WS-KCPUE-89/6

ANALYSIS AND MODELLING OF THE SOVIET SOUTHERN OCEAN KRILL FLEET, II: ESTIMATING THE NUMBER OF CONCENTRATIONS AND ANALYTICAL JUSTIFICATION FOR SEARCH DATA

M. Mangel

Abstract

In this paper, I show how data that are routinely collected by survey vessels can be used to estimate the number of concentrations of krill (Butterworth, 1988; Mangel, 1988) in a given region of the Southern Ocean. Sample computations are performed, using data collected by Soviet research/survey vessels in the early 1980s. These examples highlight the need for a navigational log as well as a fishing log in order to make accurate inferences. In the appendix, a method for correcting for the bias in the detection of concentrations is described.

Résumé

Dans ce document, je démontre comment des données qui sont habituellement recueillies par les navires de prospection, peuvent être utilisées pour estimer le nombre de concentrations de krill Butterworth (1988), Mangel (1988) dans une région donnée de l'océan Austral. Des exemples de calculs sont faits, utilisant des données recueillies par des navires de recherche/de prospection au début des années 80. Ces exemples soulignent le besoin d'un journal de navigation tout autant que d'un carnet de pêche dans le but de tirer des conclusions précises.

Резюме

В настоящей работе мною показано, каким образом данные, которые регулярно собираются поисковыми судами, могут быть использованы для оценки количества концентраций криля (Butterworth, 1988; Mangel, 1988) в каком-либо определенном районе Южного океана. При выполнении пробных расчетов были использованы данные, собранные в начале 80-х годов советскими научно-исследовательскими и поисковыми судами. Приведенные примеры указывают на то, что для вынесения точных заключений на борту судов должен иметься как навигационный судовой журнал, так и промысловый судовой журнал. В приложении описывается метод внесения поправки на погрешность в обнаружении концентраций.

Resumen

En este documento, muestro como la información recopilada rutinariamente por los navíos de investigación puede usarse para estimar el número de concentraciones de krill (Butterworth, 1988; Mangel, 1988) en una región dada del oceáno Austral.

Cálculos de muestras se realizan usando datos coleccionados por los navíos soviéticos de investigación/estudio al principio de los años 1980. Estos ejemplos subrayan la necesidad de mantener un diario de navegación además de un cuaderno de pesca para hacer deducciones adecuadas.

1. INTRODUCTION

This paper is an extension of Mangel (1989) and complements both that paper and Butterworth (1989), who suggested that krill abundance could be monitored through fishery based data if the data are properly chosen. The distributional model used in those reports was supported by the analysis of field data (Levin et al., 1989); the notation used in the models will be adopted here. In this description, individual krill (spatial scale 50 mm) aggregate into *swarms* of krill (spatial scale 100 m) which then aggregate into *concentrations* of krill (spatial scale 10 nm) in a large sector of the southern ocean (spatial scale 600 nm). Although there remain questions concerning this distributional model and its relation to other data sets (Miller and Hampton, 1988), the preliminary results are sufficiently encouraging to begin considering actual (vs. simulated) abundance estimates from the krill fisheries data.

At the meeting of the Scientific Committee for the Conservation of Antarctic Marine Living Resources in 1988, Dr J.R. Beddington proposed that the Soviet Union provide data from research vessels that can be used to estimate the number of concentrations in a sector of the ocean and that Japan provide data from commercial vessels that can be used to estimate within concentration properties of krill. Both kinds of information are needed to construct abundance indices that are responsive to change in krill abundance and have reasonable variances.

In this paper, I present examples of how research vessel data routinely collected by the Soviet Union could be used to estimate the number of concentrations in a given area. The data used in these examples are the same data analyzed in Mangel (1989). They were not collected with the intent of this estimation, so that additional assumptions are needed in order to construct the estimates. These assumptions are discussed in detail in the next section.

The conclusions are:

- The types of movement by vessels in search for concentrations of krill are important and skippers should record the nature of movement and encounters. Essentially, accurate and effective inference for the number of concentrations requires information from a navigational logbook as well as a fishing logbook.

- There is considerable variability in concentration properties (radius, catch, trawling time); coefficients of variation range between 50% and 100%.

- The distributional model used by Butterworth (1989) and Mangel (1989), in which concentration radii are uniformly distributed between 6 nm and 22 nm may be inappropriate. In particular, the distribution of concentration radii may be skewed, with a long tail, rather than uniform as assumed previously. The difficulty in drawing a conclusion is that there is a bias in detection: the radii of detected concentrations are, on average, larger than the average radius of all concentrations (see Appendix for further details).

- In general, data collected by research or survey vessels (both navigational log-book and fishing logbook information) can be effectively used to estimate the number of concentrations in a sector of the ocean. In particular, there is a need for operational data and logbooks including echo sounder information. A navigational logbook will provide two kinds of data. First, from the navigational log, one can determine whether krill are present in regions between fishing hauls. Second, the navigational log can be used to set the boundaries of the region being searched.

- Using the methods described in this paper, no inferences can be made about stock size regions that are not searched. A Bayesian approach is needed to answer that question.

- In order to determine if concentrations are double counted, it is important to know the temporal persistence of concentrations of krill.

2. THE SEARCH FOR CONCENTRATIONS OF KRILL

The motion between-concentrations (rather than within-concentrations) can be broadly divided into three types:

(i) True search for a new concentration. In this case, the fleet leaves the current concentration and begins true search for another concentration. Here "true search" means that the search path is not highly directed in that the vessel has limited information about where to search. Even if the vessel executes a directed search path, it may be reasonable to expect that the overall search will be random (e.g. Washburn 1981 for justification).

(ii) Direct movement to a new region, followed by true search. In this case, the fleet exits the current concentration and moves directly to a new region (e.g. a historically known fishing ground) and then begins a true search within this new region. That is, the initial movement of the vessel is directed, based on specific information about where to search. The total time between concentrations then consists of a portion corresponding to directed motion (in which concentrations may be discovered accidentally) and a portion corresponding to true search.

(iii) Following oceanographic conditions. Since krill swarms may move passively according to prevailing currents, a fleet might simply follow an existing concentration as it is advected by the current.

3. SOURCES FOR DATA AND DESCRIPTION OF ANALYSIS

The data used here are the same as in Mangel (1989) and correspond to research vessel (RV) cruises between 1980 and 1984.

The pertinent information for these analyses are:

(i) vessel location at the start of trawling;
(ii) time of the start of trawling;
(iii) time of end of trawling; and
(iv) krill catch.

Each combination of location, start and end times and catch is called a record.

From these, we can compute the time between trawls (TBT) and movement between trawls (MBT). Mangel (1989) analyzed 12 different data sets; four of these were selected for further analysis in this paper. They are listed in Table 1. The approximate areas of the survey are shown in Figure 1.

4. PRELIMINARY ANALYSIS: SPATIAL LOCATION OF HAULS

Since the data used here were not explicitly collected for the purpose of estimating the number of concentrations, there is no indication in the data of the type of movement, as described above, or whether the vessel moved into a new concentration or encountered concentrations during transit. Thus, before any estimation procedures were applied, the data had to be analyzed to determine the number and location of concentrations. Figures 2 to 5 show the spatial location of hauls, ignoring the timing of hauls, for each of the data sets. In these plots, hauls were separated into those less than 1 000 kg of krill and those greater than or equal to 1 000 kg of krill. Although these figues give a sense of the spatial location of survey activities (e.g. hauls may be along the shelf edge or follow the ice edge), they do not give any temporal sense of the hauls. In order to do that, one must adopt rules for defining concentrations.

5. DEFINING CONCENTRATIONS BY VESSEL MOVEMENT

In the distribution model used by Butterworth (1989) and Mangel (1989), the radius of a concentration is uniformly distributed over (5.6 nm, 11.2 nm). This means that the maximum diameter of a concentration is about 22 nm and thus a movement of 50 nm corresponds to twice the maximum diameter of a concentration. Hence, the following rule was adopted for the analysis

> New Concentration Rule: When the vessel moved more than 50 nm between trawls, I assumed that the vessel moved to a new concentration.

Given this rule, it is possible to divide each data set into groups of records corresponding to fishing in different concentrations. From the records in each concentration, we can construct the east-west extent and north-south extent of the concentration and thus estimate the area of the concentration. One degree of latitude is assumed to be 60 nm and one degree of longitude is assumed to be 30 nm.

Figures 6 to 9 show the results of the application of the rule concerning movement to a new concentration. In some cases (e.g. Figure 6 or Figure 9) nearly all hauls were made in a concentration and the path of the vessel between concentrations can be visually determined simply by considering the concentrations defined by the 50 nm rule. In other cases (e.g. Figure 7 or Figure 8), vessel movement between concentrations is indicated as well.

Corroborative data for the 50 nm rule can be obtained by considering vessel speed between hauls. One would expect that this speed would be larger between concentrations (assuming random search) than within concentrations. For example, for the data from RV *Odyssey* in 1981, the average vessel speed between concentrations determined by the 50 nm rule is 4.8 kt (σ=5.3) and the average vessel speed within concentrations is 1.8 kt (σ=3.0). Application of the Mann Whitney U-Test (Siegel 1956) to the data showed that the two distributions were different at the 0.001 level.

One conclusion from Figures 6 to 9 is that it is easy to "double count" concentrations in a *post hoc* analysis such as the one being performed here. For example, in Figure 6 it is likely that concentrations 3,5, and 6 and concentrations 4 and 7 are, in fact, the same concentration. It is not as clear if concentrations 1 and 2 are indeed the same concentration. Possible double counting of concentrations becomes important in the estimation of the number of concentrations in a given area.

6. DEFINING CONCENTRATIONS AS FOCI OF HAULS

An alternative definition of concentrations ignores the temporal distribution of hauls and simply considers the location of hauls. If concentrations persist for very long periods of time, this approach makes sense. In this case, one can use the spatial distribution of hauls and try to group hauls that appear to "naturally" aggregate. Figures 10 and 11 show the results of this approach. Although circles are drawn in these figures, the disparity in vertical and horizontal scales means that the concentrations defined in this way are, in fact, ellipses.

On a finer scale, however, it is not clear at all if the presumed smooth geometrical shape for a concentration is appropriate. For example, Figures 12-15 provide examples of the finer scale distribution of hauls. In some cases, the "shape" of the concentration is apparent, but in others it is not clear at all. In addition, Figure 15 provides an excellent example of why echo sounder information is needed. That figure shows two foci for fishing krill with a gap between them. Without echo sounder information, it is impossible to tell in post hoc analysis if the region between the two sets of hauls contained krill and the skipper was attempting to determine the boundary of the concentration or if the region between the two sets of hauls was devoid of krill.

7. THE EFFECTIVE RADII OF CONCENTRATIONS

The distributional model used by Butterworth (1989) and Mangel (1989) assumes circular concentrations. Let **$<A>$** denote the average area of the concentrations computed from the east-west and north-south extent. The simplest estimate for the radius of the concentration is then $\mathbf{r=(<A>/\pi)^{1/2}}$. We can construct a better estimate, however, by noting that concentration radii and areas are random variables. Write **$r=f(A)$**, where $\mathbf{f=(A/\pi)^{1/2}}$ and Taylor expand the expectation of **r** (Seber 1982):

$$E\{ r \} = E\{ f(A) \} = f(E\{A\}) + (1/2) f''(E\{A\}) Var\{ A\} \tag{1}$$

We estimate the expected value of **A** by **$E\{ A \}=< A >$** and the variance of **A** by the sample variance **$Var_s(A)$** to obtain

$$E\{ r \} = (<A>/\pi)^{1/2} - (1/8)\pi^{-1/2} < A >^{-3/2} Var_s\{ A\} \tag{2}$$

It should be noted, however, that there is a more serious bias in the estimation of the effective radii of concentrations. Larger concentrations are more likely to be detected than smaller concentrations. Thus, the average radius of detected concentrations is larger than the average radius of all concentrations. One can show (e.g. Feller 1971, p. 371; also see the Appendix) that

$$\begin{aligned}&E\{\text{radius of detected concentrations}\}/E\{\text{radius of all concentrations}\}\\&= (sM_1+ M_2)/(s + M_1)\end{aligned} \tag{3}$$

where s is the detection width of the vessel's sonar,
M_1 is the first moment (average) of the radius of concentrations, and
M_2 is the average of the squared radius of concentrations.

That is, if **$f(r)$** is the probability density for concentration radii and **r_{max}** is the largest possible radius, then $\mathbf{M_k = \int_0^{r_{max}} r^k f(r) dr}$. For the situation being considered here, this bias is not too severe. For example, running the survey portion of the model developed in Mangel (1989) showed that the bias was only about 10%.

8. ESTIMATING THE NUMBER OF CONCENTRATIONS

The number of concentrations in the region being surveyed can be estimated by use of the random search formula (Mangel, 1985; Mangel and Beder, 1985)

$$N = [\ n_c\ /\ (1-\exp(-Wvt_s/A_s)\ ] \qquad (4)$$

In this equation, N is the estimated number of concentrations in a sector of area A_s, $[z]$ is the integer part of z, n_c is the number of concentrations encountered by the vessel, W is the detection width of the vessel and v is the speed of the vessel while searching.

