequencies below 120 kHz may give spurious results (Greene *et al.*, 1990). Furthermore, extrapolation over a wide range of frequencies using an approach similar to that of Greene *et al.* (1990) may result in spurious projections since the backscattering amplitude varies dramatically (Chi *et al.*, 1992). Nevertheless, a new 50 kHz TS value somewhat lower than that used in Anon. (1986) and less than that at 120 kHz appears reasonable.

In the absence of krill length frequency information, it was not possible to recalculate mean weight density estimates for *Nella Dan* (see Table 2). This problem was further compounded by a lack of acoustic data essential to the determination of the coefficients of variation for the recalculated results and for the results using the new TS values. Consequently, new density estimates were not made. However, a multiplication factor was calculated from the ratio of ρ_A [new]/ρ_A [recalculated] from all other cruises using 120 kHz (N = 11 strata from Table 2) and was applied to the results for *Nella Dan* reported in Anon. (1986). The results reported here (see Tables 2, 4 and 6) use the original Anon. (1986) estimates of density and biomass for *Nella Dan* unless otherwise indicated. The same is also true for estimates of the coefficient of variation.

For 120 kHz, the average new mean density estimate is 4.86 times the recalculated estimate using the TS values from Anon. (1986). This difference supports the conclusions of Foote *et al.* (1990) and Everson *et al.* (1990) that the TS values originally used in Anon. (1986) led to significant underestimates of krill biomass. For 120 kHz the mean difference (4.86 times) between the new and old estimates is close to the multiplication factor (5.7 times) used by WG-Krill (SC-CAMLR, 1991a) to account for differences in older TS values (e.g., Anon. 1986) and used by WG-Krill in the conversion of FIBEX biomass estimates to absolute values.

Phase 2: To eliminate problems associated with the estimation of biomass in areas where cruise survey areas overlapped new strata were used (Table 3). Areas of overlap occurred between the *Marion Dufresne* and *Kaiyo Maru* cruises as well as between the *Professor Siedlecki* and *Itzumi* cruises. The recalculated densities using the old TS values are similar to those given in Table IX of Anon. (1986).

The results from combining strata to provide total estimates of biomass for the West Atlantic and Indian Ocean sectors are given in Table 4. Table 4 is comparable with Table X in Anon. (1986). In the West Atlantic the recalculated estimate of biomass using the old TS value is larger (1.5 times higher) than that reported in Anon. (1986), however, the substantial increase in the estimate for the area surveyed by *Dr Eduardo L. Holmberg* largely accounts for this. In comparison, the estimate for the West Atlantic using the new TS values is even higher (8-times higher) and is due solely to the changed TS values. In the Indian Ocean sector the recalculated estimate using the old TS value is very similar to the estimate reported in Anon. (1986), whilst the new estimate is only twice the old figure. The relatively small increase obtained using the new TS values in the Indian Ocean sector is largely due to the very small changes in TS value at 200 kHz.

For the estimates using the new TS values, some of the large difference in the West Atlantic sector is attributable to the large change in TS value at 50 kHz. The *Walther Herwig* surveyed a large area and so even a small difference in TS will exert a large influence on the calculated biomass. In the absence of more precise estimates of TS at 50 kHz and further information concerning the distribution of krill within the area surveyed by *Walther Herwig*, extreme caution needs to be exercised in further interpretation of these particular results. Taken together these uncertainties underline the need for more information on the TS of krill at 50 kHz.

3.2 Task (2) - Extension of New TS Analysis to Statistical Subareas

The second task assigned by SC-CAMLR was the calculation of density and biomass by statistical subarea (SC-CAMLR, 1991b). Most cruise survey transects ran meridionally and hence could be allocated to statistical subareas on the basis of longitude. Part of the *Walther Herwig* survey however, contained transects which extended beyond the limits of CCAMLR Subareas 48.1 and 48.2 into FAO Statistical Area 41. These transect sections were allocated into a new stratum (Table 5).

The overall combined biomass estimates for particular subareas using the new TS relationships are presented in Table 6. These results can be compared with similar estimates for Subareas 48.1, 48.2 and 48.3 undertaken by Everson (1991). Multiplying Everson's biomass indices (Everson, 1991 - Table 2) by the mean density increase (4.86 times) attributable to the most recent TS value from Greene *et al.* (1990) indicates that the current estimate for Subarea 48.3 is more or less directly comparable, the current estimate for Subarea 48.2 is about twice that expected and the current estimate for Subarea 48.1 is about three times that expected. These differences are largely due to two factors, firstly, the large change in TS at 50 kHz, the frequency used by *Walther Herwig* for surveying one of the largest areas of the FIBEX programme and secondly, the large increase in biomass attributable to the area surveyed by *Dr Eduardo L. Holmberg* following recalculation of the MVBS values.

