CCAMLR Science, Vol. 12 (2005): 119–141

A STATISTICAL METHOD FOR ESTIMATING THE LEVEL OF IUU FISHING: APPLICATION TO CCAMLR SUBAREA 48.3

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Abstract

This paper describes a new method for estimating illegal, unregulated and unreported (IUU) catches of fish and by-catch of birds. It utilises high quality, well-documented fisheries protection vessel (FPV) cruise data. The method takes explicit account of both 'seen' and 'unseen' IUU fishing by using a simulation model to arrive at statistically rigorous estimates of, and confidence intervals for, fish and bird catches by IUU vessels. In order to estimate an IUU catch there must have been at least one encounter with an FPV in a year; no encounters in a year are interpreted as zero IUU fishing. For each IUU incident detected by the FPV, a theoretical maximum time over which this IUU activity could have occurred was calculated. This was then converted to estimated actual IUU fishing time, using a model simulating IUU vessel and FPV behaviour. IUU activity was considered to have been observed when the IUU vessel and the FPV vessel were in the same place at the same time. When this occurred, the FPV was assumed to detect IUU activity according to an 'encounter probability'. The encounter probability was estimated from the known encounters of FPVs with licensed vessels. The total annual IUU catch of toothfish and birds was calculated using a second simulation model. Subarea 48.3 was divided into six areas for the purposes of the estimation of fish and bird catch associated with IUU fishing. The mean and variance of fish catch rate was calculated for each area and each year using reported catch and effort data. The catch rate of birds was estimated separately for summer and winter by bootstrapping previously published CCAMLR observer data weighted by the number of hooks observed. These data were obtained in the early licensed fishery (1997) when few vessels used mitigation measures.

Three years were analysed: 1998/99, 1999/2000 and 2000/01. Each year fully covered the period 1 October to 30 September, thus including one summer and one winter period. The estimated mean toothfish catches attributable to IUU fishing were 776, 1 019 and 198 tonnes in 1998/99, 1999/2000 and 2000/01 respectively (a total over the three years of 1 994 tonnes). The distribution of estimated total bird catch was highly skewed, with medians in the three years of 621, 2 852 and 550 birds respectively. 95% confidence limits were calculated to be 54–2 017, 468–1 779 and 22–487 tonnes respectively for fish and 162–7 752, 1 040–23 361, 140–9 023 respectively for birds. Despite continuing high levels of FPV coverage from 2001 to 2004, no further IUU activity has been detected, leading to estimates of zero fish and bird catches for the years 2001/02, 2002/03 and 2003/04.

Résumé

Ce document décrit une nouvelle méthode d'estimation des captures illicites, non déclarées et non réglementées (IUU) de poisson et de la capture accidentelle d'oiseaux. Il utilise des données de campagnes de navires de surveillance des pêches de très bonne qualité et bien documentées. La méthode tient compte explicitement de la pêche IUU «vue» et «non vue» par le biais d'un modèle de simulation pour arriver à des estimations rigoureuses sur le plan statistique, avec intervalles de confiance, des captures de poissons et d'oiseaux par les navires IUU. Pour estimer une capture IUU, il doit y avoir eu au moins une rencontre avec un navire de surveillance en une année; dans le cas contraire, la pêche IUU est considérée comme nulle. Pour chaque incident IUU détecté par le navire de surveillance, on détermine théoriquement la durée maximale de cette activité. Cette valeur est ensuite convertie en une estimation du temps de pêche IUU réel, à l'aide d'un modèle de simulation du comportement des navires IUU et des navires de surveillance. Il est considéré que l'activité IUU a été observée lorsque le navire IUU et le navire de surveillance se trouvaient au même endroit, au même moment. A ce moment-là, le navire de surveillance est présumé détecter l'activité IUU selon une «probabilité de rencontre». La probabilité de rencontre est estimée à partir des rencontres réelles entre les navires de surveillance et les navires munis de licences. Un deuxième modèle de simulation sert à calculer la capture annuelle totale IUU de légine et d'oiseaux. La sous-zone 48.3 est divisée en six secteurs pour les besoins de l'estimation de la capture de poisson et d'oiseaux associée à la pêche IUU. La moyenne et la variance du taux de capture de poisson sont calculées par secteur et par année au moyen des données de capture et d'effort de pêche déclarées. Le taux de capture d'oiseaux est estimé séparément pour l'été et l'hiver par l'amorçage des données déjà publiées, provenant des observateurs de la CCAMLR et pondérées par le nombre d'hameçons observés. Ces données datent du début des licences de pêche (1997) lorsque les navires étaient peu nombreux à utiliser les mesures d'atténuation de la capture accidentelle.

L'analyse concerne trois années : 1998/99, 1999/2000 et 2000/01. Chaque année couvre entièrement la période comprise entre le 1er octobre et le 30 septembre et comprend donc une période d'été et une période d'hiver. Les captures moyennes de légine estimées, attribuables à la pêche IUU sont respectivement de 776, 1 019 et 198 tonnes en 1998/99, 1999/2000 et 2000/01 (un total 1 994 tonnes pour les trois années). La distribution de la capture totale d'oiseaux estimée est fortement faussée, avec des médianes respectives de 621, 2 852 et 550 oiseaux pour les trois années. Le calcul des limites de l'intervalle de confiance à 95% donne 54–2 017, 468–1 779 et 22–487 tonnes respectivement pour le poisson et 162–7 752, 1 040–23 361 et 140–9 023 respectivement pour les oiseaux. Malgré les niveaux de couverture élevés des navires de surveillance de 2001 à 2004, aucune autre activité IUU n'a été détectée, entraînant des estimations nulles de capture de poisson et d'oiseaux pour les années 2001/02, 2002/03 et 2003/04.

Резюме

В данной статье описывается новый метод оценки незаконного, нерегулируемого и незарегистрированного (ННН) вылова рыбы и прилова птиц. В ней используются высококачественные, хорошо задокументированные данные, полученные в ходе рейса рыбоохранного судна (FPV). Этот метод в явном виде учитывает как «замеченный», так и «незамеченный» ННН промысел путем использования имитационной модели в целях получения статистически строгих оценок и доверительных интервалов для вылова рыбы и птиц ННН судами. Для оценки ННН вылова необходимо, чтобы произошла хотя бы она встреча с FPV в год; если в течение года не было ни одного случая, то считается, что ННН промысел равен нулю. Для каждого случая ННН промысла, замеченного судном FPV, просчитывалось теоретическое максимальное количество времени, в течение которого могла осуществляться эта ННН деятельность. Затем на основе модели, имитирующей действия ННН судна и FPV, это время пересчитывалось в оценочное реальное время ННН промысла. Считалось, что ННН деятельность наблюдалась, если ННН судно и FPV находились в одном и том же месте одновременно. Когда это происходило, то предполагалось, что FPV выявило ННН деятельность в соответствии с «вероятностью встречи». Вероятность встречи оценивалась на основании известных встреч судов FPV с лицензированными судами. Общий годовой ННН вылов клыкача и птиц рассчитывался с использованием второй имитационной модели. Подрайон 48.3 был поделен на 6 районов в целях оценки вылова рыбы и птиц, связанного с ННН промыслом. Среднее и дисперсия показателя вылова рыбы рассчитывались для каждого района и каждого года на основе зарегистрированных данных об улове и усилии. Уровень вылова птиц оценивался раздельно для лета и зимы путем бутстреппинга ранее опубликованных данных, собранных наблюдателями АНТКОМа и взвешенных на количество наблюдавшихся крючков. Эти данные были получены в начальный период ведения лицензированного промысла (1997 г.), когда лишь немногие суда применяли смягчающие меры.

Был проведен анализ по трем годам: 1998/99, 1999/2000 и 2000/01. Каждый год полностью охватывает период с 1 октября по 30 сентября, включая, таким образом, один летний и один зимний период. Средний оценочный вылов клыкача, отнесенный на счет ННН промысла, составлял соответственно 776, 1019 и 198 т в 1998/99, 1999/2000 и 2000/01 гг. (всего за три года 1994 т). Распределение общего оценочного вылова птиц было сильно смещено, со средними значениями за три года соответственно 621, 2852 и 550 птиц. Были рассчитаны 95% доверительные пределы, которые составили соответственно 54–2017, 468–1779 и 22–487 т для рыбы и 162–7752, 1040–23 361, 140–9023 для птиц. Несмотря на постоянный высокий охват судами FPV в период 2001–2004 гг., не было замечено никакой ННН деятельности, что дало нулевую оценку вылова рыбы и птиц в 2001/02, 2002/03 и 2003/04 гг.

