WG-KRILL-91/19

SMALL SCALE KRILL SURVEYS: SIMULATIONS BASED ON OBSERVED EUPHAUSIID DISTRIBUTIONS

D.J. Agnew*, S. Nicol**

Abstract

An observed distribution of aggregations of the euphausiid, *Meganyctiphanes norvegica* is used to model the effects of krill swarm orientation and shape on the success of two proposed survey designs. The simulation involves a number of random paths of parallel or radially arranged transects passing through three distributions each of which is given four rotations. The results indicate that the coefficient of variation (CV) of mean krill density varies inversely with mean density, and is lowest for the survey design utilising parallel transects set at right angles to the long axis of the aggregations. Calculations based on the power of surveys to reliably detect changes in mean density indicate that with probability of Type I and Type II errors 0.1 and 0.2 respectively, about 100 transects would be required to detect changes of 40% in the mean if CVs are as high as those obtained in the simulations.

Résumé

L'observation d'une répartition de concentrations de l'euphausiacé *Meganyctiphanes norvegica* est utilisée pour la modélisation des effets de l'orientation et de la forme des essaims de krill sur le succès de deux propositions de modèles de campagnes d'évaluation. La simulation met en jeu un certain nombre de voies aléatoires de transects parallèles ou radiaux traversant trois concentrations, chacune d'elle subissant quatre rotations. Les résultats indiquent que le coefficient de variation (CV) de la densité moyenne du krill varie inversement à la densité moyenne et qu'il atteint le taux le plus faible lorsque le modèle d'évaluation utilise les transects parallèles perpendiculaires à la longueur des concentrations. Les calculs, fondés sur la capacité qu'ont les évaluations de déceler les changements de densité moyenne d'une manière fiable, révèlent qu'avec une probabilité d'erreurs de Type I et II de 0,1 et 0,2 respectivement, et pour des CV aussi élevés que ceux obtenus lors des simulations, une centaine de transects seraient nécessaires pour déceler des changements de 40%.

Резюме

Наблюденное распределение агрегаций эвфаузиид, *Meganyctiphanes norvegica* использовано в целях моделирования влияния ориентации и формы скоплений криля на успех двух предложенных схем съемок. Моделирование предполагает несколько произвольных курсов параллельно или радиально организованных разрезов, проходящих через три распределения, каждое из

---

* CCAMLR Secretariat, 25 Old Wharf, Hobart, Tasmania 7000, Australia
** Australian Antarctic Division, Channel Highway, Kingston, Tasmania 7050, Australia

которых вращают четыре раза. Результаты показывают, что коэффициент изменчивости (CV) средней плотности криля изменяется обратно пропорционально средней плотности, и является наименьшим, когда схема съемки использует параллельные разрезы, установленные на прямых по отношению к длинной оси агрегаций углах. Вычисления, основанные на способности съемок надежно выявлять изменения в средней плотности, показывают, что при вероятности ошибок Типа I (0,1) и Типа II (0,2), для выявления изменений в среднем на 40%, потребуется около 100 разрезов, если значения CV окажутся такими же, что и при моделировании.

Resumen

A partir de una concentración de distribución conocida del eufausido *Meganyctiphanes norvegica,* se modelan los efectos de la orientación y de la forma de los cardúmenes en el logro de dos diseños de prospección propuestos. La simulación comprende varias rutas aleatorias, en transectos paralelos o radiales, que atraviesan las tres distribuciones y en las que se hacen cuatro giros en cada una. Los resultados indican que el coeficiente de variación (CV) de la densidad media del krill varía inversamente a la densidad media, y que es menor en el diseño de prospección basado en transectos paralelos dispuestos en ángulos rectos al eje longitudinal de la concentración. Los cálculos basados en la potencia de prospección para conocer las variaciones en la densidad media indican que, con la probabilidad de errores de tipo I y tipo II de 0.1 y 0.2 respectivamente, haría falta realizar unos 100 transectos para poder detectar cambios del 40%, siempre que los CV fueran tan altos como los que se obtuvieron en las simulaciones.

1. INTRODUCTION

During the FIBEX and SIBEX krill biomass surveys various systems of survey design and analysis were considered in order to produce reliable estimates of krill biomass and variance within particular regions around the Antarctic continent. BIOMASS (1980 and 1981) generally recommended that randomly placed transects should run across contour lines in krill abundance, and this meant across the mean direction of ocean currents. Some of the earlier surveys, however, were run with the main transects running east-west. This survey design was used with some success during the BIOMASS experiments (Miller and Hampton, 1989) on areas with diameters up to 500 n miles.

