FALKLAND
ISLANDS
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DEPARTMENT

Falkland calamari Stock Assessment Survey, 2^{nd} Season 2016

Vessel	Castelo (ZDLT1), Falkland Islands
Dates	14/07/2016 - 28/07/2016
Survey Report	Andreas Winter Jessica Jones Zhanna Shcherbich Verónica Iriarte

Index

Summary

1) A stock assessment survey for Falkland calamari was conducted in the 'Loligo Box' from 14th to 28th July 2016. Fifty-eight scientific trawls were taken during the survey, catching 225.31 tonnes of calamari.
2) A geostatistical estimate of 43,580 tonnes calamari (95% confidence interval: 36,471 to 55,291 t) was calculated for the fishing zone. This represents the highest 2nd-season survey biomass estimate since 2011. Of the total, 15,844 t were estimated north of 52 ºS, and 27,736 t were estimated south of 52 ºS.
3) Male and female calamari had significantly higher average maturities and greater average mantle lengths south of 52 ºS than north of 52 ºS. Males north: mean mantle length 11.72 cm; mean maturity stage 3.36, males south: mean mantle length 12.14 cm; mean maturity 3.59. Females north: mean mantle length 10.88 cm; mean maturity 2.32, females south: mean mantle length 11.98 cm; mean maturity 2.51.
4) Ninety-five taxa were identified in the catches. Falkland calamari was the largest species group at 81.4% of total catch by weight, the highest calamari proportion in a 2nd season survey since at least 2011. Biological measurements and samples were taken from calamari, rock cod, Patagonian hake, red cod, kingclip, toothfish, and opportunistic specimens of various other species.
5) Trawl widths (horizontal net openings) derived from the door spread triangulation algorithm were compared with trawl widths measured by sensors attached behind the extremities of the net wings. The average trawl width from sensor measured 81.5% of the trawl width from the door spread triangulation algorithm.

Introduction

A stock assessment survey for Falkland calamari (*Doryteuthis gahi* – Patagonian longfin squid – colloquially *Loligo*) was carried out by FIFD personnel onboard the fishing vessel *Castelo* from the 14th to 28th July 2016. This survey continues the series of surveys that have, since February 2006, been conducted immediately prior to season openings to estimate the Falkland calamari stock available to commercial fishing at the start of the season, and to initiate the in-season management model based on depletion of the stock.

Objectives of the survey were to:

1) Estimate the biomass and spatial distribution of Falkland calamari on the fishing grounds at the onset of the 2nd fishing season, 2016.
2) Estimate the biomass and distribution of rock cod (*Patagonotothen ramsayi*) in the 'Loligo Box', for continued monitoring of this stock.
3) Collect biological information on Falkland calamari, rock cod, toothfish (*Dissostichus eleginoides*) and opportunistically other commercially important fish and squid taken in the trawls.
4) Collect additional data for evaluating horizontal net opening estimation differences between the new MarPort sensors and triangulation from the trawl door spreads.

The survey was designed to cover the ‘Loligo Box’ fishing zone (Arkhipkin et al., 2008; 2013) that extends across the southern and eastern part of the Falkland Islands Interim Conservation Zone (Figure 1). The current delineation of the Loligo Box represents an area of approximately 31,118 km^2.

The F/V *Castelo* is a Falkland Islands - registered stern trawler of 67.78 m length, 1321 gross register tonnage, and 2450 main engine bhp. Like all vessels employed for these pre-season surveys, *Castelo* operates regularly in the Falkland calamari fishery and used its commercial trawl gear for the survey catches. *Castelo* is also the FIFD charter vessel for research cruises; most recently reported in Gras et al. (2016). The following personnel from the FIFD participated in the 2nd pre-season 2016 survey:

Jessica Jones	FIFD doctoral student / lead scientist
Zhanna Shcherbich	fisheries biologist
Verónica Iriarte	fisheries observer

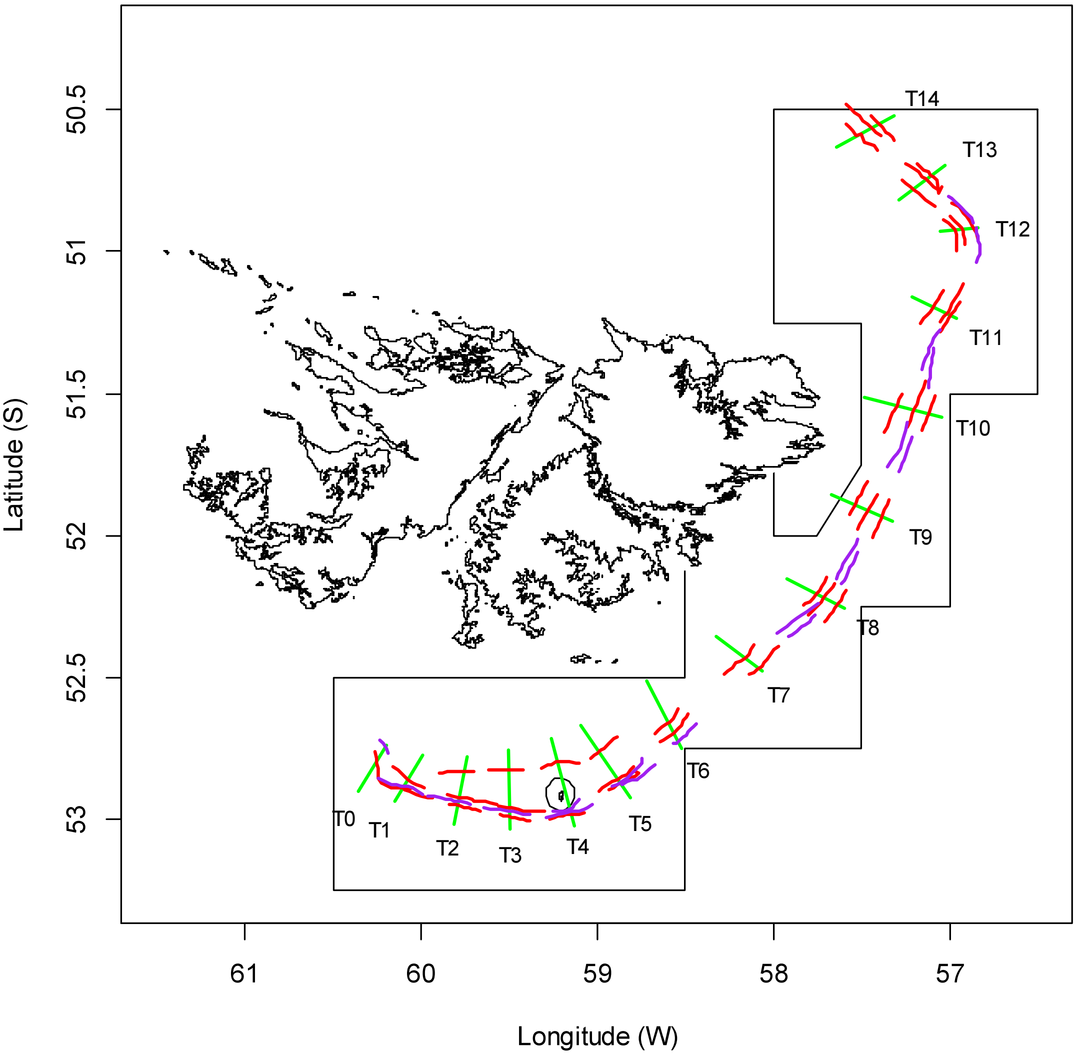

Figure 1. Transects (green lines), fixed-station trawls (red lines), and adaptive-station trawls (purple lines) sampled during the 2nd pre-season 2016 survey. Boundaries of the ‘Loligo Box’ fishing zone and the Beauchêne Island exclusion zone are traced in black.

Methods

Sampling procedures

The survey plan included 39 fixed-station trawls located on a series of 15 transects perpendicular to the shelf break around the Loligo Box (Figure 1), followed by up to 21 adaptive-station trawls selected to increase the precision of Falkland calamari biomass estimates in high-density or high-variability locations. For continuity, fixed stations were the same as the second season of previous years (Winter et al., 2014, Jones et al., 2015); with some trawl stations placed further offshore than during 1st season surveys. Trawls were designed for an expected duration of 2 hours each, and ranged in distance from 11.3 to 24.8 km (mean 15.8 km). All trawls were bottom trawls. During the progress of each trawl, GPS latitude, GPS longitude, bottom depth, bottom temperature, net height, trawl door spread, and trawl speed were recorded on the ship's bridge in 15-minute intervals, and a visual assessment was made of the quantity and quality of acoustic marks observed on the net-sounder. During this survey, acoustic marks were assessed by the vessel's bridge officers. Following the procedure described in Roa-Ureta and Arkhipkin (2007), the acoustic marks were used to apportion the calamari catch of each trawl to the 15-minute intervals and increase spatial resolution of the catches. For small catches acoustic apportioning cannot be assessed with accuracy, and any calamari amounts <100 kg were iteratively aggregated by adjacent intervals (if the total calamari catch in a trawl was <100 kg it was assigned to one interval; the middle one).