Resumen

Este documento describe un nuevo método para estimar la captura ilegal, no declarada y no reglamentada (INDNR) de peces y la captura incidental concomitante de aves, a partir de datos muy bien documentados y de alta calidad de las patrullas de los barcos guardapesca (FPV). El método toma en cuenta explícitamente la pesca INDNR "observada" y "no observada" mediante un modelo de simulación que produce estimaciones rigurosas (con intervalos de confianza) de las capturas de peces y aves realizadas por los barcos de pesca INDNR. Para poder calcular una captura INDNR es preciso que se haya producido por lo menos un encuentro con un barco guardapesca (FPV) en un año; una captura INDNR cero denota que no se han producido tales encuentros. Por cada incidente INDNR detectado por un guardapesca, se calculó teóricamente el máximo período de tiempo durante el cual podría haberse llevado a cabo la actividad INDNR. Esto se convirtió a continuación en una estimación del tiempo real de pesca INDNR, mediante un modelo que simulaba el comportamiento del barco de pesca INDNR y del guardapesca. Se consideró que se había observado la pesca INDNR cuando el barco de pesca INDNR y el guardapesca FPV se encontraron en un mismo lugar y al mismo tiempo. Cumplidas estas condiciones, se supuso que el guardapesca detectó actividades de pesca INDNR según una "probabilidad de encuentro". La probabilidad de encuentro se calculó de los encuentros conocidos de guardapescas con barcos autorizados para la pesca. La captura INDNR anual total de austromerluza y de aves se calculó mediante un segundo método de simulación. La Subárea 48.3 fue dividida en seis áreas con el fin de estimar la captura INDNR de peces y aves. Se calculó el promedio y varianza de la tasa de captura de peces para cada área y año utilizando los datos notificados de captura y esfuerzo. La tasa de captura de aves se estimó por separado para el verano e invierno con el método de bootstrap aplicado a los datos de observación (ya publicados) de la CCRVMA, ponderados por el número de anzuelos observados. Estos datos fueron obtenidos a principios de la pesca reglamentada (1997) cuando muy pocos barcos aplicaban medidas de conservación.

Se analizaron tres años: 1998/99, 1999/2000 y 2000/01. Cada año cubrió el período del 1º de octubre al 30 de septiembre , incluyendo por lo tanto un verano y un invierno. Las estimaciones del promedio de las capturas de austromerluza atribuibles a la pesca INDNR fueron de 776 en 1998/99, 1 019 en 1999/2000 y 198 toneladas en 2000/01, un total de 1 994 toneladas en tres años. La distribución de las estimaciones de la captura total de aves fue muy asimétrica, con medianas correspondientes a los tres años de 621, 2 852 y 550 aves. Los intervalos de confianza del 95% calculados fueron 54–2 017, 468–1 779 y 22–487 toneladas para peces y 162–7 752, 1 040–23 361, 140–9 023 respectivamente para las aves. A pesar de la alta cobertura proporcionada por los barcos FPV desde 2001 hasta 2004, no se ha detectado ninguna actividad INDNR, dando como resultado capturas cero de peces y aves para los años 2001/02, 2002/03 y 2003/04.

Keywords: IUU fishing, estimation of illegal/IUU fishing, encounter probability, simulation modelling, CCAMLR

Introduction

Illegal, unregulated and unreported (IUU) fishing has become one of the most important problems facing world high-seas fisheries. Reliable estimation of IUU catches, however, remains very difficult. Various approaches can be taken, such as accounting for sightings, monitoring trade, monitoring landings, making quantitative use of anecdotal information (Pitcher et al., 2002) and comparing the results of stock assessments (OECD, 2004). Of these, trade tracing is perhaps the least easy to use because it is at one remove from the IUU activity itself, and there are difficulties associated with standardising customs codes and attributing catches to areas and years (Willock, 2004). The most direct methods include estimates based on actual sightings and landings of IUU vessels. However, these suffer from being absolute and are usually minimum estimates (OECD, 2004), and they are always open to the criticism that there is 'unseen' IUU activity which is not accounted for.

CCAMLR has historically estimated IUU activity based on the number of sightings and the assumed fishing effort of those sighted vessels. This method is of course also open to the criticism that it does not account for unseen activity. The method is also only capable of producing point estimates or estimates of ranges, and does not include any indication of the variance of those estimates. However, at least in some cases, information is available that would allow estimates of levels of unseen IUU activity to be made. This paper develops a methodology, based around a simulation model of IUU vessel

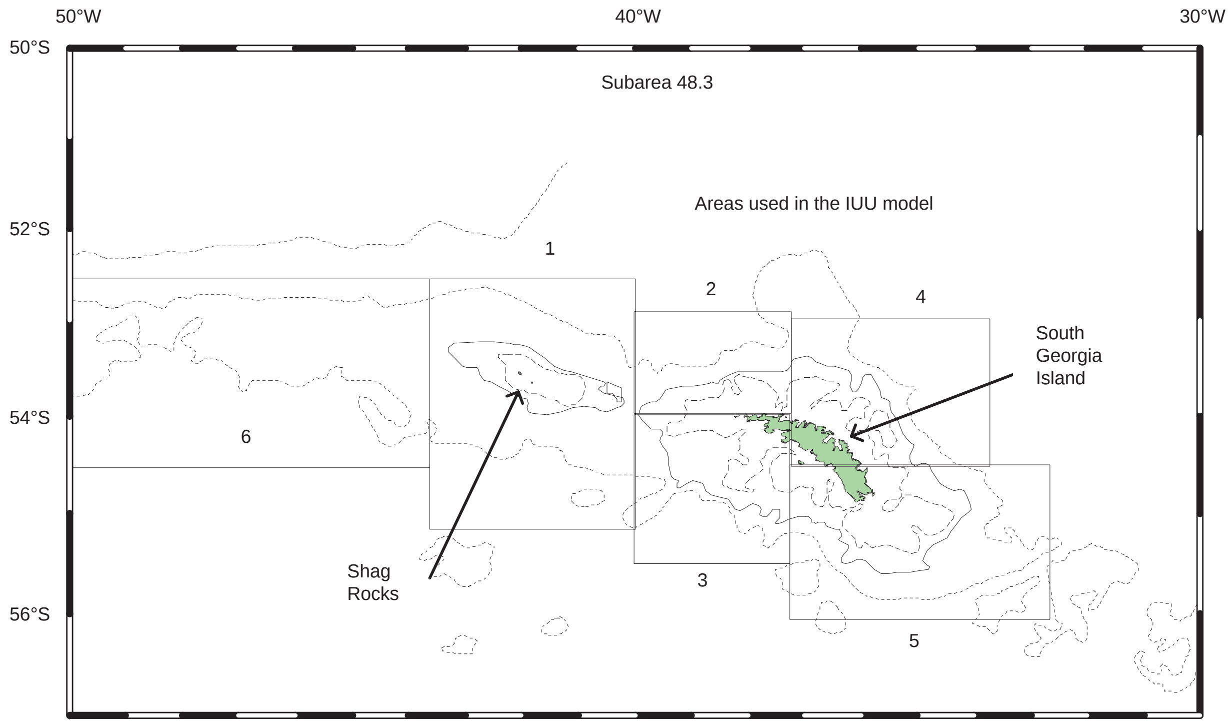

Figure 1: Definition of fishing areas within Subarea 48.3, showing 500, 1 000 and 2 000 m bathymetric contours.

Table 1: Fisheries protection vessel (FPV) sightings of IUU incidents by year (Agnew, 2004).

Year	% of the year spent patrolling in Subarea 48.3	Number of IUU incidents sighted
1998/99	8	1
1999/00	24	8
2000/01	32	1
2001/02	35	0
2002/03	37	0
2003/04	40	0

behaviour, which is capable of dealing with unseen IUU effort and can be used to derive estimates of the level of IUU fishing (with confidence intervals) and its impact on fish and birds.

In CCAMLR waters, IUU fishing started in 1992 or 1993 around South Georgia. Following a series of arrests by UK authorities, and the identification of large areas in the Indian Ocean sector where toothfish could potentially be caught, IUU operations moved to that area in 1996 and 1997. Since then, most activity has been concentrated on fishing grounds around Prince Edward and Marion Islands (South Africa), Crozet and Kerguelen Islands (France) and Heard Island (Australia).

Even though most IUU activity has now moved to the Indian Ocean, South Georgia has continued to experience low levels of IUU activity. Each year CCAMLR has made estimates of the level of IUU catch in Subarea 48.3, based on evidence from sightings of IUU vessels and estimates of the likely duration of fishing and catch rates of the vessels sighted. The waters of Subarea 48.3 have been used as a test case to develop the model presented here, and it is shown that this model can be used to estimate the level and confidence limits of IUU catches of fish and birds.

Methods

The methodology followed here uses information on sightings of IUU vessels in Subarea 48.3. There are a number of sources for such information, such as opportunistic sightings by merchant vessels, cruise ships, scientific research vessels and fishing vessels, or systematic searching performed by fisheries protection vessels (FPVs). Of these, the most reliable is FPV data. By simulating IUU activity and overlaying it with the known search pattern of the FPV (in time and space), it is possible to derive a relationship between what was detected by the FPV and what the total IUU activity was.

This results in estimates of the number of days of IUU fishing, by position within Subarea 48.3, year and time of year. The catch rates of toothfish by IUU vessels are assumed to be the same as those achieved by licensed vessels, which have been derived using CCAMLR and UK catch data. The catch rates of birds are derived from analysis of CCAMLR data, based on rates published in CCAMLR reports.

The analysis is thus spatially and temporally explicit. Six areas were defined within Subarea 48.3, based on differences in catch rates of toothfish and of birds. These are shown in Figure 1. The area of operation of the FPV covers all possible positions for toothfish fishing (approximately 500 to 2 000 m depth) within these areas, thus satisfying the assumption that if there is an IUU vessel fishing in one or more of the areas, then there is a possibility of it being encountered by the FPV.

