ANALYSIS AND MODELLING OF THE SOVIET SOUTHERN OCEAN KRILL FLEET

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Abstract

The first part of this document contains an analysis of data pertaining to the Soviet krill fleet. The data base consists of the records of 12 different cruises by 8 different research vessels between 1981 and 1984. The data are analyzed according to operational characteristics of the fishing process such as trawl duration, krill catch, or between trawl movement. Correlation analyses are presented as a means of understanding the within trawl and between trawl features of the operation. The data support the notion of a "patches within patches" model for the distribution of krill in the southern oceans.

The second part of this document contains the development and use of a simulation model of a Southern Ocean krill fleet. The objective of the work is to answer questions such as: what information do catch and effort data provide about krill abundance or how easily can significant changes in krill biomass be detected? The krill distributional model begins with individual krill which are assumed to aggregate into swarms of krill. The swarms then aggregate into concentrations, which are the foci for the fishing operation. Parameters of the model are motivated by study of the literature and FIBEX results. A model is developed for a survey vessel that does no fishing, but simply locates concentrations of krill for the fishing fleet. The fishery model involves finding concentrations, finding swarms within concentrations and fishing individual swarms. Wherever possible, operational data from Part I are used to provide distributions in Part II. General considerations about the theory of abundance indices for pelagic, schooling species are discussed. In particular, the importance of the time spent searching for swarms is highlighted. A theory for detecting changes in krill biomass is developed. Forty-four different abundance indices are considered and their effectiveness in detecting changes in krill biomass is studied. The best indices involve two separate measures: one in which survey vessel discoveries are used to track the number of concentrations and a measure of the form catch/swarm/search-time to track swarm density within concentrations and krill density within swarms. Operational recommendations are given: (i) I propose an experiment in which survey and fishing vessels operate simultaneously but independently in the same region, (ii) I recommend that fishing vessels begin to indicate in their log books the amount of between trawl time spent searching, (iii) I propose that CCAMLR consider sending a Ph.D. level modeller to sea in order to develop a truly operational model of the fishing process, and (iv) I propose abundance indices that could be used to track krill biomass.

Résumé

La première partie de ce document contient une analyse des données concernant la flottille de pêche au krill soviétique. La base de données

consiste de registres de 12 campagnes d'étude différentes menées par 8 navires de recherche différents entre 1981 et 1984. Les données ont été analysées selon les caractéristiques d'opération du processus de pêche, tels que la durée du chalutage, la prise du krill, ou les déplacements entre chalutages. Des analyses de corrélation sont présentées comme moyen de compréhension des caractéristiques de l'opération pendant les chalutages et entre les chalutages. Les données corroborent la notion d'un modèle de "regroupements à l'intérieur de regroupements" pour la distribution du krill dans les océans australs.

La seconde partie de ce document contient le développement et l'utilisation d'un modèle de simulation d'une flotille de pêche au krill dans l'océan austral. L'objectif de ce travail est de répondre aux questions telles que: quelles informations sont fournies par les données de capture et d'effort sur l'abondance du krill, ou avec quelle facilité peut-on détecter des changements importants dans la biomasse du krill? Le modèle de distribution du krill commence avec le krill individuel, que l'on présume se concentrer dans des essaims de krill. Les essaims se regroupent alors en concentrations qui sont les objets de l'opération de pêche. Les paramètres du modèle sont motivés par une étude de la littérature et des résultats de la FIBEX. Un modèle est développé pour un navire de recherche qui ne pêche pas, mais détermine simplement la position des concentrations de krill pour la flotille de pêche. Le modèle de la pêcherie implique la localisation des concentrations et des essaims à l'intérieur des concentrations, et la pêche des essaims individuels. Partout où cela est possible, des données sur les opérations de la première partie sont utilisées pour fournir les distributions dans la partie II. Des considérations générales en ce qui concerne la théorie des indices d'abondance pour les espèces pélagiques grégaires sont discutées. En particulier, l'importance du temps passé à la recherche des essaims est soulignée. Une théorie sur la détection des changements de la biomasse du krill est développée. Quarante-quatre indices d'abondance différents sont considérés et leur efficacité dans la détection des changements dans la biomasse du krill est étudiée. Les meilleurs indices entraînent deux mesurages séparés: l'un où les découvertes faites par le navire de recherche sont utilisées pour contrôler, de façon continue, le nombre de concentrations, et un mesurage de capture/essaim/temps de recherche pour un contrôle suivi de la densité des essaims à l'intérieur des concentrations et la densité du krill au sein des bancs. Les recommandations opérationnelles données sont les suivantes: (i) je propose une expérience où les navires de recherche et de pêche opèrent simultanément mais indépendamment dans la même zone, (ii) je recommande que les navires de pêche commencent à indiquer dans leurs journaux de bord le temps entre chalutages passé à la recherche, (iii) je propose que la CCAMLR envoie en mer un modeleur d'un niveau de doctorat afin de développer un modèle vraiment opérationnel du processus de pêche, et (iv) je propose des indices d'abondance qui pourraient être utilisés pour déterminer, d'une manière continue, la biomasse du krill.

Резюме

Первая часть данного документа содержит анализ данных, относящихся к советской промысловой крилевой флотилии. Данные основаны на результатах 12 различных рейсов 8 разных научно-исследовательских судов в период между 1981 и 1984 г. Данные проанализированы в соответствии с фактическими характеристиками, такими, как длительность траления, улов криля, или время между тралениями. Корреляционный анализ представлен как ключ к пониманию характеристик операции во время траления и между тралениями. Данные подтверждают идею модели "пятно в пятне" распределения криля в Южном океане.

Вторая часть этого документа включает развитие и использование моделирования южноокеанской промысловой крилевой флотилии. Цель работы заключается в ответе на следующие вопросы: какие выводы можно сделать на основании данных по улову и промысловому усилию о численности криля и о том, насколько легко можно обнаружить значительные изменения в биомассе криля. Первичным звеном в модели распределения криля являются отдельные экземпляры криля, которые образуют скопления. Скопления образуют концентрации, которые являются центром промысловой операции. Параметры модели зависят от изучения опубликованных результатов и результатов программы "FIBEX". Модель разработана для поискового судна, не занимающегося промыслом, но ведущего поиск концентраций криля для рыболовных судов. Модель промысла включает нахождение концентраций, нахождение скоплений внутри концентраций и промысел отдельных скоплений. Где возможно, фактические данные из Части 1 использованы в Части 2. Обсуждены основные аспекты теории индексов численности пелагических стайных видов. В частности придается большое значение времени, потраченому на поиск скоплений.Разработана теория выявления изменений в биомассе криля. Рассмотрены сорок два различных индекса численности и изучена их эффективность в выявлении изменений в биомассе криля. Наилучшие индексы состоят из двух отдельных частей: первая - когда результаты работы поискового судна используются для выявления количества концентраций и вторая часть по форме улов/скопление/время поиска заключается в выявлении плотности скоплений внутри концентраций и плотности криля внутри скоплений. Даны следующие оперативные рекомендации: (i) я предлагаю эксперимент, в котором поисковые и рыболовные суда работали бы одновременно, но независимо друг от друга в одном и том же районе, (ii) я рекомендую, чтобы рыболовные суда начали отмечать в судовом журнале количество времени поиска между тралениями, (iii) я предлагаю, чтобы CCAMLR рассмотрел возможность направления специалиста по моделированию на уровне доктора наук в морскую экспедицию для того, чтобы разработать полностью действующую модель процесса промысла, и (iv) я предлагаю, чтобы индексы численности использовались для выслеживания биомассы криля.

Resumen

La primera parte de este trabajo contiene un análisis de los datos relacionados con la flota de krill de la Unión Soviética. La base de datos se compone del registro de 12 cruceros diferentes realizados por 8 buques de investigación entre 1981 y 1984. Se analizan los datos según las características operativas de proceso de pesca, tales como duración del arrastre, captura de krill o movimientos entre arrastre.

Los análisis de correlación se presentan como un medio para entender las características de la operación durante el arrastre, y entre un arrastre y otro. Los datos corroboran la noción de un modelo de "manchas dentro de manchas" en la distribución del krill en el Océano Austral.

La segunda parte de este trabajo contiene el desarrollo y utilización de un modelo de simulación para una flota de krill en el Océano Austral. El objetivo del mismo es responder a cuestiones tales como: ¿Qué información proporcionan los datos de captura y esfuerzo sobre la abundancia del krill? o ¿Con qué facilidad pueden detectarse cambios significativos en la biomasa del krill? El modelo de distribución del krill se inicia con krill individual que se supone se concentra en cardúmenes. Los cardúmenes forman a continuación concentraciones, las cuales son el objetivo de la operación de pesca. Los parámetros del modelo se fundamentan en el estudio de la documentación existente y en los resultados de FIBEX. Se desarrolla un modelo para un buque de investigación que no faena, sino que solamente localiza concentraciones de krill para la flota pesquera. El modelo de pesca implica la búsqueda de concentraciones, de cardúmenes dentro de concentraciones y la pesca de cardúmenes individuales. Siempre que es posible, los datos oeprativos de la Parte I se emplean para proporcionar distribuciones en la Parte II. Se discuten las consideraciones generales sobre la teoría de los indices de abundancia para especies pelágicas que se agrupan en bancos. Se destaca, en particular, la importancia del tiempo empleado en la búsqueda de cardúmenes. Se desarrolla una teoría para detectar cambios en la biomasa del krill. Se consideran cuarenta y cuatro índices de abundancia, y se estudia su efectividad a la hora de detectar cambios en la biomasa del krill. Los mejores índices requieren dos medidas distintas: una en la que se utilizan los descubrimientos del buque de investigación para rastrear el número de concentraciones, y otra sobre la forma de la captura/cardumen/tiemp de búsqueda, para rastrear la densidad de un cardumen en las concentraciones y la densidad del krill en los cardúmenes. Se ofrecen recomendaciones operativas: (i) propongo un experimento en el cual buques de investigación y de pesca operen simultánea pero independientemente en la misma zone, (ii) recomiendo que los buques de pesca empiecen a indicar en sus cuadernos de pesca el tiempo, entre un arrastre y otro, empleado en la búsqueda, (iii) propongo que la CCRVMA considere

enviar a un modelador cualificado para que desarrolle un modelo realmente operativo para el proceso pesquero, y (iv) propongo índices de abundancia que podrían ser empleados en el rastreo de la biomasa del krill.

1. INTRODUCTION AND RECOMMENDATIONS

This document contains two distinct parts. In the first part, I present an analysis of data provided by Professor Lubimova (VNIRO Rresearch Institute, Moscow) on the Soviet krill (*Euphausia superba*) fleet. The analysis presented is based on data collected over a number of different seasons by about 10 different vessels. The second part contains a description of the krill simulation model developed in conjunction with Professor Butterworth and Dr Beddington's group in London. This document supercedes and modifies the model and results in Mangel (1987) and Mangel and Butterworth (1987).

The overall objective of this work is to provide an answer to the question: Can fishery generated data be used to monitor krill abundance? If so, what kinds of data need to be collected. Any such procedure, which is based on derived data (versus direct surveys), must also be based on the assumption that changes in abundance occur relatively quickly after periods of relative constancy. If changes occur slowly over many years or biomass fluctuates wildly from year to year, then it is unlikely, if not impossible, to detect such changes with fishery derived data.

1.1 Recommendations

Based on the statistical analysis and modelling described in the body of the report, the following three recommendations are presented:

1. Fishing and survey vessels should indicate in their log books approximately how much of the between trawl times are spent in search for swarms of krill. If possible, vessels should indicate the number of swarms fished in a haul. This would require a consistent definition of swarm (in terms of sonar ping threshold, for example).

2. CCAMLR should consider an "experiment" in which a research vessel and a fishing fleet travel together, but work independently. In particular, the fishing fleet should operate as if the survey vessel were not present, and the survey vessel should conduct krill surveys in the vicinity of regions in which the fleet fishes. By doing this, one can obtain a distributional model for krill that are considered fishable by the fleet.

3. If a detailed operational model of krill fisheries is desired, CCAMLR should consider sending a Ph.D. level modeller to sea with the fleets. This is in the best traditions of operational analysis (see, e.g. Tidman 1984) and will most likely be the only way that accurate operational models can be developed. In particular, such a field assignment will lead to accurate understanding of search operations while fishing and while not fishing and to an accurate understanding of operational fishing decisions.

4. The following indices can be used, at least temporarily, to track krill abundance:

   (a) Use the number of discoveries of fishing foci or large scale concentrations of krill by the survey vessel to track changes in the number of concentrations and the characteristic radii of concentrations.

   (b) Use one of the following indices to track within concentration changes in swarm density and krill abundance within swarms:

(Total Catch/Total Hauls) / Average {Searchtime}
(Total Catch/Swarms Fished) / Average {Searchtime}
(Total Catch/Swarms Encountered) / Average {Searchtime}.

PART I : ANALYSIS OF SOVIET DATA

2. SOVIET DATA SOURCES AND DEFINITION OF TERMS

Professor Lubimova provided a number of different sets of data obtained from research/survey vessel cruises. Table 2.1 contains a summary of the sources.

The vessels listed in Table 2.1 have similar characteristics. All except *Globus* are freezer-trawlers; the *Globus* is listed as PTMC but I could not interpret that code. The displacement of all vessels except *Globus* is about 3 800 tonnes; the displacement of the *Globus* is about 5 400 tonnes. The propulsion of all vessels except *Globus* is 2 000 horsepower; the propulsion of *Globus* is 3 880 tonnes. Table 2.2 shows net characteristics of the different vessels.

Some explanations about Table 2.1 and the associated computations are needed: (1) In the analyses described below, one degree of latitude is assumed to equal 60 n miles. and one degree of longitude is assumed to equal 30 n miles. (2) A "record" is, essentially, a trawl and concomittant information. Four different reporting methods were used, but the following information was contained in all records:

- Date
- Starting point (S,W)
- Trawling duration (starting time and ending time)
- Trawling depth
- Trawling tack
- Trawling speed (kts)
- Catch (kg) and krill catch (i.e., catch composition)

In addition, some of the data sheets contained the following information:

- Krill length (mm)
- Cloudiness (presumed to be measured in oktas)
- Wind direction and strength
- Air and water temperatures.

(3) In a few instances, multiple tacks were recorded. In such cases, the final direction was used in analysis. In a few instances multiple depths were recorded. In such cases, the largest depth was used in the analysis. Whenever a range of krill size was reported, the average was used in the analysis.

From the information contained in the data, the following quantities were constructed for each data set:

- The number of trawls per day
- Trawltime
- Trawling length
- Krill catch per trawl
- Distance moved between trawls
- Time elapsed between trawls

- Average speed of vessel between trawls (distance between trawls divided by time between trawls)
- Trawling depth
- Trawling speed
- Mean length of krill

(Some of these, obviously, need no "construction" and are simply the data entries themselves.)

For the statistical analysis reported in this part of the document, the following were computed for each of the quantities listed above:

- The mean of the quantity, over trawls within the same data set
- The standard deviation of the quantity, over trawls within the same data set
- Qualitative properties of the distribution of the quantity, particularly whether the distribution is unimodal or bimodal.

In addition, correlations between different quantities were computed. The correlation between quantity x and quantity y, denoted by r_{xy}, is defined by

$$r_{xy} = \Sigma\ (x_i - \langle x\rangle)(y_i - \langle y\rangle) \,/\, [\ \Sigma\ (x_i - \langle x\rangle)^2\ \Sigma\ (y_i - \langle y\rangle)^2\ ]^{1/2} \qquad (2.1)$$

In this equation, x_i and y_i denote the values of the quantities x and y on the i^{th} trawl, <x> and <y> are the averages of the quantities x and y and the summation is taken over the trawls in the data set. The quantity r_{xy} can be considered a "same point" correlation, since both quantities are evaluated on the i^{th} trawl. A lagged correlation can be computed in a similar fashion by evaluating the quantities on different trawls. In the analysis reported here, only single lags for the correlations were considered. The lagged correlation coefficient denoted by $r_{xy}{}^{lag}$ is defined by

$$r_{xy}{}^{lag} = \Sigma\ (x_i - \langle x\rangle)(y_{i-1} - \langle y\rangle) \,/\, [\ \Sigma\ (x_i - \langle x\rangle)^2\ \Sigma\ (y_i - \langle y\rangle)^2\ ]^{1/2} \qquad (2.2)$$

Although it is a mistake to interpret correlation as causation, the use of correlation coefficients allows one to make inferences about the operations of the vessel. For example, one could assume as a null hypothesis that all of the quantities listed above are independent. Suppose then that a value of the correlation coefficient r_{ob} is observed. The probability of obtaining a value of the correlation coefficient greater than or equal to r_{ob} if the null hypothesis were true is given by (Press et. al. 1985)

$$\text{Prob}\ \{\ |\ r\ | > r_{ob}\ ,\ \text{given that the null hypothesis is true}\ \}\ =\ \text{Erfc}\ (r_{ob}(N/2)^{1/2}) \qquad (2.3)$$

In this equation, N is the number of trawls in the data set and Erfc(z) is the complementary error function. It is related to the cumulate normal distribution by $\text{Erfc}(z) = 2(1\Phi(z/\sqrt{2}))$, where $\Phi(z)$ is the probability that a normally distributed random variable with mean 0 and variance 1 is less than z.

