FALKLAND ISLANDS FISHERIES DEPARTMENT

Loligo gahi Stock Assessment Survey, 1st Season 2011

Vessel	Venturer (ZDLP1), Falkland Islands
Dates	09/02/2011 - 23/02/2011
Scientific Crew	A. Winter, D. Davidson, M. Watson

SUMMARY

A stock assessment survey for *Loligo gahi* squid was conducted in the 'Loligo Box' from 9th to 23rd February 2011. A total catch of 66.76 mt *Loligo* was taken during the survey. Distributions of *Loligo* were low throughout the Loligo Box area, with only two moderately dense aggregations evident, north around FICZ grid XPAP, and south around FICZ grids XUAK-XVAK. *Loligo* density was statistically correlated with salinity (positive correlation at surface, negative correlation at bottom) and seawater temperature (negative correlation at surface, positive correlation at bottom). *Loligo* were at similar maturity stages north and south, with overall 67% of males immature and 31% of males maturing; 94% of females immature and 6% of females maturing. *Loligo* south showed slightly higher modal lengths, but large individuals (> 19 cm males and >17 cm females) were only encountered north.

A geostatistical estimate of 16,095 mt *Loligo* biomass was calculated for a fishing grounds area of 14,099.5 km^2. This estimate represents the lowest pre-season biomass for a first season since 2008. The highest catch densities were obtained in the later part of the survey and generally further inshore, suggesting that *Loligo* were still only beginning to out-migrate to the fishing zone.

INTRODUCTION

A stock assessment survey for *Loligo gahi* (Patagonian squid) was conducted by FIFD personnel onboard the fishing vessel *Venturer* from 9th to 23rd February 2011. 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). The 2011 delineation of the Loligo Box represents an area of approximately 31,118 km^2.

Objectives of the survey were to:

1) Estimate the biomass of *Loligo* on the fishing grounds at the onset of the 1st fishing season, 2011.
2) Examine the spatial distribution and biology of *Loligo*.
3) Examine the spatial distribution and biology of rock cod (*Patagonotothen ramsayi*), concurrently to the rock cod assessment survey on the FV *Castelo*.
4) Collect seawater salinity and temperature data along the trawls.
5) Collect biological data on *Loligo*, rock cod, ice fish (*Champsocephalus esox*), and any rare fish that were taken incidentally in the trawls.

The F/V *Venturer* is a Stanley, Falkland Islands - registered stern trawler of 84.2 m length, 1881 mt gross registered tonnage, and 2450 main engine bhp. Additional crew and equipment specifications are listed in Davidson (2011) and Watson (2011). Like all vessels employed for these pre-season surveys, *Venturer* operates regularly in the commercial *Loligo* fishery and used its commercial trawl gear for the survey catches.

The following personnel from FIFD participated in the survey:

Andreas Winter	stock assessment scientist
Deborah Davidson	observer
Michelle Watson	observer

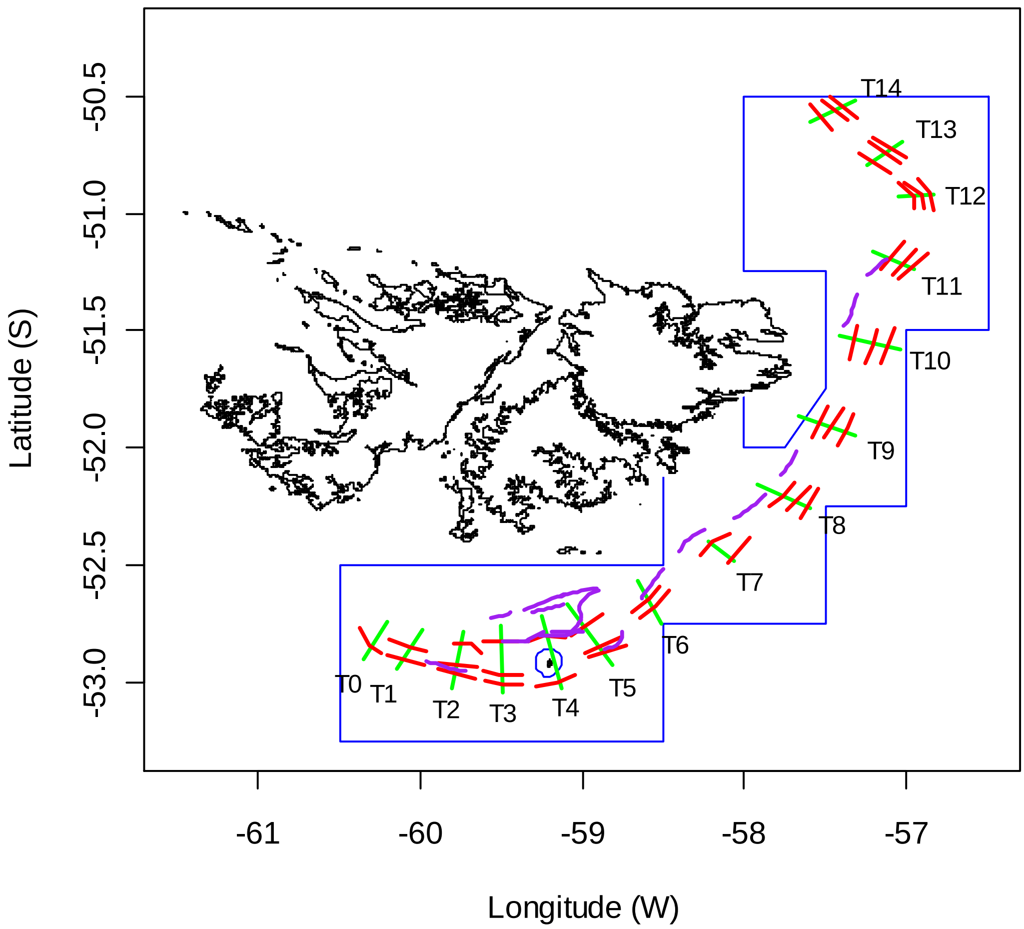


Figure 1. Transects (green lines), fixed-station trawls (red lines), and adaptive-station trawls (purple) sampled during the pre-season 1 2011 survey. Boundaries of the 'Loligo Box' fishing area and the Beauchêne Island exclusion zone are shown in blue.

