Falkland Island Fisheries Department

Fishery Report

Loligo gahi, Second Season 2007

Fishery Statistics, Biological Trends, Stock Assessment and Risk Analysis

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SUMMARY

Total catch by the *Loligo* fleet during the second season (July/15-September/15, 2007) was 24171 tonnes, an intermediate catch level in relation to the catch of the second seasons for the last 10 years. Total effort was 14740 hours of trawling, a low level similar to the last five years. Most of the catch was taken from the Beauchene (74%) and northern area (20%). Biological trends in proportion of mature individuals and proportion of females were similar to previous second seasons. The average mantle length was 14 cm, which is about 1 cm greater than in 2006. There were three squid groups that arrived sequentially to the southern area and two groups that arrived to the central-northern area. In-season stock assessment was undertaken using FIFD implementation of the stock depletion, biomass projection and risk analysis. The combined risk was calculated as the product of the probability that CPUE continue declining and the probability that projected spawning biomass by 15th of October is lower than 10000 tonnes. The fishing industry was warned, with two weeks in advance, of an early fishery closure to avoid the 10000 tonnes spawning biomass limit. After FIFD-industry meetings, where stock assessment and biomass projection results were monitored and discussed, the fishery was early closed on the 15th of September. During the post-season stock assessment a new integrated depletion model was developed to estimate simultaneously the biomass by pulse and the catchability coefficients by vessel and area. This model was fitted using Bayesian inference. The whole biomass that arrived during the fishing season was estimated at 48500 tonnes and the survival spawning biomass was estimated at 11458 tonnes. The probability that CPUE continue decreasing after the 15th of September was estimated at 0.84; the risk that spawning biomass is lower than 10000 tonnes was estimated at 0.09, and the combined risk at 0.07. Therefore the management aim to preserve a minimum escaping biomass was met with a low risk.

INTRODUCTION

Loligo biomass in the *Loligo* box just before the beginning of the second fishing season was estimated at 19 thousand tonnes (Payá 2007a). This biomass was estimated using the swept area method and it was 15% lower than the biomass estimated in the same time and area in the 2006 survey. The squids were more dispersed and were 2 cm larger than in 2006. Therefore for this fishing season it was possible to foresee a better quality (size) product but little less biomass than in the 2006 second season.

The 2007 second season started on the 15th of July and lasted until the 15th of September, when it was early closed. The fishery was monitored by means of daily catch reports and electronic logbooks sent by captains and biological sampling made by scientific observers onboard. The fishery statistics and biological data cover the whole period, except for a four-day interruption of biological sampling. Most of the fishing activity was carried out in the southern (Beauchene) and Northern area, with scarce operations in the Central area (**Fig. 1**).

During the fishing season, in-season stock assessment was made using the FIFD's implementation of the stock depletion model, catch projection, spawning biomass projection and risk analysis as described in previous reports. Fishing industry was warned, with two weeks in advance, of an early fishery closure in order to leave 10000 tonnes spawning biomass. The fishery was closed early on the 15th of September.

In after-season assessment a new integrated model was developed to estimate simultaneously the biomasses of the different squid groups and the catchability coefficients of each vessel by area. The stock assessment and risk analysis were made using Bayesian inference. The priors were noninformative Cauchy distributions and the posteriors and marginal variables were estimated using Metropolis-Hastings Markov Chain Monte Carlo (MCMC). The combined risk was calculated as the product of the probability of biomass depletion and the probability of leaving at sea less than 10000 tonnes of spawning biomass by the 15th of October.

