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STATUS OF THE FIBEX ACOUSTIC DATA FROM THE WEST ATLANTIC

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Abstract

Data from the FIBEX acoustic survey in the West Atlantic sector have been re-examined to check the consistency of krill abundance estimates derived from different survey vessels. There is a good level of consistency between the results from four of the vessels, *Itzumi, Dr Eduardo L. Holmberg, Odissey* and *Walther Herwig*. While there is an error factor due to the combination of data collected at 50 kHz (*Walther Herwig* survey) with data collected at 120 kHz (all other vessels), it is concluded that this does not materially affect the estimated biomass.

The data from the *Professor Siedlecki* survey do not provide estimates that are consistent with the other surveys. The authors can find no explanation for this difference.

Résumé

Les auteurs ont réexaminé les données de la campagne d'évaluation acoustique du secteur occidental de l'Atlantique pour vérifier la cohérence des estimations de l'abondance du krill dérivées de campagnes d'évaluation de divers navires. Les résultats de quatre de ces navires, l'*Itzumi*, le *Dr Eduardo L. Holmberg*, l'*Odissey* et le *Walther Herwig* présentent un degré de cohérence élevé. Le facteur d'erreur dû au fait que les données collectées à 50 kHz (campagne d'évaluation du *Walther Herwig*) sont combinées aux données collectées à 120 kHz (par tous les autres navires), ne semble pas avoir affecté la biomasse estimée.

Les estimations dérivées des données de la campagne d'évaluation du *Professor Siedlecki* ne sont pas compatibles avec celles des autres campagnes d'évaluation. Les auteurs ne parviennent pas à expliquer cette différence.

Резюме

Данные акустической съемки FIBEX, проведенной в западно-атлантическом секторе Южного океана, были пересмотрены с целью проверки совместимости оценок численности криля, полученных в результате съемок различных судов. Имеется хороший уровень совместимости результатов четырех судов - *Itzumi, Dr Eduardo L. Holmberg, Odissey* и *Walther Herwig*. Несмотря на то, что существует фактор ошибочности, связанный с комбинацией данных, собранных на 50 кГц (съемка *Walther Herwig*), и данных, собранных на 120 кГц (все остальные суда), сделано заключение о том, что это не сказывается существенным образом на рассчитанной биомассе.

Оценки, полученные в результате съемки судна *Professor Siedlecki*, не совместимы с оценками других съемок. Авторы не могут найти объяснения обнаруженным различиям.

Resumen

Se han examinado nuevamente los datos de la prospección acústica FIBEX, realizada en el sector occidental el océano Atlántico, con el objeto de comprobar la coherencia de los cálculos de abundancia del kril obtenidos de la información proveniente de diversos buques de investigación. Existe un buen nivel de coherencia entre los resultados de los buques *Itzumi, Dr. Eduardo L. Holmberg, Odissey* y *Walther Herwig*. Aunque existe un factor de error debido a la combinación de los datos recopilados a 50 KHz (prospección del *Walther Herwig*) con los datos recopilados a 120 KHz (el resto de los buques), se concluye que éste no afecta en gran medida a la biomasa calculada.

Los datos provenientes del *Professor Siedlecki* no conducen a estimaciones coherentes con aquellas de las otras prospecciones. El autor no puede explicar esta diferencia.

Keywords: *E. superba*, krill, biomass, density, West Atlantic, Scotia Sea, FIBEX, BIOMASS, acoustic data, CCAMLR

INTRODUCTION

In 1991 the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) set a precautionary catch limit for Antarctic krill in Statistical Area 48 (Conservation Measure 32/X). This limit was based on calculations undertaken by the Scientific Committee's (SC-CAMLR) Working Group on Krill (WG-Krill) (SC-CAMLR, 1991a - paragraphs 6.31 to 6.66) using estimates of krill biomass obtained from the results of the First International BIOMASS (Biological Investigation of Marine Antarctic Systems and Stocks) Experiment (FIBEX) (Anon., 1986).

At the time the precautionary catch limit was set, SC-CAMLR also requested that the FIBEX acoustic data be re-analysed using recent acoustic target strength (TS) estimates (SC-CAMLR, 1991b - paragraph 3.78). In fulfilling this request, Trathan *et al.* (1992) used new TS estimates derived from Greene *et al.* (1990) which they included in analyses that followed (as closely as possible) the methodology used in the original FIBEX analysis (Anon., 1986).

Although Trathan *et al.* (1992) concluded that the FIBEX acoustic dataset was the best synoptic survey currently available, their re-analysis uncovered a number of uncertainties regarding the status of various parts of the dataset. These included questions regarding the time and position of a number of acoustic integration intervals as well as queries about the parameters and constants used during the data collection. As it is now more than 12 years since the FIBEX data were collected and more than nine years since the Post-FIBEX Acoustic Workshop (Anon., 1986), it is no longer possible to clarify a number of these uncertainties, hence the definitive description of the FIBEX dataset must remain that which was made closest to the time of the data collection (i.e, Anon., 1986). In the absence of the raw acoustic data, the only changes acceptable to Trathan *et al.* (1992) were those that were absolutely necessary, or which were clearly unambiguous. Material archived at the BIOMASS Data Centre was used extensively in order to resolve queries on data collection, whilst errors in time and position were corrected by examining details of speed and course in order to produce a dataset with consistent referential integrity. In this paper, data from the FIBEX acoustic survey in the West Atlantic sector have been re-examined to check the consistency of krill abundance estimates derived from different survey vessels. The dataset as it is described here reflects the version which was distributed by the BIOMASS Data Centre to those nations which contributed to the program.

