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Directorate of Natural Resources
Fisheries Department
Stanley, Falkland Islands

Rock cod (*Patagonotothen ramasyi* (Regan, 1913)) stock asessement in the Falkland Islands

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Falkland Islands Fisheries

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Printed in Stanley, Falkland Islands, 2010.

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Signed:

Date: 25/03/2010

Distribution: Open

Circulation: Open

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1.0 Introduction

The genus *Patagonotothen* includes 14 species that inhabit the shelf waters off southern South America with the Patagonian rockcod, *P. ramsay*i, being the most abundant (Ekau 1982). This is a medium-sized fish with a maximum total length 47 cm L_T. It occurs on the Patagonian Shelf from 35°S in the north to the Burdwood Bank in the south (55°S). This species is encountered in the Straits of Magellan to the west and to the shelf edge of the Falkland Islands to the east (Thompson 1916; Ekau 1982; Nakamura et al. 1986). *Patagonotothen ramsayi* plays an important role as both predator and prey on Southwest Atlantic shelves, consuming a variety of benthic and bentho-pelagic crustaceans and being consumed by most large fish including hakes, toothfish, kingclip, redcod, rajids and others (Brickle et al. 2003; Arkhipkin 2003; Arkhipkin et al. 2003; Nyagaard et al. 2004; Laptikhovsky, 2004).

Despite its importance, the biology of *P. ramsayi* had not been thoroughly researched. Ekau (1982) found that the species exhibits a distinct sexual dichromatism. The anal fins, ventral fins and throat of the males are a deep black colour, whereas the females remain brown to green. He also revealed that spawning occurred in austral autumn on the Argentinean Shelf at 42°S and in austral spring on the Burdwood Bank. Sosinski and Janusz (2003) confirmed this difference in spawning time. Brickle et al. (2006a) examined the age and growth of *P. ramsayi* and found it to be a relatively slow growing fish, with a maximum observed age of 14 years. Its reaches 5–6 cm L_T in its first year, after which grows approximately 3 cm per year until 4 years. Brickle et al (2006b) reported that male and female *P. ramsayi* were mature at 27.6 and 24.8 cm L_T, respectively. *Patagonotothen ramsayi* is a total spawner, with a total fecundity ranging between 24,300 and 76,700 eggs. Spawning occurs on the shelf breaks between June and August with the peak in gonado-somatic indices in June. Analysis of length frequency distributions over the year and sex ratios of mature fish during the spawning season indicate the presence of nesting and nest guarding behaviour in male fish, similar to other rockcods.

The chemical composition of *P. ramsayi* flesh revealed its value as food with protein and fat contents ranging between 16–19% and 0.78–1.34%, respectively. It has a high amount of unsaturated fatty acids, especially docosahexaenoic acid (30–42%) and eicosapentaenoic acid (12–18%). It is also a potential source of minerals, with important amounts of magnesium, potassium and phosphorous. Its flesh is white, with a shellfish odour, and has a firm and elastic texture. Due to these properties González et al (2007) concluded that *P. ramsayi* is a nutritious species of high value for human consumption.

Prior to 2007 this species was not targeted due to a lack of marketability. Catches of Spanish and Falkland trawlers in the first half of 2007 were not high, probably because the species was not targeted to its full extent due to the lack of experience amongst the fishing captains. Later in the year mean daily catches sometimes exceeded 30 tonnes, with some vessels attaining as much as 60-70 tonnes per day (Figure 1), resulting in an annual catch of 30,635 tonnes. A total of 19,098 tonnes (62.3%) of medium – sized and large fish were processed as HGT and frozen and exported to Eastern Europe. Most of the rock cod was taken in the northwestern part of FICZ along the border with Argentinean waters (Figure 2). This region, since then, has become the most important fishing grounds for rock cod. Fish have been targeted between 100 and 300 m, and the best catches obtained between 150 and 200 m.