4. SOME IMPLICATIONS ARISING FROM RE-ANALYSIS OF THE FIBEX RESULTS

In carrying out the re-analysis of the FIBEX survey results a number of issues are highlighted. These include:

(i) appraisal of the survey design and whether it was appropriate;

(ii) assessment of the analysis methods reported in Anon. (1986) and whether they were correct, or whether a more suitable method should have been utilised;

(iii) consideration of whether the survey was truly synoptic or whether it actually covered an extended period;

(iv) estimation of whether the survey area was representative of the known distribution of krill and the densities actually observed;

(v) and lastly, estimation of whether the survey area is typical of the areas where the precautionary catch limits were set.

Most easily appraised are the survey design and the correctness of the analysis methods used. The design of the survey is considered unbiased (Anon., 1980) and the method of analysis appropriate (Jolly and Hampton, 1990), to the extent that this method was utilised in this paper for the re-analysis.

That the survey was quasi-synoptic and covered a large area, were attributes that were emphasised by WG-Krill as being important in order to account for krill advection between subareas (SC-CAMLR, 1991a). The start of the FIBEX survey was 16 January 1981 and the end was 12 March 1981 (excluding *Umitaka Maru* and *Melville*) a period of 56 days (Anon., 1986 - Table 1). Within the limitations of a large-scale multi-ship survey this time interval is probably as close as it is possible to get, to a truly synoptic survey for such a large area.

When assessing whether the FIBEX survey is representative of the known distribution of krill and of the densities actually observed, it should be emphasised that the FIBEX survey was limited to only one season and was carried out over a decade ago. In contrast, there are now several national data sets from specific areas within Statistical Area 48 which span a number of years (some of these have been summarised in Everson 1988; Nast *et al.*, 1988; Siegel 1988). In general, it would appear that:

(i) biomass estimates may vary within single surveys depending upon the sampling techniques or interpretation method being applied (e.g., Klindt and Zwack, 1984; Klindt 1986; Nast *et al.*, 1988);

(ii) there may be an order of magnitude in variation of biomass which is attributable to seasonal effects (e.g., Siegel, 1988; Everson, in press); and

(iii) year-to-year variability is hard to assess given that surveys may also have been taken at different times of the season, but for some years it may be substantial, for example, Priddle *et al.* (1988) present evidence of large scale fluctuations in the annual biomass of krill around South Georgia.

When estimating whether the FIBEX survey area is representative of the areas where krill precautionary catch limits were set by CCAMLR, it should be stressed that the area covered by FIBEX is substantially less than that of the CCAMLR subareas (Figures 1 and 2). Furthermore, the FIBEX survey covered areas that were thought to be regions of krill abundance (Anon., 1979). Everson and Goss (1991) have demonstrated that high concentrations are to be found on the shelf, or close to it and this has been confirmed by more recent studies in Subarea 48.1 (Ichii *et al.*, 1991; Marín *et al.*, 1991). This would indicate that most of the krill biomass in Subareas 48.1, 48.2 and 48.3 was within the geographic limits set for the FIBEX survey. This supports the original FIBEX survey strategy, at least in the West Atlantic, which assumed that the areas outside the FIBEX survey were areas that were characterised by low krill abundance (Anon., 1979).

The biomass estimate used to set the precautionary catch limit contained in Conservation Measure 32/X, (SC-CAMLR, 1991a - paragraph 6.54) was based upon the best scientific information then available. The re-analysis undertaken here, however, has highlighted various problems so that there now appears to be some justification in exploring ways to improve upon the current results. Important considerations in this regard are:

(i) whether further large-scale surveys such as FIBEX are necessary; and

(ii) and whether FIBEX results can be more meaningfully applied to specific ecological or fishing areas as opposed to statistical areas or subareas.

ACKNOWLEDGEMENTS

We are extremely grateful to all the nations and individuals who have provided FIBEX data to the BIOMASS Data Centre. We would particularly like to thank Dr K. Yudanov, Dr W. Tesler, Lic. E. Marschoff and Dr A. Madirolas for assistance with validating certain parts of the data set.

The financial and technical support of the British Antarctic Survey and the Natural Environment Research Council (NERC) Computing Services are also gratefully acknowledged. Finally, Denzil Miller would like to thank the Royal Society for financial assistance.

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Table 1: Ships, areas and acoustic frequencies used during FIBEX.

Ship	Country	Area	Echosounder Frequency (kHz)
Walther Herwig	Germany	48	50
Dr Eduardo L. Holmberg	Argentina	48	120
Itzumi	Chile	48	120
Odissey	USSR	48	120
Professor Siedlecki	Poland	48	120
*Melville**	USA	48	50
SA Agulhas	South Africa	48	120
Kaiyo Maru	Japan	58	200
Marion Dufresne	France	58	120
Nella Dan	Australia	58	120
*Umitaka Maru**	Japan	88	120

* Not used in present analysis (see text for explanation).

