FALKLAND ISLANDS FISHERIES DEPARTMENT

Loligo Stock Assessment Survey, 2nd Season 2014

Vessel	Golden Chicha (ZDLC1), Falkland Islands
Dates	07/07/2014 - 21/07/2014
Scientific Crew	A. Winter, J. Jones, D. Herrera

Summary

1) A stock assessment survey for *Loligo* squid was conducted in the 'Loligo Box' from 7th July to 21st July 2014. Fifty-eight scientific trawls were taken during the survey, catching 207.49 tonnes of *Loligo*.
2) A geostatistical estimate of 40,090 tonnes *Loligo* (95% confidence interval: 30,228 to 64,677 t) was calculated for the fishing zone. This represents the third-highest 2nd-season survey estimate since 2006, inclusively. Of the total, 17,877 t were estimated north of 52 ºS, and 22,213 t were estimated south of 52 ºS.
3) *Loligo* catches in this survey included an uncommonly high proportion of large, older individuals. North of 52 ºS, males had a bimodal mantle length distribution (10 and 17.5 cm), with 41% of males ≥13 cm at maturity stage 5. Females had a bimodal mantle length distribution (10 and 15 cm), with 53% of females ≥13 cm at maturity stage 3. South of 52 ºS, males were unimodally distributed (12.5 cm) with 42% of all individuals at maturity stage 4 and 28% at maturity stage 5. Females were unimodally distributed (13 cm) with 27% of all individuals at maturity stage 2 and 62% at maturity stage 3.
4) Seventy-five taxa were identified in the catches, of which *Loligo* made up 70.0% by weight. Biological measurements and samples were taken from *Loligo*, toothfish *Dissostichus eleginoides*, rock cod *Patagonotothen ramsayi*, shortfin squid *Illex argentinus*, hoki *Macruronus magellanicus*, and opportunistic specimens of various other species.

Introduction

A stock assessment survey for *Loligo* (*Doryteuthis gahi* - Patagonian squid) was carried out by FIFD personnel onboard the fishing vessel *Golden Chicha* from 7th July to 21st July 2014. This survey continues the series of surveys that have, since February 2006, been conducted immediately prior to the opening of *Loligo* season. These surveys provide data to estimate the *Loligo* stock available for commercial fishing at the start of the season, and to initiate the in-season management model based on depletion of the stock. Pursuant to changes in *Loligo* season scheduling implemented this year (Fisheries Committee, 2013), 7th July was the latest start to a second-season survey since the current format of surveys was established in 2006.

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.

Objectives of the survey were to:

1) Estimate the biomass and spatial distribution of *Loligo* on the fishing grounds at the onset of the 2nd fishing season, 2014.
2) Sample lengths, sex, maturity and survivability of toothfish (*Dissostichus eleginoides*) to improve the assessment of toothfish bycatch in *Loligo* trawls.
3) Collect biological information on *Loligo*, common rock cod (*Patagonotothen ramsayi*), and opportunistically other fish and squid taken in the trawls.

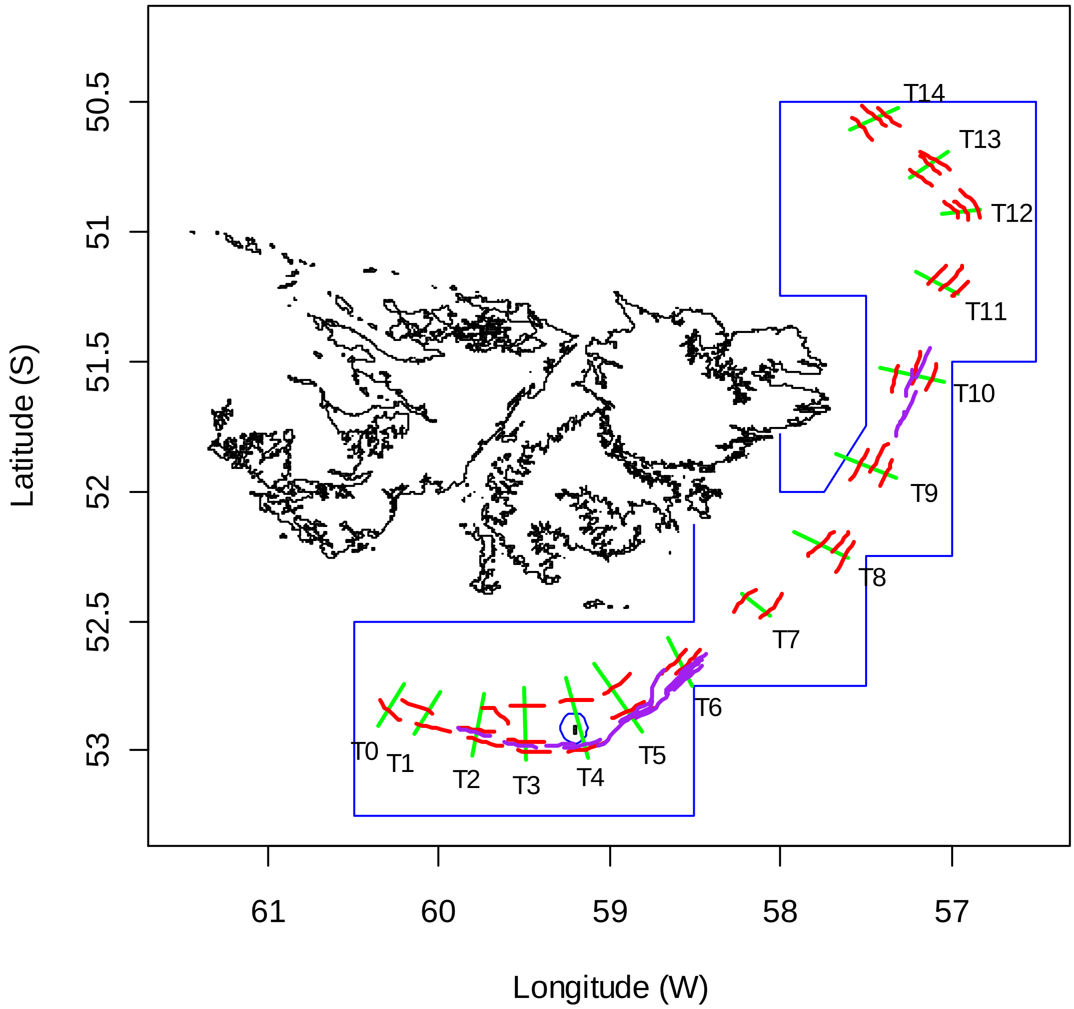


Figure 1. Transects (green lines), fixed-station trawls (red lines), and adaptive-station trawls (purple lines) sampled during the pre-season 2 2014 survey. Boundaries of the 'Loligo Box' fishing zone and the Beauchêne Island exclusion zone are shown in blue.

The F/V *Golden Chicha* is a Stanley, Falkland Islands - registered stern trawler of 69.8 m length, 1345 t gross registered tonnage, and 2200 main engine bhp. Further operational specifications are described in Sobrado (2013). Like all vessels employed for pre-season surveys, *Golden Chicha* operates regularly in the commercial *Loligo* fishery and used its commercial trawl gear for the survey. *Golden Chicha* was also used for the 1st pre-season survey in 2008 (Payá, 2008) and the 2nd pre-season surveys in 2010 and 2013 (Winter et al., 2010; Winter et al., 2013b). The following personnel from FIFD participated in this survey:

Andreas Winter	survey scientist
Jessica Jones	lead fisheries observer
Denise Herrera	fisheries observer

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 21 adaptive-station trawls selected to increase the precision of *Loligo* biomass estimates in high-density or high-variability locations. The same fixed-station plan as previous surveys (e.g., Winter et al., 2013b) was used, with trawls ranging in distance from 10.5 to 18.7 km (mean 15.3 km). The trawls were designed for an expected duration of 2 hours each, but this is variable with the fishing power of the vessel and sea conditions. All trawls were bottom trawls. During the progress of each trawl, GPS latitude/longitude, bottom depth, bottom temperature, net height, trawl door spread, and trawling speed were recorded on the ship's bridge at 15-minute intervals, and a visual assessment was made by the survey scientist 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 increase spatial resolution of the catches. For small catches acoustic apportioning cannot be assessed with accuracy, and any *Loligo* amounts <100 kg were iteratively aggregated with adjacent intervals (but if the total *Loligo* catch in a trawl was <100 kg it was assigned to one interval; the middle one).

Catch estimation

The 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 fish species and *Illex* squid were recorded in the same way, with hake and hoki trunks separated into 'large' and 'small' size categories. Processed product weights were scaled to whole weights using standard conversion factors (FIG, 2011). Discards of damaged, undersized, or commercially unvalued fish 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; 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, from the Marport net sensor system) according to the equation:

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

(www.seafish.org/media/Publications/FS40_01_10_BridleAngleandWingEndSpread.pdf)

Measurements of *Golden Chicha*'s trawl were: footrope = 95 m and bridle = 145 m.

For two trawls on one day of the survey (16th July) the Marport door distance sensor was nonoperational. Door distances that day were instead estimated from a generalized additive model (GAM) as a function of predictive variables trawl depth, trawl speed, net height and warp cable out; calculated with all other survey days' data on which the door distance sensor was operational (n = 463). All four predictive variables were statistically significant ($p < 0.003$) and the GAM resulted in 47% deviance explained. This procedure was also used in the 1st season 2010 and 1st season 2014 surveys when door distance sensors were nonoperational (Arkhipkin et al., 2010; Winter and Jürgens, 2014).