In the year 2008 the rock cod was first targeted in earnest all year round. The annual catch doubled and achieved 60,165 t. A total of 46,542 t of medium-sized and large fish (77.4% vs. 62.3% in 2007) were processed as HGT. Rock cod were targeted by trawlers with finfish licenses (50,755 t) and taken as bycatch in other fisheries. The fishing grounds were generally the same as in 2007, all across the shelf at the FICZ border with Argentina. Mean daily catches on finfish boats were 20-25 t in January – April, they gradually decreased during winter to 2-7 t in late July – early September, and then steadily increased again to 20

-30 t by the end of December. It suggested that most dense fish aggregations occur in warm season. Mean annual daily catch was 15.1 t in contrast to 8.2 t in 2007. During the *Loligo* seasons, rock cod bycatch on the southeastern shelf was also important (6,996 t).

In 2009 the annual catch of rock cod reached 58,149 t which was similar to that in the previous year. A total of 44,701 t of medium-sized and large fish (76.9%) were processed. Rock cod was targeted mainly by trawlers with finfish licenses (52,594 t) and was also taken as bycatch in other fisheries, particularly during the *Loligo* trawl fishery (4,418 t). Most rock cod was again caught on the northwestern shelf between 150 and 220 m. Mean daily CPUEs of finfish trawlers peaked up to 20-25 t in January, gradually decreased to 5-10 t in late July – early September, and then increased again to 15-20 t by the end of December. Mean annual daily catch was 13.6 t. Fish size in catches was generally smaller than in the years 2007 and 2008. This was probably a consequence of changes in stock structure because of exploitation.

In 2010 the fishery continued in the same region, but rock cod abundance was generally higher than in 2007-2009 and total catch had already achieved 41,000 t by the end of May.

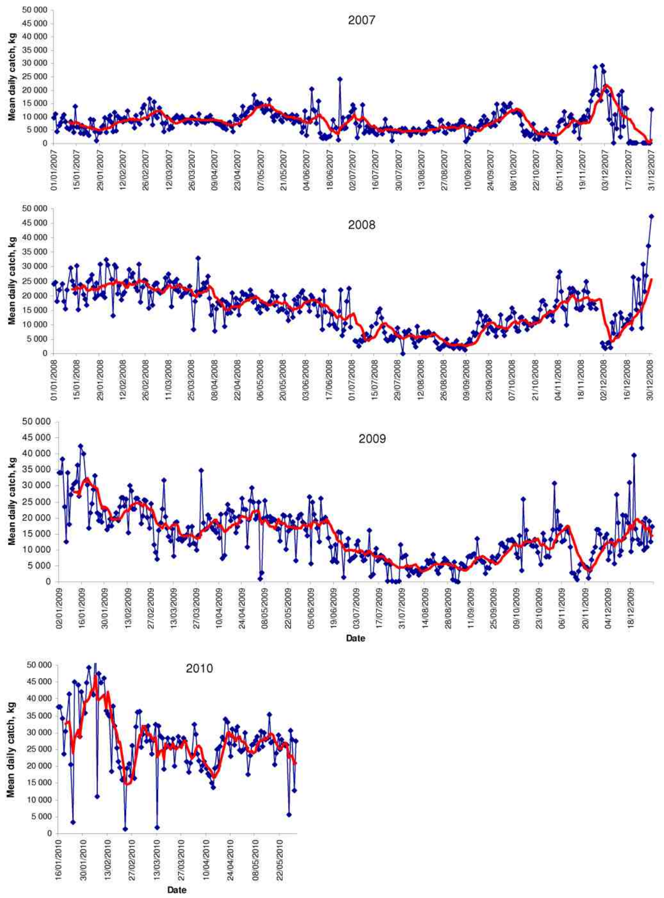

Figure 1: Daily catches of *Patagonotothen ramsayi* by year (red lines = 7 day running means)