Comprehensive FPV data are only available from 1998. Over the following four years, FPV activity increased considerably at South Georgia, with the result that after detecting a few incidents in 1999 and 2000 no further incidents were recorded (Table 1). The method used here requires there to be some encounter between the FPV and IUU activity for the true extent of that activity to be estimated, and so initially its use was restricted to the first three fishing years in the series.

For the purposes of this paper, the fishing year was defined as extending from October of one year to September of the next. This is more coincident with the periods of summer presence and winter absence of seabirds from Subarea 48.3 than either the CCAMLR fishing season (December to November) or split-year (July to June). Large numbers of birds, including albatrosses, appear to leave the fishing areas around South Georgia in April each year (around 15 April: Agnew and Croxall, 1999), and thus for the fishing data, April to September was considered to be the winter season, and October to March to be the summer season.

Model for estimating days fished and total catch

It is assumed that the FPV searches randomly for IUU activity in Subarea 48.3. Overall IUU activity can then be estimated if the relationship between the likelihood of FPV detection and the total number of days fishing that IUU vessels were engaged in during the year is known. This involves a two-step process. First, a plausible but almost certainly biased estimator of the number of days of IUU fishing that are represented by actual encounters between FPVs and IUU vessels was constructed. A simulation model was then used to estimate a correction factor to convert the initial estimate of number of days of IUU fishing to the total IUU activity in the area.

The initial estimates of number of days of IUU fishing were made with reference to the winter and summer seasons defined above. For each FPV IUU sighting, the earliest possible date from which the IUU vessel could have been fishing was determined, as was the latest possible date up to which the IUU vessel could have been fishing, based on the dates of previous and subsequent FPV cruises during which activity by that IUU vessel was not detected (assuming for the moment that the probability of detection by the FPV is one). The estimated number of days fishing for the IUU cruise[1] detected by an FPV, i, in year y, $D_{i,y}$, was thus calculated from FPV encounters with IUU vessels as:

$$D_{i,y} = L_{i,y} - E_{i,y} \tag{1}$$

where L is the latest and E is the earliest date from which the vessel can have been fishing. For instance, if FPV cruises took place in June, July and August, and an IUU vessel was detected in Area 3 in July, the earliest that that vessel can have been fishing would be the date that the FPV searched Area 3 in June and did not find anything. The latest would be the date that the FPV searched Area 3 in August and did not find anything. In determining these dates, for the time being it is assumed that IUU vessels do not change areas.

Earliest and latest dates were based on prior and subsequent cruise dates by the FPV, but information on the prior and subsequent presence of other vessels (such as fishing vessels) could also have been used. However, the areas most frequently covered by other vessels are Areas 2 and 4, whereas all recorded incidents have been in Areas 6, 1 or 3. Furthermore, although fishing vessels, cruise ships and research vessels do report sightings of vessels

[1] All mentions of cruises in this document are synonymous with 'campaigns', and refer to time spent on the fishing grounds only.

which may be fishing illegally, they are not under an obligation to do so. These reports, therefore, may not be fully reliable. For these reasons, only reports by FPVs were considered to be confirmed data. To the authors' knowledge, over the period covered by this study there were no instances of a confirmed IUU incident being reported by a non-FPV vessel, without that incident being also independently detected by an FPV.

Next, it is necessary to adjust D so that it represents accurately the total number of days of IUU fishing during a year that is indicated by the FPV encounter with an IUU vessel. If A is defined as adjusted days fishing, then

$$A_{i,y} = p_{a,y} D_{i,y} \quad (2)$$

where p is the correction factor used to convert IUU days fishing assumed from FPV encounters into real IUU days fishing. p is defined by year and area. A is the total number of days of IUU fishing that occurred during the year which are represented by the ith encounter of the FPV with an IUU vessel. The following section discusses this in more detail and presents the methodology used for estimating p.

Adjusted days fishing was then combined with area- and year-specific estimates of fish catch rates and bird by-catch rates to produce estimates of catches of fish and birds. Each IUU cruise i was assigned an area of fishing, a, corresponding to the area in which the FPV detected the vessel. Then the fish catch of the cruise was

$$C_{i,y} = A_{i,y}\, CPUE_{a,y} \quad (3)$$

where $CPUE$ was the average CPUE of licensed vessels in that area in year y. The estimated number of birds caught by that IUU cruise, B, was

$$B_{i,y} = H_{a,y} A_{i,y} (q\, M_{a,s} + (1–q)\, M_{a,w}) \quad (4)$$

where H is the average number of hooks per day used by the licensed fishery in year y (thousands) in the area in which the IUU vessel is recorded as having been fishing. The proportion of fishing days that took place in the summer is q (and in the winter is $1–q$). $M_{a,s}$ is the bird mortality rate (per thousand hooks) in summer in area a, and in winter this is $M_{a,w}$. The methodology used for estimating bird by-catch rates is detailed later in this paper.

The total estimated fish and bird by-catch is estimated for each year by

$$C_y = \Sigma C_{i,y} \quad (5)$$

$$B_y = \Sigma B_{i,y} \quad (6)$$

for all i in year y.

In order to calculate both point estimates and confidence intervals for the annual fish and bird catches, 10 000 sets of values of CPUE, H and M were drawn from probability distributions determined through analyses of existing fish catch and effort and bird by-catch data described in subsequent sections of this paper. The estimate of the correction factor, p, used in these calculations was obtained using the method described in the next section.

Estimating p using a simulation model of IUU fishing activity

For a number of reasons, as noted earlier, calculations based solely on earliest and latest dates, D, of IUU cruises actually detected by the FPV are not likely on their own to produce unbiased estimates of IUU fishing effort, A (see equations 1 and 2). Firstly, it is possible that an IUU vessel arrives and departs the zone between FPV cruises and is not recorded. This may occur when the IUU vessel cruise duration is less than inter-FPV-cruise duration. Secondly, FPVs may have an imperfect detection rate. Thirdly, by basing D on the prior and subsequent FPV cruises, it is effectively assumed that after detection by an FPV, IUU vessels continue fishing right up to the date of the next FPV cruise, regardless of the encounter with the FPV. While theoretically possible, it would be surprising if an encounter with an FPV did not have some deterrent effect on an IUU vessel[2]. Thus the detected IUU cruise might be expected to be curtailed, being completed some time between the encounter and the next time the FPV is in the area or the planned end of the IUU cruise. Fourthly, and by the same token, it is assumed that the earliest that an IUU vessel can have been present was just after the last FPV cruise, but in fact the IUU vessel would have arrived in the area some time between the last FPV cruise and the encounter (i.e. a shorter time).

[2] Obviously, when a vessel is arrested it will stop fishing immediately. While arrests have been made, it has been more common to encounter longline buoys alone, which are subsequently removed. Vessels have also been encountered outside the South Georgia Management Zone, in international waters inside the CCAMLR Convention Area, in which case they are either inspected (if they are CCAMLR Members) or asked to leave the Convention Area (non-CCAMLR Members). Sometimes vessels are encountered which are strongly suspected of engaging in IUU fishing, but where direct evidence is not of sufficient quality for an arrest.

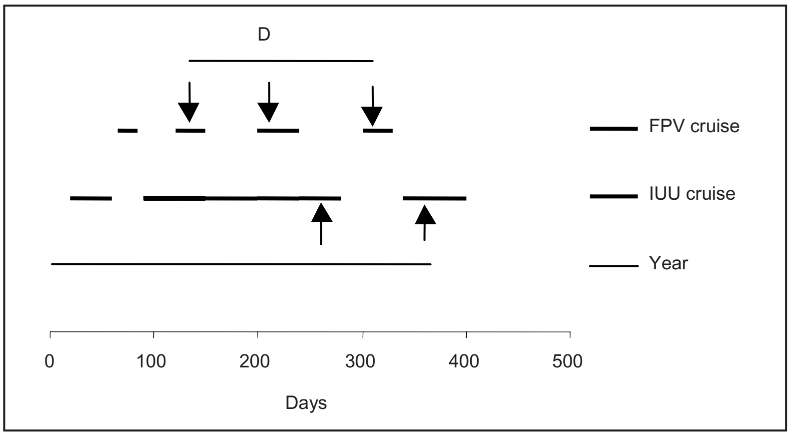

Figure 2: Schematic representation of the stochastic model.

The estimation of the correction factor p in equation 2 was carried out using simulation modelling. Taking the actual FPV record for a year (October to September), an IUU cruise was randomly placed within the year, selecting start date from a uniform distribution U[1,365], and assigning it an IUU cruise duration drawn randomly from another uniform distribution bounded by assumed maximum and minimum durations (see 'IUU cruise length and strategy'). It was assumed that an IUU vessel conducts fishing on each day during its cruise in one of the areas in Subarea 48.3. It is not known which area this is, or when the FPV will search it. The search date is therefore assigned a random position within the FPV cruise, again selected from a uniform distribution. If the IUU vessel has not arrived in the zone at this point, or has departed, then the FPV will miss it. If the IUU vessel is in the zone, there is still a chance that the FPV will miss it. The chance that the IUU vessel will not be observed will be a combination of the probability that it is simply not seen even though the FPV searched the area(s) within which it was fishing, and the probability that it has never been fishing in the same area as the FPV was searching. This combined probability is called the encounter probability.