Previous survey reports (Winter et al., 2012; 2013b) found that *Loligo* catches taken in daylight were significantly higher than those that extended into darkness, due to *Loligo*'s diel vertical migratory behaviour (Roper and Young, 1975). The daylight effect was re-examined in this survey by assigning to every 15-minute trawl interval (and its corresponding apportioned *Loligo* catch density) an index of whether or not it was completed within the period of daytime, from sunrise to sunset. Sunrise and sunset times at each location were calculated using the algorithms of the NOAA Earth System Research Laboratory (www.esrl.noaa.gov/gmd/grad/solcalc/calcdetails.html). 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. The estimate that obtained the best geostatistic model was taken as the final result.

Biomass density estimates were extrapolated to the survey area using geostatistical methods (Petitgas, 2001). The same survey area as the previous 2nd season (Winter et al., 2013b) was delineated (Figure 2), which is more restricted than the survey area of the 1st season (Winter et al., 2013a; Winter and Jürgens, 2014). The present delineated survey area is 14,865.7 km^2, and partitioned for analysis as 592 area units of 5×5 km. Previous *Loligo* surveys used the approach of separately modelling positive (non-zero) catch densities, and the probability of occurrence (presence/absence) of the positive catch densities (Pennington, 1983), but for the current survey better variogram fits were obtained by modelling all catch densities per interval together. Due to transformation functions within the geostatistic algorithm, input density values could not equal zero, and therefore a total of 1% of *Loligo* catch weight in each trawl was subtracted from the intervals to which it was assigned and added back to all intervals (in both cases proportionally to their duration).

Uncertainty in 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). To this uncertainty was added a measure of error of the acoustic apportionment of the *Loligo* catch data. Assessing the acoustic marks (as described above; Sampling Procedures) is a visual judgement, and does not objectively differentiate *Loligo* from other echo targets entering the net. There is therefore no definitive way to quantify the potential error of this assessment. A surrogate measure was instead calculated using the linear coefficient of determination (R^2) between total acoustic score per trawl (Σ (acoustic mark quantity × quality)$_{trawl}$) and total *Loligo* catch per trawl. Acoustic scores are relative values referenced to each individual trawl, but as all were assigned by the same survey scientist, their absolute values should be consistent across all trawls[1]. The unexplained error of the linear relationship ($1 - R^2$) was multiplied by each interval catch of each trawl and randomly either added to or subtracted from the interval catch:

[1] For comparison, error of acoustic apportionment was also calculated retrospectively for the 2nd season 2011 survey, in which the scientist of this survey did not participate, and acoustic scores had instead been assigned by the fishing master. Comparisons are discussed in the Appendix.

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

Thus, if the relationship was perfect ($R^2 = 1$) there would be no random effect, and if the relationship was null ($R^2 = 0$) each interval would be randomly either doubled or set to zero (a negative slope is for this purpose considered equivalent to null). The set of $r\,C_{\text{interval}}$ for each trawl was re-standardized to the total *Loligo* catch weight of that trawl, then put through the same algorithms of density and geostatistic extrapolation as the empirical results. The randomization was iterated 1000× and the coefficient of variation of the mean geostatistic density retained as the measure of error of acoustic apportionment[2].

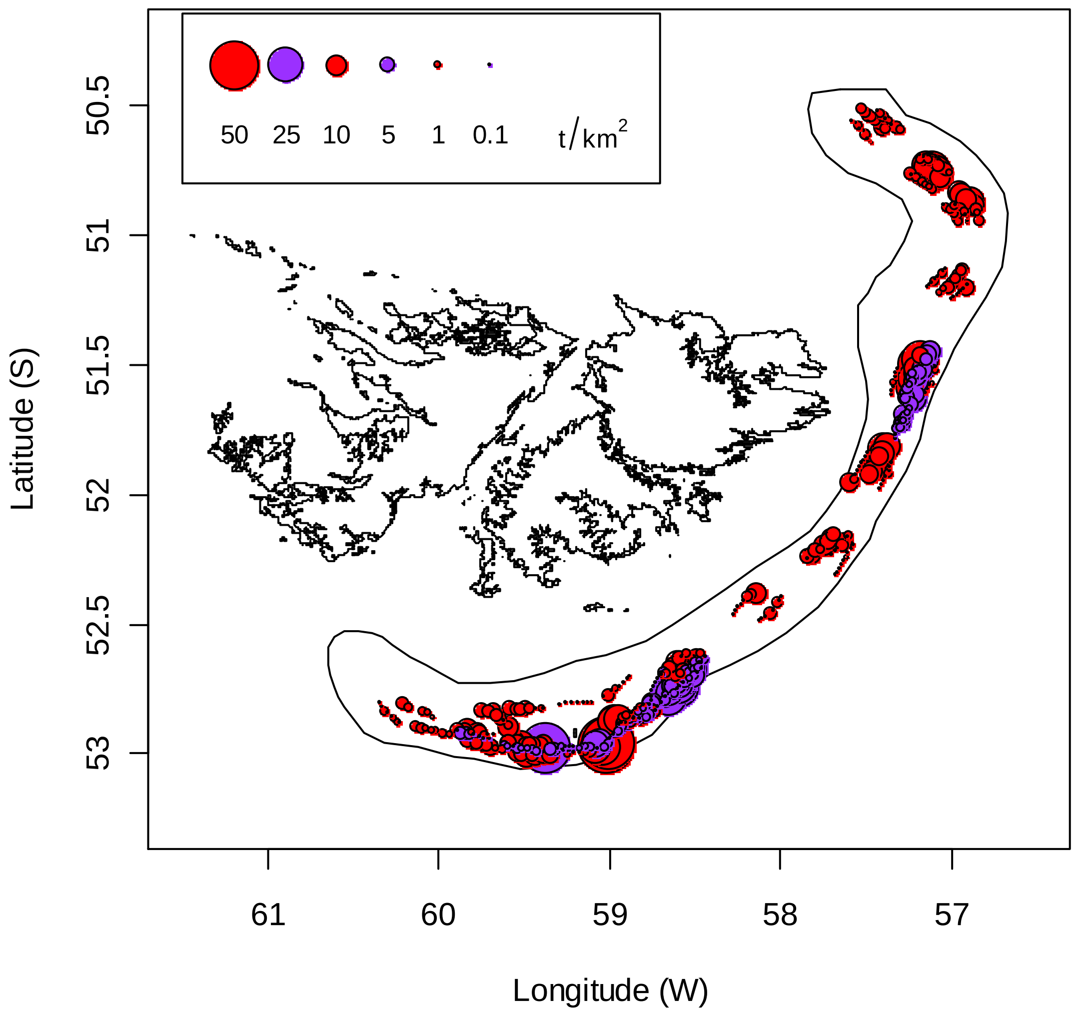


Figure 2. *Loligo* CPUE (t km^{-2}) of fixed-station trawls (red) and adaptive trawls (purple), per 15-minute trawl interval. The boundary of the survey area is outlined.

[2] 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 thereby biased lower. Thus only the relative value of the coefficient of variation is used.

Sea temperature and wind data

Sea bottom temperatures were recorded by the vessel's net sounder, and near-surface temperatures were recorded by a hull-mounted sensor. Additionally, sea wind and sea surface temperatures on a daily time resolution and 0.25° grid were obtained from the NOAA National Climatic Data Center websites. Sea wind data are blended observations from multiple satellites with wind speed (m/s) resolved into north-south and east-west vectors (Zhang et al., 2006). Sea surface temperature data are observations from the Advanced Very High Resolution Radiometer (AVHRR) (Reynolds et al., 2007). Four days across the survey period are shown for illustration in Figures 3 and 4.