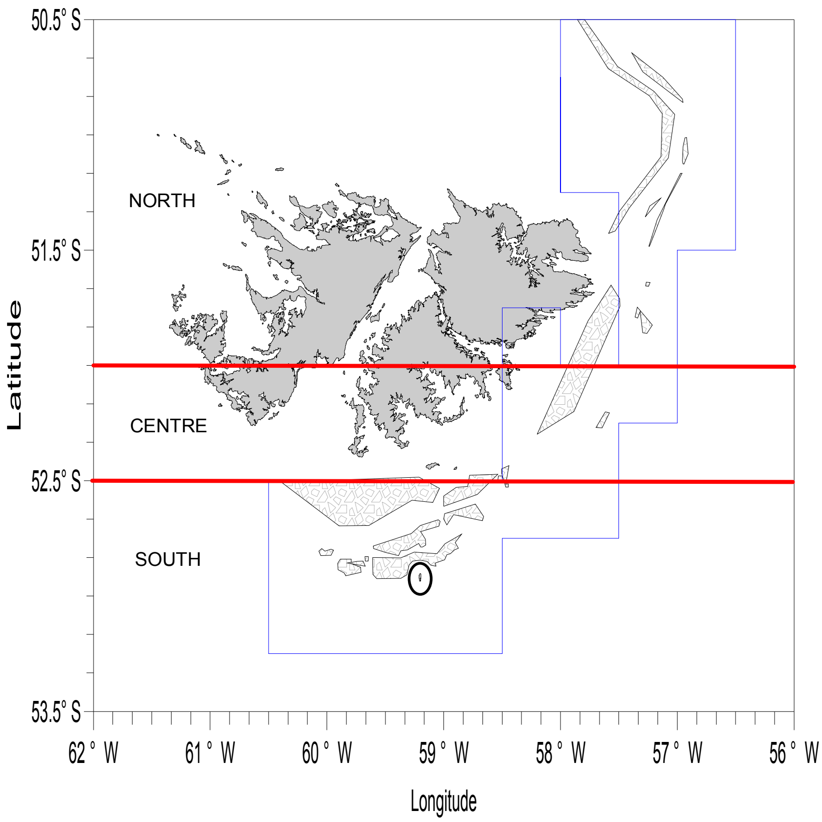


Fig. 1.- Fishing grounds and rocky bottoms around the Falkland Islands. In blue, the *Loligo* box, and in black, the three-nm exclusion area around Beauchene Island.

PART 1 – FISHERY STATISTICS

Total Catch and Total Effort in Historical Perspective

Despite of the early fishery closure, the catch in the second season was at medium level and similar to 2006 (**Fig. 2 and Table 1**). CPUE have been similar during the last three years (**Fig. 3)**. From 1997 to 2005, second season catches increased; fishing efforts decreased and CPUE increased. Historical CPUE trend is not clearly correlated with stock biomass estimations, probably because there have been some local changes in the biomass by fishing area and some failures of the depletion models (**Fig. 3 and Table 1**). Nevertheless, there have been methodological changes since the second season of 2004 and it is necessary to carry out a re-analysis of the old data.