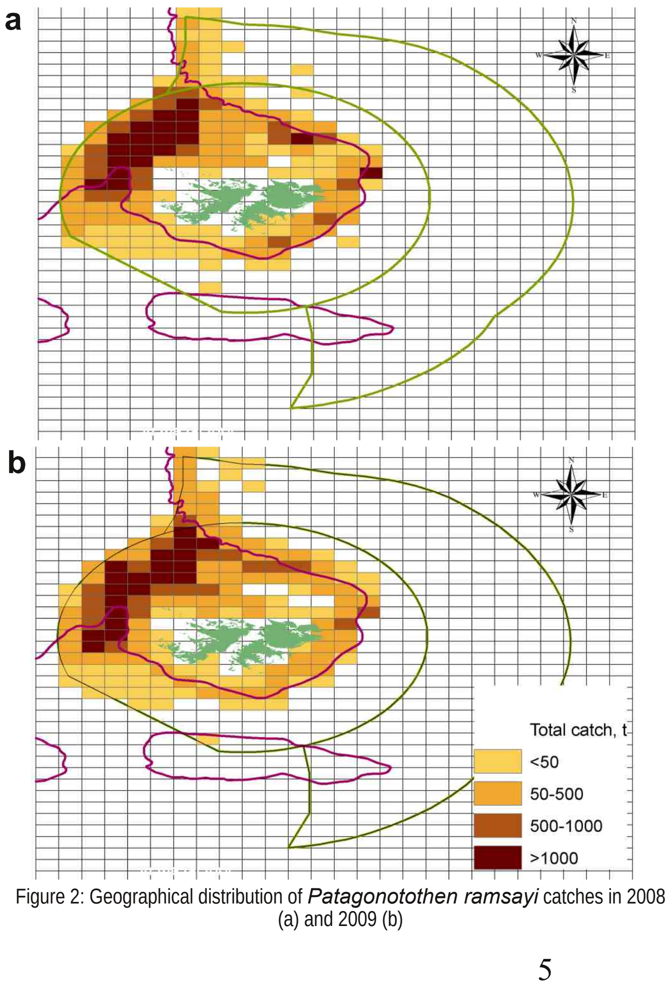

Figure 2: Geographical distribution of *Patagonotothen ramsayi* catches in 2008 (a) and 2009 (b)

2.0 Methods

In early 2010 trawl surveys were undertaken by the FIFD to assess the biomass of the *P. ramsayi* population on the Falkland Islands shelf. The surveys were conducted by two vessels concurrently: the RV Castelo and the FV Beagle.

2.1 RV Castelo survey procedures

Bottom trawling was conducted at 90 stations between 30th January and 22nd February 2010. However, three trawls (Stations 465, 478, and 501) were not used in the biomass estimates as they were damaged and were aborted early. The bottom time was 60 minutes with the exception of the aborted trawls.

During the cruise a total of 206,633 kg was caught comprising over 129 species (Table). In terms of catch weight, the most abundant species were rock cod (*Patagonotothen ramsayi*), hoki (*Macruronus magellanicus*), red cod (*Salilota australis*), grenadier (*Coelorhynchus fasciatus*) and southern blue whiting (*Micromesistius australis*).

For each species being assessed density was calculated as kg/km^2 for each trawl station by using the ship's speed and duration and either trawl horizontal opening or trawl door spread. Trawl horizontal opening was considered more appropriate for *P. ramsayi* and *L. gahi*.

Catches were assigned to the mean position between the trawl start and end positions and a calculated density values was assigned to them. These data were then gridded in Surfer V 8.02 using the Kriging Algorithm with a 23 km search ellipse (23 km X 23 km). A blanking file was created in order to select the survey area and a contour map of iso-densities was created. The total fishable biomass was calculated using the 'Grid Volume Computations' facility within Surfer resulting in three estimates and determined by the Trapezoidal Rule, Simpson's Rule and Simpson's 3/8 Rule.

Figure 3 shows the trawl stations on the Castelo Survey. For more details please see Falkland Islands Government (2010).