METHODS

Sampling procedures

The survey plan was designed to include 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 *Loligo* biomass estimates in high-density or high-variability locations. 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 supervisor. 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.

Biomass calculations

Biomass density estimates of *Loligo* per trawl were calculated as catch weight divided by swept-area; 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 by acoustic sensors, as:

trawl width = (door dist. × footrope length) / (footrope + sweep + bridle lengths)

whereby the measurements of *Venturer*'s trawl were: footrope = 104 m, sweep = 165 m, and bridle = 30 m.

Biomass density estimates were extrapolated to the fishing grounds area using geostatistical methods described in Roa-Ureta and Niklitschek (2007) and Paya (2009). The methods are based on the approach of separately modelling positive (nonzero) catch densities, and the probability of occurrence (presence/absence) of the positive catch densities (Pennington, 1983). Positive catch densities were modelled with spatial correlation using a fitted variogram (Cressie, 1993) and Box-Cox transformation to normalize the data (MacLennan and MacKenzie, 1988). Presence/absence was modelled with spatial correlation by simulation using a Monte Carlo Markov Chain (MCMC) (Christensen, 2004; Roa-Ureta and Niklitschek, 2007). The same delineated fishing area of 14,099.5 km^2 as the previous season (Winter et al., 2010) was assumed, and partitioned for analysis as 453 area units of 5×5 km.

Sea temperature and salinity measurements

Sea temperature and salinity measurements were recorded using a mini-CTD instrument (Valeport Ltd., UK) attached to the trawl. At the start of each survey day, the instrument was lashed to the headrope near the centre of the net, inside a protective mesh cover prepared by the boatswain of the *Venturer* (Figure 2). The instrument recorded conductivity (mS/cm), temperature (ºC) and pressure (dBar) continuously at a frequency setting of 1 Hz. Pressure was converted to depth as:

Depth (m) = dBar / 1.01325 (one atmosphere)

Conductivity was converted to salinity units according to the practical salinity scale PSS-78 (UNESCO 1983).

For this report, surface temperature and salinity, and bottom temperature and salinity were examined. Surface temperature and salinity were defined as the average of measurements within 2 m of the surface after deployment and before retrieval; thus two data each per trawl. Surface positions were assigned as the start and end trawl positions. While this is not technically accurate (start and end trawl positions are recorded when the net is in fishing position), it is a sufficient approximation for area coverage. Bottom temperature and salinity were defined as all measurements sequentially recorded while the trawl was on the sea bottom, determined by inspection of the depth profile. This resulted in several thousand measurements for most trawls. Bottom positions were assigned by interpolating the start and end trawl positions. Surface and bottom temperature and salinity were then mapped across the fishing area by interpolation from the assigned measurement positions. Relationships between sea temperatures and salinities, and *Loligo* densities, were analyzed using generalized additive models (GAM) (Hastie and Tibshirani, 1990).

Figure 2. The Valeport mini-CTD, being lashed to the headrope of the net at the start of a day's survey trawling.

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. Relationships between dorsal mantle length or maturity stage, and depth, were analyzed using GAM. 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, 2005). 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. Ice fish were frozen for stomach content analysis, and rare or unknown fish were frozen for identification, to be conducted at FIFD.