3. RESULTS OF ANALYSIS OF THE SOVIET DATA

Preliminary analysis of the data showed that 11 of the 12 data sets were bimodal. For this reason, cutoff values for quantities were introduced in the course of statistical analysis.

The following cutoff values were chosen for the quantities that required them:

- Trawling depth: 250 m
- Trawling time: 4 hours
- Trawling length: 8 n miles
- Time elapsed between trawls: 40 hours
- Distance moved between trawls: 100 n miles.

Table 3.1 contains a summary of the means and standard deviations of the particular quantities. In this table, the first entry in a column is the mean and the second entry is the variance. Thus, for example, for data set 1, the mean number of trawls per day is 1.78 and the standard deviation is 0.91. If two sets of numbers are given, then the first set are the mean and standard deviation when the cutoff values were used in the computations and the second set is the mean when no cutoff was used and the number of data points greater than the cutoff. The second set of numbers is included only if there is a significant difference (at least 20%) between the mean when the cutoff value is applied and when it is not applied. Thus, for example, for data set 1 when the cutoff values are used, the mean value of trawl depth is 44.9 m and the standard deviation is 22.2; there are 4 data points greater than the cutoff value of 250 m and the mean value of trawl depth using all data points is 58 m.

In rest of this chapter, the statistical analysis of the Soviet data will be reported. Implications for modelling are described in the next chapter. The results presented in Table show that all but Data Set 6 exhibit some form of bimodality of the data. Figure 3.1 shows an example of the bimodal distribution of between trawl movement for data set 10 (which has the largest differential between mean movement when the cutoff is applied and when it is not applied). There are very many small movements - less than 10 n miles, fewer moderate movements and again many large movements between trawls.

Correlations were computed as described in the previous chapter. The correlations are presented in Tables 3.2 - 3.25. In these tables, the following notation is used:

- TT = trawling time
- TL = trawling length
- KC = krill catch
- BTM = distance moved between trawls
- BTT = time elapsed between trawls
- D = trawling depth
- L = krill length (not always available in the data).

The correlations will be presented in matrix form. Each data set has two tables associated with it: the first table contains correlation information when no cutoff values were applied in the computation of statistics and the second table contains correlation information when cutoff values were applied in the computation of statistics. Each pair of quantities in the correlation table has two entries associated with it. The upper entry is the unlagged correlation. The lower entry is the lagged correlation, with the column quantity corresponding to the i+1st trawl and the row quantity corresponding to the ith trawl. Correlations are reported according to the supposition of the null hypothesis described in the previous chapter. That is, if the value of the correlation is such that the probability of observing it when the null hypothesis is true is greater than .05, then a 0 is reported. If the probability is less than .05, then the sign of the correlation is reported. For example, for data set 1 when all data are used (Table 3.2) the unlagged correlation between trawl time and krill catch has a value such that the probability of observing it if the null hypothesis is true is greater than .05. On the other hand, the lagged correlation between trawl time on trawl i-1 and krill catch on trawl i has a value such that the probability of observing it if the null hypothesis is true is less than .05 and the correlation is positive.

When reading these tables, a number of issues should be kept in mind. First, there are obvious positive correlations. The non-lagged correlation of a quantity with itself is always 1. Second, as the number of data points increases (so that the value of N increases in Eqn 2.3) the probability that the correlation will be judged significant at the .05 level increases. Thus, data sets with many records may, in fact, have spurious correlations. Third, the presence of zeroes in the correlation matrix suggests that the trawls are independent, or at least that the quantities derived from the trawls are independent.

4. IMPLICATIONS FOR MODELLING

The results presented in the previous chapter have a number of implications for the modelling of Southern Ocean krill fisheries described in the second part of this document. Perhaps most important is the bimodal nature of the data. This bimodality, especially for between trawl times and movement, suggests that the fundamental distributional model developed in the following chapters is feasible.

It is not clear from the data analyzed thus far if the vessels used vertical echo sounders or directional sonars. Since the latter have much larger detection widths, this would impact the search process.

It is also not clear from the data how one can estimate the time in active search between trawls. One of the recommendations is that vessels record search times or estimates of search times between trawls.

It must also be kept in mind that the data analyzed here were provided by research, and not commercial fishing, vessels. Thus processing time and considerations are minimal. This may account for some of the exceptionally large trawl times and distances as well as krill catches far in excess of 10 tonnes, the limit used by Mangel (1987) and Butterworth (1987).

In some cases, the net was trawled at two, three or four depths. In the model described in the next sections, veering and hauling times are assumed to be drawn from a probability distribution characterizing depths.

PART II : SIMULATION MODEL OF A SOUTHERN OCEAN KRILL FLEET

5. OBJECTIVES AND GUIDING PRINCIPLES

The overall objective of this work is to develop a framework in which one can ask questions such as:

- What information do catch and effort data provide about abundance levels of krill. In particular, what kinds of abundance indices can be developed from data that would be generated by a fishery?
- How easily can significant changes in krill biomass be detected? In particular, what are the properties of the abundance indices? The most important properties are linearity (so that changes in abundance indices accurate reflect changes in krill biomass) and variability (so that mean changes are not swamped by variance, i.e. "noise").

The krill are fished when they are in dense aggregations, which will be called swarms in this document. The swarms are scattered over the ocean in a non-uniform manner and thus the fishing process involves search for concentrations of aggregations (fishing foci) and fishing aggregations once concentrations and aggregations within the concentrations are found. The simplest biomass estimates for krill population in swarms is:

$$\text{Total Biomass} = (\text{Number of Swarms}) \times (\text{Biomass per swarm}) \qquad (5.1)$$

and the question then becomes how one estimates both the number of swarms and the biomass per swarm.

A model of any natural system must, be necessity, be less complicated than the true system. We should strive to build sufficient realism into the model so that it captures the main features of the system of interest, but is still as parsimonious as possible. Thus, for example, the model described in this document does not attempt to simulate the entire Southern Ocean, or even a large portion of it, in the computer nor does the model simulate the decisions of skippers on a very short time scale (say 5 minutes). Instead, a relatively featureless section of ocean is considered and larger time scales for vessel motion and decisions are used. In a study such as this one, it is large qualitative changes in abundance indices that are most important for operational recommendations.

6. BASIC DEFINITIONS AND SCALES

The Southern Ocean fishery for krill is a pelagic fishery operating on dense aggregations of krill. There are many different temporal and spatial scales associated with the fishery. It is this wide variety of scales, in fact, that makes analysis of the problem as difficult as it is. Thus, it is important to consider and identify all of the the scales of interest from the outset.

To begin, there are individual krill. These organisms have a length of the order of 40-70 mm and are assumed to move at about 15 cm/sec ≈ 500 m/hr. The lifetime of a krill may be many years (Rosenberg et. al. 1986).

Individual krill aggregates into swarms of krill. In this document, a swarm is assumed to consist of krill in surface densities in excess of about 100 g/m^2, over a surface spatial extent on the order of 50 m. The swarms can be envisioned in the following way: Krill are actually distributed in an aggregation at a certain volume density (e.g. 5 g/m^3) and we "integrate" over that volume to concentrate the entire volume in a surface layer (e.g. if the volume is 20 m deep, this gives a surface density of 20 m x 5 g/m^3 = 100 g/m^2). Swarms persist on a temporal scale of at least a few days. (For the model here, swarms are presumed to persist for over the course of 14 days.) The actual operational definition of a swarm is determined by the interaction of the krill, the echosounder or sonar used to detect them, and the operator. For example, Everson (1982, Figure 1) gives excellent examples of the difference between swarms of krill at night and during the daytime. During the daytime, krill are typically "compact, discrete swarms" (Watkins 1986). In addition, Watkins et. al. (1986) report that "variability between swarms in close temporal or spatial proximity suggests that the swarm is the basic unit of organization of the krill population" .

Swarms of krill are further aggregated into concentrations or fishing foci. Concentrations are thus collections of swarms of krill over a large spatial extent, of the order of 10 nautical miles = 20 000 m (here and in the rest of this document, the conversion of 1 n miles = 2 000 m is adopted). A concentration with a length scale of 15 n miles is presumed to contain of the order of 5 000-10 000 individual swarms of krill, randomly placed within the concentration. The temporal scale of the concentration is assumed to be constant for the entire 14 day period considered in this report, although concentrations are allowed to move. The basic model thus consists of "patches within patches".

For the model developed in this document, a sector of the Southern Ocean consists of a "featureless" area of ocean 600 n miles on a side. The sector is treated as a square, so that its area, denoted by A_s, is 1.44×10^{12} m^2. In this context, featureless means that there are no large land masses in the sector and that there are no large scale oceanic currents that would move either concentrations or individual krill across the sector. Including large scale oceanic currents is a natural extension of the model and easily done. The motivation for adopting a featureless sector of ocean is the following: If catch and effort indices are not effective in detecting changes in krill biomass in a featureless ocean, they most likely will not be effective in detecting changes in krill biomass in an ocean with large land masses and currents. If the indices do appear to be effective in detecting changes, then a further modelling effort could couple many sectors by linking them with currents and adding land masses to the sectors.

Fishing for krill is done by a fleet of 5 fishing vessels, a research/survey vessel and sufficient processing vessels that backlogs do not occur. In this document, a fishing period of 14 days is considered. The fishing process consists of two main activities: search for concentrations and swarms of krill and fishing individual swarms. The fishing vessels and survey vessel each have temporal and spatial scales. The survey vessel is assumed to move constantly at 10 n miles/hour for the entire 14 day period in which the fishing fleet is operating. The survey vessel is assumed to use a forward looking sonar with a detection width of about 500 m (further details are given in the next chapter).

The fleet of 5 commercial vessels are assumed to operate in perfect cooperation, so that they search for concentrations of krill together and share information about discovered concentrations. All vessels are assumed to fish in the same concentration. When searching for concentrations, the commercial vessels are assumed to have the same equipment as the survey vessel. Once within a concentration, and thus searching for individual swarms of krill, the survey vessels are assumed to use a vertical echosounder with a detection width of 35 m. The width of the net used by the fishing vessels is assumed to be 20 m.

7. KRILL DISTRIBUTIONAL MODEL

This chapter contains a description of the model for the spatial and temporal distribution of krill in the sector of ocean of interest. As mentioned above, the basic model is a "patches within patches" model: the large sector of ocean contains concentrations (fishing foci) of swarms of krill. Parameters described in this chapter correspond to the "base case" scenario; in succeeding chapters ways that the biomass of krill in the sector could change are documented.

The number of concentrations in the sector is denoted by N_c and in the base case

- $N_c = 36$.

Throughout this document, concentrations are indexed by the letter i, thus i runs from 1 to 36 in the base case. The location of concentrations within the sector is specified by the location of the center of the concentration. I assume that there is a "habitat structure" to the sector, defined in the following way. The sector is divided into 5 different habitats, stratified in the North-South direction, but not the East-West direction. If the southern-most edge of the sector is taken to be 0, the boundaries for the habitats are 75 n miles, 150 n miles, 300 n miles , 450 n miles and 600 n miles. Thus, for example, habitat H_1 consists of the "rectangle" 600 n miles in the EW direction and the southern most 75 n miles in the NS direction and habitat H_2 consists of the "rectangle" 600 n miles in the EW direction and contains the region from 76 n miles to 150 n miles in the NS direction.

Centers of concentrations are randomly placed in the sector, using habitat structure to determine the probability that a concentration is placed in a particular sector. The following probability distribution for habitat structure is adopted, motivated by distributions of krill predators (cetaceans and birds) and fishing boats in the Southern Ocean. Define the probability p_k by

$$p_k = \text{Probability that a concentration is placed in habitat } k \quad (7.1)$$

The following values are assumed:

Habitat	Value of p_k
1	1 / 3
2	1 / 6
3	2 / 9
4	1 / 6
5	1 / 9

Thus, when N_c= 36, there are on average 12 concentrations in habitat 1, 6 concentrations in habitat 2, 8 concentrations in habitat 3, 6 concentrations in habitat 4 and 4 concentrations in habitat 5. Note that the NS extent of the first two habitats is half of the NS extent of the other three habitats. The per unit area krill density in habitat H_2 is thus twice as great as the krill density in habitat H_4, although the two habitats contain the same number of concentrations. The center of the ith concentration is denoted by (x_i, y^i). The value of x_i is chosen randomly from a uniform distribution on [0,600 nmi] and the value of y_i is chosen according to the probability distribution given above.

Each concentration has a radius that determines the number of swarms in the concentration. The radius of the ith concentration is denoted by L_i. The radius is given by

$$L_i = L_c(1 + \mathbf{U}) \quad (7.2)$$

In this equation **U** denotes a randomly variable uniformly distributed on [0,1] and L_c denotes the <u>concentration characteristic radius</u>. For the base case, it is

- $L_c = 10/(\pi)^{.5}$ n miles = 5.64 n miles.

Thus, on average the radius of a concentration is about 8.5 n miles.

The number of swarms in the ith concentration is denoted by N_i and is assumed to be given by

$$N_i = D_i \pi \ (L_i)^2 \quad (7.3)$$

In this equation, D_i is the per unit area density of swarms in the ith concentration. It is given by

$$D_i = D_c \exp(\mathbf{X}_{.1}) \quad (7.4)$$

In this equation D_c is the <u>concentration characteristic density</u>. For the base case, it is

• D_c = 20 (n miles)$^{-2}$.

Also in Eqn (7.4), $\mathbf{X}_\sigma$ denotes a normally distributed random variable with mean 0 and standard deviation σ. In the sequel, it is useful to know that the expected value of $\exp(k\,\mathbf{X}_\sigma)$ is given by $E\{\ \exp(k\,\mathbf{X}_\sigma)\ \} = \exp(\ .5\ k^2\,\sigma^2\ )$. Thus, using Eqn (7.3) on average a concentration will contain $(20)(\exp(.5(.01))\ \pi\ (8.46)^2$ swarms or about 4 500 swarms.

Swarms within concentrations are indexed by j, so that the subscript ij denotes the j^{th} swarm within the i^{th} concentration. Swarms are characterized by their radii and the density of krill within them. The radius of the j^{th} swarm within the i^{th} concentration is denoted by r_{ij} and is given by

$$r_{ij} = r_c \ \exp(\mathbf{X}_{1.1}) \qquad (7.5)$$

In this equation, r_c denotes the swarm characteristic radius. It is

• r_c = 50 meters.

The density of krill within the j^{th} swarm in the i^{th} concentration is denoted by δ_{ij} and is given by

$$\delta_{ij} = \delta_c \exp(\mathbf{X}_{1.4}) \qquad (7.6)$$

In this equation, δ_c denotes the swarm characteristic density of krill. It is

• δ_c = 150 g/m^2

The model described above shows that the density of swarms, the radii of swarms and the density of krill within swarms all follow a log-normal distribution. This distributional model is based on extensive study of the literature, use of FIBEX data and conversations with numerous scientists involved in both FIBEX and SIBEX. In particular, Professor Butterworth and I spent a morning with SIBEX participants discussing this distributional model. The following issues were raised:

- FIBEX, taken around Elephant Island, may not be representative of the entire Antarctic area. In particular, the density of krill may be higher than on average. On the other hand, commercial fishing was occurring independently of but concommitant with the FIBEX data collection. This supports the use of the distributional model.

- Swarms may aggregate in concentrations, so that swarms are not randomly distributed within the concentration. This would affect the number of swarms that a vessel tows through.

- The actual definition of a swarm is not clear, since it depends on the threshold used with the sonar. Thus what appears to be one large swarm at a given ping threshold may be separated into a number of smaller swarms at a different threshold.

- The radii of concentrations and the density of swarms within concentrations may depend upon the location of the concentration within the habitat structure. In particular, concentrations may be more densely aggregated near the ice edge.

- One can't guarantee that the fishing vessels actually fish the swarm that they target on.

Even with these caveats, the general feeling of SIBEX participants was that the distributional model described above, while undoubtedly flawed, cannot be significantly improved upon at this time. (Naturally changes in the model could be implemented, but it is not clear that the resulting model would be superior.)

The FIBEX study estimated that the standing biomass of krill in the Southern Ocean is 90 million tonnes. How does that compare with the krill distributional model just described? There are 36 swarms, each with about 4 500 concentrations. The average area of a swarm is π E { (50 exp($\mathbf{X}_{1.1}$)^2) } = π $(50)^2$ exp(2.42) = 8.64 x 10^4 m^2 . The average density of krill in a swarm is 150 exp(.98)= 4 x 10^2 g/m^2.. Thus, the average biomass of krill in the swarm is 34.6 x 10^6 g. Using the conversion of 1 tonne = 1 000 kg, the average swarm contains about 35 tonnes of krill. This value is low when compared to other reported values (e.g. Witek et. al. 1987) but may be due to a selection process in which only the larger swarms are targeted. A selection mechanism is described in the fishing submodel. A concentration then contains 35 x 4 500 = 15.8 x 10^4 tonnes of krill and the sector considered in this document thus contains 36 x 15.8 x 10^4 = 5.7 x 10^6 tonnes of krill. Since the Southern Ocean would contain 18 sectors similar to the one described here, the overall estimate for krill biomass in the Southern Ocean is about 100 million tonnes. This is consistent with the FIBEX results.