Table 2: Mean density and biomass estimates from FIBEX acoustic survey cruises, with original BIOMASS results (BIO), recalculated results (OLD) and re-analysis using new CCAMLR TS (NEW). See text for further details. [Transect length in km = TL; area in km^2 = AREA • 10^3; density in gm^{-2} = ρA; biomass in tonnes = Bw • 10^3; coefficient of variation (%) = CV].

Ship/Strata	Transect Number	TL	Area	ρ_A			Ratio ρA	Bw			CV		
				BIO	OLD	NEW	OLD:NEW	BIO	OLD	NEW	BIO	OLD	NEW
Walther Herwig	1-13	3549.5	220.7	1.7	1.7	70.1	40.92	372.0	381.8	15479.2	28.0	27.9	27.9
Dr Eduardo L. Holmberg	1-22	2627.4	83.8	2.8	18.6	82.8	4.45	234.0	1559.4	6937.4	55.0	34.9	34.9
Itzumi (Bransfield)	1-24	1440.9	26.5	32.3	32.6	159.6	4.89	854.0	864.3	4228.7	20.0	19.7	19.7
Itzumi (East Drake)	34-40	313.0	8.3	8.8	13.7	66.9	4.89	73.0	113.5	555.2	94.0	65.0	65.0
Itzumi (West Drake)	26-33	240.08	4.7	24.0	18.8	91.9	4.89	112.0	88.3	432.1	34.0	43.1	43.1
Odissey (South Georgia)	51-58	497.8	25.3	15.6	12.6	59.7	4.76	395.0	317.8	1511.1	38.0	37.9	37.9
Odissey (Scotia A)	1-13	2196.0	68.3	17.3	18.8	89.3	4.76	1185.0	1284.0	6102.5	23.0	20.1	20.1
Odissey (Scotia B)	14-15	322.1	33.3	3.5	3.5	16.8	4.76	115.0	117.3	557.9	7.0	7.5	7.5
Prof. Siedlecki (Bransfield)	12-21	520.4	29.1	4.7	5.2	21.9	4.24	136.0	150.5	638.2	42.0	37.7	37.7
Prof. Siedlecki (Drake)	1-11	2245.9	160.1	0.4	0.4	1.5	4.24	62.0	56.4	239.2	31.0	31.1	31.1
SA *Agulhas*	1-9	3037.3	576.0	1.1	1.2	8.0	6.78	610.0	682.6	4626.4	19.0	22.9	22.9
Marion Dufresne	1-3	1493.1	240.3	0.2	0.2	1.0	4.84	50.5	50.2	242.9	43.0	41.1	41.1
Kaiyo Maru	1-6	1894.6	537.5	4.3	4.4	4.3	0.98	2310.0	2300.0	2230.0	28.0	30.5	30.5
*Nella Dan**	-	3000.2	1091.6	1.5	-	7.1*	4.86*	1578.0	-	7696.9*	38.0	-	-

Difference in <u>TOTAL</u> Bw is ± 2.1%; BIO = 6.27 • 10^6 tonnes; OLD = 6.41 • 0^6 tonnes (excluding *Nella Dan* and *Dr Eduardo L. Holmberg*).

* For *Nella Dan* the NEW ρ_A is derived by multiplying the BIO estimate by the mean incrase due to the new TS value (see text for details).

Table 3: Mean density and biomass estimates for various strata from FIBEX acoustic survey cruises, with original BIOMASS results (BIO), recalculated results (OLD) and re-analysis using new CCAMLR TS (NEW). See text for further details. [Transect length in km = TL; area in km^2 = AREA • 10^3; density in gm^{-2} = ρA; biomass in tonnes = Bw • 10^3; coefficient of variation (%) = Cv].

Ship/Strata	Transect Number	TL	Area	ρA			Bw			CV		
				BIO	OLD	NEW	BIO	OLD	NEW	BIO	OLD	NEW
CENTRAL BRANSFIELD												
Central Bransfield	-	1431.6	24.9	6.3	6.8	28.2	155.9	170.1	703.1	31.0	73.8	88.7
Itzumi	1-16	911.2	24.9	32.3	35.3	172.8	854.6	935.8	4302.2	20.0	22.9	22.9
Prof. Siedlecki	12-21	520.4	29.1	4.7	5.2	21.9	136.0	150.5	638.2	42.0	37.7	37.7
EAST BRANSFIELD												
Itzumi	17-24	529.7	8.6	27.2	28.0	136.9	234.1	240.6	1177.0	41.0	41.5	41.5
DRAKE PASSAGE												
Prof. Siedlecki	1-11	2245.9	160.1	0.4	0.4	1.5	62.0	56.4	239.2	31.0	31.1	31.1
INDIAN OCEAN												
Marion Defresne	2-3	800.2	81.7	0.1	0.1	0.5	8.0	8.7	41.9	45.0	28.2	28.2

Table 4: Mean density and biomass estimates from FIBEX acoustic survey cruises for the West Atlantic sector and the Indian Ocean sector, with original BIOMASS results (BIO), recalculated results (OLD) and re-analysis using new CCAMLR TS (NEW). See text for further details. [Transect length in km = TL; area in km^2 = AREA • 10^6; density in gm^{-2} = ρA; biomass in tonnes = Bw • 10^6; coefficient of variation (%) = CV].