RESULTS and CONCLUSIONS

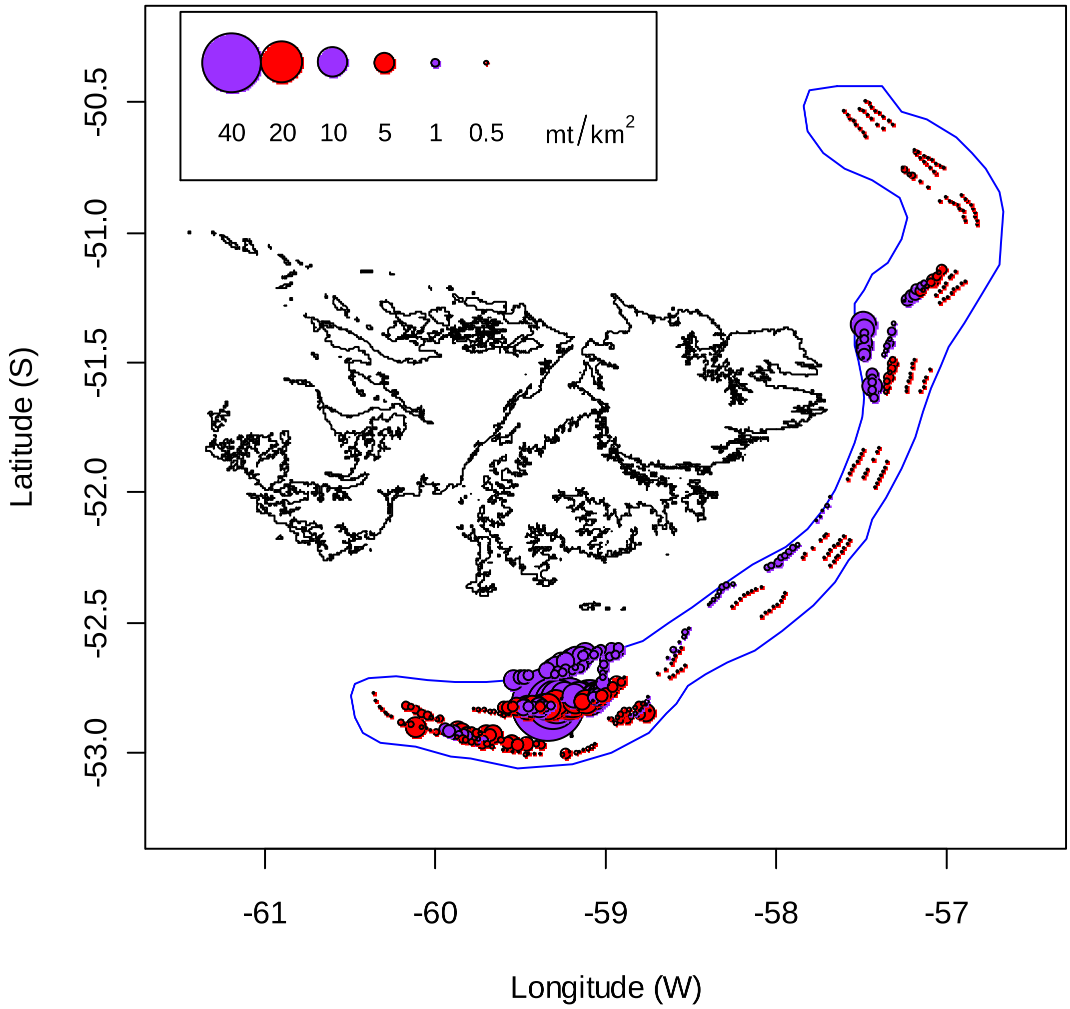


Figure 3. *Loligo* CPUE (mt km^{-2}) of fixed-station trawls (red) and adaptive trawls (purple), per 15-minute trawl interval. The boundary of the fishing area is shown in blue.

Catch rates and distribution

As in prior seasons (Arkhipkin et al., 2010; Winter et al., 2010), the survey was started with fixed-station trawls in the north of the Loligo Box (on transect 14; Figure 1) and proceeded southward. Fifty-nine scientific trawls were recorded during the survey: 39 fixed station trawls catching 16.84 mt *Loligo* and 20 adaptive trawls catching 33.50 mt *Loligo*. Additionally, three optional trawls (made after survey hrs) yielded 16.42 mt *Loligo*, bringing the total catch for the survey to 66.76 mt. Overall *Loligo* catches were significantly lower than in either pre-season survey of 2010 (Arkhipkin et al., 2010; Winter et al., 2010), averaging (among fixed-station trawls)

0.11 mt km^{-2} north of 52º S and 0.94 mt km^{-2} south of 52º S. The total fixed-station trawl density average (north + south) was 0.56 mt km^{-2}, vs. 2.97 mt km^{-2} for the total adaptive trawl density average. Adaptive trawls were mostly further inshore than the fixed-station trawls (Figure 3), and in accordance with the survey design, were taken later. The relatively much higher average densities of adaptive trawls thus suggest that *Loligo* were still only beginning to out-migrate.

Biomass estimation

The best variogram fit for positive catch densities was obtained with an exponential correlation function censored to ≤260 km, and logarithmic transformation of catch densities (Figure 4). This variogram function converged with a range of 203.8 km, indicating that *Loligo*, where present, spatially correlated over a maximum of 203.8 km separation distance. Semi-variances were higher still at >260 km, but with a clear disjunction in the trend. This suggests that *Loligo* that far apart

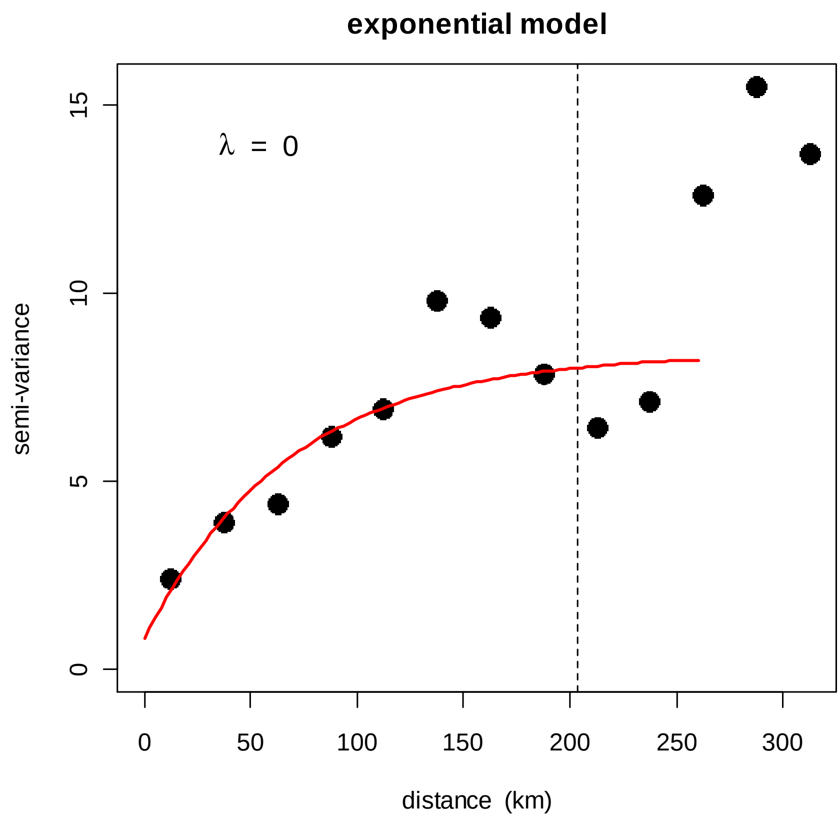


Figure 4. Empirical variogram (black points) and exponential model variogram (red line) of *Loligo* positive catch density distributions. The model variogram had a correlation range of 203.8 km (dotted line). λ = 0 indicates that catch densities were log-transformed.