EXAMINATION OF THE FIBEX DATASET

During this examination of the FIBEX dataset a number of descriptive plots were produced for each cruise. The plots comprise: maps of survey area - one for each cruise (Figure 1); frequency distributions of Mean Volume Backscattering Strength (MVBS) - one for each cruise (Figure 2); and krill density distributions (gm^{-2}) - one for each cruise (Figure 3). Only daytime acoustic data were used, as in Trathan *et al.* (1992), and estimates of density and standing stock have been made in the same manner as described in Trathan *et al.* (1992). The major features for the individual FIBEX cruises are as follows:

Itzumi (Chile) Cruise - Data Collected at 120 kHz

Itzumi covered the Bransfield Strait as well as areas around the South Shetland Islands (Figure 1a). Results from the survey were supplied to the BIOMASS Data Centre as MVBS with an integration interval of 1 852 m. A frequency plot of MVBS (Figure 2a) shows a large number of values at -100 dB, which is an arbitrary figure representing almost zero density. Other MVBS values representing a density above zero show a nearly normal distribution with a mode between -75 and -70 dB. For *Itzumi*, the biomass within the area showed a very patchy distribution with a number of integration intervals having a very high density (Figure 3a). As the acoustic integration interval adopted by the *Itzumi* was different to that used by other cruises, the plot of density distribution (Figure 3a) can only be used to examine the distribution within the *Itzumi* cruise and not used for comparison with other cruises.

No problems have been found for the *Itzumi* acoustic data, and use of the 120 kHz TS estimate derived from Greene *et al.* (1990) is considered to be appropriate.

Odissey (USSR) Cruise -
Data Collected at 120 kHz

Odissey covered two adjoining areas within the Scotia Sea as well as the area to the north of South Georgia (Figure 1b). Results from the survey were originally sent to the BIOMASS Data Centre expressed as tonnes n mile^{-2} with an integration interval of 9 760 m; however, for the re-analysis carried out by Trathan *et al.* (1992), data were required to be expressed as MVBS. Following correspondence with Drs K. Yudanov and W. Tesler, Trathan *et al.* (1992) concluded that the appropriate methods for converting the data to MVBS were those that were described in archived material from Anon. (1986) and presented in Trathan *et al.* (1992), Appendix 1. A frequency plot of MVBS shows a nearly normal distribution with a mode of -70 to -65 dB (Figure 2b). The biomass within the area shows a patchy distribution (Figure 3b) with a number of high density values. The high densities are mainly concentrated within one of the Scotia Sea survey areas.

Following conversion to MVBS, no further problems have been found for the *Odissey* acoustic data. Use of the 120 kHz TS estimate derived from Greene *et al.* (1990) is considered to be appropriate.

Walther Herwig (Germany) Cruise -
Data Collected at 50 kHz

Walther Herwig covered the area to the east of Elephant Island (Figure 1c) and the survey results were supplied to the BIOMASS Data Centre expressed as MVBS with a modal integration interval of 11 112 m. A frequency plot of MVBS shows a nearly normal distribution, with a mode of -85 to -80 dB (Figure 2c). The biomass shows a patchy distribution with a number of very high density values. The high densities lie mainly to the south of Elephant Island (Figure 3c).

No problems have been found for the *Walther Herwig* data, but the use of the 50 kHz TS estimate derived from Greene *et al.* (1990) must be considered with some caution. This warning is based upon reservations about the extrapolation of individual TS values, particularly where the wavelength is greater than the bodylength of the scatterer (MacLennan and Simmonds, 1991). Extrapolation to other frequencies using an approach similar to that of Greene *et al.* (1990) can result in spurious projections, since the backscattering amplitude varies dramatically (Chi *et al.*, 1992), having frequency-dependent peaks.

Given these reservations, an alternative means of determining a 50 kHz TS estimate would be preferable. One alternative method would be to apply an empirical correction based on the differences found in the field for the MVBS value found at 50 kHz and the value found at a separate frequency. However, in the absence of new experimental information at 50 kHz, this is not possible.

At 38 kHz, where new experimental information is available, it is possible to compare the theoretical extrapolation of Greene *et al.* (1990) with an empirical correction. Using 38 kHz and 120 kHz, Madureira *et al.* (1993) and Everson *et al.* (1993) found an MVBS difference of -5 dB, Hampton (1990) found a difference of -7 dB, and Foote *et al.* (1990) a difference of between -6 and -11 dB. In comparison, the theoretical projection of 38 kHz and 120 kHz using the method of Greene *et al.* (1990) produces an MVBS difference of -5 dB. The wide range of empirical corrections found at 38 kHz suggests that this method should also be considered with some caution. However, the congruence between the theoretical projection and a number of the estimates does suggest that the method of Greene *et al.* (1990) may be acceptable.

To carry out the analysis of the FIBEX acoustic data, Trathan *et al.* (1992) found it necessary to derive a new 50 kHz TS estimate. In the absence of new experimental information and in order to be consistent with the methods used for the rest of the FIBEX dataset, a theoretical correction using the method of Greene *et al.* (1990) was used.

Dr Eduardo L. Holmberg (Argentina) Cruise - Data Collected at 120 kHz

Dr Eduardo L. Holmberg covered those areas of the Scotia Sea to the west and north of Coronation Island (Figure 1d). Survey results were originally sent to the BIOMASS Data Centre expressed as tonnes n mile^{-2} with a modal integration interval of 3 706 m. Therefore, prior to the re-analysis carried out for the 1992 meeting of WG-Krill, correspondence was exchanged with Dr E. Marschoff in an attempt to convert the data to MVBS. This was only partially successful, and more recently, one of us (Dr I. Everson) in conjunction with Dr A.O. Madirolas used the original *Dr Eduardo L. Holmberg* acoustic chart rolls to measure millimetres deflection and hence directly calculate MVBS (Everson and Madirolas 1993). It should be noted that the expression for MVBS used by Everson and Madirolas (1993) and reported in Appendix 1 of Trathan *et al.* (1992) contains a typographic error, in that the term $10log_{10}(ct/2)$ has been omitted. The new MVBS values derived from Everson and Madirolas (1993) produce estimated densities which are much greater than previous estimates for the cruise; however, the method employed by Everson and Madirolas (1993) and recommended by Trathan *et al.* (1992) is consistent with the methods used for the other FIBEX cruises and is preferred to the original net calibration (Anon., 1986 - Appendix G). A frequency plot of MVBS shows a nearly normal distribution, with a mode of -70 to -65 dB (Figure 2d). The biomass distribution within the survey area was very patchy with a number of very high density values (Figure 3d). The high densities were found mainly to the west of Coronation Island.