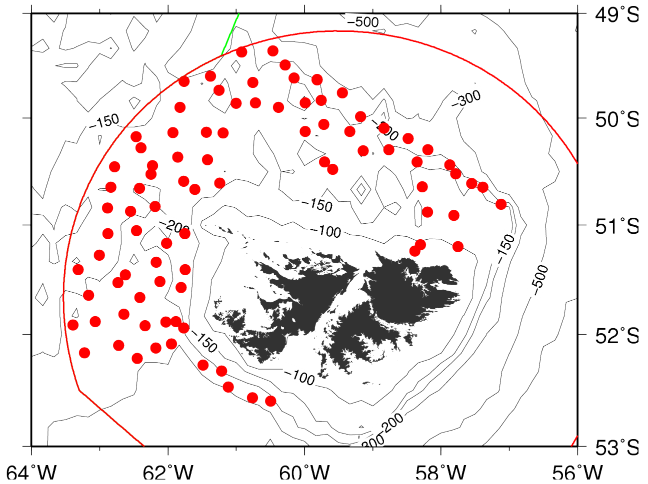

Figure 3: Chart illustrating the positions of the trawl stations on the Castelo Survey

2.2 FV Beagle survey procedures

The shelf area southeast of the Falkland Islands was surveyed by the stern trawler Beagle from 9th to February 23rd February 2010. The Beagle was rigged for commercial fishing with a bottom trawl of 44 m headrope length. Fifty-five trawls were taken along the shelf break at depths ranging from 86 to 308 m. Biomass density estimates of rock cod were calculated by the swept-area method as catch weight divided by the product of trawl speed, trawl duration, and trawl net width calculated from the spread between trawl doors. The acoustic sensors for trawl door spread failed on the sixth day of survey activity, after 21 trawls completed. A model was calculated to estimate trawl width as a function of trawl depth (m), net height (m), and trawling speed (knots). These parameters were logged at 15 min intervals during the course of trawls, resulting in 175 data points available. The function was calculated using a generalized additive model (GAM); a non-parametric extension of regression that does not require the assumption of a linear relationship (Swartzman et al. 1992). This GAM explained 78% of deviance of the trawl widths, and the ranges of trawl depth, net height, and trawling speed of the 175 data encompassed 98% of the ranges of these parameters in all subsequent trawls. Trawl width of all subsequent trawls was therefore calculated from this model. A random sample of approximately 100 rock cod was taken from each trawl, measured for total length to the nearest centimetre, and assessed for sex and maturity.

Figure 4 illustrates the trawl stations conducted on the FV Beagle during the pre-recruit survey.

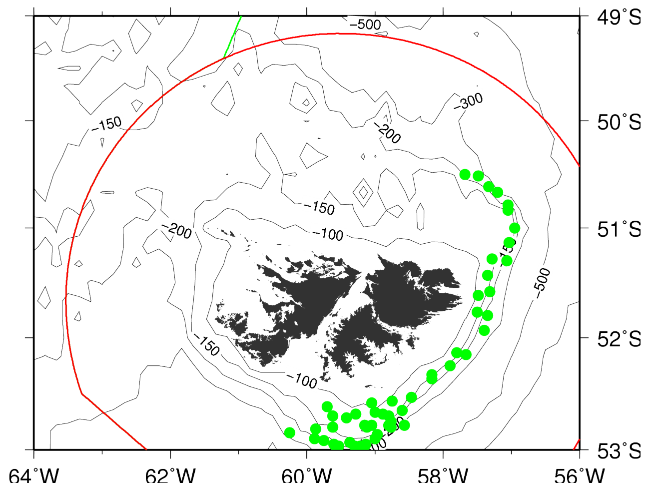

Figure 4: Chart illustrating the positions of the trawl stations on the Beagle Survey

2.3 Geostatistical model

Biomass densities from the Castelo survey and Beagle survey were combined in an empirical variogram and fit to a kriging model. This kriging model was extrapolated to the fishing grounds area to estimate total stock biomass of rock cod. Error distribution of this stock estimate was calculated from the variance of the kriging model, plus the variability of a randomized permutation of trawl locations. Trawls extend over several hundred to several thousand meters distance; catches may be patchy along this distance, and a simplifying assumption that all catch occurred at the midpoint of the trawl can miss potential uncertainty in the spatial distribution of the catch. The kriging model was therefore iterated 1000×, and at each iteration each trawl was randomly assigned either its start, mid, or end position in the calculation. The variance among iterations was added to the variance of the original kriging model.