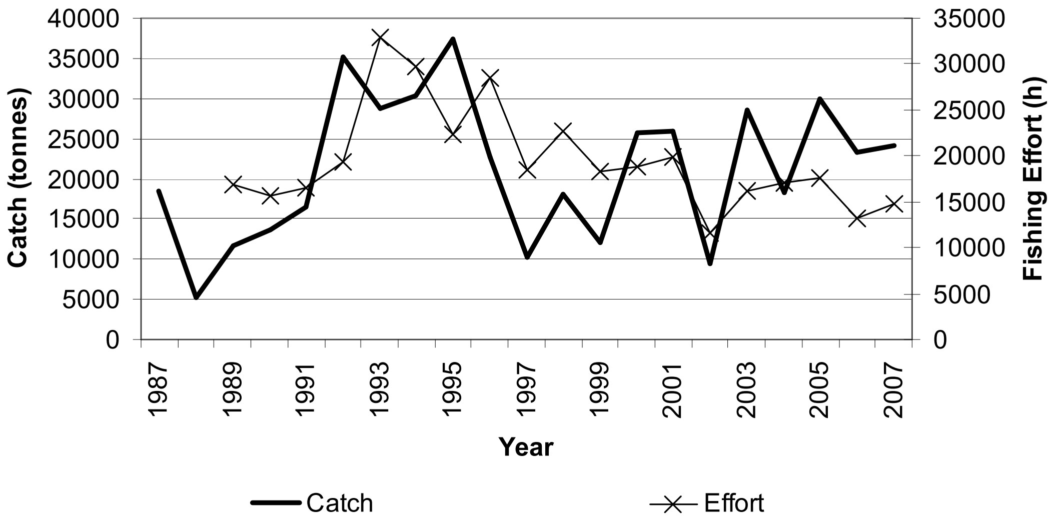


Fig. 2.- Historical catches and fishing effort of the second season.

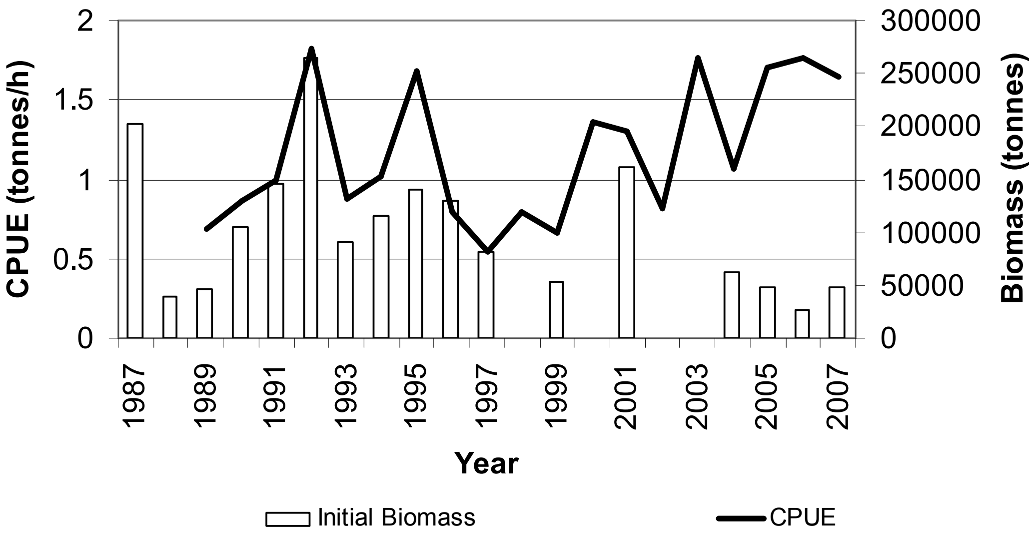


Fig. 3.- Historical CPUE and initial biomass of the second season.

Table 1.- Fishery statistics and initial biomass for the known history of the *Loligo gahi* fishery of the Falkland Islands. 'Failure' indicates that stock depletion model could not produce a reasonable estimate of initial biomass. From 1970 to 1985 the source is Csirke (1986), from 1987 to the present the source is either RRAG (for initial biomass up to 2003) or FIFD (catch and effort and initial biomass from 2004). Biomass in bold italic is the sum of the biomass at the beginning of the season and the biomass of squid groups that arrived during the season.

Year	First Fishing Season			Second Fishing Season			Annual Catch (tonnes)
	Catch (tonnes)	Effort (h)	Initial Biomass (tonnes)	Catch (tonnes)	Effort (h)	Initial Biomass (tonnes)	
1970							200
1971							100
1972							100
1973							250
1974							200
1975							140
1976							129
1977							354
1978							911
1979							925
1980							1111
1981							631
1982							18452
1983							38256
1984							36450
1985							36430
1986							
1987	64063		101000	18484		202000	82547
1988	48664		115000	5267		39000	53931
1989	106186	33159	165000	11671	16881	46000	117857
1990	69366	24177	206000	13624	15713	104000	82990
1991	37353	13808	53000	16462	16610	146000	53815
1992	48157	15406	97000	35227	19291	264000	83384
1993	23567	16065	47000	28711	32950	90000	52278
1994	35502	19891	55000	30254	29687	116000	65756
1995	60293	10913	195000	37486	22365	141000	97779
1996	38679	16438	31000	22694	28420	130000	61373
1997	15962	16766	40000	10159	18486	82000	26121
1998	33379	16835	60000	18178	22762		51557
1999	22863	19642	44826	12008	18266	53737	34871
2000	38713	21034	63683	25781	18869		64494
2001	27624	20955	26000	25935	19841	162234	53559
2002	14198	20824	21000	9513	11570		23711
2003	18973	8494	40350	28447	16166	Failure	47420
2004	8609	8740	Failure	18229	17024	62732	26838
2005	28747	7292	114878	30047	17658	47201	58794
2006	19056	8521	39218	23238	13150	26500	42294
2007	17229	8780	***37517***	24171	14740	***48500***	41400