Sector/Strata	TL	Area	ρA			Bw			CV		
			BIO	OLD	NEW	BIO	OLD	NEW	BIO	OLD	NEW
West Atlantic	13399.87	0.63	4.46	6.60	52.33	2.65	4.13	32.71	14.00	23.60	16.67
Indian Ocean	8732.29	2.29	1.97	2.03*	3.74*	4.51	4.63*	8.55*	19.70	24.02*	20.79*

* Uses BIO density and variance estimates for *Nella Dan* - see text for details

Table 5: Mean density and biomass estimates for three strata [Subarea 48.1 (southwest), Subarea 48.2 (east) and Statistical Area 41 (northwest) from FIBEX *Walther Herwig* acoustic survey cruise, using new CCAMLR TS (NEW). See text for further details. [Transect length in km = TL; area in km^2 = AREA • 10^3; density in gm^{-2} = ρA; biomass in tonnes = Bw • 10^3; coefficient of variation (%) = CV].

Ship/Strata	Transect Number	TL	Area	ρA NEW	Bw NEW	CV NEW
Walther Herwig (East)	6-7	773.1	56.5	35.6	2008.7	40.1
Walther Herwig (South West)	1-5 8-13 (South of 60°S)	1892.4	89.4	94.2	8420.4	38.0
Walther Herwig (North West)	1-5 8-13 (North of 60°S)	884.0	74.8	48.9	3657.4	29.6

Table 6: Mean density and biomass estimates for strata combined according to statistical areas and subareas from FIBEX acoustic survey cruises, using new CCAMLR TS (NEW). See text for further details. [Transect length in km = TL; area in km² = AREA • 10^5; density in gm^{-2} = ρA; biomass in tonnes = Bw • 10^6; coefficient of variation (%) = CV].

Area/Subarea/Strata	Ship/Strata	TL	Area	ρA	Bw	CV
41	*Walther Herwig* (North West)	884.0	0.75	48.90	3.66	29.57
48.1	*Walther Herwig* (South West)	6099.5	2.83	37.24	10.54	35.00
	Central Bransfield					
	East Bransfield					
	Drake Passage					
48.2	*Walther Herwig* (East)	5918.6	2.42	64.52	15.61	22.19
	Dr Eduardo L. Holmberg					
	Odissey (Scotia A)					
	Odissey (Scotia B)					
48.3	*Odissey* (South Georgia)	497.8	0.25	59.73	1.51	37.95
48.6	*Agulhas*	3037.3	5.76	8.03	4.63	22.95
58.4.2*	*Marion Dufresne*	5695.0*	17.11*	2.29*	3.93*	32.00*
	Kaiyo Maru					
	*Nella Dan**					

* Uses BIO density and variance estimates for *Nella Dan* - see text for details.