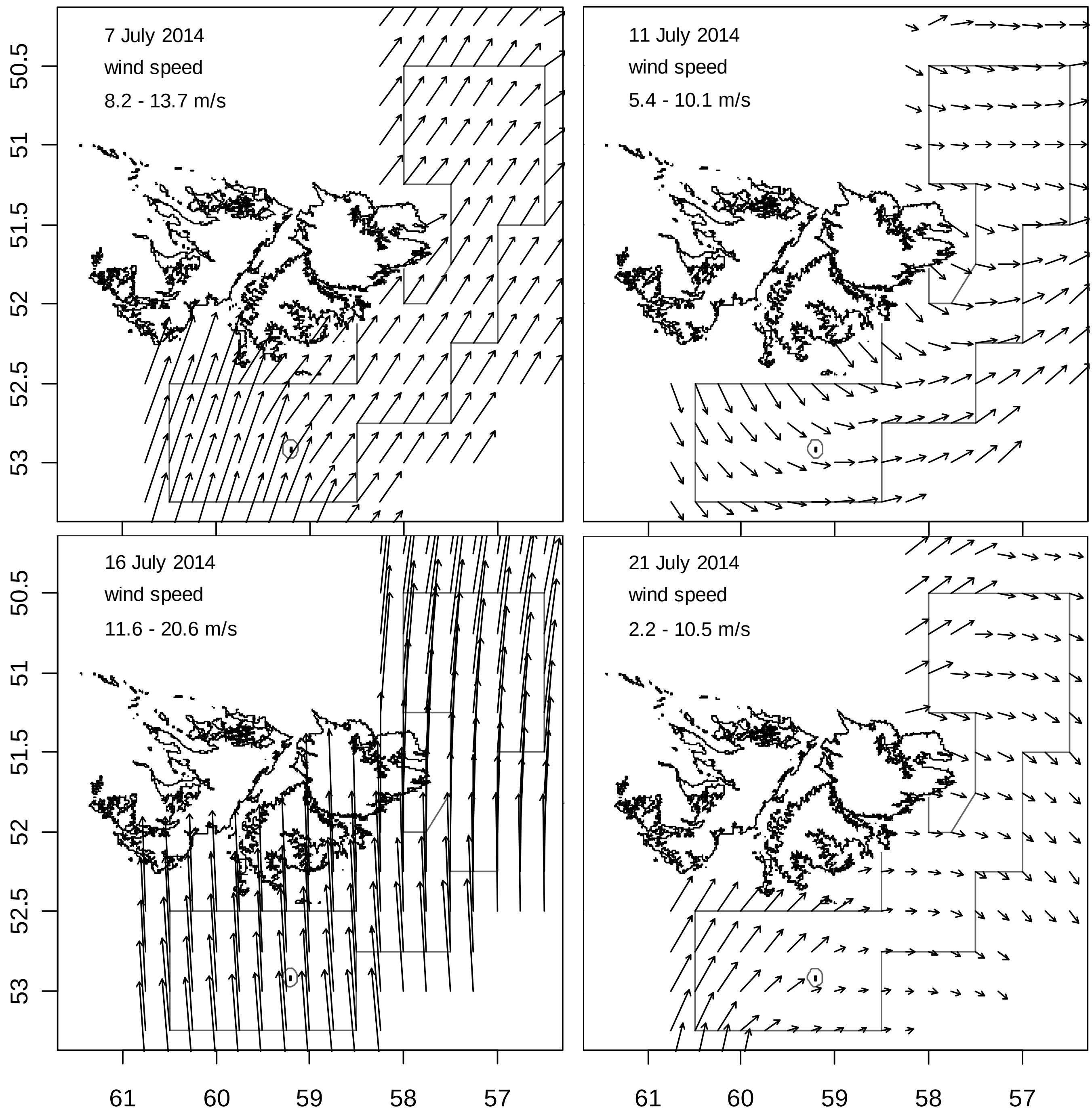


Figure 3 [previous page]. Sea wind vectors at 0.25° resolution, from satellite observations, on four days of the survey period.

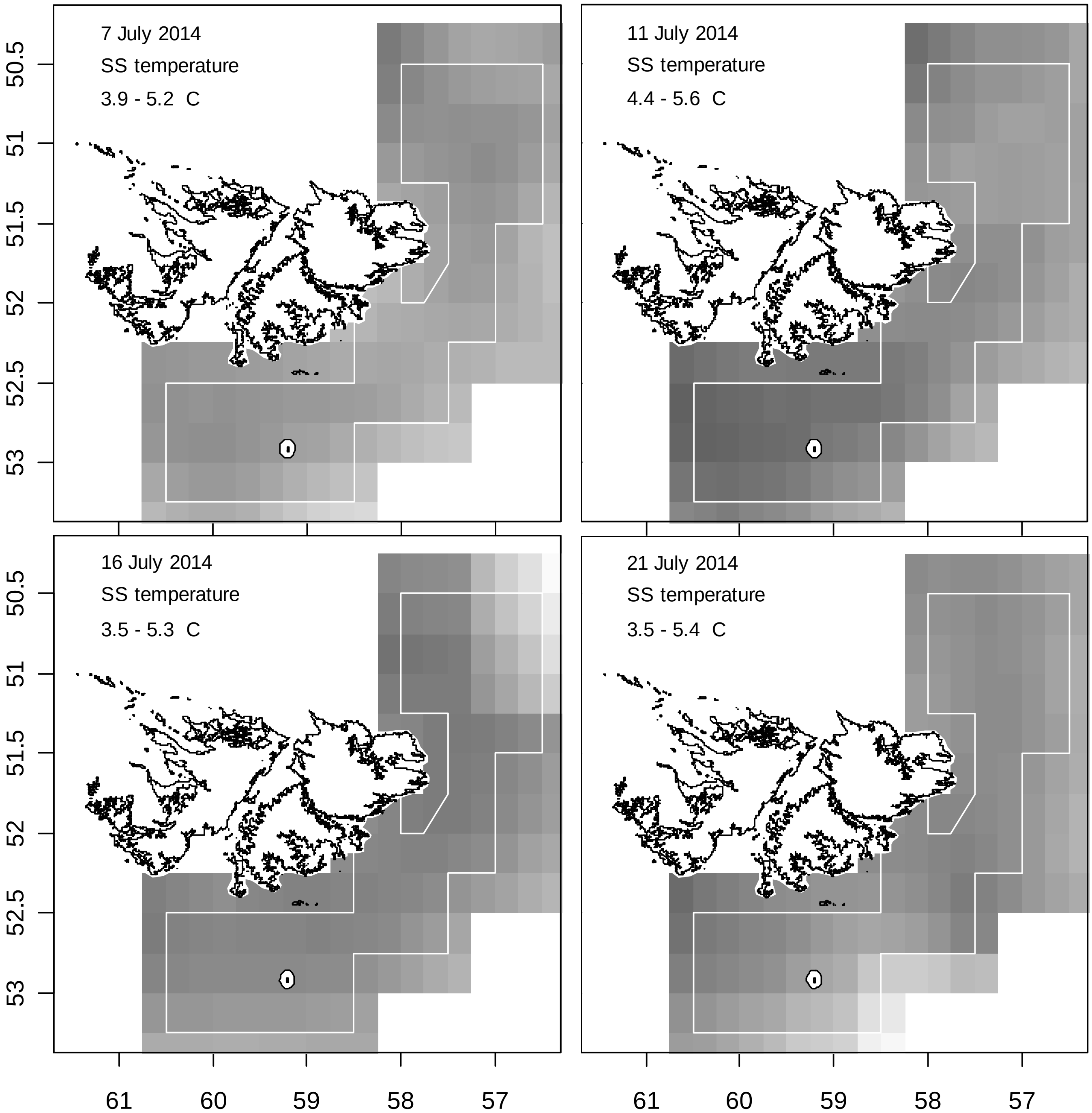


Figure 4. Sea surface temperature data at 0.25° resolution, from AVHRR observations, on four days of the survey period.

Biological analyses

Samples of 126 to 314 *Loligo* were collected from the factory at all trawl stations except one (fourth trawl on 15th July) which had minimal *Loligo* catch; 10125 in total. Biological analysis at sea included measurements of the dorsal mantle length (ML) rounded down to the nearest half-centimetre, sex, and maturity stage. The length-weight relationship $W = \alpha \cdot L^{\beta}$ (Froese, 2006) for *Loligo* was calculated by optimization from a subset of individuals that were weighed as well as measured. This subset included non-randomly selected individuals, to increase representation of the size ranges. Other subsets of *Loligo* were selected according to area stratification (north, central, south) and depth (shallow, medium, deep) of the trawl, and frozen for statolith extraction and age analysis (Arkhipkin, 2005). Length-frequency and weight measurements were also taken from 301 rock cod, 229 toothfish, 63 *Illex argentinus*, 22 hoki *Macruronus magellanicus*, 15 white-spotted skate *Bathyraja albomaculata*, 11 red cod *Salilota australis*, 10 southern blue whiting *Micromesistius australis*, and <10 of icefish *Champsocephalus esox*, grenadier *Macrourus carinatus*, hakes *Merluccius hubbsi* and *Merluccius australis*, mullet *Eleginops maclovinus*, yellowbelly *Paranotothenia magellanica*, redfish *Sebastes oculatus*, and other skates. Toothfish were scored on a 3-point survivability scale: 1 – dead, 2 – extensive injury and likely to die, 3 – little injury and likely to live.

Results

Catch rates and distribution

The survey started with fixed-station trawls in the north of the Loligo Box and proceeded south, reaching the furthest south-west trawl station on the 10th day (Appendix Table A1). Adaptive trawling was then targeted especially on grid units XVAL and XUAL (Figure 1), where fixed station trawls had shown high variability over short distances (Figure 2). The last day's trawls were taken in grid unit XQAP, to be in position to disembark the FIFD survey personnel close to Port William.

A schedule of four scientific trawls per day was maintained except for three on July 8th, when a large 2nd trawl catch (10 t *Loligo*, 12 t hoki, 20 t rock cod; Table A2) exceeded processing capacity for more than one additional trawl that day, and 3 on July 16th, when rough weather forced delay of trawling until 11:15 (Table A1).

Table 1. *Loligo* 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

In total 58 scientific trawls were recorded during the survey: 39 fixed station trawls catching 119.20 t *Loligo* and 19 adaptive trawls catching 88.29 t *Loligo*. The third trawl on July 12th (observer station 740) had to be hauled and re-set because the net picked up scrap metal containers that had apparently drifted over from a nearby dumping area. All catch in that trawl was assumed to have come from after the re-set, reducing the effective trawling time to little over an hour. Optional trawls (made after survey hrs) yielded an additional 136.69 t *Loligo*, bringing the overall total catch for the survey to 344.18 t. The scientific catch of 207.49 t was the highest for a 2nd season since 2011, and the third-highest overall for a 2nd season since 2006 (Table 1).

Average *Loligo* catch density among fixed-station trawls was 4.35 t km^{-2} north of 52º S and 4.10 t km^{-2} south of 52º S. Average *Loligo* catch density among adaptive-station trawls was 5.05 t km^{-2} north of 52º S and 5.35 t km^{-2} south of 52º S. These densities represent the highest level of evenness between fixed and adaptive stations, and (for fixed stations) the highest level of evenness between north and south, of any season since at least 2010, suggesting that the one-week delayed start may have given the *Loligo* population additional time to distribute throughout the zone. Average *Loligo* catch densities calculated only from trawl intervals in daytime were: 5.09 t km^{-2} for fixed-station trawls north of 52º S, 5.61 t km^{-2} for fixed-station trawls south of 52º S, 6.20 t km^{-2} for adaptive-station trawls north of 52º S, and 6.01 t km^{-2} for adaptive-station trawls south of 52º S.