2.4 Yield model

The stock biomass estimate was then used as the basis for calculating confidence ranges of sustainable yield. Calculations of sustainable yield are typically derived from biomass dynamic models (Hilborn and Walters 1992). However, the short time series of targeted fishing on rock cod around the Falkland Islands did not allow for a biomass dynamic model to be applied. Instead, estimation of sustainable yield was derived from Beddington and Kirkwood's (2005) formulation of the relationship between yield and life-history parameters:

$$Y / ExB_0 = a(L_c)\, K \qquad (1)$$

where the ratio of yield (Y) over unexploited fishable biomass (ExB0) is a function of the von Bertalanffy growth parameter (K) multiplied by a constant parameter a(Lc) of length at first capture as a proportion of asymptotic maximum length.

A probability distribution of yield (Y) estimates was computed by setting prior ranges for the parameters ExB0, K, and a(Lc), iterating the yield equation 100,000×, and at each iteration randomly selecting a value of each input parameter from its range. Prior ranges for the parameters ExB_0, K, and $a(L_c)$ were obtained from the surveys, other data of the Falkland Islands rock cod population, and as necessary, information of comparable fish stocks in other marine systems:

• The range for ExB_0 was based on the survey-estimated stock biomass from the kriging model, plus the maximum biomass commercially caught in any of the five preceding years (60,575 tonnes). This biomass (B) was modelled as a normal distribution with the standard deviation of the kriging model plus the standard deviation of commercial catches of the preceding five years. Catch (both survey and commercial) is itself a function of catchability (q); the efficiency of the gear in a given fishing environment (Hilborn and Walters 1992, Arreguin-Sanchez 1996). Catchability of rock cod has not been specifically evaluated, and therefore q was iterated as a random variable in the uniform range of [0.3 to 1.0]. The lower limit 0.3 (meaning that a trawl will catch 30% of all rock cod in its direct path) was obtained from Harley et al. (2001) based on data from Sparholt (1990), for species that share morphometric and ecological characteristics with rock cod. The upper limit 1.0 was set relatively high (e.g., Harley and Myers 2001) because rock cod biomass density is presently high and catchability is known to increase with density (Godo et al. 1999). ExB0 was then defined, at each iteration, as the stock biomass divied by the catchability (B_i/q_i)

• K was defined at each iteration as a normally distributed random variable with a mean of 0.25, (Brickle et al. 2006a), and a 95% confidence interval of [0.23 to 0.27].

• The parameter $a(L_c)$ includes three components: length at first capture (L_c), asymptotic maximum length (L_{max}), and an empirical multiplier (Figure 3 in Beddington and Kirkwood 2005) of the spawner-recruit steepness (h). Lc was approximated by taking the difference in relative catch-size distribution of rock cod between the Castelo and Beagle surveys (that trawled smaller mesh) and commercial fisheries under A or W licence since 2007 (that trawled larger mesh). The relative difference peaked sharply at 16.5-17.5 cm total length, suggesting that this is the size below which commercial trawls no longer capture rock cod efficiently. Given the potential variability of this factor L_c was defined at each iteration as a random normal variable with mean of 17.5 cm and 95% confidence interval of [12.5 to 22.5 cm]. L_{max} was defined as a random uniform variable in the range of [43 to 47 cm], based on FIFD observer data. Spawner-recruit steepness (Haddon 2001) of rock cod is not known. It was therefore defined as a random variable in the range of [0.25 to 1], where 0.25 = a near-linear relationship (twice as many spawners will give twice as many recruits) and 1 = constant recruitment (recruitment independent of the spawning stock size). Since rock cod biomass is high and targeted commercial fishing is only recent, it was hypothesized that steepness for this population is likely to be high and the random variable was therefore defined geometrically, i.e., $\log_{10}(\exp([0.25 \text{ to } 1]))$.