The requirements of prey monitoring for CEMP are, for more localised surveys, directed at regions around CEMP sites for the duration of CEMP predator parameter monitoring; these may be described as having a radius of 50 to 100 km (27 to 50 n miles) (SC-CAMLR-IX, Annex 4, Table 3) and the same criteria as for the BIOMASS surveys (contours of krill abundance) are unlikely to apply. Everson (1987) has considered the requirements of these types of surveys and concluded that a radial transect design may be more suitable and easier to perform than parallel transects.

The analysis suggested for both these designs is that recommended by BIOMASS (1986) and consists of obtaining mean density estimates for krill for a number of transects and combining these using ratio estimator techniques within strata. This assumes that transects are independent (co-variance is not included) and that variance increases with transect length.

The areal shape of euphausiid aggregations has been reviewed by Miller and Hampton (1989) but information on the spatial relationships of aggregations within known distributions is rare. To our knowledge the only studies of this type are those of Hampton (1985), using side-scan sonar on *Euphausia superba* swarms, and aerial photographs of surface swarms of another euphausiid, *Meganyctiphanes norvegica* (Nicol, 1986). These data show that swarms are predominantly elongated along one axis, and do not generally have shapes that can be approximated by circles, the case that is usually assumed for simulation studies (Butterworth, 1988 has considered some of the consequences of elongated swarms). Furthermore, Nicol (1986) shows that aggregations within an area may be elongated in one direction, presumably in response to current structures in the area.

This paper considers the effect of krill swarm orientation on survey design using real data on the distribution of euphausiid swarms collected by Nicol (1986). We examine the behaviour of random parallel transect and radial transect designs under a number of scenarios, and discuss the implications for the extent and frequency of transects required for the purposes of the CEMP program.

2. METHODS

Two maps of euphausiid distributions are shown in Figures 1(a) and 1(b). Although these are not *E. superba* (being *Meganyctiphanes*) and are on a very small scale (60 m diameter) they are used here to model the types of distributions shown by krill on larger scales. The most important feature of these distributions is that the swarms were observed to be moving and are orientated in a particular direction.

These krill distributions were coded into two areas, divided by 100 x 100 grids (distributions A and B, Figure 1a,). An additional distribution (C) was constructed from distribution A with the addition of two swarms duplicated within distribution A (Figure 1(c)). Each occurrence of krill in a grid square was taken to represent a unit krill density. Random transects were taken over the area and the proportion of krill encountered was expressed as a percentage and taken to represent mean krill density for the transect. This is an equivalent process to that used to calculate mean krill density in $g \cdot m^{-2}$ over a single transect in previous studies (BIOMASS, 1986).

Figures 2(a) and (b) give examples of random transects overlying krill distributions. The parallel transects were overlaid vertically on the grid, and calculation of percentage cover involved searching each pass for krill occurrence. Radial transects were designed on a 90° arc from the origin at the bottom left hand corner with a constant radius of 100 units, but they had a gap close to the origin to simulate the sort of pattern suggested by Everson (1987). Because transects estimate krill density over a larger arc the further they are from the origin, estimates of percentage cover were weighted by the distance from the origin.

Mean density and variance for the whole area was calculated from a number of transects (equation 4 of BIOMASS (1986) simplifies to a standard calculation of variance when transects are all the same length). For comparison, the actual mean density of krill in the area was calculated by taking the total possible area that the transects covered (the total survey area) and calculating the known percentage cover of krill in this area.

For each survey pattern, a number of rotations of the distributions were used to investigate the effects of starting surveys at different positions with regard to the swarms.

3. RESULTS

The results of 10 000 transects on each of the distributions rotated sequentially through 90° intervals is shown in Table 1. It is apparent that the coefficient of variation is usually very high (between 100% and 160%), a result of the high number of passes encountering no krill. Larger surveys are unlikely to have so severe a problem of zero encounters. Krill densities were log normally distributed apart from the zero values. Despite this, the calculated mean density, taken as the mean of all untransformed transect densities, converged on the known mean (Table 1). Figure 3 shows that there was a relationship between the means and the standard deviations. There was a great deal of variation in coefficient of variation (CV) (calculated as standard deviation divided by the mean) using the radial design, in general more so than using the parallel design. The lowest CVs were obtained using the parallel designs with the transects going across the axis of movement of the swarms.