Biomass estimation

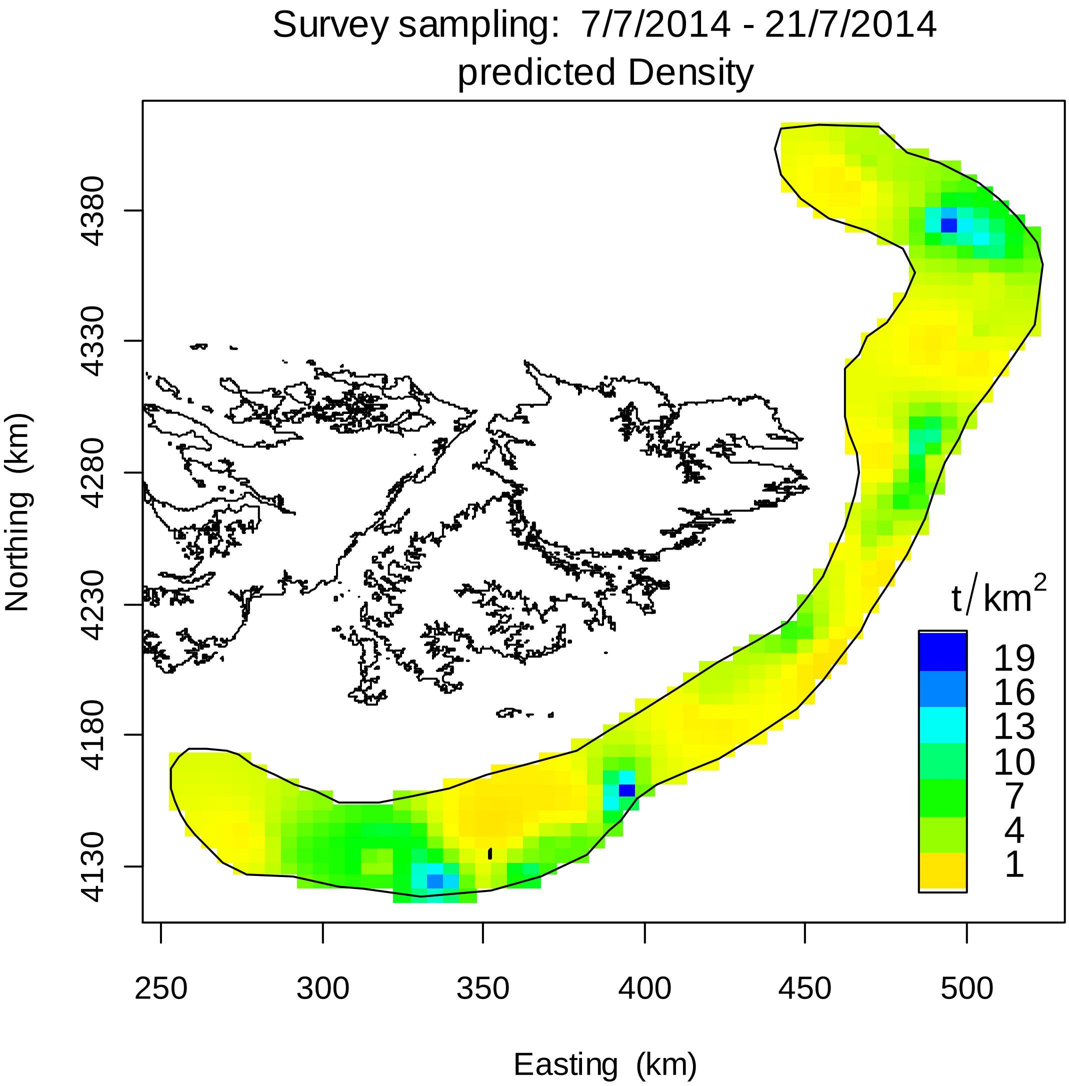
Density estimates from all trawl intervals were modelled with an exponential covariance function and λ = 0.01 Box-Cox transformation. The variogram was fit to a maximum lag distance of 280 km, and resulted in a practical range of 50.73 km, i.e. *Loligo* densities were found to spatially correlate up to a maximum separation distance of 50.73 km (Appendix Figure A1-left). The mean *Loligo* biomass density estimate of this variogram model was 2.70 t km^{-2}, and centred well on the distribution mode of conditional simulations (Figure A1-right).

Trawl time taken only in daytime according to the NOAA ESRL algorithm represented 64.2% of the total (301/468 intervals). Density estimates from only daytime intervals were also modelled with an exponential covariance function, λ = 0.01, and 280 km maximum lag distance. The resulting variogram had a practical range of 139.38 km (Figure A2-left) and mean *Loligo* biomass density estimate of 4.51 t km^{-2}. However, the distribution of conditional simulations was centred significantly lower than the mean (Figure A2-right), indicative that this variogram did not strongly represent the structure of the data. In effect, the daytime variogram had a 'shallower' slope (compare Figures A1-left and A2-left), which means that most extrapolations, in most simulations, will gain relatively less influence from the small proportion of high density values.

Based on these outcomes, the *Loligo* biomass was estimated with the inclusion of all trawl intervals, and further calculations refer to the 'all data' model (Figure A1). Regression between total acoustic score per trawl and total *Loligo* catch per trawl resulted in R^2 = 0.445 (Figure A3-top). The coefficient of variation for acoustic apportionment derived with the randomization algorithm was = 0.063. The total coefficient of variation, combining variogram conditional simulations and acoustic apportionment, was = 0.200.

From these calculations total *Loligo* biomass in the fishing area was estimated at 40,090 t, with a 95% confidence interval of [30,228 to 64,677 t]. High concentrations of *Loligo* were projected in the usual area south of Beauchêne Island, but unlike the previous three 2nd seasons, high concentrations were also projected further east around grid unit XUAL, and in the north around grid unit XLAN (Figure 5). Of the estimated total, 17,877 t [11,299 to 31,199 t] were north of 52 ºS, and 22,213 t [14,172 to 35,957 t] were south of 52 ºS. Like the survey catch itself, the biomass estimate of 40,090 t was the highest for a 2nd season since 2011, and the third-highest overall for a 2nd season since 2006 (Table 1).

Figure 5 [below]. *Loligo* predicted density estimates per 5 km^2 area units. Coordinates were converted to WGS 84 projection in UTM sector 21F using Quantum GIS software.



Biological data

Seventy-five taxa were identified in the catches (Appendix Table A2), of which *Loligo* made up 70.0% by weight. Compared to 1st season (Winter and Jürgens, 2014), the catch composition was characterized by lower abundances of medusae and red cod, and higher abundances of *Illex*. Compared to 2nd season of last year (Winter et al., 2013b), the catch composition was characterized by lower abundance of medusae and red cod, and higher abundances of *Illex*, whiting and hoki. Rock cod was the highest finfish catch in all three surveys.

Loligo catches in this survey included an uncommonly high proportion of large individuals; predominantly male 5 (Figure 6). North of 52 ºS, both male and female length distributions were bimodal. Males <13 cm were 37% maturity stage 2 and 49% maturity stage 3; males ≥13 cm were 53% maturity stage 4 and 41% maturity stage 5. Females <13 cm were 84% maturity stage 2 and 13% maturity stage 3; females ≥13 cm were 27% maturity stage 2 and 53% maturity stage 3. South of 52 ºS, male and female length distributions were unimodal. Males were 26% maturity stage 3, 42% maturity stage 4, and 28% maturity stage 5. Females were 27% maturity stage 2, 62% maturity stage 3, and 9% maturity stage 4.