Catch and Effort per Fishing Ground and Cumulative Catch

Most of squid (74%) were caught in the southern area, where the fleet did 69% of the whole trawling hours (**Table 2**). The catch in the northern area was 20% of the whole catch and in the central area was only 6%. CPUE (tonnes/h) in the southern area was 28% greater than in the others areas, where the CPUE were similar.

Table 2.- Effort and catch statistics of *Loligo* second season 2007 by fishing ground.

Fishing Ground	Catch tonnes	Effort Vessel-Days	Effort Hours	CPUE tonnes/V-D	CPUE tonnes/h
South	17944	640	10169	28.0	1.76
Centre	1413	69	1028	20.5	1.37
North	4814	257	3543	18.7	1.36
Total	24171	966	14740	25.0	1.64

The daily cumulative catch was very close to the best year during the first week but later started to decline (**Fig. 4**). Like in previous seasons, it is probable that the first weeks of fishing were highly successful because the fleet knew in advance, as a result of the research survey, where to find the highest concentration of squids.

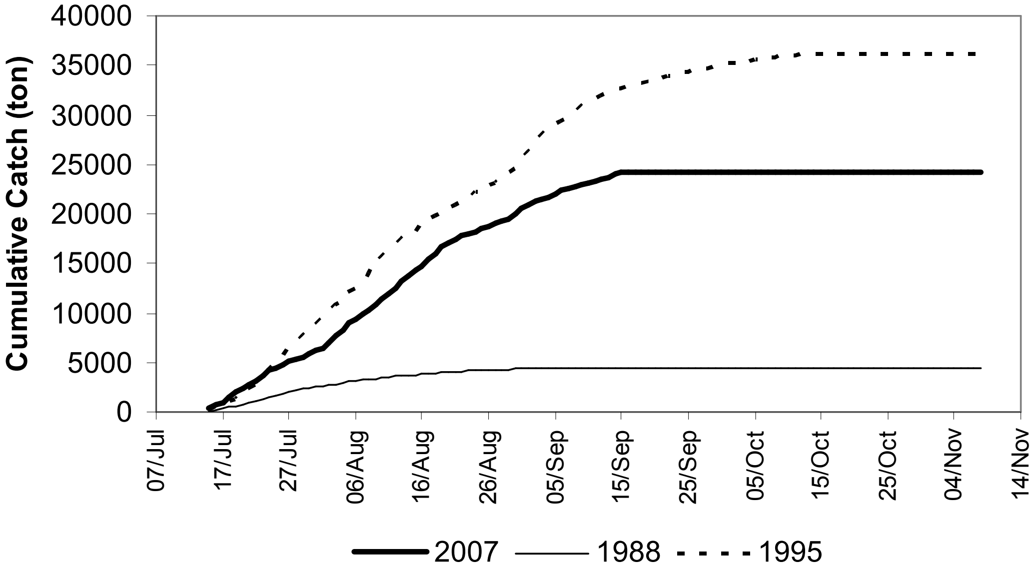


Fig. 4.- Cumulative catch versus date in the second season of 2007 compared with the cumulative catch of the second seasons that yielded the highest (year 1995) and lowest (year 1988) historical catches on exactly the same date range (displaced back 15 days to cover the same period of time).