8. SURVEY VESSEL MODEL

This chapter contains a description of the operational model for the research survey vessel. At the extreme interpretation,which is adopted here, a research vessel does no fishing. Instead, the operation of the research vessel consists entirely of large scale surveying of the oceanic sector and detecting concentrations of krill.

The path of the research vessel is modelled on a daily basis, assuming that the vessel executes an "exhaustive search" (Koopman 1980) of the region. That is, the vessel starts at the southwest corner or the sector and traverses the sector in an easterly direction. When the eastern boundary of the sector is reached, the vessel moves north and traverses the sector in a westerly direction. The speed of the vessel is assumed to be 10 kts, so that in 24 hours the vessel's track length is 240 n miles. As a lower bound for search effectiveness, the assumption used in the model is that the vessel covers a block of 200 n miles in each day. The remaining track length is assumed to be used for investigation of discoveries of possible concentrations; although the discovery process is not explicitly modelled here. Since the length of the sector is 600 n miles, it takes three days for the vessel to traverse the sector in the EW direction. After one traverse, assume that the vessel moves 20 n miles north and traverses the sector in the direction opposed to the most recently completed traverse. This survey process is modelled for 14 days, with the vessel starting at the point (0, 15 n miles) on day 1. Other search patterns can easily be incorporated . For example, in the current search pattern Habitats 4 and 5 are not covered at all. This could be changed by modifying northward motion of the vessel at the end of each EW traverse. Detections by the research vessel are monitored on a daily basis. I assume that the vessel uses a forward looking sonar with a detection width 500 m on either side of the search path. Thus, during a single day the vessel sweeps out a rectangular area 200 n miles = 4 x 10^5 m long and 1 000 m wide. Any concentration that extends into this rectangular area is assumed to be detected by the vessel.

At the end of each survey day, the concentrations are "moved". I assume that the center of each concentration is displaced by a distance corresponding to the krill speed v_k = 15 cm/sec in a randomly chosen direction. The daily displacement distance is (15 cm/sec) x (.01 m/cm) x (3 600 sec/hr) x (24 hr/day)∞13 x 10^3 m/day. Thus, if (x_i,y_i) is the location of the center of the concentration on day d, the location of the center of the concentration on day d +1 is (x_i+ 13 x10^3 x cos(ø) , y_i+ 13 x 10^3 x sin(ø)), where ø is a randomly chosen direction. That is, ø is uniformly distributed with range [0, 360°].

The discovery history of the research vessel consists of a daily list of the location of concentrations that it has encountered. The discovery history has two main uses in the model. First, the discovery history is used to place the fishing fleet into a concentration whenever the fleet is not in one (e.g., at the start of the fishing period, if bad weather causes the fleet to lose the concentration, or if the fleet chooses to exit a concentration because catch is low). Second, the discovery history can be used to estimate the number of concentrations present in the oceanic sector. Mangel and Beder (1985) analyzed a problem similar to this one and showed that if a search time t_s lead to n_e encounters with concentrations, then an estimate for the number of concentrations is

$$N = n_e / (\varepsilon_r \ t_s) \qquad (8.1)$$

where ε_r is a search parameter associated with the operation of the research survey vessel. For the model described here, the parameter ε_r is computed according to the rule

$$\begin{aligned} \varepsilon_r &= \text{(Vessel speed) x (Detection Width) / Area of Sector} \\ &= (2 \times 10^4 \text{ m/hr}) \times (10^3 \text{ m}) / (6 \times 10^2 \times 2 \times 10^3 \text{m})^2 \\ &= 1.38 \times 10^{-5} \text{ /hr.} \end{aligned} \qquad (8.2)$$

Note that the search parameter is measured in hours; hence a 14 day search interval corresponds to a search time t_s = 14 days x 24 hrs/day=336 hours. The basis of Eqn (8.2) is the "random search formula" (Koopman 1980, Mangel 1985) and allows for double counting concentrations . is, there is no way to "mark" concentrations after a detection. For example, concentrations may be discovered on day d and on day d+1 in which case it is easily conceivable that the same concentration has been discovered. On the other hand, the same concentration may be discovered on day d and day d+5, due to movement of the vessel and concentration, in which case it is not so obvious that this concentration was discovered once before. The estimate obtained from Eqn (8.2) may thus be larger than the true number of concentrations.

9. FISHERY MODEL

The fishing period considered in this document is 14 days long. Fishing is assumed to occur in mid-summer (e.g. February) and sufficiently far south that daylight is essentially 24 hours. The fishing model consists of the following components:

(i) The cooperative search by the fleet and research vessel for concentrations. This occurs at the start of the fishing period, if the fleet loses the concentration because of bad weather or if the fleet exits a concentration because of low catch rates.

(ii) The search within concentrations by individual vessels for swarms of krill.

(iii) The fishing of swarms of krill.

(iv) The fleet decision process.

Each of these is a submodel of the fishing model.

(i) Finding Concentrations

The model developed in this document treats a "cooperative fishery" consisting of the research survey vessel and 5 identical fishing vessels. The vessels cooperate in that they share search information and all fish in the same concentration when they are fishing.

If the research survey vessel discovers one or more concentrations on the first day of the fishing period, then the fleet simply moves to the first concentration discovered and begins fishing there. Otherwise, the fleet itself begins searching for concentrations. I assume that each vessel in the fleet has both echosounder used for targeting on swarms during the fishing process and a forward looking sonar with a detection width of 500 m on either side of the vessel track used for search for concentrations and that the fishing vessels can also search at 10 n miles/hr. If the fleet must search for a concentration, the following procedure is applied. All concentrations within 24 hours steaming of the current position of the fleet are identified. The five vessels are assumed to search independently for concentrations and the time to detect an individual concentration is assumed to follow an exponential distribution with parameter proportional to the search speed and inversely proportional to the area of the habitat in which the vessel is operating. Thus, more than one concentration may be discovered; I assume that the first one discovered is the one that the fleet moves to. Detection of a concentration is determined by drawing a random number from the appropriate distribution. If at least one concentration is detected, then the concentration selected for fishing is determined by a weighted measure of the distance between the fleet and the different concentrations within 24 hours steaming. If no concentrations are detected, the fleet moves towards the center of habitat H_1.

(ii) Within Concentration Search by Individual Vessels: The Swarm Encounter Model

Once the fleet has encountered a concentration, individual vessels begin searching for swarms within the concentration. This section contains a description for the search by vessels for individual swarms. Since there are 36 concentrations, with about 4 500 swarms in each concentration, there are of the order of 162 000 swarms in the entire sector. Very few of these swarms will be fished, since the fishing period only lasts 14 days and I will assume (in the next section) that each fishing vessel makes no more than 11 hauls per day. Thus, tracking the location of each swarm is unnecessary, and consumes valuable computer time and memory. In order to save memory space in the computer and speed the running of the model, I adopt the following procedure for modelling the within concentration search behavior of individual vessels. First, a detailed model of the within concentration search behavior of the vessels will be described. This search model is called the <u>swarm encounter model</u> and provides parameter estimates that are used in the fishing model of the next section. The model described here actually tracks the detailed motion of a vessel and all 4 500 swarms in a concentration. In the next section, I use the distributions and parameters developed in this section, so that vessel positions and swarm locations do not need to be tracked.

To begin, consider a concentration that has characteristic radius 8.5 n miles and contains about 2 500 swarms. A vessel in this concentration searches at a speed of 2 n miles/hr and uses a sonar with a detection width of 35 m on either side of the vessel. The vessel starts its search at a randomly chosen point in the concentration. The swarms are randomly located within the concentration, swarm radii are log-normally distributed .

Time is explicitly considered in this encounter model, using increments of dt = .01 hours. Both the vessel and swarms of krill are assumed to use "random tour" models (Washburn 1969). Thus, let $(x_v(t), y_v(t))$ and $(x_j(t), y_j(t))$ denote respectively the positions of the vessel and the j^{th} swarm of krill at time t. The dynamics of the motion of the vessel are

$$x_V(t+dt) = x_V(t) + 4000 \cos(\theta)\, dt$$
$$y_V(t+dt) = y_V(t) + 4000 \sin(\theta)\, dt \qquad (9.1)$$

where θ is the direction of search. When t= 0, the value θ = 45° is chosen. Until a detection occurs, every 10 dt hours the direction of search is changed to a new direction, within 30° of the previous direction. The only constraint on the motion in Eqn (9.1) is that the vessel is not allowed to leave the concentration. The 4 000 in Eqn (9.1) is the vessel speed and dt is the time increment.

Similarly, the dynamics of the center of a swarm are given by

$$x_j(t+dt) = x_j(t) + 540 \cos(\omega)\, dt$$
$$y_j(t+dt) = y_j(t) + 540 \sin(\omega)\, dt \qquad (9.2)$$

where the ω denotes the direction of motion of the swarm of krill. I assume that in each time interval , ω is randomly chosen in the range [0°, 360°].

Detection of a swarm of krill occurs when the distance between the vessel and the center of the swarm is less than the sum of the radius of the swarm and the detection width of the sonar. Since initial location of the swarms and vessel and motion of the swarms and vessel involve random components, the detection times will also be random variables. With the same initial conditions, the encounter model can be iterated many times using Monte Carlo simulation. Hence introduce the detection time distribution function F(t) defined by

F(t) = Fraction of iterations in which the detection occurred before time t (9.3)

The distribution F(t) was determined by simulation, choosing a wide variety of initial conditions on swarm numbers (ranging from 200 to 8 000). In all of the cases studied, the empirical distribution was fit well by an exponential distribution of the form

$$F(t) = 1 - \exp(-\beta t) \qquad (9.4)$$

The mean time to detection for the expotential distribution is 1/β. A "base case" for the swarm encounter model was chosen with the following parameters:

- Number of swarms = N_{base} = 2 500
- Concentration radius = L_{base} = 8.46 n miles
- Characteristic swarm radius = r_{base} = 50 m.

For this case, the mean time to detect a swarm was .0356 hours and the fit between the empirical distribution (based on 110 iterations) and the exponential model is shown below:

Detection interval	Fraction of Detections in the Detection Interval	
	Encounter Simulation	Exponential Model
0 - .05 hours	.70	.75
.06 -.1 hours	.082	.185
.11 - .15 hours	.064	.045
> .16 hours	.154	.02

These results show that the exponential distribution underweights the likelihood of longer detection times.

The exponential distribution arises in the famous random search formula. This formula is based on two assumptions:

1. The time to detection is exponential distributed, so that Prob {detection time $< t$ } $= 1 - \exp(-\beta t)$.

2. The parameter β is given by the formula $\beta = Wv/A$, where W is the detection width of the vessel's sonar, v is the speed of the vessel and A is the area in which the vessel is searching.

In this document, the first assumption is retained but the second assumption is dropped and is replaced as follows. Let $\beta_{base} = .05$ hours denote the approximate value of the parameter β when the base parameters are used. Consider a concentration of radius L containing N_s swarms in which the characteristic swarm radius is r. The detection parameter for the concentration is assumed to be given by

$$\beta = \beta_{base}\ (N_S/N_{base})(\ L_{base}/\ L)^{\ 2}(\ [W_{echo} + \ r\exp(.605)]/\ [W_{echo} + r_{base}\exp(.605)]) \qquad (9.5)$$

In this equation, W_{echo} is the detection width of the echosounder and the term exp(.605) comes from the expectation of the log-normally distributed swarm radius. The logic behind this equation is the following: the rate of detections should increase as the number of swarms increases or the detection width increases (either from the echo sounder or changes in swarm radius) and should decrease as the area increases.

The actual search time for a swarm will consist of (i) an encounter time t_{enc} following the exponential distribution described above and (ii) an identification time t_{id} in which the signal is determined to be an actual swarm. I assume that identification time consists of a fixed period of 2 minutes and a variable period given by variable $t_{id} = 5(1-\exp(-B_s/10))$ min, where B_s is the biomass of the encountered swarm, measured in tonnes.

Even so, the encounter and total detection time described above appear to be considerably less than what we can infer from logbook data. Consequently, following Butterworth (1987), a selectivity process is introduced. An encountered swarm with biomass B_s is accepted for fishing only if its biomass exceeds a threshold. In particular, the encountered swarm is accepted for fishing only if $B_s > B_{threshold}\ \exp(\mathbf{X}_{.2})$. Here $B_{threshold}$ is the basic value for the threshold (set to be 50 tonnes in the base case) and $\mathbf{X}_{.2}$ is a normally distributed random variable with mean 0 and variance 0.2.

(iii) Fishing Submodel

It is now possible to describe the fishing submodel. The setup is as follows: The entire fleet is located in a single concentration, ready to begin fishing. Although the vessels are assumed to search cooperatively and pool catches when making decisions about leaving concentrations, the micro-operations of the vessels (i.e. individual trawls) are treated independently. It is thus sufficient to consider a single vessel, with the understanding that the modelling process for the fishing of one vessel is repeated 5 to include all vessels of the fleet. (Naturally, the vessels are treated independently. This means independent draws of random variables during the simulation.)

Fishing is assumed to take place in periods of 24 continuous hours of daylight. Even so, there are limits to the number of hauls and the total catch per vessel. I assume that the vessels make no more than 7 hauls per 24 hours and that because of processing constraints, the vessels draw their nets when the nets contain 20 tonnes of krill. Thus, the maximum catch by a single vessel is 140 tonnes per day, or 700 tonnes for the entire 14 day fishing period. The maximum catch for a fleet of 5 identical vessels is thus 9 800 tonnes for the 14 day period.

I assume that if the fleet is already within a concentration, each fishing day starts with the search for swarms. At the start of the day, the operational time remaining, which is denoted by T_R, is 24 hours. The time until a swarm is detected, which is denoted by T_{search}, is determined as described above. After a swarm is detected and selected for fishing, the vessel lowers its net. In light of the mean surface density (150 g/m^2), it will usually be true that more than one swarm is fished per haul of the net. To take this into account, I use the Poisson approximation to the binomial to determine the number of additional swarms within 35 m of the vessel as it tows for a maximum of 8 n miles. After a swarm is fished, the distance travelled to reach the next swarm is uniformly distributed and is determined by the inter swarm center to center distance (computed from the number of swarms and characteristic radius of the concentration). The haul ends when either (i) more than 4 n miles have been traversed with the net in the water , or (ii) more than 20 tonnes are in the net (presumed to be estimated from the echosounder). The 4 n miles limit is applied with liberty (although it rarely ever is binding).

The actual catch is computed by considering a the tow of a net through a circular swarm. I assume that the towed area can be modelled by a rectangle, that the width of the net is 20 m, so that the maximum area swept is the net width times the diameter of the swarm, i.e. the maximum area swept is 20x 2x r = 40 r m^2. (This assumes that diameter of the swarm exceeds 20 m and must be modified if the diameter of the swarm is less than the width of the net. In general, 40r m^2 is replaced by 2r min(20,2r) m^2.

The time spent towing is determined in the following way. The vessel's speed while towing is assumed to be v_{tow} = (2.5 + 2 **U**) m/hour, where **U** is a random variable uniformly distributed on the interval [0,1]. The tow through a swarm with radius r_{ij} takes $(2r_{ij}/v_{tow})$ hr. Let d_{ij} denote the distance between swarm j in concentration i and the next swarm fished. I assume that the tow time is given by

$$T_{tow} = [\Sigma_j \ (2r_{ij} + d_{ij})/v_{tow}] \qquad (9.6)$$

The summation on the right hand side of Eqn (9.6) is the total time to tow through all of the swarms.

At the end of a tow, the net is hauled. I assume a hauling/veering rate of 150 m/hr and use the empirical distribution of depths from the Soviet data to randomly select an associated veering/hauling time. After the net is brought on board, the vessel has a period of "dead time" in which processing occurs. Dr Ichii (personal communication) provided the following information on processing time:

Catch per haul (tonnes)	Processing time (hours)
0 - 10	1.5
11- 15	2.0
> 15	2.5

The time remaining is then decremented by the total of search time + trawl time + hauling time + processing time. This fishing model is repeated for each vessel each day until either time remaining reaches 0 or the number of hauls exceeds 7. The model is then repeated for the entire fleet for 14 days of fishing. The data generated by this submodel are search times, tow times, and catch times.

(iv) Fleet Decision and Bad Weather Models

Dr Ichii (personal communication) kindly provided information on fleet decisions and on bad weather. Based on this information, I assume that at the end of each day the daily value of catch/haul is computed. If this value exceeds 3 tonnes/haul, then the fleet stays in the current concentration. If the daily value is below 3 tonnes/haul, then the fleet exits the current concentration and begins search for another concentration.

Dr Ichii also provided data on the frequency and duration of bad weather experienced in operations by JAMAC between 1973-74 and 1985-86. Based on these data, the probability of bad weather terminating fishing is assumed to be .02. If bad weather does occur, the duration of the bad weather spell is one day with probability .68., two days with probability .28 and three days with probability .04. I assume that if bad weather occurs, the fleet is displaced 50 n miles from the concentration in which it was fishing and that the fleet must search for a concentration at the end of the bad weather period.

