CCAMLR Science, Vol. 17 (2010): 139–154

ESTIMATING OPTIMAL OBSERVER COVERAGE IN THE ANTARCTIC KRILL FISHERY

D.J. Agnew[1]✉, P. Grove[2], T. Peatman[1], R. Burn[2] and C.T.T. Edwards

[1] MRAG Ltd
18 Queen Street
London W1J 5PN
United Kingdom
Email – d.agnew@mrag.co.uk

[2] Statistical Services Centre
University of Reading
Reading RG6 6FN
United Kingdom

Abstract

Data collected as part of the CCAMLR Scheme of International Scientific Observation from conventional krill trawl vessels fishing in South Georgia (CCAMLR Subarea 48.3) were analysed using variance components analysis (VCA) to determine the relationship between observer coverage and our ability to reliably estimate parameters of interest, in this case the mean (or median) krill length and the rate of larval fish by-catch. A partial coverage sampling program has been implemented in South Georgia since 2002: observers have been placed on approximately 50% of vessels fishing in any one season, and have been present on board for about 30% of that season. They have achieved a rate of krill sampling equivalent to 18% of total hauls per vessel per season and 31% per vessel per season for larval fish. Between-vessel and between-haul variance was estimated. For krill mean length and larval fish by-catch rate, between-vessel variance (about 45% of total variance) was slightly lower than between-haul variance. However, the ratio is sufficiently close to 50% that sampling needs to be efficient at both vessel and haul level. It is proposed that an efficient sampling proportion, at least for South Georgia, should be >50% of vessels sampled each season, 20% of total season hauls sampled for krill and an equivalent or higher sampling proportion for larval fish. The Scientific Committee's method of systematic partial coverage appears to have been sufficient in South Georgia to determine appropriate coverage levels in that fishery. The South Georgia data suggest that such strategies should be pursued for at least four years before the Scientific Committee will have sufficient data to determine appropriate sampling strategies in a particular area.

Résumé

Les données collectées dans le cadre du Système international d'observation scientifique de la CCAMLR sur les chalutiers conventionnels à krill en pêche en Géorgie du Sud (sous-zone 48.3 de la CCAMLR) ont été analysées au moyen d'une analyse en composantes de la variance (VCA) pour déterminer la relation entre le degré d'observation et notre capacité à estimer de manière fiable les paramètres présentant de l'intérêt, soit dans ce cas la longueur moyenne (ou médiane) du krill et le taux de capture accessoire de poissons larvaires. Un programme d'échantillonnage couvrant partiellement la Géorgie du Sud est mis en oeuvre depuis 2002 : des observateurs ont été placés sur environ 50% des navires pêchant en une saison et étaient présents à bord pendant environ 30% de la saison. Ils sont parvenus à échantillonner le krill à raison de 18% de tous les traits par navire et par saison, ainsi que 31% par navire et par saison pour les poissons larvaires. Une estimation de la variance entre les navires et entre les traits a été réalisée. En ce qui concerne la longueur moyenne du krill et le taux de capture accessoire de poissons larvaires, la variance entre les navires (soit environ 45% de la variance totale) était légèrement moins importante que celle entre les traits. Toutefois, le rapport est suffisamment proche des 50% dont l'échantillonnage a besoin pour être efficace tant au niveau du navire qu'à celui du trait. Il est proposé que le taux d'échantillonnage efficace, pour la Géorgie du Sud, au moins, soit fixé à >50% des navires en chaque saison, à 20% du total des traits échantillonnés pour le krill et à l'équivalent ou une proportion plus élevée pour l'échantillonnage des poissons larvaires. La méthode du Comité scientifique consistant à couvrir systématiquement une partie des opérations de pêche semble s'être révélée suffisante en Géorgie du Sud pour déterminer le niveau d'observation approprié dans cette pêcherie. Les données sur la Géorgie du

Sud semblent indiquer que de telles stratégies devraient être mises en œuvre pendant au moins quatre ans avant que le Comité scientifique ne dispose de suffisamment de données pour déterminer des stratégies d'échantillonnage qui se prêtent à une région donnée.

Резюме

Собранные в соответствии с принятой в АНТКОМ Системой международных научных наблюдений данные, полученные на обычных крилевых траулерах, которые вели промысел в районе Южной Георгии (Подрайон АНТКОМ 48.3), были проанализированы с использованием анализа составляющих дисперсии (VCA) с целью определения взаимосвязи между охватом наблюдателями и нашей способностью правильно оценить интересующие нас параметры; в данном случае это – средняя (или медианная) длина криля и доля личинок рыбы в прилове. Начиная с 2002 г. в районе Южной Георгии выполняется программа проведения выборок с частичным охватом: наблюдатели размещаются примерно на 50% судов, ведущих промысел в один из сезонов, и остаются на судах примерно в течение 30% этого сезона. Они добились для криля коэффициента отбора проб, равного 18% всех выборок на судно за сезон, а для личинок рыбы – 31% на судно за сезон. Была проведена оценка дисперсии между судами и между выборками. Для средней длины криля и коэффициента прилова личинок рыбы дисперсия между судами (около 45% общей дисперсии) была немного ниже, чем дисперсия между выборками. Однако это соотношение является достаточно близким к 50%, которые необходимы для того, чтобы отбор проб был эффективным на уровне и судов, и выборок. Предлагается, чтобы эффективная доля сбора проб, по крайней мере для Южной Георгии, составляла >50% судов, по которым пробы отбираются каждый сезон, 20% общего числа выборок за сезон, по которым проводится отбор проб криля, и такая же или бóльшая доля для личиночной рыбы. Принятый Научным комитетом метод систематического частичного охвата, судя по всему, является достаточным для определения адекватных уровней охвата этого промысла в районе Южной Георгии. Данные по Южной Георгии говорят о том, что такой стратегии необходимо придерживаться по крайней мере четыре года, прежде чем у Научного комитета будет достаточно данных для определения адекватных стратегий отбора проб в конкретном районе.