No further problems were found following the conversion of the *Dr Eduardo L. Holmberg* data, and use of the 120 kHz TS estimate derived from Greene *et al.* (1990) is considered to be appropriate.

Professor Siedlecki (Poland) Cruise - Data Collected at 120 kHz

Professor Siedlecki covered areas within the Bransfield Strait and Drake Passage (Figure 1e). Acoustic data were supplied to the BIOMASS Data Centre as MVBS values for individual aggregations. These aggregations were combined during the Post-FIBEX Acoustic Workshop (Anon., 1986) in order to provide MVBS values for 1-hour intervals. These combined MVBS values were stored in the BIOMASS dataset. A frequency plot of MVBS shows a markedly skewed distribution (Figure 2e), with no separation between the arbitrary MVBS value representing zero density and the rest of the distribution. A plot of biomass within the survey area shows a patchy distribution with the highest values closest to the South Shetland Islands (Figure 3e). Unlike the other FIBEX cruises, however, there are no very high values and all of the density values are less than 300 gm^{-2}.

Unlike all other cruises, *Professor Siedlecki* integration intervals were based upon time rather than distance steamed. Further, the integration time used by *Professor Siedlecki* was long (one hour), hence reducing the resolution of the dataset.

The use of the 120 kHz TS estimate derived from Greene *et al.* (1990) is considered to be appropriate.

DISCUSSION

There has been a substantial increase in the estimate for the standing stock of krill in the West Atlantic since the original FIBEX assessment (Anon., 1986). This is attributable to, firstly, the change in TS used for all cruises (Greene *et al.*, 1990) and, secondly, to the change in methodology used to calculate MVBS for *Dr Eduardo L. Holmberg* (Everson and Madirolas, 1993). The estimated mean density and biomass from the different cruises are summarised in Table 1. These estimates, apart from the estimate from *Dr Eduardo L. Holmberg* which is now considerably higher, are the same as those presented at the 1992 meeting of WG-Krill. Following the change to the *Dr Eduardo L. Holmberg* estimate, the analysis presented in WG-Krill-92/20 was updated before publication in *Selected Scientific Papers, 1992 (SC-CAMLR-SSP/9)* (Trathan *et al.*, 1992).

All the surveys indicate that the distribution of krill was extremely patchy throughout the FIBEX survey area. This conclusion is consistent with previous studies on krill distribution. The ranges of krill density values from the *Itzumi*, *Dr Eduardo L. Holmberg* and *Odissey* surveys are broadly similar, while the *Walther Herwig* survey includes a small number of very high values. The *Professor Siedlecki* survey provided no high values and the estimated densities generally appeared low when compared with the other survey results.

Table 1: Estimated krill density and krill biomass from the FIBEX acoustic survey in the West Atlantic.

Vessel/Stratum	Area (km^2 * 10^3)	Transect Length (km)	Density (A) (gm^{-2})	Biomass (tonnes * 10^3)	CV (%)
Walther Herwig	220.7	3 549.5	70.1	15 479.2	27.9
Dr Eduardo L. Holmberg	83.8	2 627.4	82.8	6 937.8	34.9
Itzumi (Bransfield Strait)	26.5	1 440.9	159.6	4 228.7	19.7
Itzumi (East Drake Passage)	8.3	313.0	66.9	555.2	65.0
Itzumi (West Drake Passage)	4.7	240.8	91.9	432.1	43.1
Odissey (South Georgia)	25.3	497.8	59.7	1 511.1	37.9
Odissey (Scotia Area 1)	68.3	2 196.0	89.3	6 102.5	20.1
Odissey (Scotia Area 2)	33.3	322.1	16.8	557.9	7.5
Professor Siedlecki (Bransfield Strait)	29.1	520.4	21.9	638.2	37.2
Professor Siedlecki (Drake Passage)	160.1	2 245.9	1.5	239.2	31.1
Central Bransfield (Combined stratum)	24.9	1 431.6	28.2	703.1	88.7
East Bransfield	8.6	529.7	136.9	1 177.0	41.5
West Atlantic	625.0	13 399.9	52.3	32 707.0	16.7

The highest values from the *Walther Herwig* survey were all concentrated around 61°S, 55°W adjacent to Elephant Island. This is an area where a 'super-swarm' of krill was reported around the time of the FIBEX survey (Mathisen and Macaulay, 1983; Macaulay *et al.*, 1984). The survey reported by Mathisen and Macaulay (1983) was not carried out in a manner that allowed a biomass estimate of the 'super-swarm' to be made, however, it is likely that the very high densities reported for this region during FIBEX included parts of the 'super-swarm'. The highest values from the *Itzumi* survey include the area of the Elephant Island 'super-swarm' as well as locations close to the South Shetland Islands which have been the focus of commercial fishing activity in recent years (Everson and Goss, 1991).

Low estimated density values found during the *Itzumi, Dr Eduardo L. Holmberg, Odissey* and *Walther Herwig* surveys tend to relate to areas away from the shelf and over deep water where krill density tends to be low. Even so, an extensive 'larval swarm' was reported from a large part of the *Walther Herwig* survey area (Mathisen and Macaulay, 1983) which could have increased the mean density over the whole area for that survey.

During the 1992 meeting of WG-Krill, questions were asked as to the reasons for the high biomass estimated from the *Walther Herwig* part of the survey relative to the other survey areas (SC-CAMLR, 1992 - paragraph 4.57). The results and analyses presented in this paper indicate that although the biomass estimate from the *Walther Herwig* survey contributed about 80% to the total for Subarea 48.1, the density levels are consistent with those from *Itzumi, Dr Eduardo L. Holmberg* and *Odissey*. This suggests that the difference was real and not due to an error in target strength.