10. GENERAL CONSIDERATIONS ON ABUNDANCE INDICES FOR PELAGIC, SCHOOLED STOCKS

This chapter contains a general discussion of considerations for a theory of abundance indices for pelagic, schooling species. Particular indices will be developed and employed in the next chapter. The objective here is to discuss desirable properties of indices and also to discuss.how indices can be used to detect changes in abundance.

The general question is how one develops a biomass index (or indices) with the following desirable properties:

- Consistency: Changes in actual abundance and changes in the index should always be in the same direction. This is crucial for a system such as the Southern Ocean krill fishery in which many parameters determine ultimate abundance and more than one parameter may change at a time.
- Linearity: Changes in actual abundance should be reflected by proportional changes in the index.
- Small variability: The inherent variability in the index should be small, so that the probability of detecting changes in the index is large.

For the underlying "patches within patches" system as described here, a biomass estimate B_{est} should take the form:

$$B_{est} = \text{(Number of Concentrations) (Swarms Per Concentration) (Biomass Per Swarm)} \qquad (10.1)$$

The number of concentrations can clearly be estimated from the data generated by the research/survey vessel, so let us consider estimates of swarms per concentration and biomass per swarm.

10.1 Estimating Swarms per Concentration

The exponential model for detection of swarms is equivalent to the assertion that when N_s swarms are present

$$\text{Prob\{ detect one swarm by time } t \mid N_s \text{ swarms are present \}} = 1 - \exp(\beta t N_s) \qquad (10.2)$$

so that the expected value of the search time t_{srch} before a swarm is detected is

$$E\{t_{srch}\} = 1/\beta N_S \quad (10.3)$$

Eqn (10.3) suggests that the number of swarms present in a concentration could be estimated by

$$N_{s,est} = 1/\beta E\{t_{srch}\} \quad (10.4)$$

Note that when the exponential distribution is used, the expected value of $1/t_{srch}$ does not exist. That is, $\int_0^\infty (1/t)\beta N_s \exp(-\beta N_s t)\, dt$ is infinite.

The actual search model described above has a fixed identification time, which means that the minimum value of $t_{srch} = t_{id,fixed}$ (which is 2 minutes here). This would lead one to consider changing the exponential distribution in Eqn(10.2) and replacing it by

$$F(t) = \text{Prob}\{\text{ detection in search time} \le t\} = \begin{cases} 0 & \text{if } t \le t_{id} \\ 1 - \exp\{-\beta N_s(t-t_{id})\} & t>t_{id} \end{cases} \quad (10.5)$$

The search process is now a renewal process and the mean search time (including detection as part of the search process) is

$$E\{t_{srch}\} = (1/\beta N_s) + t_{id} \quad (10.6)$$

so that the estimate for the number of swarms becomes

$$N_{s,est} = [\, b(E\{t_{srch}\} - t_{id}\,)]^{-1} \quad (10.7)$$

These considerations show that reciprocal search times may play an important role in estimating the number of swarms per concentration.

10.2 Estimating Biomass/Swarm

"Conventional" wisdom suggests that biomass/swarm can be accurately estimated by some measure of catch rate, e.g. catch per towtime. Such thinking is based on the fundamental premise that the sampled organism is smoothly distributed over the region of interest. For a highly aggregated stock, in which there may be big gaps between swarms, catch per towtime may be a very poor estimator - severely under-diasing estimates of swarm biomass. Alternatives such as catch per selected swarm, catch per fished swarm or catch per encountered swarm may be much better.

10.3 Detecting Changes in Abundance Indices

Suppose now that the same abundance index (e.g. catch/swarm) has been computed in two different situations (e.g. the situation in which all parameters assume their base case values and the situation in which one of the parameters, say characteristic radius, is changed). Let X_b denote the abundance index for the base case parameters and X_c denote the abundance index when the parameters are changed. The simulation model described in the previous section allows one to compute an entire distribution for X_b and X_c. From that distribution, the following information is extracted:

- The mean values of the abundance indices. These are denoted by μ_b and μ_c respectively.
- The standard deviations of the abundance indices. These are denoted by σ_b and σ_c respectively.
- The ranges of the abundance indices observed in the simulation. For the base case, the lowest value of the abundance index will be denoted by $x_{lb,sim}$ and the greatest value by $x_{ub,sim}$. For the case in which parameters are changed the extremes will be denoted by $x_{lc,sim}$ and $x_{uc,sim}$ respectively.

We are interested in detecting changes in the abundance indices. One natural, and obvious measure is a comparison of the means, so that one would consider the ratio μ_c/μ_b. This was done, for example, by both Butterworth (1987) and Mangel (1987). Various statistical tests can be applied to determine the likelihood that the two means came from the same underlying distribution. There is , however, a fundamental problem with using such a test. In real life, one value of the abundance index will be observed. That is, the Southern Ocean fishery will not be "replicated" fifty times over in a single year. Thus, even if the abundance indices for the base case and changed parameter case do arise from different distributions, a particular value of the index in the changed parameter case may be very close, say, to the mean of the index for the base parameter case. It is here that the observed ranges of the abundance indices become so important.

In general, there will be overlap of the ranges, as shown below:

Base Parameters

|________________________________|

$x_{lb,sim}$ $x_{ub,sim}$

Changed Parameters

|________________________________|

$x_{lc,sim}$ $x_{uc,sim}$

For this situation, the overlap region consists of values of the abundance indices in the range $x_{lb,sim}$ to $x_{uc,sim}$. In addition to comparing the means of the abundance indices, one wants to compute the probability that a shift can be detected. Two methods for computing the probability of detecting a change will now be described.

The first method could be called a "non-parametric" or simulation based computation. In this case,

Prob{detect a change in abundance indices } =
1 - [Number of Data Points in the Overlap Region]/Total Number of Simulations (10.8)

That is, one simply counts the number of simulation iterations for the case of changed parameters in which the abundance index falls within the range $[x_{lb,sim}, x_{ub,sim}]$ and divides this by the total number of simulation iterations. The resulting value is the fraction of simulation iterations for changed parameters in which the abundance index falls in the range of base case parameters. The probability of detecting a change is defined as 1 minus this fraction.

The second method for computing the probability of detecting a change in abundance indices is based on a normal approximation. That is, one assumes ad hoc that the abundance indices are normally distributed with the mean and standard deviation observed in the simulations. Since a normal distribution with mean μ and variance σ has more than 99% of its probability mass concentrated in the interval $[\mu - 3\sigma, \mu + 3\sigma]$, the ranges for the base case are redefined as:

$$x_{ub} = \max[x_{ub,sim}, \mu_b + \sigma_b] \quad \text{and} \quad x_{lb} = \max[x_{lb,sim}, \mu_b + \sigma_b] \tag{10.9}$$

Given these new ranges and μ_c and s_c, the probability of detecting a change in this case is defined as

Prob{detect a change in abundance indices}
= 1 - Prob{ a point from the normal distribution with mean and standard deviation μ_c and σ_c falls in the range $[x_{lb}, x_{ub}]$ (10.10)

A small computation shows that

Prob{detect a change in abundance indices}

$$=1 - \{ \Phi([x_{ub} - \mu_c]/\sigma_c) - \Phi([x_{lb} - \mu_c]/\sigma_c) \} \tag{10.11}$$

where $\Phi(z)$ is the cumulative distribution function for a normally distributed random variable with mean 0 and variance 1.

11. ABUNDANCE INDICES FOR THE SOUTHERN OCEAN KRILL FISHERY MODEL AND BASE CASE RESULTS

In this chapter, 44 different abundance indices that could be computed from fishery generated data are described along with the mean, standard deviation and range for the base case parameters. These values are computed from 50 iterations of the simulation model.

Total catch (tonnes). This is the total catch by the 5 vessels over the 14 day fishing period.

Mean	Standard Deviation	Range
4642	428	2585,5270

Total number of hauls. This is also the total number of swarms that were selected for fishing.

Mean	Standard Deviation	Range
394	30.7	230,418

Total number of swarms fished. This index is based on the assumption that the vessels can identify individual swarms during the fishing process.

Mean	Standard Deviation	Range
2088	195	1192,2392

Total number of swarms encountered.

Mean	Standard Deviation	Range
7268	596	4214,7888

Total towtime (hours). This is the total time that the vessels have nets in the water.

Mean	Standard Deviation	Range
415	32.5	252,451

Total searchtime (hours). This is the total time that the vessels are searching for krill.

Mean	Standard Deviation	Range
429	36.7	255,473

Total reciprocal searchtime (1/hours). This is the total of the reciprocal of times spent searching for krill.

Mean	Standard Deviation	Range
813	87.2	425,1002

Total number of discoveries by the research/survey vessel.

Mean	Standard Deviation	Range
11.6	3.5	3,21

Number of different concentrations fished.

Mean	Standard Deviation	Range
1.2	.523	1,4

Total catch per total towtime. (tonnes/hour). This index is computed by dividing the total catch by the total towtime.

Mean	Standard Deviation	Range
11.2	.434	10.1,11.8

Average catch per towtime (tonnes/hour). This index is computed by averaging over individual hauls within a simulation iteration the quantity {catch/towtime}.

Mean	Standard Deviation	Range
13.6	.575	12.3,14.5

Average catch per searchtime (tonnes/hour). This index is computed by averaging over individual hauls within a simulation iteration the quantity {catch/searchtime}.

Mean	Standard Deviation	Range
24.2	1.93	20.2,30.3

Average of catch per towtime per searchtime (tonnes/hour^2). This index is computed by averaging over individual hauls within a simulation iteration the quantity {(catch/towtime)(1/searchtime)}.

Mean	Standard Deviation	Range
27.8	2.52	22.8,35.5

Catch per day (tonnes/day). This index is computed by dividing total catch by the length of the fishing period.

Mean	Standard Deviation	Range
332	30.6	185,376

Catch per haul (tonnes). This index is computed by dividing the total catch in a simulation iteration by the total number of hauls in that simulation iterations.

Mean	Standard Deviation	Range
11.8	.422	10.8,13.0

Hauls per concentration discovered. This index is computed by dividing the total number of hauls in a simulation iteration by the total number of concentrations discovered by the research/survey vessel and fleet.

Mean	Standard Deviation	Range
38.6	18.4	11.5,134

Fraction of swarms selected. This index is computed by dividing the total number of hauls by the total number of swarms encountered.

Mean	Standard Deviation	Range
.054	.0019	.0503,.0595

Average trawl length (n miles).

Mean	Standard Deviation	Range
1.37	.033	1.31,1.44

Discoveries times catch (10^4 tonnes). This index is computed by multiplying the total number of concentrations discovered by the survey vessel and fleet and the total catch.

Mean	Standard Deviation	Range
5.35	1.61	1.44,9.63

Discoveries times hauls times catch (10^7 tonnes). This index is computed by multiplying the total number of concentrations discovered by the total number of hauls and by the total catch.

Mean	Standard Deviation	Range
2.12	.682	.576,3.85

Discoveries times catch per towtime times swarms fished (10^5 tonnes/hour). This index is computed by multiplying the total number of discoveries by the total catch and by the total of swarms fished and dividing by the total towtime.

Mean	Standard Deviation	Range
2.69	8.17	.663,4.88

Discoveries times average catch per towtime times swarms fished (10^5 tonnes/hour). This index is computed by multiplying the total number of discoveries by the average catch per towtime and by the total number of swarms fished.

Mean	Standard Deviation	Range
3.27	.996	.804,6.04

Average catch per towtime divided by average searchtime (tonnes/hr^2).

Mean	Standard Deviation	Range
12.5	.905	10.8,14.7

Average catch per towtime times average reciprocal searchtime (tonnes/hr^2).

Mean	Standard Deviation	Range
28.0	2.06	22.7,34.5

Discoveries times total catch divided by total towtime(tonnes/hour).

Mean	Standard Deviation	Range
129	39.1	32.7,232

Discoveries times average catch per towtime divided by average searchtime (tonnes/hour^2).

Mean	Standard Deviation	Range
145	44.8	35.5,255

Discoveries times average catch per towtime times average reciprocal searchtime (tonnes/hour^2).

Mean	Standard Deviation	Range
325	103	76.6,605

Discoveries times average {(catch per towtime) (reciprocal searchtime)} (tonnes/hour^2).

Mean	Standard Deviation	Range
322	100	74,593

Discoveries times total catch divided by total towtime divided by average searchtime (tonnes/hour^2).

Mean	Standard Deviation	Range
119	36.9	29.3,206

Discoveries times total catch times average reciprocal searchtime divided by total towtime (tonnes/hour^2).

Mean	Standard Deviation	Range
267	84.8	63.2,84.9

Discoveries times total catch times number of selected swarms divided by total towtime (10^4 tonnes/hour).

Mean	Standard Deviation	Range
5.07	1.53	1.31,9.23

Discoveries times average catch per towtime times number of selected swarms (10^4 tonnes/hour).

Mean	Standard Deviation	Range
6.17	1.86	1.59,11.1

Discoveries times total catch times number of swarms encountered divided by total towtime (10^5 tonnes/hour).

Mean	Standard Deviation	Range
9.35	2.78	2.78,16.9

Discoveries times average catch per towtime times number of swarms encountered (10^6 tonnes/hour).

Mean	Standard Deviation	Range
1.14	.339	.287,2.09

Discoveries times total catch per total towtime times hauls per concentration fished (10^4.tonnes/hour).

Mean	Standard Deviation	Range
4.75	1.81	1.81,9.23

Discoveries times average catch per towtime times hauls per concentration fished (10^4 tonnes/hour).

Mean	Standard Deviation	Range
5.78	2.2	1.3,11.1

Discoveries times total catch per total towtime times swarms fished per concentration (10^5 tonnes/hour).

Mean	Standard Deviation	Range
2.52	.964	.602,4.88

Discoveries times average catch per towtime times swarms fished per concentration (10^5 tonnes/hour).

Mean	Standard Deviation	Range
3.06	1.17	.724,6.04

Total catch per total hauls divided by average searchtime (tonnes/hour).

Mean	Standard Deviation	Range
10.8	.685	9.24,12.8

Discoveries times total catch per total hauls divided by average searchtime (tonnes/hour).

Mean	Standard Deviation	Range
122	39.1	40.4,207

Total catch per swarms fished per average searchtime (tonnes/hour).

Mean	Standard Deviation	Range
2.03	.088	1.88,2.3

Discoveries times total catch per swarms fished per average searchtime (tonnes/hour).

Mean	Standard Deviation	Range
22.9	7.2	7.92,37.2

Catch per swarms encountered per average searchtime (tonnes/hour).

Mean	Standard Deviation	Range
.581	.0445	.483,.695

Discoveries times catch per swarms encountered per average searchtime (tonnes/hour).

Mean	Standard Deviation	Range
6.56	2.14	2.21,11.3

12. PERFORMANCE OF THE INDICES IN DETECTING CHANGES IN KRILL BIOMASS

This chapter contains results on the efficacy of the different abundance indices in detecting changes in krill abundance. Krill abundance will change if any of the basic parameters change.

Biomass is indexed by the product of characteristic parameters:

- Biomass index = $N_c\ D_c(L_c)^2\ \delta_c(r_c)^2$

Two types of parameter changes were implemented. First, only one parameter was changed at a time, leading to drops in biomass to either 2/3 or 1/3 of the base case level. This was done by changing the parameters as follows:

- L_c multiplied by $\sqrt{2/3}$ or $\sqrt{1/3}$
- r_c multiplied by $\sqrt{2/3}$ or $\sqrt{1/3}$
- δ_c multiplied by 2/3 or 1/3
- N_c multiplied by 2/3 or 1/3
- D_c multiplied by 2/3 or 1/3.

The multiplicative factor is 2/3 (1/3) or $\sqrt{2/3}$ ($\sqrt{1/3}$) depending on the way that the parameter enters into the determination of biomass (linearly or squared).

Second, more than one parameter was changed simultaneously, leading to changed biomass levels that ranged from 0.2 to 1.2 times the biomass in the base case. The parameter values for these cases are shown in Table 12.1 (the base case parameters are also shown, for easy reference).

Finally, the effect of adaptive behavior by the fishing fleet was studied by considering changes in the threshold for accepting a krill swarm for fishing. The other two values of the threshold used were B_{thr} = 40 tonnes and B_{thr} = 0 tonnes. Naturally, changing the threshold for accepting swarms does not change the underlying krill biomass, but it may change the abundance indices and thus lead to a belief that the underlying biomass was indeed changed.

Tables 12.2 to 12.46 show the results. Shown in these tables are the biomasses relative to the base case, the ratio of the mean abundance index for the changed parameters (μ_c) to the mean abundance index for the base case parameters (μ_b) and the probability of detecting the change in biomass based on the simulation (non-parametric) and normal approximation calculations described previously.

13. DISCUSSION OF THE SIMULATION RESULTS

When considering the results presented in the last chapter, it is useful to separate changes in biomass index caused by changes of within concentration parameters (that is D_c, r_c and δ_c) and changes of between concentration parameters (L_c and N_c). No single index is capable of tracking both kinds of changes. Study of the results leads to the following conclusions:

- Many of the indices are ineffective for tracking changes in krill abundance because they have inconsistent changes (both increases and decreases in the abundance index or no change in the abundance index) with the biomass index.