Resumen

Los datos recopilados por observadores de acuerdo con el Sistema de Observación Científica Internacional de la CCRVMA a bordo de los barcos arrastreros que pescan kril con el método tradicional en Georgia del Sur (Subárea 48.3 de la CCRVMA) fueron sometidos a un análisis de componentes de la varianza (ACV) para determinar la relación entre la cobertura de observación y nuestra capacidad para estimar de manera fidedigna los parámetros de interés, en este caso, el promedio (o la mediana) de la talla de kril y la tasa de captura secundaria de larvas de peces. Desde 2002 se ha implementado en Georgia del Sur un programa de muestreo de cobertura parcial: se han asignado observadores para aproximadamente 50% de los barcos que pescan en una temporada cualquiera, permaneciendo éstos a bordo durante un 30% de la temporada. La tasa de muestreo de kril conseguida es equivalente al 18% del total de los lances por barco y por temporada, con una tasa de muestreo de larvas de peces fue de 31% por barco y por temporada. Se estimó la varianza entre los barcos y entre los lances. Para el promedio de la talla de kril y para la tasa de captura secundaria de larvas de peces, la varianza entre barcos (cerca del 45% de la varianza total) fue ligeramente inferior a la varianza entre lances. Sin embargo, la proporción es tan cercana a 50% como para inferir que se requiere un muestreo eficiente tanto a nivel de barco como de lance. Se propone que la proporción eficiente de muestreo, por lo menos para Georgia del Sur, debiera ser >50% de los barcos muestreados cada temporada, 20% del total de los lances dirigidos a kril por temporada y una proporción de muestreo equivalente o más alta para las larvas de peces. El método del Comité Científico – una cobertura sistemática parcial – parece haber sido suficiente en Georgia del Sur para determinar los niveles de cobertura apropiados en esa pesquería. Los datos de Georgia del Sur indican que estas estrategias debieran aplicarse por lo menos durante cuatro años para que el Comité Científico tenga suficientes datos como para determinar las estrategias de muestreo apropiadas para un área en particular.

Keywords: Scheme of International Scientific Observation, krill, variance components analysis, CCAMLR

Introduction

In recent years, the fishing industry has shown increasing interest in harvesting krill in the CAMLR Convention Area. In association with this development, the CCAMLR Scientific Committee has expressed concern that such an increase should be accompanied by the acquisition of good-quality observer data from which it will be possible to monitor the impact of the fishery on the krill population, and assess levels of by-catch. While the CCAMLR Scheme of International Scientific Observation has applied to all fishing vessels since its inception (Sabourenkov and Appleyard, 2005), prior to 2000 it was rarely used to place observers on krill vessels. Furthermore, the data collected were infrequently submitted to the CCAMLR Secretariat. In 2007, the Scientific Committee called for increased and systematic observer coverage to understand the behaviour of the fishery and to undertake routine monitoring, including collection of data on the biological characteristics of krill, the by-catch in the fishery, particularly of larval fish, and the interactions with, and incidental mortality of, seabirds, seals and cetaceans (SC-CAMLR, 2007). In 2009, CCAMLR agreed a conservation measure to require observer coverage on 30% of vessels in the 2009/10 fishing season and 50% thereafter (CCAMLR, 2009; Conservation Measure 51-06). This agreement was contingent on the Scientific Committee defining an appropriate sampling strategy within these general parameters.

Despite these decisions, there is still a debate within CCAMLR about the most appropriate coverage scheme for krill observers. However, this dilemma is fortunately not without precedent. Many fisheries worldwide are now subject to a significant level of observer coverage to obtain high-quality biological data (Babcock and Pikitch, 2003). Within the Convention Area, toothfish longline and icefish midwater trawl vessels have been subject to 100% observer coverage since the mid-1990s. Observer coverage has also been specifically addressed in the North Pacific observer programs operated by the National Marine Fisheries Service of the USA (Barbeaux et al., 2005). Most observer schemes operate at least a two-stage design, involving sampling of vessels, of hauls within vessels, and often a third stage of samples within hauls. The optimum sampling strategy (proportion of effort devoted to each stage) is dependent on the relative variance components at each stage of the sampling design (Volstad et al., 1997). Probability proportional to size (PPS) may be used to assign sampling proportions in less structured programs (Cotter et al., 2002).

International and national scientific observers have been placed on krill vessels in the Atlantic sector at least since the 1999/2000 fishing season. Observers from a number of Members – Japan, Ukraine, UK, USA and Uruguay – have been placed on vessels from Japan, Republic of Korea, Norway, Poland, Russia, Ukraine, USA and Vanuatu. The scientific observer sampling scheme includes protocols for recording the catch and by-catch, the interaction of the gear with fish, birds and seals, sampling protocols for krill length, sex and maturity and, from 2008, larval fish by-catch.

Most of these observers have been placed on vessels fishing in South Georgia, and Subarea 48.3 is the only subarea where multiple observer placements have been made in each year since 2002. This dataset was chosen to examine the observer data that have been reported to CCAMLR with two aims. First, to determine the relationship between observer coverage and the 'accuracy' of parameters estimated from the data. Two estimated parameters were examined, namely the mean length of krill and the fish larval by-catch rate. Second, to determine how many years of data collected under a partial sampling regime are required before the variance properties of derived quantities can be accurately partitioned. This partitioning is necessary for the adjustment of observer coverage so that required levels of accuracy can be met.

What can be considered 'accurate' is of course subjective, and dependent on the particular scenario being investigated. Nevertheless, it is of central importance to hypothesis testing and considerations of statistical power, a key component of management that is often neglected (Peterman, 1990; Mangel, 1993). Given a desired level of accuracy (i.e. a level that generates enough power to resolve the hypothesis in question) it is then necessary to design a suitable sampling regime (e.g. Hilborn and Mangel, 1997). Thus, the relation between observer coverage and accuracy is an important first step in designing sampling strategies that ensure downstream management has a sufficiently robust statistical basis.

Methods

Variance components analysis

Catch and observer data from krill fishing around South Georgia since 2002 were acquired from CCAMLR and pooled over years and areas (see below for a discussion of this data aggregation). Variance components analysis (VCA) was then used to investigate the relative importance of sampling at either the inter-vessel or intra-vessel level (the latter combining the variance contributions from between hauls within vessels and between samples within hauls).

An unbiased estimator of the variance for a population level parameter y, which is estimated from a two-stage nested sampling design (Thompson, 2002), is

$$VAR\left(\hat{Y}\right) = N\frac{N-n}{n}\sigma_U^2 + \frac{N}{n}\sum_{i=1}^{N} M_i\left(M_i - m_i\right)\frac{\sigma^2}{m_i} \qquad (1)$$

where
N: number of primary units (vessels)
M_i: number of secondary units (hauls for vessel i)
n: number of primary units that are sampled
m_i: number of secondary units that are sampled
σ_U^2: sample variance between vessels
σ^2: sample variance within vessels.

