FALKLAND

ISLANDS

FISHERIES

DEPARTMENT

Loligo gahi Stock Assessment Survey, 2nd Season 2011

Vessel	*Igueldo* (ZDLE1), Falkland Islands
Dates	30/06/2011 - 14/07/2011
Report by	A. Winter, L. Juergens, Z. Shcherbich

SUMMARY

A stock assessment survey for *Loligo gahi* squid was conducted in the '*Loligo* Box' from 30th June to 14th July 2011. A catch of 275.62 tonnes *Loligo* was taken in fifty-nine scientific trawls. The highest concentrations of *Loligo* occurred in the Beauchêne area, but substantial catches were taken both north and south of 52ºS latitude. *Loligo* were on average larger and more mature south of 52ºS, and larger and more mature in catches deeper than 200 m.

Interpolation of the catch densities gave a mean biomass estimate of 51,562 tonnes *Loligo* (95% confidence interval: 30,092 to 82,075 tonnes) present in the fishing area of 14,099.5 km^2.

INTRODUCTION

A stock assessment survey for *Loligo gahi* (Patagonian squid) was conducted by FIFD personnel onboard the fishing vessel *Igueldo* from 30th June to 14th July 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:

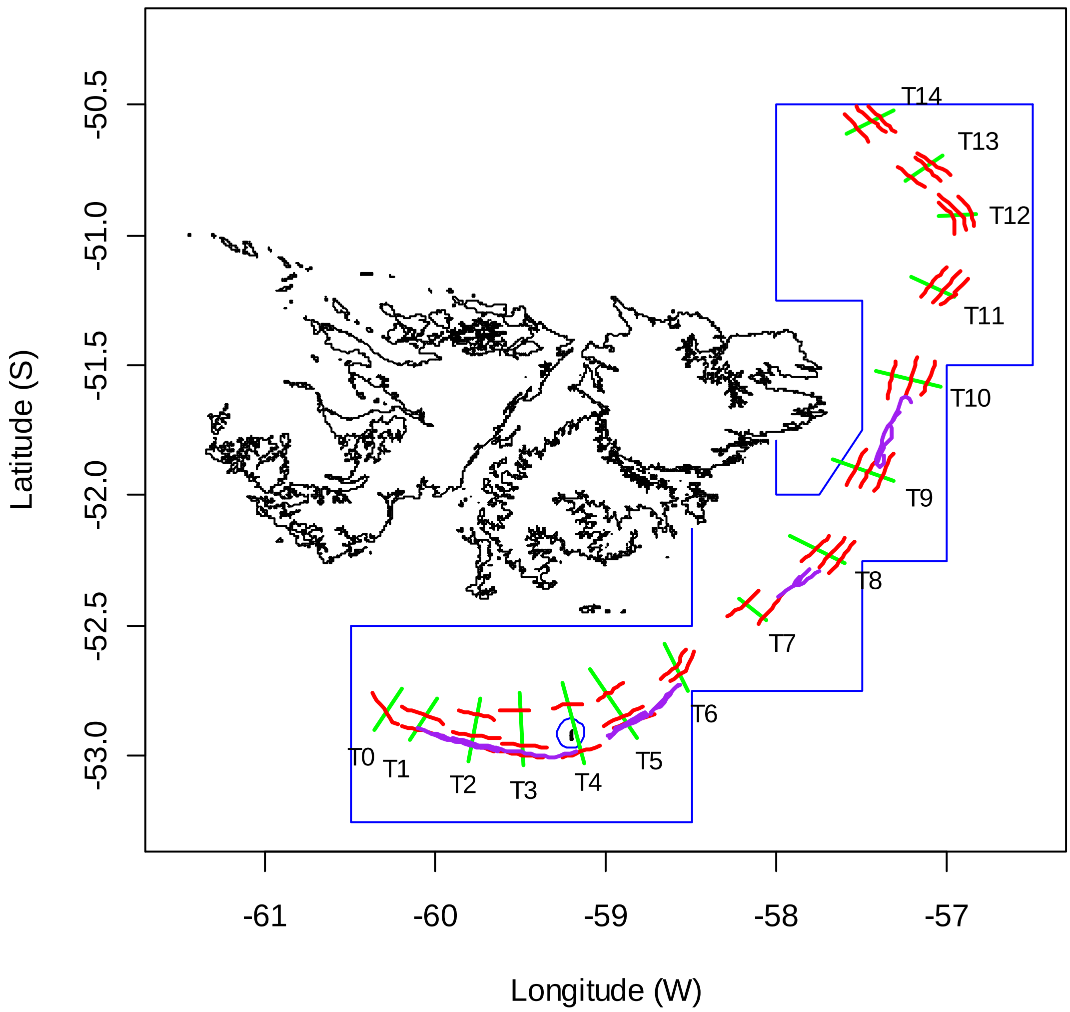
1) Estimate the biomass and spatial distribution of *Loligo* on the fishing grounds at the onset of the 2nd fishing season, 2011.
2) Estimate the biomass and spatial distribution of rock cod (*Patagonotothen ramsayi*).
3) Collect biological data on *Loligo*, rock cod, and any rare fish taken incidentally in the trawls.

