Falkland Island Fisheries Department

Loligo gahi Stock Assessment Survey, 2nd Season 2010

Vessel	Golden Chicha (ZDLC1)
Flag	Falkland Islands
Dates	30/06/2010-14/07/2010
Scientific Crew	A. Winter, D. Davidson, Z. Shcherbich

SUMMARY

A stock assessment survey for *Loligo gahi* squid was conducted in the 'Loligo Box' from 30th June to 14th July 2010. A total catch of 164.71 mt *Loligo* was taken during the survey. Distributions of *Loligo* were fairly even throughout the Loligo Box area, with aggregations occurring north and south, and at all depths surveyed; from ~105 m to ~315 m. *Loligo* were generally larger and more mature in the southern part of the Loligo Box, with 37% of males and 6% of females mature, while in the northern part of the Loligo Box 14% of males and 2% of females were mature. Average lengths and (for males) average maturities increased with depth.

A geostatistical estimate of 51,754 mt *Loligo* biomass was calculated for a fishing grounds area of 14,099.5 km^2. Modelling analyses showed that this could still be an underestimate of >10,000 mt due to 1) relatively low trawling power of the survey vessel, and 2) low catch efficiency of trawls that were completed after sunset. However, 51,754 mt represents the highest second pre-season survey total since 2005, and indicates that a strong *Loligo* fishing season may be anticipated.

INTRODUCTION

A stock assessment survey for *Loligo gahi* squid was conducted by FIFD personnel onboard the fishing vessel *Golden Chicha* from 30th June to 14th July 2010. This survey continues the series of surveys that have, since February 2006, been conducted immediately prior to *Loligo* season openings to estimate the *Loligo* 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.

The survey was designed to cover the 'Loligo Box' fishing area (Arkhipkin et al., 2008) that extends across the southern and eastern part of the Falkland Islands Interim Conservation Zone (Figure 1).

Objectives of the survey were:

1) To estimate the biomass of *Loligo* on the fishing grounds at the onset of the 2nd fishing season, 2010.
2) To examine the spatial distribution and biology of *Loligo*. In this survey, particular attention was given to sampling stomach contents of *Loligo* to study their relative consumption patterns of euphausiids and *Themisto* amphipods.
3) To examine the distribution and biology of rock cod (*Patagonotothen ramsayi*), as a follow-up to the rock cod assessment surveys conducted earlier in 2010 (Winter et al., 2010).

The survey vessel F/V *Golden Chicha* is a Stanley, F.I. - registered stern trawler of 69.8 m length, 4.9 m draft, and 1345 mt gross registered tonnage. The ship is powered by a 2200 hp main engine and used a 4-panel EuroRed bottom net with a wing-spread trawl width of 32 m. Additional equipment specifications are listed in Chapman (2009). The *Golden Chicha* was also the vessel used for the 2008 pre-season 1 *Loligo* survey (Paya, 2008)

The following personnel from FIFD participated in the survey:

Andreas Winter	survey chief scientist
Deborah Davidson	catch composition sampling, observer data
Zhanna Shcherbich	biological sampling and collection