For the majority of computations reported below **v=10 kt**; the other parameters are determined by the data. The search time t_s is the time between the last trawl in one concentration and the first trawl in the next concentration for which the movement between trawls is at least 50 nm.

The detection width **W** is set equal to twice the average radius of concentrations (thus ignoring the contribution from the detection width of the vessel's sonar). Since concentrations vary in size, **W** is a random variable and the estimate given in Equation (4) will be biased. Proceeding in a manner similar to Equation (1) shows that

$$E\{N(W)\} = N(E\{W\}) + (1/2)N_{ww}(E\{W\})Var(W) \qquad (5)$$

where E{W} and Var{W} are the mean and variance of W (estimated from the data); and N_{ww} is the second derivative of N(W) given in Equation (4), and is

$$N_{ww} = (vt_s/A_s)^2 \exp(-Wvt_s/A_s)n/(1- \exp(Wv_s/A_s)^2$$
$$+ 2(vt_s/A_s)^2 \exp(-2Wvt_s/A_s)n/(1- \exp(Wvt_s/A_s)^3 \qquad (6)$$

The general properties of the estimate **N** can be determined by examination of Equation (4). The parameters enter into Equation (4) in such a way that the estimated number of concentrations only depends upon the combination Wvt_s/A_s. From this, we see that:

(i) An increase in any of **W**, **v**, or t_s will decrease the estimated number of concentrations **N**; and

(ii) An increase in A_s will increase the estimated number of concentrations. For this reason, it is important to have navigational logbook information that can be used to determine the boundaries of the region being searched.

As the combination Wvt_s/A_s increases, the estimated number of concentrations **N** approaches the number of discovered concentrations n_c. As the combination Wvt_s/A_s decreases, the estimated number of concentrations increases without bound (as long as $n_c>0$).

For the results reported below, the following procedure was adopted:

Step 1. Use the 50 nm rule to determine concentrations and the spatial extent of concentrations. The east-west extent of concentration **i** in data set **j** is denoted by EWE_{ij} and the north-south extent of the same concentration is denoted by NSE_{ij}.

Step 2. Compute the effective radius of concentrations using Equations (1 and 2). In addition, compute the radius of concentration **i** in data set **j**, denoted by

r_{ij}, from the formula $r_{ij}=(\ EWE_{ij}NSE_{ij}/\pi)^{1/2}$. Compute the mean $<r>_j$ radius of concentrations in data set **j** and the variance of radii.

Step 3. Set the detection width in data set j equal to $W_j=2<r>_j$. Apply Equations (5 and 6) to these data. In doing this, since $W=2r$, then $Var(W)=4\ Var(r)$. (Figure A6 of Appendix 5 of the Krill CPUE Working Group Report contains an error for the curve in which bias is included. That error is corrected here.)

Tables 2 to 5 show the results of Step 1 of this process. Note the following limitations in trying to post-hoc interpret the data:

(i) Although the new concentration rule specifies that movements greater than 50 nm correspond to new concentrations, vessels can cover much larger areas by making smaller, directed movements within a concentration. For example, three movements of 40 nm each could cover 120 nm, but under the 50 nm rule, the vessel would still be "in the same concentration". Such records probably correspond to more than one concentration, but there is no way of determining how many different concentrations were really present.

(ii) Another interpretation of large concentration areas is that the concentration radius is not uniformly distributed as assumed by Butterworth (1989) and Mangel (1989), but has a skewed distribution with a long tail. The large concentrations might also represent the detection bias described previously.

(iii) There are instances in which very long trawl times are reported in concentrations for which the catch is very small. It is possible that the vessel was actually doing operations other than fishing during some of this time, but there is no way to tell if this is true (or what the operations were) from the logbooks. Additional annotations in logbooks are needed.

Table 6 contains results of Steps 2 and 3 for the estimated number of concentrations in the region and the radius of the concentrations. Two radii are given. The first is the effective radius, based on Equations (1 and 2). The second is the simple average $<r>_j$ computed in Steps 2 and 3. Table 7 shows summary statistics for catch and trawling times. Concentrations were divided into "poor" concentrations and "good" concentrations: a concentration with CFT (catch per fishing time) less than 500 kg/hour is considered poor. From these tables, we see that the coefficients of variation of concentration properties are very large - typically between 50% and 100%.

Since concentrations are not marked in any way upon encounter, they might be re-encountered and viewed as a new concentration. For example, some concentrations actually overlap in space but not in time (e.g. 4 and 7 in Figure 2). Table 8 shows the possible double counts and the time between the encounters of the double counts.

I presume that when consecutively numbered concentrations are nearly contiguous in space, they are probably being doubled counted. The question is more difficult for non-consecutive concentrations. These are concentrations 3, 6 and 4, 7 for the data collected by the RV *Professor Derugin*, concentrations 1,4 for the data collected by the RV *Odyssey* and concentrations 4, 8 and 1, 14 for the data collected by the RV *Mys Tihiy*. The times between the last trawl in one concentration and the first trawl in the possibly double counted concentration range from 101.4 hrs to 1 290.4 hrs, with a mean of 565.6 hrs. The only way in which we can determine if these are really different concentrations is to know the time scale on which concentrations persist. (In the models used by Butterworth (1989) and Mangel (1989) concentrations are presumed to persist for the entire fishing period of14 to 30 days.)

9. A MORE DETAILED ANALYSIS OF THE DATA FROM RV *MYS TIHIY*

Figure 16 shows a histogram of the radii of concentrations encountered by RV *Mys Tihiy*. In order to obtain an idea of how the estimated number of concentrations depends upon the area of the sector $\mathbf{A_s}$, Equation (4) was used to compute **N** as a function of varying $\mathbf{A_s}$, using **W=2<r>**. The results are shown in Figure 17 (which corrects Figure A6 in Appendix 5 of the Krill CPUE Workshop Report (see CCAMLR, 1989)).

10. CONCLUSIONS

The results presented in this paper lead to the following conclusions:

- The types of movement by vessels in search for concentrations of krill are important and skippers should record the nature of movement and encounters. Essentially, accurate and effective inference for the number of concentrations requires information from a navigational logbook as well as a fishing logbook.

- There is considerable variability in concentration properties (radius, catch, trawling time); coefficients of variation range between 50% and 100%.

- The distributional model used by Butterworth (1989) and Mangel (1989), in which concentration radii are uniformly distributed between 6 nm and 22 nm may be inappropriate. In particular, the distribution of concentration radii may be skewed, with a long tail, rather than a uniform distribution as assumed previously. The difficulty in drawing a conclusion is that there is a bias in detection: the radii of detected concentrations are, on average, larger than the average radius of all concentrations.

- In general, data collected by research or survey vessels (both navigational logbook and fishing logbook information) can be effectively used to estimate the number of concentrations in a sector of the ocean. In particular, there is a need for operational data and logbooks including echo sounder information. The navigational logbook will provide two kinds of data. First, from the navigational log, one can determine whether krill are present in regions between fishing hauls. Second, the navigational log can be used to set the boundaries of the region being searched.

- Using the methods described in this paper, no inferences can be made about stock size regions that are not searched. A Bayesian approach is needed to answer that question.

- In order to determine if concentrations are double counted, it is important to know the temporal persistence of concentrations of krill.

ACKNOWLEDGMENTS

I thank Professor Lubimova, All Union Research Institute for Marine Fisheries and Oceanography for use of the research vessel data.

I thank Susan Mangel for data entry. Particpants at the Krill CPUE Workshop provided useful comments, as did Ray Hilborn and Carl Walters. This work was partially funded by CCAMLR and also supported by the Institute for Theoretical Dynamics, University of California, Davis.

REFERENCES

CCAMLR, 1989. Report of the Workshop on the Krill CPUE Simulation Study. *SC-CAMLR-VIII, Annex 4*: 83-137.

BUTTERWORTH, D.B. 1989. A simulation study of krill fishing by an individual Japanese trawler. Scientific Committee for the Conservation of Antarctic Marine Living Resources (Hobart, Tasmania, Australia), Part I. *SC-CAMLR-SSP/5*: 1-108.

FELLER, W. 1971. *An Introduction to Probability Theory and Its Applications, Volume 2.* New York: Wiley.

LEVIN, S.A., A. MORIN, and T. POWELL. 1989. Patterns and processes in the distribution and dynamics of Antarctic krill. Scientific Committee for the Conservation of Antarctic Marine Living Resources (Hobart, Tasmania, Australia), Part I. *SC-CAMLR-SSP/5*: 281-300.

MANGEL, M. 1985. Search models in fisheries and agriculture. Lecture Notes in: *Biomathematics 61*: 105-138.

MANGEL, M. and J.H. BEDER. 1985. Search and stock depletion: theory and applications. *Canadian Journal on Fisheries and Aquatic Sciences 42*: 150-163.

MANGEL, M. 1989. Analysis and modelling of the Soviet southern ocean krill fleet. Scientific Committee for the Conservation of Antarctic Marine Living Resources (Hobart, Tasmania, Australia), Part I. *SC-CAMLR-SSP/5*: 127-236.

MILLER, D.G.M. and I. HAMPTON. 1988. Krill aggregation characteristics: spatial distribution patterns from hydroacoustic observations. CCAMLR Document SC-CAMLR-VI/BG/13. CCAMLR, Hobart, Tasmania, Australia.

SEVBER, G.A.F. 1982. *The Estimation of Animal Abundance.* 2nd Ed. New York: MacMillan.

SIEGEL, S. 1956. *Nonparametric Statistics.* New York: McGraw-Hill.

WASHBURN, A. 1981. *Search and Detection.* Arlington, VA.: Military Operations Research Society.

APPENDIX

ESTIMATING THE BIAS IN THE SIZE OF DETECTED CONCENTRATIONS

Since a large concentration is more likely to be detected than a small concentration, there will be a bias in estimating concentration size from the dimensions of concentrations that are encountered.

In this appendix, I show how to calculate the bias. Assuming that the survey vessel runs a straight tack, one need only consider a problem in one dimension. Assume that concentration centers are uniformly placed across an interval of length **2R** and that the survey vessel sits at the center of this interval with detection width **2s**.

Let **C** denote the location of the center of a concentration and **W** the radius of a concentration. Thus **C** is uniformly distributed on **[-R,R]** and **W** has a density function $f_0(w)$, so that $\mathrm{Prob}\{\ w \le W \le\ w + dw\} = f_0(w)dw$. A concentration is assumed to be detected if part of it falls within the detection width of the survey vessel. Thus

Prob{ concentration of radius W is detected}
$= \mathrm{Prob}\{\ C< 0,\ W+C >-s\} + \mathrm{Pr}\{\ C> 0,\ C-W < s\}$ (A1)

Since the concentrations are uniformly distributed over the interval, the joint probabilities can be rewritten as

$\mathrm{Prob}\{\ C<0,\ W+C> -s\} = (1/2)\mathrm{Prob}\{W+C>-s|\ C <0\}$
$\mathrm{Prob}\{\ C>0,\ C-W< s\} = (1/2)\mathrm{Prob}\{C-W< s|\ C >0\}$ (A2)

Because of the symmetry of the problem, $\mathrm{Prob}\{W+C > -s|C <0\} = \mathrm{Prob}\{C\ W < s|\ C> 0\}$ so that

Prob{concentration of radius w is detected}= $\mathrm{Prob}\{C < s+w \mid C > 0\} = (s+w)/R$ (A3)

Strictly speaking, the term $(s+w)/R$ in (A3) should be replaced by $\min(1, (s+w)/R)$; I assume that $s+w< R$ always. This can always be achieved by assuming that $f_0(w)$ vanishes at some finite value of w which is less than **R-s**.

Equation (A3) gives the probability that a concentration of radius W will be detected. We want to compute, however, the probability that a concentration has radius approximately **w**, given that it is detected. This can be found by an application of the definition of conditional probability:

Prob{ concentration has radius approximately w, given that it is detected}
= Prob{concentration has radius approximately w and it is detected}/
Prob{ concentration is detected} (A4)

The numerator in (A4) is $f_0(w)\ dw\ (s+w/R)$ and the denominator is the integral of the numerator over all possible values of **w**.

Hence

Prob{ concentration has radius approximately w, given that it is detected}

$$= (s+w)\ f_0(w)\ dw / \int f_0(w)[(s+w)]dw$$

$$= (s+w)f_0(w)dw/(s + E\{W\}) \qquad (A5)$$

where **E{W}** is the expected radius of a concentration. The expected value of the radii of detected concentrations is then

E{ radii of detected concentrations}

$$= \int [sw + w^2]f_0(w)\ dw/(s+ E\{W\}) \qquad (A6)$$

$$= (s\ E\{W\} + M_2)/(s + E\{W\}) \qquad (A7)$$

where M_2 is the second moment of the concentration radii.

Since $M_2 = Var\{W\} + E\{W\}^2$, (A7) can be rewritten as

E{radii of detected concentrations }

$$= (s\ E\{W\} + E\{W\}^2 + Var\{W\})/ (s + E\{W\}) \qquad (A8)$$

This result is derived, in general, by Feller (1971, p. 371).