The process is illustrated in Figure 2. The year is illustrated by a line extending 365 days. The first simulated IUU cruise occurs from day 20 to day 60. Since this is prior to any FPV cruise, it is undetected and the IUU cruise is assigned its full, simulated, number of days. The second IUU cruise takes place just after the end of the first FPV cruise, but overlaps with the next two FPV cruises. It is missed by the first one (modelled using the encounter probability acting at the time of the downward-pointing arrow) but correctly located by the third FPV cruise (at the second downward-pointing arrow). Each of the upper row of downward-pointing arrows is the (random) day on which the FPV searches an area in which the IUU vessel is fishing.

Following the encounter between the FPV and the IUU vessel, the IUU vessel modifies its behaviour and leaves at some random time before the next FPV cruise. This may be before the end of its planned cruise duration, earlier than it would have if it had remained undetected (shown by the first upwards-pointing arrow in Figure 2). By modelling the behavioural response this way, we are in fact saying that if the IUU vessel is encountered close to the end of its planned cruise it will probably take the risk and finish it. If it has a long time still to run on its cruise it will not want to extend its fishing time in Subarea 48.3 by very much and will, in any case, finish its cruise some time before the FPV is next in the area. Note that this is a more conservative assumption of IUU vessel response than that of the IUU vessel leaving Subarea 48.3 immediately.

The estimate of the number of days fishing, according to the methodology outlined above, is the duration D – the time between the previous search of the area in which the IUU fishing was detected and the next search of the area.

The final case is the third IUU cruise, which starts on day 340 after the last FPV cruise and has a randomly chosen cruise duration of 60 days. These simulations were run individually for each year of the study period, because each has a quite different set of FPV cruises. Therefore, the IUU fishing days were only assigned up to the end of the year and the IUU cruise is stopped at the second upwards-pointing arrow. This introduces a small edge effect, which is unlikely to have a significant effect on the results.

The above model probably mimics the interaction of IUU and FPVs fairly well. However, the choice of a random time during the FPV cruise for a possible 'sighting' of the IUU vessel is at first sight counter-intuitive. One might think that it would be