The F/V *Igueldo* is a Stanley, Falkland Islands - registered stern trawler of 83.5 m length, 2305 mt gross registered tonnage, and 3000 main engine bhp. Additional crew and equipment specifications are listed in May (2010) and Juergens (2011). Like all vessels employed for these pre-season surveys, *Igueldo* 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:

Lars Juergens	fisheries biologist / survey chief scientist
Zhanna Shcherbich	fisheries biologist

Figure 1 [next page]. Transects (green lines), fixed-station trawls (red lines), and adaptive-station trawls (purple) sampled during the pre-season 2 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 the 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 defined as 0.35272 of the distance between trawl doors as determined by the acoustic door sensors. The fraction 0.35272 is the mean of trawl width scaling factors of five preceding surveys: 2008 season 1 and 2, 2009 season 1 and 2, 2011 season 1. Not included were 2010 season 1 (acoustic door sensors had failed; Arkhipkin et al., 2010), and 2010 season 2 (a fixed trawl width had been assumed; Winter et al., 2010).

Biomass density estimates were extended to the fishing area by cubic interpolation (Akima, 1996). In contrast to previous seasons (Arkhipkin et al., 2010; Winter et al., 2010; Winter et al., 2011), the *Loligo* catches did not show significant spatial correlation, and therefore geostatistical methods were not implemented. Point interpolations were censored to a maximum of 1.5× the highest observed density, and to a minimum of zero. A previous survey report (Winter et al., 2010) had concluded that trawl catches taken in daylight were significantly higher than those that extended into twilight or darkness, due to *Loligo*'s diel migratory behaviour (Rodhouse, 2005). To examine this effect in the current season, biomass density estimates were calculated first from all data, then from data corresponding only to daylight as determined by reference to the U.S. Naval Observatory website www.usno.navy.mil/USNO/astronomical-applications/data-services/rs-one-year-world. Additionally, cubic interpolation can be computed strictly over the convex bounds of the survey tracks, or it can be extrapolated to the entire fishing area of interest. Both options were applied to the data.

Confidence intervals of all versions of the interpolated density estimates were calculated using a re-sampling algorithm (Forsythe and Hartigan, 1970) in three components: a) proportional acoustic mark weights per 15-minute interval were randomly increased, decreased, or unchanged by 50% of the average in each trawl, b) the trawl width scaling factor was random uniformly varied between the minimum and maximum of the reference scaling factors, c) 80% of the adaptive trawls were randomly re-sampled, without replacement. Re-sampling was iterated 5000×. The biomass density point estimate and confidence interval interpolations were applied to the same delineated fishing area of 14,099.5 km^2 as the previous seasons (Winter et al., 2010; Winter et al., 2011), partitioned for analysis as 571 area units of 5×5 km. Estimates of total biomass were calculated by multiplying mean densities by the fishing area of 14,099.5 km^2.