A nondimensional measure of the bias caused by detection of larger concentrations is

E{radii of detected concentrations}/E{radii of all concentrations}

$$= (s\ E\{W\} + E\{W\}^2 + Var\{W\})/ (s\ E\{W\} + E\{W\}^2) \qquad (A9)$$

The quantity in (A9) can easily be evaluated. For example, if **W** is uniformly distributed on the interval $[0,\alpha R]$, then

E{radii of detected concentrations}/E{radii of all concentrations}

$$= (2/3)\ [\ 2(\alpha R/s) + 3\ ]/[\ (\alpha R/s) + 2] \qquad (A10)$$

Alternatively, one can consider the case in which s is vanishingly small (i.e. the detection width of the survey vessel is very small, compared to the radii of concentrations). In that case, (A9) becomes

E{radii of detected concentrations}/E{radii of all concentrations}

$$= (E\{W\}^2 + Var\{W\})/ (E\{W\}^2)$$

$$= 1 + CV(W)^2 \qquad (A11)$$

where **CV{W}** is the coefficient of variation of the concentration radius distribution.

Table 1: Data sets used for the analysis.

Vessel Name	Period of Survey	Region of Survey	Number of Records
1. *Professor Derugin*	18.02.82 - 05.05.82	61.2°E - 112.4°E 62.9°S - 67.1°S	118
2. *Oydssey*	09.01.81 - 19.03.81	35.3°W - 55.7°W 53.6°S - 61.3°S	39
3. *Mys Dalniy*	07.02.84 - 29.04.84	105.6°E - 163.9°E 64.3°S - 77.9°S	65
4. *Mys Tihiy*	02.01.81 - 08.04.81	116.7°E - 167.6°E 65°S - 68.4°S	155

Table 2: Analysis of data for the cruise by RV *Professor Derugin*.

Concentration	Extent East-West (nm)	Extent North-South (nm)	Krill Catch (kg)	Trawl Time (hrs)	Search Time* (hrs)	CFT**
1	24	2	15 000	19.2	19.3	781
2	41.5	26	178 000	151	5.3	1 179
3	23.5	5	69 500	60.7	9.8	1 145
4	38	15	54 510	57.7	14.2	945
5	81.5	10	156 600	197.5	17.6	793
6	49	33	364 800	209	10.9	1 746
7	41.5	10	247 200	204	9.1	1 212

* Trawl time is the total time spent trawling in the concentration. Search time is the time between the last trawl in the i^{th} concentration and the first trawl in the $i+1^{st}$ concentration.

** CFT = Catch-per-fishing time = Catch/Trawl Time. Units are kg/hour.

Table 3: Analysis of data for the cruise by RV *Odyssey*.

Concentration	Extent East-West (nm)	Extent North-South (nm)	Krill Catch (kg)	Trawl Time (hrs)	Search Time* (hrs)	CFT**
1	15.5	20	53 412	285.6	304.3	187
2	24	42	15 000	174.6	135.4	85.9
3	51.5	39	3 100	79.7	23.8	38.9
4	8.5	9	27 802	105.8	57.5	262.8

* Trawl time is the total time spent trawling in the concentration. Search time is the time between the last trawl in the i^{th} concentration and the first trawl in the $i+1^{st}$ concentration.

** CFT = Catch-per-fishing time = Catch/Trawl Time. Units are kg/hour.

Table 4: Analysis of data for the cruise by RV *Mys Dalniy*.

Concentration	Extent East-West (nm)	Extent North-South (nm)	Krill Catch (kg)	Trawl Time (hrs)	Search Time* (hrs)	CFT**
1	48.5	16	17 500	60.2	133.8	291
2	0.5	1	6 000	4	112	1 500
3	10.5	6	21 000	30.9	167.2	680
4	12.5	9	30 200	58.4	223.8	517
5	56	25	7 900	55.7	183	142
6	53.5	24	56 200	118.7	37.5	474

* Trawl time is the total time spent trawling in the concentration. Search time is the time between the last trawl in the i^{th} concentration and the first trawl in the $i+1^{st}$ concentration.

** CFT = Catch-per-fishing time = Catch/Trawl Time. Units are kg/hour.

Table 5: Analysis of data for the cruise by RV *Mys Tihiy*.

Concentration	Extent East-West (nm)	Extent North-South (nm)	Krill Catch (kg)	Trawl Time (hrs)	Search Time* (hrs)	CFT**
1	9	28	1 173	28.7	61.3	40.9
2	12	4	22 800	14.9	65.6	1 530
3	16	6	28 000	78	18.7	359
4	83.5	44	118 200	134.5	41.6	879
5	39	17	43 700	48.2	2.58	907
6	182.5	68	13 400	72.8	114	184
7	39	78	24 700	46.5	252	531
8	54.5	71	171 050	272	157.7	629
9	4.5	1	9 000	9.8	49.3	918
10	43	13	4 500	11.4	61.2	395
11	24	21	35 000	28	21.7	1 250
12	4.5	5	29 500	51	28.4	578
13	7.5	0.3	650	104.3	110.7	6.2
14	43	43	16 200	46.2	35	351

* Trawl time is the total time spent trawling in the concentration.
Search time is the time between the last trawl in the i^{th} concentration and the first trawl in the $i+1^{st}$ concentration.

* * CFT = Catch-per-fishing time = Catch/Trawl Time. Units are kg/hour.

Table 6: Estimates for the number of concentrations and concentration properties.

Vessel	Estimated Number of Concentrations	Concentration Radii Equations (1 and 2) (nm)	Concentration Radii Average $\langle r \rangle_j$ (nm)
Professor Derugin	20; 24*	14.6	13.2 (6.16)**
Odyssey	12; 38	16.7	15.1 (7.06)
Mys Dalniy	34; 52	13.9	11.3 (8.04)
Mys Tihiy	25; 42	24.7	17.9 (17.1)

* The first value pertains to Equation (5); the second includes the bias.

* * Standard deviations are shown in parentheses.

Table 7: Summary of catch and trawling time data.

Vessel	Concentration Properties Catch (kg)	Concentration Properties Trawling Time (hrs)	Concentration Types Poor	Concentration Types Good
Professor Derugin	155 087 (0.73)*	128 (0.58)*	None	All
Odyssey	24 829 (0.75)	161 (0.49)	All	None
Mys Dalniy	23 133 (0.73)	54.6 (0.64)	1,5,6	2,3,4
Mys Tihiy	36 991 (1.26)	72.8 (0.92)	1,3,6,10 13,14	2,4,5 7,8,9,11,12

* Coefficient of variation is shown in parentheses.

Table 8: Possible double counting of concentrations and the time between encounters.

Number of concentrations that might be double counted	Time between last trawl in one concentration and first trawl in the next
3,5,6	89.5 hrs (3-5), 10.9 hrs (5-6)
4,7	444 hrs
Odyssey	
1,4	296.4 hrs
2,3	23.8 hrs
Mys Dalniy	
4,5	182.6 hrs
Mys Tihiy	
2,3	18.9 hrs
4,8,9	693.6 (4-8), 61.2 (8-9)
1,14	1 290.4

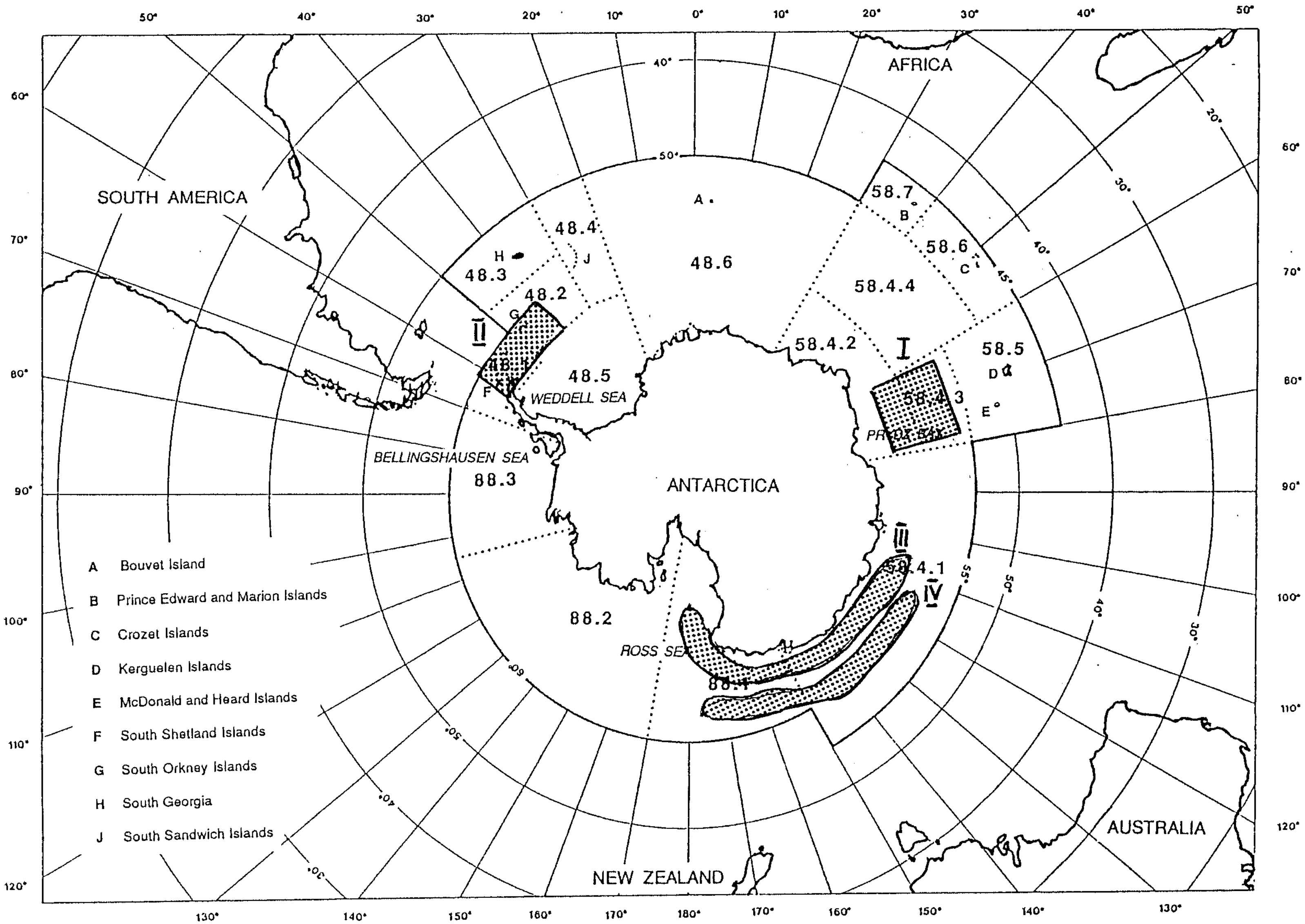

Figure 1: Approximate location of the four survey vessel activities, superimposed upon CCAMLR areas, subareas and divisions. The scale of the survey activity has been slightly enlarged to enhance viewing.

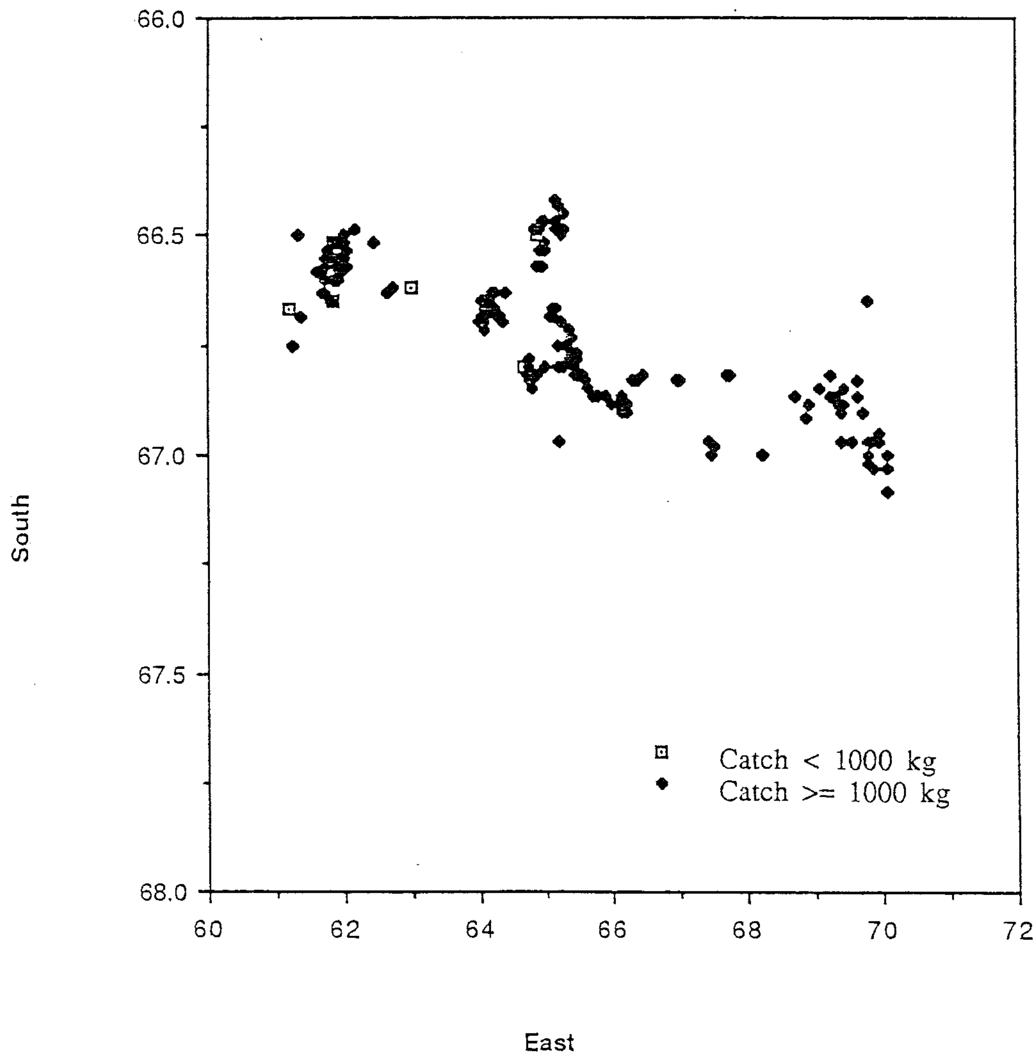

Figure 2: Spatial location of hauls by RV *Professor Derugin*. Hauls are separated according to the size of catch. On this scale there is almost a continuous series of hauls.