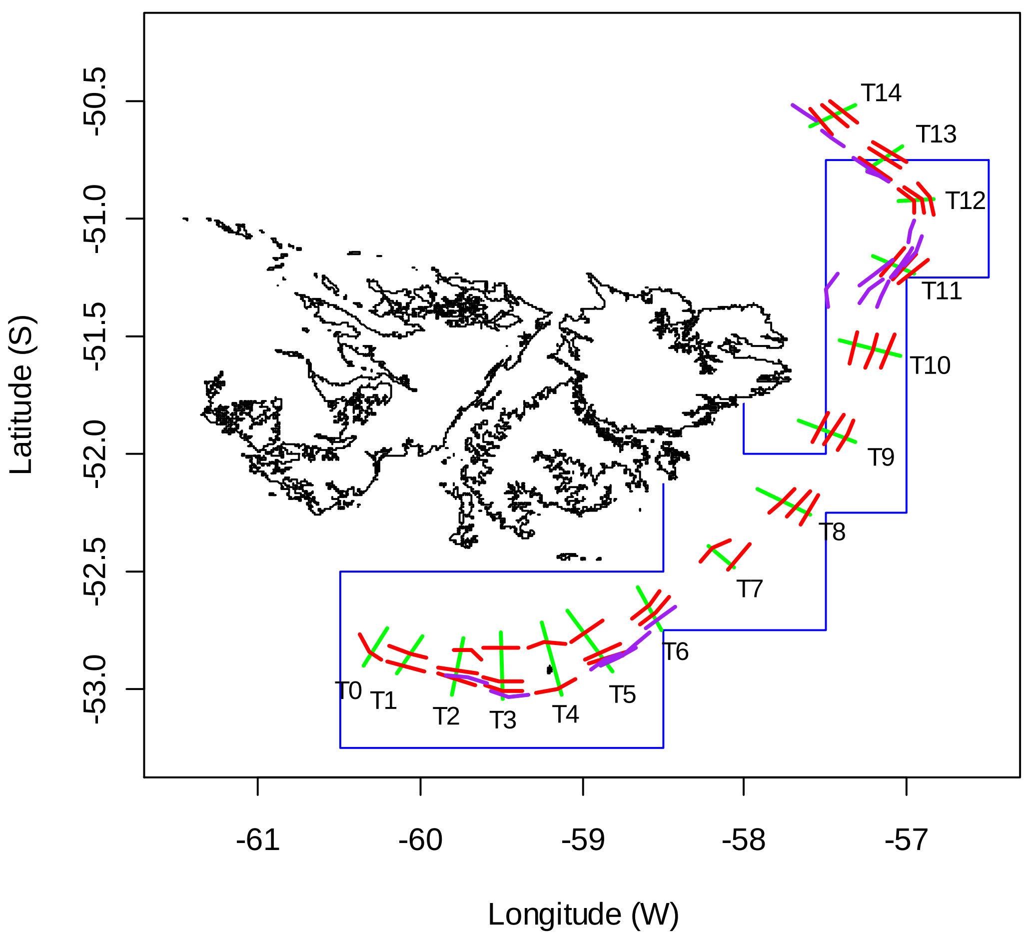

Figure 1. Transects (green lines), fixed-station trawls (red lines), and adaptive-station trawls (purple) sampled during the pre-season 2 2010 survey. The boundary of the 'Loligo Box' commercial fishing area is shown in blue.

METHODS

Sampling procedures

The survey plan was designed to include 40 fixed-station trawls located on a series of 15 transects perpendicular to the shelf break around the Loligo Box (Figure 1), followed by 20 adaptive-station trawls to maximize *Loligo* catch and increase the precision of estimates in high-density localities (hot spots). In conformity with previous surveys (Paya, 2008; Paya and Winter, 2009), the trawls were set to standard durations of 2 hours and conducted 4 times per day. 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 trawling 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. Following the procedure described in Roa-Ureta and Arkhipkin (2007), the acoustic marks were used to apportion the *Loligo* catch of each trawl to the 15-minute intervals and thereby increase spatial resolution of the catches.

Catch estimation

Catch of every trawl was processed separately by the factory crew and retained catch weight of *Loligo*, by size category, was estimated from the number of standard-weight blocks of frozen *Loligo* recorded by the factory boss. Catch weights of commercially valued finfish species, including rock cod, were recorded in the same way, although without size categorization. Discards of damaged, undersized, or commercially unvalued finfish and squid were estimated by FIFD survey personnel either visually (for small quantities) or by noting the ratio of discards to commercially retained fish and squid in sub-portions of the catch (for larger quantities). Discards were added to the product weights (as applicable) to give total catch weights of all fish and squid.

Biological analyses

Random samples of approximately 150 *Loligo* were collected from the factory conveyer belt at all trawl stations. Biological analysis at sea included measurements of the dorsal mantle length (ML) rounded down to the nearest half-centimetre, sex, and maturity stage. Several samples of *Loligo* were taken according to stratification by area (north, central, south) and depth (shallow, medium, deep), and frozen for statolith extraction and age analysis (Arkhipkin, 1993) at FIFD. Additional samples of *Loligo* were taken for diet analysis from trawls in which significant numbers were found to have full stomachs. These were either dissected and photographed at sea for colour-scale estimation of stomach contents (Figure 2), or frozen whole for processing at FIFD. Random samples of up to 100 rock cod were collected from trawls in which rock cod were caught. Biological analysis of rock cod included measurements of total length (TL) rounded down to the nearest centimetre, sex, and maturity stage, and specimen collection for fat tissue analysis. Rare fish in the trawls were frozen for further analysis at FIFD.

Figure 2. Dissected *Loligo* from a trawl sample showing stomachs filled primarily with pale pink euphausiids (left), or dark brown *Themisto* amphipods (right).

Biomass analyses

Biomass density estimates of *Loligo* per trawl were calculated as catch weight divided by swept-area: the product of trawl distance × trawl width, where 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, and trawl width was defined as the mean wing-spread of 32 m. These biomass density estimates were extrapolated to the fishing grounds area using geostatistical methods described in previous reports (Paya, 2009; Paya and Winter, 2009); which are based on the approach of separately calculating presence/absence probabilities of positive (non-zero) densities, and the expected values of positive densities where present (Pennington, 1983).

In a previous survey report (Paya, 2008), the issue was raised that biomass density estimation may be a function of the fishing power of the survey vessel itself, and therefore a source of uncontrolled variability when different vessels are used in different surveys. The issue is pertinent to the present survey as the *Golden Chicha* has the lowest main engine horsepower of the five *Loligo* survey vessels used since 2008 (Table 1). Therefore, a comparison of CPUE of these five vessels was calculated. The scope of the comparison was similar to that reported by Paya (2008), but based on an index of CPUE that explicitly standardizes for average net width of the different vessels. The comparison is calculated from in-season catches, since that is when vessels are fishing at the same time in the same areas. However, in-season the fishing efforts are reported by trawl duration, and not by swept-area. As long as a vessel maintains constant speed the trawl duration is proportional to trawl distance, but not to trawl width; which must be standardized. Accordingly, a CPUE index (iCPUE) was calculated as kg of *Loligo* catch per hour per metre of trawl width from daily catch reports in the FIFD database. For each of the five seasons from 2008-1 to 2010-1, iCPUE was analyzed in a generalized linear model (GLM) as a function of three categorical predictor variables (Paya, 2008):

$$\log(\text{iCPUE}) \sim T_{10} + \text{Day\_Pos} + \text{Vessel}$$

where T_{10} was the 10-day time block from the start of the season, Day_Pos (daytime position) was the FICZ grid unit (0.25º lat × 0.5º lon) at midday, and (V)essels were identified by callsign. The iCPUE were log-transformed to normalize the distributions. Model outputs were back-transformed and added to the lognormal bias correction factor $exp\ (\varepsilon - 0.5\sigma^2)$ (Maunder et al., 2006), where ε is the deviation between observed and modelled *log* (iCPUE) and σ^2 is the variance of observed *log* (iCPUE). Significance of the Vessel factor was examined by calculating the GLM for each GLM without 'Vessel' and determining whether this increased or decreased the Akaike Information Criterion (AIC) of the model.