Catch estimation

Catch of every trawl was processed separately by the vessel crew and retained catch weight of calamari, by size category, was estimated from the number of standard-weight blocks of whole frozen calamari recorded by the factory supervisor. Catch weights of commercially valued fish species were recorded in the same way, although without size categorization. Total catch composition per trawl, including commercially unvalued species, damaged fish, and undersized fish, was estimated using a combination of visual assessment and basket data. Between 1 and 6 observer baskets of unsorted catch were collected at intervals from each survey trawl, depending on its volume and the sampling schedule. These baskets were hand-sorted by the FIFD survey personnel and species weighed separately. The aggregate quantities of bycatch species in baskets were proportioned to the whole trawl. Scarce species were collected and weighed entirely from each trawl. Non-commercial bycatches were then added to the factory production weights (as applicable) to give total catch weights of all fish and squid.

Biomass calculations

Biomass density estimates of calamari per trawl were calculated as catch weight divided by swept-area; which is the product of trawl distance × trawl width. Trawl distance was defined as the sum of distance measurements from the start GPS position to the end GPS position of each 15-minute interval. Trawl width was derived from the distance between trawl doors (determined per interval) according to the equation (Seafish, 2010):

trawl width = (door distance × footrope length) / (footrope + sweep + bridle)

Measurements of *Castelo*'s trawl, provided by the vessel master, were: footrope = 107 m, sweep = 20 m, bridle = 80 m.

As for prior 2nd seasons (winter seasons), a daylight effect was examined because the diel migratory behaviour of Falkland calamari (Roper and Young, 1975) is likely to make calamari less available to trawls during darkness. Each 15-minute trawl interval (and its corresponding apportioned calamari catch density) was assigned a 0 / 1 index of completion within the period of daytime, from sunrise to sunset. Sunrise and sunset times at each trawl location were calculated using the algorithms of the NOAA Earth System Research Laboratory[a]. Two sets of biomass density estimates were then calculated according to the methods described below; one using all trawl intervals, and the other using only trawl intervals completed during daytime. 66.9% of trawl intervals were completed during daytime. Biomass density distributions using all trawl intervals were found to give more consistent geostatistic models, and were therefore used for calculating the survey estimates.

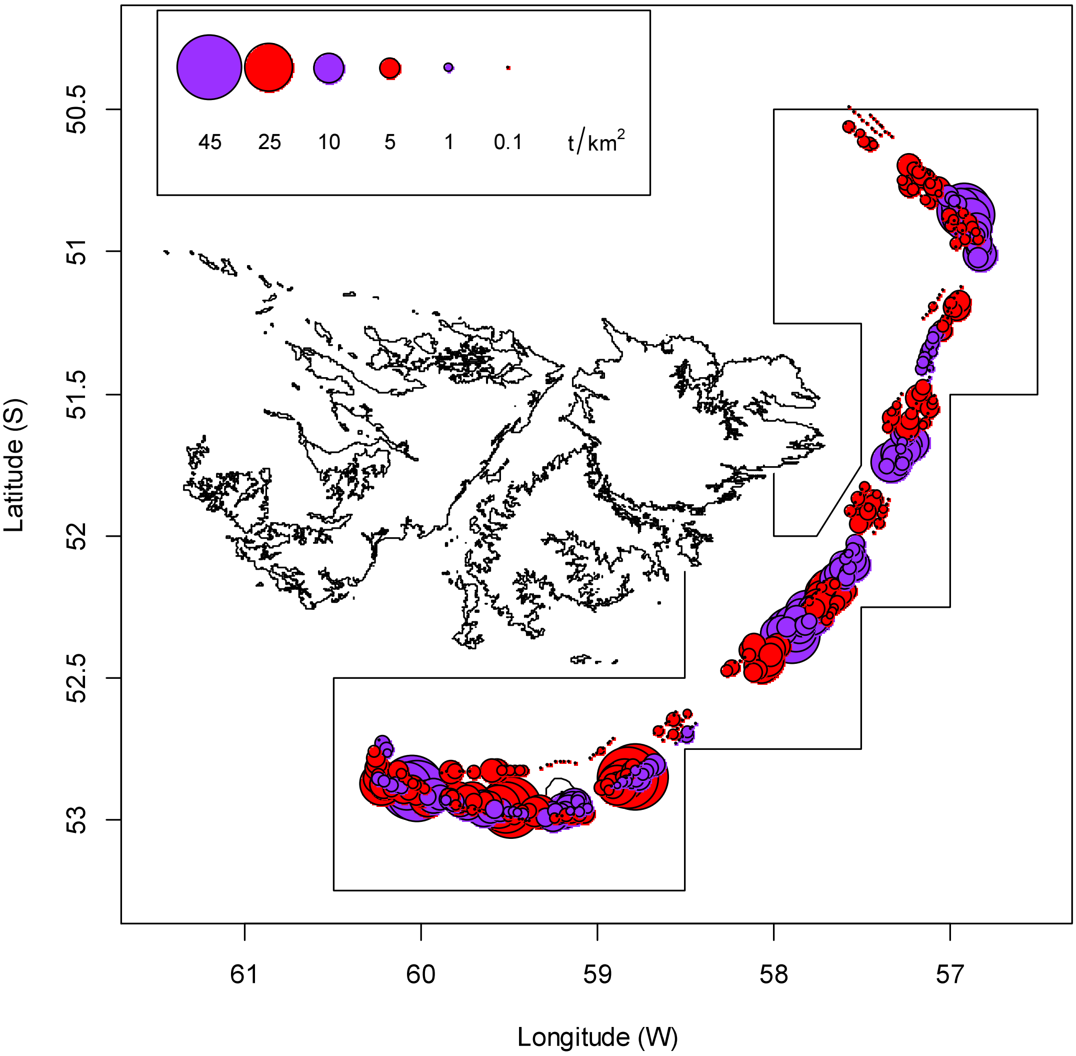

Figure 2. Falkland calamari CPUE (t km^{-2}) of fixed-station trawls (red) and adaptive trawls (purple), per 15-minute trawl interval. The boundary of the survey area is outlined.

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[a] www.esrl.noaa.gov/gmd/grad/solcalc/calcdetails.html

Biomass density estimates were extrapolated to the survey area using geostatistical methods (Petitgas, 2001). The delineated survey area for 2^{nd} season is 14,800 km^2, partitioned for analysis as 592 area units of 5×5 km. A zero-inflated approach was used of fitting geostatistic variograms separately to positive (non-zero) calamari catch densities, and to the probability of occurrence (presence/absence) of the positive catch densities (Pennington, 1983). Positive catch densities were normalized with Box-Cox transformations (MacLennan and MacKenzie, 1988).

Uncertainty of the geostatistical model of biomass density was estimated by conditional simulation (Woillez et al., 2009), performed in the R software package 'geoR' (Ribeiro and Diggle, 2001). Conditional simulations of positive catch densities and presence / absence were randomly drawn and multiplied together 250000× for a combined variability distribution. To this uncertainty was added a measure of error of the acoustic apportionment of the calamari catch data. Assessing the acoustic marks (as described above; Sampling Procedures) is a visual judgement, and does not objectively differentiate calamari from other echo targets entering the net. There is therefore no definitive way to quantify the potential error of this assessment. In three previous surveys (Winter et al., 2014, 2015, Jones et al., 2015) a surrogate measure was calculated using the linear coefficient of determination (R^2) between total acoustic score (Σ (acoustic mark quantity × quality$)_{trawl}$) and total calamari catch among all trawls. In the last survey (Winter et al., 2016), an approximate average of these ($R^2 = 0.5$) was used because acoustic scores were assessed by various vessel officers, voiding the assumption of consistency among all trawls. In the current survey acoustic scores were again assessed by vessel officers, and $R^2 = 0.5$ was used as the average coefficient of determination. To estimate error of acoustic apportionment the unexplained variability of the linear relationship ($1 - R^2 = 0.5$) was multiplied by each interval catch of each trawl and randomly either added to or subtracted from the interval catch:

$$r\,C_{interval} = C_{interval} + (C_{interval} \times (1 - R^2) \times \sim r[-1 \mid 1])$$

The set of $r\,C_{interval}$ for each trawl was re-standardized to the total calamari catch weight of that trawl, then processed through the same algorithms of density distribution and geostatistic extrapolation as the empirical results. In a change from the previous procedure, iterative aggregations of small catches (< 100 kg) were summed towards intervals randomly selected within each trawl, not automatically the middle interval. The full randomization was repeated 10000× and the coefficient of variation of the mean geostatistic density retained as the measure of error of acoustic apportionment[b].