4. DISCUSSION

The coefficients of variation seen in Figure 3(b) are very high, but are similar to those obtained by Higginbottom *et al.* (1988) from 1 n mile integration intervals along transects taken for FIBEX, ADBEX-II and SIBEX-II (mean CV = 1.6). Most reported density and biomass estimates and variances are not directly comparable to those calculated here because following the procedures suggested in BIOMASS (1986) they are variances of the mean densities within a transect $\overline{\rho}_k$, where that transect is typically several hundreds of nautical miles long. Because of the scale used in this study the more appropriate estimates of variance are those of the variance of integration intervals within a transect.

It is not appropriate here to comment on the magnitude of variances that are likely to be obtained in whole surveys of this nature, because of the very small scale of our distributions. However, it is apparent that:

(i) parallel survey designs that travel at right angles to the orientation of krill swarms have lower variances than either parallel designs parallel to their orientation or radial designs. The former is predictable but the latter somewhat surprising - radial designs appear to exacerbate the effect of swarm orientation; and

(ii) with greater mean density of krill the CV obtained by either survey declines.

For the purposes of monitoring krill biomass for CEMP the magnitude of the CV is extremely important. The effect of CV on the power of a survey to detect changes in mean biomass is dependent on the number of transects used. Figure 4 shows the relationship between CV and number of transects required to confidently detect changes in mean densities of 20 to 50% (probability of Type I error = 0.1, probability of Type II error = 0.2) (Sokal and Rohlf, 1981). The number of transects required to reliably detect changes of 20%, for instance, is 28 when the CV is 0.3 and 310 when it is 1.0. Everson (1987) estimates that 10 transects in a CEMP survey could be completed in 10 days. Thus even under favourable conditions, when the CV is close to 0.3, prey surveys may take 30 or more days to complete if sufficient power for inter-annual comparisons is required by the CEMP program.

REFERENCES

BIOMASS. 1980. FIBEX acoustic survey design. *BIOMASS Report Series 14.*

BIOMASS. 1981. Post - FIBEX data interpretation workshop. *BIOMASS Report Series 20.*

BIOMASS. 1986. Post - FIBEX acoustic workshop. *BIOMASS Report Series 40.*

BUTTERWORTH, D.S. 1988. A simulation study of krill fishing by an individual Japanese trawler. In: *Selected Scientific Papers, 1988 (SC-CAMLR-SSP/5).* CCAMLR, Hobart, Australia: 1-108.

EVERSON, I. 1987. Prey monitoring surveys. A discussion of the characteristics necessary in prey surveys. *Selected Scientific Papers, 1987 (SC-CAMLR-SSP/4).* CCAMLR, Hobart, Australia: 375-391.

HAMPTON, I. 1985. Abundance, distribution and behaviour of *E. superba* in the Southern Ocean between 15 and 30°E during FIBEX. In: SIEGFRIED, W.R., P.R. CONDY and R.M. LAWS (Eds). *Antarctic Nutrient Cycles and Food Webs* Berlin: Springer-Verlag. pp. 294-303.

HIGGINBOTTOM, I.R., K.R. KERRY, and S.E. WAYTE. 1988. Hydroacoustic surveys of the distribution and abundance of krill: Prydz Bay region - FIBEX, ADBEX II and SIBEX II, MV *Nella Dan. ANARE Res. Notes. 62.*

MILLER, D.G.M. and I. HAMPTON. 1989. Biology and ecology of the Antarctic krill (*Euphausia superba* Dana): A review. *BIOMASS Scientific Series 9.*

NICOL, S. 1986. Shape, size and density of daytime surface swarms of the euphausiid *Meganyctiphanes norvegica* in the Bay of Fundy. *J. Plankton Res. 8*(1): 29-39.

SC-CAMLR. 1990. *Report of the Ninth Meeting of the Scientific Committee (SC-CAMLR-IX).* CCAMLR, Hobart, Australia.

SOKAL, R.R. AND F.J. ROHLF. 1981. *Biometry,* Second Edition. New York: W.H. Freeman and Company. pp. 859.

Table 1: Mean and standard deviation of krill density calculated from 10 000 random transects on four separate orientations of three krill distributions shown in Figure 1. Direction of rotation is anticlockwise. With this number of transects the standard deviation is taken to approximate σ.