- Even those indices that do exhibit consistent changes also exhibit the problem of "convexity": a change of biomass index to 2/3 or 1/3 of the base case leads to a ratio of μ_c/μ_b that is greater than 2/3 or 1/3. That is, the abundance indices are not linear in the biomass index.

- Even those indices for which μ_c/μ_b is considerably less than 1 and close to 2/3 or 1/3 may have a small probability of detecting the shift. This is caused by the large variability in the abundance indices for fixed krill distributional parameters.

- Simple indices appear to perform better than more complicated indices. This is true at two levels. For example, the index
  (Total Catch / Total Towtime)/ Average {Searchtime}
  performs better than the index

Average { (Catch/Towtime) / {Searchtime }
where the average is taken over individual hauls. Similarly, indices in which the number of discoveries is multiplied by a within-swarm abundance index perform more poorly than indices without that multiplier (compare Tables 12.40, 12.42 and 12.44 with Tables 12.41, 12.43 and 12.45).

- Although a number of abundance indices are effective in tracking changes in biomass caused by single changes in parameters, none is effective when many parameters change at once. This is caused by the confounding effects of multiple changes in parameters. This suggests that determining the most likely sources of biomass change is an important future project. That is, effort should be spent determining the parameters that are most likely to change and the directions in which they will change.

- The most effective tracking of krill abundance could be done with the following abundance indices:

  1. Use the number of discoveries by the survey vessel to track changes in the number of concentrations and the characteristic radii of concentrations.

  2. Use one of the following indices to track within concentration changes of swarm density and krill abundance within swarms:

     (Total Catch / Total Hauls) / Average{Searchtime}
     (Total Catch/Swarms Fished) / Average{Searchtime}
     (Total Catch/Swarms Encountered)/Average{Searchtime}.

  Note that since the total number of hauls equals the number of swarms selected for fishing, all of these indices have the form catch per "swarm" per searchtime. This is consistent with the theoretical concepts presented in Chapter 10.

- The adaptive behavior of fishing vessels may be important for the accurate interpretation of abundance indices. For example, a changing threshold for acceptance of a swarm for fishing or a changing catch continuation parameter might drastically effect abundance indices and lead to inaccurate interpretations of their meaning. Refishing might also affect abundance indices, depending upon the effectiveness of the search procedure during refishing (Butterworth 1987, Mangel 1987)

14. CONCLUSION AND RECOMMENDATIONS

Although the model developed in the body of this report contains many operational uncertainties (e.g. what exactly is search time), it is still possible to make a number of recommendations. In particular the following are suggested :

1. Fishing and survey vessels should indicate in their log books approximately how much of the between trawl times are spent in search for swarms of krill. If possible, vessels should indicate the number of swarms fished in a haul. This would require a consistent definition of swarm (in terms of sonar ping threshold, for example).

2. CCAMLR should consider an "experiment" in which a research vessel and a fishing fleet travel together, but work independently. In particular, the fishing fleet should operate as if the survey vessel were not present, and the survey vessel

should conduct krill surveys in the vicinity of regions in which the fleet fishes. By doing this, one can obtain a distributional model for krill that are considered fishable by the fleet.

3. If a detailed operational model of krill fisheries is desired, CCAMLR should consider sending a Ph.D. level modeller to sea with the fleets. This is in the best traditions of operational analysis (see, e.g. Tidman 1984) and most likely is the only way that accurate operational models can be developed. In particular, such a field assignment will lead to accurate understanding of the role of search in the overall fishing operation and to an accurate understanding of operational fishing decisions.

4. The following indices can be used, at least temporarily, to track krill abundance:

   (a) Use the number of discoveries by the survey vessel to track changes in the number of concentrations and the characteristic radii of concentrations.

   (b) Use one of the following indices to track within concentration changes in swarm density and krill abundance within swarms:

   (Total Catch / Total Hauls) / Average {Searchtime}
   (Total Catch/Swarms Fished) / Average {Searchtime}
   (Total Catch/Swarms Encountered) / Average {Searchtime}.

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Table 2.1: Summary of Soviet Cruise Sources

Data Set	Vessel Name	Region	Period	Number of Records
1	Akademik Knipovich	12.6°E - 56° W 52.1°S -69.8°S	5.3.81- 23.5.81	92
2	Akademik Knipovich	46.1°W-135.7°W 60.3°S - 69.3°S	20.3.82- 7.5.82	39
3	Akademik Knipovich	27.5°E-67.7°E 48.1°S -69°S	12.1.84- 29.3.84	177
4	Odyssey	35.3°W -55.7°W 53.6°S -61.3°S	9.1.81- 19.3.81	39
5	Professor Derugin	59.5°E -94.5°E 61.7°S -69°S	15.1.81- 20.4.81	417
6	Professor Derugin	61.2°E -112.4°E 62.9°S -67.1°S	18.2.82- 5.5.82	188
7	Argus	32.3°W -39°W 51.1°S -54.5°S	23.4.81- 27.6.81	229
8	Argus	44.2°W -55.6°W 59.4°S -61°S	27.1.84- 8.4.84	236
9	Globus	56.9°E - 68.4°E 60.5°S - 67°S	2.2.84- 9.4.84	306
10	Mys Dalniy	105.6°E -163.9°E 64.3° S - 72.1°S	7.2.84- 29.4.83	65
11	Mys Unony	135.5°E - 172.8°E 65.1°S -77.9°S	20.1.82- 9.4.84	47
12	Mys Tihiy	116.7°E -167.6°E 64° S - 68.4°S	2.1.81- 8.4.81	155

Table 2.2: Net Characteristics of the Vessels

	Trawl Mouth Length (m)	Effective Trawl Mouth Section (m^2)	Mesh Size (mm)	Mesh Bar Length (mm)
Akademik Knipovich	87.6	49	40	20
Odysssey	36.6	78	40	20
Argus	66	163	40	20
Professor Derugin	49.5	26	35	12
Globus	110	72	35	12
Mys Dalniy	77.4	50	35	11
Mys Unony	77.4	50	35	11
Mys Tihiy	77.4	50	35	11

Table 3.1: Summary of Means and Variances of Quantities Derived from Soviet Data. (See text for a full discussion of how to read the table.)

Quantity	Data Set					
	1	2	3	4	5	6
Trawls per day	1.78,.91	2,.73	2.8,1.6	1.3,.44	4.6,2.4	4.5,2.4
Trawling depth (meters)	44.9,22.2 (58,4)	64,54	66,47	80,45	20.3,15.3	37,21
Trawling Speed (knots)	4.3,.32	2.8,.26	3.4,.5	2.9,1	2.7,.26	2.9,.22
Trawling time (hours)	1.0,.65	1.1,.52	.89,.53	1.2,.71 (1.8,3)	1.1,.52 (1.3,13)	.72,.52 (.87,1)
Trawling length (n miles)	3.7,1.8 (4.5,24)	3.1,1.4 (3.6,3)	2.9,1.7 (3.1,8)	2.9,2.2 (5.4,10)	3.0,1.5 (3.3,12)	2.1,1.6
Krill Catch (tonnes)	8391, 5822	4053, 3097	2386, 2906	4505, 3778	4008, 8147	5814, 3983
Krill Size (mm)	45,3.5	48,3.6	44,3.7	51,2.9	No data	39,3.6
Between Trawlings Time (hours)	11.4,8.8 (17,8)	9.0,9.0 (24.6,6)	7.2,6.2 (10.8,6)	14,8.2 (36.4,11)	4.6,7.2	4.2,5.2
Between Trawlings Movement (n miles)	18,15.4 (41,13)	6.5,7.6 (58,12)	25.7,17.8 (60,36)	18.5,17.4 (54,5)	13.2,18.5 (20,19)	5.6,9.9

Quantity	Data Set					
	7	8	9	10	11	12
Trawls per day	3.5,1.9	3.4,1.3	5.7,4.9	2.6,1.3	2.7,2.6	3.2,1.9
Trawling depth (meters)	43,36	88.6,27	17,15.7	17.3,16.6	52,45	26,14
Trawling Speed (knots)	3.3,.24	3.5,.14	3.0,.17	2.8,.22	3.6,.28	2.7,.32
Trawling time (hours)	1.41,.86	.77,.66 (.93,2)	.9,.9 (1.1,11)	1.4,.4	2.3,.76 (2.8,5)	1,.6 (1.2,3)
Trawling length (n miles)	3.8,1.9 (4.8,34)	2.2,1.3 (3.0,16)	2.2,2.1 (3.3,8)	4.0,1.4 (4.3,3)	5.7,1.4 (10,30)	2.7,1.7 (3.4,6)
Krill Catch (tonnes)	4133, 4081	2534, 5035	7193, 4876	2192, 2364	10435, 8123	3512, 3205
Krill Size (mm)	39,3.6	48,4.2	No data	No data	No data	No data
Between Trawlings Time (hours)	5.8,7.6 (6.4,1)	5.6,4.6 (5.8,1)	3.0,4.3 (4.6,7)	7.4,10.3 (18,14)	6.2,8.0 (24,6)	6.5,8.9 (13,9)
Between Trawlings Movement (n miles)	9.6,12.8 (11.6,3) (37,15)	21.8,15.6 (25,4)	5.6,9.9 (10.6,5)	15.2,20.5 (83,9)	10,14 (29,3)	12,20

Table 3.2: Correlations for Data Set 1, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+	+	0	-	0	0	0
	+	+	+	-	0	0	0
TL	+	+	0	-	0	0	0
	+	+	+	-	0	0	0
KC	0	0	+	-	0	0	0
	+	+	0	-	0	0	0
BTM	-	-	-	+	+	0	0
	-	-	-	+	0	0	0
BTT	0	0	0	+	+	0	0
	0	0	0	0	0	0	0
D	-	0	0	0	0	+	0
	0	0	0	+	+	0	0
L	0	0	0	0	0	0	+
	0	0	0	0	0	0	+

Table 3.3: Correlations for Data Set 1, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+	+	0	-	0	-	0
	+	+	+	-	0	-	0
TL	+	+	+	-	0	0	0
	+	0	0	-	-	0	0
KC	0	0	+	0	-	-	0
	+	0	0	-	0	0	0
BTM	-	-	0	+	+	0	0
	-	0	0	+	0	0	0
BTT	0	0	-	+	+	0	0
	-	0	0	0	0	0	0
D	-	0	0	0	0	+	0
	0	0	0	+	+	0	0
L	0	0	0	0	0	0	+
	0	0	0	0	0	0	+

Table 3.4: Correlations for Data Set 2, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+	+	0	0	0	0	0
	+	+	0	0	0	0	0
TL	+	+	0	0	0	0	0
	+	0	0	0	0	0	0
KC	0	0	+	0	0	0	0
	0	0	0	0	0	0	0
BTM	0	0	0	+	+	+	-
	0	0	0	0	0	0	0
BTT	0	0	0	+	+	+	-
	0	0	0	0	0	0	0
D	0	0	0	+	+	+	-
	0	0	0	+	+	0	-
L	0	0	0	-	-	-	+
	0	0	0	-	-	0	+

Table 3.5: Correlations for Data Set 2, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+	+	0	0	0	0	0
	0	0	0	0	0	0	0
TL	+	+	0	0	0	0	0
	0	0	0	0	0	0	0
KC	0	0	+	0	0	0	0
	0	0	0	0	0	0	0
BTM	0	0	0	+	+	+	0
	0	0	0	0	0	+	-
BTT	0	0	0	+	+	+	0
	0	0	0	0	0	0	0
D	0	0	0	+	+	+	-
	0	0	0	0	0	0	-
L	0	0	0	0	0	-	+
	0	0	0	0	-	0	+

Table 3.6: Correlations for Data Set 3, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+	+	+	0	0	0	0
	0	0	0	+	+	0	0
TL	+	+	+	0	0	0	0
	0	0	0	0	+	0	0
KC	+	+	+	-	0	-	0
	0	0	+	0	0	-	0
BTM	0	0	-	+	+	0	0
	0	0	0	+	+	0	0
BTT	0	0	0	+	+	0	0
	+	+	0	0	+	0	0
D	0	0	-	0	0	+	0
	0	0	-	0	0	0	0
L	0	0	0	0	0	0	+
	0	0	0	0	-	0	+

Table 3.7: Correlations for Data Set 3, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+	+	+	0	0	0	0
	0	+	0	0	+	0	0
TL	+	+	+	0	0	0	0
	0	0	0	0	+	0	0
KC	+	+	+	-	0	-	0
	0	0	+	-	0	-	0
BTM	-	0	-	+	+	0	0
	0	0	-	+	0	0	0
BTT	0	0	0	+	+	0	0
	0	0	0	+	+	0	0
D	0	0	-	0	0	+	0
	-	-	-	0	0	+	0
L	0	0	0	0	0	0	+
	0	0	0	0	0	0	+

Table 3.8: Correlations for Data Set 4, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+ 0	+ 0	0 0	0 0	0 0	+ 0	- 0
TL	+ 0	+ 0	0 0	0 0	0 0	+ +	0 0
KC	0 0	0 0	+ 0	0 0	0 0	0 0	0 0
BTM	0 0	0 0	0 0	+ 0	+ 0	0 0	0 0
BTT	0 0	0 0	0 0	+ 0	+ 0	0 0	0 0
D	+ 0	+ 0	0 0	0 0	0 0	+ 0	- 0
L	- -	- -	0 0	0 0	0 0	- -	+ -

Table 3.9: Correlations for Data Set 4, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+ 0	+ 0	0 0	0 0	0 0	0 0	0 0
TL	+ 0	+ 0	0 0	0 0	0 0	0 0	0 0
KC	0 0	0 0	+ 0	0 0	0 0	0 +	0 0
BTM	0 0	0 +	0 -	+ +	0 0	- 0	+ +
BTT	0 0	0 0	0 0	+ 0	0 0	0 0	0 0
D	0 0	0 0	0 0	- 0	0 0	+ +	0 -
L	0 0	0 0	0 0	+ +	0 0	0 -	+ +

Table 3.10: Correlations for Data Set 5, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+	+	0	+	+	0
	0	0	0	0	+	0
TL	+	+	0	+	+	0
	0	0	0	0	+	0
KC	0	0	+	0	0	0
	0	0	+	0	0	0
BTM	+	+	0	+	+	+
	0	0	0	+	0	0
BTT	+	+	0	+	+	+
	0	0	0	+	0	0
D	0	0	0	+	+	+
	0	0	0	0	0	+

Table 3.11: Correlations for Data Set 5, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+	+	0	0	0	0
	+	+	-	0	0	0
TL	+	+	0	0	0	0
	+	+	-	0	0	+
KC	0	0	+	-	0	0
	0	0	+	-	0	-
BTM	0	0	-	+	+	0
	0	0	0	+	0	0
BTT	0	0	0	+	+	+
	0	0	0	+	0	0
D	0	0	0	0	+	+
	0	0	0	0	0	+

Table 3.12: Correlations for Data Set 6, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+	+	0	0	0	0
	0	0	0	0	0	0
TL	+	+	0	0	0	0
	0	0	0	0	0	0
KC	0	0	+	0	0	0
	0	0	+	0	0	0
BTM	0	0	0	+	+	0
	0	0	+	0	0	+
BTT	0	0	0	+	+	+
	0	0	0	0	0	0
D	0	0	0	0	0	+
	+	+	0	0	0	+

Table 3.13: Correlations for Data Set 6, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+	+	0	0	0	+
	+	+	0	0	+	0
TL	+	+	+	0	0	+
	+	+	0	0	+	0
KC	0	+	+	0	0	0
	0	0	+	-	+	0
BTM	0	0	0	+	+	0
	0	0	0	0	0	+
BTT	0	0	0	+	+	0
	0	0	0	0	0	0
D	+	+	0	0	0	+
	+	+	0	0	0	+

Table 3.14: Correlations for Data Set 7, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+ +	+ +	0 0	0 0	0 0	0 0	0 0
TL	+ +	+ +	0 0	0 0	0 0	0 0	0 0
KC	0 0	0 0	+ 0	0 0	0 0	0 0	0 0
BTM	0 0	0 0	0 0	+ +	+ 0	0 0	0 0
BTT	0 0	0 0	0 0	+ 0	+ 0	0 0	0 0
D	0 0	0 0	0 0	0 0	0 0	+ +	0 0
L	0 0	0 0	0 0	0 0	0 0	0 0	+ 0

Table 3.15: Correlations for Data Set 7, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+ +	+ +	0 0	0 0	- 0	0 0	0 0
TL	+ +	+ +	+ 0	0 0	- 0	0 0	0 0
KC	0 0	+ 0	+ 0	0 0	0 +	0 0	0 0
BTM	0 0	0 0	0 0	+ +	+ 0	+ 0	0 +
BTT	- 0	- 0	0 0	+ 0	+ 0	- 0	0 0
D	0 0	0 0	0 0	0 +	0 0	+ +	0 0
L	0 0	0 0	0 0	0 0	0 0	0 0	+ 0