Biological analyses

Random samples of calamari (target n = 200, as far as available) were collected from the factory at all trawl stations. Of these samples, n = 100 were sub-set for statolith extraction. Biological analysis at sea included measurements of the dorsal mantle length rounded down to the nearest half-centimetre, sex, and maturity stage. The length-weight relationship $W = \alpha \cdot L^{\beta}$ (Froese, 2006) for calamari was calculated

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[b] The actual randomization outcomes were not interpretable as true estimates of geostatistic density. Because randomization blurs stretches of high acoustic backscatter vs. low acoustic backscatter (i.e., the original patterns are not random), spatial correlation is typically weaker, and given the distribution skewness resulting from a small number of high density data, the randomized geostatistic estimates are biased lower. Thus only the relative value of the coefficient of variation is used.

by optimization from a subset of individuals that were weighed as well as measured. The 95% confidence interval of the length-weight relationship was calculated by Monte-Carlo resampling. Additional specimens of calamari (LOL) were collected according to area stratification (north, central, south) and depth (shallow, medium, deep), and frozen for statolith extraction and age analysis (Arkhipkin, 2005). A sample of 100 common rock cod (PAR) was taken at every trawl station. All catches of toothfish (TOO) were collected from all trawl stations to maximize the time series catch and biological information base for juvenile toothfish. Specimens of crocodile fish (AGO; *Agonopsis chilensis*), red cod (BAC; *Salilota australis*), hairlip brotula (CAM; *Cataetyx messieri*), frogmouth (CGO; *Cottoperca gobio*), yellowfin rock cod (COG; *Patagonotothen guntheri*), eelpout (EEL; *Iluocoetes fimbriatus*), Argentine shortfin squid (ILL; *Illex argentinus*), greater hooked squid (ING; *Moroteuthis ingens*), kingclip (KIN; *Genypterus blacodes*), moonfish (LAR; *Lampris immaculatus*), orange benthoctopus (MLA; *Muusoctopus longibrachus akambei*), patchy benthoctopus (MUE; *Muusoctopus eureka*), yellowbelly (NOW; *Paranotothenia magellanica*), large purple octopus (OCM; *Octopus megalocyathus*), Patagonian hake (PAT; *Merluccius australis*), and driftfish (SER; *Seriolella caerulea*) were taken opportunistically for length-frequency measurement and / or otolith analysis.

Horizontal net opening

As described above (section Biomass Calculations), biomass density in a trawl survey is estimated from trawl catch divided by the area swept: trawl width × trawl distance. Trawl width is commonly derived using a trigonometric algorithm (Seafish, 2010) that calculates horizontal net opening as a proportion of the trawl door spread. Trawl door spread is measured by wireless sensors mounted on the doors. However, the trigonometric algorithm is approximate as it assumes the trawl door spread and bridle plus footrope length to form a perfect right-angled triangle. Door sensor measurements may furthermore be missing, a situation experienced in several Falkland calamari surveys (Jones et al., 2015) and apparently not uncommon in other fishery surveys (Fraser et al., 2007). To address these limitations, the FIFD acquired a set of Marport Scala M4 sensors for the Castelo (as the charter research vessel), that are attached 2 m behind the extremities of the net wings to measure horizontal net opening directly (Gras, 2016). These net sensors were used for the first time during the finfish biomass survey in February 2016 (Gras et al., 2016). In the present calamari survey, the Marport net sensors were used to compare their direct horizontal net opening measurements (sensor measures) with the trigonometric algorithm based on the trawl doors (door measures).

The Marport net sensors were operational starting from the 4th scientific trawl of the survey. The vessel's bridge officers recorded sensor measures at 15-minute intervals along with the other trawl metrics including door spread. A generalized linear model was used to compare sensor measures with door measures, setting the door measures as the predictor variable. Preliminary inspection suggested that the relationship between sensor measures and door measures was non-linear, therefore a quadratic equation was tested: sensor measures ~ door measures + door measures ^{2}. Additional predictor variables tested were trawl speed and depth (Gras, 2016). The best model combination of predictor variables was selected by the lowest Akaike information criterion (AIC). All 15-minute intervals of all trawls were included in the generalized linear model, but because intervals of the same trawl are not statistically independent, variability was estimated by randomly re-sampling 10000× with replacement the data on two levels: re-sampling the trawls and re-sampling the intervals within trawls.

As the procedure of calamari surveys records catch estimation in 15-minute intervals, this survey also provided the opportunity to examine differences between sensor measures and door measures progressively during trawls. Cumulative calamari catches per trawl interval were plotted against the interval difference of door measure trawl width minus net sensor trawl width. The plot was restricted to trawls that comprised ≥95% calamari in their catches, because there is no accurate way to estimate cumulative catch per trawl interval for any species other than calamari. The trend of the plot was examined with a generalized additive model (GAM), as GAM requires no assumption about the functional form of a data relationship (Swartzman et al., 1992).

A calamari biomass estimate was calculated substituting the net sensor measures for the standard door measures of trawl width; all other steps of the biomass calculation processed the same. The two biomass estimates were compared for how much the trawl width measure difference influences the final outcome.

Results

Catch rates and distribution

The survey started as usual with fixed-station trawls in the north and proceeded to the south-west end of the Loligo Box. Adaptive trawls covered a wide range of the survey (Figure 1, Figure 2, Appendix Table A1) and included stations that were the furthest north for adaptive trawls since 2nd season 2010 (Winter et al., 2010). The same delineation of the survey area was kept for comparability with previous years. A schedule of 4 survey trawls per day was maintained except for the last day, July 28th, when only two survey trawls were taken to allow time for the vessel's port call to offload catch. In total 58 scientific trawls were recorded during the survey: 39 fixed station trawls catching 113.62 t calamari and 19 adaptive trawls catching 111.69 t calamari. Fourteen optional trawls (made after survey hrs) yielded an additional 59.55 t calamari, bringing the total catch for the survey to 284.86 t. The scientific survey catch of 225.31 t is the highest for a 2nd season since 2011 (Table 1).

Table 1. Falkland calamari pre-season survey scientific catches and biomass estimates (in metric tonnes). Before 2006, surveys were not conducted immediately prior to season opening.

Year	First season			Second season		
	No. trawls	Catch	Biomass	No. trawls	Catch	Biomass
2006	70	376	10213	52	240	22632
2007	65	100	2684	52	131	19198
2008	60	130	8709	52	123	14453
2009	59	187	21636	51	113	22830
2010	55	361	60500	57	123	51754
2011	59	50	16095	59	276	51562
2012	56	128	30706	59	178	28998
2013	60	52	5333	54	164	36283
2014	60	124	34673	58	207	40090
2015	57	184	36424	53	137	25422
2016	57	65	21729	58	225	43580

Average calamari catch density among fixed-station trawls was 1.23 t km^{-2} north of 52° S and 4.57 t km^{-2} south of 52° S. The average fixed-station catch density north was almost exactly the same as in last year's 2nd-preseason survey (Jones et al., 2015), but the average fixed-station catch density south was the highest since at least 2011. Average calamari catch density among adaptive-station trawls was 5.57 t km^{-2} north of 52° S and 6.05 t km^{-2} south of 52° S.

Biomass estimation

Density estimates from positive catch trawl intervals were modelled with an exponential covariance function and $\lambda = 0$ (logarithmic) Box-Cox transformation. The variogram was fit with unrestricted lag distance, and resulted in a practical range of 25.22 km, i.e. calamari densities were found to spatially correlate up to a maximum separation distance of 25.22 km (Appendix Figure A1-left). The mean calamari biomass density estimate of this variogram model was 4.53 t km^{-2}, equivalent to the modal value of its distribution of conditional simulations (Figure A1-right). Presence / absence of catch in trawl intervals was modelled with a Cauchy covariance function, $\lambda = 1$ (no transformation, as appropriate for count data; O'Hara and Kotze, 2010), binomial error distribution, and unrestricted lag distance (Figure A2-left). The mean number of positive catch intervals estimated per 5×5 km area unit was 1.81, and centred well on the distribution mode of conditional simulations (Figure A2-right). The coefficient of variation for acoustic apportionment derived with the randomization algorithm using $R^2 = 0.5$ was = 0.179.

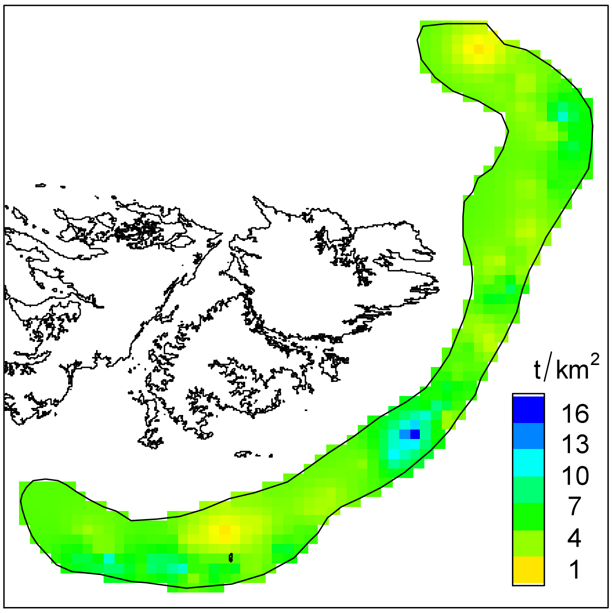
From these calculations, total Falkland calamari biomass in the fishing area was estimated at 43,580 t, with a 95% confidence interval of [36,471 to 55,291] t. The highest concentrations of calamari biomass were inferred more centrally in the Loligo Box than usual for either 1st or 2nd season; around grid XSAN (Figure 3, main plot). Distribution of biomass was relatively even with positive catch projections between 1.72 and 9.08 t km^{-2} in 95% of area units (Fig. 3, top left), and presence probabilities between 0.53 and 0.72 in 95% of area units (Figure 3, top right). Of the estimated total biomass, 15,844 t [11,571 to 22,194 t] were north of 52 °S, and 27,736 t [22,085 to 36,562 t] were south of 52 °S. Like the survey catch of calamari, the survey biomass estimate of 43,580 t was the highest for a 2nd season since 2011 (Table 1).