Dataset and Method Used	Real density of Krill in Surveyed Area	Calculated Mean Krill Density After 10 000 Transects	Standard Deviation of Density (σ)
Parallel Survey:			
Area A	4.6	4.59	5.18
Area A rotated 90°	4.6	4.46	6.17
Area B	2.24	2.21	2.87
Area B rotated 90°	2.24	2.19	3.18
Area C	7.85	7.78	6.86
Area C rotated 90°	7.85	7.88	7.04
Radial Survey:			
Area A	5.92	5.89	7.74
Area A rotated 90°	2.28	2.41	3.9
Area A rotated 180°	5.71	5.6	7.49
Area A rotated 270°	5.09	5.04	6.16
Area B	2.56	2.51	3.81
Area B rotated 90°	2.08	2.01	3.17
Area B rotated 180°	2.68	2.59	3.21
Area B rotated 270°	2.86	2.81	3.21
Area C	9.85	9.67	8.18
Area C rotated 90°	6.5	6.64	8.25
Area C rotated 180°	9.94	9.9	8.27
Area C rotated 270°	8.48	8.54	10.58

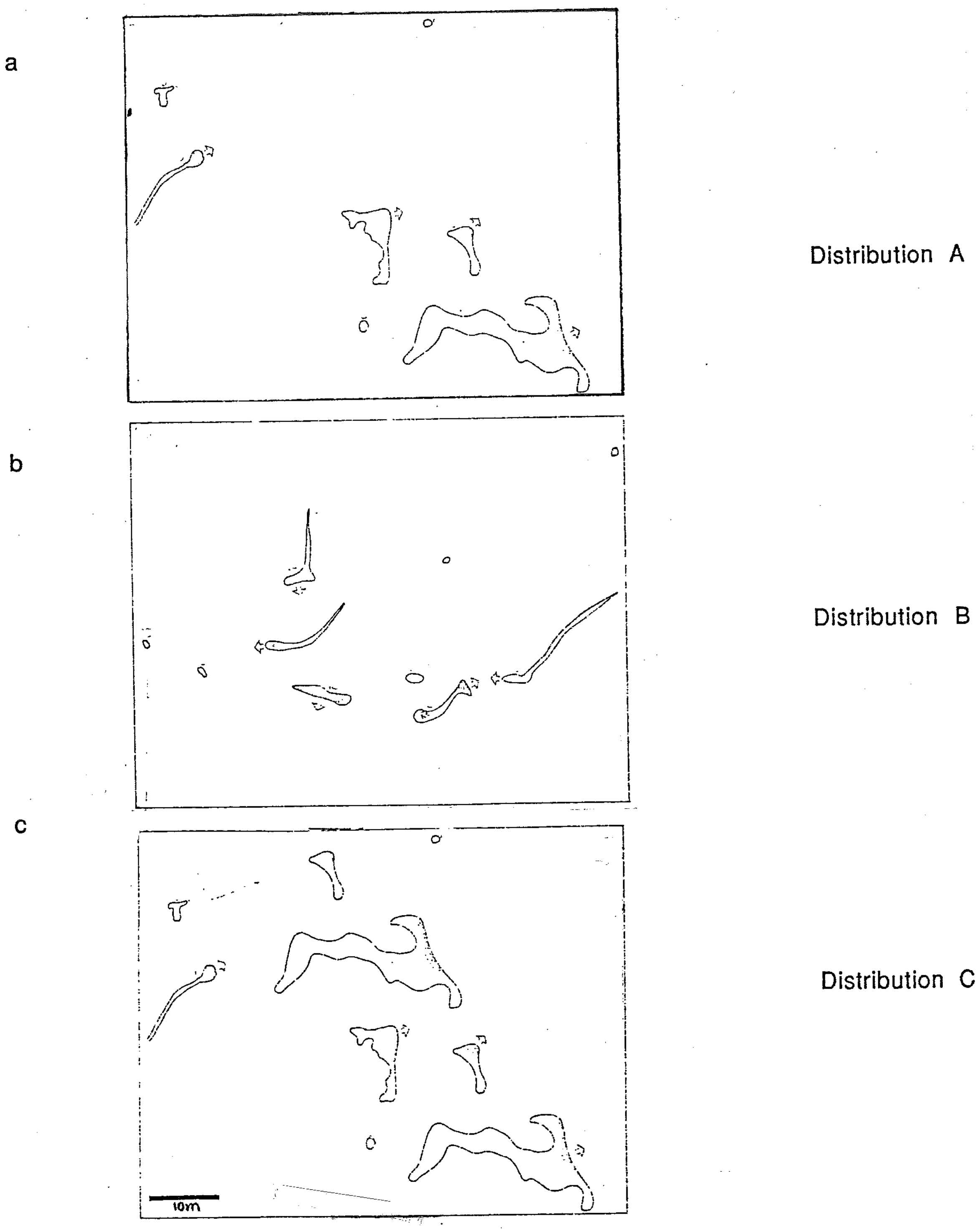

Figure 1: Krill distribution patterns used in the study. Direction of movement of individual swarms is shown by arrows and in general is east-west. The distributions are shown in their unrotated states, and rotation proceeded anticlockwise.

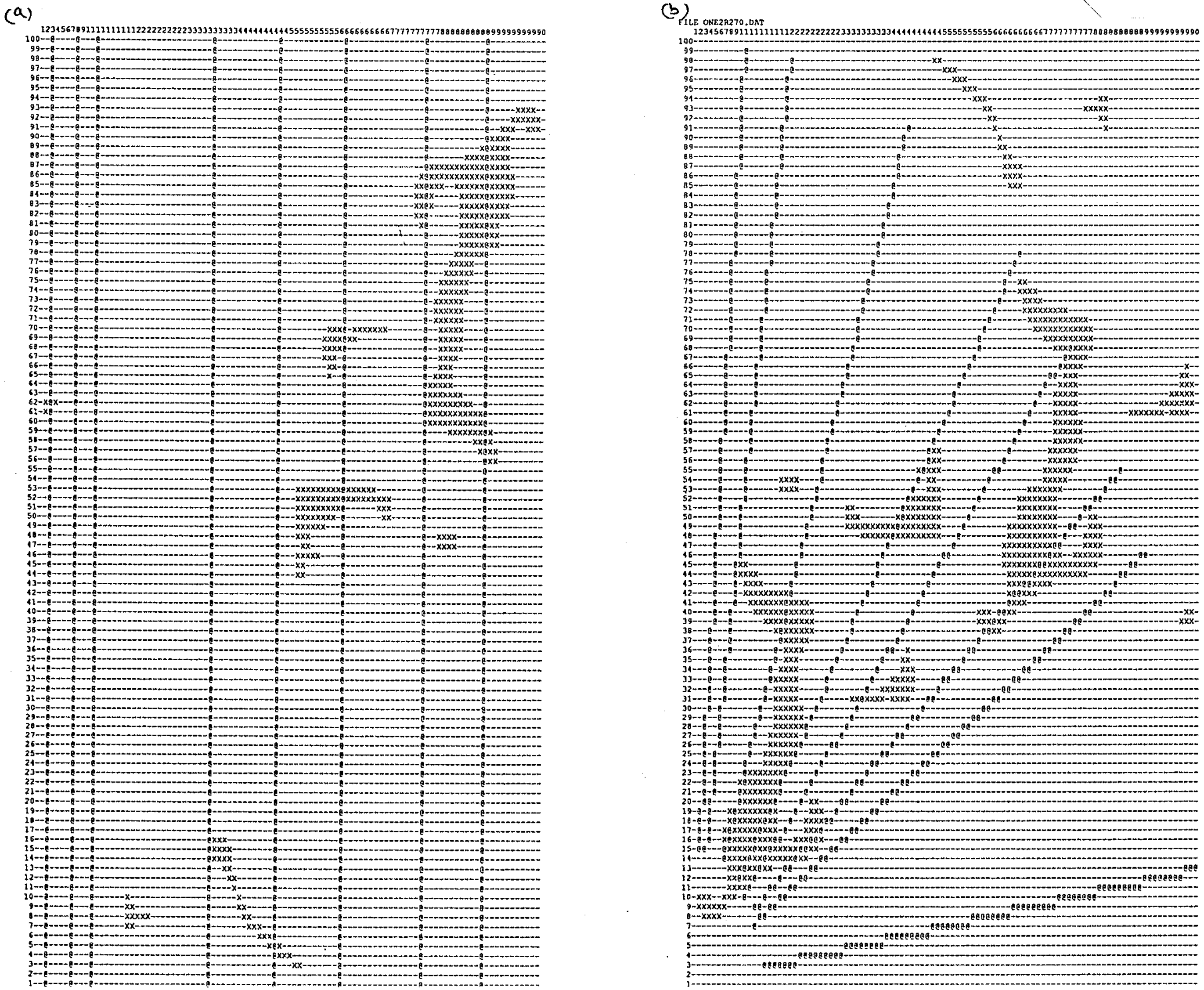

Figure 2: Random parallel (a) and radial (b) transects overlaid on distribution A (90° rotation) and B (270° rotation) respectively.