3.0 Results

3.1 Geostatistical model

The best-fitting variogram for the Castelo + Beagle survey densities was modelled using a spherical covariance function with Box-Cox transformation parameter $\lambda = 0.5$ (Figure 5). The furthest three data points of the empirical variogram (beyond 400 km) were excluded from the model, because the semi-variance showed a net decrease at these distances. That decrease may be an artefact due to densities very distant from each other being increasingly similar, as they are at the margins of the survey area and therefore all low. The effective range of the model variogram (distance until an asymptote is reached) was 325 km.

The entire survey area comprised three areas: the area covered by the Beagle, the area covered by the Castelo, and a zone subjacent to the northern part of the Castelo sub-area that was not surveyed due to logistic constraints (Figure 6). Surface areas and rock cod biomass estimates ± 1 standard error of the three sub-areas are shown in Table 1.

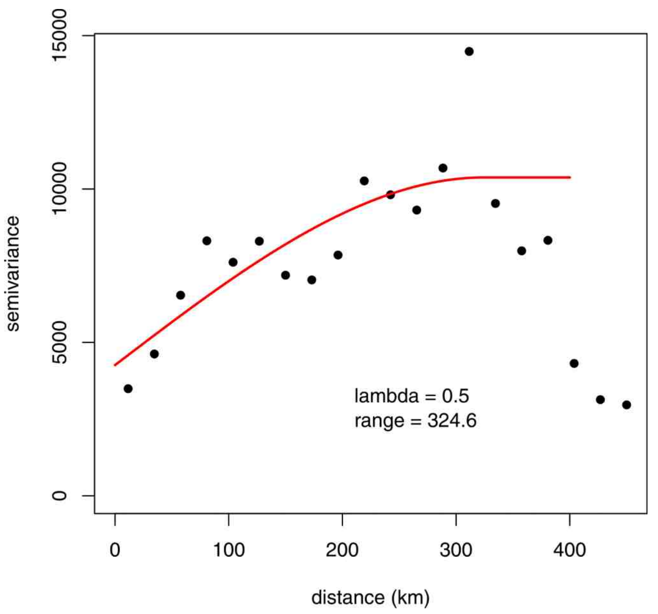

Figure 5: Empirical variogram (black circles) of rock cod catch densities from the Castelo and Beagle surveys, with spherical covariance model variogram (red line). The last three points (beyond 400 km) were excluded from the model

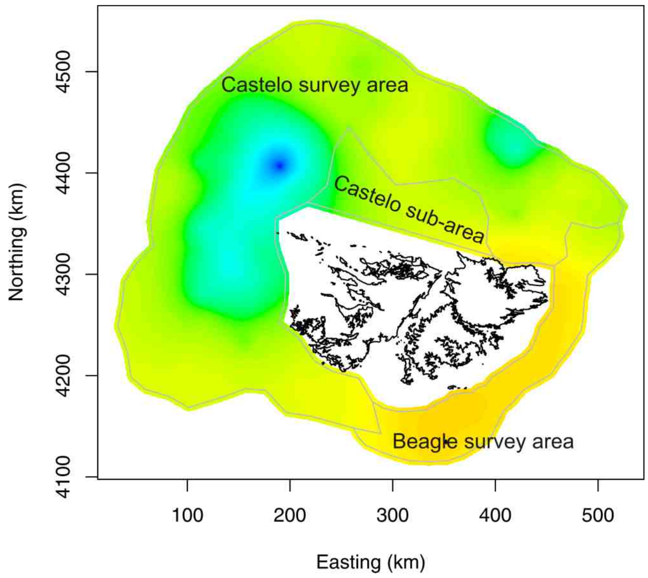

Figure 6: Density of Patagonotothen ramsayi (kg/km^2) as calculated by the kriging model (high density = blue, low density = yellow)