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. Correlations between male or female dorsal mantle length or maturity, vs. depth stratum (<150 m, 150 to 200 m, >200 m) and area (north or south of 52ºS latitude), were examined using ANOVA. The allometric 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. Several samples of *Loligo* were also retained 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. Rare or unknown fish were frozen for identification to be conducted at FIFD.

RESULTS

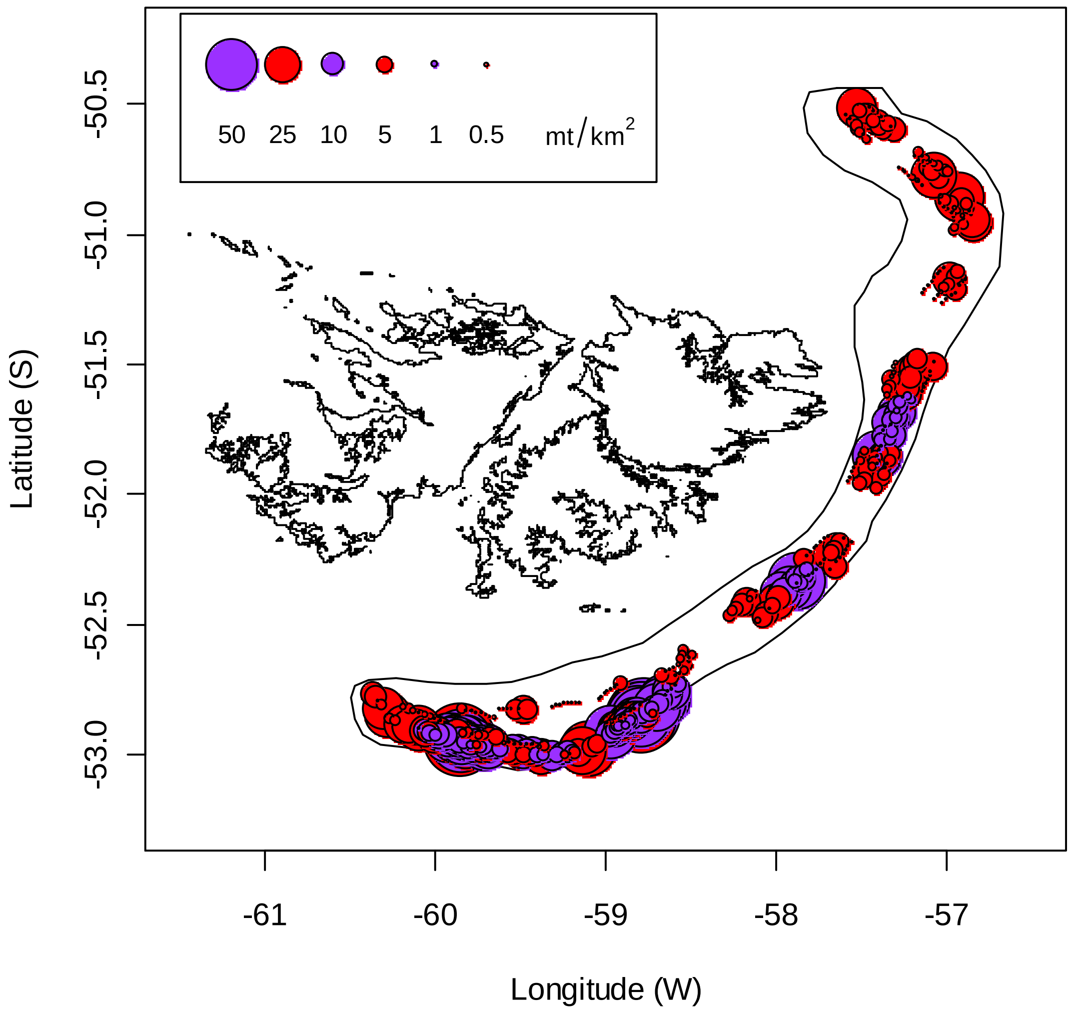


Figure 2. *Loligo* CPUE (mt km^{-2}) of fixed-station trawls (red) and adaptive trawls (purple), per 15-minute trawl interval. The boundary of the fishing area is outlined.