Note that the secondary sampling level is referred to as the number of hauls for a given vessel (m_i). Since σ^2 includes intra-vessel variation from both between hauls and between samples within hauls, the terminology used here implicitly assumes a constant level of sampling within hauls. To derive an unbiased estimator for the variance of a population mean, equation (1) is divided by N^2 and M^2 for the first and second term respectively. Substituting $f = n/N$ and $g = m/M$ (i.e. f is the proportion of vessels that are sampled and g is the proportion of hauls that are sampled) and assuming a constant value for m and M, gives

$$VAR\left(\hat{Y}\right) = \frac{1}{N}\frac{(1-f)}{f}\sigma_U^2 + \frac{N}{M}\frac{(1-g)}{g}\sigma^2. \qquad (2)$$

The variances σ_U^2 and σ^2 were estimated through VCA, which is more fully described in the Results section. This allowed the relation between coverage (reflected in values of f and g) and accuracy in the resultant estimate ($\hat{y}$) to be derived.

To determine how many years of partial observer coverage of vessels are required before the variance properties of derived estimates can be partitioned, thus allowing coverage to be adjusted to meet required accuracy criteria, the ratio of inter- and intra-vessel variance was examined assuming the availability of only 2002 data, up to the complete dataset of 2002 to 2008.

Data availability

A total of 4 009 hauls have been observed on vessels fishing around South Georgia over the period 2002–2008. However, many of these were only observed for catches and interactions with birds and seals. Only 1 813 hauls have been sampled for krill biological parameters and only 310 for fish by-catch. Furthermore, until the larval fish protocol was developed in 2007, only adult fish were recorded, with 2008 the first year that larval fish were routinely sampled, although some additional scientific sampling was undertaken in 2005 (Ross et al., 2006). It should be noted that only data from traditional trawls were considered in this analysis, with all samples collected from the continuous trawl method discarded.

Observer coverage has therefore only been partial, with an average of 62% of hauls observed during an observer's placement and of those only 55% being sampled for krill biological parameters (Table A1). This corresponds to average observer coverage per vessel of 35% of total hauls and average krill sampling per vessel of 18% of total hauls (Table A1). For the larval fish by-catch rate, an average of 95% of observed trawls per vessel were sampled in 2008, yielding an average coverage per vessel of 31% of the total trawls (Table A2).

The coverage of vessels, areas and months has been reasonable. Every vessel, except the *Acamar* and the *Acrux*, has been observed at least once in the seven-year period, and the overlap of observed hauls with total hauls in both space and time is good, particularly towards the end of the time period (Figure A1).

Results

Mean krill length

The availability of data on krill length is shown in Table A3, with mean krill length given in Table A4. Krill length data from 2001 were excluded, as krill length sampling coverage was comparatively low and this was the first year of CCAMLR krill length sampling and the sampling procedure and results are likely to be less reliable than in subsequent seasons.

An exploratory generalised additive model (GAM) was first used to investigate factors that have an important influence on the parameter of interest in this study. It was found that mean krill length varies with year, vessel and month but not (significantly) between 'East' and 'West' areas (separated by 37°W). The data are not orthogonal across vessels and years (i.e. not all vessels appear in all years) so that the year and vessel effect are to some degree confounded. The data were pooled over years to estimate the variances in the mean krill length (as described below). Although the month effect was significant, the aim here was to

Table 1: Results of variance components analysis (VCA) (note that units are given on the transformed scale).

Parameter	Mean krill length (z^{λ})	Fish by-catch rate ($(z+k)^{\lambda}$)
$\hat{\mu}$	77 483.44	0.6653
$\hat{\sigma}_U^2$	341 806 493	0.06117
$\hat{\sigma}^2$	393 386 797	0.08593
$\left(\hat{\sigma}_U^2 / \left(\hat{\sigma}^2 + \hat{\sigma}_U^2\right)\right)$	0.46	0.42
Sample size	1 604	90

design a sampling scheme that would be suitable for any (unspecified) future month. Thus the data were also pooled across month. Neither a year nor month effect were therefore included in the final model. Not only did this make the analysis more tractable, but it was also a more efficient use of the data and consistent with the objectives of this study, namely to estimate the variances at different sampling levels (inter- and intra-vessel) and thus inform the design of future sampling protocols.

The VCA assumes normality of the response variable z, in this case mean krill length. Since z is not normally distributed, it was treated to a Box-Cox power transform of the form

$$y_{ij} = \left(z_{ij}\right)^{\lambda} \tag{3}$$

with transformation parameter λ, where i is the sample, j is the vessel and z represents the mean krill length in mm. In order to determine the value of λ, a regression of the vessel effect against y was performed for a range of λ values, with the log-likelihood recorded for each fit. The value $\lambda = 3$ was chosen as that which corresponded to the maximum of the resultant log-likelihood profile. A preliminary regression of the vessel effect against y showed the residuals to be approximately normal.

To partition the variance in the data, a random intercepts model $y_{ij} = \mu + U_j + \varepsilon_{ij}$ was fitted with random vessel effect U_j. Normal distributions $U_j \sim N\left(0, \sigma_U^2\right)$ and $\varepsilon_{ij} \sim N\left(0, \sigma^2\right)$ were assumed, where σ_U^2 is the inter-vessel variance in y and σ^2 is the remaining intra-vessel variance (representing the variance both within and between hauls for a particular vessel). The VCA was undertaken in R, with results shown in Table 1.