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        Time-->
FPV         -------------------
IUU1                       xxxxxxxxxxxx
IUU2        xxxxxxxxxxxx
```

Figure 3: Effect of different timings of IUU cruises.

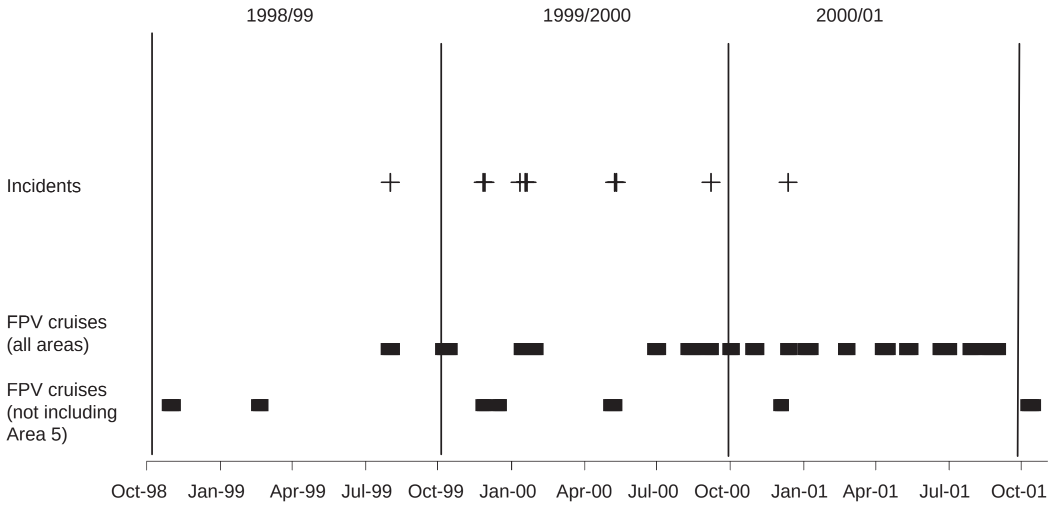

Figure 4: Duration of fishery protection vessel (FPV) cruises in Subarea 48.3. Labels correspond to the first of each month. The lower line shows cruises that covered Subarea 48.3, but did not make a complete circuit of South Georgia (missed Area 5 – see Figure 1). The central line shows cruises that did complete a circuit of the island. Crosses are incidents in which IUU activity was encountered.

better to assign the random sighting time during the period of overlap of the IUU and FPV cruises rather than for the whole FPV cruise. But this would mean that there was no increased probability of detection of an IUU vessel with increased overlap between the FPV and IUU cruises – there would be as much chance of detection if the two cruises overlapped by one day as by eight days. According to the diagram in Figure 3, it would naturally be expected that the IUU1 cruise would be more difficult for the FPV to detect than IUU2.

Each IUU cruise simulated therefore generates a real number of days fished and an FPV-estimated number of days fished. The ratio of real to estimated days fishing over 1 000 simulated IUU cruises is p, and this is used to adjust the estimates of IUU fishing days made from real encounters of FPVs and IUU according to equation 2.

Simulations of 1 000 IUU fishing operations were run for each year under a number of scenarios of assumed distributions of IUU trip length. Estimates of p derived from these runs (i.e. for sightings in 1998, 1999 and 2000) were then used in the main model.

IUU cruise length and strategy

IUU cruises are likely to be shorter than licensed cruises. Licensed vessels are usually able to operate in Subarea 48.3 for two to three months without having to tranship their catch. This explains why many vessels are able to fish through May and June, transhipping only in July. Hold capacities of longliners licensed to fish in South Georgia and the South Sandwich Islands have a mean of 355 tonnes (SD 177, n = 56), equivalent to about 585 tonnes wet weight of fish. Filling a hold of this size will take about three months at catch rates of 4–6 tonnes/day.

IUU vessels, on the other hand, operate (or are thought to operate) on much shorter time scales. Industry sources (Peter Thomson, Argos Evergreen Ltd, pers. comm.) estimate that cruises (i.e. time spent on the fishing grounds) may normally last four to six weeks around South Georgia. SC-CAMLR (1999, 2000) also estimated typical IUU cruise duration as being between 30 and 40 days in this period.

One would expect that cruises of this duration would be more difficult to detect, but would take fewer fish and birds than the longer cruises made by licensed vessels. Since it was also interesting to see what the effect of assuming longer cruises would have on the estimates of IUU fishing, simulations of two different cruise lengths were carried out: short (4–6 weeks: cruise duration sampled from U[28,42] days) and long (8–12 weeks, cruise duration sampled from U[56,84] days).

Results

Parameter estimates

Encounters of IUU activity

The frequency of FPV cruises has increased over the three years analysed (Figure 4). Most FPV cruises have covered the whole of Subarea 48.3, although some (especially early in the series) did not cover the areas to the southeast of South Georgia. Ten incidents were identified in which the FPV encountered IUU activity, either by detecting a vessel or buoyed longlines. These incidents were in Area 1 (November 1999, September 2000), in Area 3 (January 2000, December 2000), in Area 5 (August 1999) and five in Area 6 (December 1999, January 2000, January 2000, January 2000, May 2000, May 2000). Four of them involved Argentine-flagged vessels (*Crystal Marino* in December 1999 and again in January 2000, *Kinsho Maru* in January 2000 and *Toshi Maru* in January 2000). Reports of inspections and other proceedings against these vessels have been made to the Standing Committee on Observation and Inspection (SCOI) by Argentina (CCAMLR, 2000).

Some additional information about incidents 2 and 5[3], deriving from the Argentine port inspections of the *Crystal Marino* and *Kinsho Maru* (CCAMLR, 2000), is available. The Argentine inspection reports suggest that the vessels may have been in Subarea 48.3 fishing illegally in the Convention Area for 10 and 8 days respectively (although these might be considered to be minimum estimates), but had on board 262 and 311 tonnes (processed weight) of toothfish. The tables from the model (Tables 2 and 3), however, suggest IUU fishing periods of 50 and 98 days (246 and 374 tonnes round weight respectively in this simulation). Why, then, are the inspection report data not simply substituted to calculate total IUU catch for these vessels?

Firstly, it is difficult to interpret these data; they are contradictory (10 days is not sufficient time to catch 262 tonnes), and it is not known how much of the 262 tonnes was caught in Convention Area waters. However, the more important reason is that the created simulation model does **not** attempt to estimate the IUU catch of any particular cruise. The model simply estimates the total number of IUU fishing days **represented** by the FPV encounters, taking into account vessels that are known about and those that are not. Thus it is consistent with the model approach that the actual IUU days fishing represented by these encounters is 50 and 98 days, and it is not necessary (though very interesting) to have additional port-inspection data to estimate IUU catch.

Encounter probability

Encounter probability for the simulation model was estimated using the FPV cruises that have coincided with periods when the licensed longline fishery for toothfish is open. During these times, it is known exactly which days the FPV was in Subarea 48.3, and it is also known which licensed fishing vessels were present on these. A ‘sightings rate’ can be generated from these data.

The situation with licensed vessels mimics, fairly well, the likely real situation with IUU vessels and the situation in the simulation model. It is assumed, in the simulation model, that the timing of the cruise of an IUU vessel will, on occasion, overlap with that of an FPV, and that at some randomly defined time during this overlap (when they are in the same area, for instance), the FPV will have a chance of spotting the IUU vessel. This is precisely the same situation as pertains when the cruise of a licensed vessel overlaps with an FPV cruise.

The sightings rate does not correspond directly to the encounter probability used in the simulation model. In the model, the presence of an IUU vessel is simulated and then an encounter probability is applied. Unfortunately, in the real data, the licensed vessels were rarely all in the area simultaneously, but what is required is the sightings rate when all licensed vessels were in the area at the same time as the FPV. However, as Figure 5 shows, there is a linear relationship between the sightings rate and the average time that fishing vessels spend in the area during the observation period of the FPV cruise, from which an appropriate sightings rate can be calculated when licensed fishing vessels are present for the full duration of the FPV cruise

[3] Also incident number 6, the second sighting of the *Crystal Marino* in January 2000, but the details in the inspection report are not as complete as for the first *Crystal Marino* sighting or the *Kinsho Maru*.

Table 2: Bird by-catch rate data from the fishery in 1997. 'Season' refers to summer (S) – fishing up to 1 April 1997, and winter (W) – fishing from 15 April 1997. Vessels with multiple entries undertook a number of fishing trips, each of which is counted as a different cruise. To simplify the bootstrap procedure, a weighting factor was calculated as the number of hooks divided by 10 000.

Season	Vessel name	Start date	End date	Cruise ID code	Hooks set (thousands)	Hooks observed (thousands)	Number of birds recorded killed	Catch rate (birds/thousand hooks)	Weighting factor
S	*Argos Helena*	26-Feb-97	20-Aug-97	9	303.49	91.91	142	1.545	9
S	*Cisne Verde*	20-Mar-97	30-May-97	6	99.84	10.244	4	0.39	1
S	*Elqui*	16-Mar-97	15-May-97	7	183.6	73.2	36	0.492	7
S	*Isla Camila*	20-Feb-97	12-Apr-97	17	322.72	58.055	43	0.741	6
S	*Isla Isabel*	01-Mar-97	09-Apr-97	11	186.56	21.648	252	11.641	2
W	*Argos Helena*	26-Feb-97	20-Aug-97	9	949.35	189.3	14	0.074	19
W	*Cisne Verde*	20-Mar-97	30-May-97	6	366.34	89.329	4	0.045	9
W	*Cisne Verde*	13-Jun-97	04-Sep-97	8	951.88	411.41		0	41
W	*Elqui*	16-Mar-97	15-May-97	7	324	152	15	0.099	15
W	*Elqui*	24-May-97	16-Jul-97	29	695.42	639.17		0	64