Fleet Movement Dynamics, Catch and Catch Rate

During the first day of the season the fleet fished in the southern area, where the *Loligo* survey had found the highest *Loligo* concentrations. After few days the fleet moved to the northern area, and remained there for some days before splitting its effort mainly between the northern and the southern areas (**Fig. 5a and 5b**). During the next 3 weeks (from 3rd to the 23rd of August) the fleet fished mainly in the southern area. After this period the fleet continued fishing mainly in the southern area but with operations in the northern area also. During the last week the fleet relocated in the northern area.

During the first week the northern CPUE was greater than the southern CPUE, but it had a declining trend (**Fig, 5c**). During the last week the northern CPUE increased again, as a result of the arrival of a new squid group (see biological section in this report). The southern CPUE had three peaks (23rd of July, 2nd of August and 13th of August) produced by the sequential arrivals of three squid groups. There were other CPUE peaks but they were associated with fleet behaviour, these peaks appeared because the whole fleet suddenly concentrated in a very small locality of high squid abundance. The central CPUE was high during the first 3 weeks but they did not produce high catches because the fishing effort was small.

The graphical interface, that displays patterns of fleet movements and allows the study of local depletion events (Payá, 1996), was improved incorporating new scroll controls to select different vessels and areas to be displayed (**Fig. 6**). Also a new macro to save the images in gif format files was programmed. Furthermore, to compare the commercial CPUE with the *Loligo* survey CPUE, the starting day was set equal to the initial day (30th of June) of the scientific survey.

During the first day of commercial fishing the fleet was split between the southern and northern area, in the southern area the fleet was concentrated in the western zone, where the *Loligo* survey had found the best squid concentrations (**Fig. 6**). The commercial CPUE was half of the CPUE of the last day of the *Loligo* survey. On the 31rst of July, after the CPUE declining, the fleet searched along the whole *Loligo* box, and found the highest CPUE in the western zone of the southern area (**Fig. 7**). In the following days the fleet moved to southern area and remained in the western zone, where on the 19th of August achieved the highest CPUE for the season (**Fig. 8**). Most of the southern catches during the whole season came from this small fishing ground. On the 29th of August, after another CPUE depletion, the fleet searched again over the whole *Loligo* box, and found the highest CPUE in front of Stanley in the northern area and in the western zone of the southern area (**Fig. 9**). During the rest of the season the fleet was concentrated mostly in these two fishing grounds (**Fig. 10**). During the last 5 days of the season the fleet also fished near to the northern boundary of the *Loligo* box, where it found low CPUE, confirming the depletion condition of the biomass along the whole *Loligo* box (**Fig. 11**).

As an example of the advantages of the improved version of the graphical interface the **figure 12** shows the same day than the **figure 11** but with data limited to the southern area. The upper graph of **figure 12** shows the average CPUE of the fleet along the fishing season for the selected area.