Biological data

Ninety-five taxa were identified in the catches (Appendix Table A2), of which calamari made up 81.4% by weight, the highest proportion since at least 2011. Rock cod made up 13.0% of catch by weight (concomitantly the lowest proportion since at least 2011), followed by *Chrysaora* (jellyfish) at 2.7%. Most rock cod were undersized for commercial value and discarded.

12724 calamari were measured for length and maturity in the survey (6077 males, 6647 females). The calamari length-weight relationship was calculated from 962 sub-sampled individuals (412 males, 550 females), resulting in optimized parameters $\alpha = 0.12776$ and $\beta = 2.32183$ (Figure 4).

Figure 3 [next page]. Falkland calamari predicted density estimates per 5 km^2 area units. Top left: catch density distribution from variogram model of positive catches. Top right: probability of positive catch modelled from MCMC of presence/absence. Main plot: Predicted density = positive catch × probability of positive catch. Coordinates were converted to WGS 84 projection in UTM sector 21F using the R library rgdal (proj.maptools.org).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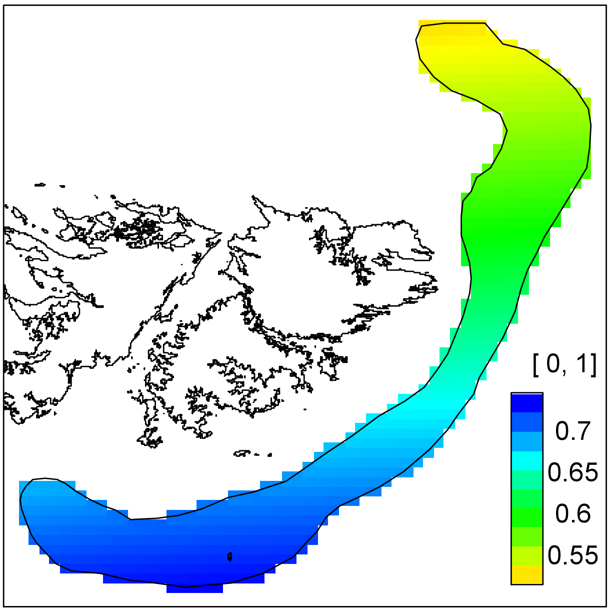
predicted Density from Positive Catch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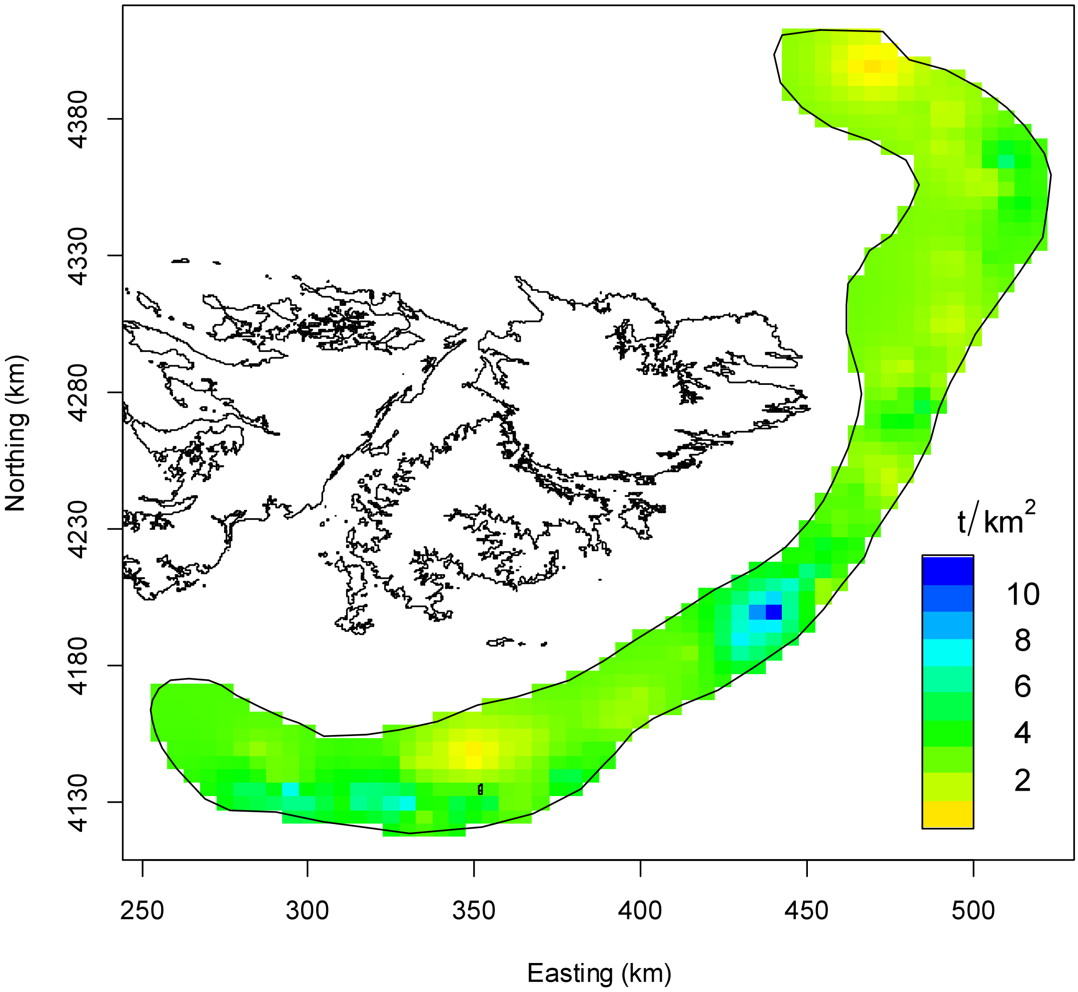
probability of Positive Catch (presence / absence)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total predicted Density