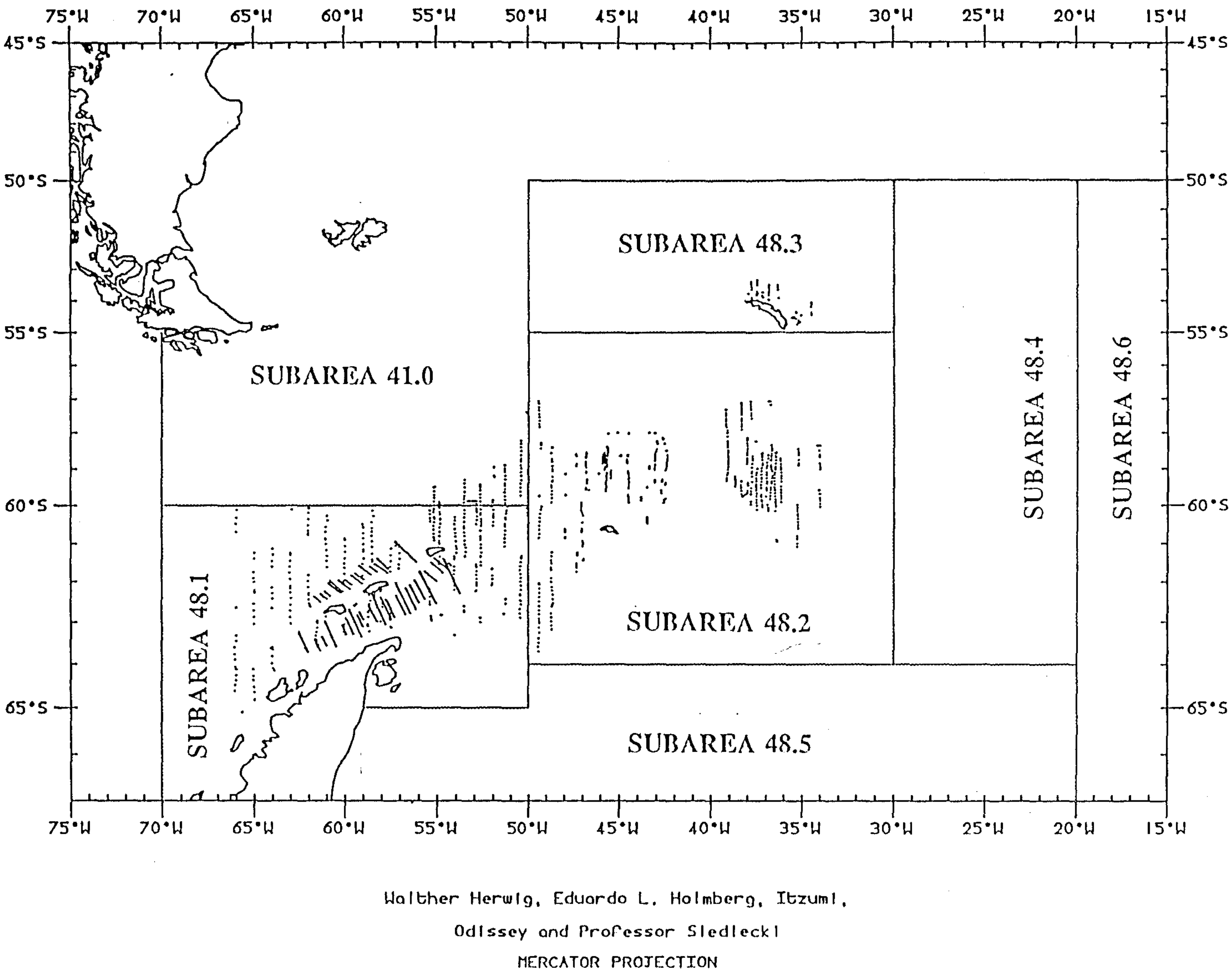

Figure 1: FIBEX survey areas and CCAMLR statistical subareas in the West Atlantic sector.