W	*Elqui*	24-Jul-97	08-Sep-97	10	456.94	326.08		0	33
W	*Ercilla*	09-Apr-97	02-Jun-97	14	512.35	316.91	24	0.076	32
W	*Ercilla*	08-Jun-97	10-Jul-97	15	343.98	157.94		0	16
W	*Ercilla*	01-Aug-97	08-Sep-97	16	243.74	152.42		0	15
W	*Ibsa Quinto*	10-Apr-97	31-Aug-97	25	1178.1	353.05	34	0.096	35
W	*In Sung 66*	20-Mar-97	09-Sep-97	28	1345.8	328.26		0	33
W	*Isla Camila*	15-Apr-97	12-Jun-97	18	489.29	93.45	9	0.096	9
W	*Isla Camila*	29-Jun-97	23-Aug-97	19	459.84	44.268		0	4
W	*Isla Isabel*	18-Apr-97	16-Jun-97	12	537.1	289.8	4	0.014	29
W	*Isla Isabel*	19-Jun-97	18-Aug-97	13	431.21	199.7		0	20
W	*Jacqueline*	28-Jun-97	06-Sep-97	20	380.93	19.84	10	0.504	2
W	*Jacqueline*	28-Jun-97	06-Sep-97	21	683.03	41.71	6	0.144	4
W	*Koryo Maru 11*	30-Mar-97	11-Aug-97	39	820.4	820.4	1	0.001	82
W	*Pescarosa Primero*	12-Apr-97	05-Jul-97	26	288.52	236.04	2	0.008	24
W	*Pescarosa Primero*	12-Jul-97	11-Sep-97	27	163.2	137.73		0	14

Table 3: Simulation results: the ratio of real IUU days fishing to assumed IUU days fishing, as calculated from sightings made by FPV cruises.

	Short IUU cruise (4–6 weeks, 28–42 days)		Long IUU cruise (8–12 weeks, 56–84 days)	
Area	1–5	6	1–5	6
1998/99	0.879	0.920	0.956	0.869
1999/00	0.874	0.712	0.836	0.677
2000/01	0.628	0.677	0.679	0.653

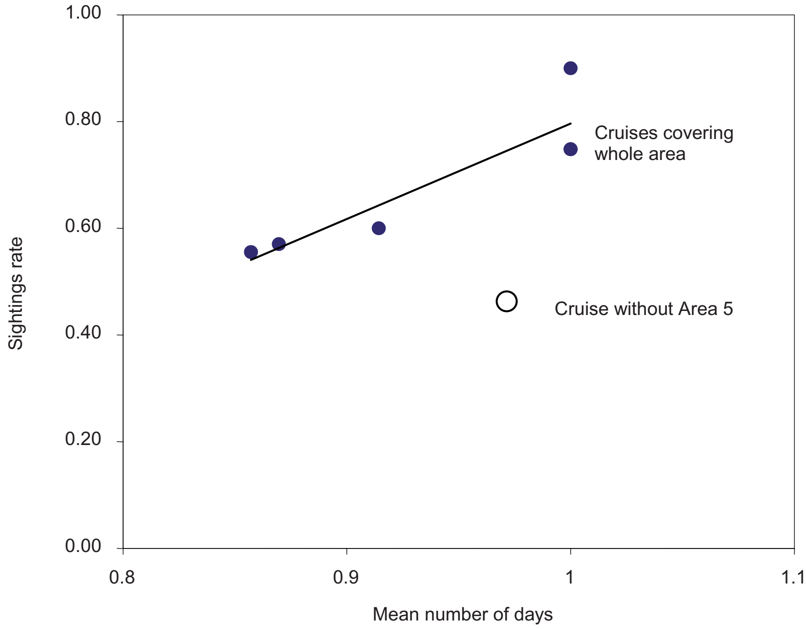

Figure 5: Sightings rate plotted against mean number of days on which fishing vessels were in the zone during the observation period, expressed as a proportion of the total observation days.

(i.e. when the x-axis in Figure 5 equals 1). At this point the sightings rate approximates the encounter probability.

If it is assumed that IUU vessels behave similarly to licensed vessels, then the sightings rate for licensed vessels can be used as the encounter probability in the simulation model. Note that more avoidance can be expected from IUU vessels than from licensed vessels, which would tend to lower the encounter rate. Unfortunately there is no way of estimating the size of this avoidance effect, and therefore the relationship is implemented as seen in Figure 5.

Figure 5 also shows that when the FPV does not cover Area 5 (i.e. the southeast of the area) its sightings rate drops considerably (note however that this observation is based on only one cruise). Assuming that a similar relationship between fishing vessel presence and sightings rate exists for all types of cruises, it is estimated that the encounter probability for FPV cruises which do not include Area 5 (and do not circuit South Georgia) is about 0.5, and for cruises that include all areas, 0.8.

Target (toothfish) and by-catch (bird and fish) catch rates

It is assumed that IUU vessels would catch fish at the same rate as legitimate vessels. Normal quantile plots suggest that a square-root transformation is appropriate for normalising catch/day, and a log transformation for hooks/day. Catch rates are different in different areas and years, because of the changing practice of the licensed fleet, as well as the different fishing conditions of the various areas (for instance, fewer hooks can be set in deeper areas because hauling time is greater). However, all the evidence available to date suggests that catch rates are the same in summer and winter, apart from the month around spawning time (July: Agnew et al., 1999). Accordingly, square-root and log-transformed catch (tonnes)/day and hooks (thousands)/day (with variances) were derived for each area and year separately. The stochastic model sampled from each of these distributions to obtain estimates of IUU catches of fish. The mean over all years and areas was 3.996 (tonnes/day) and 13 844 (hooks/day).

The by-catch rate of birds in IUU activities is assumed to be higher than for the legitimate fleet, since IUU vessels have little incentive to use mitigation methods. For obvious reasons, no data exist on the by-catch of birds on IUU vessels. However, CCAMLR has previously assumed that in 1997 the level of mitigation measures used by the licensed fleet was so low as to approximate IUU operations. Fortunately there were observers on board vessels in this fleet, so good records of the bird by-catch rates are available.

Agnew and Croxall (1999) have shown that there is a progressive reduction in the number of birds available to be caught by the fishery during the first two weeks of April, as they depart South Georgia for their winter feeding areas. Bird by-catch rates in summer and winter can therefore be expected to be quite different. Fortunately, in 1997 the fleet operated from the end of February to the start of August, so there are data on bird by-catch rates over this whole period, which have previously been published by SC-CAMLR (1997). Because the number of birds around South Georgia declines rapidly over the period from 1 to 15 April, it is assumed that the best estimates of summer bird by-catch rates would be from the 1997 fleet fishing before 1 April, and the best estimates of winter by-catch rate would be from fishing after 15 April.

Consistent differences in bird by-catch rate between the various areas could not be found, because vessels tend to fish predominantly in one area and thus the area and cruise factors in any model are inseparable. However, tracking of seabirds tagged at South Georgia indicates that bird densities are much lower in Area 6 than in Areas 1 to 5 (Berrow et al., 2000). It is therefore assumed that the bird by-catch rate for Area 6 was 50% of the bird by-catch rate for other areas.

Unlike the situation with fish catch data, the data on bird by-catch rates (SC-CAMLR, 1997) are too sparse to allow characterisation by a probability density function. The stochastic model therefore used the raw data to bootstrap bird by-catch rates. Agnew and Kirkwood (2002) described simple bootstrapping, but following comments from the Working Group on Fish Stock Assessment (WG-FSA) weighted bootstrapping was introduced, where the weights were the number of hooks observed. Bird by-catch rate data are shown in Table 2.

The justification for using a lower summer and winter rate for bird by-catches in Area 6 may seem somewhat tenuous, given that there are few reliable data from which to make this assumption. Therefore, a scenario in which the bird by-catch rate for Area 6 is assumed to be the same as for Areas 1 to 5 has also been included.

Not enough is yet known about catch rates of other species (rays, macrourids etc.) in IUU fishing. General comparisons could be drawn with the licensed fleet. However, even here, catch rates are difficult to ascertain. For example, it is known that in 2000/01 the licensed fishery took 14 tonnes of skates and rays and 5 tonnes of macrourids, as part of a catch of 4 047 tonnes of toothfish (SC-CAMLR, 2004). However, little is known about the variance of these rates, how by-catch is taken and handled, what its discard mortality is, etc. The choice was therefore made not to create estimates of takes of by-catch species by IUU vessels. The reader may apply the abovementioned proportions to the results of this study to see what possible effect IUU fishing might be having on by-catch fish species.

Model Results

The first simulation model: estimation of *p* in an IUU–FPV encounter model

The simulation as described above assumes a single 'encounter opportunity' for each FPV cruise. But the normal cruise track of an FPV always passes twice through Areas 6 and 1. Area 1 is sufficiently large to be able to contain two slightly different tracks, for instance north and south of Shag Rocks, and therefore can be seen in somewhat the same light as Areas 2 to 5 – i.e. that the FPV is taking one pass at it. The simulation assumptions therefore conform reasonably well to reality for Area 1. Area 6, on the other hand, contains only very restricted fishing grounds. The FPV passes through the area, which are usually separated by more than four days, are thus best considered as two separate (if not entirely independent) incidents. Other differences between Areas 1 to 5 and 6 have been pointed out previously, not least being the inclusion of Areas 1 to 5 in the South Georgia Management Zone and the concentration of cruise effort in these areas.

Each pass through Area 6 has therefore been treated as a separate FPV cruise. In consequence, there are twice as many FPV cruises to Area 6 as there are to Areas 1 to 5. In addition to running the simulation model for the three years 1998/99, 1999/2000, 2000/01 and for two lengths of IUU cruise, the model was run for Areas 1 to 5 and Area 6 separately.

Table 3 demonstrates that the FPV-derived estimates of IUU days fishing are always greater than the real IUU days fishing. This is consistent with the assumption that they represent 'maximum possible' days fishing in the areas. As expected, the ratio of real to assumed IUU days is smaller for the 2000/01 year, with its more comprehensive cover of FPV activity, than for the 1998/99 year. In most cases the ratio is higher for short IUU cruises than for long ones, although relatively little of the difference between ratios is attributed to the length of IUU cruises.