represented different aggregations or sub-populations, and distances >260 km were therefore not included in the model. The positive catch density model showed two zones of moderately high density: north around FICZ grid XPAP, and south around FICZ grids XUAK-XVAK (Figure 5A). The MCMC for presence/absence was modelled on the binomial distribution; also with an exponential function for spatial correlation. Including spatial correlation resulted in highly increased likelihood of the model, as determined by the Akaike Information Criterion. The MCMC for presence/absence predicted *Loligo* catch probability >50% in 398 of the 453 units (Figure 5B). Acoustic marks along the actual survey tracks had been recorded ‘positive’ on 370 of 434 track intervals. Paradoxically, the low yield of catches during this survey resulted in comparatively more ‘positive’ intervals than otherwise, because the method of visual assessment (Roa-Ureta and Arkhipkin, 2007) relies on observable differences from interval to interval. When all intervals of a trawl are indistinguishably near-zero, then whatever small amount of *Loligo* catch does come out has to be averaged among them, and therefore all intervals are ‘positive’.

Total *Loligo* biomass in the fishing area was estimated by the geostatistical model at 16,095 mt, with a standard error of ± 4,722 mt. Of this estimated total, 6,889 mt were north of 52 ºS, and 9,206 mt were south of 52 ºS. The median density per area unit was 0.27 mt km^{-2}, with a 95% confidence interval of 0.0009 to 8.46 mt km^{-2}. Since presence/absence probabilities were high, the distribution of total predicted density (Figure 5C) is very similar to the distribution of positive catch densities (Figure 5A). The biomass estimate is the lowest for a first season since 2008, and the survey catch is the lowest since surveys in this format were initiated in 2006 (Table 1). Because survey catches were concentrated around two separate zones far apart (Figure 3), the geostatistical model still projected a moderate overall biomass. In first seasons 2006, 2007, and 2008, total *Loligo* catches had been higher, but they were concentrated only in the south (Paya and Roa-Ureta, 2006; Paya, 2007; 2008).

Table 1. *Loligo* pre-season survey 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			

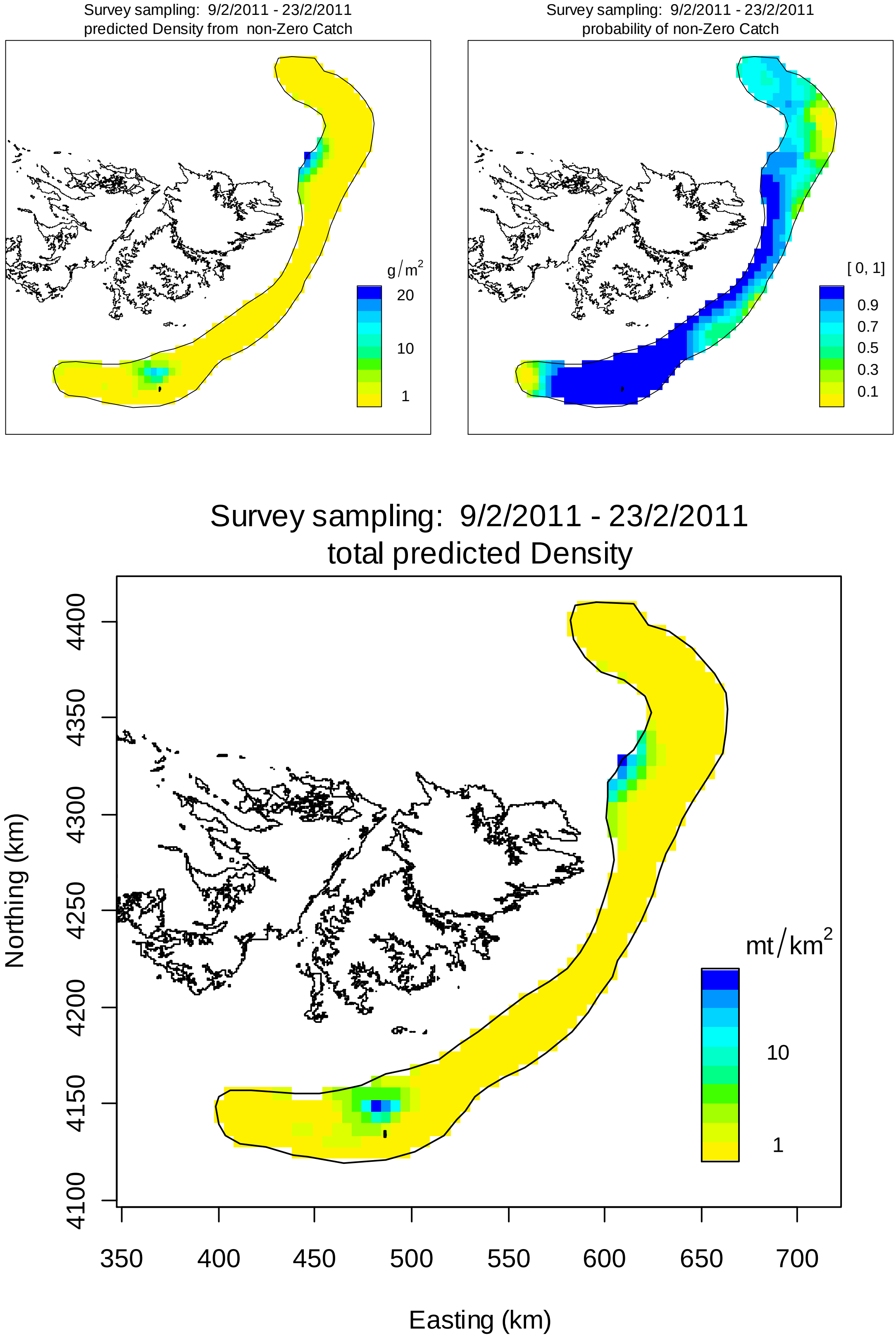
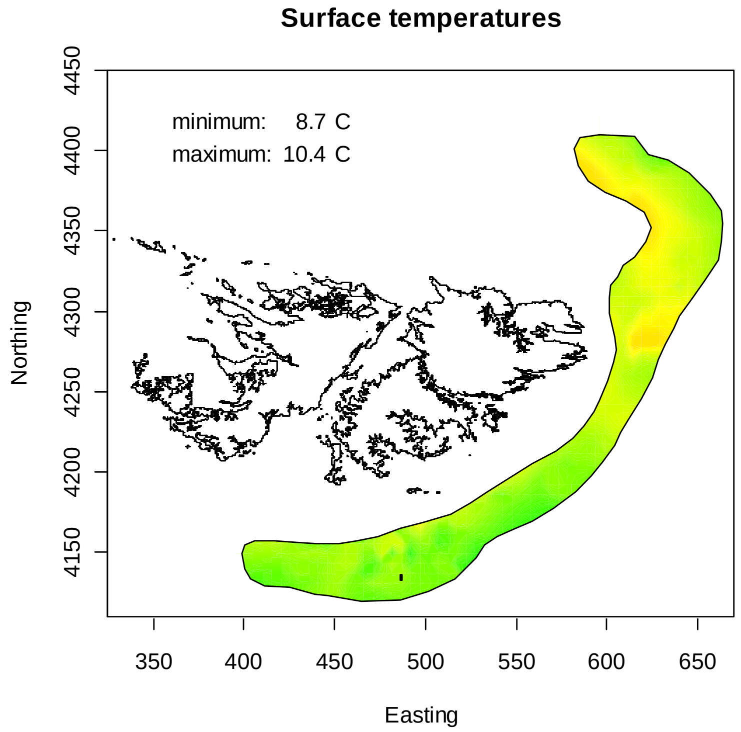