Table 3.16: Correlations for Data Set 8, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+ / 0	+ / 0	0 / 0	0 / 0	0 / 0	- / -	0 / 0
TL	+ / 0	+ / +	0 / +	0 / 0	0 / 0	- / -	+ / 0
KC	0 / 0	0 / 0	+ / 0	0 / 0	0 / 0	- / -	0 / 0
BTM	0 / 0	0 / 0	0 / 0	+ / +	+ / 0	0 / 0	0 / 0
BTT	0 / 0	0 / 0	0 / 0	+ / 0	+ / 0	0 / 0	0 / 0
D	- / -	- / -	- / -	0 / 0	0 / 0	+ / +	0 / -
L	0 / 0	+ / 0	0 / 0	0 / 0	0 / 0	- / -	+ / +

Table 3.17: Correlations for Data Set 8, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D	L
TT	+ / +	+ / +	+ / +	- / -	0 / 0	- / -	+ / +
TL	+ / +	+ / +	+ / +	- / -	0 / 0	- / -	0 / 0
KC	+ / +	+ / +	+ / +	- / -	- / 0	- / -	+ / +
BTM	- / -	- / -	- / -	+ / +	+ / +	+ / +	- / 0
BTT	0 / -	0 / 0	- / 0	+ / +	+ / 0	+ / 0	0 / 0
D	- / -	- / -	- / -	+ / +	+ / 0	+ / +	- / -
L	+ / +	0 / 0	+ / +	- / -	0 / 0	- / -	+ / +

Table 3.18: Correlations for Data Set 9, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+ +	+ +	+ +	0 0	+ +	+ +
TL	+ +	+ +	+ +	0 0	+ 0	+ +
KC	+ +	+ +	+ +	0 0	0 0	+ +
BTM	0 0	0 0	0 0	+ +	0 0	0 0
BTT	+ 0	+ 0	0 0	0 0	+ 0	0 0
D	+ +	+ +	+ +	0 0	0 0	+ +

Table 3.19: Correlations for Data Set 9, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+ +	+ +	+ +	+ +	+ +	+ +
TL	+ +	+ +	+ +	+ +	+ +	+ +
KC	+ +	+ +	+ +	0 0	0 0	+ +
BTM	+ +	+ +	0 0	+ +	+ 0	+ 0
BTT	+ 0	+ 0	0 0	+ 0	+ -	0 0
D	+ +	+ +	+ +	+ 0	0 0	+ +

Table 3.20: Correlations for Data Set 10, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+ 0	+ 0	+ 0	0 0	0 0	0 0
TL	+ 0	+ 0	+ 0	0 0	0 0	0 0
KC	+ 0	+ 0	+ +	0 -	0 0	0 0
BTM	0 0	0 0	0 0	+ 0	+ 0	0 0
BTT	0 0	0 0	0 0	+ 0	+ 0	0 0
D	0 0	0 0	0 0	0 +	0 0	+ +

Table 3.21: Correlations for Data Set 10, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+ 0	+ 0	0 0	0 0	0 0	0 0
TL	+ 0	+ 0	0 0	0 0	0 0	0 0
KC	0 0	0 0	+ +	0 -	0 0	0 0
BTM	0 0	0 0	0 0	+ 0	+ 0	0 0
BTT	0 0	0 0	0 0	+ 0	+ 0	0 0
D	0 0	0 0	0 0	0 0	0 0	+ +

Table 3.22: Correlations for Data Set 11, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+	+	+	0	0	0
	0	0	+	0	0	0
TL	+	+	+	0	0	0
	0	0	+	0	0	0
KC	+	+	+	0	0	0
	+	+	+	-	0	0
BTM	0	0	0	+	+	+
	0	0	0	+	0	0
BTT	0	0	0	+	+	0
	0	0	0	+	0	0
D	0	0	0	+	0	+
	0	0	0	+	0	0

Table 3.23: Correlations for Data Set 11, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+	+	0	0	0	0
	0	0	0	0	0	0
TL	+	+	0	0	0	0
	0	0	0	0	0	0
KC	0	0	+	0	0	0
	0	0	+	-	0	0
BTM	0	0	0	+	+	0
	0	0	0	0	0	0
BTT	0	0	0	+	+	0
	0	0	0	0	0	0
D	0	0	0	0	0	+
	0	0	0	0	0	0

Table 3.24: Correlations for Data Set 12, all Data Used (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+	+	+	0	0	+
	+	+	0	0	0	+
TL	+	+	+	0	0	+
	+	+	0	0	0	+
KC	+	+	+	0	0	0
	0	0	0	0	0	0
BTM	0	0	0	+	+	0
	0	0	0	+	0	0
BTT	0	0	0	+	+	0
	0	0	0	+	0	0
D	+	+	0	0	0	+
	+	+	0	0	0	+

Table 3.25: Correlations for Data Set 12, Cutoff Values applied (see text for a discussion of how to read the table)

Quantities	TT	TL	KC	BTM	BTT	D
TT	+	+	+	0	0	+
	+	+	0	0	0	0
TL	+	+	+	0	0	+
	+	+	+	0	0	0
KC	+	+	+	0	-	0
	+	0	0	0	0	0
BTM	0	0	0	+	+	0
	0	0	0	0	0	0
BTT	0	0	-	+	+	0
	0	0	0	0	0	0
D	+	+	0	0	0	+
	+	+	0	0	0	+

Table 12.1: Parameter Values for Multiple Parameter Changes in Biomass

Parameter					Biomass Relative to Base Case
N_c	L_c	δ_c	r_c	D_c	
48	5.11	87.1	44.0	8.09	.20
60	6.60	237.2	16.5	20.4	.40
57	2.66	124.1	77.7	17.2	.61
54	3.84	134.7	84.5	9.05	.81
36	5.60	150	50	20	1.0 (Base Case)
37	6.89	48.9	68.5	25.6	1.2

Table 12.2: Detection Properties of Abundance Index "Total Catch"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.01	0	0
$r_c \times \sqrt{2/3}$	.91	0	0
$\delta_c \times 2/3$	.80	0	0
$D_c \times 2/3$	.91	0	0
$N_c \times 2/3$	1.01	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	0	0
$r_c \times \sqrt{1/3}$	.72	0	0
$\delta_c \times 1/3$	.51	.96	.92
$D_c \times 1/3$	.78	0	0
$N_c \times 1/3$	1	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.53	.62	.68
.4 of Base Case	.63	0	.02
.61 of Base Case	1.05	.08	0
.81 of Base Case	.98	0	0
1.2 of Base Case	.64	0	.01
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.62	.08	.09
B_{thr} = 40 tonnes	.99	0	0

Table 12.3: Detection Properties of Abundance Index "Total Hauls (Total Number of Swarms Selected)"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection: Simulation	Probability of Detection: Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.01	0	0
$r_c \times \sqrt{2/3}$	.93	0	0
$\delta_c \times 2/3$	.94	0	0
$D_c \times 2/3$	.96	0	0
$N_c \times 2/3$	1.0	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.99	0	0
$r_c \times \sqrt{1/3}$	.77	0	0
$\delta_c \times 1/3$	.82	0	0
$D_c \times 1/3$	.88	0	0
$N_c \times 1/3$	.99	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.76	0	0
.4 of Base Case	.59	.22	.30
.61 of Base Case	1.05	.64	0
.81 of Base Case	1.05	.76	0
1.2 of Base Case	.95	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	1.29	.98	.83
B_{thr} = 40 tonnes	1.03	.34	0

Table 12.4: Detection Properties of Abundance Index "Total Number of Swarms Fished"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection: Simulation	Probability of Detection: Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.02	.02	0
$r_c \times \sqrt{2/3}$	.95	0	0
$\delta_c \times 2/3$	.98	0	0
$D_c \times 2/3$	.84	0	0
$N_c \times 2/3$	1	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	0	0
$r_c \times \sqrt{1/3}$	.79	0	0
$\delta_c \times 1/3$	.88	0	0
$D_c \times 1/3$	.64	.04	.03
$N_c \times 1/3$	1	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.58	.32	.35
.4 of Base Case	.59	.32	.3
.61 of Base Case	1.01	.02	0
.81 of Base Case	.81	0	0
1.2 of Base Case	1.15	.64	.06
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	1.4	.98	.91
B_{thr} = 40 tonnes	1.06	.14	0

Table 12.5: Detection Properties of Abundance Index "Total Number of Swarms Encountered"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.01	.04	0
$r_c \times \sqrt{2/3}$	1.17	.9	.14
$\delta_c \times 2/3$	1.19	.98	.24
$D_c \times 2/3$	.93	0	0
$N_c \times 2/3$	1.01	.04	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	.04	0
$r_c \times \sqrt{1/3}$	1.541	.98	
$\delta_c \times 1/3$	1.67	1	.99
$D_c \times 1/3$	.82	0	0
$N_c \times 1/3$	1	.04	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	1.16	.86	1
.4 of Base Case	1.98	1.99	
.61 of Base Case	.76	0	0
.81 of Base Case	.63	.16	.1
1.2 of Base Case	1.37	1	.95
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.47	1	.99
B_{thr} = 40 tonnes	.93	0	0

Table 12.6: Detection Properties of Abundance Index "Total Trawl Time"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection: Simulation	Probability of Detection: Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.01	0	0
$r_c \times \sqrt{2/3}$	.92	0	0
$\delta_c \times 2/3$	.97	0	0
$D_c \times 2/3$	.96	0	0
$N_c \times 2/3$	.99	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.99	0	0
$r_c \times \sqrt{1/3}$	.74	0	0
$\delta_c \times 1/3$	.87	0	0
$D_c \times 1/3$	.89	0	0
$N_c \times 1/3$	.99	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.77	0	0
.4 of Base Case	.55	.9	.93
.61 of Base Case	1.11	.7	.02
.81 of Base Case	1.1	.76	.04
1.2 of Base Case	1.06	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	1.23	.94	.48
B_{thr} = 40 tonnes	1.03	.16	0

Table 12.7: Detection Properties of Abundance Index "Total Search Time"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1	.02	0
$r_c \times \sqrt{2/3}$	1.24	.92	.42
$\delta_c \times 2/3$	1.19	.86	.21
$D_c \times 2/3$	1.11	.52	.01
$N_c \times 2/3$	.99	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.99	.04	0
$r_c \times \sqrt{1/3}$	1.76	1	.99
$\delta_c \times 1/3$	1.66	1	.99
$D_c \times 1/3$	1.41	.98	.95
$N_c \times 1/3$	1	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	1.9	1	.99
.4 of Base Case	2.47	1	.99
.61 of Base Case	.69	.06	.01
.81 of Base Case	.71	0	0
1.2 of Base Case	1.12	.72	.01
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.1	1	1
B_{thr} = 40 tonnes	.87	0	0

Table 12.8: Detection Properties of Abundance Index "Total Reciprocal Search Time"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.01	0	0
$r_c \times \sqrt{2/3}$	.76	0	0
$\delta_c \times 2/3$	.81	0	0
$D_c \times 2/3$	.088	0	0
$N_c \times 2/3$	1.01	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	0	0
$r_c \times \sqrt{1/3}$	.44	.96	.95
$\delta_c \times 1/3$	.52	0	.51
$D_c \times 1/3$	.64	.96	.03
$N_c \times 1/3$	.98	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.41	1	.98
.4 of Base Case	.22	1	.99
.61 of Base Case	1.42	.94	.82
.81 of Base Case	1.35	.84	.58
1.2 of Base Case	.86	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	7.91	1	.99
B_{thr} = 40 tonnes	1.15	.12	.03

Table 12.9: Detection Properties of Abundance Index "Number of Discoveries by the Survey Vessel"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.76	0	0
$r_c \times \sqrt{2/3}$	.92	0	0
$\delta_c \times 2/3$	.97	0	0
$D_c \times 2/3$	1.01	0	0
$N_c \times 2/3$	.65	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.62	.04	0
$r_c \times \sqrt{1/3}$	.96	.02	0
$\delta_c \times 1/3$	1	.97	0
$D_c \times 1/3$	.94	0	0
$N_c \times 1/3$	.35	.18	.05
Multiple Parameter Changes Biomass =			
.2 of Base Case	1.15	0	0
.4 of Base Case	1.95	.62	.54
.61 of Base Case	.77	0	0
.81 of Base Case	.98	0	0
1.2 of Base Case	1.15	.02	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	1	0	0
B_{thr} = 40 tonnes	.99	0	0

Table 12.10: Detection Properties of Abundance Index "Average {Catch/Towtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1	.06	0
$r_c \times \sqrt{2/3}$	1	.04	0
$\delta_c \times 2/3$	.83	.98	.86
$D_c \times 2/3$	.94	.18	.03
$N_c \times 2/3$	1.01	.06	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	.16	0
$r_c \times \sqrt{1/3}$	.99	.08	0
$\delta_c \times 1/3$	.57	1	.99
$D_c \times 1/3$	.86	.84	.56
$N_c \times 1/3$	1.01	.08	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.69	1	.99
.4 of Base Case	1.19	.98	.87
.61 of Base Case	.92	.28	.07
.81 of Base Case	.87	.8	.47
1.2 of Base Case	.58	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.47	1	.99
B_{thr} = 40 tonnes	.95	.16	.02

Table 12.11: Detection Properties of Abundance Index "Average {Catch/Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1	0	0
$r_c \times \sqrt{2/3}$	.8	0	.25
$\delta_c \times 2/3$	.74	.9	.57
$D_c \times 2/3$	.86	.36	.05
$N_c \times 2/3$	1.02	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1.01	0 0	
$r_c \times \sqrt{1/3}$	.53	1	.99
$\delta_c \times 1/3$	.39	1	.99
$D_c \times 1/3$	.64	1	.97
$N_c \times 1/3$	1	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.38	1	.99
.4 of Base Case	.39	1	.99
.61 of Base Case	1.33	.86	.87
.81 of Base Case	1.19	.26	.27
1.2 of Base Case	.61	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	2.77	1	.99
B_{thr} = 40 tonnes	1.08	0	0

Table 12.12: Detection Properties of Abundance Index "Average {(Catch/Towtime)/ Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection: Simulation	Probability of Detection: Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1	0	0
$r_c \times \sqrt{2/3}$	.83	.48	.08
$\delta_c \times 2/3$	.36	1	.99
$D_c \times 2/3$	.87	.2	.01
$N_c \times 2/3$	1.03	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1.01	0	0
$r_c \times \sqrt{1/3}$	.56	1	.99
$\delta_c \times 1/3$	.36	1	.99
$D_c \times 1/3$	.63	1	.93
$N_c \times 1/3$	1.01	.02	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.37	.64	.99
.4 of Base Case	.45	1	.99
.61 of Base Case	1.25	.4	.37
.81 of Base Case	1.11	.04	.04
1.2 of Base Case	.53	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	2.74	1	.99
B_{thr} = 40 tonnes	1.07	0	0

Table 12.13: Detection Properties of Abundance Index " Catch Per Day"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection: Simulation	Probability of Detection: Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.01	0	0
$r_c \times \sqrt{2/3}$	.91	0	0
$\delta_c \times 2/3$	.8	0	0
$D_c \times 2/3$	.91	0	0
$N_c \times 2/3$	1.01	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	0	0
$r_c \times \sqrt{1/3}$	.72	0	0
$\delta_c \times 1/3$	.51	.94	.92
$D_c \times 1/3$	.78	0	0
$N_c \times 1/3$	1	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.53	.64	.68
.4 of Base Case	.63	0	.02
.61 of Base Case	1.05	.08	0
.81 of Base Case	.98	0	0
1.2 of Base Case	.64	.96	.01
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.62	.92	.09
B_{thr} = 40 tonnes	.99	0	0

Table 12.14: Detection Properties of Abundance Index "Catch Per Haul"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection: Simulation	Probability of Detection: Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.99	0	0
$r_c \times \sqrt{2/3}$	.97	0	0
$\delta_c \times 2/3$	.85	.98	.87
$D_c \times 2/3$	.94	.18	.05
$N_c \times 2/3$	1	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	0	0
$r_c \times \sqrt{1/3}$	.94	.26	.03
$\delta_c \times 1/3$	.61	1	.99
$D_c \times 1/3$	.87	.98	.81
$N_c \times 1/3$	1	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.7	.1	.99
.4 of Base Case	1.05	.04	.09
.61 of Base Case	.99	0	0
.81 of Base Case	.93	0.	.09
1.2 of Base Case	.67	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.48	1	.99
B_{thr} = 40 tonnes	.96	1	.01

Table 12.15: Detection Properties of Abundance Index "Hauls Per Concentration Discovered"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.38	0	0
$r_c \times \sqrt{2/3}$	1.03	0	0
$\delta_c \times 2/3$	.89	0	0
$D_c \times 2/3$	.93	0	0
$N_c \times 2/3$	1.5	.04	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1.66	.04	.03
$r_c \times \sqrt{1/3}$	.77	0	0
$\delta_c \times 1/3$	.80	0	0
$D_c \times 1/3$	.89	0	0
$N_c \times 1/3$	3.1	.28	.45
Multiple Parameter Changes Biomass =			
.2 of Base Case	.63	0	0
.4 of Base Case	.27	.68	0
.61 of Base Case	1.31	0	0
.81 of Base Case	1.02	0	0
1.2 of Base Case	.77	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	1.23	1	0
B_{thr} = 40 tonnes	1	0	0