The biomass estimates from the *Professor Siedlecki* survey are very different from those from the other FIBEX cruises and in particular from the *Itzumi*, despite there being a substantial overlap in the two survey areas and an almost complete overlap in their timing, i.e. February 1981. This suggests that there are substantial differences in the results from the two cruises. Problems with the FIBEX analysis of the *Professor Siedlecki* data have been reported previously (Miller and Hampton, 1989); similar problems were revealed by our analyses. It is possible that the combination of aggregations at the Post-FIBEX Acoustic Workshop (Anon., 1986) introduced a number of errors into the data.

Given that the shelf area around the South Shetland Islands has been shown to have a high krill biomass (Everson and Goss, 1991), a high density estimate is to be expected from the *Itzumi* survey. In comparison, a lower density estimate is to be anticipated for the *Professor Siedlecki* survey which extended much further into the Drake Passage where the expected krill biomass is lower. Where *Professor Siedlecki* covered areas similar to those of the *Itzumi* survey, comparable biomass estimates should result; however, this is clearly not the case.

We have considered the possibility that the difference between the *Itzumi* results and the *Professor Siedlecki* results may be partially attributed to an artefact of the processing method. The *Professor Siedlecki* data were integrated over 1-hour time intervals, whereas the data from the *Itzumi* were integrated at 1 n mile intervals. If krill patches were spread out, then the longer integration interval would tend to depress the density value for the higher density intervals without affecting the overall biomass estimate. In order to examine the possibility of such an artefact, we have combined the *Itzumi* data into approximately 1-hour intervals and plotted these (Figure 4) for comparison with the *Professor Siedlecki* data (Figure 3e). Examination of the plots (Figure 3e and Figure 4) indicates that the differences are not the result of an artefact in the processing method.

Whichever way the *Professor Siedlecki* data are examined, they appear to indicate a very much lower density and standing stock than the other four surveys conducted by *Itzumi*, *Dr Eduardo L. Holmberg*, *Odissey* and *Walther Herwig*. We can see no reason for this difference and do not have the basic information to allow a more detailed examination of the results.

CONCLUSIONS

Following a close re-examination of the FIBEX results for the West Atlantic sector, we conclude that there is a good level of consistency between the results from four of the vessels, *Itzumi*, *Dr Eduardo L. Holmberg*, *Odissey* and *Walther Herwig*. While there is a high but unquantifiable possibility of error due to the combination of data collected at 50 kHz (*Walther Herwig* survey) with data collected at 120 kHz (*Itzumi*, *Dr Eduardo L. Holmberg*, *Odissey* and *Professor Siedlecki*), we feel that attempts to combine the data are justified.

The data from the *Professor Siedlecki* survey do not provide estimates that are consistent with the other surveys and we can find no reason for this anomaly.

RECOMMENDATION

Following full validation of the FIBEX data it is not possible to provide a complete dataset without any reservations, however, the dataset is the best quasi-synoptic coverage of the West Atlantic available and is therefore of major importance.

To provide a better and more up-to-date estimate of the krill biomass in the West Atlantic, a new large-scale survey, as recommended by Trathan *et al.* (1992), is probably appropriate.

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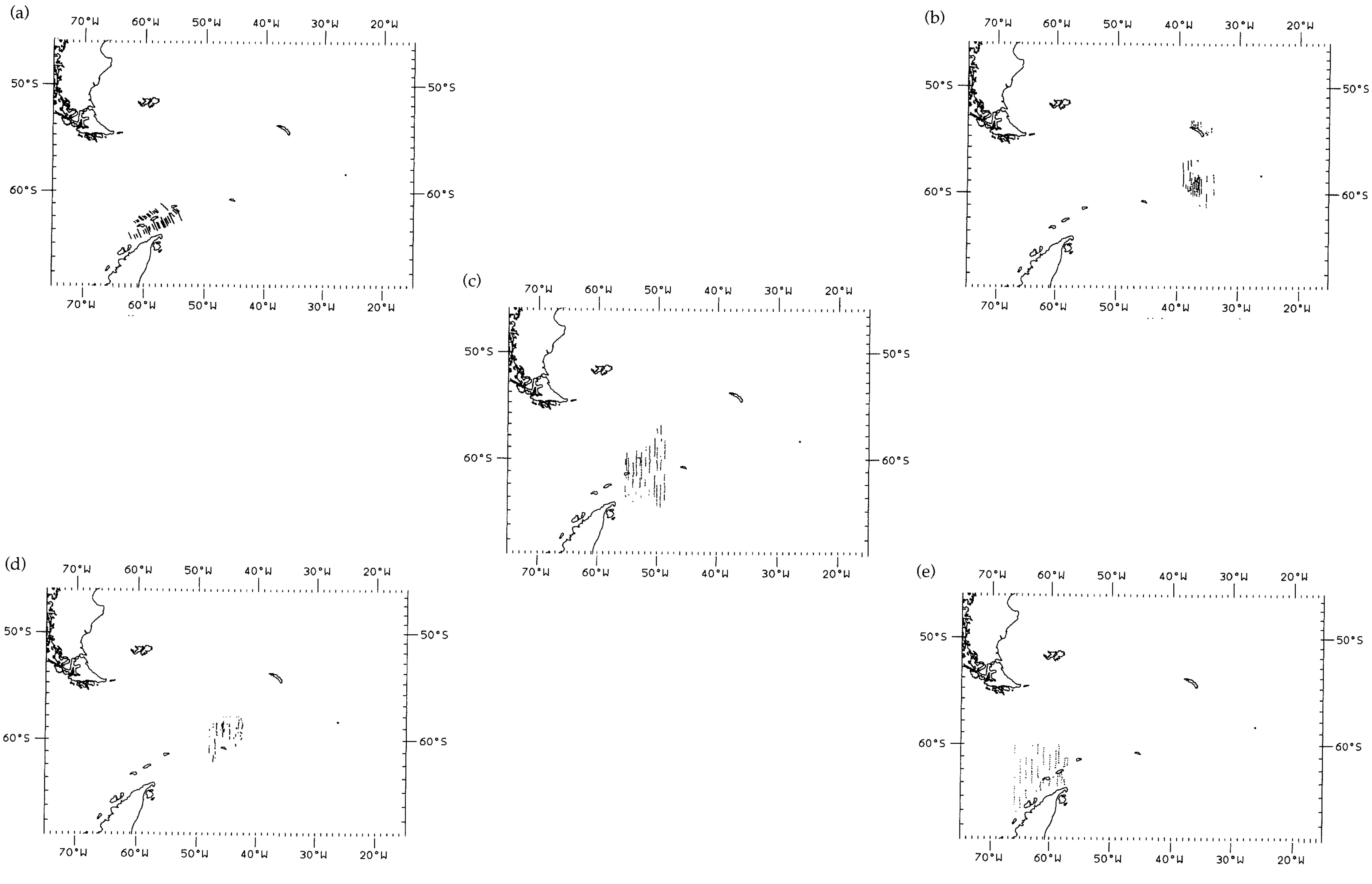