Figure 5. *Loligo* density estimates per 5 × 5 km area units. Top left (A): catch density distribution from variogram model of positive catches. Top right (B): probability of positive catch modelled from MCMC of presence/absence. Main plot (C): predicted density = A × B. For calculating geostatistical estimates, coordinates are converted to WGS 84 projection (using GeoConv software, www.kolumbus.fi/eino.uikkanen/geoconvgb/index.htm).

Sea temperature and salinity

The Valeport mini-CTD returned useable data from 56 of the 59 scientific trawls. The manufacturer's rating for the instrument battery appears to have been overstated, as recording fell short of complete trawl duration on a number of stations.



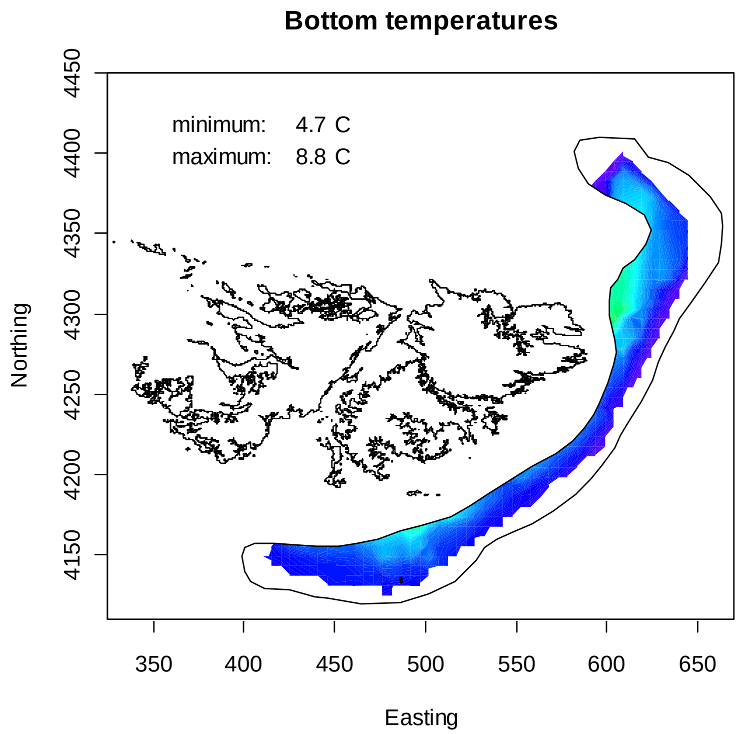
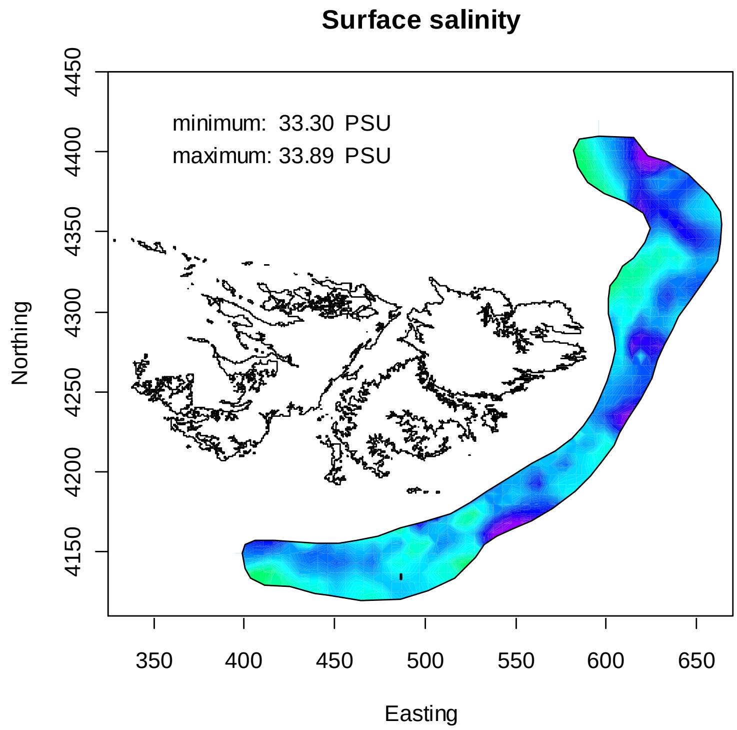
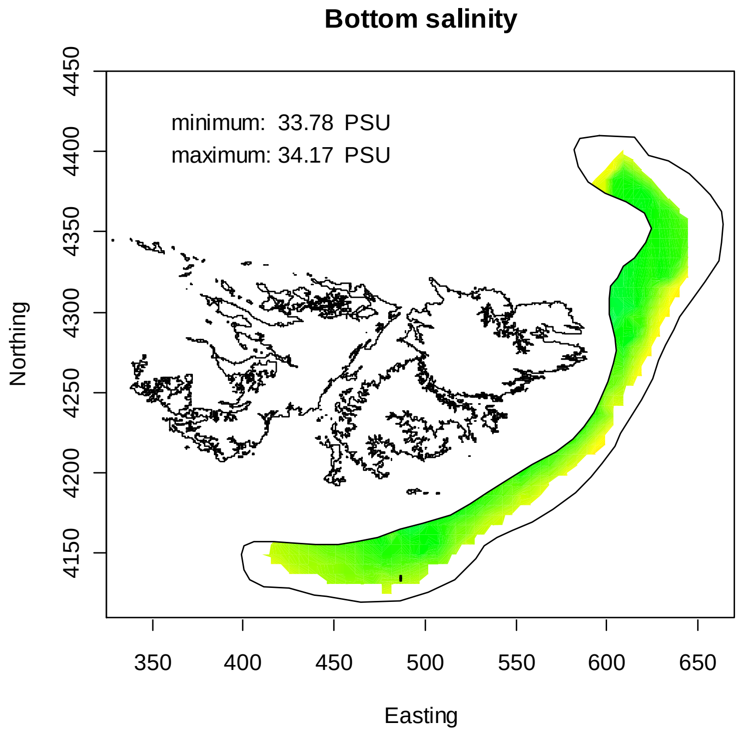