Relationships between *Loligo* density and co-variables latitude, longitude, bottom temperature from net sensors, bottom depth, and time-of-day were analyzed with generalized additive models (GAM), which allow non-linear relationships to be observed (Swartzman et al., 1992). Time-of-day was included because *Loligo* aggregate near-bottom primarily during daylight (Rodhouse, 2005). The survey plan was to trawl during daylight, but due to winter hours it was not uncommon for first trawls to be started before sunrise and last trawls to finish after sunset. To evaluate whether this influenced catch densities, time-of-day was included as a factorial of three categories: day (between sunrise and sunset), twilight (dawn or dusk), and otherwise night. Categories were interpolated from the corresponding dates, times, and coordinates on the US Naval Observatory website www.usno.navy.mil /USNO/astronomical-applications/data-services/rs-one-year-world. The GAM were analyzed per 15-minute interval and, as for the geostatistical estimates (above), were analyzed separately by presence/absence of positive densities and values of positive densities where present. Values of positive densities were log-transformed for the GAM to normalize the distributions. Best-fitting combinations of the co-variables in the GAM were determined by comparing their Akaike Information Criteria (AIC).

RESULTS

Catch rates and distribution

The survey started with fixed-station trawls in the northern area of the Loligo Box (on transect 14; Fig. 1) and proceeded southward, before heading north again to complete adaptive trawling. Fifty-seven scientific trawls were recorded during the survey: 39 fixed station trawls catching 67.63 mt *Loligo* and 18 adaptive trawls catching 55.42 mt *Loligo*. Additionally, 15 optional trawls (made after survey hrs) yielded 41.66 mt *Loligo*, bringing the total catch for the survey to 164.71 mt.

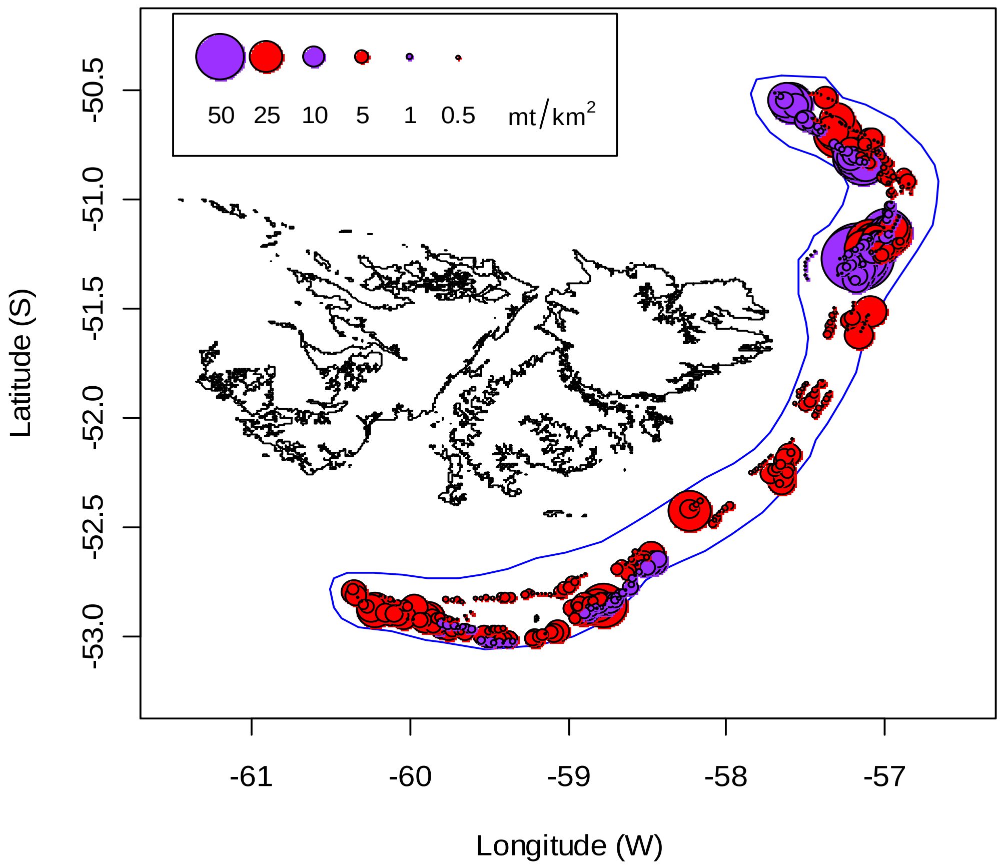

Figure 3. *Loligo* CPUE (mt km^{-2}) of fixed-station trawls (red) and adaptive trawls (purple), per 15-minute trawl interval. The boundary of the fishing area is shown in blue.