Figure 1: Maps showing positions of daytime survey tracks from FIBEX cruises: (a) *Itzumi*; (b) *Odissey*; (c) *Walther Herwig*; (d) *Dr Eduardo L. Holmberg*; (e) *Professor Siedlecki.*

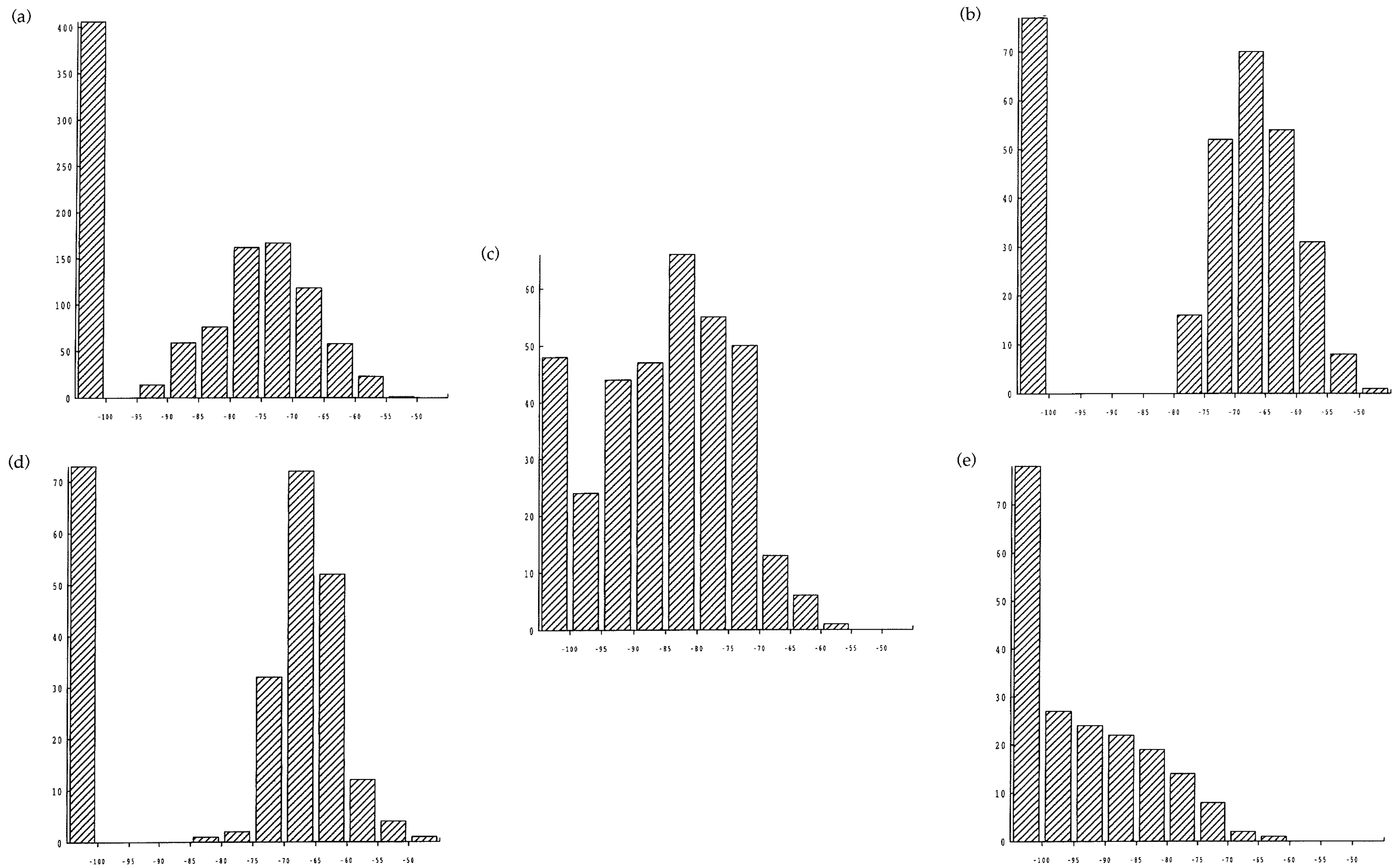
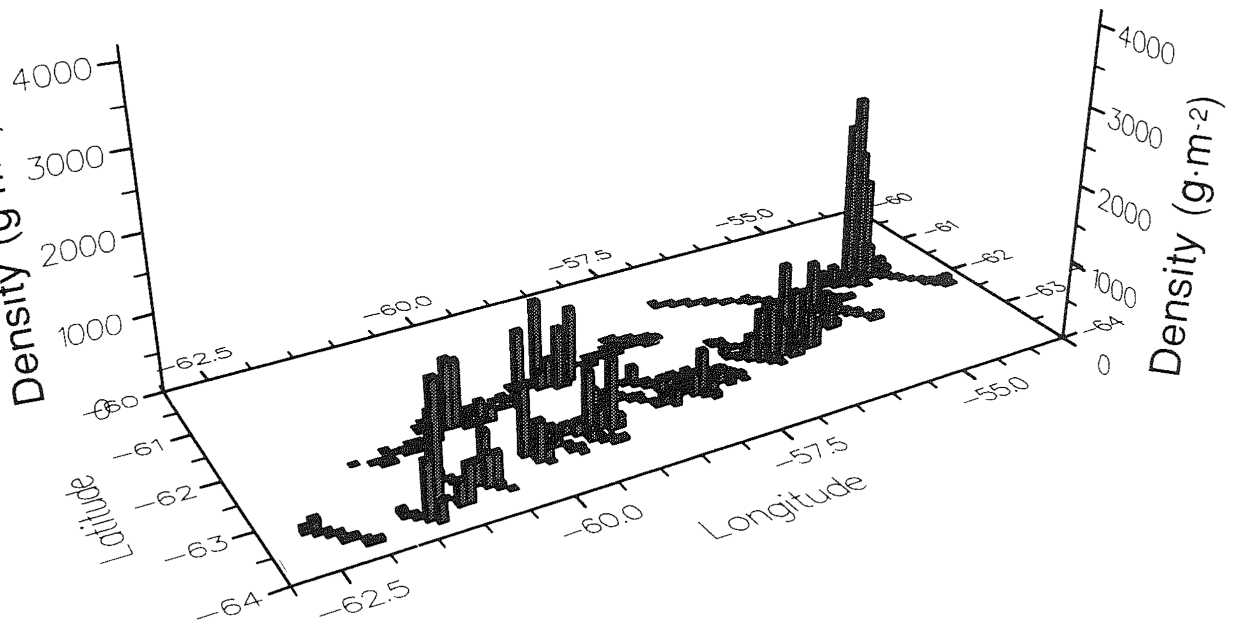