Catch rates and distribution

As in prior seasons (Arkhipkin et al., 2010; Winter et al., 2010; Winter et al., 2011), 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 114.70 tonnes *Loligo* and 20 adaptive trawls catching 160.92 tonnes *Loligo*. Additionally, thirteen optional trawls (made after survey hrs) yielded 31.66 tonnes *Loligo*, bringing the total catch for the cruise to 307.28 tonnes. *Loligo* catches were the highest since 1st season 2010 (Table 1), but distributed more evenly throughout the fishing area (Figure 2 this report; compare with Figure 2 in Arkhipkin et al., 2010).

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

Biomass estimation

With the largest *Loligo* catches being concentrated near the southern boundary of the survey area (Figure 2), biomass density estimates were significantly higher calculated with extrapolation than with interpolation only. And as expected, trawl intervals taken strictly in daylight averaged higher catches than trawl intervals taken in twilight or darkness. Trawl intervals strictly in daylight comprised 66% of the total. There is thus a trade-off between daylight-only data being potentially more precise, but all data being more extensive and more broadly representative of the survey area. Likewise, interpolation-only data are more precise than extrapolations, but may ignore trends of increasing density beyond the immediate bounds of the survey tracks. To give the most plausible likelihood distribution of total *Loligo* biomass, results were therefore combined from three versions of the interpolation algorithm: all data; without extrapolation, daylight-only data; without extrapolation, and all data; with extrapolation.

The combined likelihood distribution is shown in Figure 3. Maximum likelihoods of the three versions of the interpolation are 34,365 tonnes *Loligo* (all data; without extrapolation), 49,031 t (daylight-only data; without extrapolation), 71,289 t (all data with extrapolation). The combined likelihood average is 51,562 t