Table 12.16: Detection Properties of Abundance Index "Fraction of Swarms Selected For Fishing"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection: Simulation	Probability of Detection: Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.99	.02	0
$r_c \times \sqrt{2/3}$	.79	1	.99
$\delta_c \times 2/3$	.79	1	.99
$D_c \times 2/3$	1.04	.12	.05
$N_c \times 2/3$	.99	.04	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.99	.02	0
$r_c \times \sqrt{1/3}$	.5	1	.99
$\delta_c \times 1/3$	.49	1	.99
$D_c \times 1/3$	1.08	.32	.27
$N_c \times 1/3$	.98	.06	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.65	1	.99
.4 of Base Case	.3	1	1
.61 of Base Case	1.38	1	.99
.81 of Base Case	1.66	1	.99
1.2 of Base Case	.71	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	2.74	1	.99
B_{thr} = 40 tonnes	1.11	.58	.53

Table 12.17: Detection Properties of Abundance Index "Average Trawl Length"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.01	.04	0
$r_c \times \sqrt{2/3}$	.97	.42	.05
$\delta_c \times 2/3$	1.07	1	.5
$D_c \times 2/3$	.7	.22	0
$N_c \times 2/3$	1	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1.01	.04	.01
$r_c \times \sqrt{1/3}$	.91	1	.78
$\delta_c \times 1/3$	1.16	1	.99
$D_c \times 1/3$	1.01	.12	.02
$N_c \times 1/3$	1	.04	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	1.03	.14	.08
.4 of Base Case	.79	1	.99
.61 of Base Case	1.13	.98	.97
.81 of Base Case	1.11	.98	.94
1.2 of Base Case	1.33	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.86	1	.99
B_{thr} = 40 tonnes	1	.02	0

Table 12.18: Detection Properties of Abundance Index "Discoveries x Total Catch"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.77	0	0
$r_c \times \sqrt{2/3}$	.85	.02	0
$\delta_c \times 2/3$	.78	0	0
$D_c \times 2/3$	.93	0	0
$N_c \times 2/3$	.66	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.04	0
$r_c \times \sqrt{1/3}$	.7	0	0
$\delta_c \times 1/3$	.49	.04	0
$D_c \times 1/3$	.74	0	0
$N_c \times 1/3$	.36	.34	.06
Multiple Parameter Changes Biomass =			
.2 of Base Case	.62	0	0
.4 of Base Case	1.24	.04	0
.61 of Base Case	.81	0	0
.81 of Base Case	.97	0	0
1.2 of Base Case	.74	1	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.63	0	0
B_{thr} = 40 tonnes	.99	0	0

Table 12.19: Detection Properties of Abundance Index "Discoveries x Total Hauls x Total Catch"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection: Simulation	Probability of Detection: Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.78	0	0
$r_c \times \sqrt{2/3}$	.8	.04	0
$\delta_c \times 2/3$	.74	0	0
$D_c \times 2/3$	.9	0	0
$N_c \times 2/3$	.66	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.06	0
$r_c \times \sqrt{1/3}$	.54	.06	0
$\delta_c \times 1/3$	.41	.04	0
$D_c \times 1/3$	.66	0	0
$N_c \times 1/3$	.36	.36	.03
Multiple Parameter Changes Biomass =			
.2 of Base Case	.47	.12	0
.4 of Base Case	.74	0	0
.61 of Base Case	.86	0	0
.81 of Base Case	1.02	0	0
1.2 of Base Case	.71	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.82	0	0
B_{thr} = 40 tonnes	1.03	0	0

Table 12.20: Detection Properties of Abundance Index "Discoveries x (Total Catch/Total Towtime) x Swarms Fished "

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.78	0	0
$r_c \times \sqrt{2/3}$	.88	.02	0
$\delta_c \times 2/3$	.5	.04	0
$D_c \times 2/3$	.81	0	0
$N_c \times 2/3$	.68	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.04	0
$r_c \times \sqrt{1/3}$	.75	0	0
$\delta_c \times 1/3$	.5	.04	0
$D_c \times 1/3$	.53	.02	0
$N_c \times 1/3$	.36	.2	.05
Multiple Parameter Changes Biomass =			
.2 of Base Case	.47	.08	0
.4 of Base Case	1.34	.06	.04
.61 of Base Case	.74	0	0
.81 of Base Case	.71	0	0
1.2 of Base Case	.81	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.71	0	0
B_{thr} = 40 tonnes	1.02	0	0

Table 12.21: Detection Properties of Abundance Index "Discoveries x Average {Catch/Towtime} x Swarms Fished "

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.78	0	0
$r_c \times \sqrt{2/3}$	.89	.02	0
$\delta_c \times 2/3$	.79	0	0
$D_c \times 2/3$	.81	0	0
$N_c \times 2/3$	.68	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.04	0
$r_c \times \sqrt{1/3}$	.77	0	0
$\delta_c \times 1/3$	.49	.04	0
$D_c \times 1/3$	.52	.02	0
$N_c \times 1/3$	.36	.22	.05
Multiple Parameter Changes Biomass =			
.2 of Base Case	.47	.08	0
.4 of Base Case	1.4	.1	.06
.61 of Base Case	.73	0	0
.81 of Base Case	.7	0	0
1.2 of Base Case	.78	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.67	0	0
B_{thr} = 40 tonnes	1.01	0	0

Table 12.22: Detection Properties of Abundance Index "Total Catch/Total Towtime"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1	0	0
$r_c \times \sqrt{2/3}$	.98	.14	0
$\delta_c \times 2/3$	.82	1	.93
$D_c \times 2/3$	.94	.5	.04
$N_c \times 2/3$	1.01	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	0	0
$r_c \times \sqrt{1/3}$	.97	.18	0
$\delta_c \times 1/3$	.58	1	.99
$D_c \times 1/3$	.87	1	.63
$N_c \times 1/3$	1	.04	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.7	1	.99
.4 of Base Case	1.15	.98	.75
.61 of Base Case	.93	.06	.06
.81 of Base Case	.88	.64	.44
1.2 of Base Case	.6	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.5	1	.99
B_{thr} = 40 tonnes	.95	.32	.02

Table 12.23: Detection Properties of Abundance Index "Average {Catch/Towtime} / Average {Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.01	0	0
$r_c \times \sqrt{2/3}$	.75	1	.67
$\delta_c \times 2/3$	.65	1	.99
$D_c \times 2/3$	.82	1	.23
$N_c \times 2/3$	1.02	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	.48	.01
$r_c \times \sqrt{1/3}$	.43	1	.99
$\delta_c \times 1/3$	.28	1	.99
$D_c \times 1/3$	.54	1	.99
$N_c \times 1/3$	1	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.28	1	.99
.4 of Base Case	.29	1	.99
.61 of Base Case	1.43	1	.99
.81 of Base Case	1.28	.86	.73
1.2 of Base Case	.49	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	5.75	1	.99
B_{thr} = 40 tonnes	1.12	.08	.12

Table 12.24: Detection Properties of Abundance Index "Average {Catch/Towtime} x Average {Reciprocal Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1	0	0
$r_c \times \sqrt{2/3}$	.82	.52	.26
$\delta_c \times 2/3$	.71	.9	.82
$D_c \times 2/3$	.83	.16	.19
$N_c \times 2/3$	1.03	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1.01	0	0
$r_c \times \sqrt{1/3}$	.56	1	.99
$\delta_c \times 1/3$	.36	1	.99
$D_c \times 1/3$	.63	1	.99
$N_c \times 1/3$	1.01	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.37	1	.99
.4 of Base Case	.44	1	.99
.61 of Base Case	1.25	.54	.59
.81 of Base Case	1.11	0	.08
1.2 of Base Case	.53	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	2.92	1	.99
B_{thr} = 40 tonnes	1.06	0	0

Table 12.25: Detection Properties of Abundance Index "Discoveries x Total Catch/Total Towtime"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection: Simulation	Probability of Detection: Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.76	0	0
$r_c \times \sqrt{2/3}$	.92	.02	0
$\delta_c \times 2/3$	.8	0	0
$D_c \times 2/3$	.97	0	0
$N_c \times 2/3$	.66	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.62	.04	0
$r_c \times \sqrt{1/3}$	.94	0	0
$\delta_c \times 1/3$	.56	.02	0
$D_c \times 1/3$	.82	0	0
$N_c \times 1/3$	.36	.22	.05
Multiple Parameter Changes Biomass =			
.2 of Base Case	.3	.4	.59
.4 of Base Case	2.24	.8	.75
.61 of Base Case	.73	0	0
.81 of Base Case	.87	0	0
1.2 of Base Case	.7	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.5	0	0
B_{thr} = 40 tonnes	.95	0	0

Table 12.26: Detection Properties of Abundance Index "Discoveries x Average {Catch/Towtime} / Average {Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.77	0	0
$r_c \times \sqrt{2/3}$	.69	.04	0
$\delta_c \times 2/3$	.63	0	0
$D_c \times 2/3$	.84	0	0
$N_c \times 2/3$	.67	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.62	.04	0
$r_c \times \sqrt{1/3}$	.42	0	0
$\delta_c \times 1/3$	.27	.34	0
$D_c \times 1/3$	.51	.02	0
$N_c \times 1/3$	.35	.22	.03
Multiple Parameter Changes Biomass =			
.2 of Base Case	.32	.12	0
.4 of Base Case	.56	0	0
.61 of Base Case	1.1	.04	0
.81 of Base Case	1.26	.08	.02
1.2 of Base Case	.57	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	5.76	1	.98
B_{thr} = 40 tonnes	1.11	0	0

Table 12.27: Detection Properties of Abundance Index "Discoveries x Average {Catch/Towtime} x Average {Reciprocal Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.76	0	0
$r_c \times \sqrt{2/3}$	.76	.02	0
$\delta_c \times 2/3$	.69	0	0
$D_c \times 2/3$	.88	0	0
$N_c \times 2/3$	.67	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.04	0
$r_c \times \sqrt{1/3}$	.55	.02	0
$\delta_c \times 1/3$	.35	.08	0
$D_c \times 1/3$	.59	0	0
$N_c \times 1/3$	.35	.22	.03
Multiple Parameter Changes Biomass =			
.2 of Base Case	.43	.08	0
.4 of Base Case	.87	0	0
.61 of Base Case	.96	0	0
.81 of Base Case	1.09	0	0
1.2 of Base Case	.61	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	2.91	.86	.86
B_{thr} = 40 tonnes	1.05	0	0

Table 12.28: Detection Properties of Abundance Index "Discoveries x Average {(Catch/Towtime) / Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.76	0	0
$r_c \times \sqrt{2/3}$	.76	.02	0
$\delta_c \times 2/3$	.7	0	0
$D_c \times 2/3$	.89	0	0
$N_c \times 2/3$	.68	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.04	0
$r_c \times \sqrt{1/3}$	.54	.02	0
$\delta_c \times 1/3$	.35	.1	0
$D_c \times 1/3$	.6	0	0
$N_c \times 1/3$	.35	.2	.04
Multiple Parameter Changes Biomass =			
.2 of Base Case	.43	.06	0
.4 of Base Case	.88	0	0
.61 of Base Case	.97	0	0
.81 of Base Case	1.09	.02	0
1.2 of Base Case	.61	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	2.74	.82	.83
B_{thr} = 40 tonnes	1.05	0	0

Table 12.29: Detection Properties of Abundance Index "Discoveries x (Total Catch/Total Towtime) / Average {Searchtime} "

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection	
		Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.77	0	0
$r_c \times \sqrt{2/3}$	.69	.04	0
$\delta_c \times 2/3$	.63	0	0
$D_c \times 2/3$	.83	0	0
$N_c \times 2/3$	.67	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.62	.04	0
$r_c \times \sqrt{1/3}$	.41	.06	0
$\delta_c \times 1/3$	.28	.34	0
$D_c \times 1/3$	.51	.02	0
$N_c \times 1/3$	.35	.22	.03
Multiple Parameter Changes Biomass =			
.2 of Base Case	.32	.22	0
.4 of Base Case	.54	0	0
.61 of Base Case	1.11	.04	0
.81 of Base Case	1.28	.08	.03
1.2 of Base Case	.59	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	6.13	1	.98
B_{thr} = 40 tonnes	1.11	0	0

Table 12.30: Detection Properties of Abundance Index "Discoveries x (Total Catch/Total Towtime) x Average {Reciprocal Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.76	0	0
$r_c \times \sqrt{2/3}$	.75	.02	0
$\delta_c \times 2/3$	.69	0	0
$D_c \times 2/3$	.88	0	0
$N_c \times 2/3$	.67	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.04	0
$r_c \times \sqrt{1/3}$	.53	0	0
$\delta_c \times 1/3$	.35	.08	0
$D_c \times 1/3$	.6	0	0
$N_c \times 1/3$	.35	.22	.03
Multiple Parameter Changes Biomass =			
.2 of Base Case	.43	.08	0
.4 of Base Case	.84	0	0
.61 of Base Case	.98	0	0
.81 of Base Case	1.11	0	0
1.2 of Base Case	.63	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	3.1	.9	.89
B_{thr} = 40 tonnes	1.05	0	0

Table 12.31: Detection Properties of Abundance Index "Discoveries x (Total Catch/Total Towtime) x Number of Selected Swarms"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.77	.02	0
$r_c \times \sqrt{2/3}$	.86	.02	0
δ_c x 2/3	.76	0	0
D_c x 2/3	.94	0	0
N_c x 2/3	.67	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.04	0
$r_c \times \sqrt{1/3}$	.73	0	0
δ_c x 1/3	.47	.06	0
D_c x 1/3	.73	0	0
N_c x 1/3	.36	.24	.06
Multiple Parameter Changes Biomass =			
.2 of Base Case	.62	.02	0
.4 of Base Case	1.35	.06	.03
.61 of Base Case	.77	0	0
.81 of Base Case	.92	0	0
1.2 of Base Case	.66	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.66	0	0
B_{thr} = 40 tonnes	.98	0	0

Table 12.32: Detection Properties of Abundance Index "Discoveries x Average {Catch/ Towtime} x Number of Selected Swarms"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.75	.02	0
$r_c \times \sqrt{2/3}$	.87	.02	0
$\delta_c \times 2/3$	.76	0	0
$D_c \times 2/3$	.94	0	0
$N_c \times 2/3$	.67	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.04	0
$r_c \times \sqrt{1/3}$	.74	0	0
$\delta_c \times 1/3$	.46	.04	0
$D_c \times 1/3$	.73	0	0
$N_c \times 1/3$	.36	.18	.06
Multiple Parameter Changes Biomass =			
.2 of Base Case	.61	0	0
.4 of Base Case	1.4	.1	.05
.61 of Base Case	.76	0	0
.81 of Base Case	.91	0	0
1.2 of Base Case	.65	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.62	0	0
B_{thr} = 40 tonnes	.98	0	0

Table 12.33: Detection Properties of Abundance Index "Discoveries x (Total Catch/Total Towtime) x Number of Encountered Swarms"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.77	.02	0
$r_c \times \sqrt{2/3}$	1.08	.06	.02
$\delta_c \times 2/3$	.97	0	0
$D_c \times 2/3$	.91	0	0
$N_c \times 2/3$	.67	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.04	0
$r_c \times \sqrt{1/3}$	1.45	.16	.18
$\delta_c \times 1/3$	.95	0	0
$D_c \times 1/3$	.68	0	0
$N_c \times 1/3$	.36	.22	.07
Multiple Parameter Changes Biomass =			
.2 of Base Case	.95	0	0
.4 of Base Case	4.48	1	.99
.61 of Base Case	.56	.06	0
.81 of Base Case	.55	0	0
1.2 of Base Case	.93	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.24	.56	.03
B_{thr} = 40 tonnes	.89	0	0

Table 12.34: Detection Properties of Abundance Index "Discoveries x Average {Catch/Towtime} x Number of Swarms Encountered"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.77	.02	0
$r_c \times \sqrt{2/3}$	1.09	.06	.02
$\delta_c \times 2/3$	.96	0	0
$D_c \times 2/3$	.9	0	0
$N_c \times 2/3$	.68	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.04	0
$r_c \times \sqrt{1/3}$	1.49	.16	.21
$\delta_c \times 1/3$	.94	0	0
$D_c \times 1/3$	.67	0	0
$N_c \times 1/3$	.36	.24	.07
Multiple Parameter Changes Biomass =			
.2 of Base Case	.94	0	0
.4 of Base Case	4.66	1	.99
.61 of Base Case	.55	.06	0
.81 of Base Case	.54	0	0
1.2 of Base Case	.9	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.22	.58	.04
B_{thr} = 40 tonnes	.88	0	0

Table 12.35: Detection Properties of Abundance Index "Number of Different Concentrations Fished by the Fleet"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.98	0	0
$r_c \times \sqrt{2/3}$	1.08	0	0
$\delta_c \times 2/3$	1.06	0	0
$D_c \times 2/3$	1.11	0	0
$N_c \times 2/3$	1.13	0	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1.05	0	0
$r_c \times \sqrt{1/3}$	1.10	0	0
$\delta_c \times 1/3$	1	0	0
$D_c \times 1/3$	1.05	0	0
$N_c \times 1/3$	1.08	0	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.98	0	0
.4 of Base Case	1.03	0	0
.61 of Base Case	1.18	0	0
.81 of Base Case	1.08	0	0
1.2 of Base Case	1.01	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	1	0	0
B_{thr} = 40 tonnes	1.06	0	0