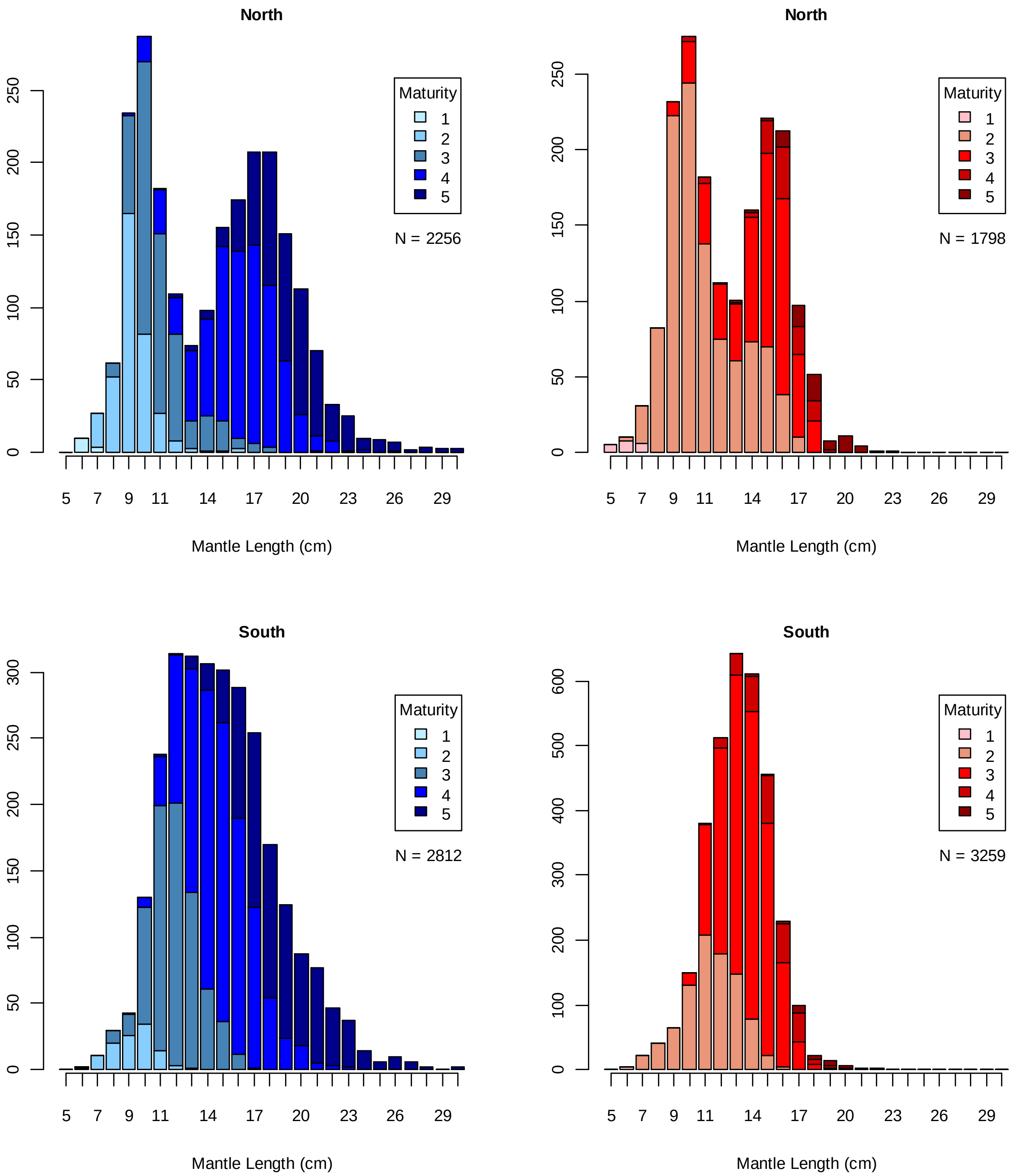


Figure 6. Mantle length-frequency distributions by maturity stage of male (blue) and female (red) *Loligo* from trawls north (top) and south (bottom) of latitude 52 ºS. The histograms are censored to a maximum length of 30 cm; 4 males were actually longer than 30 cm.

The large sizes and maturities of *Loligo* in this survey together with the high catches of *Illex*; both during this survey and during this year's commercial fishery (Mercopress, 2014), suggest an interaction or common environmental cause. *Illex* are predators and competitors of *Loligo* (Arkhipkin and Middleton, 2002; Rosas-Luis et al., 2014), and it is conjectured that the high abundance of *Illex* may have impeded large, older *Loligo* from their usual migrations into deeper water (Hatfield et al., 1990); instead keeping them on the shelf. The potential for interaction was visualized by plotting the survey to highlight stations with high proportions (>25%; approx. the 80th percentile) of maturity stage 5 *Loligo* vs. stations of high *Illex* CPUE (50 kg h^{-1}; approx. the median of CPUE $\geq$ 1 kg h^{-1}). Stations with high proportions of maturity stage 5 *Loligo* were concentrated mainly in two areas, and these were bounded by the stations with high *Illex* CPUE, but showing little overlap (Figure 7). Overall *Loligo* CPUE (all sizes) had no significant correlation with *Illex* CPUE. These patterns indicate the possibility that the uncommon distributions of larger, older *Loligo* were influenced by the presence of *Illex*.

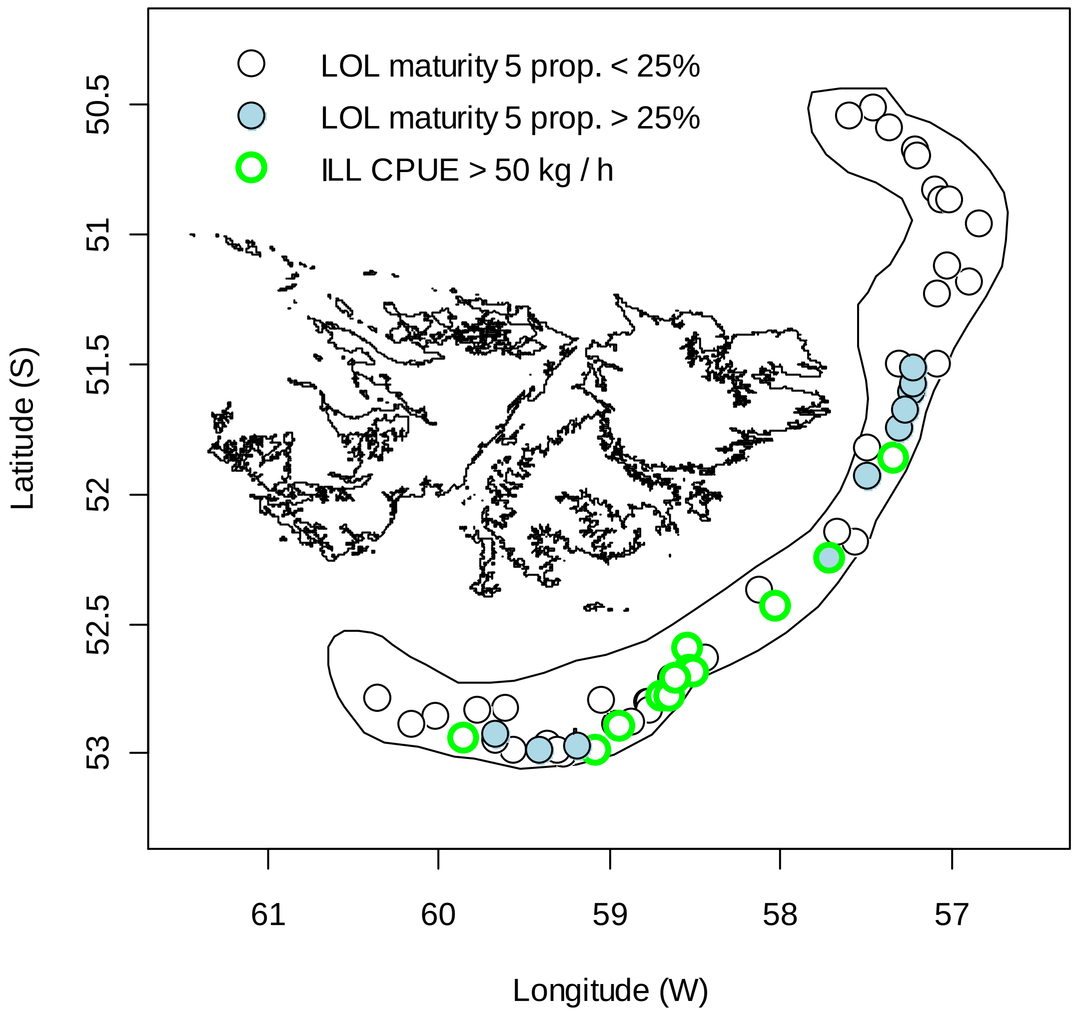


Figure 7. Comparison of survey stations with high proportions of maturity 5 *Loligo* vs. survey stations with high *Illex* CPUE.

The *Loligo* length-weight relationship was calculated from 881 individuals (499 males, 382 females) sampled during the survey, resulting in parameters α = 0.13508 ± 0.04903 and β = 2.27820 ± 0.01434 (± 1 sd) (Figure 8).

The 42.5 cm male (Figure 8), which was caught on July 21st in 241 m depth, is tied with 5 other males as the second-longest *Loligo* recorded in the FIFD observer database; the longest at 44.5 cm being a male sampled also onboard the *Golden Chicha*, on 19th May 2005, in 152 m depth. The published maximum mantle length for *D. gahi* is 38 cm (Hatfield, 1991). The large deviance between this survey's 42.5 cm individual measured weight (418.5 g) and modelled weight (692.5 g; off the scale on Figure 8) suggests that the two-parameter power function may not be appropriate for the length-weight relationship of very large squid. However, given the prevalent use of the power function in FIFD analyses and bulletins, and the comparative rarity of such large individuals, the power function is retained at this time.

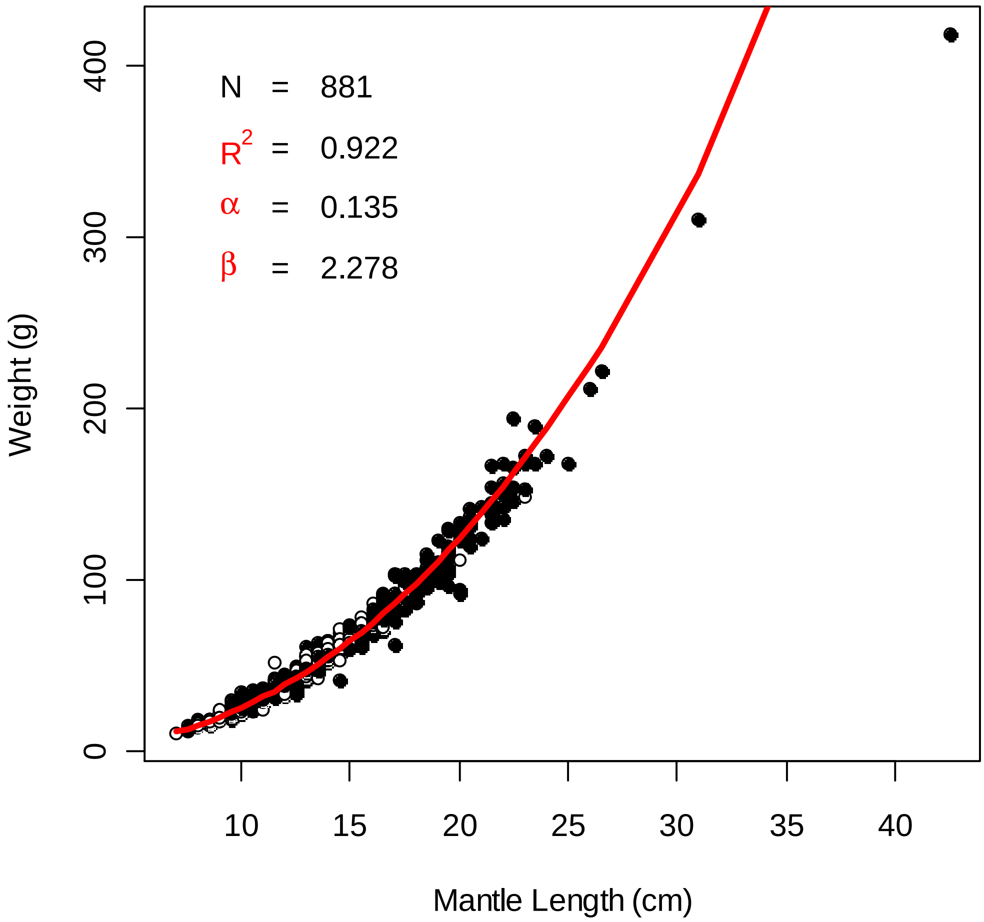


Figure 8. Length – weight relationship of *Loligo* sampled during the survey. Filled circles: males, open circles: females.