The second simulation model: model scenarios

Tables 4 and 5 show the construction of the model to estimate fish and bird by-catches. The methodology outlined above calls for assumed days fishing from each IUU incident. The method of calculating this must be the same as is used in the simulation model and equation 1 – i.e. the time that has elapsed since the FPV was last in the area in which an IUU vessel was found, plus the time that will elapse until the FPV is next in the area, with allowance for the end of each year.

It can be seen that the corrected estimates of number of days fished are high, especially for incident 1. The problem here derives from the poor FPV coverage in 1998/99. In August 1999 the FPV detected some buoys in Area 5 but had not visited this area previously. An early date of 24 February 1999 had to be assumed for this incident, although on the February cruise the FPV did not visit Area 5 and so this assumption is not entirely consistent with the simulation in this study. This gives an estimated mean catch of 670 tonnes, which is beyond the hold capacity of an average longliner. Data on legitimate vessels suggest an average capacity of 355 tonnes processed weight (SD 177, $n = 56$), which equates to 585 tonnes of wet weight (assuming a conversion factor of 1.65). Note, however that this does not matter; the model is estimating the total catch represented by the encounter by the FPV of one IUU vessel, not the catch by that vessel alone.

A number of different scenarios were run. Scenario 1, the baseline run, was considered to be the most plausible, and to generate the most accurate estimates of fish and bird IUU by-catch. Scenarios 2 and 3 were run as sensitivity tests.

<u>Scenario 1 (baseline scenario)</u>: The model inputs in Tables 2 and 3, assume a simulation model IUU fishing trip duration of four to six weeks (see Table 1) and that bird by-catch rates in Area 6 are 50% of those in other areas.

<u>Scenario 2</u>: This is the same as Scenario 1 except that the assumed IUU fishing trip duration is 8 to 12 weeks.

<u>Scenario 3</u>: This is the same as Scenario 1 except for the assumption that bird by-catch rates in Area 6 are not different from those in the other areas.

Second simulation model results

Estimates of fish and bird by-catch for each scenario are given in Table 6 and Figure 6. The model estimated mean catches of toothfish in 1999, 2000 and 2001 to be 776, 1 019 and 198 tonnes respectively. Since there were no sightings of IUU activity in the years 2002 to 2004, despite FPV activity exceeding that in the previous three years, the model estimates a zero catch in these years.

Different assumptions about IUU fishing trip length in the simulation model have a negligible effect on estimates of IUU toothfish catch and bird by-catch. Increasing the assumed IUU trip length has the effect of marginally increasing the apparent IUU catch in 1999 because FPV coverage was so low in that year that there was in effect no greater chance of detecting long trips than short trips, and of course longer IUU trips catch more fish. Conversely in 2000, because FPV coverage was high, the increase in detectability of long IUU trips outweighed any possible increase in catch for these trips. In Scenario 3, using the same bird by-catch rates for all areas within Subarea 48.3 had a very minor effect on estimates of bird by-catch, and then only for 2000 (the only year in which fishing was detected in Area 6). The reason that the estimated bird by-catches in 1999 are much lower than the estimated catches in 2000, despite only a small difference in estimated toothfish catch, is that only 20% of the fishing effort is estimated to have taken place in summer in 1999 (Table 4).

Table 4: Catch estimation model: incident information. Earliest and latest dates are taken from FPV cruise data, and the days fishing estimate is calculated from the difference between them. Calculation of the proportion of fishing days that occurred in summer uses the winter start date shown and the earliest and latest dates (thus the corrected days fishing are assumed to have the same distribution through the year as the incident days).

Incident information									
Incident number	Incident area	Incident date	Earliest date	Latest date	Days fishing estimate	Correction factor	Corrected days fishing	Winter start date	Prop. fishing in summer
1	5	03-Aug-99	24/02/99	10/10/99	228	0.879	200.4	15/04/99	0.22
					Total		200.4		
2	1	28-Nov-99	20/10/99	16/12/99	57	0.874	49.8	15/04/00	1.00
3	6	01-Dec-99	28/11/99	16/12/99	18	0.712	12.8	15/04/00	1.00
4	6	14-Jan-00	22/12/99	22/01/00	31	0.712	22.1	15/04/00	1.00
5	3	19-Jan-00	10/10/99	30/01/00	112	0.874	97.9	15/04/00	1.00
6	6	21-Jan-00	15/01/00	29/01/00	14	0.712	10.0	15/04/00	1.00
7	6	12-May-00	06/05/00	29/06/00	54	0.712	38.4	15/04/00	0.00
8	6	13-May-00	06/05/00	29/06/00	54	0.712	38.4	15/04/00	0.00
9	1	09-Sep-00	23/08/00	02/10/00	40	0.874	35.0	15/04/00	0.00
					Total		304.4		
10	3	14-Dec-00	02/11/00	12/01/01	71	0.628	44.6	15/04/01	1.00
					Total		44.6		

Table 5: Catch estimation model: parameter distributions. Each run of the model takes a fish catch rate from the distribution given in the table, number of hooks from a similar distribution in the table, and a bird by-catch rate from bootstrapped 1997 data.

Incident number	Fish catch rate		Number of hooks		Approx. catch (tonnes)
	mean $\sqrt{tonnes/day}$	SD	mean ln(thousand hooks/day)	SD	
1	1.83	0.69	2.62	0.45	669.8
					669.8
2	2.23	0.77	2.71	0.43	247.0
3	1.00	0.25	2.58	0.39	12.9
4	1.00	0.25	2.58	0.39	22.2
5	1.95	0.65	2.60	0.57	374.1
6	1.00	0.25	2.58	0.39	10.0
7	1.00	0.25	2.58	0.39	38.7
8	1.00	0.25	2.58	0.39	38.7
9	2.23	0.77	2.71	0.43	173.3
					916.9
10	1.99	0.65	2.61	0.50	177.3
					177.3

Table 6: Results of calculations of IUU fish and bird by-catch over a number of different scenarios. The model was constructed in Excel using Crystal Ball. 10 000 simulations were performed to acquire confidence intervals. 1999 = fishing year from October 1998 to September 1999. Scenario 1 was the base-case with short IUU fishing trips, Scenario 2 had long IUU fishing trips, and Scenario 3 had short IUU fishing trips but assumed higher rates of bird by-catch in Area 6 than in Scenario 1.

	1999 fish catch (tonnes)	2000 fish catch (tonnes)	2001 fish catch (tonnes)	1999 bird by-catch	2000 bird by-catch	2001 bird by-catch
Scenario 1						
Mean	776	1 019	198	1 288	4 860	1 255
Median	687	983	177	621	2 852	550
SD	518	339	122	2 280	6 077	2 425
Lower 95%	54	468	22	162	1 040	140
Upper 95%	2 017	1 779	487	7 752	23 361	9 023
Scenario 2						
Mean	835	969	211	1 422	4 792	1 323
Median	733	935	190	670	2 783	599
SD	564	319	129	2 592	6 053	2 519
Lower 95%	52	442	25	173	1 005	147
Upper 95%	2 196	1 693	513	10 074	22 699	9 212
Scenario 3						
Mean	769	1 017	195	1 238	5 478	1 236
Median	676	978	176	609	3 368	555
SD	524	335	119	2 193	6 356	2 340
Lower 95%	44	465	23	160	1 304	136
Upper 95%	2 039	1 768	477	8 567	23 423	9 193

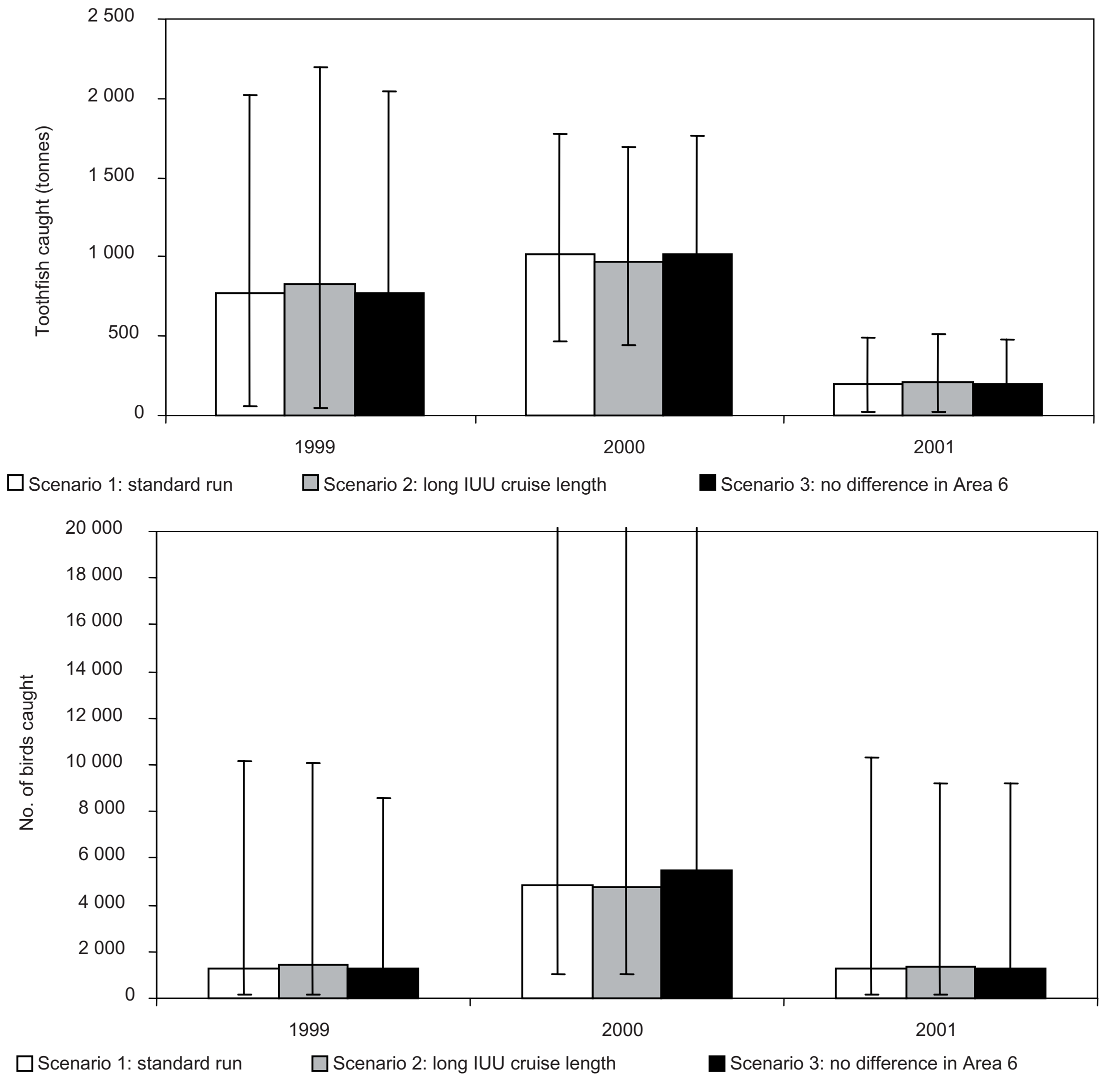

Figure 6: Comparison of toothfish catch and bird by-catch estimates (+95% confidence interval) by scenario. The model estimated zero IUU catch of toothfish or birds in 2002, 2003 and 2004, so these years have been omitted from the figure.

Table 7: Comparison of approaches taken in this paper and previously by CCAMLR.

	CCAMLR	This paper
Days fishing estimate	Sum of combined sightings and reports of total catch.	FPV sighting information and a simulation model of IUU fishing activity explicitly takes into account all IUU fishing that may have taken place.
Fish catch	Sum of reports of total catch with calculations of average catch rate of licensed vessels multiplied by days fishing, estimating ranges.	Stochastic model, separated by fishing area and year, generating mean/mode and confidence intervals.
Bird by-catch	Estimates of total days fishing, combined with mean and upper limits of estimates of bird catch rates for various combinations of summer:winter distribution.	Stochastic model, bootstrapping from 1997 bird by-catch data, generating mean/mode and confidence intervals.

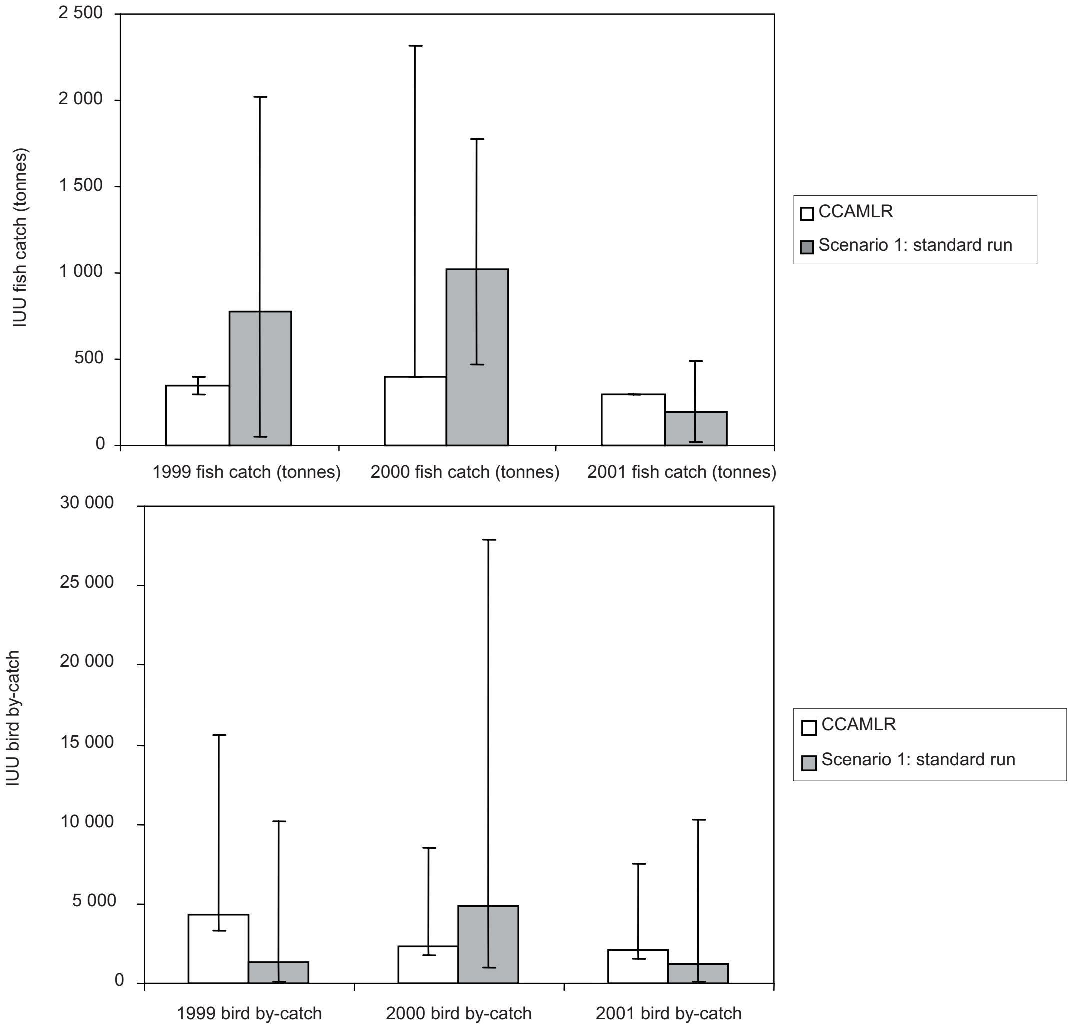

Figure 7: Comparison of the results of this study (Scenario 1) with CCAMLR estimates. In its assessments CCAMLR has sometimes estimated upper and lower bounds, which are presented in the figure but which are not strictly comparable with the estimates of 95% confidence intervals presented here. For birds, the CCAMLR upper limit is a maximum limit, whereas in this study it is the 95% limit. The CCAMLR lower limit is actually the lowest mean catch rate estimate, which does not equate to the 5% limit presented here. Note that CCAMLR years refer to fishing seasons, 1 December to 30 November, whereas the year is defined in this study to be 1 October to 30 September, but since there is no fishing in the period 1 October to 1 December, these are effectively the same definitions. In the absence of sightings, the model used here calculates a zero IUU catch, which has been added to the figure.