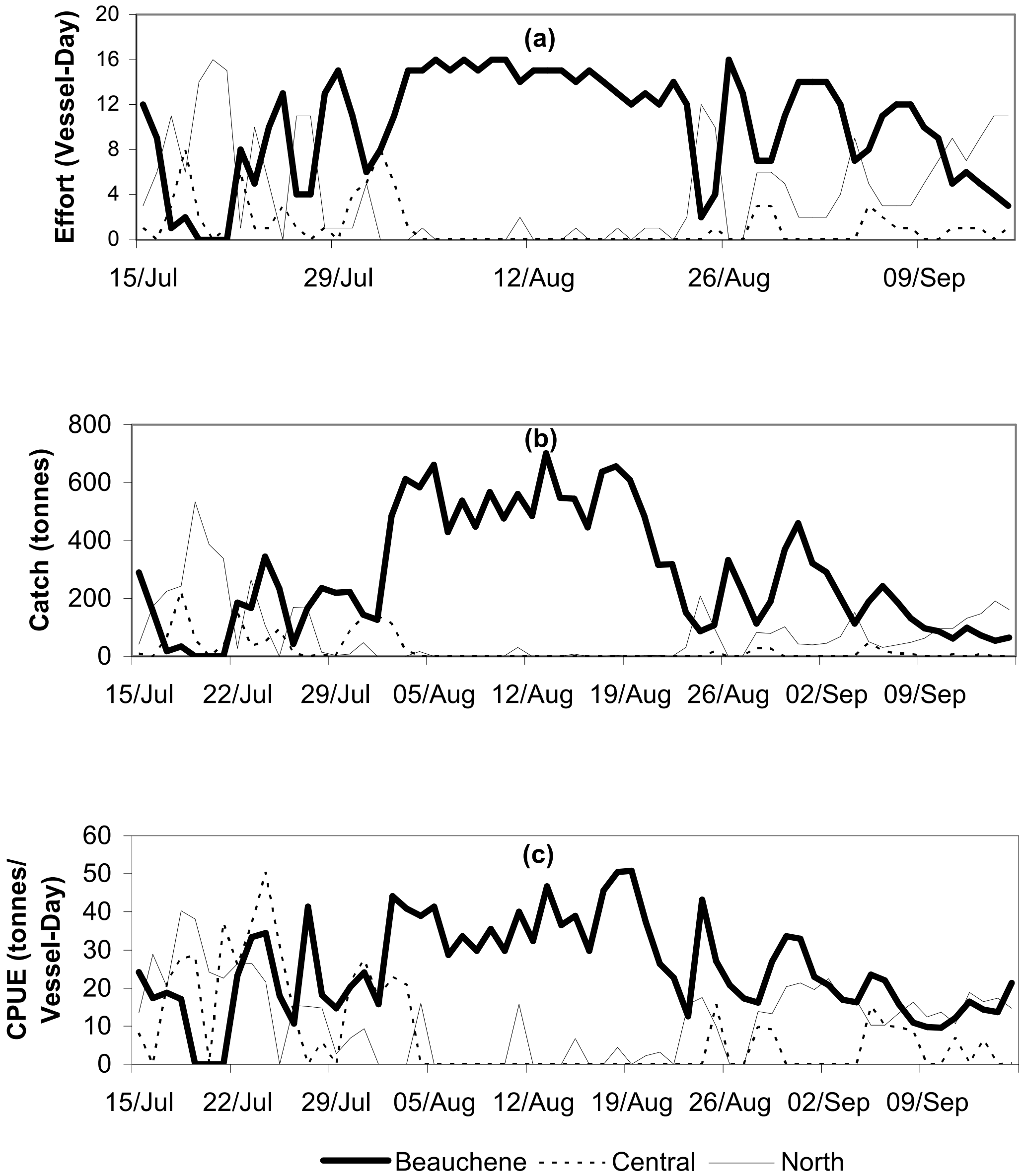


Fig. 5.- Daily evolution of effort (a), catch (b), and catch per unit of effort (c) in the *Loligo* fishery during the second season of 2007.