References

Arkhipkin, A.I. 2005. Statoliths as 'black boxes' (life recorders) in squid. Marine and Freshwater Research 56: 573-583.

Arkhipkin, A.I., Middleton, D.A.J. 2002. Inverse patterns in abundance of *Illex argentinus* and *Loligo gahi* in Falkland waters: possible interspecific competition between squid? Fisheries Research 59: 181-196.

Arkhipkin, A.I., Middleton, D.A., Barton, J. 2008. Management and conservation of a short-lived fishery-resource: *Loligo gahi* around the Falkland Islands. American Fisheries Societies Symposium 49:1243-1252.

Arkhipkin, A., Winter, A., May, T. 2010. *Loligo gahi* stock assessment survey, first season 2010. Technical Document, FIG Fisheries Department. 13 p.

Arkhipkin, A., Barton, J., Wallace, S., Winter, A. 2013. Close cooperation between science, management and industry benefits sustainable exploitation of the Falkland Islands squid fisheries. Journal of Fish Biology 83: 905-920.

FIG. 2011. Conversion factors 2011. Fisheries Dept., Directorate of Natural Resources, Falkland Islands Government, 1 p.

Fisheries Committee. 2013. Re-allocation of fishing effort between 1st and 2nd *Loligo* seasons. Proposal to the Fisheries Committee, December 2013. 4 p.

Froese, R. 2006. Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. Journal of Applied Ichthyology 22:241-253.

Hatfield, E.M.C. 1991. Post-recruit growth of the Patagonian squid *Loligo gahi* (d'Orbigny). Bulletin of Marine Science 49: 349-361.

Hatfield, E.M.C., Rodhouse, P.G., Porebski, J. 1990. Demography and distribution of the Patagonian squid (*Loligo gahi* d'Orbigny) during the austral winter. Journal du Conseil international pour l'Exploration de la Mer 46: 306-312.

Mercopress. 2014. http://en.mercopress.com/2014/05/17/falkland-islands-establish-record-catch-of-illex-squid-268.223-tons.

Payá, I. 2008. *Loligo gahi* stock assessment survey, first season 2008. Technical Document, FIG Fisheries Department. 26 p.

Pennington, M. 1983. Efficient estimators of abundance, for fish and plankton surveys. Biometrics 39:281-286.

Petitgas, P. 2001. Geostatistics in fisheries survey design and stock assessment: models, variances, and applications. Fish and Fisheries 2: 231-249.

Reynolds, R.W., Smith, T.M., Liu, C., Chelton, D.B., Casey, K.S., Schlax, M.G. 2007. Daily high-resolution-blended analyses for sea surface temperature. Journal of Climate, 20: 5473–5496.

Ribeiro, P.J., Diggle, P.J. 2001. geoR: a package for geostatistical analysis. R-NEWS 1: 15-18.

Roa-Ureta, R., Arkhipkin, A.I. 2007. Short-term stock assessment of *Loligo gahi* at the Falkland Islands: sequential use of stochastic biomass projection and stock depletion models. ICES Journal of Marine Science 64:3-17.

Roper, C.F.E., Young, R.E. 1975. Vertical distribution of pelagic cephalopods. Smithsonian Contributions to Zoology 209: 1-51.

Rosas-Luis, R., Sánchez, P., Portela, J.M., del Rio, J.L. 2014. Feeding habits and trophic interactions of *Doryteuthis gahi*, *Illex argentinus* and *Onykia ingens* in the marine ecosystem off the Patagonian Shelf. Fisheries Research 152: 37-44.

Sobrado, F. 2013. Observer Report 969. Technical Document, FIG Fisheries Department. 23 p.

Winter, A., Davidson, D., Shcherbich, Z. 2010. *Loligo gahi* stock assessment survey, 2nd season 2010. Technical Document, FIG Fisheries Department. 17 p.

Winter, A., Shcherbich, Z., Hancox, E. 2012. *Loligo* stock assessment survey, 2nd season 2012. Technical Document, FIG Fisheries Department. 19 p.

Winter, A., Jürgens, L., Monllor, A. 2013a. *Loligo* stock assessment survey, 1st season 2013. Technical Document, FIG Fisheries Department. 15 p.

Winter, A., Blake, A., Sobrado, F. 2013b. *Loligo* stock assessment survey, 2nd season 2013. Technical Document, Falkland Islands Fisheries Department. 17 p.

Winter, A., Jürgens, L. 2014. *Loligo* stock assessment survey, 1st season 2014. Technical Document, Falkland Islands Fisheries Department. 18 p.

Woillez, M., Rivoirard, J., Fernandes, P.G. 2009. Evaluating the uncertainty of abundance estimates from acoustic surveys using geostatistical simulations. ICES Journal of Marine Science 66: 1377-1383.

Zhang, H.-M., Bates, J.J., Reynolds, R.W. 2006. Assessment of composite global sampling: Sea surface wind speed. Geophysical Research Letters, 33: L17714.

Appendix

Table A1. Survey stations with total *Loligo* catch. Time: local (Stanley, F.I.), latitude: °S, longitude: °W.

Transect Station	Obs Code	Date	Start			End			Depth (m)	*Loligo* (kg)
			Time	Lat	Lon	Time	Lat	Lon		
14 - 39	719	7/07/2014	7:10	50.51	57.45	9:11	50.59	57.30	293	939.8
14 - 38	720	7/07/2014	10:18	50.61	57.36	12:20	50.51	57.52	256	2139
14 - 37	721	7/07/2014	13:37	50.54	57.59	15:48	50.64	57.46	142	325
13 - 36	722	7/07/2014	17:07	50.68	57.21	19:25	50.76	57.01	299	1889.4
13 - 34	723	8/07/2014	6:59	50.83	57.09	9:13	50.76	57.24	133	1207.4
13 - 35	724	8/07/2014	10:07	50.70	57.20	12:10	50.78	57.06	259	10038.6
12 - 31	725	8/07/2014	15:53	50.87	57.06	17:55	50.95	56.96	120	881.5
11 - 30	726	9/07/2014	6:55	51.18	56.89	8:58	51.25	56.99	292	413
11 - 29	727	9/07/2014	10:03	51.24	57.08	11:58	51.13	56.93	149	2306.8
12 - 33	728	9/07/2014	13:11	50.97	56.84	15:20	50.84	56.95	267	7237.6
12 - 32	729	9/07/2014	16:13	50.87	57.00	18:15	50.95	56.90	122	705.8
11 - 28	730	10/07/2014	7:04	51.12	57.02	9:13	51.20	57.14	125	229.5
10 - 27	731	10/07/2014	11:29	51.50	57.08	13:39	51.61	57.14	288	287
10 - 26	732	10/07/2014	14:37	51.61	57.23	16:39	51.47	57.18	226	14737
10 - 25	733	10/07/2014	17:42	51.50	57.30	19:36	51.62	57.35	151	108
9 - 22	734	11/07/2014	7:03	51.82	57.48	9:23	51.96	57.59	165	906.2
9 - 23	735	11/07/2014	10:08	51.94	57.49	12:05	51.81	57.37	224	9065
9 - 24	736	11/07/2014	12:53	51.86	57.34	14:56	51.98	57.42	287	186.4
8 - 21	737	11/07/2014	16:40	52.18	57.56	18:46	52.31	57.67	330	86.6
8 - 20	738	12/07/2014	6:52	52.25	57.71	8:34	52.16	57.60	266	964.5
8 - 19	739	12/07/2014	9:15	52.15	57.66	11:23	52.25	57.84	204	4632.5
7 - 18	740	12/07/2014	12:35	52.38	57.97	15:29	52.49	58.11	267	534
7 - 17	741	12/07/2014	16:44	52.37	58.12	18:41	52.46	58.28	183	1482.6
5 - 13	742	13/07/2014	6:56	52.80	58.77	9:04	52.88	58.99	147	4861
5 - 14	743	13/07/2014	9:47	52.89	58.96	11:52	52.83	58.74	192	2664.5
6 - 16	744	13/07/2014	13:00	52.72	58.64	14:59	52.61	58.47	233	3661
6 - 15	745	13/07/2014	15:48	52.59	58.54	17:57	52.70	58.70	164	3260
3 - 8	746	14/07/2014	7:12	52.97	59.36	9:37	52.96	59.60	180	5763
3 - 9	747	14/07/2014	10:24	52.99	59.57	12:15	53.01	59.35	243	6087.2
4 - 11	748	14/07/2014	13:03	53.00	59.27	15:14	52.96	59.01	257	16111.2
5 - 12	749	14/07/2014	16:38	52.80	59.05	18:35	52.71	58.88	124	453.5
2 - 5	750	15/07/2014	6:57	52.93	59.66	9:16	52.91	59.89	170	2791.6
2 - 6	751	15/07/2014	10:04	52.94	59.86	12:07	52.98	59.63	240	3110.7
3 - 7	752	15/07/2014	13:28	52.83	59.61	15:24	52.83	59.38	148	2257.4
4 - 10	753	15/07/2014	15:59	52.82	59.32	17:49	52.80	59.10	107	25
1 - 2	754	16/07/2014	11:15	52.86	60.01	13:04	52.81	60.21	202	1475
0 - 1	755	16/07/2014	14:10	52.79	60.35	16:00	52.88	60.23	254	436.1
1 - 3	756	16/07/2014	16:45	52.89	60.17	18:39	52.93	59.94	228	1760.5
A - 1	757	17/07/2014	6:59	52.97	59.18	9:03	52.98	59.38	174	5912.6
A - 2	758	17/07/2014	9:42	52.98	59.40	11:45	52.97	59.62	204	1313.8
A - 3	759	17/07/2014	12:25	52.95	59.67	14:24	52.91	59.89	180	1136.4
2 - 4	760	17/07/2014	15:25	52.83	59.78	17:17	52.90	59.59	156	3182.4
A - 4	761	18/07/2014	6:52	52.99	59.31	8:53	52.96	59.05	180	3962
A - 5	762	18/07/2014	9:53	52.99	59.10	11:59	52.88	58.91	236	1537.2
A - 6	763	18/07/2014	12:51	52.90	58.94	15:03	52.81	58.75	180	5082.2
A - 7	764	18/07/2014	15:49	52.81	58.76	17:53	52.89	58.94	148	2210.7
A - 8	765	19/07/2014	6:46	52.83	58.77	8:57	52.69	58.68	152	335.8
A - 9	766	19/07/2014	9:56	52.68	58.53	11:48	52.77	58.66	262	12285.4
A - 10	767	19/07/2014	12:45	52.78	58.69	14:53	52.67	58.52	249	13635.6
A - 11	768	19/07/2014	15:38	52.68	58.50	17:46	52.78	58.67	271	12186.7
A - 12	769	20/07/2014	6:49	52.88	58.87	9:02	52.78	58.66	264	3436
A - 13	770	20/07/2014	9:48	52.78	58.64	11:54	52.67	58.46	279	610.6
A - 14	771	20/07/2014	12:50	52.63	58.44	14:50	52.74	58.60	257	3934.6