Figure 2: Plots showing distribution of MVBS values for daytime integration intervals from FIBEX cruises (note different vertical axes scale): (a) *Itzumi*; (b) *Odissey*; (c) *Walther Herwig*; (d) *Dr Eduardo L. Holmberg*; (e) *Professor Siedlecki*.

3(a)



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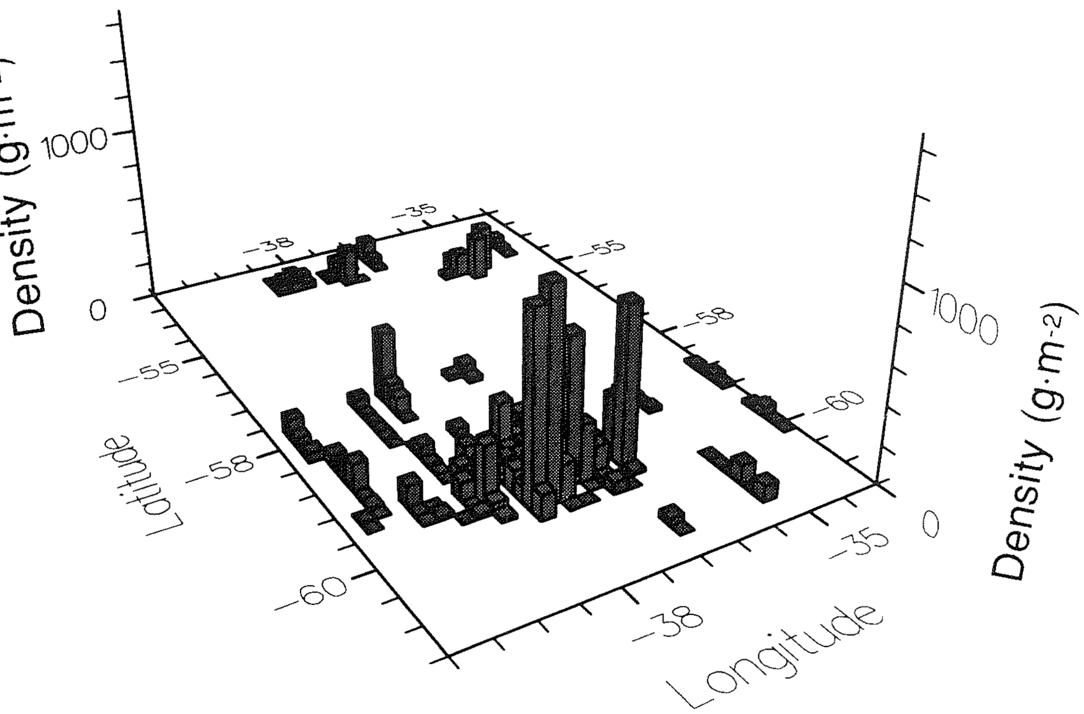
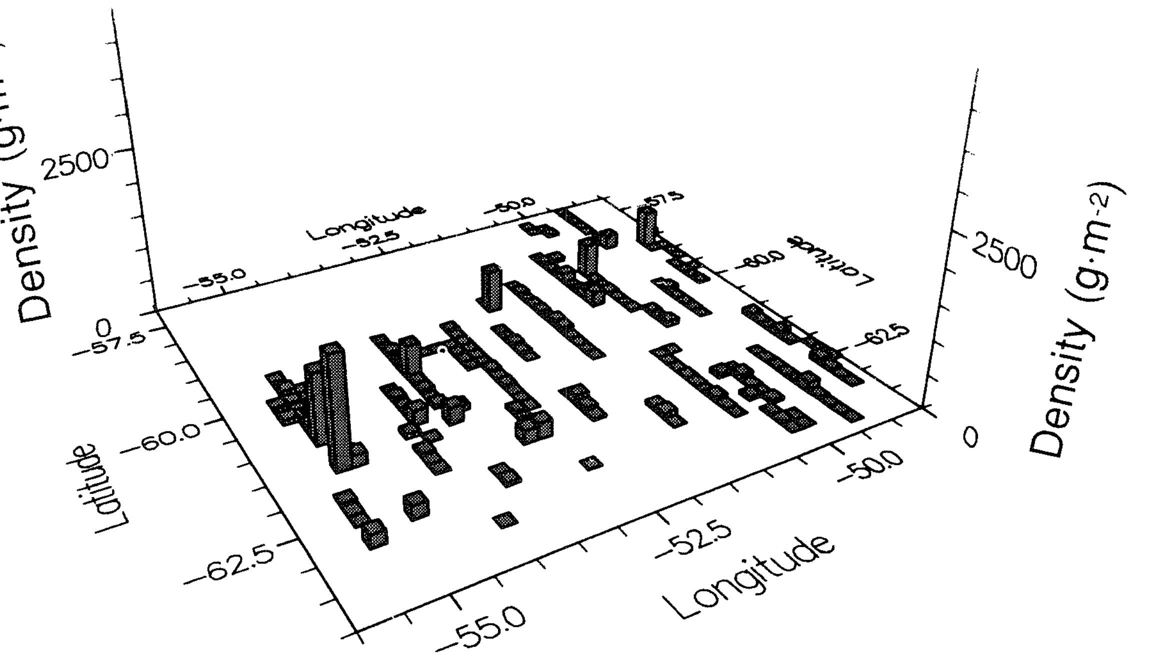