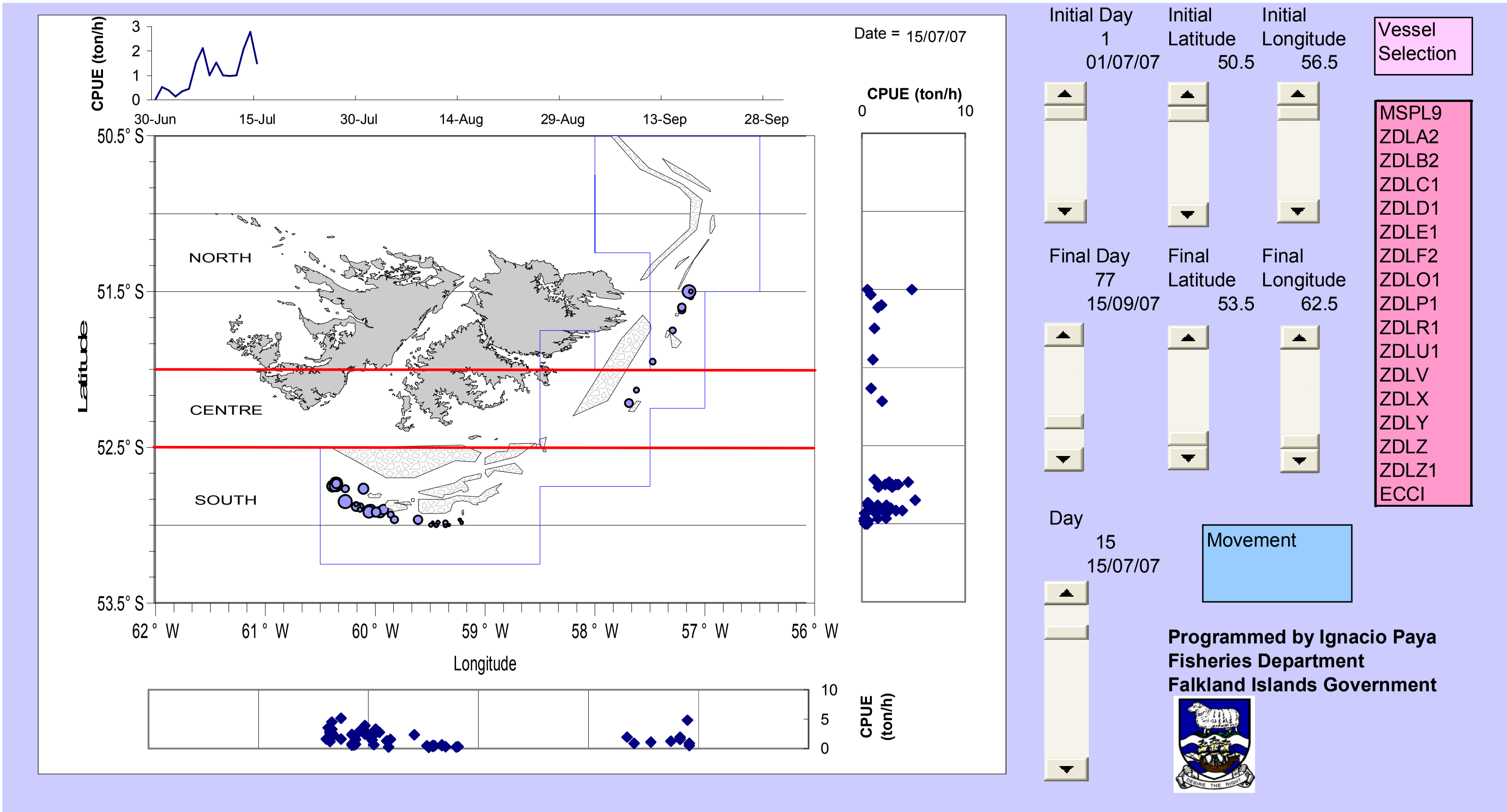


Fig. 6.- Improved graphical interface to display fleet movements and catch rates. It incorporates additional scroll and button controls to select vessels and area to be displayed. The central plot shows the *Loligo* box (blue); the boundaries of the fishing areas (red lines); the rocky bottoms (hatched polygons); and the CPUE (tonnes/h) of each haul (blue circles size proportional to CPUE value). For a better understanding of the CPUE values the right plot shows the CPUE by latitude and the bottom plot the CPUE by longitude. The upper left plot shows the average CPUE of the selected vessels from the beginning of the *Loligo* scientific survey until the date that is displayed in the right upper corner of the frame. The data displayed correspond to the first day of the fishing season.