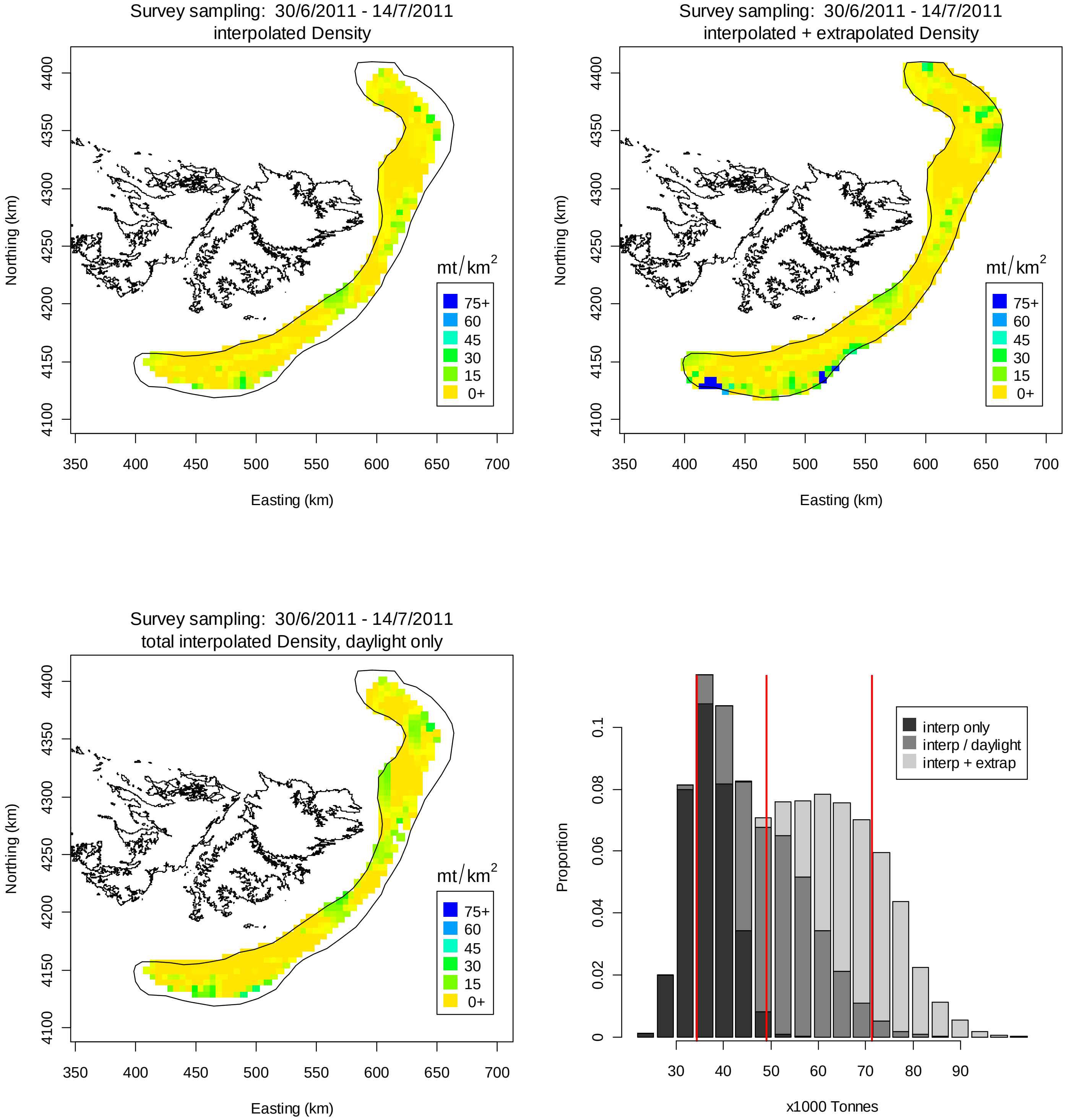


Figure 3. First three panels: *Loligo* density estimates per 5 × 5 km area units, calculated by three versions of the interpolation algorithm. For areal calculations, coordinates are converted to WGS 84 projection (i.e., 'Easting' and 'Northing'), using GeoConv software, www.kolumbus.fi/eino.uikkanen/geoconvgb/index.htm. Fourth panel: combined likelihood distribution of the *Loligo* biomass. Vertical red lines indicate maximum likelihoods of the three versions of the interpolation algorithm.

with a 95% confidence interval of [30,092 – 82,075 t]. This represents a biomass only marginally lower than second season of last year, and the 2^{nd}-highest second season biomass since the current survey format was initiated in 2006 (Table 1). Of the estimated total, 21,850 tonnes were north of 52 ºS (3.19 mt/km^2), and 29,712 tonnes were south of 52 ºS (4.09 mt/km^2). Averaged by depth strata, an estimated 11,841 tonnes occurred over grounds <150 m (2.35 mt/km^2), 8,552 t between 150 and 200 m (3.02 mt/km^2), and 31,169 t >200 m (5.49 mt/km^2).

Biological sampling

Sixty-three taxa were identified in the catch, and 21 taxa were processed for a total of 14,996 random samples (Table 2). These included statoliths sampled from 778 *Loligo* and 13 *Illex argentinus*; and otoliths sampled from 285 finfish of 15 different species. An additional 1040 *Loligo* and 20 rock cod were sampled non-randomly to determine the length-weight relationships.

Table 2. Summary of survey random samples.