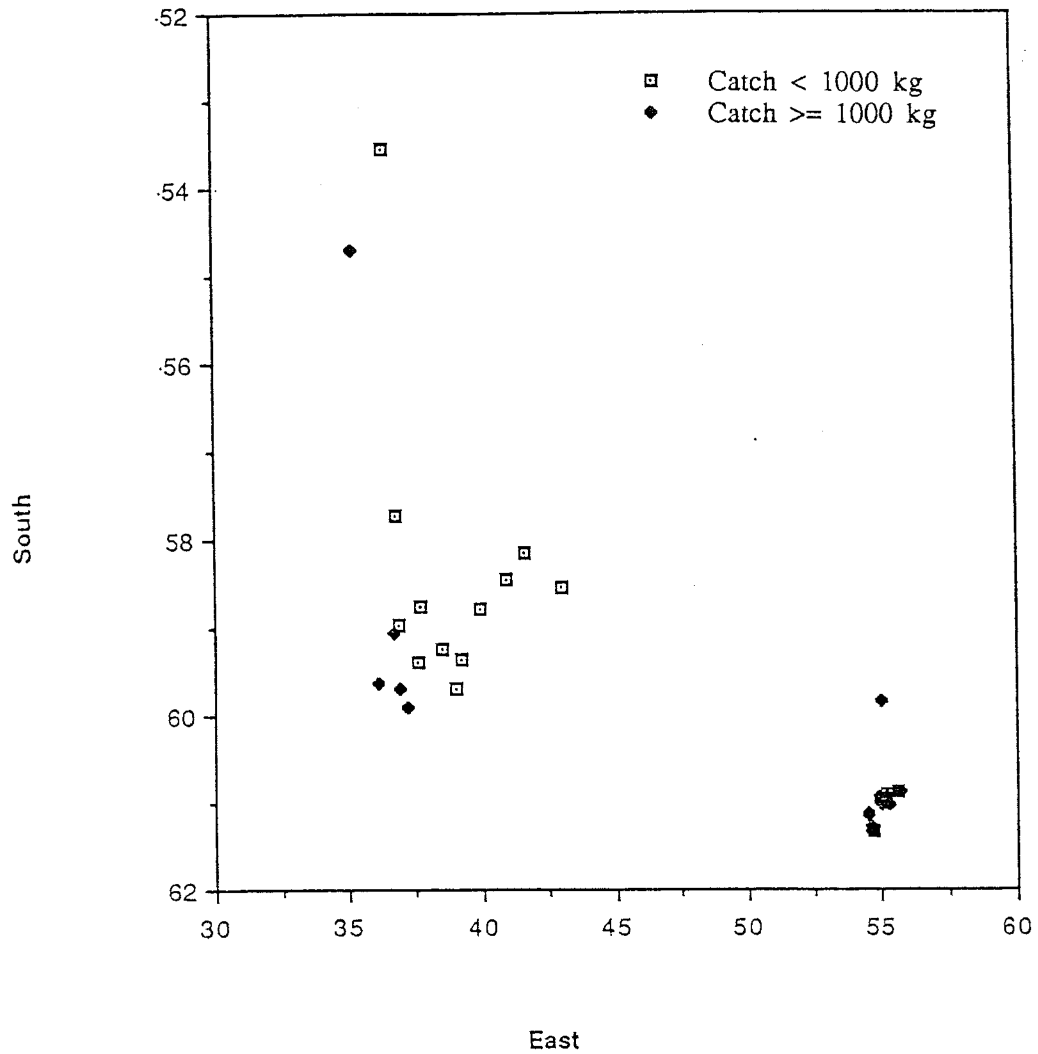

Figure 3: Spatial location of hauls by RV *Odyssey*. Hauls are separated according to the size of catch. Note the large number of hauls with relatively small catch and the spatial dispersion of fishing activity.

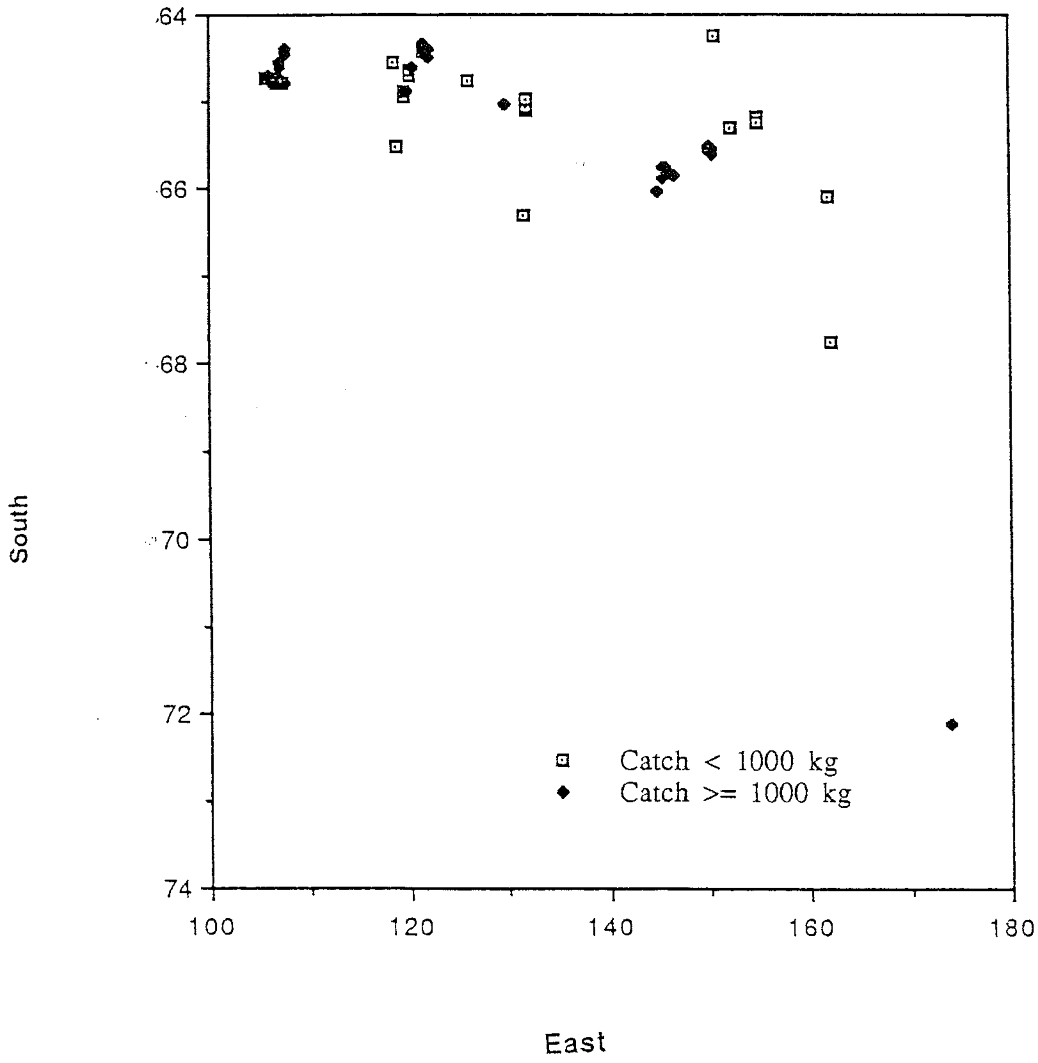

Figure 4: Spatial location of hauls by RV *Mys Dalniy*. Hauls are separated according to the size of catch. Note the apparent separation of hauls on this spatial scale.

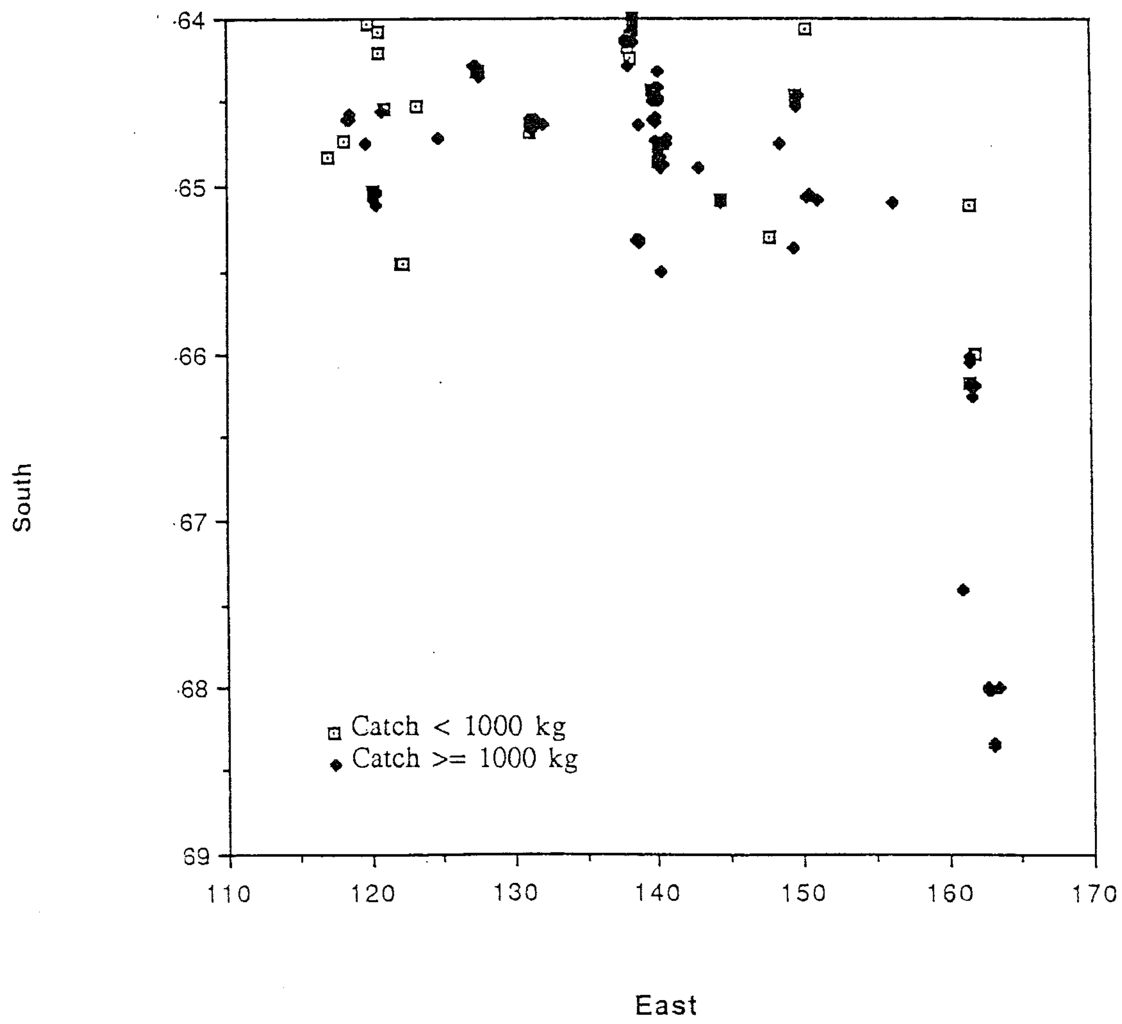

Figure 5: Spatial location of hauls by RV *Mys Tihiy*. Hauls are separated according to the size of catch.