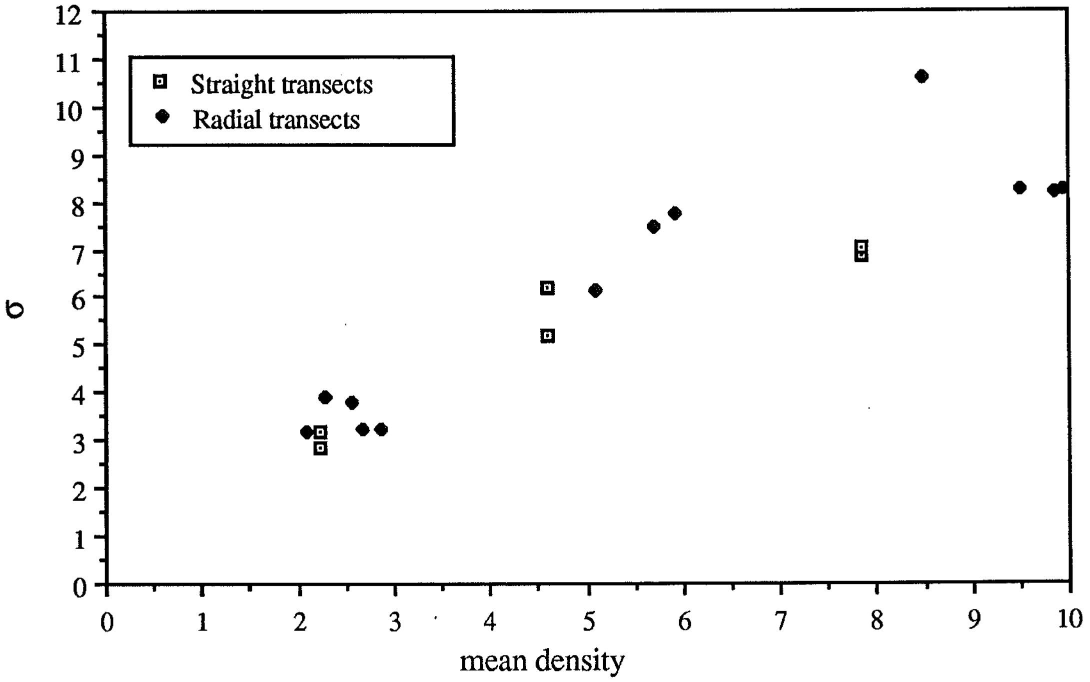

Figure 3(a): Expected mean density versus standard deviation of 10 000 random transects for all three areas in four rotated states. For more explanation of the rotations applied see Table 1.