Compared to the 2010 1st season (Arkhipkin et al., 2010), catches were fairly even through-out the survey area (Figure 3), averaging (among fixed-station trawls) 3.53 mt km^{-2} north of 52º S and 3.06 mt km^{-2} south of 52º S. The combined fixed-station trawl average (north + south) was 3.28 mt km^{-2}, vs. 6.86 mt km^{-2} for the combined adaptive trawl average.

Biomass estimation

Loligo density was estimated from the combined geostatistical model as the probability of positive (non-zero) catch per spatial unit multiplied by the model-predicted *Loligo* density per positive catch. A simulation by Markov chain Monte Carlo (Metropolis and Ulam, 1949) with binomial distribution was used to model the probabilities of positive catch. An exponential variogram model (Cressie, 1993) was used to model the positive catch densities, with spatial correlation.

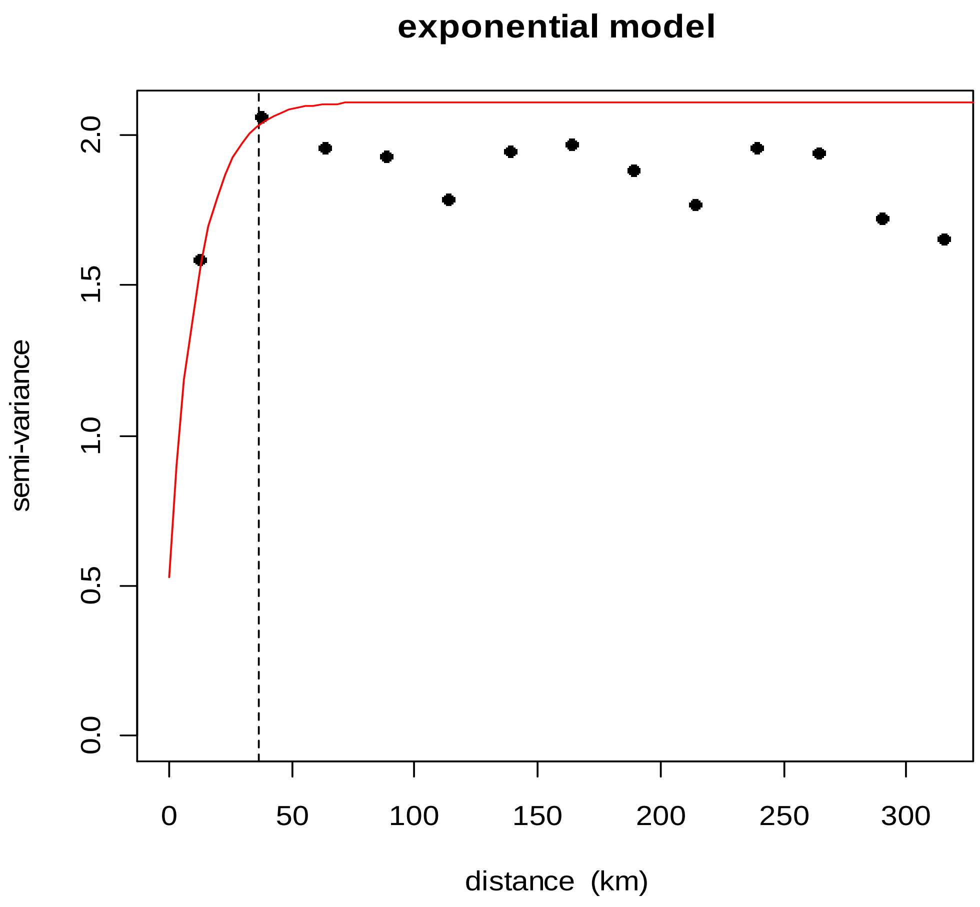

Figure 4. Empirical (black points) and model (red line) variograms of positive *Loligo* density distributions. The model variogram had an autocorrelation range of 36.4 km (dotted line).

The exponential model (Figure 4) converged with a range of 36.4 km, implying that catch densities had spatial auto-correlation only up to a maximum of 36.4 km separation distance. A fishing area of 14,099.5 km^2 was delineated by eye around the trawl track positions (Figure 3). This is somewhat more conservative than the 15,522.1 km^2 delineated during the first season, and primarily due to more restriction assumed over poorly trawlable ground in the southern Beauchene area.