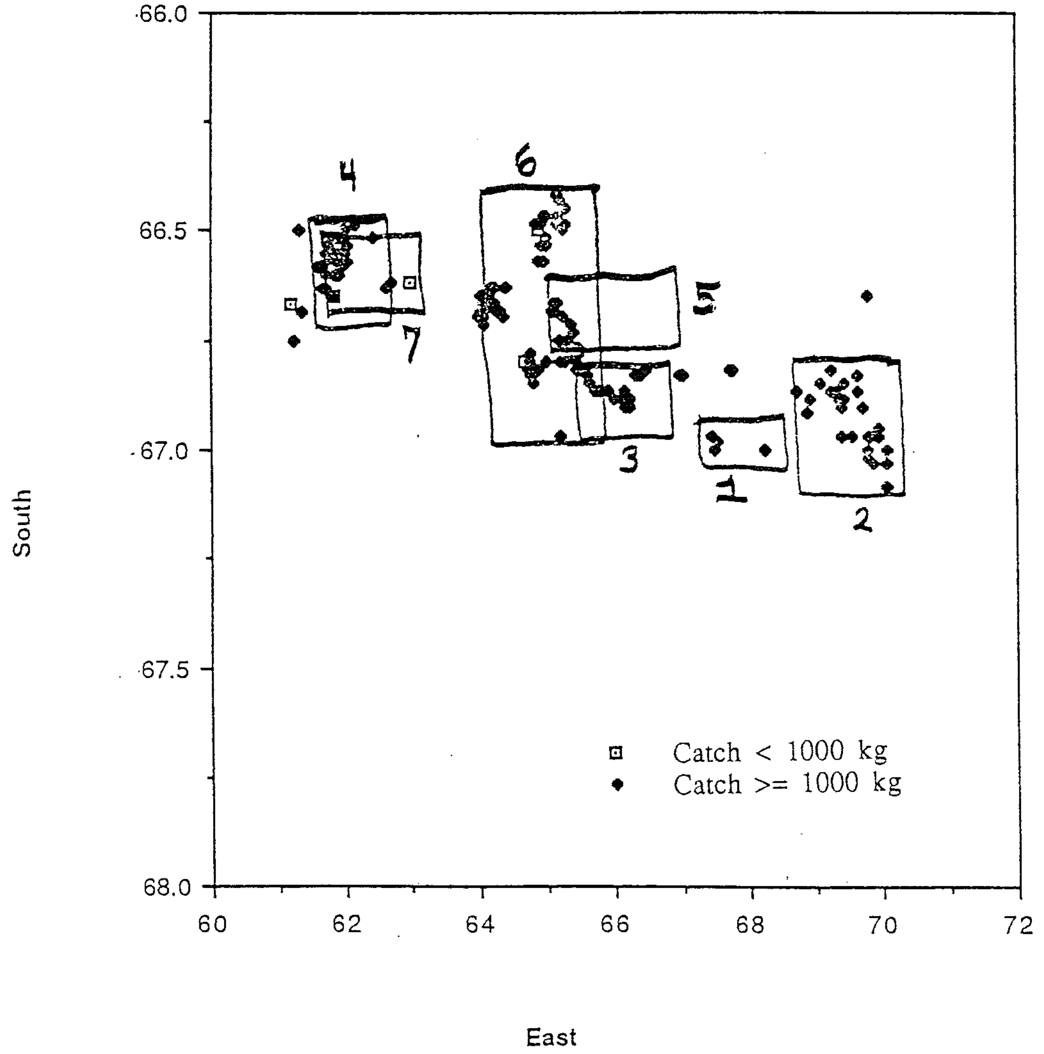

Figure 6: Spatial location of hauls by RV *Professor Derugin*, showing concentrations determined by the 50 nm rule. Concentrations are drawn approximately to scale. It is likely that concentrations 3, 5, and 6 and 4 and 7 are the same, but were encountered in a temporarl sequence that makes a firm conclusion difficult.

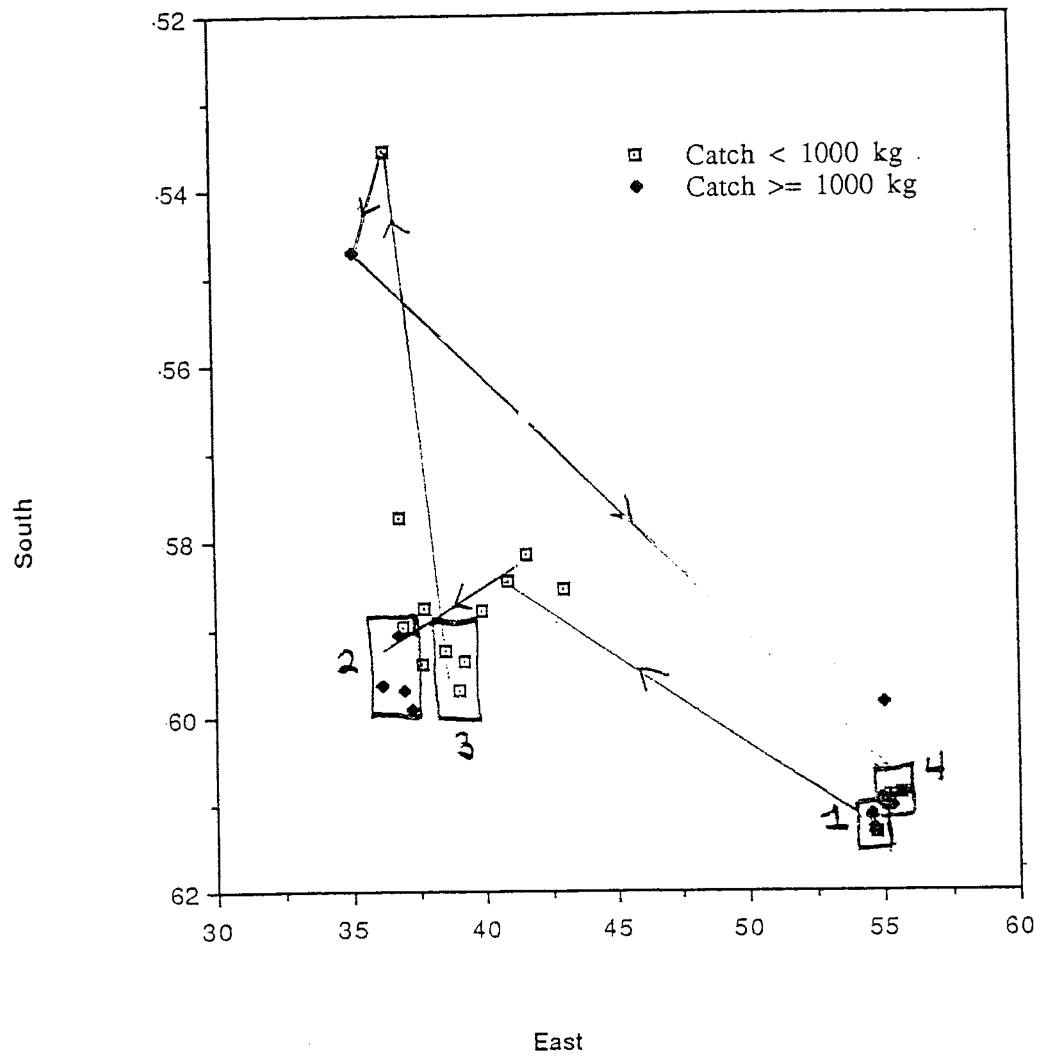

Figure 7: Spatial location of hauls by RV *Odyssey*, showing concentrations determined by the 50 nm rule. Concentrations are drawn approximately to scale. In addition, the vessel path between concentrations is shown. It is likely that concentrations 1 and 4 are the same and that 2 and 3 are in fact part of a larger concentration.

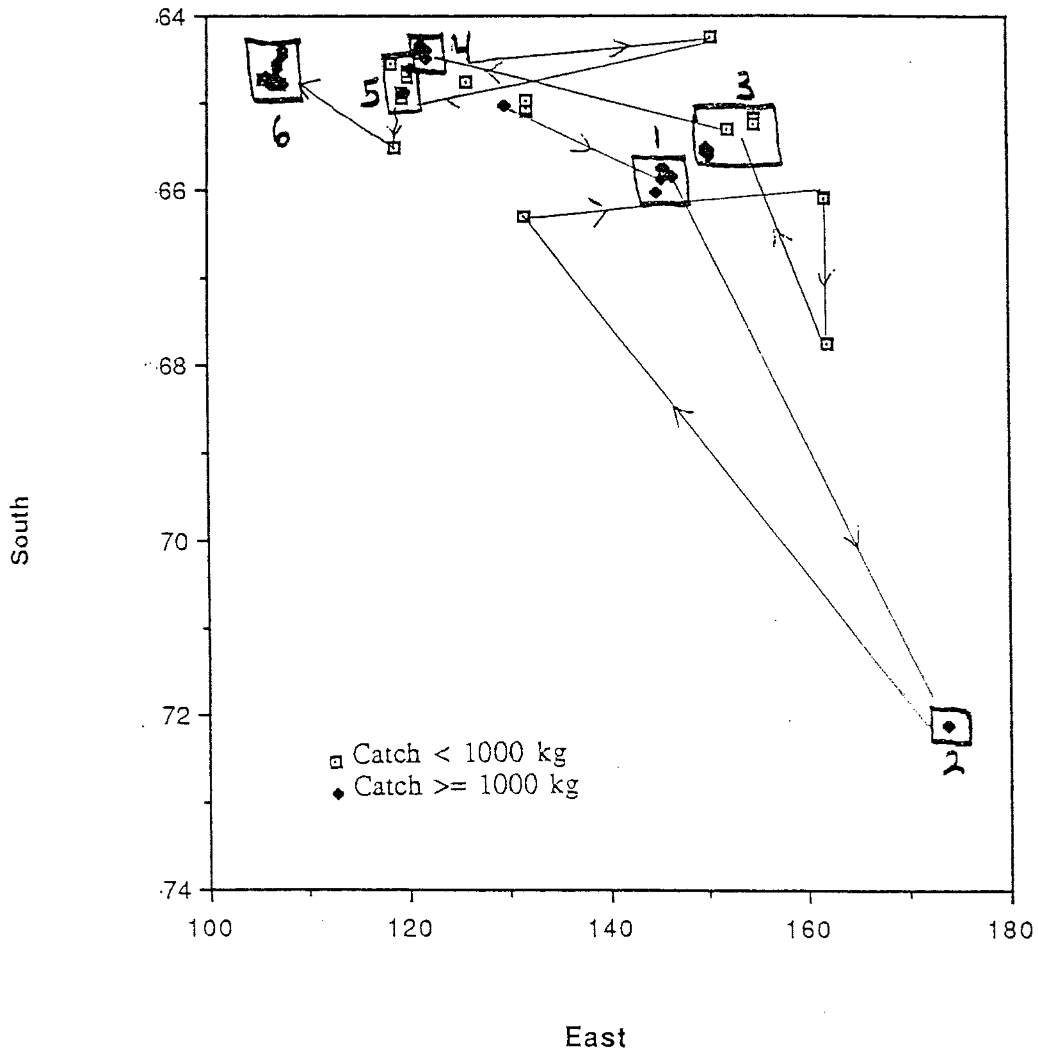

Figure 8: Spatial location of hauls by RV *Mys Dalniy*, showing concentrations determined by the 50 nm rule. Concentrations are drawn approximately to scale. In addition, the vessel path between concentrations is shown.

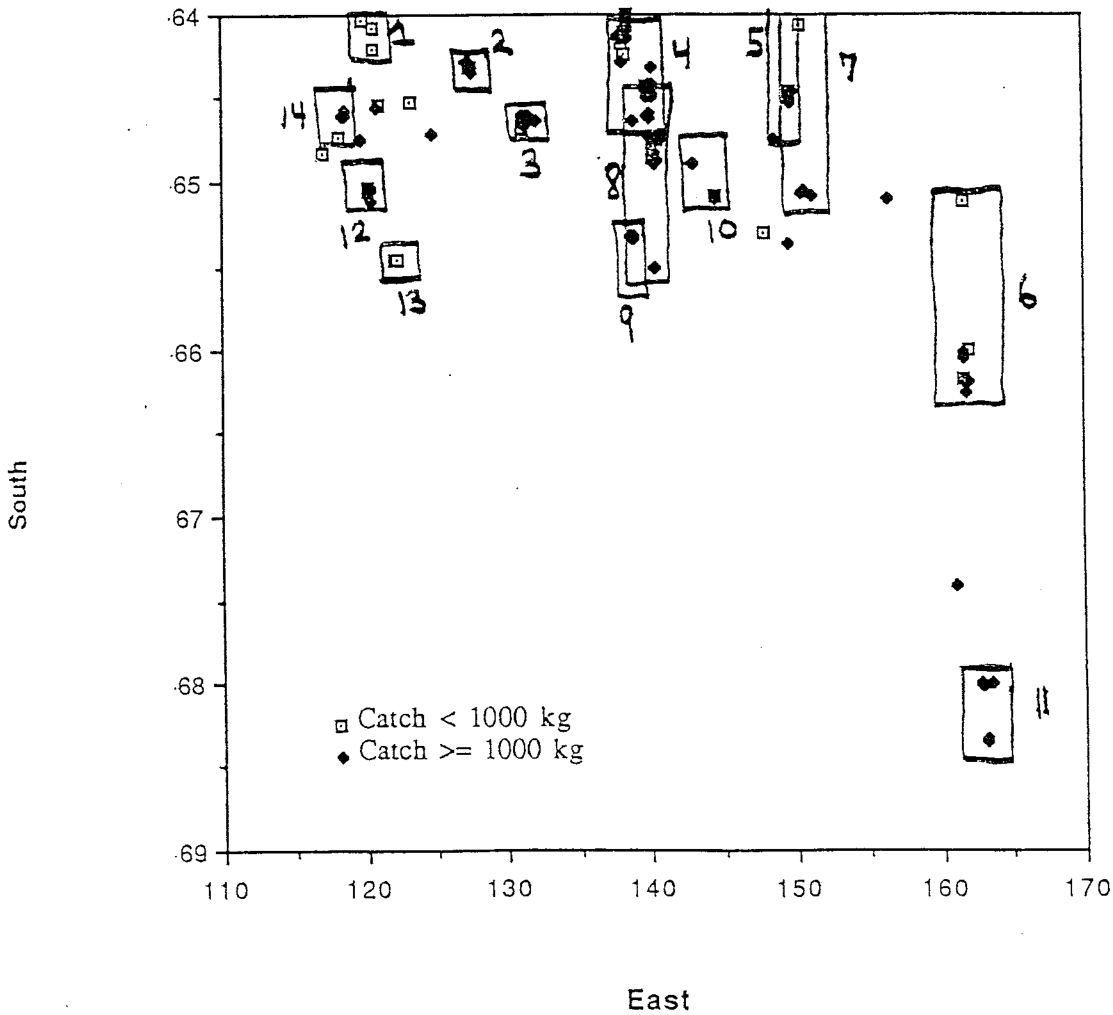

Figure 9: Spatial location of hauls by RV *Mys Tihiy*, showing concentrations determined by the 50 nm rule. Concentrations are drawn approximately to scale. In addition, the vessel path between concentrations is shown. It is likely that concentrations 1 and 14; 4, 8, and 9; and 5 and 7 are the same, but they were encountered in a temporal sequence that makes such identification difficult.