Table 1: Surface areas and rock cod biomass estimates ± 1 standard error of sub-areas

	Area (km^2)	Biomass (tonnes)
Beagle	13,347.86	25,205.7 ± 02,776.2
Castelo	83,058.18	480,725.1 ± 35,845.5
Castelo - sub	9,347.69	43,358.6 ± 3,823.4
Total	**105,753.73**	**549,289.4 ± 36,155.6**

3.2 Yield model

Distribution ranges of the input parameters to the yield model are shown in Figure 7 (a-f). In particular, the unexploited fishable biomass (ExB_0) was estimated at a median value of 937,942 tonnes with a 95% confidence interval of [594,797 to 1,941,325 tonnes].

The probability distribution of sustainable yield (Y), based on the input parameter ranges and equation (1), is shown in Figure 8. Median sustainable yield (Y) was estimated at a value of 72,547 tonnes with a 95% confidence interval of [17,181 to 184,848 tonnes]. Risks of overfishing (effecting a level of fishing mortality that jeopardizes the capacity of the fishery to produce the maximum sustainable yield on a continuing basis, SFA 1996) are calculated as the proportions of the yield probability distribution that are below a given level of catch. Hypothetical annual rock cod catches and corresponding estimated risk levels are shown in Table 2.

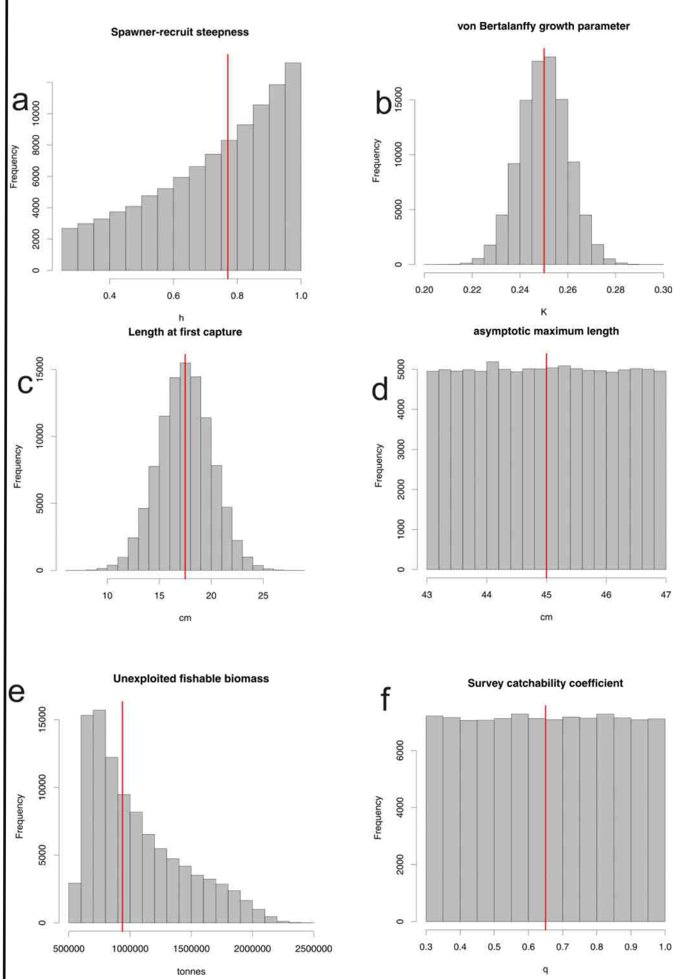

Figure 7: Distributions of input parameters for yield calculations. Red lines are the median of each distribution