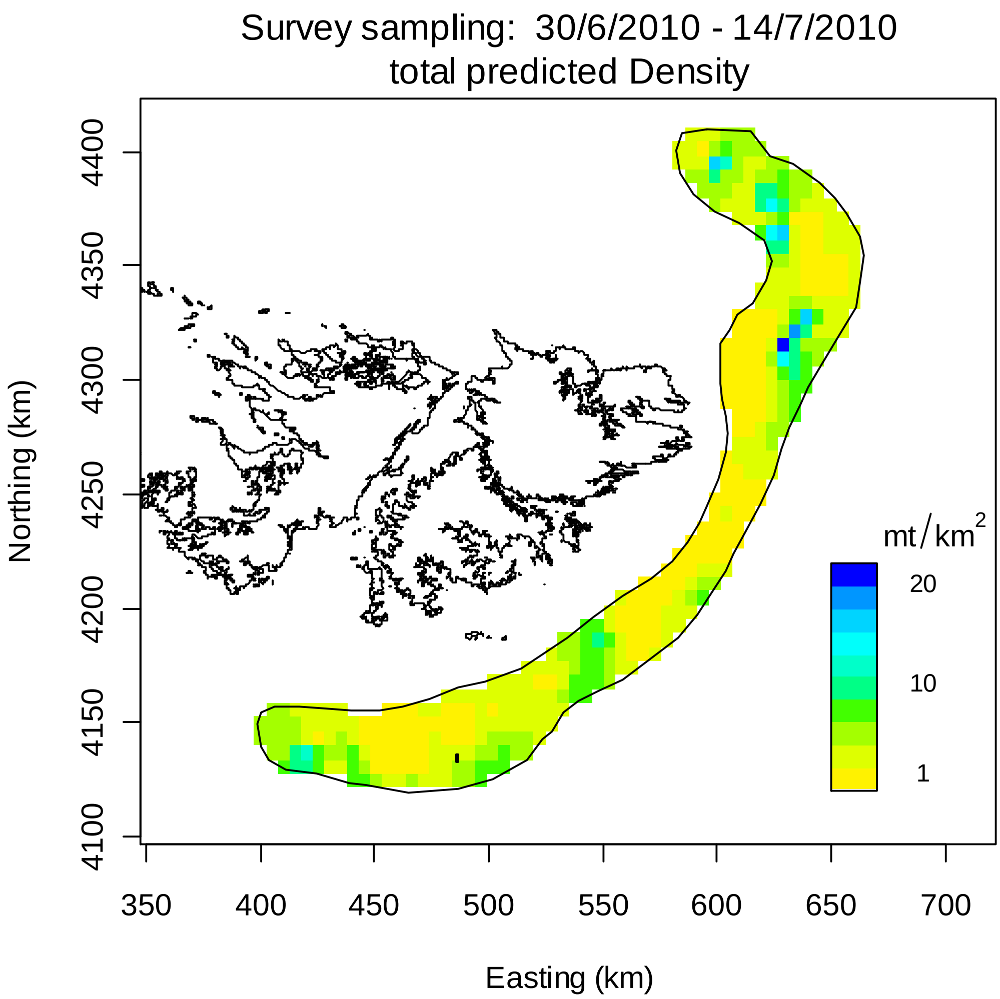

Figure 5. *Loligo* density estimates by 5 × 5 km survey grid cells. Estimates are calculated from kriged probabilities of presence × kriged densities of positive catches. Note that for calculating geostatistical estimates, coordinates are converted to WGS 84 (using GeoConv software, www.kolumbus.fi/eino.uikkanen/geoconvgb/index.htm).

For geostatistical extrapolation, the season's fishing area was modelled as 453 grid squares of 5×5 km (Figure 5). The median density per grid square was 3.07 mt km^{-2}, with a 95% confidence interval of 0.53 to 9.36 mt km^{-2}. Total *Loligo* biomass in the fishing area was estimated by the geostatistical model at 51,754 mt, with a standard error of ± 5,248.09 mt. Of this estimated total, 27,243 mt were north of 52 ºS, and 24,511 mt were south of 52 ºS (Figure 5). The biomass estimate is the highest for second season since 2005 (Arkhipkin and Roa-Ureta, 2005).

Table 1. Size and fishing power characteristics of vessels used for the *Loligo* pre-season surveys since 2008.

Survey	Survey Vessel	LOA	GRT	Main HP	Net width*
2008 1	*Golden Chicha*	62.98 m	1345	2200	40.89 m
2008 2	*Argos Vigo*	70.75 m	2075	3000	45.33 m
2009 1	*Castelo*	59.65 m	1321	2450	42.69 m
2009 2	*Baffin Bay*	68.20 m	1871	3300	42.05 m
2010 1	*Beagle*	92.23 m	2849	2944	41.54 m

* Average from pre-season survey

Table 2. Average standardized CPUE indices (iCPUE; kg per hour per m trawl width) predicted from GLM. Asterisks indicate vessel factors that were significantly different ($p <$ 0.05) from the *Golden Chicha* in each season's GLM.

Survey Vessel	Season				
	2008 1	2008 2	2009 1	2009 2	2010 1
Golden Chicha	55.5	27.8	25.5	27.3	65.6
Argos Vigo	64.5	27.8	30.6*	23.5	64.9
Castelo	58.3	28.0	30.5	26.5	67.3
Baffin Bay	65.3*	31.8*	31.3	31.1*	86.2*
Beagle	70.3*	36.3*	38.6*	62.9*	92.5*

The 'Vessel' factor (Table 1) was significant in the GLM of *log* (iCPUE) in each season. Average iCPUE per vessel per season are summarized in Table 2. The *Golden Chicha* had the lowest average iCPUE in most seasons, and differences were statistically significant with the *Baffin Bay*, *Beagle*, and in one season, the *Argos Vigo*. These three vessels are the largest and most powerful of the five (Table 1), but the factor that appears closest related to the distribution of significant iCPUE differences is the ratio of horsepower over trawl width. This ratio is presumably proportional to trawl speed, which Paya (2008) concluded was the determinant criterion for relative fishing power. In the two most recent surveys (2010-1 and 2010-

2; the present survey), the *Beagle* and *Golden Chicha* averaged trawl speeds of 4.7 and 4.1 kts, respectively. Applying these speeds to the iCPUE of season 2010-1 in Table 2, for example, gives catch densities of 10.63 mt km^{-2} for the *Beagle* and 8.64 mt km^{-2} for the *Golden Chicha*[1]; a difference equivalent to the *Golden Chicha* having a little more than 80% of the catching power of the *Beagle*. A compensatory factor was not applied to the catches of the present survey, because the purpose of the survey is to provide a minimum estimate of fishable biomass. It should, however, be taken into consideration that along with escapement over the trawl net (Paya and Winter, 2009), the survey vessel's own speed and power may represent a variable constraint on catchability.