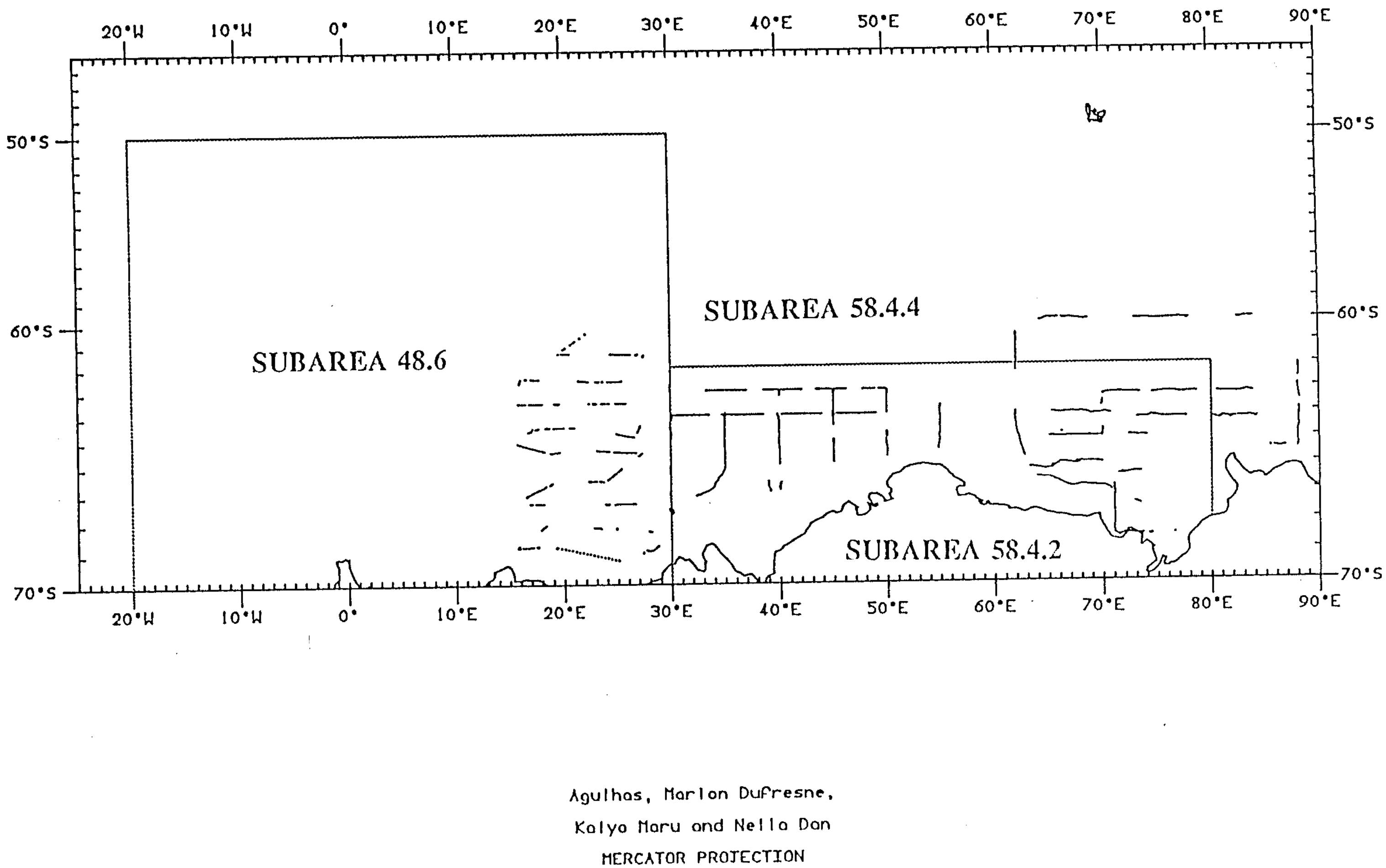

Figure 2: FIBEX survey areas and CCAMLR statistical subareas in the Indian Ocean sector.