FIFD code	Species	Samples	%
LOL	*Loligo gahi*	9492	63.3
PAR	*Patagonotothen ramsayi*	5029	33.5
TOO	*Dissostichus eleginoides*	327	2.2
COG	*Patagonotothen guntheri*	71	0.5
NOW	*Paranotothenia magellanica*	23	0.2
ILL	*Illex argentinus*	13	0.1
LAR	*Lampris immaculatus*	5	<0.1
MLA	*Muusoctopus longibrachus akamb*	5	<0.1
RBR	*Bathyraja brachyurops*	5	<0.1
PAE	*Patagonotothen elegans*	4	<0.1
OCM	*Octopus megalocyathus*	4	<0.1
AGO	*Agonopsis chilensis*	3	<0.1
SEC	*Seriolella caerulea*	3	<0.1
RAL	*Bathyraja albomaculata*	2	<0.1
RFL	*Dipturus chilensis*	2	<0.1
RGR	*Bathyraja griseocauda*	2	<0.1
SEP	*Seriolella porosa*	2	<0.1
RED	*Sebastes oculatus*	1	<0.1
MAM	*Mancopsetta milfordi*	1	<0.1
RMU	*Bathyraja multispinis*	1	<0.1
CAM	*Cataetyx messieri*	1	<0.1
Total		14996	100.0

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 4).