Table 12.36: Detection Properties of Abundance Index "Discoveries x (Total Catch/Total Towtime) x (Hauls/Concentration Fished)"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.76	.02	0
$r_c \times \sqrt{2/3}$	.8	.02	0
$\delta_c \times 2/3$	.71	0	0
$D_c \times 2/3$	.83	0	0
$N_c \times 2/3$	.61	.06	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.6	.08	0
$r_c \times \sqrt{1/3}$	.68	.04	0
$\delta_c \times 1/3$	.45	.1	0
$D_c \times 1/3$	.71	.04	0
$N_c \times 1/3$	.34	.36	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.06	.04	.19
.4 of Base Case	1.29	.06	.02
.61 of Base Case	.67	.04	0
.81 of Base Case	.87	0	0
1.2 of Base Case	.64	.02	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.65	.06	0
B_{thr} = 40 tonnes	.95	0	0

Table 12.37: Detection Properties of Abundance Index "Discoveries x Average {Catch/Towtime} x (Hauls/Concentration Fished)"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.76	.02	0
$r_c \times \sqrt{2/3}$	.81	.02	0
$\delta_c \times 2/3$	.71	0	0
$D_c \times 2/3$	.83	0	0
$N_c \times 2/3$	.61	.16	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.6	.08	0
$r_c \times \sqrt{1/3}$	.70	.02	0
$\delta_c \times 1/3$	.45	.08	0
$D_c \times 1/3$	.70	.04	0
$N_c \times 1/3$	.34	.40	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.61	.04	0
.4 of Base Case	1.34	.12	.03
.61 of Base Case	.66	.04	0
.81 of Base Case	.86	.02	0
1.2 of Base Case	.62	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.61	.08	0
B_{thr} = 40 tonnes	.94	0	0

Table 12.38: Detection Properties of Abundance Index "Discoveries x (Total Catch/Total Towtime) x Swarms Fished per Concentration"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.77	.02	0
$r_c \times \sqrt{2/3}$	.82	.02	0
$\delta_c \times 2/3$	.49	.06	0
$D_c \times 2/3$	.72	0	0
$N_c \times 2/3$	.62	.06	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.61	.08	0
$r_c \times \sqrt{1/3}$	.7	.04	0
$\delta_c \times 1/3$	.49	.06	0
$D_c \times 1/3$	.51	.12	0
$N_c \times 1/3$	.34	.36	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.47	.08	0
.4 of Base Case	1.29	.06	.03
.61 of Base Case	.64	.04	0
.81 of Base Case	.67	0	0
1.2 of Base Case	.77	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.71	.02	0
B_{thr} = 40 tonnes	.98	0	0

Table 12.39: Detection Properties of Abundance Index "Discoveries x Average {Catch/Towtime} x Swarms Fished per Concentration"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.77	.02	0
$r_c \times \sqrt{2/3}$	.83	.02	0
$\delta_c \times 2/3$	.74	0	0
$D_c \times 2/3$	.72	0	0
$N_c \times 2/3$	.62	.06	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.61	.08	0
$r_c \times \sqrt{1/3}$	.72	.04	0
$\delta_c \times 1/3$	.48	.1	0
$D_c \times 1/3$	.5	.12	0
$N_c \times 1/3$	.34	.34	0
Multiple Parameter Changes Biomass =			
.2 of Base Case	.47	.06	0
.4 of Base Case	1.34	.1	.04
.61 of Base Case	.64	.04	0
.81 of Base Case	.66	.06	0
1.2 of Base Case	.69	0	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	.66	.04	0
B_{thr} = 40 tonnes	.97	0	0

Table 12.40: Detection Properties of Abundance Index "(Total Catch/Total Number of Hauls) / Average {Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.04	.02	.01
$r_c \times \sqrt{2/3}$	.74	.98	.89
$\delta_c \times 2/3$	.66	1	.99
$D_c \times 2/3$	.82	.68	.41
$N_c \times 2/3$	1.01	.02	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	0	0
$r_c \times \sqrt{1/3}$	.41	1	.99
$\delta_c \times 1/3$	.29	1	.99
$D_c \times 1/3$	.55	1	.99
$N_c \times 1/3$	1.03	0	.01
Multiple Parameter Changes Biomass =			
.2 of Base Case	.28	1	.99
.4 of Base Case	.25	1	1
.61 of Base Case	1.54	1	.99
.81 of Base Case	1.37	.96	.96
1.2 of Base Case	.57	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	5.88	1	.99
B_{thr} = 40 tonnes	1.12	.18	.21

Table 12.41: Detection Properties of Abundance Index "Discoveries x (Total Catch/Total Number of Hauls) / Average {Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.86	0	0
$r_c \times \sqrt{2/3}$	.77	0	0
$\delta_c \times 2/3$	.66	.04	0
$D_c \times 2/3$	.8	0	0
$N_c \times 2/3$	.7	.06	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.64	.1	0
$r_c \times \sqrt{1/3}$	.38	.3	0
$\delta_c \times 1/3$	.33	.54	0
$D_c \times 1/3$	.56	.04	0
$N_c \times 1/3$	.37	.46	.05
Multiple Parameter Changes Biomass =			
.2 of Base Case	.33	.46	0
.4 of Base Case	.47	.06	0
.61 of Base Case	1.14	.06	.01
.81 of Base Case	1.32	.2	.07
1.2 of Base Case	.8	.02	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	6.0	1	.98
B_{thr} = 40 tonnes	1.09	.06	0

Table 12.42: Detection Properties of Abundance Index "(Total Catch/Number of Swarms Fished) / Average {Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.01	.04	0
$r_c \times \sqrt{2/3}$	.72	1	.99
$\delta_c \times 2/3$	.65	1	.99
$D_c \times 2/3$	.93	.32	.11
$N_c \times 2/3$	1	.16	.04
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	.12	.02
$r_c \times \sqrt{1/3}$	.39	1	.99
$\delta_c \times 1/3$	.28	1	1
$D_c \times 1/3$	.77	1	.97
$N_c \times 1/3$	1.01	.06	.04
Multiple Parameter Changes Biomass =			
.2 of Base Case	.37	1	.99
.4 of Base Case	.25	1	1
.61 of Base Case	1.62	1	.99
.81 of Base Case	1.76	1	.99
1.2 of Base Case	.48	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	5.41	1	.99
B_{thr} = 40 tonnes	1.09	.96	.27

Table 12.43: Detection Properties of Abundance Index "Discoveries x (Total Catch/Number of Swarms Fished) / Average {Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.85	0	0
$r_c \times \sqrt{2/3}$	.76	0	0
$\delta_c \times 2/3$	.65	.06	0
$D_c \times 2/3$	.93	0	0
$N_c \times 2/3$	.69	.06	0
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.63	.1	.01
$r_c \times \sqrt{1/3}$	.37	.42	0
$\delta_c \times 1/3$	.31	.75	0
$D_c \times 1/3$	.78	0	0
$N_c \times 1/3$	.37	.48	.07
Multiple Parameter Changes Biomass =			
.2 of Base Case	.44	.24	0
.4 of Base Case	.48	.1	0
.61 of Base Case	1.2	.82	.02
.81 of Base Case	1.72	.46	.33
1.2 of Base Case	.68	.06	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	5.5	1	.99
B_{thr} = 40 tonnes	1.06	.04	0

Table 12.44: Detection Properties of Abundance Index "(Total Catch/Swarms Encountered) / Average {Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	1.04	.06	.01
$r_c \times \sqrt{2/3}$	.59	1	.99
$\delta_c \times 2/3$	.53	1	.99
$D_c \times 2/3$	.86	.32	.12
$N_c \times 2/3$	1.01	0	.01
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	1	.02	.01
$r_c \times \sqrt{1/3}$	.2	1	1
$\delta_c \times 1/3$	.15	1	1
$D_c \times 1/3$	.61	1	.99
$N_c \times 1/3$	1.04	.04	.03
Multiple Parameter Changes Biomass =			
.2 of Base Case	.18	1	1
.4 of Base Case	.07	1	1
.61 of Base Case	2.16	1	.99
.81 of Base Case	2.27	1	.99
1.2 of Base Case	.41	1	.99
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	16.11	1	.99
B_{thr} = 40 tonnes	1.24	.76	.55

Table 12.45: Detection Properties of Abundance Index "Discoveries x (Total Catch/Swarms Encountered) / Average {Searchtime}"

Biomass Relative to Base Case	μ_c/μ_b	Probability of Detection Simulation	Probability of Detection Normal Approx
Biomass = 2/3 of Base Case			
$L_c \times \sqrt{2/3}$	.87	0	0
$r_c \times \sqrt{2/3}$	.62	0	0
$\delta_c \times 2/3$	.53	.12	0
$D_c \times 2/3$	.85	0	0
$N_c \times 2/3$	.37	.44	.05
Biomass = 1/3 of Base Case			
$L_c \times \sqrt{1/3}$	.64	.02	0
$r_c \times \sqrt{1/3}$	.19	.98	0
$\delta_c \times 1/3$	.16	1	0
$D_c \times 1/3$	.61	.02	0
$N_c \times 1/3$	.37	.44	.05
Multiple Parameter Changes Biomass =			
.2 of Base Case	.21	.96	0
.4 of Base Case	.14	1	0
.61 of Base Case	1.61	.38	.25
.81 of Base Case	2.21	.72	.62
1.2 of Base Case	.58	.12	0
Adaptive Behavior by Fleet			
B_{thr} = 0 tonnes	16.46	1	.99
B_{thr} = 40 tonnes	1.21	.08	.02

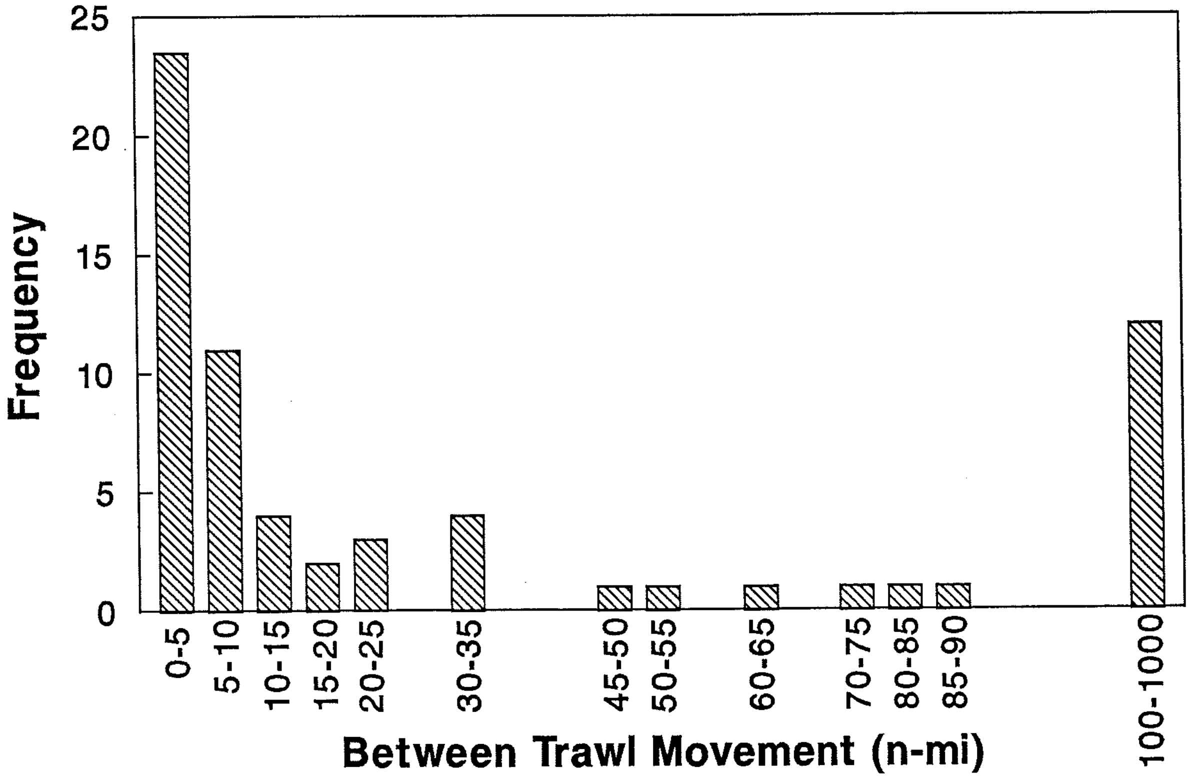

Figure 3.1 Example of the bimodal distributions obtained in the analysis of the between trawl movement data for data set 10

Légendes des tableaux

Légende de la figure

Заголовки к таблицам

Таблица 12.7 Параметры обнаружения (концентраций криля), присущие индексу численности "Общее время поиска".

Таблица 12.8 Параметры обнаружения (концентраций криля), присущие индексу численности "Общее эквивалентное время поиска".

Таблица 12.9 Параметры обнаружения (концентраций криля), присущие индексу численности "Число обнаружений, сделанных поисковым судном".

Таблица 12.10 Параметры обнаружения (концентраций криля), присущие индексу численности "Средняя величина {улов/время траления}".

Таблица 12.11 Параметры обнаружения (концентраций криля), присущие индексу численности "Средняя величина {улов/время поиска}".

Таблица 12.12 Параметры обнаружения (концентраций криля), присущие индексу численности "Средняя величина {(улов/время траления) / время поиска}".

Таблица 12.13 Параметры обнаружения (концентраций криля), присущие индексу численности "Улов за сутки".

Таблица 12.14 Параметры обнаружения (концентраций криля), присущие индексу численности "Улов за траление".

Таблица 12.15 Параметры обнаружения (концентраций криля), присущие индексу численности "Число тралений на обнаруженную .концентрацию".

Таблица 12.16 Параметры обнаружения (концентраций криля), присущие индексу численности "Доля скоплений, отобранных для промысла".

Таблица 12.17 Параметры обнаружения (концентраций криля), присущие индексу численности "Средняя длина тралений".

Таблица 12.18 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение х общий улов".

Таблица 12.19 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение х все траления њ общий улов".

Таблица 12.20 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение х (общий улов/общее время траления) х облавливаемые скопления".

Таблица 12.21 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение х средняя величина {улов/время траления} х облавливаемые скопления".

Таблица 12.22 Параметры обнаружения (концентраций криля), присущие индексу численности "Общий улов/общее время траления".

Таблица 12.23 Параметры обнаружения (концентраций криля), присущие индексу численности "Средняя величина {улов/время траления}/ средняя величина {время поиска}".

Таблица 12.24 Параметры обнаружения (концентраций криля), присущие индексу численности "Средняя величина {улов/время траления} ћ средняя величина {эквивалентное время поиска}".

Таблица 12.25 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение ћ общий улов/общее время траления".

Таблица 12.26 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x средняя величина {улов/время траления} / средняя величина {время поиска}".

Таблица 12.27 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x средняя величина {улов/время траления} x средняя величина {эквивалентное время поиска}".

Таблица 12.28 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x средняя величина {(улов/время траления) / время поиска}".

Таблица 12.29 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x (общий улов/общее время траления) / средняя величина {время поиска}".

Таблица 12.30 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x (общий улов/общее время траления) x средняя величина {эквивалентное время поиска}".

Таблица 12.31 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x (общий улов/общее время траления) x количество выбранных скоплений".

Таблица 12.32 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x средняя величина {улов/время траления} x количество выбранных скоплений".

Таблица 12.33 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x (общий улов/общее время траления) x количество встретившихся скоплений".

Таблица 12.34 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x средняя величина {улов/время траления} x количество встретившихся скоплений".

Таблица 12.35 Параметры обнаружения (концентраций криля), присущие индексу численности "Количество различных концентраций, облавливаемых флотилией".

Таблица 12.36 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x (общий улов/общее время траления) x (количество тралений/облавливаемая концентрация)".

Таблица 12.37 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x средняя величина {улов/время траления} x (Количество тралений/облавливаемая концентрация)".

Таблица 12.38 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x (общий улов/общее время траления) x облавливаемые скопления на концентрацию".

Таблица 12.39 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x средняя величина {улов/время траления} x облавливаемые скопления на концентрацию".

Таблица 12.40 Параметры обнаружения (концентраций криля), присущие индексу численности "(Общий улов/общее количество тралений)/средняя величина { время поиска}.

Таблица 12.41 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x (общий улов/общее количество тралений)/средняя величина {время поиска}.

Таблица 12.42 Параметры обнаружения (концентраций криля), присущие индексу численности "(Общий улов/количество облавливаемых скоплений)/средняя величина {время поиска}.

Таблица 12.43 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x (общий улов/количество облавливаемых скоплений) / средняя величина {время поиска}.

Таблица 12.44 Параметры обнаружения (концентраций криля), присущие индексу численности "(Общий улов/встретившиеся скопления)/средняя величина {время поиска}".

Таблица 12.45 Параметры обнаружения (концентраций криля), присущие индексу численности "Обнаружение x (общий улов/встретившиеся скопления)/средняя величина {время поиска}.

Подписи к рисункам

Рисунок 3.1 Пример бимодальных распределений, полученных из анализа данных по движению судна в период между тралениями, для серии данных 10.

Encabezamientos de las Tablas

Tabla 2.1 Resumen de los datos originales del crucero soviético

Leyenda de la Figura