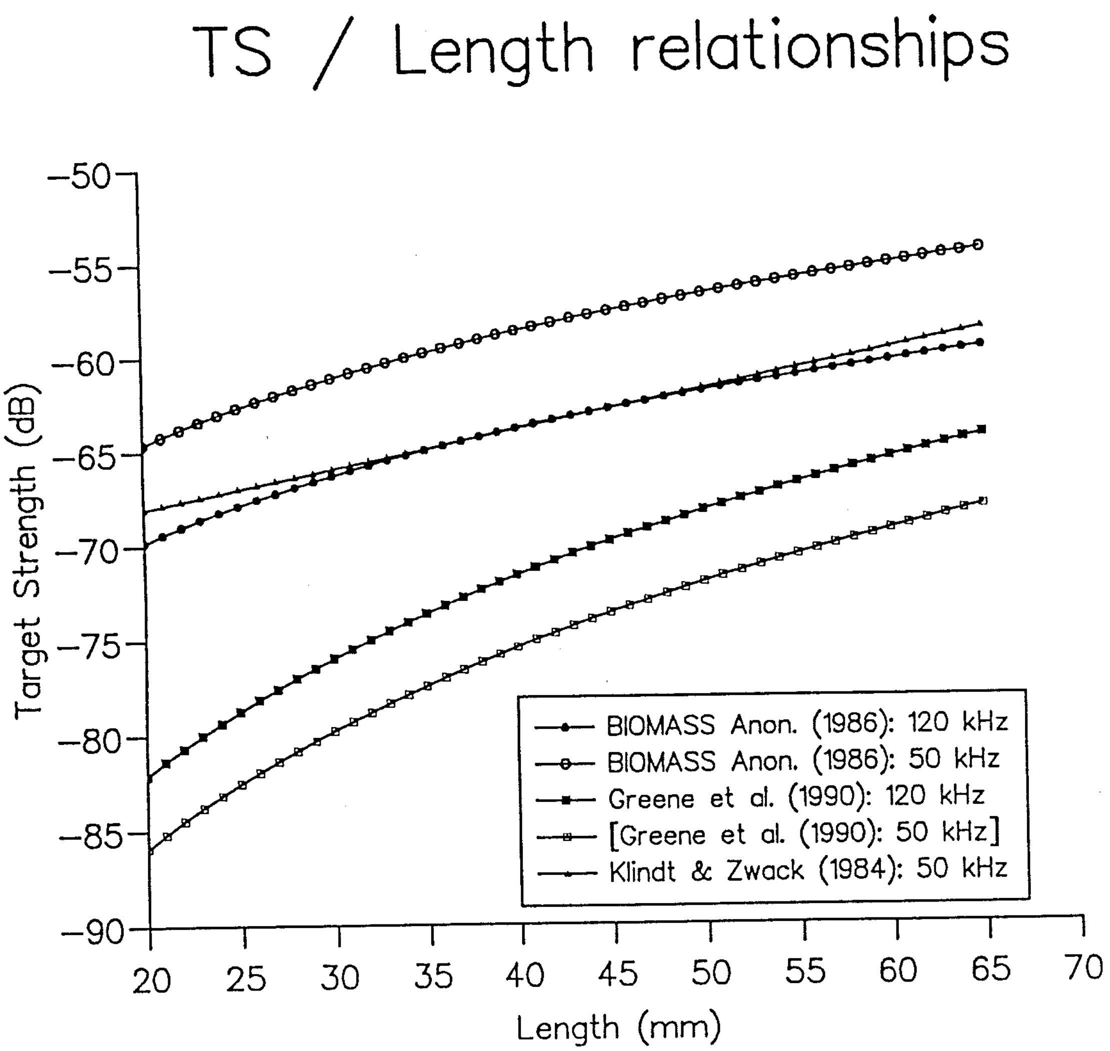

Figure 3: Relationship between krill target strength (TS) and krill length.

Légende des tableaux

Tableau 1: Navires, zones et fréquences acoustiques utilisés pendant la FIBEX.

Tableau 2: Densité moyenne et estimations de biomasse à partir des campagnes d'évaluation acoustique FIBEX, avec les résultats originaux de BIOMASS (BIO), les résultats à nouveau calculés (OLD) et la nouvelle analyse utilisant la nouvelle réponse acoustique CCAMLR TS (NEW). Se référer au texte pour davantage de précisions. [Longueur de la radiale en km = TL; aire en km^2 = AREA x 10^3; densité en gm^{-2} = ρA; biomasse en tonnes = Bw x 10^3; coefficient de variation (%) = CV].

Tableau 3: Densité moyenne et estimations de biomasse de diverses strates à partir des campagnes d'évaluation acoustique FIBEX, avec les résultats originaux de BIOMASS (BIO), les résultats à nouveau calculés (OLD) et la nouvelle analyse utilisant la nouvelle réponse acoustique CCAMLR TS (NEW). Se référer au texte pour davantage de précisions. [Longueur de la radiale en km = TL; aire en km^2 = AREA x 10^3; densité en gm^{-2} = ρA; biomasse en tonnes = Bw x 10^3; coefficient de variation (%) = CV].

Tableau 4: Densité moyenne et estimations de biomasse à partir des campagnes d'évaluation acoustique FIBEX pour les secteurs de l'Atlantique Ouest et de l'océan Indien, avec les résultats originaux de BIOMASS (BIO), les résultats à nouveau calculés (OLD) et la nouvelle analyse utilisant la nouvelle réponse acoustique CCAMLR TS (NEW). Se référer au texte pour davantage de précisions. [Longueur de la radiale en km = TL; aire en km^2 = AREA x 10^6; densité en gm^{-2} = ρA; biomasse en tonnes = Bw x 10^6; coefficient de variation (%) = CV].

Tableau 5: Densité moyenne et estimations de biomasse pour trois strates [sous-zone 48.1 (sud-ouest), sous-zone 48.2 (est) et zone statistique 41 (nord-ouest)] à partir de la campagne d'évaluation acoustique du *Walther Herwig* de la FIBEX, en utilisant la nouvelle réponse acoustique CCAMLR TS (NEW). Se référer au texte pour davantage de précisions. [Longueur de la radiale en km = TL; aire en km^2 = AREA x 10^3; densité en gm^{-2} = ρA; biomasse en tonnes = Bw x 10^3; coefficient de variation (%) = CV].

Tableau 6: Densité moyenne et estimations de biomasse pour des strates combinées selon les zones et sous-zones statistiques à partir des campagnes d'évaluation acoustique FIBEX en utilisant la nouvelle réponse acoustique CCAMLR TS (NEW). Se référer au texte pour davantage de précisions. [Longueur de la radiale en km = TL; aire en km^2 = AREA x 10^5; densité en gm^{-2} = ρA; biomasse en tonnes = Bw x 10^6; coefficient de variation (%) = CV].

Légende des figures

Figure 1: Secteurs d'étude FIBEX et sous-zones statistiques de la CCAMLR du secteur Atlantique occidental.

Figure 2: Secteurs d'étude FIBEX et sous-zones statistiques de la CCAMLR du secteur de l'océan Indien.

Figure 3: Rapport entre la réponse acoustique (TS) et la longueur du krill.

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RECREATION OF *ODISSEY* AND *DR EDUARDO L. HOLMBERG* MVBS DATA

ODISSEY

Density values (ρ_s) expressed in tonnes • n mile² were used to calculate MVBS values (Sv) following the reverse of the procedure given in archived material from Anon. (1986).

$$Sv = 10 \cdot \log_{10}(\rho_v) + \text{TS}$$

where the following 120 kHz TS/length relationship applies:

$$\text{TS} = 20\log l - 77.2 \ (l \text{ in cm})$$

and

$$\rho_v = \frac{\rho_s}{(3.43 w \Delta R)}$$

and the conversion from n mile² to km² is 3.43 (1.852²), and ρ_v is density in gm^{-2}, ρ_s is density in tonnes • n mile², w is mean weight (g) and ΔR is the integration depth range.