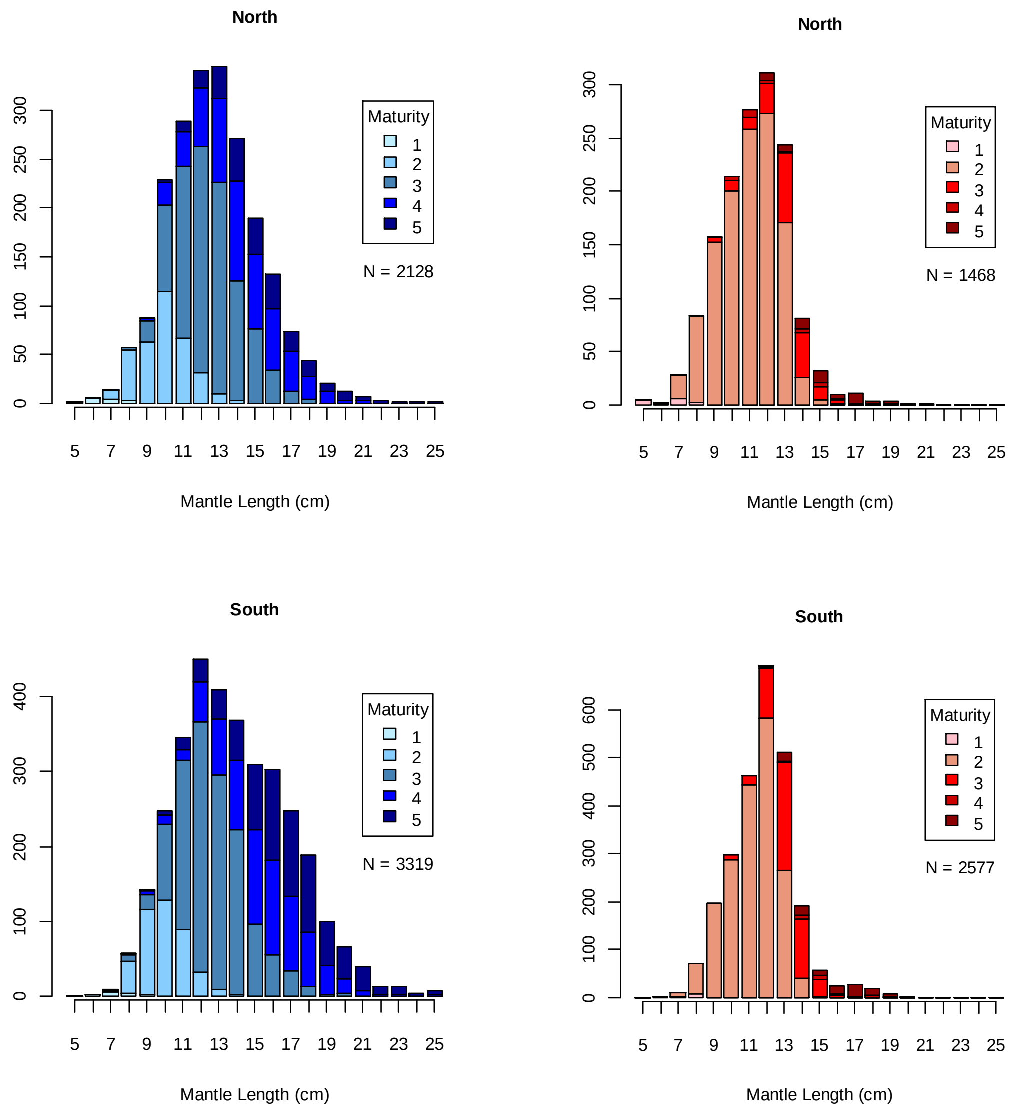


Figure 4. Length-frequency distributions by maturity stage of male (blue) and female (red) *Loligo* from trawls north (top) and south (bottom) of latitude 52 ºS.

North of 52 ºS, 17% of male *Loligo* were immature (maturity stages 1 and 2), 71% were maturing (maturity stages 3 and 4), and 12% were mature at stage 5. Of female *Loligo*, 82% were immature, 14% were maturing, and 4% were mature. South of 52 ºS, 13% of male *Loligo* were immature, 65% were maturing, and 22% were mature. Of female *Loligo*, 74% were immature, 22% were maturing, and 4% were mature.

Male maturities were significantly higher south of 52 ºS, and significantly higher in the stratum deeper than 200 m (Table 3). Male mantle lengths were significantly greater south of 52 ºS, and significantly greater with each deeper stratum (Table 4). Female maturities were significantly higher south of 52 ºS, and significantly different in each depth stratum, with the stratum from 150 to 200 m having the lowest maturities (Table 5). Female mantle lengths were significantly greater south of 52 ºS, and significantly greater in the stratum deeper than 200 m (Table 6). Males averaged significantly higher maturities, and significantly greater mantle lengths, than females.

Table 3. Average male maturities and 2-way ANOVA for depth stratum and area (N / S).

	Area	
Depth	N	S
<150	3.0	3.3
150-200	2.8	3.2
>200	3.5	3.7

	df	SSq	MSq	F	p
Depth	2	287.4	143.7	169.1	< 0.001
Area	1	73.2	73.2	86.1	< 0.001
Depth : Area	2	8.7	4.4	5.1	< 0.010
Residual	5441	4624.6	0.9		

Table 4. Avg. male mantle lengths and 2-way ANOVA for depth stratum and area (N / S).

	Area	
Depth	N	S
<150	11.1	12.0
150-200	10.8	12.6
>200	13.7	14.5

	df	SSq	MSq	F	p
Depth	2	6427	3213	444.2	< 0.001
Area	1	1417	1417	195.8	< 0.001
Depth : Area	2	227	114	15.7	< 0.001
Residual	5441	39363	7		

Table 5. Average female maturities and 2-way ANOVA for depth stratum and area (N / S).

	Area	
Depth	N	S
<150	2.4	2.6
150-200	2.2	2.3
>200	2.3	2.4

	df	SSq	MSq	F	p
Depth	2	19.7	9.9	19.5	< 0.001
Area	1	11.4	11.4	22.6	< 0.001
Depth : Area	2	2.4	1.2	2.3	< 0.100
Residual	4039	2041.8	0.5		

Table 6. Avg. female mantle lengths and 2-way ANOVA for depth stratum and area (N / S).