The variance of the untransformed variable $z = y^{\frac{1}{\lambda}}$ was approximated using the delta method as

$$VAR(z) = VAR\left(y^{\frac{1}{\lambda}}\right) \cong \left(\frac{d}{dy}_{y=\bar{y}}\, y^{\frac{1}{\lambda}}\right)^2 VAR(y) \tag{4}$$

$$SE(z) \cong \tfrac{1}{\lambda}\bar{y}^{\left(\frac{1}{\lambda}-1\right)} SE(y). \tag{5}$$

The coefficient of variation for z was derived as

$$CV(z) = \tfrac{SE(z)}{E(z)} \tag{6}$$

where $E(z) = E\left(y^{\frac{1}{\lambda}}\right) < E(y)^{\frac{1}{\lambda}}$ since $\lambda > 1$. Thus, ignoring any bias in the approximation of $SE(z)$:

$$CV(z) > \left[\tfrac{1}{\lambda}\bar{y}^{\left(\frac{1}{\lambda}-1\right)}\right]\tfrac{SE(y)}{\bar{y}^{\frac{1}{\lambda}}} = \tfrac{SE(y)}{\lambda\bar{y}}. \tag{7}$$

Since $\bar{y} = \hat{\mu}$ a lower bound for the coefficient of variation is obtained

$$CV(z) > \tfrac{SE(y)}{\lambda\hat{\mu}}. \tag{8}$$

Using estimates $\hat{\sigma}_U^2$ and $\hat{\sigma}^2$ in equation (2) to obtain $SE\left(\hat{Y}\right)$, equation (8) was applied to achieve an estimate of how $CV\left(\hat{Z}\right)$ is likely to change with different levels of vessel and haul sampling effort. Finite population sizes for vessels ($N = 10$) and available hauls ($M = 600$), approximating reality (Table A3), were assumed. Results are illustrated in Figure 1.

Larval fish by-catch

CCAMLR data were collected following the introduction of the new larval fish sampling method, which included random sampling and on-board processing by observers. Data from South Georgia were only available for 2008 (Table A2). Following a similar logic to that applied for the analysis of mean krill length, data were pooled across months. Species composition was available from this dataset, with mackerel icefish and lanternfish accounting for the majority of the by-catch, but the analysis here was performed on only the total

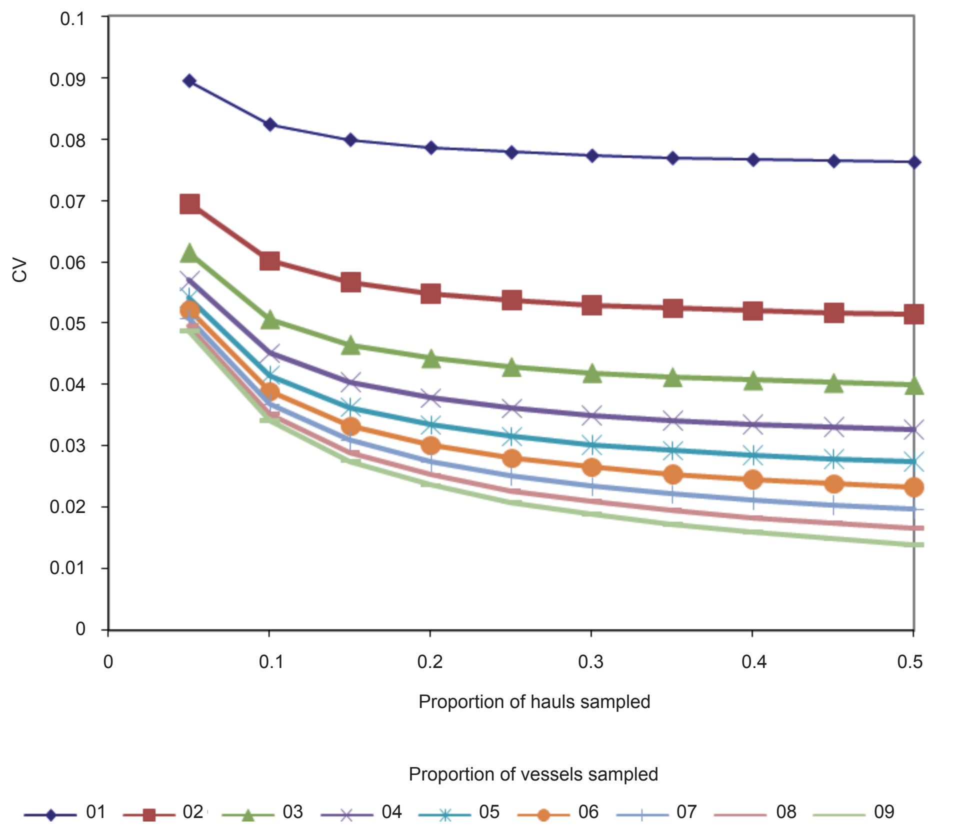

Figure 1: CV of mean krill length for different haul sample coverage rates for varying levels of vessel sample coverage.

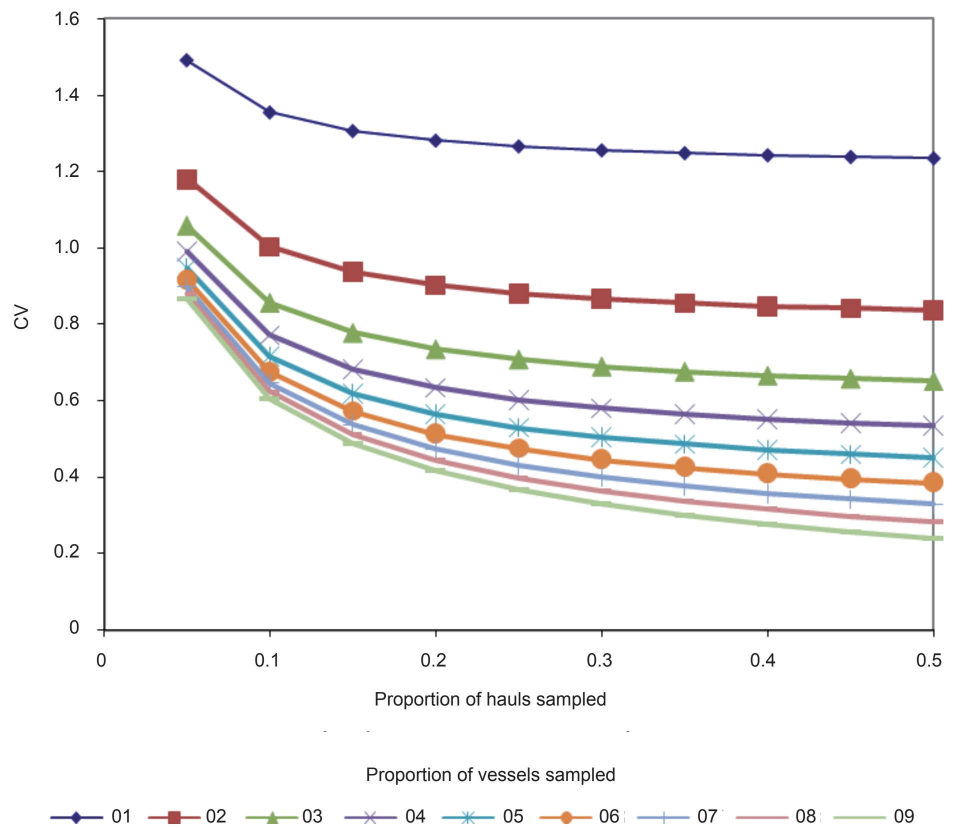

Figure 2: Estimated overall CV in larval by-catch numbers for different levels of observer coverage of hauls and vessels.