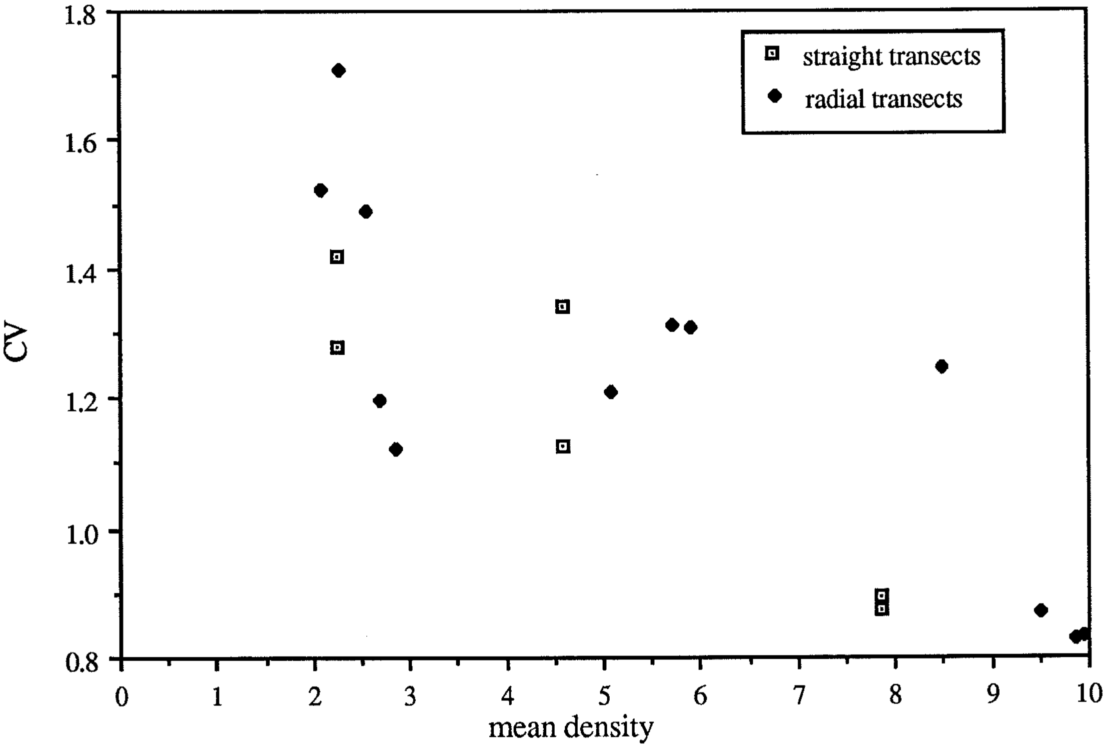

Figure 3(b): Expected mean density versus coefficient of variation of 10 000 random straight and radial transects of four rotations of three krill distributions.

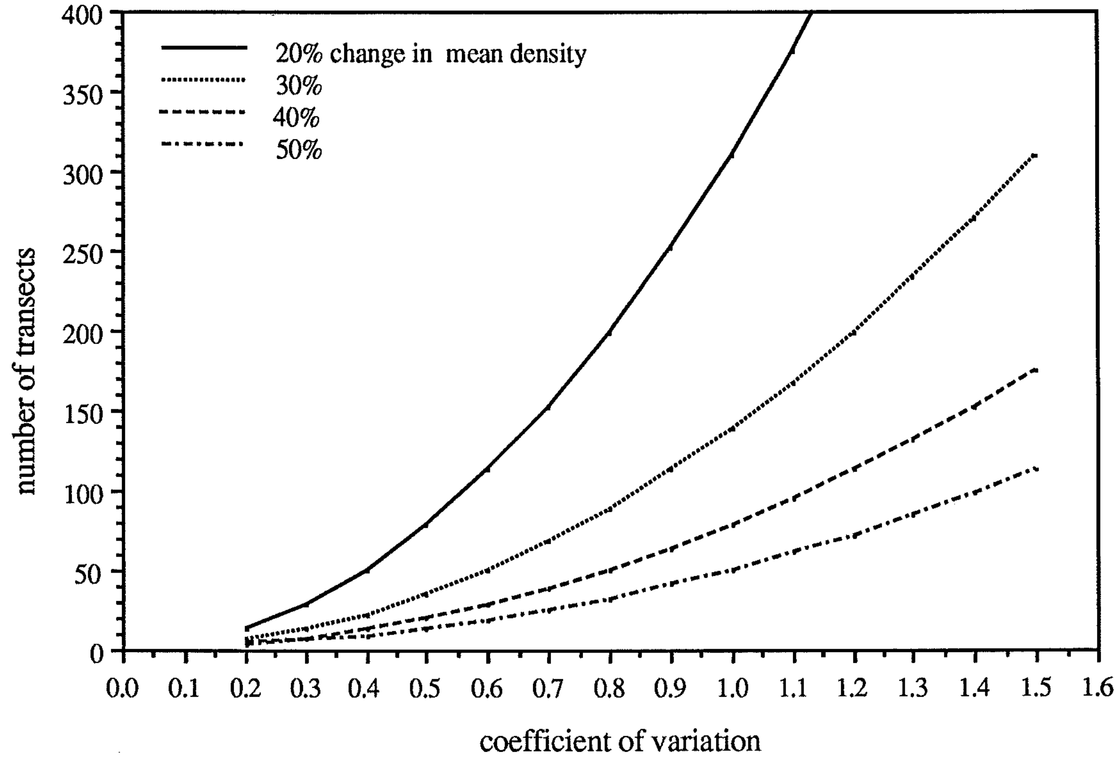

Figure 4: Sample size required to detect a change in mean krill density with alpha = 0.1 and power = 0.8.