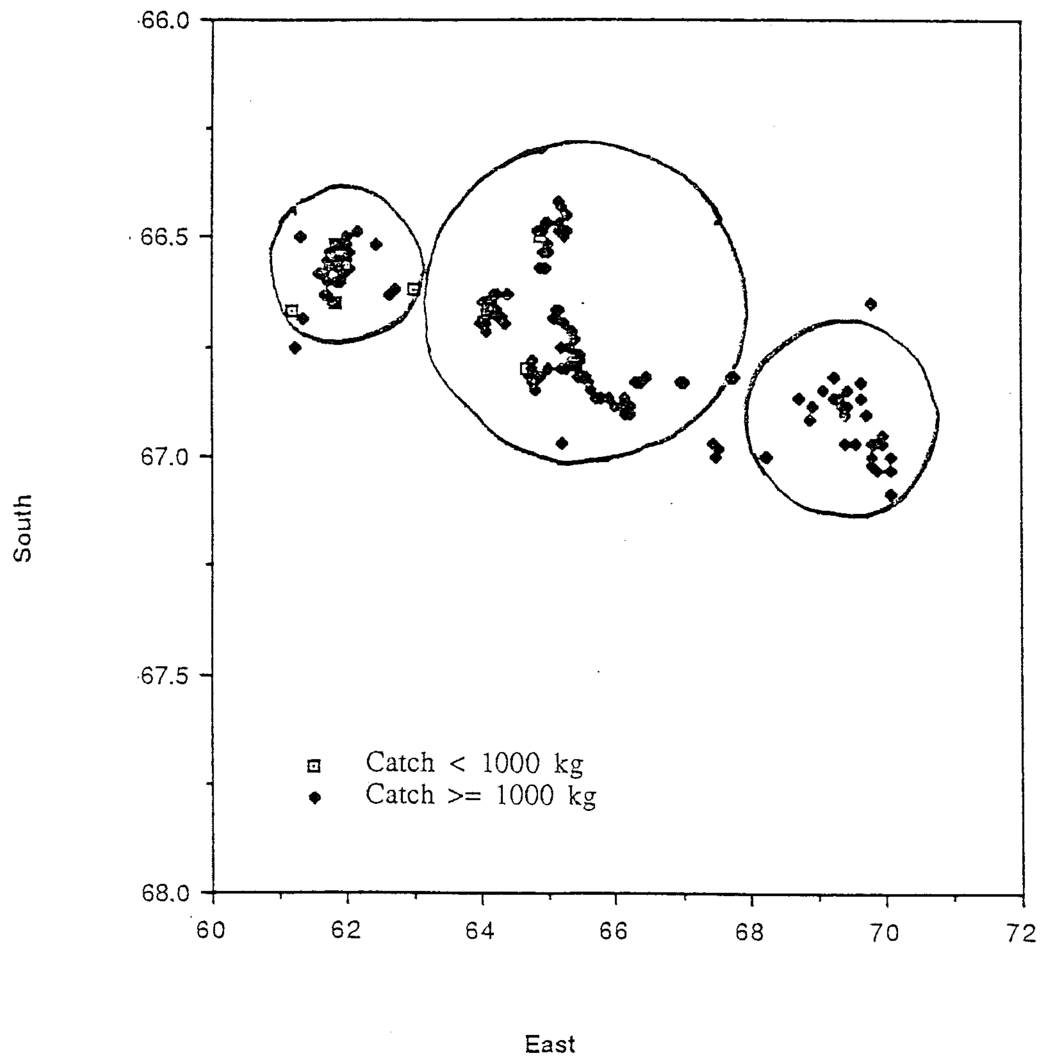

Figure 10: An alternate definition of concentrations, for the data from RV *Professor Derugin*. Circles were drawn around collections of points that appear to "aggregate" naturally. Because of the difference in spatial scales, the actual shape of the concentrations would be elliptical.

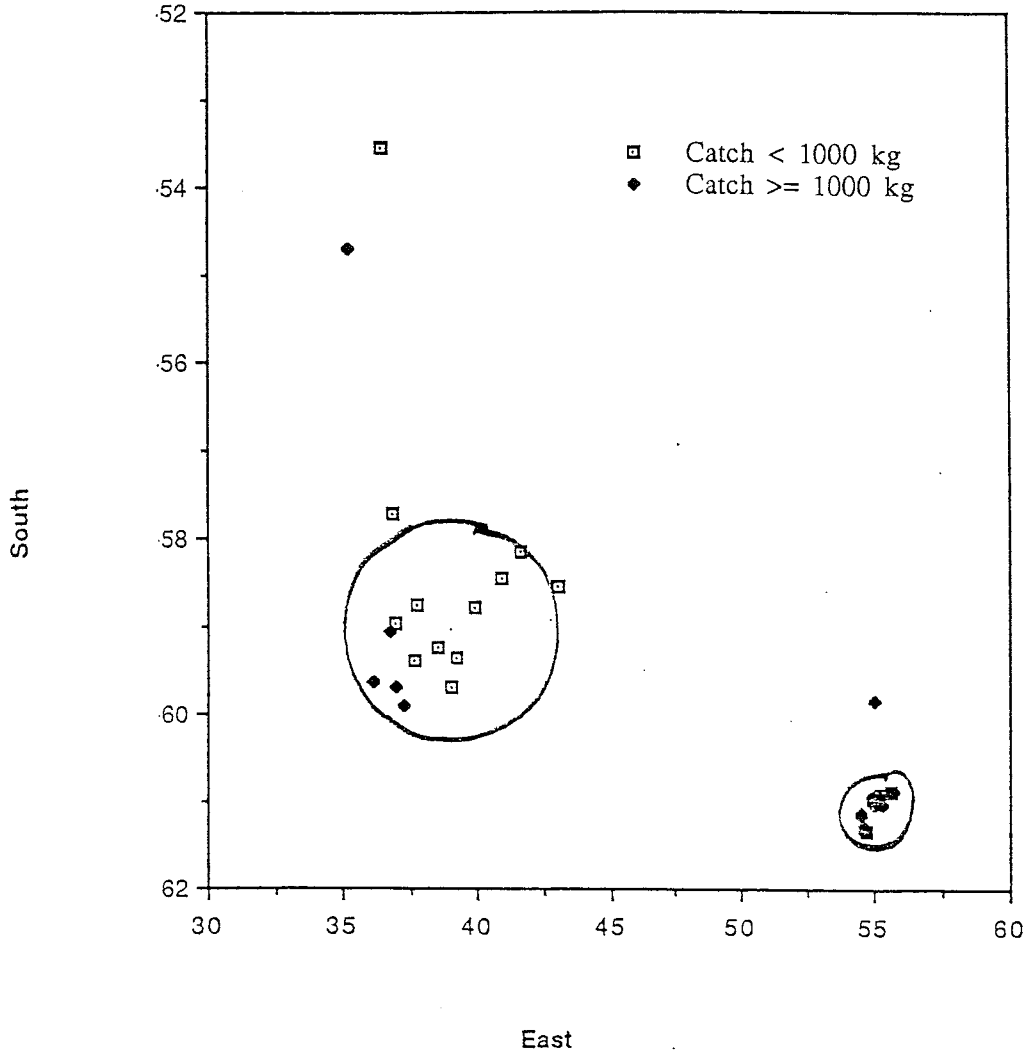

Figure 11: An alternate definition of concentrations, for the data from RV *Odyssey*. Circles were drawn around collections of points that appear to "aggregate" naturally. Because of the difference in spatial scales, the actual shape of the concentrations would be elliptical.

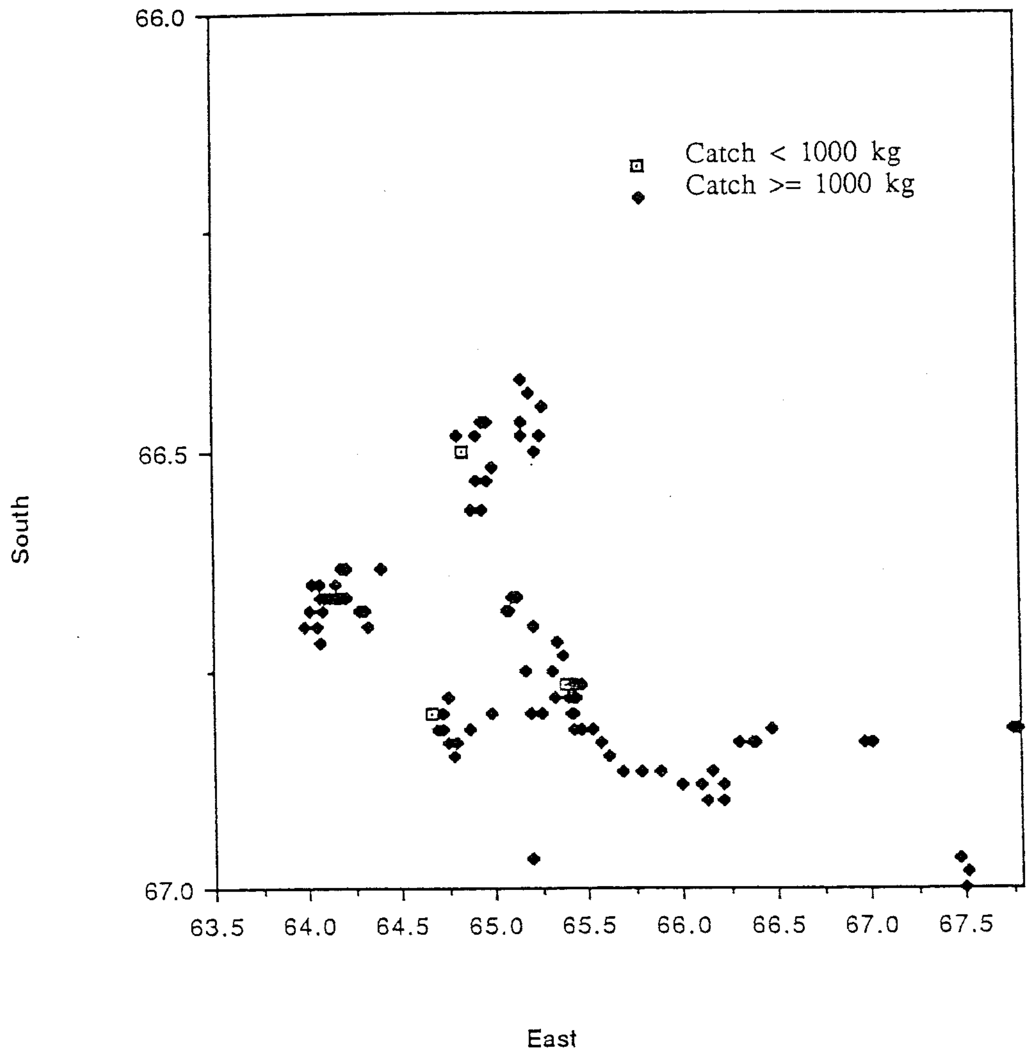

Figure 12: A finer scale spatial plot of hauls by RV *Professor Derugin*, showing concentrations 3, 5, and 6. At this spatial resolution, three foci of fishing appear in the plot, but it is not known if the gaps between the clumps of activity are devoid of krill.