A - 15	772	20/07/2014	15:40	52.72	58.61	17:48	52.63	58.44	250	3909.8
A - 16	773	21/07/2014	6:46	51.75	57.31	8:55	51.61	57.21	251	4666
A - 17	774	21/07/2014	9:42	51.61	57.23	12:20	51.45	57.12	241	7439.5
A - 18	775	21/07/2014	13:30	51.51	57.22	15:23	51.63	57.27	215	2264.6
A - 19	776	21/07/2014	16:02	51.67	57.26	17:50	51.78	57.32	239	2426.5

Table A2. Survey total catches by species / taxon.

Species Code	Species / Taxon	Total catch (kg)	Total catch (%)	Sample (kg)	Discard (kg)
LOL	*Doryteuthis (Loligo) gahi*	207489	70.0	625	628
PAR	*Patagonotothen ramsayi*	50025	16.9	31	49003
BLU	*Micromesistius australis*	12646	4.3	5	2182
WHI	*Macruronus magellanicus*	11790	4.0	22	5090
ILL	*Illex argentinus*	7085	2.4	34	277
CHR	*Chrysaora* sp.	3463	1.2	0	3463
KIN	*Genypterus blacodes*	712	0.2	0	5
BAC	*Salilota australis*	571	0.2	8	118
PTE	*Patagonotothen tessellata*	426	0.1	0	426
HAK	*Merluccius hubbsi*	378	0.1	1	5
CGO	*Cottoperca gobio*	342	0.1	0	342
DGS	*Squalus acanthias*	294	0.1	0	293
ZYP	*Zygochlamys patagonica*	226	0.1	0	226
EEL	*Iluocoetes fimbriatus*	189	0.1	0	189
RAY	Rajidae	175	0.1	0	95
UCH	Sea urchin	107	<0.1	0	107
RAL	*Bathyraja albomaculata*	107	<0.1	4	105
TOO	*Dissostichus eleginoides*	62	<0.1	62	46
RDO	*Amblyraja doellojuradoi*	53	<0.1	1	53
SPN	Porifera	46	<0.1	0	46
GOC	*Gorgonocephalas chilensis*	27	<0.1	0	27
RBR	*Bathyraja brachyurops*	14	<0.1	1	13
ING	*Moroteuthis ingens*	14	<0.1	0	14
RMC	*Bathyraja macloviana*	13	<0.1	0	13
PAT	*Merluccius australis*	13	<0.1	3	10
GRC	*Macrourus carinatus*	11	<0.1	3	7
ANM	Anemone	10	<0.1	0	10
SQT	*Ascidiacea*	9	<0.1	0	9
NEM	*Neophyrnichthys marmoratus*	7	<0.1	0	7
GRF	*Coelorhynchus fasciatus*	7	<0.1	0	7
RSC	*Bathyraja scaphiops*	6	<0.1	4	2
RPX	*Psammobatis* spp.	5	<0.1	2	5
RMG	*Bathyraja magellanica*	4	<0.1	1	4
MUE	*Muusoctopus eureka*	4	<0.1	0	4
RBZ	*Bathyraja cousseauae*	3	<0.1	0	3
MLA	*Muusoctopus longibrachus akambei*	3	<0.1	0	3
RGR	*Bathyraja griseocauda*	2	<0.1	0	2
RED	*Sebastes oculatus*	2	<0.1	0	2
OCM	*Octopus megalocyathus*	2	<0.1	0	2
NOW	*Paranotothenia magellanica*	2	<0.1	0	1
MUL	*Eleginops maclovinus*	2	<0.1	2	2
SUN	*Labidaster radiosus*	1	<0.1	0	1
POA	*Porania antarctica*	1	<0.1	0	1
OPL	*Ophiuroglypha lymanii*	1	<0.1	0	1
ODM	*Odontocymbiola magellanica*	1	<0.1	0	1
LOS	*Lophaster stellans*	1	<0.1	0	1

LIA	*Lithodes antarcticus*	1	<0.1	0	1
EUL	*Eurypodius latreillei*	1	<0.1	0	1
THO	Thouarellinae	<0.1	<0.1	0	0
SEC	*Seriolella caerulea*	<0.1	<0.1	0	0
PYX	Pycnogonida	<0.1	<0.1	0	0
POL	Polychaeta	<0.1	<0.1	0	0
PES	*Peltarion spinosulum*	<0.1	<0.1	0	0
PAM	*Pagurus comptus*	<0.1	<0.1	0	0
OPV	*Ophiacanta vivipara*	<0.1	<0.1	0	0
OPH	Ophiuroidea	<0.1	<0.1	0	0
ODP	*Odontaster pencillatus*	<0.1	<0.1	0	0
NUD	Nudibranchia	<0.1	<0.1	0	0
MYF	*Myxine fernholmi*	<0.1	<0.1	0	0
MMA	*Mancopsetta maculata*	<0.1	<0.1	0	0
MAV	*Magellania venosa*	<0.1	<0.1	0	0
HYD	Hydrozoa	<0.1	<0.1	0	0
FUM	*Fusitriton m. magellanicus*	<0.1	<0.1	0	0
EUO	*Eurypodius longirostris*	<0.1	<0.1	0	0
CYX	*Cycethra* sp.	<0.1	<0.1	0	0
CTA	*Ctenodiscus australis*	<0.1	<0.1	0	0
CRY	*Crossaster* sp.	<0.1	<0.1	0	0
COT	*Cottunculus granulosus*	<0.1	<0.1	0	0
CHE	*Champsocephalus esox*	<0.1	<0.1	0	0
CEX	*Ceramaster* sp.	<0.1	<0.1	0	0
CAZ	*Calyptraster* sp.	<0.1	<0.1	0	0
BAO	*Bathybiaster loripes*	<0.1	<0.1	0	0
BAL	*Bathydomus longisetosus*	<0.1	<0.1	0	0
AST	Asteroidea	<0.1	<0.1	0	0
ASA	*Astrotoma agassizii*	<0.1	<0.1	0	0
		296,357		809	62,856

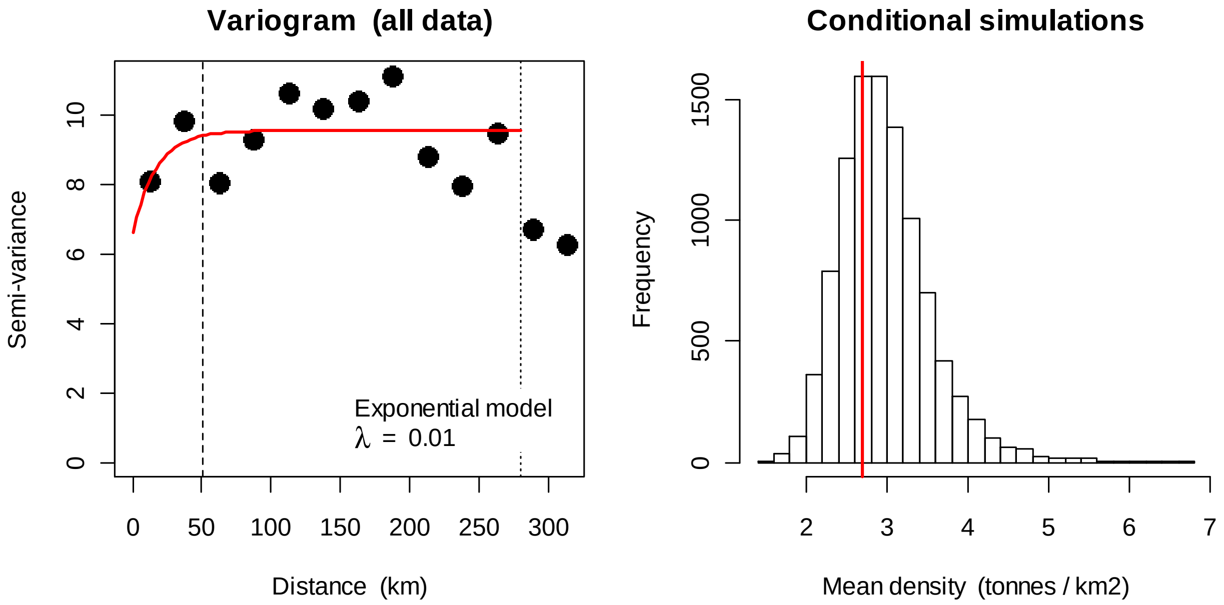


Figure A1. Left: Empirical variogram (black circles) and model variogram (red line) of *Loligo* biomass density distributions, modelled on all data. Broken vertical line: practical correlation range of the model at 50.73 km. Dotted vertical line: maximum modelled lag distance at 280 km. Right: histogram of conditional simulations of mean density estimates resulting from the model variogram at left. Vertical red line: empirical mean density estimate at 2.70 t km^{-2}.