The model analysis of co-variables excluded two trawls for which bottom temperature and depth had not been recorded. The remaining 55 trawls covered a total of 15-minute 414 intervals. The best-fitting GAM for positive catch densities included all co-variables latitude, longitude, bottom temperature, bottom depth, and time-of-day per 15-minute interval. Generally, these co-variables had significant relationships over parts of their ranges: *log* of positive catch density decreased northward from about latitude 52.5 ºS to 52 ºS and increased northward from 50.7 ºS to 50.5 ºS; increased eastward from longitude 57.5 ºW to 57.2 ºW; increased marginally with increasing temperature from 5.4 ºC to 5.6 ºC; and increased with depth from about 130 m to 140 m depth (Figure 6). Average positive density in daytime intervals (6.10 mt km^{-2}) was significantly higher than in twilight (4.89 mt km^{-2}) or night (5.40 mt km^{-2}) intervals, but twilight and night were not significantly different from each other. The best-fitting GAM for presence / absence included co-variables latitude, longitude, bottom temperature, and time-of-day, but not depth. The probability of positive catch increased northward between latitude 51.5 ºS and 51 ºS and decreased northward between 51 ºS and 50.5 ºS; decreased eastward from longitude 58 ºW to 57 ºW; increased with temperature from 5.2 ºC to 5.3 ºC and decreased with temperature from 5.4 ºC to 5.8 ºC (Figure 7). Average probability of positive catch in daytime intervals (.894) was significantly higher than in twilight (.688) or night (.647) intervals, but twilight and night were not significantly different from each other. The combined GAM output of (back-transformed) positive catch densities × presence / absence probabilities was highly significantly correlated with the original, measured,

[1] Calculated as 92.5 kg / (m × hr x (4.7 × 1852 m hr^{-1})), and 65.6 kg / (m × hr x (4.1 × 1852 m hr^{-1}))

catch densities per interval ($p << 0.001$), although at a coefficient of determination (R^2) of only 0.135. The results indicate that distributions of *Loligo* in the Falklands zone are influenced by geographic and environmental factors; comparably to what has been found for *Loligo* species in other systems (Roberts and Sauer, 1994; Robin and Denis, 1999; Denis et al., 2002), but the predictive power of these factors is not high.