Figure 3: Plots showing distribution of krill density values for daytime integration intervals from FIBEX cruises (note different vertical axes scale): (a) *Itzumi;* (b) *Odissey;* (c) *Walther Herwig;* (d) *Dr Eduardo L. Holmberg;* (e) *Professor Siedlecki.*

3(c)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0
Longitude
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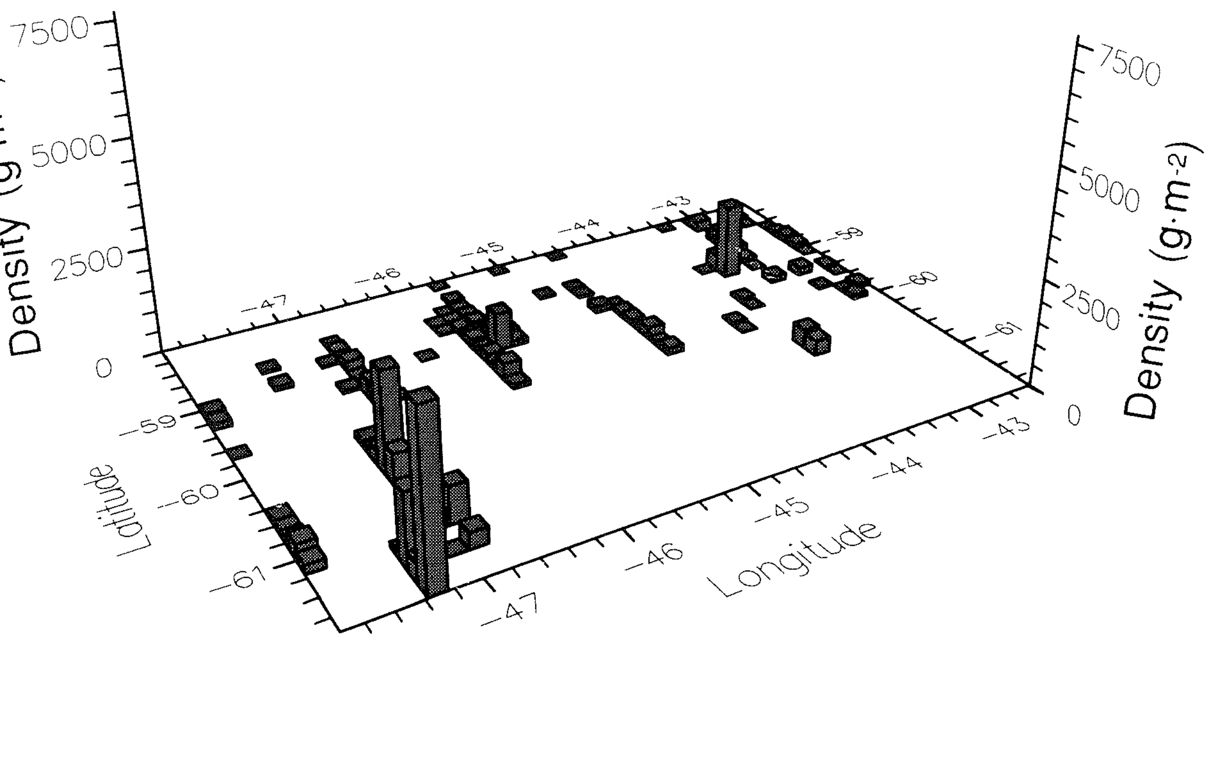
-52.5
-50.0
-57.5
-60.0
-62.5
Latitude
Density (g·m-2)
2500
0
-50.0
-52.5
-55.0
Longitude

3(d)