Liste des tableaux

Tableau 1: Ecart moyen et écart-type de densité du krill calculés à partir de 10 000 transects choisis au hasard sur quatre orientations distinctes de trois concentrations de krill illustrées sur la figure 1. La rotation est effectuée dans le sens inverse des aiguilles d'une montre. Pour ce nombre de transects, l'écart-type présumé est proche de σ.

Liste des figures

Figure 1: Schémas de répartition du krill utilisés dans l'étude. La direction du mouvement des essaims individuels, en général d'est en ouest, est représentée par des flèches. La répartition est illustrée avant toute rotation, cette dernière étant effectuée dans le sens inverse des aiguilles d'une montre.

Figure 2: Transects droits (a) et radiaux (b) placés au hasard des répartitions A (rotation de 90°) et B (rotation de 270°) respectivement.

Figure 3a): Densité moyenne escomptée par opposition à l'écart type de 10 000 transects disposés au hasard dans les trois zones et pour quatre rotations. Pour le détail des rotations appliquées, voir le tableau 1.

Figure 3b): Densité moyenne escomptée par opposition au coefficient de variation de 10 000 transects droits et radiaux disposés au hasard, de quatre rotations de trois répartitions de krill.

Figure 4: Taille de l'échantillon requis pour déceler un changement de densité moyenne de krill pour alpha = 0,1 et capacité = 0,8.

Список таблиц

Таблица 1: Среднее и стандартное отклонения плотности криля, вычисленные из 10 000 произвольных разрезов на четырех отдельных ориентациях трех распределений криля, изображенных на Рисунке 1. Направление вращения - против часовой стрелки. При этом количестве разрезов стандартное отклонение считается приблизительным к σ.

Список рисунков

Рисунок 1: Модели распределения криля, использованные в данном исследовании. Направление движения отдельных скоплений показано стрелками и, в основном, указывает на движение с востока на запад. Распределения показаны в состоянии покоя. Вращение - против часовой стрелки.

Рисунок 2: Произвольные параллельные (а) и радиальные (b) разрезы, перекрывающие распределение А (вращение 90°) и В (вращение 270°) соответственно.

Рисунок 3(a): Ожидаемая средняя плотность в сравнении со стандартным отклонением 10 000 произвольных разрезов на всех трех участках в четырех состояниях вращения. В Таблице 1 дается больше информации о применяемых вращениях.

Рисунок 3(b): Ожидаемая средняя плотность в сравнении с коэффициентом изменчивости 10 000 произвольных параллельных и радиальных разрезов в четырех вращениях трех распределений криля.

Рисунок 4: Количество проб, необходимое для выявления изменения в средней плотности криля, где альфа = 0.1 и мощность = 0.8.

Lista de las tablas

Tabla 1: Desviación cuadrática y media de la densidad del krill, calculada a partir de 10 000 transectos aleatorios aplicando cuatro giros diferentes a las tres distribuciones de krill de la Figura 1. La dirección de la rotación es sinistrorsa. La desviación cuadrática para este número de transectos es aproximadamente σ.

Lista de las figuras

Figura 1: Modelos de distribución empleados en este estudio. Las flechas indican la dirección del giro para cada cardúmen que, por lo general, es este-oeste. Las distribuciones se muestran antes de hacer la rotación, siendo ésta contraria a la de las agujas del reloj.

Figura 2: Transectos aleatorios en línea paralela (a) y radial (b) superpuestas en la distribución A (rotación de 90°) y B (rotación 270°) respectivamente.

Figura 3(a): Densidad media prevista comparado con la desviación cuadrática de 10 000 transectos aleatorios efectuados en las tres áreas con cuatro rotaciones distintas. Véase tabla 1 para más detalles de las rotaciones aplicadas.

Figura 3(b): Densidad media supuesta comparada con el coeficiente de variación de 10 000 transectos en línea recta y radiales de cuatro rotaciones de las tres distribuciones.

Figura 4: Tamaño de muestra necesario para detectar un cambio en la densidad media del krill con alpha = 0.1 y potencia = 0.8.