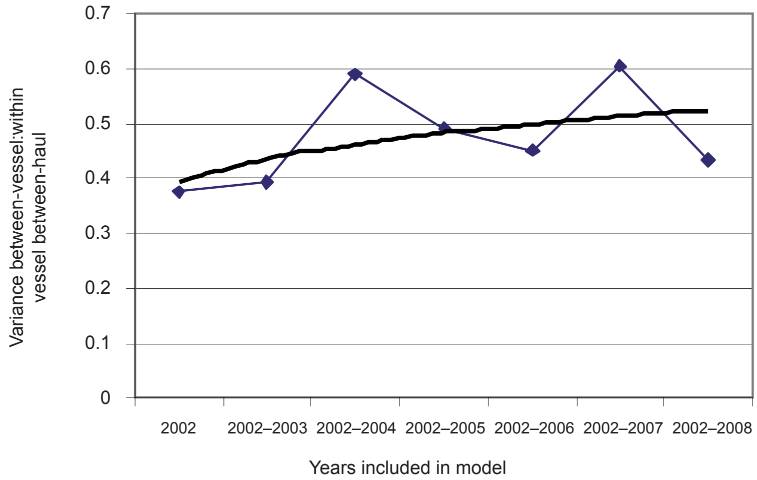

Figure 3: The proportion of total variance accountable to between-vessel variation for different periods of partial observer coverage. The trend line is a simple power function fitted by Excel.

fish by-catch (i.e. the data were summed across fish species). Data for other species groups (e.g. amphipods) were ignored.

The VCA used in the analysis of krill length assumes normality of the response variable. A suitable transformation was required for normality in the by-catch response variable. Again, a Box-Cox power transformation was used. However, Box-Cox power transformation requires a positive response and due to the nature of by-catch data, there were many zeros in the dataset. Consequently, the number of by-catch was modified to make it positive in the Box-Cox power transformation using

$$y_{ij} = \left(z_{ij} + k\right)^{\lambda} \qquad (9)$$

with shift parameter k and transformation parameter λ, where z refers to the fish count per haul. As before, a value of λ was chosen using a log-likelihood profile, giving $\lambda = -0.5$. The value of k was selected with a certain amount of subjectivity through examination of the residuals, giving $k = 1$. Note that since $\lambda < 0$

$$CV(z) < \frac{SE(y)}{\lambda\hat{\mu}}. \qquad (10)$$

Results of the VCA for the 2008 observer dataset for four vessels are given in Table 1.

Suitability of partial observer coverage

The results in Figures 1 and 2 allow tailoring of the level of coverage to achieve a specified accuracy in estimates derived from observer data. It is apparent that different combinations of partial vessel and haul coverage can deliver similar expected sample CVs. How best to achieve a given CV depends critically on the ratio of inter-vessel to intra-vessel variance. Higher inter-vessel variance will suggest that more vessels need to be sampled: higher intra-vessel variance will suggest that more hauls need to be sampled.

The Scientific Committee has recommended either a long period of partial coverage or a short period of 100% coverage to allow it to sufficiently understand the statistical properties of observer sampling on krill trawls to be able to determine an appropriate sampling strategy. (Note that this is 100% of vessels – not necessarily 100% of hauls.) A key question to ask in this context is whether the partial coverage achieved at South Georgia since 2002 can be regarded as sufficient to accurately estimate the ratio of inter-vessel to intra-vessel variance. If so, this would give confidence that the CV for a population level parameter of interest could be adjusted using the above results to the desired level of accuracy.

This question was approached by repeating the VCA for mean length, but with untransformed data, and for various cumulative combinations of years from 2002 onwards. The results (Figure 3) clearly show that about four years of partial sampling were required to achieve an asymptote in the estimate of the variance ratio $\left(\hat{\sigma}_U^2 / \left(\hat{\sigma}^2 + \hat{\sigma}_U^2\right)\right)$. The final variance ratio (i.e. 2002–2008) was 0.43, very similar to that estimated from the fully transformed data (Table 1).

Discussion

The variance components have been estimated for a two-stage observer sampling strategy, using data on mean krill length and fish by-catch rates. This allowed insight into the levels of sampling required at the inter- and intra-vessel levels to achieve a desired level of accuracy (CV). The relative contributions of inter- and intra-vessel variation to total variation were measured by the variance ratio. Although data in this study suggest a slightly lower variance ratio for larval fish than for krill parameters (42% versus 46%; Table 1), this difference was not sufficient to generate different conclusions about sampling strategies. Variance ratios indicate that slightly less than 50% of the variation is due to inter-vessel variation and slightly more than 50% to intra-vessel variation. The conclusions from these analyses can be summarised as follows:

- there are substantial gains in the precision of estimates of krill and larval fish parameters with increases in the proportion of vessels sampled up to about 50% of vessels, and smaller improvements thereafter;

- there are substantial gains in the precision of estimates of krill and larval fish parameters with increases in the proportion of hauls sampled up to about 20% of hauls, and smaller improvements thereafter.

These conclusions assume that the number of samples per haul remains constant at current levels. They are broadly consistent with those reached by Babcock and Pikitch (2003) and others (e.g. Karp and McElderry, 1999; working with the North Pacific groundfish fishery) that sampling for common events, such as target biometrics, can be achieved effectively with relatively low levels of observer sampling, particularly if it is stratified (e.g. Rochet et al., 2002). Caution, however, is necessary, since insufficient coverage can lead to unacceptable levels of imprecision or bias (e.g. Hall, 1999).