Figure 6 [previous page]. Surface (upper) and bottom (lower plot) sea temperatures interpolated from measurements of the mini-CTD attached to the trawl. Both plots to same scale; temperature increasing purple → yellow.

Figure 7 [below]. Surface (upper) and bottom (lower plot) salinities interpolated from measurements of the mini-CTD attached to the trawl. Both plots to same scale; salinity increasing purple → yellow.





Approximately 84% of targeted CTD data was acquired in all. Surface temperatures and salinities were cubic-spline interpolated, which allowed extrapolation to the entire fishing area (Figures 6 and 7, upper plots). Bottom temperatures and salinities were linear-interpolated, because the irregular spacing of data (very close within trawls, much further among trawls) gave unreliable results to the cubic spline function. Data could therefore not be extrapolated beyond the convex hull of the trawl samples (Figures 6 and 7, lower plots).

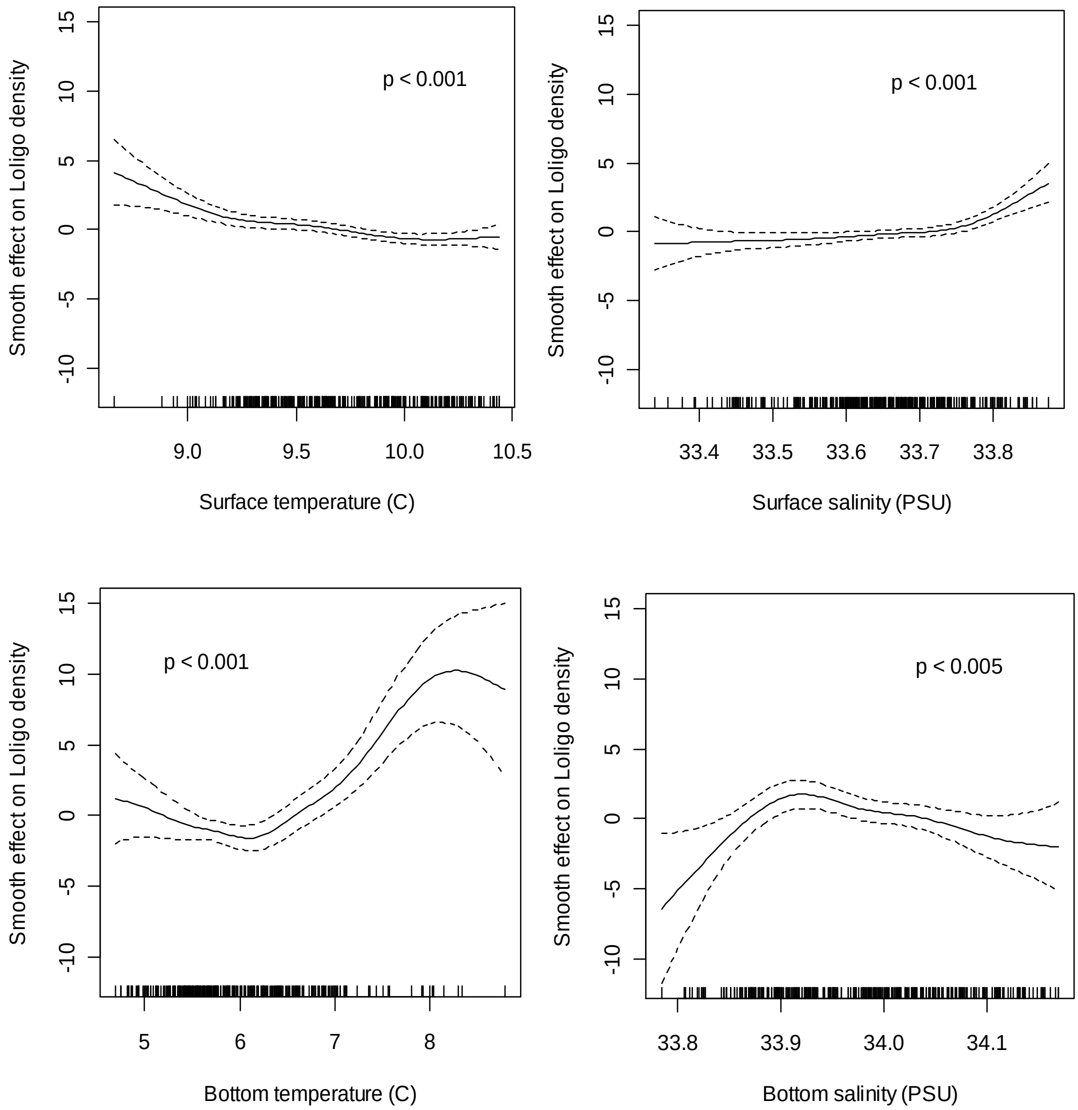


Figure 8. GAM smooths of oceanographic co-variables related to *Loligo* density. The GAM was calculated jointly on the four co-variables, thus each plot shows the partial effect. Dotted lines are the 95% confidence intervals.

The spatial distribution of *Loligo* densities (Figure 5C) was significantly related to surface and bottom temperatures and salinities. The most parsimonious GAM (as determined by lowest Akaike Information Criterion) included all four variables jointly:

Loligo density ~ *s*(surf. temp.) + *s*(surf. salinity) + *s*(bot. temp.) + *s*(bot. salinity),

resulting in 56.1% of *Loligo* density deviance explained. *Loligo* density increased with increasing bottom temperature between 6.2 ºC and 8.0 ºC and increasing surface salinity above 33.6 PSU (Figure 8). *Loligo* density decreased with increasing surface temperature up to 10.0 ºC, and with increasing bottom salinity above 33.9 PSU (Figure 8).

***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 9).

North of 52 ºS, 69% of male *Loligo* were immature (maturity stages 1 and 2), 29% were maturing (maturity stages 3 and 4), and 2% were mature at stage 5. Of female *Loligo*, 91% were immature, and 9% were maturing. South of 52 ºS, 67% of male *Loligo* were immature, 32% were maturing, and 1% was mature. Of female *Loligo*, 94% were immature, and 6% were maturing. North of 52 ºS, maturities of male and female *Loligo* had a significant negative relationship with trawl depth, i.e., more mature *Loligo* were caught in shallower water (Figure 10). South of 52 ºS, the relationship between maturity and trawl depth was also negative for males and females, but only marginally significant for females (Figure 10).

Mantle lengths did not have any significant relationship with depth, for males or females, north or south. North of 52 ºS, modal mantle lengths were 12 cm for males and 11 cm for females, and both mantle length distributions were characterized by a small number of high values: up to 25 cm. South of 52 ºS, modal mantle lengths were 13 cm for males and 12 cm for females, but no lengths above 19 cm (males) and 17 cm (females) were encountered (Figure 9).