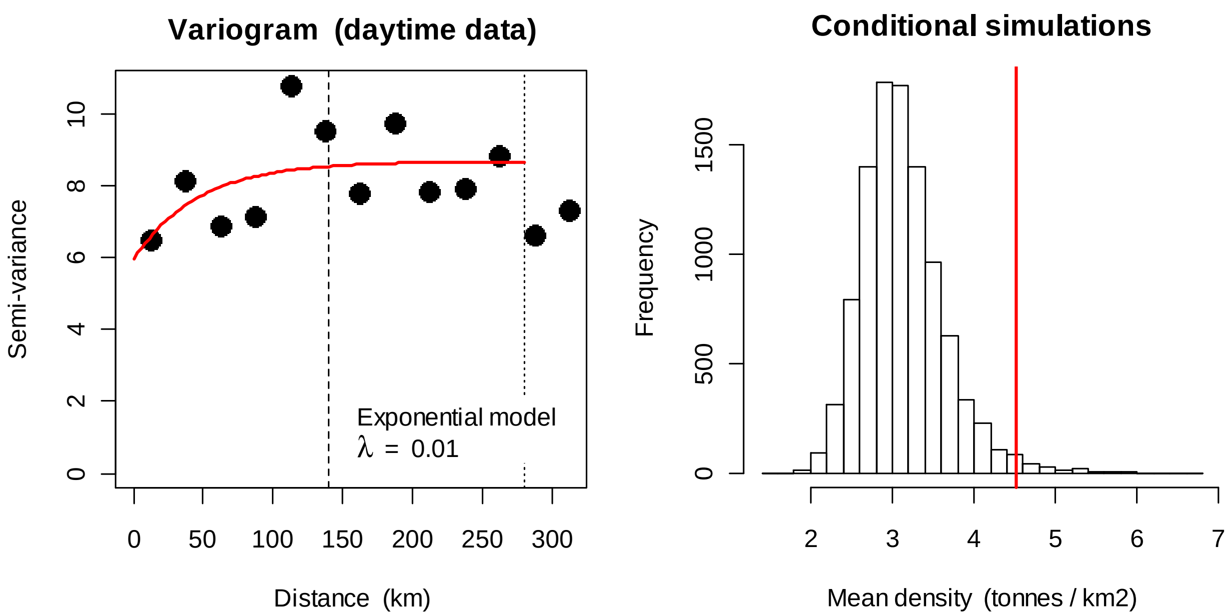
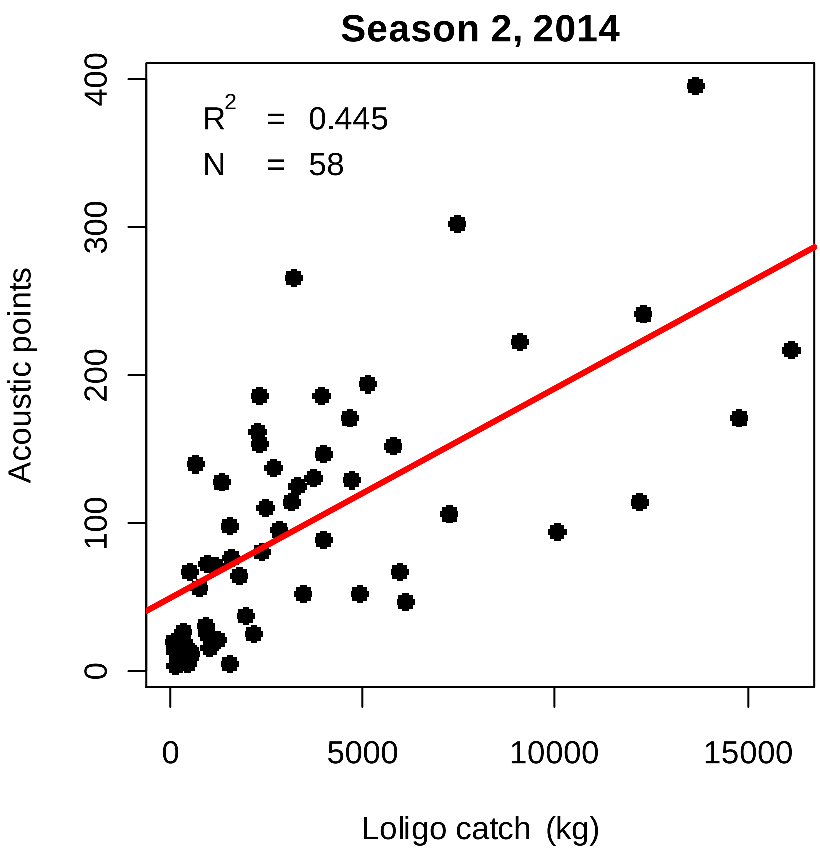


Figure A2. Left: Empirical and model variograms of *Loligo* biomass density distributions, modelled on daytime data. Broken vertical line: practical correlation range of the model at 139.38 km. Dotted vertical line: maximum modelled lag distance at 280 km. Right: histogram of conditional simulations of mean density estimates resulting from the model variogram at left. Vertical red line: empirical mean density estimate at 4.51 t km^{-2}.


Season 2, 2014
R2 = 0.445
N = 58
Acoustic points
0
100
200
300
400
0
5000
10000
15000
Loligo catch (kg)

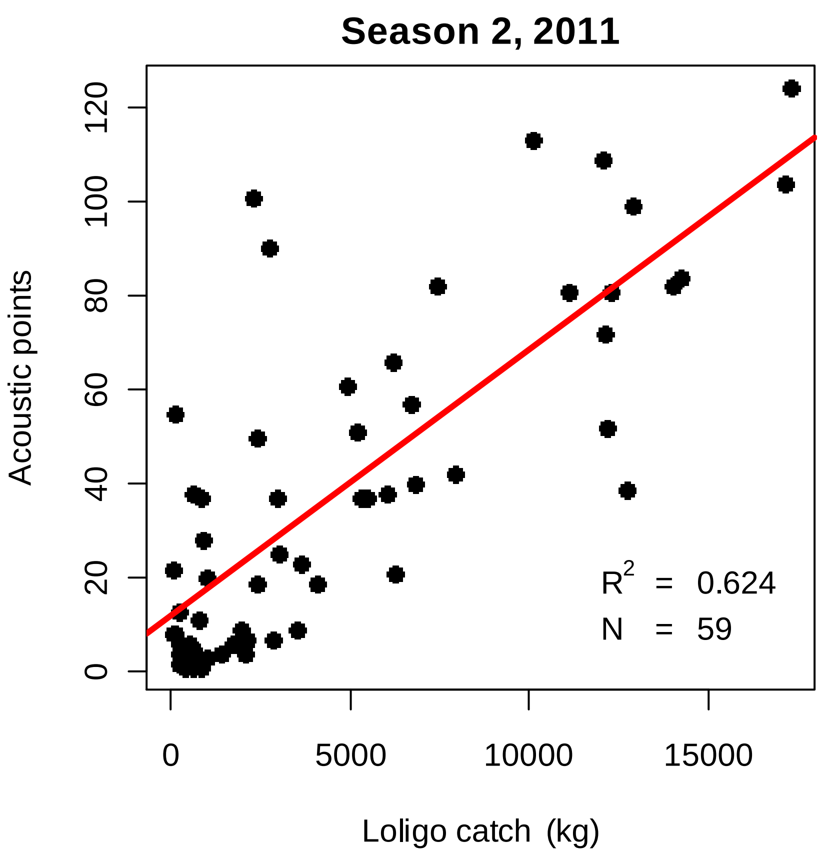

Season 2, 2011
R2 = 0.624
N = 59
Acoustic points
0
20
40
60
80
100
120
0
5000
10000
15000
Loligo catch (kg)

Figure A3 [previous page]. Total *Loligo* catch vs. total acoustic score of survey trawls in the second season of 2014 (top) and 2011 (bottom), with regression slope plotted on either graph (red lines).

The regression slope between *Loligo* catches and acoustic scores showed a lower correlation in the 2^{nd} season 2014 (when acoustic scoring was performed by the FIFD survey scientist) than in the 2^{nd} season 2011 (when acoustic scoring was performed by the vessel's fishing master). However, the 2^{nd} season 2011 had a higher proportion of *Loligo* in the total catch and lower proportions of fish with swim bladders such as hakes and whiting, which have the strongest potential for confounding acoustic sign. The acoustic scoring of the two surveys is thus considered qualitatively compatible.