From Figure 1 it can be concluded that coverage levels of 10% of hauls and 50% of vessels would be sufficient for accurate estimation of krill population characteristics in South Georgia (CV <5%). However, due to the biological consistency of local krill populations (Reid et al., 1999) this may not hold true for other CCAMLR subareas, where much more attention may need to be given to spatial and temporal variability in designing a sampling program. For rarer events, higher sampling rates are usually required, although unless very accurate estimates of an endangered species are needed, 100% coverage may not be necessary (Babcock and Pikitch, 2003, suggest 50% of hauls). Larval fish by-catch can be considered an infrequent, if not a rare event (Ross et al., 2006). This suggests that a higher sampling rate for by-catch would be required to reach a similar precision (CV) for the mean krill length and by-catch rates. Spatial and temporal variability in larval fish occurrence in the water column (Ross et al., 2006) requires observer coverage of all months and areas. It is therefore desirable to cover as many vessels as possible, with overlapping representation by month and area. According to the results presented here, even sampling of 50% of vessels and 30% of hauls will only deliver a CV of around 40% (Figure 2). This is close to the most efficient sampling strategy for larval fish, since additional sampling effort would yield minimal benefits.

In South Georgia, UK observers achieved an average vessel sampling proportion of 56% across years (data not shown), an average krill haul sampling proportion of 18% (Table A1) and average larval fish sampling proportion of 31% (Table A2). These percentages represent the number of hauls sampled expressed as a proportion of total hauls set over the entire season by vessels which had an observer on board for some part of that season. In South Georgia, observers are often designated to vessels for only a part of a fishing season, in order to maximise the possibility for deployment on different vessels during the same year (to estimate the vessel effect). Furthermore, they only observe a proportion of the hauls made whilst on board, with an average observation rate of 62% (Table A1). Of the hauls observed, 55% (Table A1) and 95% (Table A2) were sampled for mean krill length and by-catch respectively.

Conclusions

The Scientific Committee was correct in its suggestion that several years of partial observer coverage would be sufficient to understand the statistical properties of krill sampling. The analysis presented here would suggest that this number should be four years or more. It was not possible to test, with this dataset, whether one year of full observer coverage would have been equivalently adequate to understand the statistical properties, but this is probably the case.

The level of partial observer coverage achieved in South Georgia could be easily implemented in other CCAMLR subareas. The authors suggest that minimum requirements would be:

- a target coverage rate of >50% of vessels each year;
- a target of >20% of hauls set by a vessel per season being sampled;
- all vessels being observed at least once every two years;
- all areas and seasons within a subarea being covered by an observer each year;
- partial coverage of at least four years.

These recommended coverage levels are appropriate only for the determination of the quantities analysed. They may not be appropriate for other objectives of a sampling program, for instance the identification of rare bird/mammal impacts or compliance purposes. Furthermore, these conclusions are dependent on the inherent variability in the krill population being studied. If natural variability is different in other subareas, a different level of observer coverage may be required.

The above scheme was implemented in Conservation Measure 51-06 (CCAMLR, 2009), influenced by an earlier version of this paper (Agnew et al., 2009). The target rate of >20% of haul coverage could be delivered by high levels of krill sampling for low proportions of the year. However, as was the case for this study (Figure A1), comprehensive coverage in space and time is likely to be necessary for accurate estimation of parameters, and preferable to a higher-intensity concentrated sampling program. This is particularly important for subareas where seasonal or spatial variation in the krill population parameters of interest is high, in contrast to the more stable situation in South Georgia.

References

Agnew, D.J., P. Grove, T. Peatman, R. Burn and C.T.T. Edwards. 2009. Analysis of krill observer coverage in Subarea 48.3. Document *WG-EMM-09/25*. CCAMLR, Hobart, Australia.

Babcock, E.A., E.K. Pikitch and G. Hudson. 2003. How much observer coverage is enough to adequately estimate bycatch? Pew Institute for Ocean Science, Miami, FL, and Oceana, Washington.

Barbeaux, S.J., S. Gaichas, J.N. Ianelli and M. Dorn. 2005. Evaluation of biological sampling protocols for at-sea groundfish observers in Alaska. *Alaska Fish. Res. Bull.*, 11 (2): 82–101.

CCAMLR. 2009. *Report of the Twenty-eighth Meeting of the Commission (CCAMLR-XXVIII)*. CCAMLR, Hobart, Australia: 203 pp.

Cotter, A.J.R., G. Course, S.T. Buckland and C. Garrod. 2002. A PPS sample survey of English fishing vessels to estimate discarding and retention of North Sea cod, haddock, and whiting. *Fish. Res.*, 55: 25–35.

Hall, M.A. 1999. Estimating the ecological impacts of fisheries: what data are needed to estimate bycatches? In: Nolan, C.P. (Ed.). *International Conference on Integrated Fisheries Monitoring*, Sydney (Australia), 1–5 February 1999. FAO, Rome, Italy: 175–184.

Hilborn, R. and M. Mangel. 1997. Incidental catch in fisheries: seabirds in the New Zealand squid trawl fishery. In: *The Ecological Detective: Confronting Models with Data*. Princeton University Press: 94–105.

Karp, W.A. and H. McElderry. 1999. Catch monitoring by fisheries observers in the United States and Canada. In: Nolan, C.P. (Ed.). *International Conference on Integrated Fisheries Monitoring*, Sydney (Australia), 1–5 February 1999. FAO, Rome, Italy: 261–284.

Mangel, M. 1993. Effects of high-seas driftnet fisheries on the northern right whale dolphin *Lissodelphis borealis*. *Ecol. Appl.,* 3 (2): 221–229.

Peterman, R.M. 1990. Statistical power analysis can improve fisheries research and management. *Can. J. Fish. Aquat. Sci.,* 47: 2–15.

Reid, K., J.L. Watkins, J.P. Croxall and E.J. Murphy. 1999. Krill population dynamics at South Georgia 1991–1997 based on data from predators and nets. *Mar. Ecol. Progr. Ser.,* 177: 103–114.

Rochet, M.-J., I. Péronnet and V.M. Trenkel. 2002. An analysis of discards from the French trawler fleet in the Celtic Sea. *ICES J. Mar. Sci.,* 59 (3): 538–552.

Ross, K.A., L. Jones, M. Belchier and P. Rothery. 2006. By-catch of small fish in a sub-Antarctic krill fishery. Document *WG-EMM-06/7*. CCAMLR, Hobart, Australia.

Sabourenkov, E.N. and E. Appleyard. 2005. Scientific observations in CCAMLR fisheries – past, present and future. *CCAMLR Science*, 12: 81–98.

SC-CAMLR. 2007. *Report of the Twenty-sixth Meeting of the Scientific Commission (SC-CAMLR-XXVI)*. CCAMLR, Hobart, Australia: 702 pp.