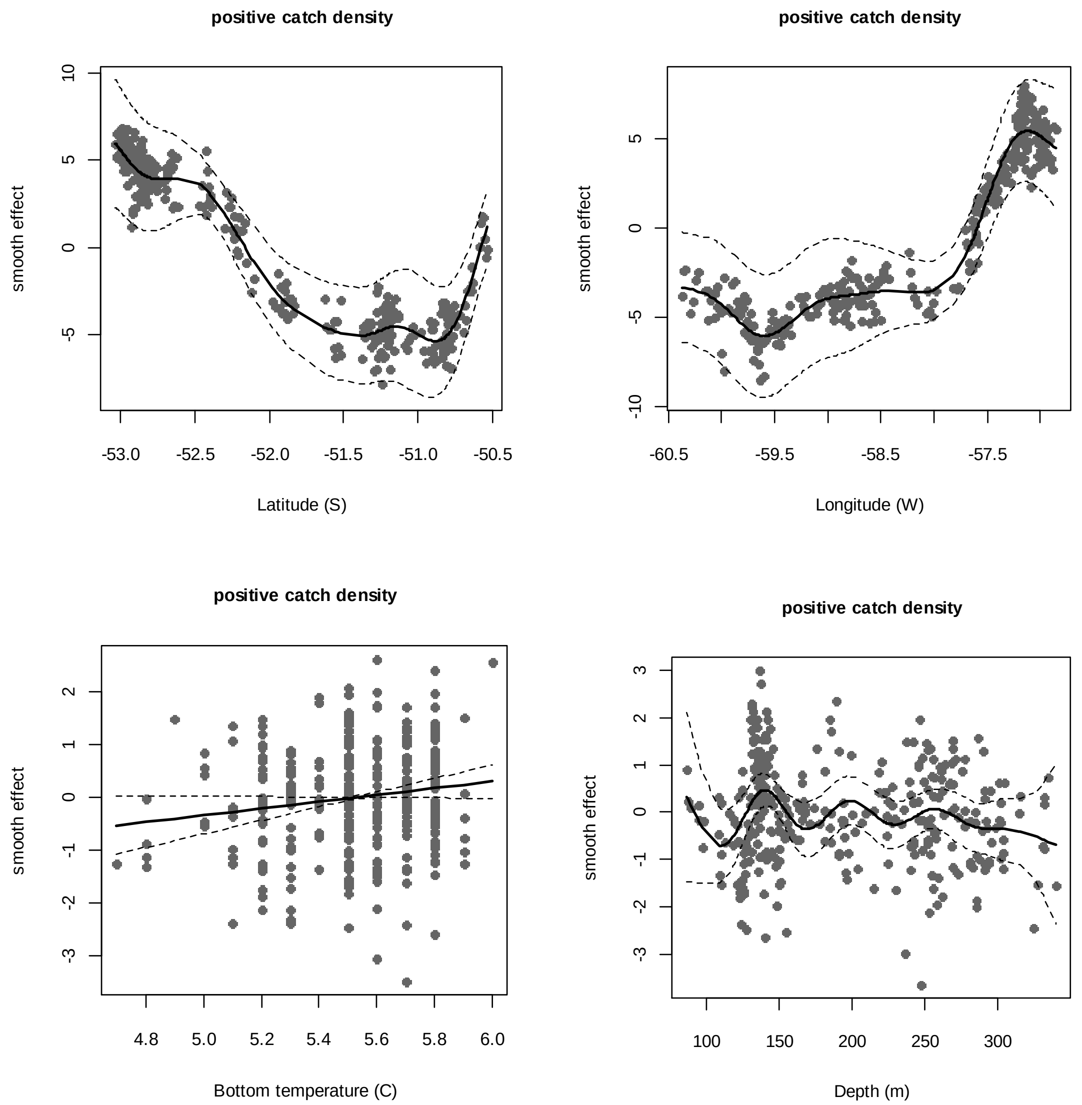

Figure 6. GAM smooth (black line) and partial residual (gray point) plots of the co-variables related to positive catch densities of *Loligo*. Dotted lines are 95% confidence intervals of the smooths. Statistically significant sections of each plot can be visualized by the rule of thumb that a horizontal line would intersect the 95% confidence intervals.

The proportion of survey trawl intervals corresponding strictly to daytime was 63%. Because of the statistical significance of catch density differences between daytime and twilight / nighttime, an additional version of the geostatistical model was calculated using only daytime intervals. The total *Loligo* biomass estimated from this version of the model was 73,088 ± 8,638 mt; 21,334 mt higher than the estimate calculated using all survey trawl intervals.

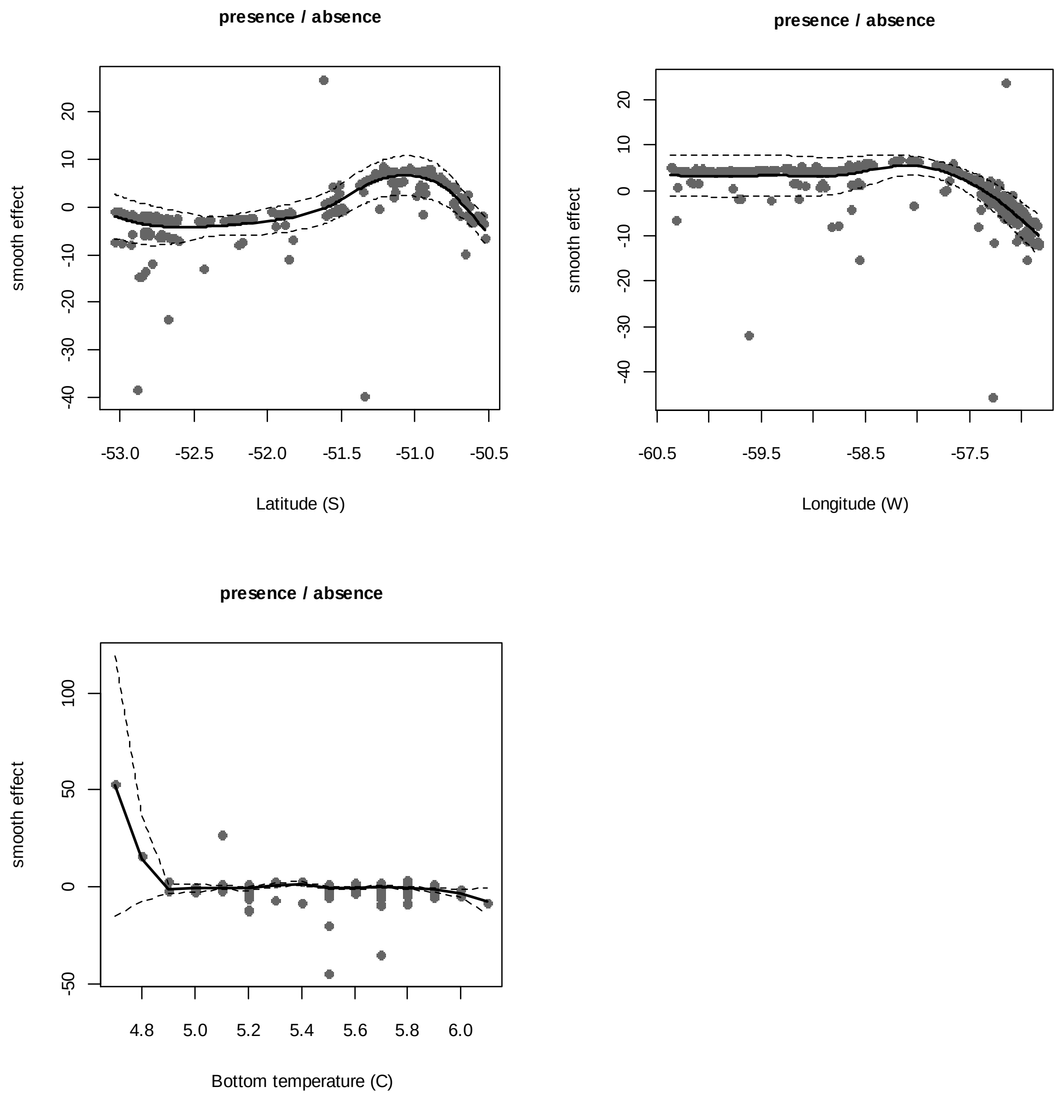

Figure 7. GAM smooth (black line) and partial residual (gray point) plots of the co-variables related to the presence / absence probability of positive *Loligo* catch. Dotted lines are 95% confidence intervals of the smooths. Statistically significant sections of each plot can be visualized by the rule of thumb that a horizontal line would intersect the 95% confidence intervals.