The following constants were used for particular regions:

for South East Scotia Sea:	$w = 0.61$ g, $l = 4.3$ cm
for South Georgia:	$w = 0.36$ g, $l = 3.7$ cm.

DR EDUARDO L. HOLMBERG

The integrator deflections, D, measured from the *Dr Eduardo L. Holmberg* acoustic echocharts archived from the FIBEX cruise were substituted into the following equation (SIMRAD, 1975) and re-arranged to give MVBS (Sv):

$$Sv = 10\log D - 10\log R - SL - VR + TVG - 10\log\psi - 10\log L + 10\log C - G$$

where the QM integrator with a 50 mm full scale deflection required an integration factor, E, of 3.8 in order to convert echogram integration values to 50 mm scale; the integration range (deep - shallow: 100 - 4 = 96 m) is R; the source level, SL, is 215.0 dB; the voltage response, VR, is -108.1 dB; the maximum time varied gain, TVG, is 47.0 dB; the velocity of sound in seawater, c, is 1 500 m s^{-1}; the pulse duration, τ, is 0.6 ms; the beam pattern factor, 10 log ψ is -18.0 dB; the integration distance is L; the conversion factor C, needed to convert the integrator deflection on a 50 mm scale to V^2 per n mile • m^{-1} is 1.54; and the integrator gain, G is 10 dB.

EQUATIONS USED DURING CURRENT ANALYSES OF FIBEX RESULTS

EQUATION 1: MEAN WEIGHT DENSITY PER ECHO-INTEGRATOR INTERVAL

The mean weight density per echo-integrator interval, ρ_i is:

$$\bar{\rho}_i = c\Delta R_i 10^{0.1\bullet\left[(\bar{S}v)_i - D\right]} \frac{\sum_{j=1}^{N} n_j l_j^a}{\sum_{j=1}^{N} n_j l_j^{0.1\bullet B}}$$

where a and c are constants in the length/weight expression:

$$\text{Weight} = c\, l^{\,a} \qquad \text{(a)}$$

and B and D are constants in the TS/length relationship:

$$TS = B \log l + D \qquad \text{(b)}$$

and l is length, ΔR is the depth range (deep - shallow), i is the reset interval, j is the length class, n_j is the number of animals in length class j, Sv is the MVBS. Note also $0.1B = b$ and $10^{0.1D} = d$ where b and d are constants in the equation relating mean reflectivity of scatterers to length (see Anon., 1986 - Appendix A).

EQUATION 2: COMBINATION OF RESET DENSITIES WEIGHTED BY RESET LENGTH

The mean weight density for transect k, ρ_k is:

$$\bar{\rho}_k = \frac{1}{L_k} \sum_{i=1}^{M_k} (\rho_k)_i (D_k)_i$$

where ρ_{ki} is the mean weight density for the i-th reset interval on transect k, M_k is the number of intervals in the k-th transect, D_{ki} is the length of the i-th interval on the k-th transect and the length of the k-th transect, L_k, over which data is selected (i.e., during the daytime), is given by:

$$L_k = \sum_{i=1}^{M_k} (D_k)_i$$

EQUATION 3: MEAN DENSITY BY STRATUM WEIGHTED BY TRANSECT LENGTH

The mean density for a stratum, ρ_A is:

$$\bar{\rho}_A = \frac{\sum_{k=1}^{K} \bar{\rho}_k L_k}{\sum_{k=1}^{K} L_k}$$

Biomass is derived through multiplication by the stratum area. Densities from overlapping strata (i.e., Central Bransfield Strait) were combined with separate density estimates being weighted by the inverse of their variance.

EQUATION 4: VARIANCE OF DENSITY IN STRATUM

The variance of density in a stratum was estimated using equation 4 of Anon. (1986):

$$\mathrm{Var}(\bar{\rho}_A) = \frac{K}{K-1} \frac{\sum_{k=1}^{K} (\bar{\rho}_k - \bar{\rho}_A)^2 L_k^2}{\left(\sum_{k=1}^{K} L_k \right)^2}$$

EQUATIONS 5 AND 6: CALCULATION OF COMBINED MEAN WEIGHT DENSITY FOR OVERLAPPING STRATA

The mean weight density for overlapping strata, ρ_c is:

$$\bar{\rho}_c = \sum_{i=1}^{N} w_i (\bar{\rho}_A)_i$$

where the weight, w_i, for each separate density estimate is:

$$w_i = \frac{\frac{1}{\mathrm{Var}(\bar{\rho}_A)_i}}{\sum_{i=1}^{N} \frac{1}{\mathrm{Var}(\bar{\rho}_A)_i}}$$