Thompson, S.K. 2002. *Sampling*. Second Edition. Wiley, New York.

Vølstad, J.H., W.R. Richkus, S. Gaurin and R. Easton. 1997. Analytical and statistical review of procedures for collection and analysis of commercial fishery data used for management and assessment of groundfish stocks in the U.S. Exclusive Economic Zone off Alaska. Versar, Inc. ESM Operations.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

Table A1: Summary of CCAMLR observer data from krill vessels fishing around South Georgia.

Vessel	Year	Hauls	Hauls with observer on board	Hauls observed	Observation rate (%)	Hauls with krill sampling	Total hauls observed (%)	Observed hauls with krill sampling (%)	Total hauls with krill sampling (%)
Acamar	2002	307							
Acrux	2002	354							
Chiyo Maru No. 5	2002	937	357	266	75	52	28	20	6
Feolent	2002	520	236	177	75	168	34	95	32
Foros	2002	250	90	72	80	28	29	39	11
Niitaka Maru	2002	883							
Top Ocean	2002	209	259	205	79	37	98	18	18
Chiyo Maru No. 5	2003	932	326	207	63	151	22	73	16
Top Ocean	2003	371	271	86	32	77	23	90	21
Niitaka Maru	2003	383							
Koyo Maru 8	2003	1079	388	127	33	112	12	88	10
Konstruktor Koshkin	2003	417							
Insung Ho	2003		212	124	58	138		111	
Dongsan Ho	2003		510	365	72	0		0	
Acamar	2003								
Foros	2003	581	219	164	75	16	28	10	3
Atlantic Navigator	2004	95	15	13	87	12	14	92	13
Top Ocean	2004	345	548	432	79	186	125	43	54
Niitaka Maru	2004	876	209	156	75	32	18	21	4
Konstruktor Koshkin	2004	385	248	111	45	0	29	0	0
Insung Ho	2004		103	95	92	40		42	
Esperanza	2004	48	22	22	100	21	46	95	44
Argos Vigo	2004	12							
Acamar	2004								
Chiyo Maru No. 5	2004	600							

(continued)

Table A1 (continued)

Vessel	Year	Hauls	Hauls with observer on board	Hauls observed	Observation rate (%)	Hauls with krill sampling	Total hauls observed (%)	Observed hauls with krill sampling (%)	Total hauls with krill sampling (%)
Konstruktor Koshkin	2005	382							
Niitaka Maru	2005	879	385	282	73	122	32	43	14
Insung Ho	2005		406	97	24	58		60	
Foros	2005	463	224	137	61	56	30	41	12
Feolent	2005	431	436	326	75	78	76	24	18
Atlantic Navigator	2005	303	54	40	74	29	13	73	10
Acamar	2005	214					0		0
Niitaka Maru	2006	710	394	181	46	27	25	15	4
Dalmor II	2006	159							
Dalmor II	2007	521	128	77	60	28	15	36	5
Dongsan Ho	2007	308							
Insung Ho	2007	629							
Niitaka Maru	2007	661	157	48	31	20	7	42	3
Saga Sea	2007	303	307	69	22	69	23	100	23
Juvel	2008	14	14	14	100	12	100	86	86
Dalmor II	2008	595	225	46	20	44	8	96	7
Maxim Starostin	2008	71	55	21	38	21	30	100	30
Averages					62		35	55	18

Note: The table only includes information for vessels in 2008 carrying a CCAMLR observer. The data presented in this table are preliminary, but are likely to be close to the actual values. Note that the records of total number of hauls are incorrect or missing for some vessels either because they did not report them or, in the case of the continuous hauling vessels, because methods of recording individual 2-hourly periods were not developed.

Table A2: Sample sizes by vessel and year – CCAMLR data, 2008, South Georgia.

Vessel	Hauls	Hauls with observer on board	Hauls observed	Observation rate (%)	Hauls sampled for larval fish	Total hauls observed (%)	Observed hauls sampled for larval fish (%)	Total hauls sampled for larval fish (%)
Dalmor II	595	225	46	20	44	8	96	7
Insung Ho	1185	138	13	9	13	1	100	1
Juvel	14	14	14	100	12	100	86	86
Maxim Starostin	71	55	21	38	21	30	100	30
Averages				42		35	95	31

Table A3: Number of traditional trawls sampled for krill length by vessel and season. Hauls with zero catch have been removed.

Vessel	Season							Overall
	2002	2003	2004	2005	2006	2007	2008	
Atlantic Navigator			12	29				41
Chiyo Maru No. 5	52	151						203
Dalmor II						28	44	72
Esperanza			21					21
Feolent	161			78				239
Foros	28	16		56				100
Insung Ho		138	40	58				236
Juvel							12	12
Konstructor Koshkin			59					59
Koyo Maru 8		112						112
Maxim Starostin							8	8
Niitaka Maru			32	122	27	20		201
Top Ocean	37	77	186					300
Overall	278	494	350	343	27	48	64	1604

Table A4: Average of mean krill length (mm) per vessel per season. Hauls with zero catch have been removed.

Vessel	Season							Overall
	2002	2003	2004	2005	2006	2007	2008	
Atlantic Navigator			37.27	38.12				37.87
Chiyo Maru No. 5	43.47	48.06						46.89
Dalmor II						30.13	42.83	37.89
Esperanza			37.92					37.92
Feolent	44.82			38.23				42.67
Foros	42.23	44.77		39.96				41.36
Insung Ho		46.76	41.75	37.82				43.71
Juvel							45.53	45.53
Konstructor Koshkin			39.25					39.25
Koyo Maru 8		47.91						47.91
Maxim Sorokin							45.31	45.31
Niitaka Maru			42.22	39.71	43.64	32.52		39.92
Top Ocean	45.91	46.15	38.27					41.24
Overall	44.45	47.26	39.14	38.96	43.64	31.12	43.64	42.54