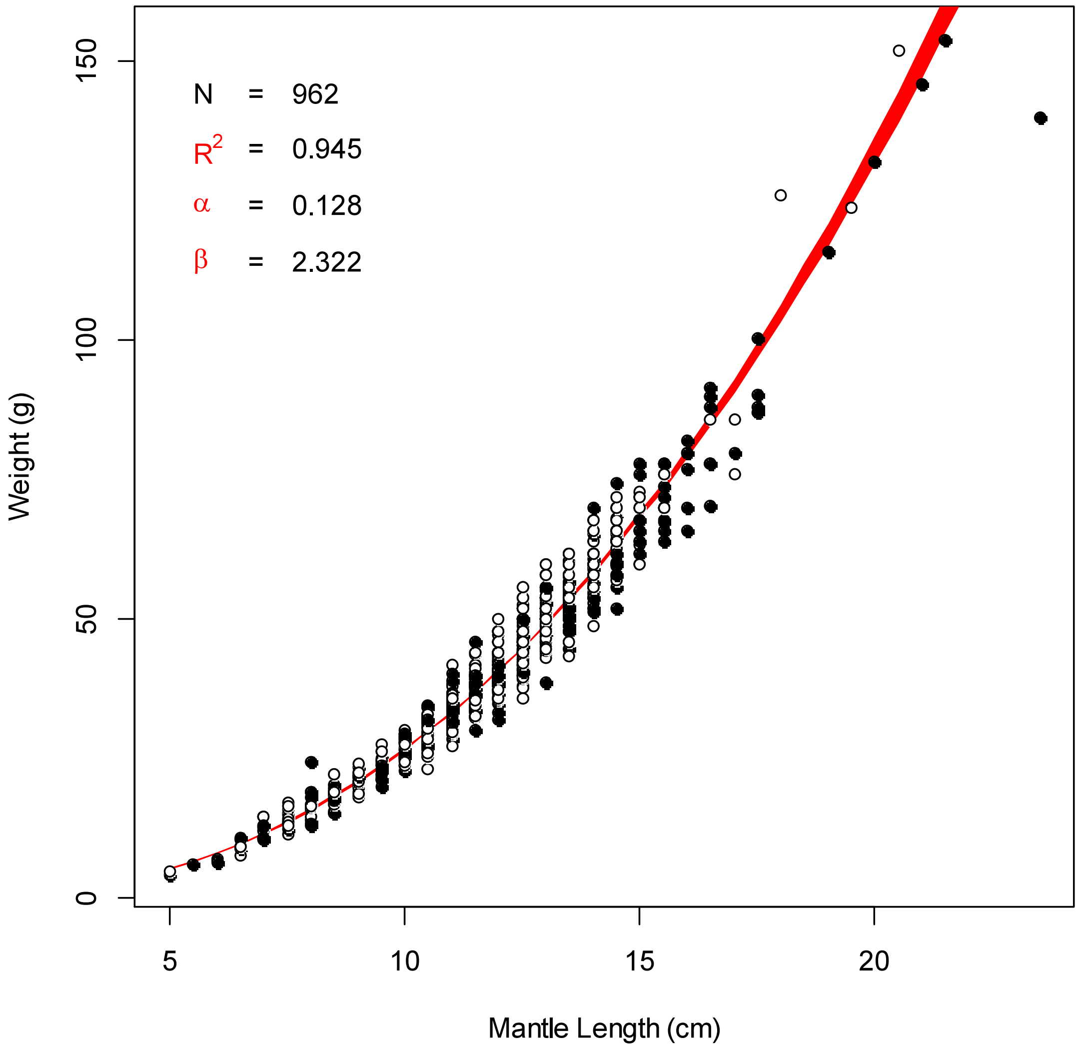
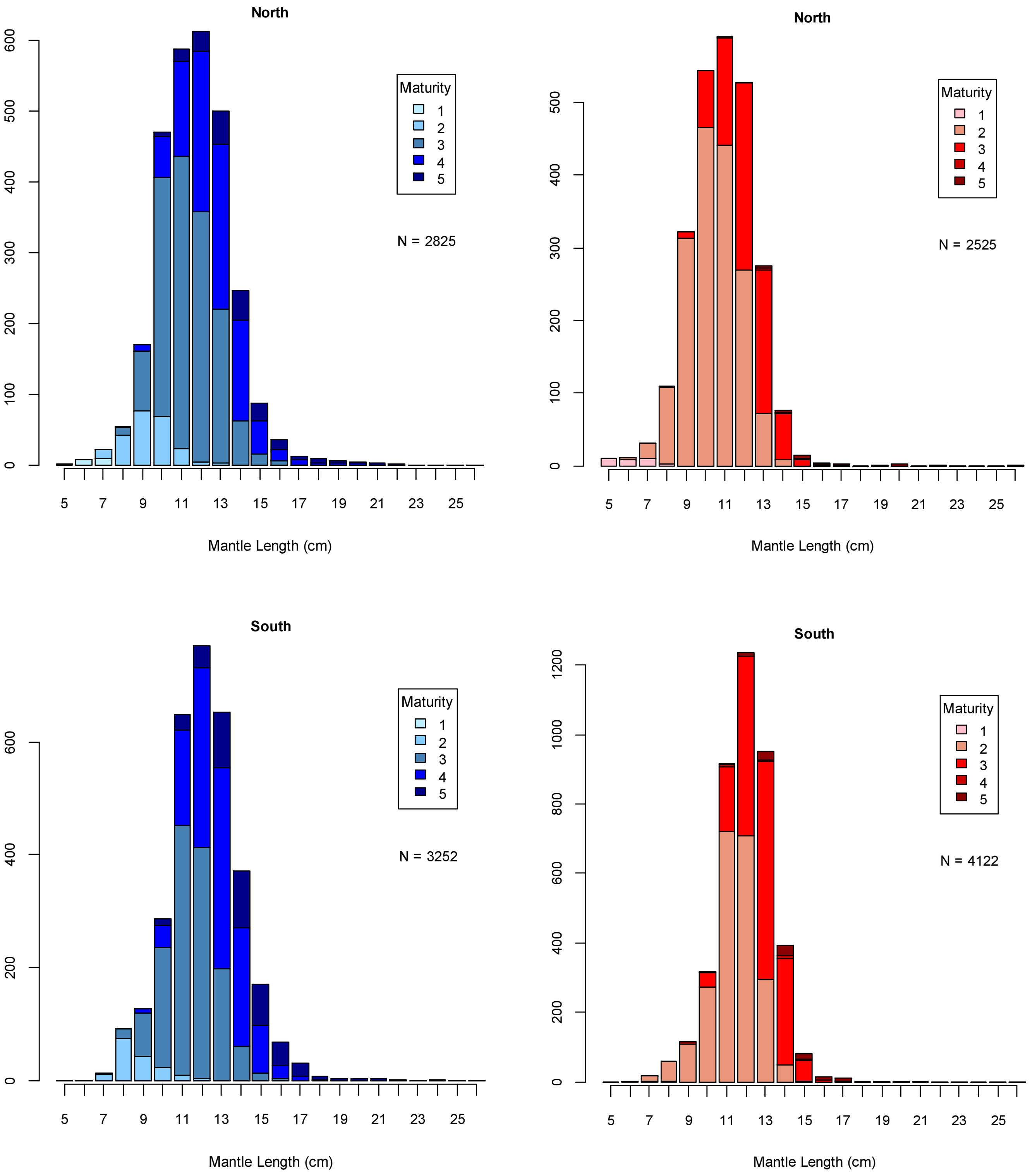


Figure 4. Length-weight relationship of Falkland calamari sampled during the survey. Black points: male, white: female. Parameters refer to the combined sexes' length-weight relationship; the red swath is the 95% confidence interval.

Calamari mantle length and maturity distributions north and south of 52° S are plotted in Figure 5. For both males and females, size and maturity distributions were significantly different between north and south (Kruskal-Wallis test, $p < 0.001$ all comparisons). For males north: mean mantle length 11.72 cm; mean maturity stage 3.36 (on a scale of 1 to 5), males south: mean mantle length 12.14 cm; mean maturity stage 3.59. Females north: mean mantle length 10.88 cm; mean maturity stage 2.32, females south: mean mantle length 11.98 cm; mean maturity stage 2.51.

Figure 5 [next page]. Length-frequency distributions by maturity stage of male (blue) and female (red) Falkland calamari from trawls north (top) and south (bottom) of latitude 52 °S. N = total numbers of sampled individuals.



Horizontal net opening

A quadratic function of door measures (door measures + door measures ^{2}) was found to be the best generalized linear model for predicting net sensor horizontal net opening. Adding depth as an additional predictor variable gave a marginally lower AIC (by 0.2), which however is an insufficient margin to represent a conclusively better model (Burnham and Anderson, 2002). The model fit was:

$$\text{sensor measures} = 1.202 \times \text{door measures} - 0.006 \times \text{door measures}^2 - 1.492$$

Among the 488 interval measurements (Figure 6), the mean ratio of trawl width by sensor measures over trawl width by measures was 81.5% (range 74.4% to 93.3%). Among the 55 trawl stations with net sensor data, 44 stations had a higher coefficient of variation among the door measures trawl widths per interval and 11 stations had a higher coefficient of variation among the net sensors trawl widths per interval.