	Area	
Depth	N	S
<150	10.4	10.6
150-200	9.4	11.1
>200	12.0	12.3

	df	SSq	MSq	F	p
Depth	2	2332	1166	390	< 0.001
Area	1	341	341	114	< 0.001
Depth : Area	2	395	197	66	< 0.001
Residual	4039	12075	3		

The *Loligo* length-weight relationship was calculated from 1711 individuals (Figure 5), resulting in parameters $\alpha = 0.19990 \pm 0.01099$ and $\beta = 2.15469 \pm 0.02009$ ($\pm$ 1 sd). Optimized separately, the 970 male and 741 female data gave slightly but statistically different length-weight relationships (likelihood ratio test, df = 2, $\chi^2 = 21.96$, $p < 0.001$), characterized by males having higher weight per mantle length.

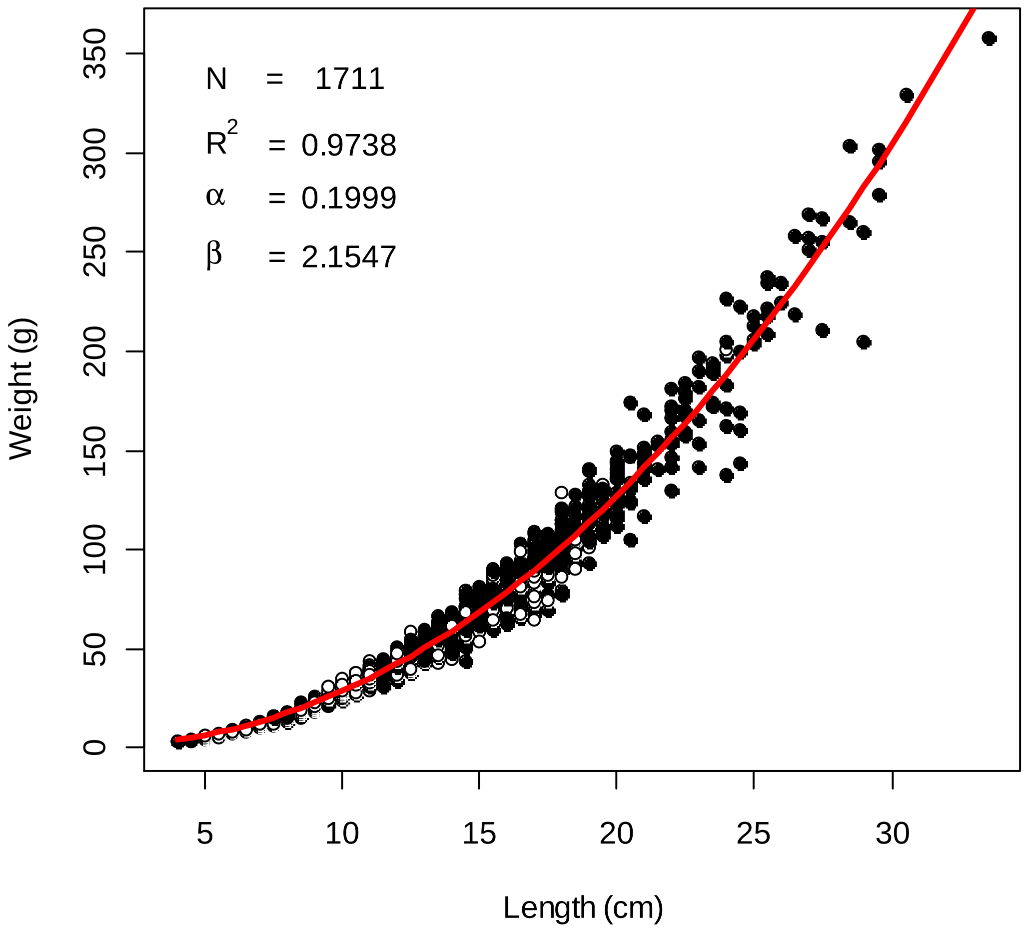


Figure 5. Length – weight relationship of *Loligo* sampled during the survey. Filled circles: males, open circles: females.

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