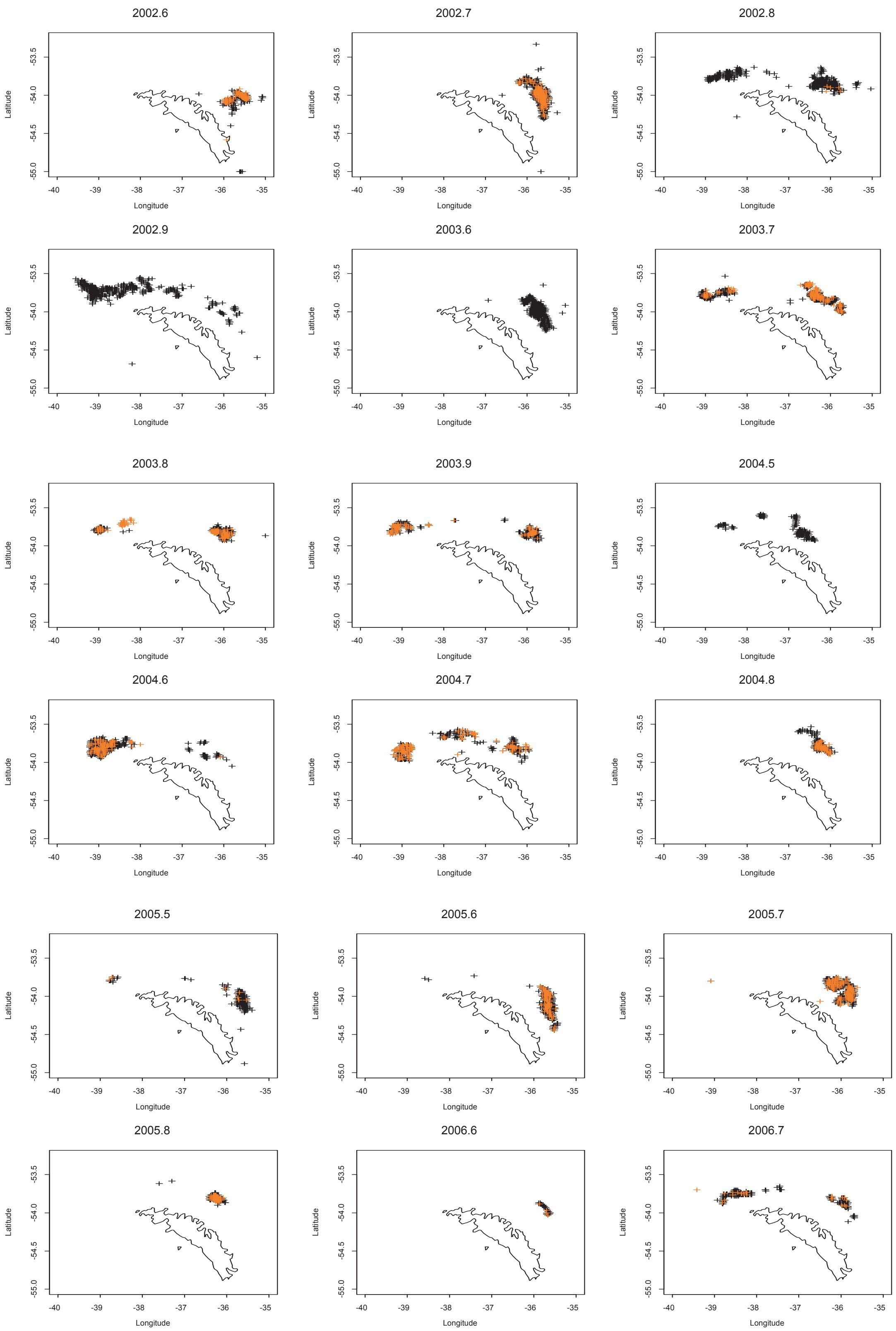

Figure A1: Spatial and temporal overlap between hauls sampled for krill biological parameters and the total fishery hauls. Headings are year and month, black is fishery hauls, yellow is krill biological samples.

(continued)

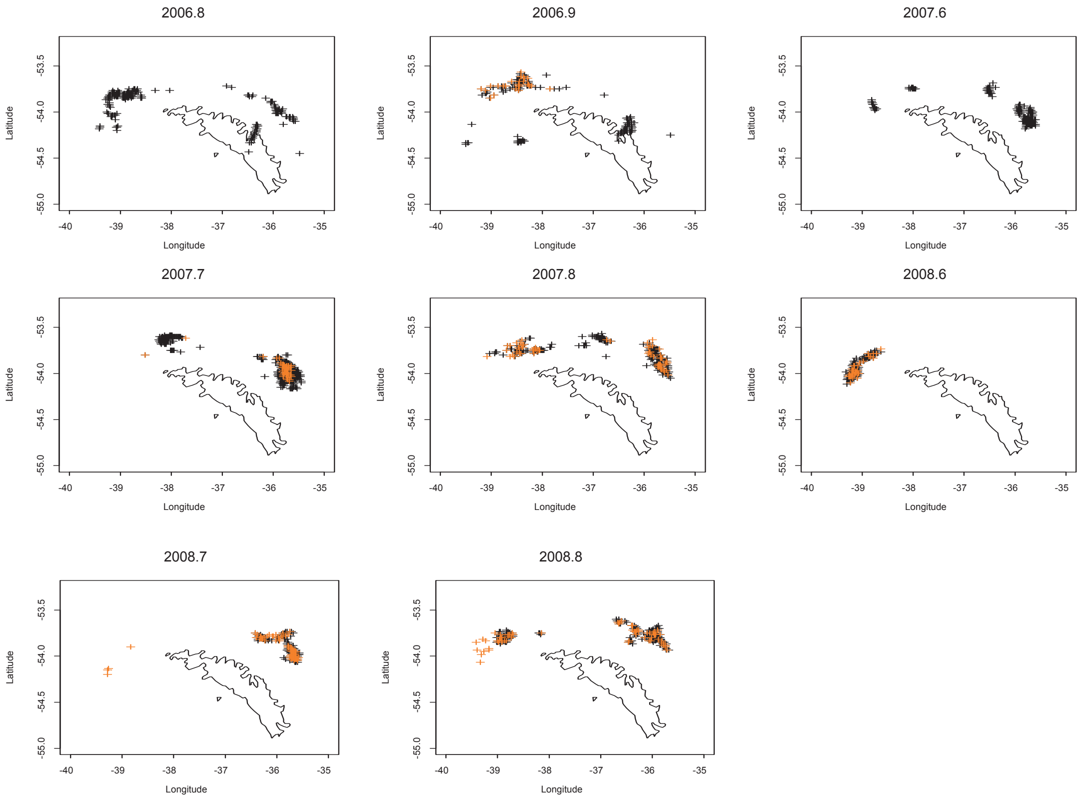

Figure A1 (continued)