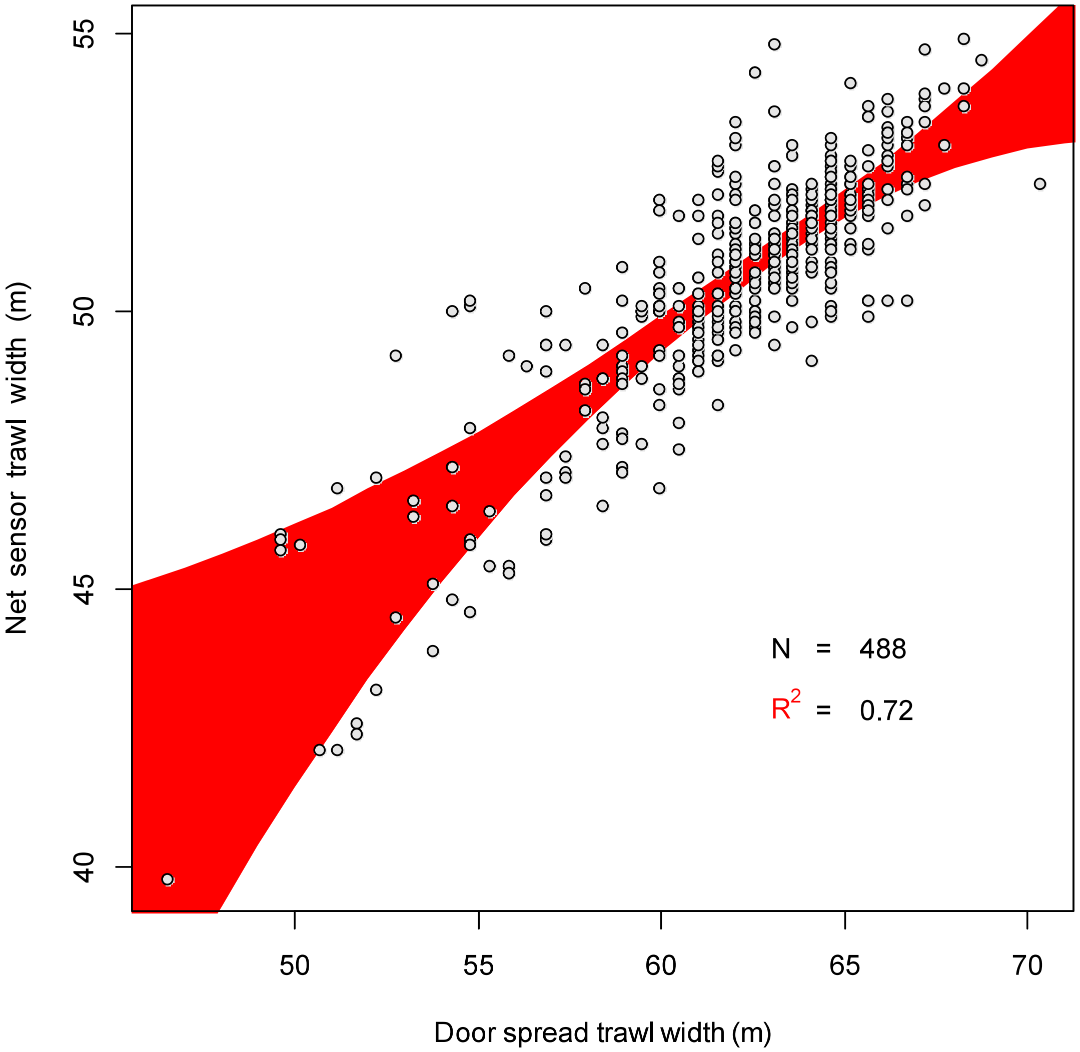


Figure 6. Quadratic relationship between trawl width estimated from door spread using the trigonometric algorithm and trawl width measured from the net sensors. The red swath is the 95% confidence interval of the relationship, by randomized re-sampling.

Twenty-one trawls comprised ≥95% calamari in the catch. The cumulative interval catches ($n = 189$) of these twenty-one trawls showed a significant negative GAM relationship ($p < 0.002$) with the difference in door measures vs. net sensor measures trawl widths, indicative that the more trawls fill the more accurate the triangulation algorithm for trawl width becomes. However, the plot of the GAM relationship did not suggest that the difference would tend to zero over any range of catches plausible in the Falkland calamari fishery (Figure 7).

Total calamari survey biomass obtained using net sensor trawl width instead of door measure trawl width for swept-area was 53,769 t (95% confidence interval: 44,900 to 68,894 t). This biomass estimate represents a difference of 18.9% (1 – 43,580/53,769), very close to the average trawl width difference of 18.5% (1 – 81.5%; above). Trawl width difference thus showed an essentially linear relationship with biomass estimation, as trawl width differences were not related to any extraneous variables such as depth.

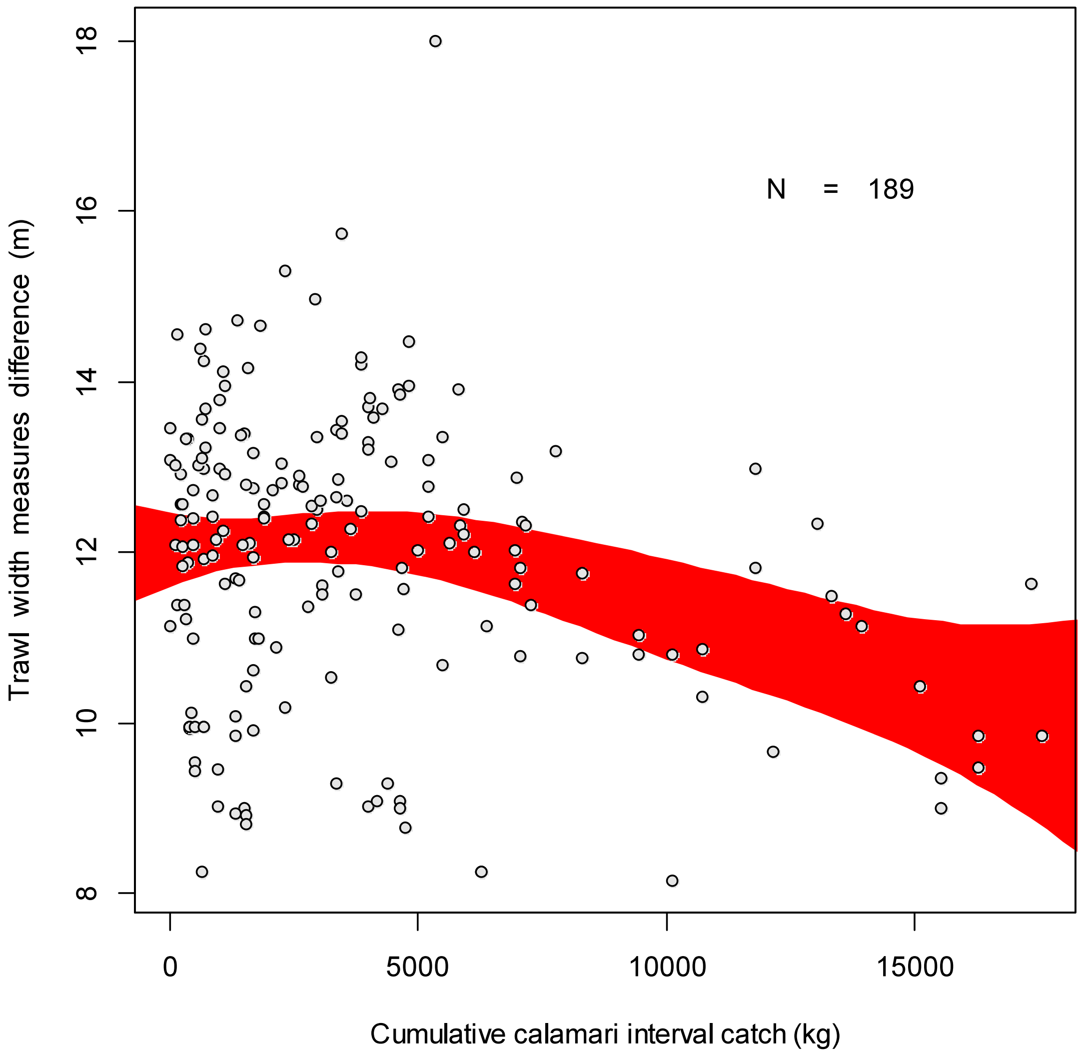


Figure 7. GAM relationship between the cumulative interval catch of calamari and the difference in trawl width of door measures minus trawl width of net sensor measures. The red swath is the 95% confidence interval of the GAM relationship.

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Appendix

Table A1. Survey stations with total Falkland calamari catch. Time: local (Stanley, F.I.), latitude: °S, longitude: °W. Transects labelled E were adaptive trawls.