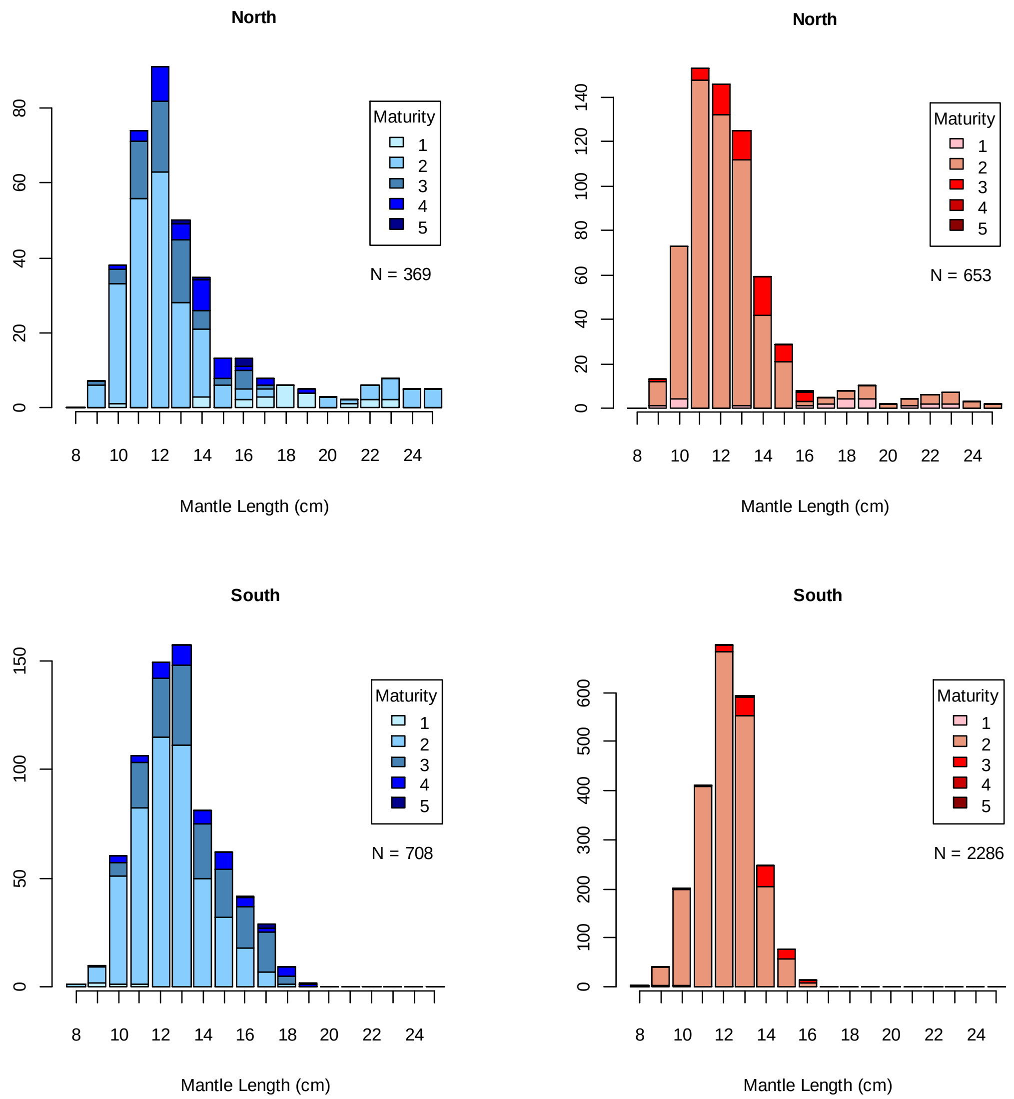
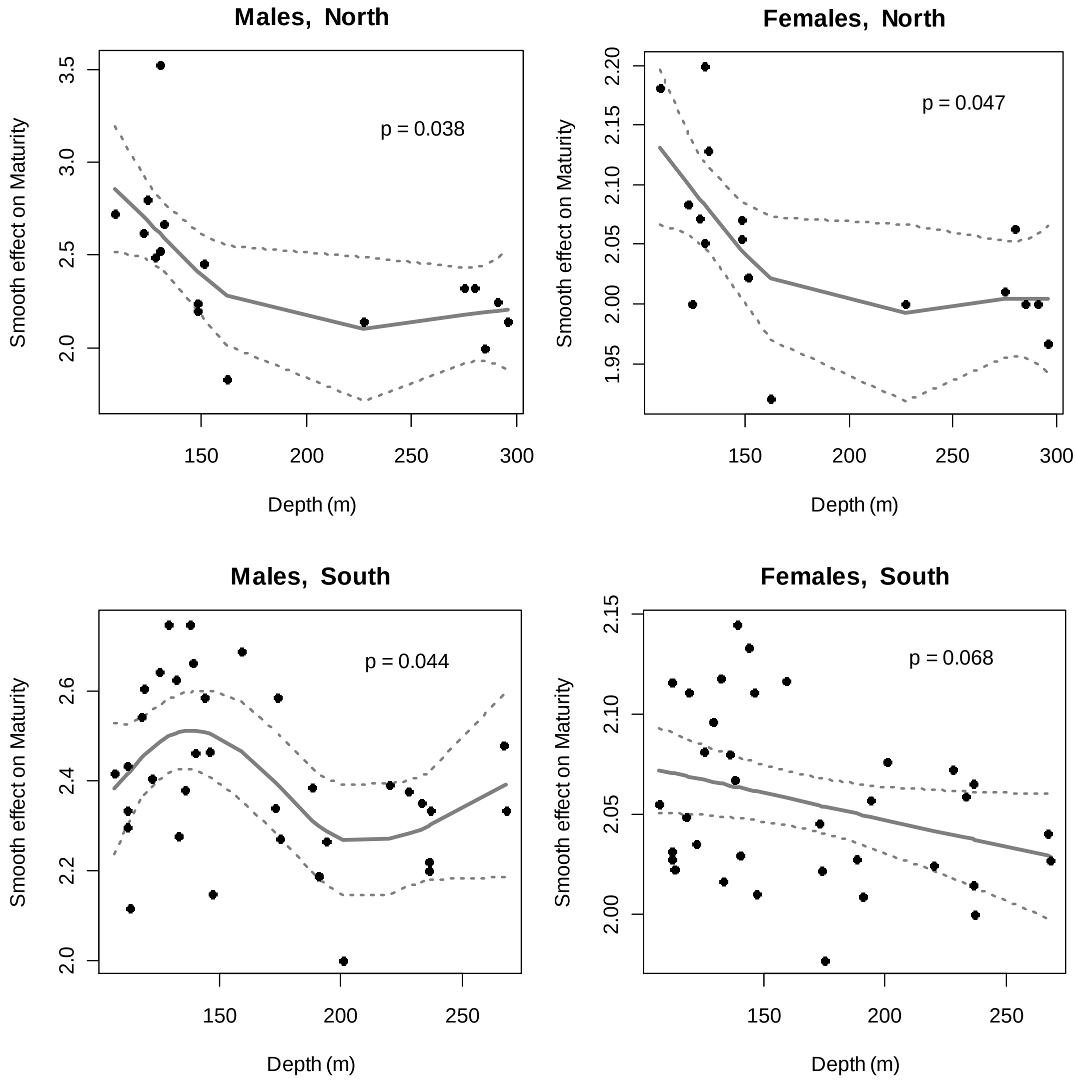


Figure 9. Length-frequency distributions by maturity stage of male (blue) and female (red) *Loligo* from trawls north (top) and south (bottom) of latitude 52 °S.

Figure 10 [next page]. GAM smooths (gray lines) and sample data (black circles) of *Loligo* maturity as a function of depth. Dotted lines are the 95% confidence intervals. Statistically significant sections of each plot can be visualized by the rule of thumb that a horizontal line would intersect the 95% confidence intervals.



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