***Loligo* size and maturity**

Length-frequency distributions and maturities of male and female *Loligo* were analysed separately for trawl catches north and south of 52 ºS (Figure 8). North of 52 ºS, 14% of male *Loligo* were immature (maturity stages 1 and 2), 72% were maturing (maturity stages 3 and 4), and 14% were mature at stage 5. Of female *Loligo*, 91% were immature, 7% maturing, and 2% mature. Average mantle lengths were 12.2 cm for males and 11.1 cm for females. Maturity and size were more advanced south of 52 ºS, where 7% of male *Loligo* were immature, 56% were maturing, and 37% were mature. Of female *Loligo*, 78% were immature, 15% maturing, and 6% mature. Average mantle lengths were 14.3 cm for males and 12.5 cm for females. Both north and south of 52 ºS, average mantle lengths of male and female *Loligo* had a significant ($p < 0.05$) positive linear relationship with trawl depth. Average maturities of male *Loligo* also had a significant positive linear relationship with trawl depth, but average maturities of female *Loligo* did not.

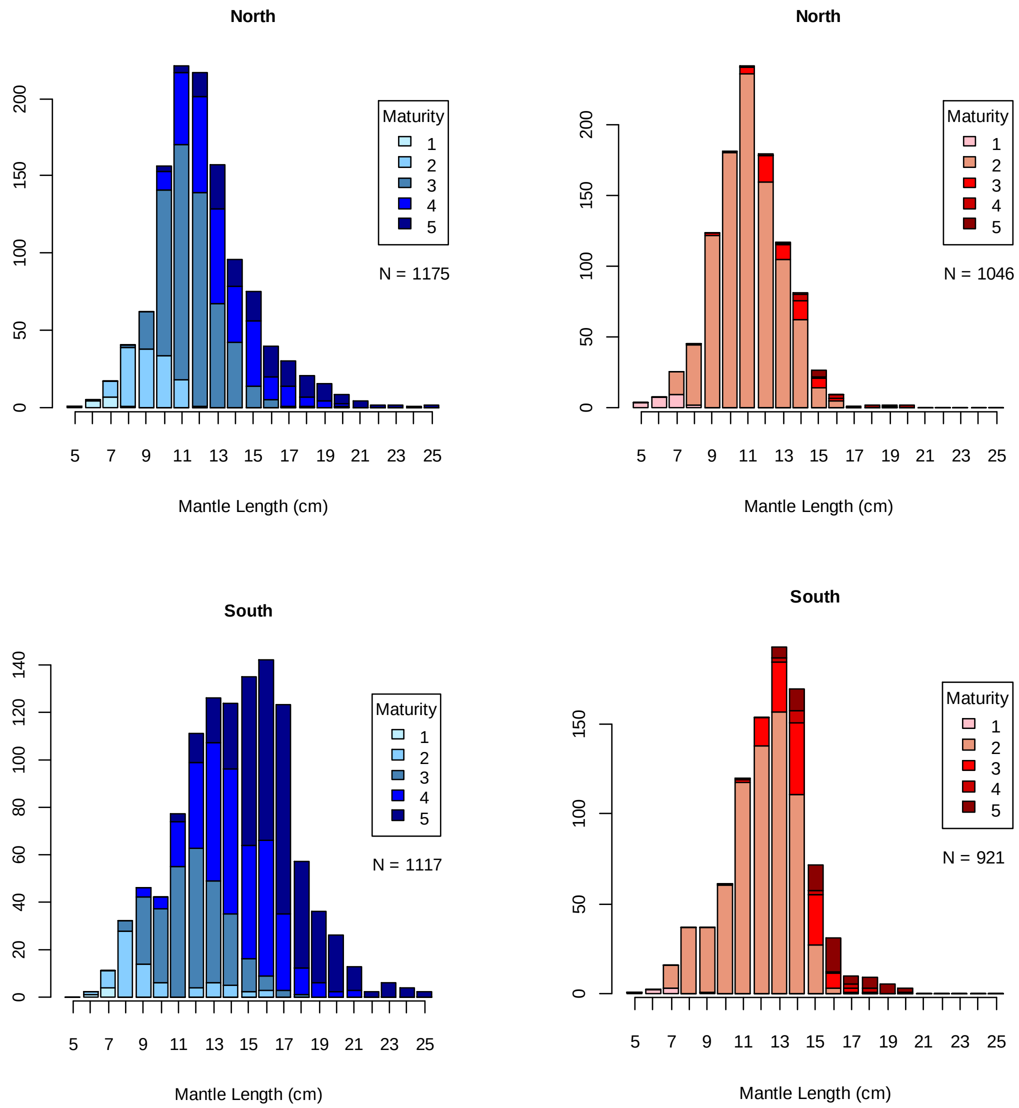

Figure 8. Length-frequency distributions by maturity stage of male (blue) and female (red) *Loligo* from trawls north (top) and south (bottom) of latitude 52 ºS.

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