Transect	Obs	Date	Start			End			Depth	Calamari
Station	Code		Time	Lat	Lon	Time	Lat	Lon	(m)	(kg)
14 - 37	2098	14/07/2016	7:15	50.55	57.59	9:15	50.64	57.41	139	1040.0
14 - 38	2099	14/07/2016	10:10	50.59	57.39	12:10	50.48	57.59	254	17.9
14 - 39	2100	14/07/2016	13:20	50.52	57.45	15:20	50.61	57.31	289	4.8
13 - 36	2101	14/07/2016	16:40	50.69	57.18	18:40	50.77	57.04	289	149.4
13 - 35	2102	15/07/2016	7:10	50.78	57.06	9:10	50.69	57.24	247	4004.1
13 - 34	2103	15/07/2016	10:15	50.75	57.27	12:15	50.84	57.08	132	1707.5
12 - 32	2104	15/07/2016	13:05	50.88	56.99	15:05	50.97	56.91	117	669.0
12 - 33	2105	15/07/2016	16:05	50.95	56.84	18:05	50.83	56.98	247	1229.0
12 - 31	2106	16/07/2016	7:05	50.88	57.03	9:05	51.00	56.96	116	366.2
11 - 28	2107	16/07/2016	10:25	51.13	57.03	12:25	51.25	57.17	130	126.6
11 - 29	2108	16/07/2016	13:20	51.24	57.05	15:20	51.11	56.92	147	205.9
11 - 30	2109	16/07/2016	16:20	51.18	56.94	18:20	51.28	57.05	249	2747.6
10 - 25	2110	17/07/2016	7:15	51.50	57.27	9:15	51.63	57.37	159	870.5
10 - 26	2111	17/07/2016	10:20	51.62	57.24	12:20	51.45	57.13	241	3991.3
10 - 27	2112	17/07/2016	13:30	51.51	57.08	15:30	51.63	57.16	290	934.6
9 - 24	2113	17/07/2016	17:25	51.88	57.34	19:25	52.01	57.44	287	389.9
9 - 22	2114	18/07/2016	7:15	51.93	57.57	9:15	51.81	57.46	166	647.5
9 - 23	2115	18/07/2016	10:20	51.85	57.41	12:20	51.98	57.52	222	3368.1
8 - 20	2116	18/07/2016	13:55	52.17	57.65	15:55	52.28	57.8	248	9950.2
8 - 19	2117	18/07/2016	17:00	52.25	57.83	19:00	52.15	57.7	208	267.5
8 - 21	2118	19/07/2016	7:15	52.20	57.59	9:15	52.30	57.7	313	2318.0
7 - 18	2119	19/07/2016	10:45	52.39	57.97	12:45	52.49	58.14	269	8470.6
7 - 17	2120	19/07/2016	14:15	52.39	58.11	16:15	52.49	58.28	203	2295.0
6 - 16	2121	19/07/2016	17:40	52.63	58.48	19:40	52.73	58.64	246	289.3
5 - 12	2122	20/07/2016	7:20	52.78	59.04	9:20	52.71	58.89	124	48.9
5 - 13	2123	20/07/2016	10:20	52.81	58.79	12:20	52.9	58.99	149	2848.5
5 - 14	2124	20/07/2016	13:05	52.90	58.94	15:05	52.83	58.78	218	17560.5
6 - 15	2125	20/07/2016	16:55	52.70	58.67	18:55	52.61	58.54	173	352.2
4 - 10	2126	21/07/2016	7:10	52.82	59.32	9:10	52.80	59.1	109	2.1
4 - 11	2127	21/07/2016	10:35	52.98	59.07	12:35	53.00	59.27	222	1678.4
3 - 9	2128	21/07/2016	13:45	53.01	59.38	15:45	52.98	59.55	234	349.1
3 - 8	2129	21/07/2016	16:45	52.96	59.56	18:45	52.98	59.3	180	16295.4
3 - 7	2130	22/07/2016	7:10	52.83	59.42	9:10	52.83	59.62	151	1768.0
2 - 4	2131	22/07/2016	10:05	52.83	59.70	12:05	52.84	59.9	166	907.0
2 - 5	2132	22/07/2016	13:00	52.91	59.85	15:00	52.95	59.56	174	7049.4
2 - 6	2133	22/07/2016	16:50	52.97	59.66	18:50	52.95	59.84	233	308.6
1 - 2	2134	23/07/2016	7:10	52.89	59.98	9:10	52.82	60.16	193	1728.6
E - 40	2135	23/07/2016	*10:00	52.77	60.18	*10:45	52.72	60.23	203	648.3
0 - 1	2136	23/07/2016	11:55	52.77	60.27	13:55	52.89	60.16	226	7209.6
1 - 3	2137	23/07/2016	15:20	52.88	60.20	17:20	52.93	59.93	224	9449.3
E - 41	2138	24/07/2016	7:15	52.86	60.24	9:15	52.91	59.99	201	15529.1
E - 42	2139	24/07/2016	10:20	52.92	59.96	12:20	52.95	59.72	196	8318.1
E - 43	2140	24/07/2016	13:25	52.96	59.65	15:25	52.98	59.38	194	5929.3
E - 44	2141	24/07/2016	16:25	53.00	59.29	18:25	52.95	59.02	181	4800.7
E - 45	2142	25/07/2016	7:20	52.67	58.44	9:20	52.74	58.57	289	353.0
E - 46	2143	25/07/2016	10:30	52.81	58.67	12:30	52.88	58.85	278	3170.3
E - 47	2144	25/07/2016	13:45	52.89	58.92	15:45	52.79	58.74	168	468.5
E - 48	2145	25/07/2016	17:55	52.93	59.10	19:55	52.97	59.25	165	4629.5
E - 49	2146	26/07/2016	7:15	52.28	57.76	9:15	52.36	57.92	272	10732.2
E - 50	2147	26/07/2016	10:30	52.34	57.98	12:30	52.24	57.75	233	13330.2
E - 51	2148	26/07/2016	13:45	52.15	57.64	15:45	52.02	57.52	228	5909.4
E - 52	2149	26/07/2016	16:50	52.06	57.52	18:50	52.17	57.61	267	3869.9

E - 53	2150	27/07/2016	7:30	50.80	57.01	9:30	50.90	56.86	270	11800.8
E - 54	2151	27/07/2016	10:45	50.92	56.85	12:45	51.04	56.84	257	6290.0
E - 55	2152	27/07/2016	15:25	51.34	57.09	17:25	51.48	57.12	266	170.0
E - 56	2153	27/07/2016	18:20	51.41	57.16	20:20	51.27	57.05	232	2407.0
E - 57	2154	28/07/2016	7:20	51.65	57.21	9:20	51.78	57.29	269	5009.5
E - 58	2155	28/07/2016	10:35	51.76	57.35	12:35	51.60	57.23	231	8327.4

* The trawl filled with *Munida gregaria*, requiring early termination.

Table A2. Survey total catches by species / taxon.

Species Code	Species / Taxon	Total catch (kg)	Total catch (%)	Sample (kg)	Discard (kg)
LOL	*Doryteuthis gahi*	225309	81.4	560	494
PAR	*Patagonotothen ramsayi*	35901	13.0	314	35395
CHR	*Chrysaora* sp.	7498	2.7	0	7498
HAK	*Merluccius hubbsi*	1644	0.6	0	0
MUG	*Munida gregaria*	1300	0.5	0	1300
RBR	*Bathyraja brachyurops*	1115	0.4	0	99
CGO	*Cottoperca gobio*	585	0.2	4	585
TOO	*Dissostichus eleginoides*	423	0.2	415	2
SPN	Porifera	298	0.1	0	298
BAC	*Salilota australis*	298	0.1	0	138
BLU	*Micromesistius australis*	226	0.1	0	226
SQT	Ascidiacea	224	0.1	0	224
RFL	*Zearaja chilensis*	220	0.1	0	30
RAL	*Bathyraja albomaculata*	215	0.1	0	16
DGH	*Schroederichthys bivius*	179	0.1	118	60
PTE	*Patagonotothen tessellata*	171	0.1	0	171
ALG	Algae	110	<0.1	0	110
RBZ	*Bathyraja cousseauae*	109	<0.1	0	2
STA	*Sterechinus agassizi*	99	<0.1	0	99
ANM	Anemone	82	<0.1	0	82
RMC	*Bathyraja macloviana*	79	<0.1	0	4
LAR	*Lampris immaculatus*	74	<0.1	74	0
RSC	*Bathyraja scaphiops*	73	<0.1	0	37
GOC	*Gorgonocephalas chilensis*	65	<0.1	0	65
ZYP	*Zygochlamys patagonica*	49	<0.1	0	49
ODM	*Odontocymbiola magellanica*	39	<0.1	0	39
WHI	*Macruronus magellanicus*	32	<0.1	0	22
PAT	*Merluccius australis*	29	<0.1	29	0
OPV	*Ophiacanta vivipara*	23	<0.1	0	23
SAR	*Sprattus fuegensis*	20	<0.1	0	20
ING	*Moroteuthis ingens*	17	<0.1	1	17
RPX	*Psammobatis* spp.	14	<0.1	0	14
RMG	*Bathyraja magellanica*	14	<0.1	0	5
RGR	*Bathyraja griseocauda*	12	<0.1	0	4
GRC	*Macrourus carinatus*	12	<0.1	0	12
EEL	*Iluocoetes fimbriatus*	11	<0.1	3	10
RDO	*Amblyraja doellojuradoi*	10	<0.1	0	6
SUN	*Labidaster radiosus*	8	<0.1	0	8
KIN	*Genypterus blacodes*	7	<0.1	0	0
MUL	*Eleginops maclovinus*	6	<0.1	0	5
FUM	*Fusitriton m. magellanicus*	6	<0.1	0	6
CHE	*Champsocephalus esox*	6	<0.1	0	6
NEM	*Neophyrnichthys marmoratus*	5	<0.1	0	5
AST	Asteroidea	5	<0.1	0	5
SEC	*Seriolella caerulea*	4	<0.1	4	4