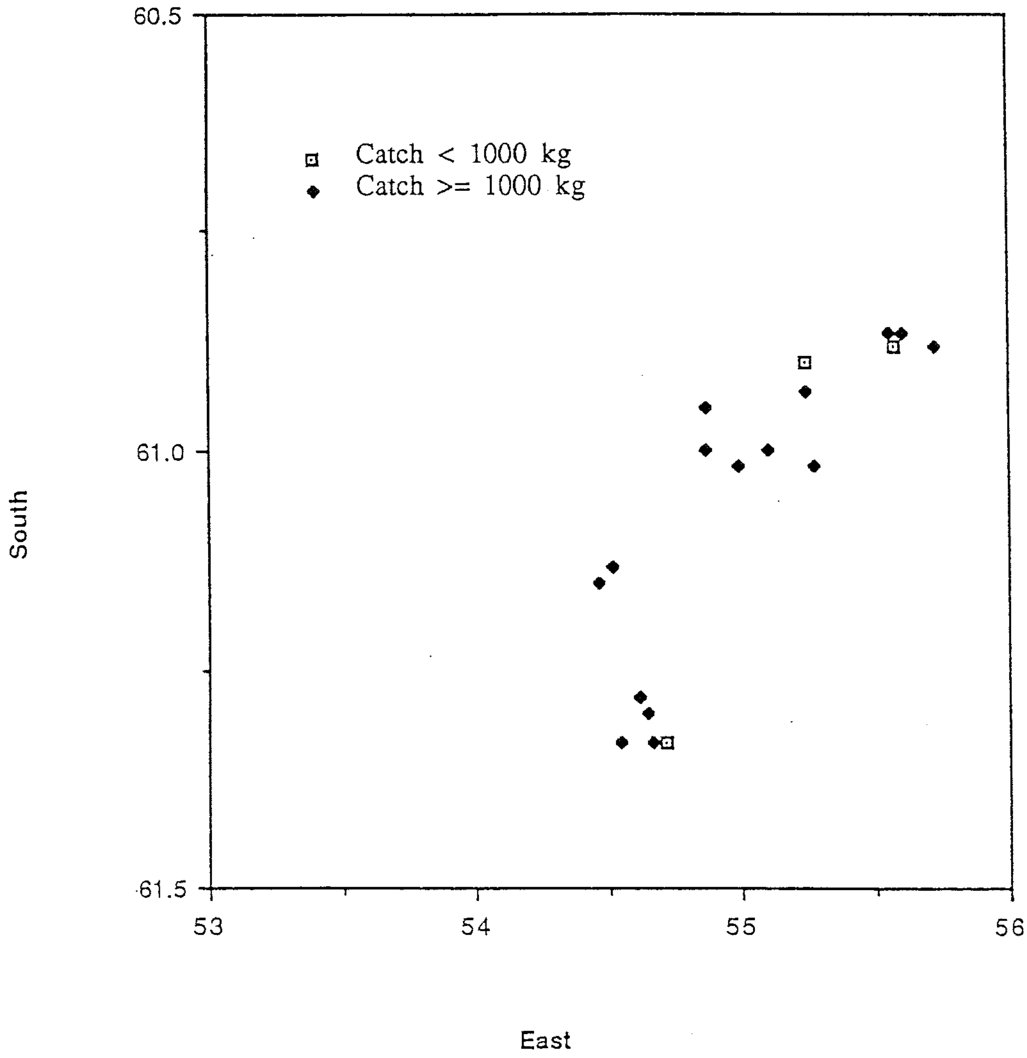

Figure 13: A finer scale spatial plot of hauls by RV *Odyssey* in concentration 1.

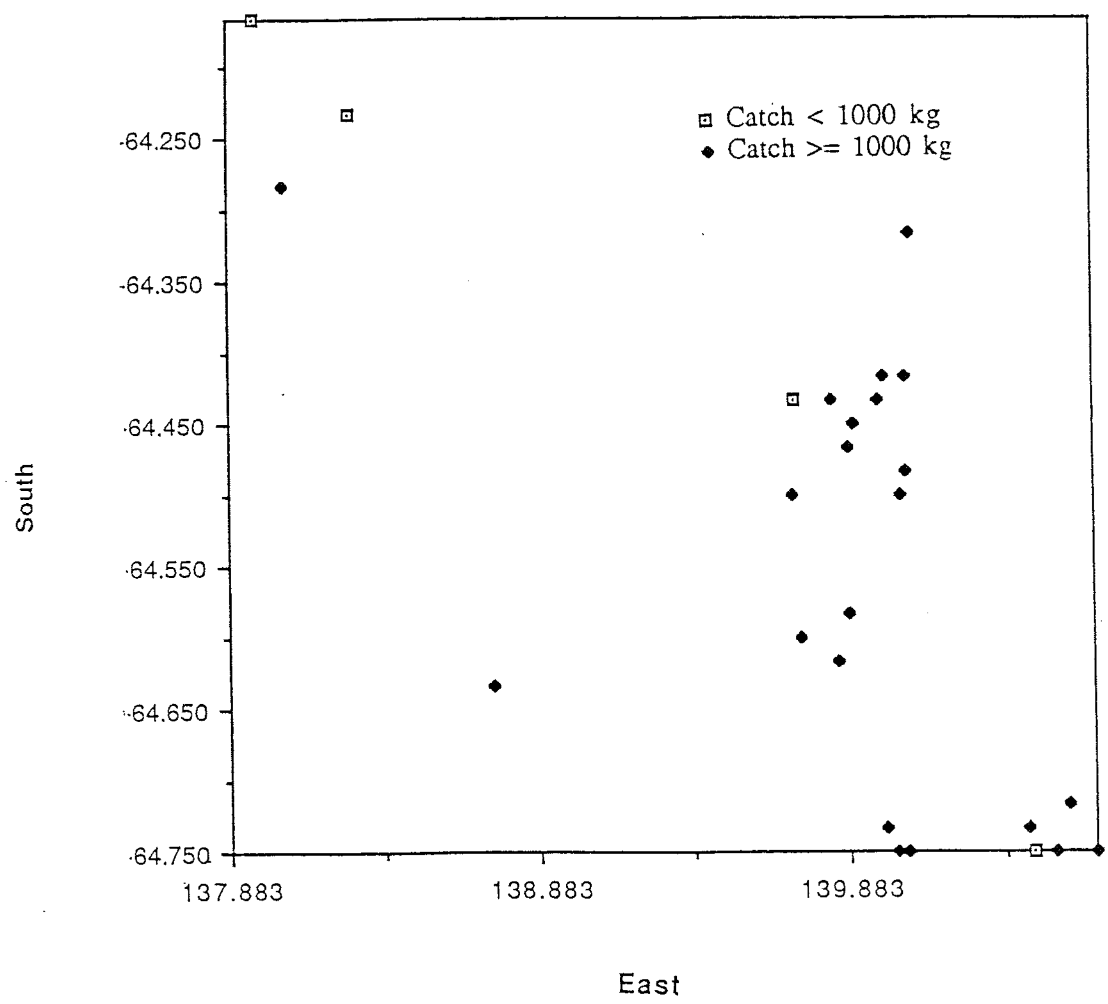

Figure 14: A finer scale spatial plot of hauls by RV *Mys Tihiy* in concentration 4.

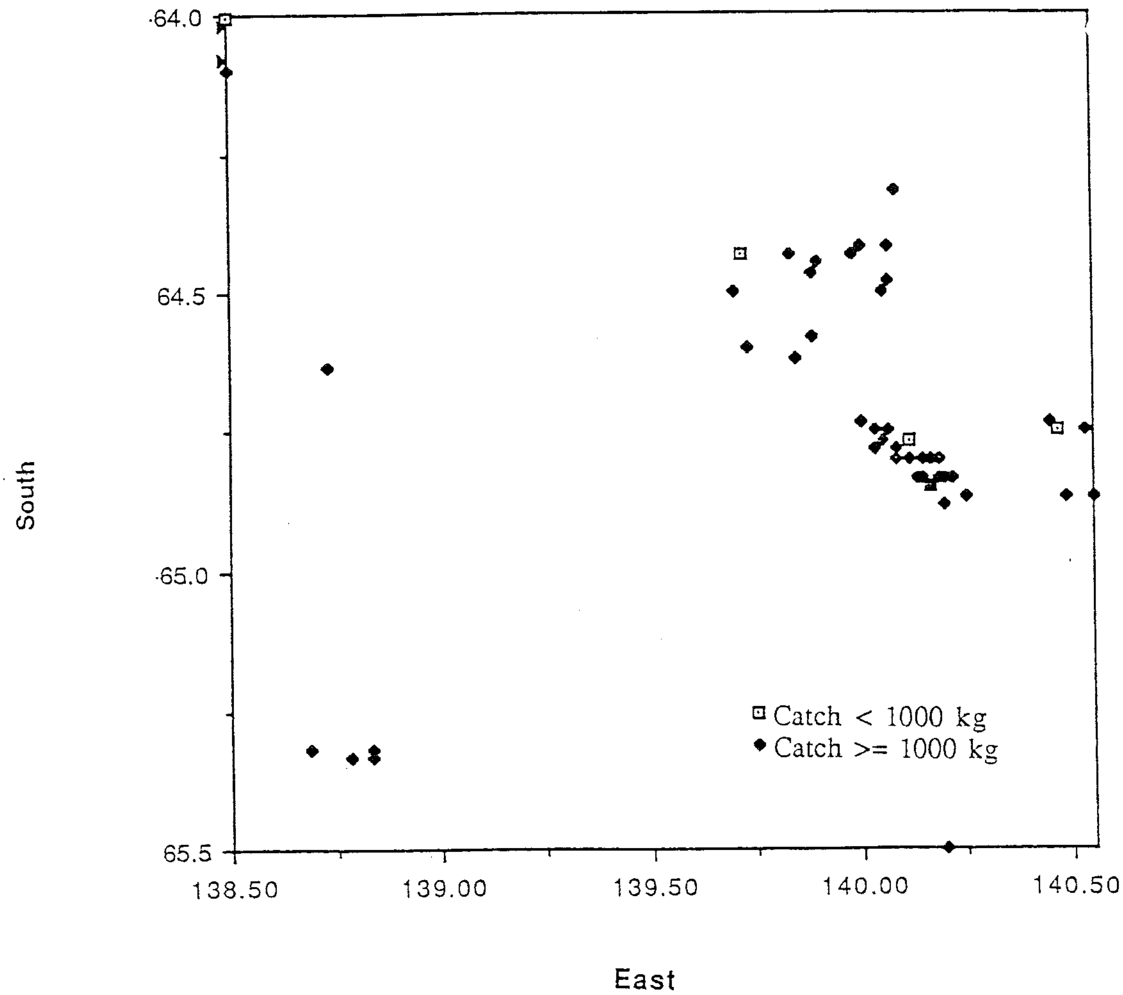

Figure 15: A finer scale spatial plot of hauls by RV *Mys Tihiy* in concentration 8. Note the large gap in fishing activity. From log-book data it is impossible to tell if krill were present in this region and no fishing was attempted because the boundary of the concentration was being delineated or if krill at fishable levels were absent from the region.

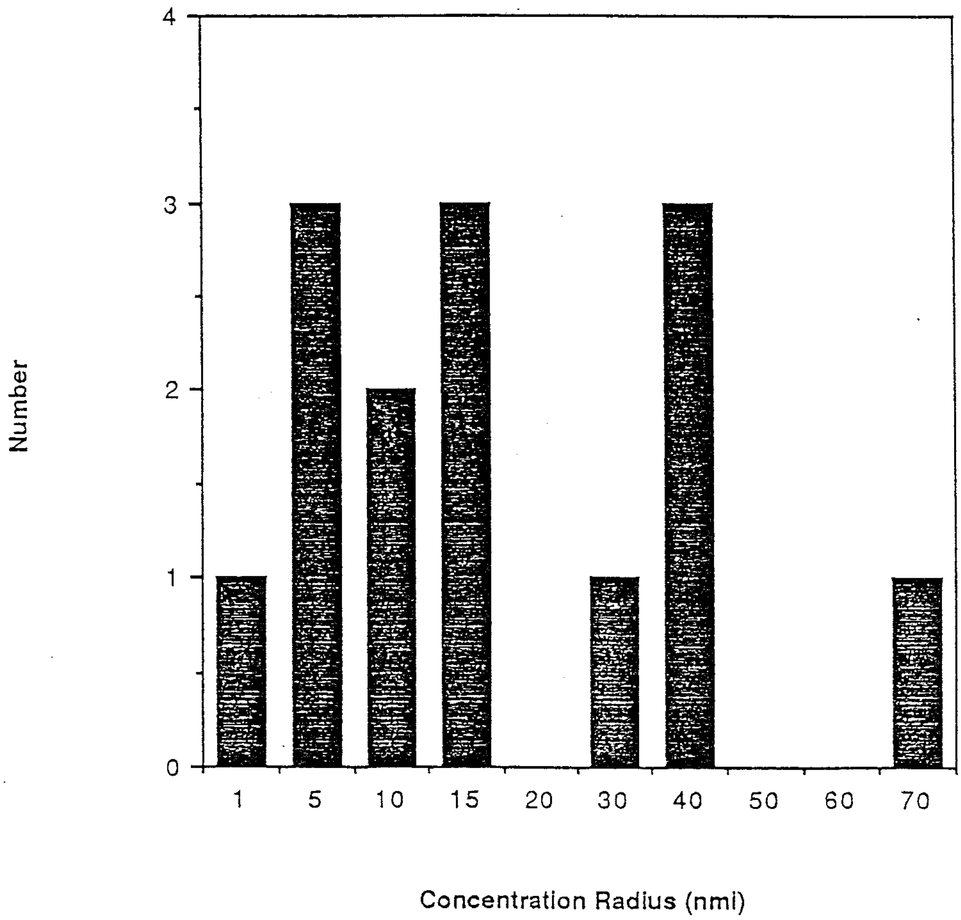

Figure 16: Histogram of the radii of concentrations encountered by RV *Mys Tihiy*.