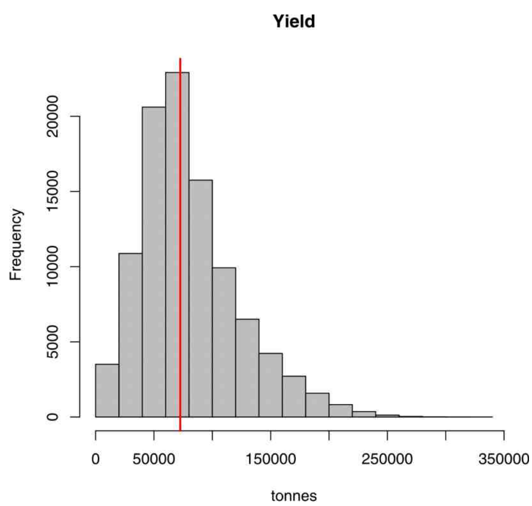

Figure 8: Distribution of yield estimates from randomized combinations of the input parameters. Red line is the median of the distribution

Table 2: Annual rock cod catches and corresponding risk

Annual Catch (tonnes)	Risk of Overfishing (%)
72,547	50
100,000	74
75,000	53
60,000	35
50,000	24

4.0 Conclusions

The current status of the rock cod population around the Falkland Islands is characterized by a high degree of uncertainty. Targeted catches of rock cod have increased significantly since they were first reported in 2007, but over this timeline of ~3 years the fishery is still in its initial 'fishing-down' phase (Hilborn et al. 2006), and the long-term response of the population to fishing pressure can not yet be reliably evaluated. In effect, 3 years is shorter than it takes one generation of rock cod to reach sexual maturity (Brickle et al. 2006b). Based on the presently available survey and commercial fishery data, we have reached the following conclusions and recommendations:

- The median estimate of maximum sustainable yield is calculated to be 72,547 tonnes based on the present maximum probability distribution of 50% chance of overfishing/under fishing. Due to the uncertainty in a number of parameters such as reported catch and catchabilty (see below) we recommend that the total fishing effort in 2011 remain the same as that for 2010.

- The concern is that by the end of May 2010 40,000 tonnes had already been caught in the fishery. Therefore it is likely that the annual catch may over shoot the MSY.

- It is clear with this level of biomass and the previous studies on the trophic interactions of marine predators that rock cod are critically important to the Patagonian Shelf Ecosystem. Estimates for the Falkland Islands, only, suggest that the wider Patagonian Shelf could contain well in excess of 1 million tonnes of rock cod.

5.0 Recommendations

- There is uncertainly in the daily reported catches with some vessels not adding their discard figures of rock cod to their factored production figures. The extent of this needs to be investigated and we propose that an observer protocol be established that involves sampling discards for length frequency analyses in order to calculate the total catch in a given trawl.

- The catchabilty coefficients of rock cod in the fishery are unknown and are thus, potentially, a large source of error. This is an important facet of this type of analyses and we propose a research project employing camera equipment on trawls in order to examine the behaviour of rock cod in relation to trawls.

- This survey should be repeated every year until we are in a position to model the biomass by other means.

- An otolith programme should be initiated with the laboratory work being conducted within FIFD. The readings from the Sea Fisheries Institute in Poland differ from ours quite considerably. Both first annulus and subsequent annuli have been validated by FIFD scientists. We suspect the source of error comes from the Sea Fisheries Institute reading the otoliths whole immersed in water. The use of otoliths will be central to any future age based assessment methods and thus it is important to ensure accuracy and precision.

- Currently the fleet discards a large, variable but unknown quantity of undersized (commercial size) rock cod. We propose that an investigation into mesh sizes used in the fishery be initiated. This may reduce the discard of small rock cod (and the annual catch) and will also have some implications to discard management with respect to seabird mortality.

6.0 Acknowledgements

We are grateful to the following personnel who participated in the RV Castelo and FV Beagle cruises: Andy Black, Pia Schuchert, Lars Jürgens, Helen Ake and Tiffany May.

Our thanks go to the officers and crew of the survey vessels whose participation was crucial to this study.

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