7500
Density (g·m-2)
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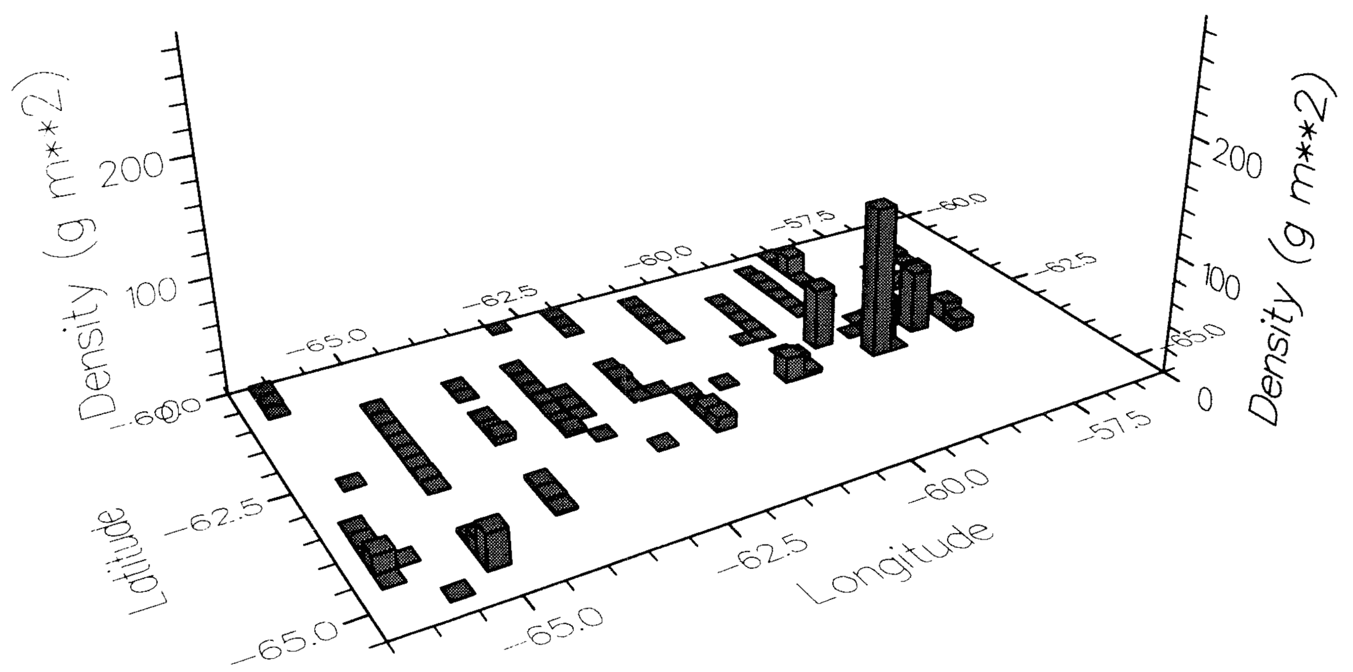
2500
0
-47
-46
-45
-44
-43
-59
-60
-61
Latitude
7500
5000
2500
0
Density (g·m-2)
-43
-44
-45
-46
-47
Longitude

3(e)



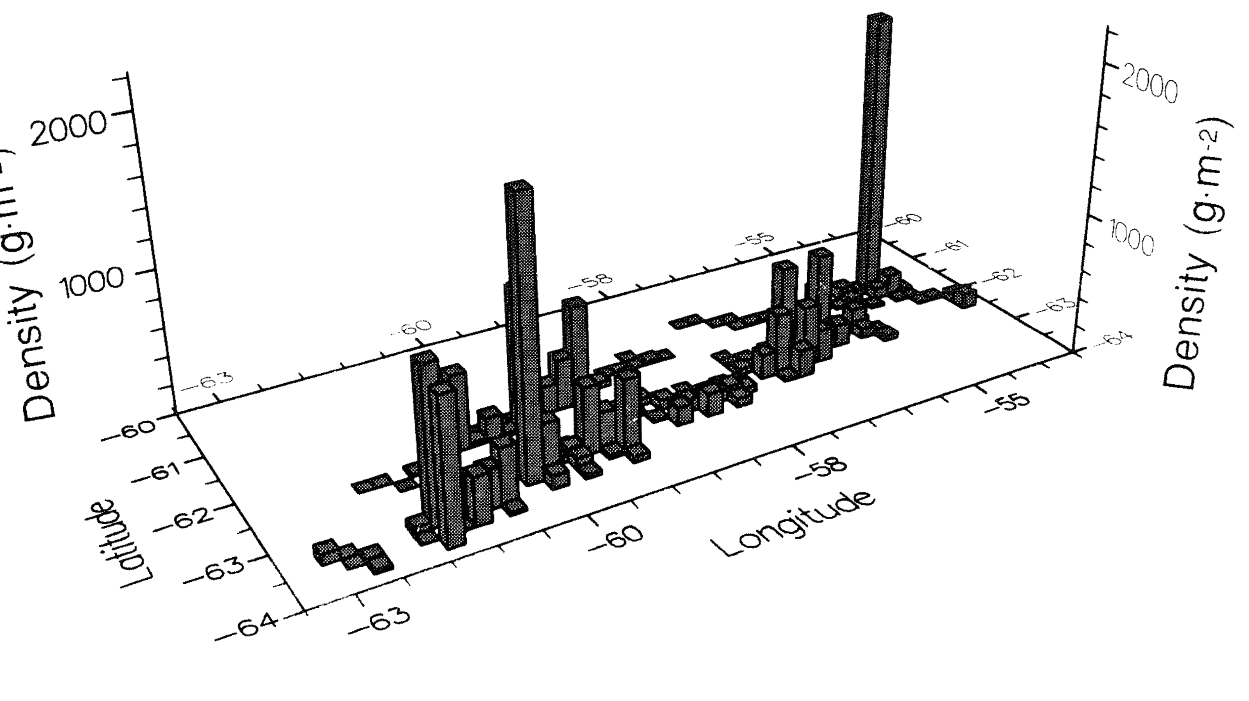


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Figure 2: Tracés indiquant la distribution des valeurs de MVBS (intensité moyenne de rétrodiffusion par volume) pendant la journée, pour les intervalles d'intégration des campagnes FIBEX (noter les différentes échelles des axes verticaux) : (a) *Itzumi*; (b) *Odissey*; (c) *Walther Herwig*; (d) *Dr Eduardo L. Holmberg*; (e) *Professor Siedlecki*.

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Figure 4: Tracés indiquant la distribution des valeurs de densité du krill pendant la journée pour les intervalles d'intégration de l'*Itzumi*, ces données ayant été assignées à des intervalles de une heure.

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