Discussion

Comparison with CCAMLR estimates

CCAMLR assessments already take estimates of IUU fishing into account, but those estimates were calculated using quite different methods from those described above (Table 7).

The new estimates of IUU catch presented here are similar to CCAMLR estimates, with the exception that for the first time they provide statistically rigorous confidence limits (Figure 7).

The new estimates of IUU catch in Subarea 48.3 were presented to CCAMLR in 2002 and have since been taken into account in assessments. The differences between these and previous estimates have a negligible effect on the assessment. It is worth noting that even in 1998/99 and 1999/2000, the IUU catch in Subarea 48.3 is only 9–13% of the total IUU catch in the Convention Area estimated by CCAMLR. Recent calculations by Traffic (Lack and Sant, 2001) have estimated the total IUU catch in the Convention Area to have been much higher in 1999/2000 than the CCAMLR estimates (up to 17 000 tonnes more). This difference is not thought to have come from the Atlantic Ocean sector. If these estimates are to be believed, the Subarea 48.3 proportion of these IUU catches for 1999/2000 would drop to 6%.

IUU vessel behaviour

In the absence of encounters between an FPV and an IUU vessel for a particular year, the model presented here calculates a zero IUU catch (e.g. for 2002, 2003 and 2004). However, it can be argued that although the model currently takes account of unseen IUU activity and uncertainty in the level of IUU activity in years in which some activity is detected, it is unable to do this in years in which there is no IUU activity. One way to deal with this in the current formulation would be to combine several years within the model. However, a better solution would be to reformulate the model. Instead of deriving a correction factor to account for uncertainty and unseen IUU activity, one could calculate the probability that a certain level of IUU activity would be seen. This would allow the estimation of an upper confidence limit for IUU activity in years in which no sightings are made: the lower confidence limit and the point estimate would of course still be zero. Note also that a single correction factor (Table 3) is currently calculated over 1 000 runs of the IUU–FPV encounter model in the second simulation model. An alternative would be to sample this correction factor from a distribution in the second model. This is complicated by the fact that the results from the IUU–FPV include many zero encounters (and approximate a delta distribution), but it was achieved in other applications of the model.

A second criticism of the model could be that it does not account for active evasion of FPV patrols by IUU vessels. The encounter probability is simply a random encounter effect, dependent upon the path of the FPV. It should, however, be noted that since 2000/01 almost all patrols have included Area 5, so the potential for encounters should have been high.

The difficulty with including active avoidance into the model is that it is very difficult to estimate (Charles et al., 1999). It could be argued that the discovery of gear alone confirms that IUU vessels have been actively evading the FPV, and with more data it might be possible to use the ratio of encounters of vessels to encounters with gear as an estimate of avoidance behaviour. On the other hand, it might be expected that evasion would involve the IUU vessel leaving the area entirely, leaving no traces, and thus the discovery of gear indicates that the vessel has not taken effective advance action. It is true, however, that any additional evasion would decrease the encounter rate and increase the estimate of IUU catch.

An interesting example of how IUU vessels were operating in 2000 is provided by the *San Rafael 1* (Belize) which was encountered in Area 6 on 1 December 1999. Four days earlier, when the FPV encountered the *Crystal Marino* in Area 1, a second vessel had been seen steaming rapidly away in the opposite direction from the *Crystal Marino*, and this was assumed to have been the *San Rafael 1*. The pattern of movement, leaving Area 1, which is under national jurisdiction, for the more remote international waters of Area 6, would be consistent with the two sightings, and would suggest that although some avoidance action had been taken, this was only by some 100 km. Thus the assumption has been made that during the period in question there was rather little attempt to avoid the FPV, possibly because it was not perceived to be particularly active in the area or a particular threat to IUU fishing operations.

Has there been more avoidance behaviour since 2001? The simplest form of avoidance would be similar to that shown by the *San Rafael 1*, i.e. to avoid fishing in Areas 1 to 5 during the period that the FPV is active around South Georgia, retreating to the international waters of Area 6. The FPV has not encountered any unlicensed fishing in Area 6 since 2001, despite FPV activity increasing year on year (Agnew, 2004 and Table 1). This suggests that either avoidance is very large scale (movement of several 100s of km, out of Subarea 48.3), or that there has been no or negligible IUU activity in Subarea 48.3 since 2001.

Summary

1. The features of this analysis are that:

    - it utilises high quality, well-documented and recorded FPV cruise data;

    - these FPV data cover all possible fishing areas within Subarea 48.3, the presumed distribution of the toothfish stock in Subarea 48.3;

    - it takes explicit account of both ‘seen’ and ‘unseen’ IUU fishing through a simulation model to arrive at a statistically rigorous best estimate of the number of days fishing by IUU vessels over the period 1999 to 2001;

    - it utilises the CCAMLR dataset on licensed vessels to arrive at year- and area-specific statistical estimates of fish catch rates;

- it utilises the 1997 CCAMLR data, when most vessels were not applying effective mitigation measures, to estimate bird by-catch rates;

- the final model is expressed stochastically so as to generate estimates of fish and bird by-catch with statistically rigorous confidence intervals.

2. These new calculations result in an increase in IUU catches over those already assumed by CCAMLR, but this has a negligible effect on estimates of current population status or catch limit. The present calculations result in a decreased estimate of IUU bird by-catch in comparison to those used by CCAMLR in all years, but to a lesser degree in 2000 than in 1999 and 2001.

3. There have been no sightings of IUU vessels in Subarea 48.3 since December 2000, despite increasing FPV activity. This is interpreted, in terms of the present model, as indicating that the decline in IUU catch seen in 2000/01 has continued and that IUU catch levels in Subarea 48.3 are now negligible or zero.

Acknowledgements

The authors are extremely grateful to the UK Government in respect of South Georgia and the South Sandwich Islands for permission to examine FPV records in detail, and for permission to report surveillance data in this paper. They also gratefully acknowledge initial plots and data extractions performed by John Pearce, and helpful suggestions on the text from Graeme Parkes, John Beddington and two referees.

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Figure 7: Comparaison entre les résultats de la présente étude (scénario 1) et les estimations de la CCAMLR. Dans ses évaluations, la CCAMLR a quelquefois estimé des limites supérieures et inférieures qui, bien que présentées dans la figure, ne sont pas strictement comparables aux estimations des intervalles de confiance à 95% présentés ici. Pour les oiseaux, la limite supérieure de la CCAMLR est une limite maximale, alors que dans cette étude, elle correspond à la limite à 95%. La limite inférieure de la CCAMLR est en fait

l'estimation la plus faible du taux de capture moyen qui ne correspond pas à la limite à 5% qui est présentée ici. Il convient de noter que les années CCAMLR correspondent aux saisons de pêche du 1[er] décembre au 30 novembre, alors que l'année est définie dans cette étude comme étant la période du 1[er] octobre au 30 septembre mais, comme la période comprise entre le 1[er] octobre et le 1[er] décembre est fermée à la pêche, il s'agit en fait des mêmes périodes. En l'absence d'observations, le modèle utilisé ici calcule une capture IUU nulle qui est ajoutée sur la figure.

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