OCM	*Octopus megalocyathus*	3	<0.1	3	0
LOS	*Lophaster stellans*	3	<0.1	0	3
OPL	*Ophiuroglypha lymanii*	2	<0.1	0	2
MLA	*Muusoctopus longibrachus akambei*	2	<0.1	2	0
POA	*Porania antarctica*	1	<0.1	0	1
NOW	*Paranotothenia magellanica*	1	<0.1	1	1
MUE	*Muusoctopus eureka*	1	<0.1	1	0
LIC	*Lithodes confundens*	1	<0.1	0	0
ILL	*Illex argentinus*	1	<0.1	1	1
GRF	*Coelorhynchus fasciatus*	1	<0.1	0	1
GOR	Gorgonacea	1	<0.1	0	1
CRY	*Crossaster* sp.	1	<0.1	0	1
COL	*Cosmasterias lurida*	1	<0.1	0	1
CIR	Cirripedia	1	<0.1	0	1
CAZ	*Calyptraster* sp.	1	<0.1	0	1
ANT	Anthozoa	1	<0.1	0	1
WRM	*Chaetopterus variopedeatus*	<0.1	<0.1	0	0
THO	Thouarellinae	<0.1	<0.1	0	0
RMU	*Bathyraja multispinis*	<0.1	<0.1	0	0
PYX	Pycnogonida	<0.1	<0.1	0	0
POL	Polychaeta	<0.1	<0.1	0	0
PLU	Primnoellinae (unbranched)	<0.1	<0.1	0	0
PLB	Primnoellinae (branched)	<0.1	<0.1	0	0
PES	*Peltarion spinosulum*	<0.1	<0.1	0	0
OPH	Ophiuroidea	<0.1	<0.1	0	0
NUD	Nudibranchia	<0.1	<0.1	0	0
MYX	*Myxine* spp.	<0.1	<0.1	0	0
MIR	Mirostenella sp.	<0.1	<0.1	0	0
MAV	*Magellania venosa*	<0.1	<0.1	0	0
HYD	Hydrozoa	<0.1	<0.1	0	0
HOL	Holothuroidea	<0.1	<0.1	0	0
GYN	*Gymnoscopelus nicholsi*	<0.1	<0.1	0	0
GAT	*Gaimardia trapesina*	<0.1	<0.1	0	0
EUO	*Eurypodius longirostris*	<0.1	<0.1	0	0
EUL	*Eurypodius latreillei*	<0.1	<0.1	0	0
ERR	*Errina* sp.	<0.1	<0.1	0	0
EGG	Eggmass	<0.1	<0.1	0	0
CTA	*Ctenodiscus australis*	<0.1	<0.1	0	0
COT	*Cottunculus granulosus*	<0.1	<0.1	0	0
COG	*Patagonotothen guntheri*	<0.1	<0.1	0	0
CEX	*Ceramaster* sp.	<0.1	<0.1	0	0
CAM	*Cataetyx messieri*	<0.1	<0.1	0	0
BRY	Bryozoa	<0.1	<0.1	0	0
BAO	*Bathybiaster loripes*	<0.1	<0.1	0	0
AUL	*Austrolycus laticinctus*	<0.1	<0.1	0	0
AUC	*Austrocidaris canaliculata*	<0.1	<0.1	0	0
ASA	*Astrotoma agassizii*	<0.1	<0.1	0	0
ALC	Alcyoniina	<0.1	<0.1	0	0
AGO	*Agonopsis chilensis*	<0.1	<0.1	0	0
ACS	*Acanthoserolis schythei*	<0.1	<0.1	0	0
		276,652		1,531	47,211

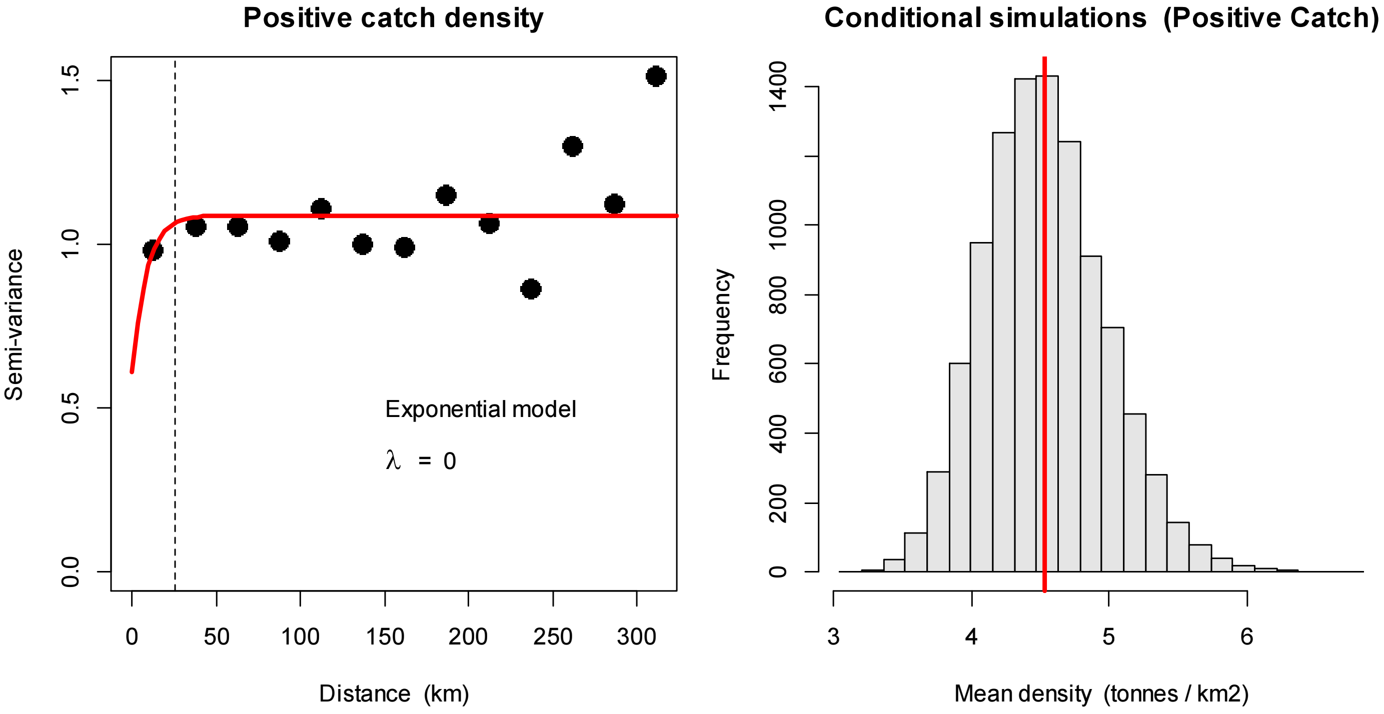
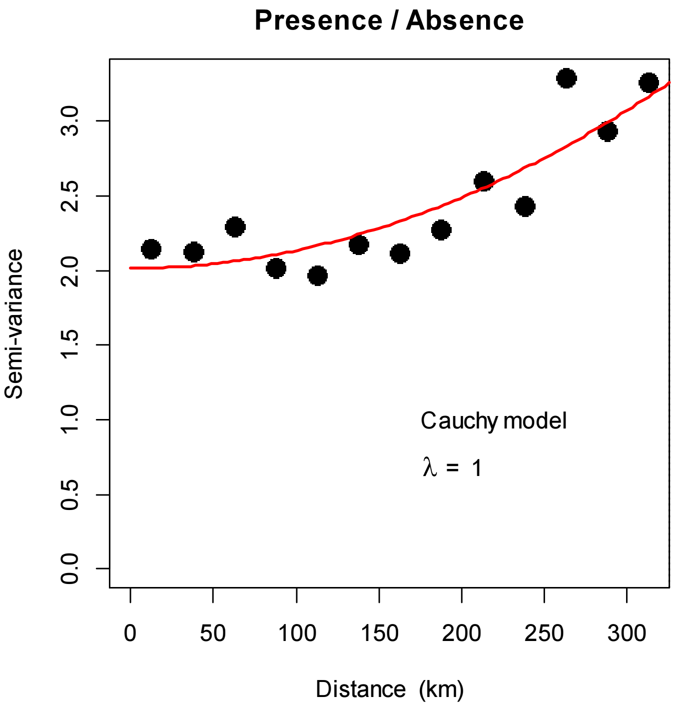


Figure A1. Left: Empirical variogram (black circles) and model variogram (red line) of calamari biomass density distributions from positive catch trawl intervals. Broken vertical line: practical correlation range of the model at 25.22 km. Right: histogram of conditional simulations of mean density estimates resulting from the model variogram at left. Vertical red line: empirical mean density estimate at 4.53 t km^{-2}.



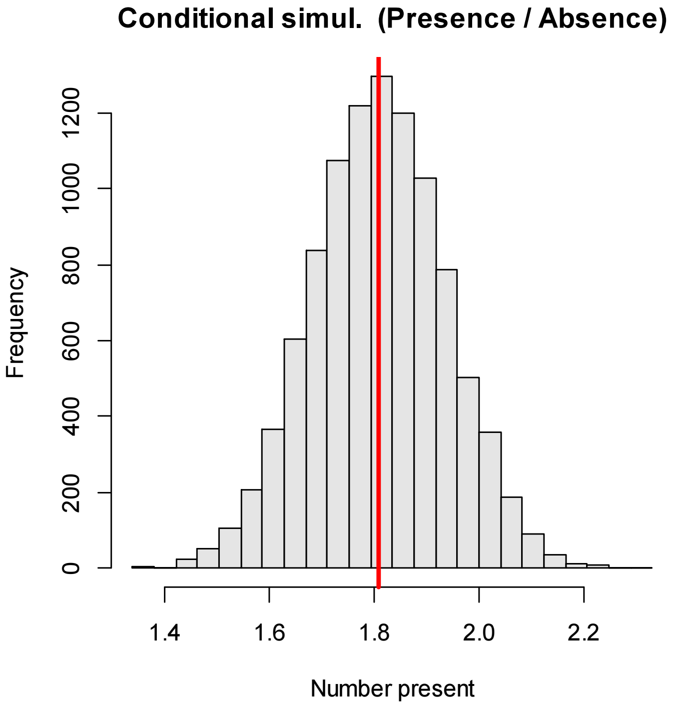


Figure A2 [previous page]. Left: Empirical variogram (black circles) and model variogram (red line) of numbers of positive catch intervals present per 5 × 5 km area unit. Right: histogram of conditional simulations of positive catch interval numbers resulting from the model variogram at left. Vertical red line: empirical mean number present at 1.81.