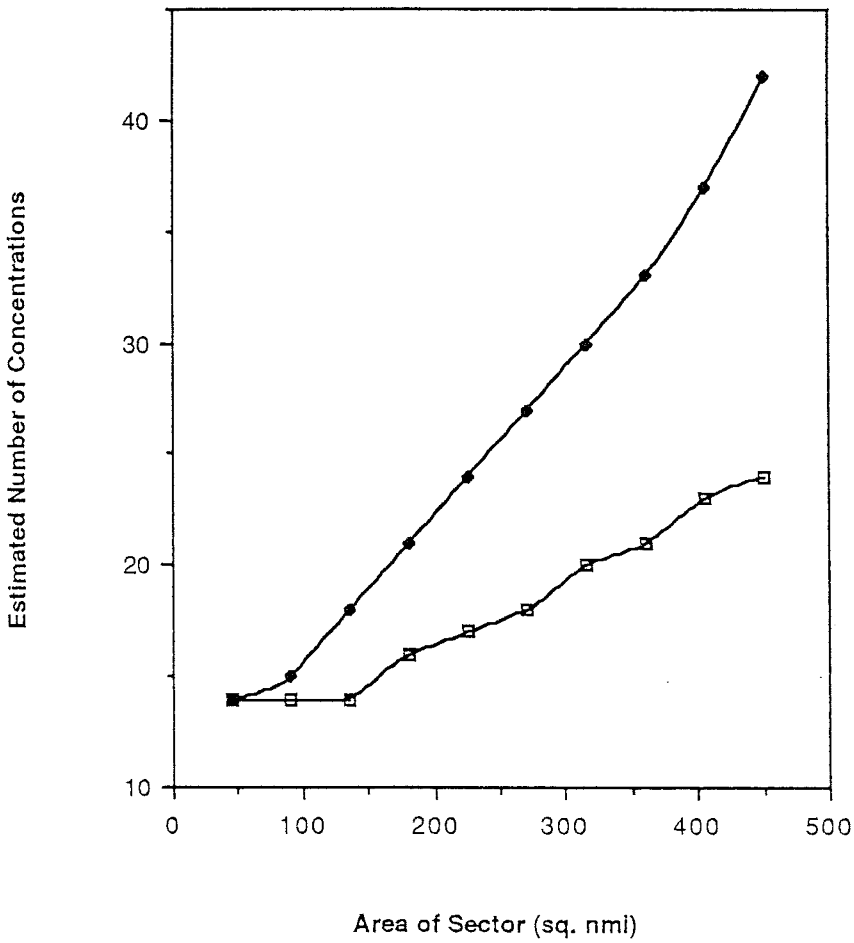

Figure 17: Estimated number of concentrations for the data collected by RV *Mys Tihiy* as a function of area of the sector. The lower curve corresponds to the uncorrected estimate (Equation 4) and the upper curve to the corrected estimate, taking variance concentration radii into account. This figure corrects Figure A6 of Appendix 5 of the Krill CPUE Workshop Report.

Liste des tableaux

Liste des figures

Figure 8: Position spatiale des chalutages du navire *Mys Dalniy*, montrant des concentrations déterminées par la règle des 50 milles nautiques. Les concentrations sont dessinées approximativement à l'échelle. De plus, le trajet du navire entre les concentrations est montré.

Figure 9: Position spatiale des chalutages du navire *Mys Tihiy*, montrant des concentrations déterminées par la règle des 50 milles nautiques. Les concentrations sont dessinées approximativement à l'échelle. De plus, le trajet du navire entre les concentrations est montré. Il est probable que les concentrations 1 et 14; 4, 8 et 9; et 5 et 7 soient les mêmes, mais elles ont été rencontrées dans une succession temporelle qui rend une telle identification difficile.

Figure 10: Une autre définition des concentrations, pour les données provenant du navire *Professor Derugin*. Des cercles sont dessinés autour de points groupés qui semblent "se réunir" naturellement. En raison de la différence entre les échelles spatiales, la forme réelle des concentrations devrait être elliptique.

Figure 11: Une autre définition des concentrations, pour les données provenant du navire *Odyssey*. Des cercles sont dessinés autour de points groupés qui semblent "se réunir" naturellement. En raison de la différence entre les échelles spatiales, la forme réelle des concentrations devrait être elliptique.

Figure 12: Un tracé spatial à échelle plus précise des chalutages du navire *Professor Derugin*, montrant les concentrations 3, 5 et 6. A cette résolution spatiale, trois centres de pêche apparaissent sur le tracé, mais on ignore si les espaces entre les groupements d'activité sont dépourvus de krill.

Figure 13: Un tracé spatial à échelle plus précise des chalutages du navire *Odyssey* dans la concentration 1.

Figure 14: Un tracé spatial à échelle plus précise des chalutages du navire *Mys Tihiy* dans la concentration 4.

Figure 15: Un tracé spatial à échelle plus précise des chalutages du navire *Mys Tihiy* dans la concentration 8. Il faut remarquer le grand vide dans l'activité de pêche. A partir des données relevées sur le carnet de pêche, il est impossible de dire si le krill était présent dans cette région, et la pêche n'a pas été tentée parce que les limites de la concentration étaient en train d'être tracées, ou si le krill, à des niveaux exploitables, était absent de cette région.

Figure 16: Histogramme des rayons de concentrations rencontrées par le navire *Mys Tihiy.*

Figure 17: Nombre estimé de concentrations à partir des données recueillies par le navire *Mys Tihiy* en fonction de la surface du secteur. La courbe du bas correspond à l'estimation non corrigée (Eqn 4), et la courbe du haut correspond à l'estimation corrigée, prenant en compte la variance des rayons de concentration. Cette figure corrige la figure A6 de l'Appendice 5 du rapport de l'Atelier sur la CPUE du krill.

Список таблиц

Список рисунков

морских миль. Концентрации изображены приблизительно в том же масштабе. Помимо этого указывается курс судна при перемещении между концентрациями. Вероятно, что концентрации 1 и 4 являются одной и той же концентрацией, а также, что концентрации 2 и 3 являются частями более крупной концентрации.

Рисунок 8: Местоположение тралений, выполненных судном *Мыс Дальний,* и местоположение концентраций, определенных в соответствии с правилом "50 морских миль". Концентрации изображены приблизительно в том же масштабе. Помимо этого указывается курс судна при перемещении между концентрациями.

Рисунок 9: Местоположение тралений, выполненных судном *Мыс Тихий,* и концентраций, определенных в соответствии с правилом "50 морских миль". Концентрации изображены в приблизительно том же масштабе. Помимо этого указывается курс судна при перемещении между концентрациями. Вероятно, что концентрации 1 и 14, 4, 8 и 9, а также 5 и 7 являются одними и теми же, но последовательность их обнаружения затрудняет точное определение.

Рисунок 10: Альтернативное определение концентраций по данным судна *Профессор Дерюгин.* Окружности вычерчены вокруг скоплений точек, которые "формируются" естественным образом. В связи с различием пространственных масштабов, в действительности концентрации имеют форму эллипса.

Рисунок 11: Альтернативное определение концентраций по данным судна *Одиссей.* Окружности вычерчены вокруг скоплений точек, которые "формируются" естественным образом. В связи с различием пространственных масштабов, в действительности концентрации имеют форму эллипса.

Рисунок 12: Нанесенное на карту более подробное изображение местоположения тралений, выполненных судном *Профессор Дерюгин,* показывающее концентрации 3,5 и 6. При подобном пространственном масштабе на карте наблюдаются три основных участка промысла, при этом неизвестно, имеется ли криль в промежутках между основными участками промысла.

Рисунок 13: Нанесенное на карту более подробное изображение местоположений тралений, выполненных судном *Одиссей* в пределах концентрации 1.

Рисунок 14: Нанесенное на карту более подробное изображение местоположений тралений, выполненных судном *Мыс Тихий* в пределах концентрации 4.

Рисунок 15: Нанесенное на карту более подробное изображение местоположений тралений, выполненных судном *Мыс Тихий* в пределах концентрации 8. Обратите внимание на отсутствие промысловой деятельности на значительной площади. По записям в судовом журнале невозможно определить, присутствовал ли криль в этом районе и по какой причине не проводился промысел: в связи с тем, что определялись границы распространения концентрации, или же пригодный для промысла криль отсутствовал.

Lista de las tablas

Lista de las figuras

Figura 4: Localidad espacial de los arrastres hechos por el navío Mys Dalniy. Los arrastres están separados de acuerdo a la cantidad de la captura. Notése la separación aparente de arrastres en esta escala espacial.

Figura 5: Localidad espacial de los arrastres hechos por el navío *Mys Tihiy*. Los arrastres están separados de acuerdo a la cantidad de la captura.

Figura 6: Localidad espacial de los arrastres hechos por el navío *Professor Derugin*, mostrando concentraciones determinadas por el reglamento de 50 mn. Concentraciones están aproximadamente a escala. Es posible que las concentraciones 3,5, y 6 y 4 y 7 sean la misma, pero fueron encontradas en una secuencia temporaria lo cual no permite hacer una conclusión precisa.

Figura 7: Localidad espacial de los arrastres hechos por el navío *Odyssey*, mostrando concentraciones determinadas por el reglamento de 50 mn. Concentraciones están aproximadamente a escala. En adición, se muestra la trayectoria del navío entre las concentraciones. Es posible que las concentraciones 1 y 4 sean la misma y que 2 y 3 sean en realidad parte de una concentración mayor.

Figura 8: Localidad espacial de los arrastres hechos por el navío *Mys Dalniy*, mostrando concentraciones determinadas por el reglamento de 50 mn. Concentraciones están aproximadamente a escala. En adición, se muestra la trayectoria del navío entre las concentraciones.

Figura 9: Localidad espacial de los arrastres hechos por el navío *Mys Tihiy*, mostrando concentraciones determinadas por el reglamento de 50 mn. Concentraciones están aproximadamente a escala. En adición, se muestra la trayectoria del navío entre las concentraciones. Es posible que las concentraciones 1 y 14; 4, 8 y 9; y 5 y 7 sean las mismas, pero fueron encontradas en una secuencia temporaria lo cual no permite hacer una conclusión precisa.

Figura 10: Una definición alternativa de las concentraciones, para los datos provenientes del navío *Professor Derugin*. Círculos se han dibujado alrededor de grupos de puntos que parecen "agregarse" naturalmente. Debido a la diferencia en las escalas espaciales, la configuración verdadera de las concentraciones sería elíptica.

Figura 11: Una definición alternativa de las concentraciones, para los datos proveniente del navío *Odyssey*. Círculos se han dibujado alrededor de grupos de puntos que parecen "agregarse" naturalmente. Debido a la diferencia en las escalas espaciales, la configuración verdadera de las concentraciones sería elíptica.

Figura 12: Un gráfico de la escala espacial más detallado de los arrastres hechos por el navío *Professor Derugin*, mostrando las concentraciones 3,5 y 6. En esta resolución espacial, tres centros de pesca aparecen en el gráfico, pero no se sabe si los espacios entre los grupos de actividad están desprovistos de krill.

Figura 13: Un gráfico de la escala espacial más detallado de los arrastres hechos por el navío *Odyssey* en la concentración 1.

Figura 14: Un gráfico de la escala espacial más detallado de los arrastres hechos por el navío *Mys Tihiy* en la concentración 4.

Figura 15: Un gráfico de la escala espacial más detallado de los arrastres hechos por el navío *Mys Tihiy* en la concentración 8. Nótese el gran espacio en actividad pesquera. Según la información obtenida de los diarios de bitácora es imposible poder decir si el krill se encontraba presente en esta región y no se atentó pescar porque los límites de la concentración estaba recién siendo delimitada o porque el krill a niveles apropiados para pesca estaban ausentes de esta región.

Figura 16: Histograma del radio de concentración encontrada por el navío *Mys Tihiy*.

Figura 17: Número estimado de las concentraciones según los datos recopilados por el navío *Mys Tihiy* como función del área del sector. La curva inferior corresponde a la estimación sin rectificación (Ecn 4) mientras la curva superior es la estimación rectificada, tomando en consideración la variación en los radios de concentración. Esta figura amenda Figura A6 del Apéndice 5 del Informe del Taller sobre Krill CPUE.