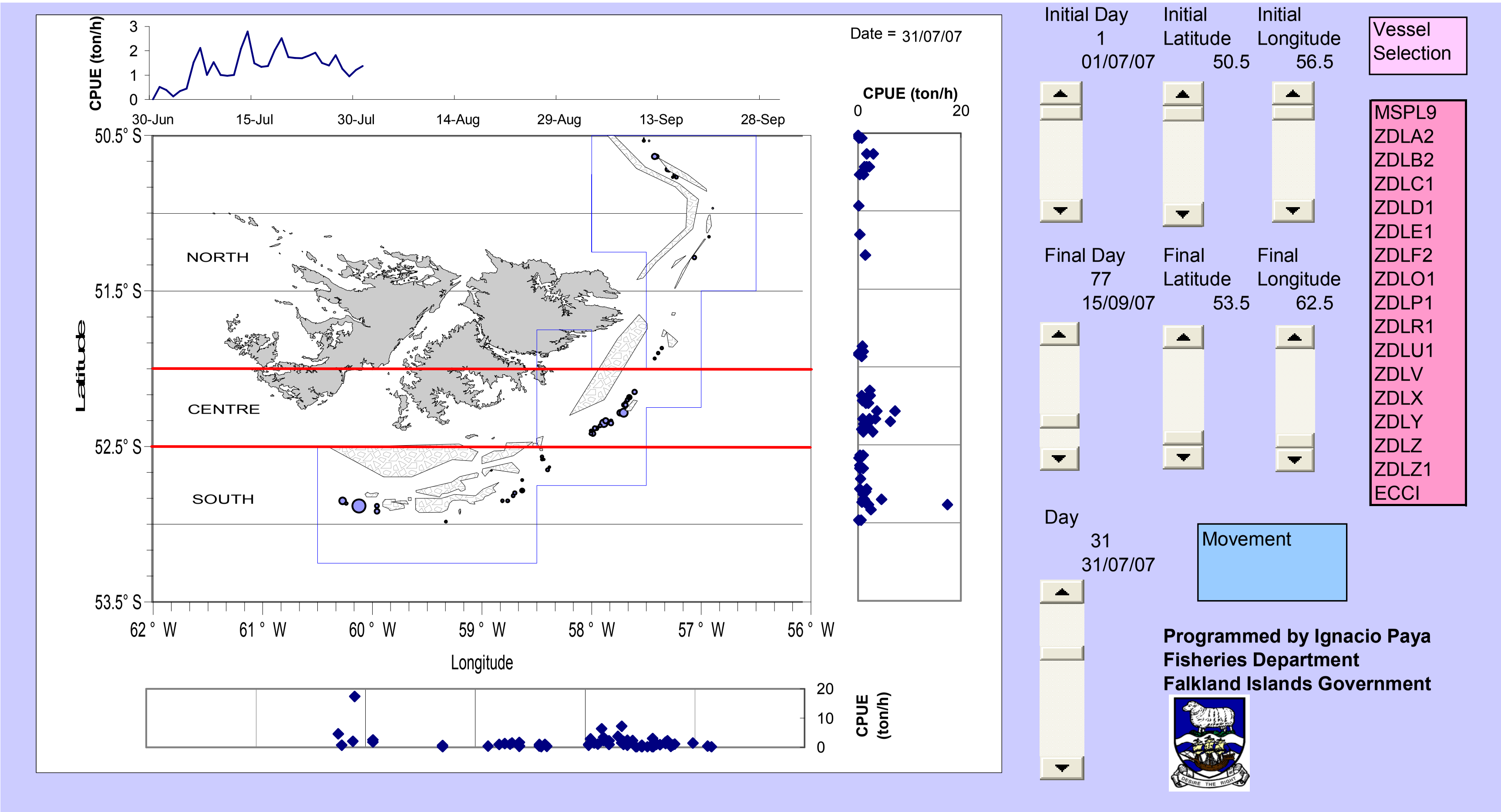


Fig. 7.- On the 31[rst] of July the fleet searched along the whole area and found the best catch rate in the southern area.

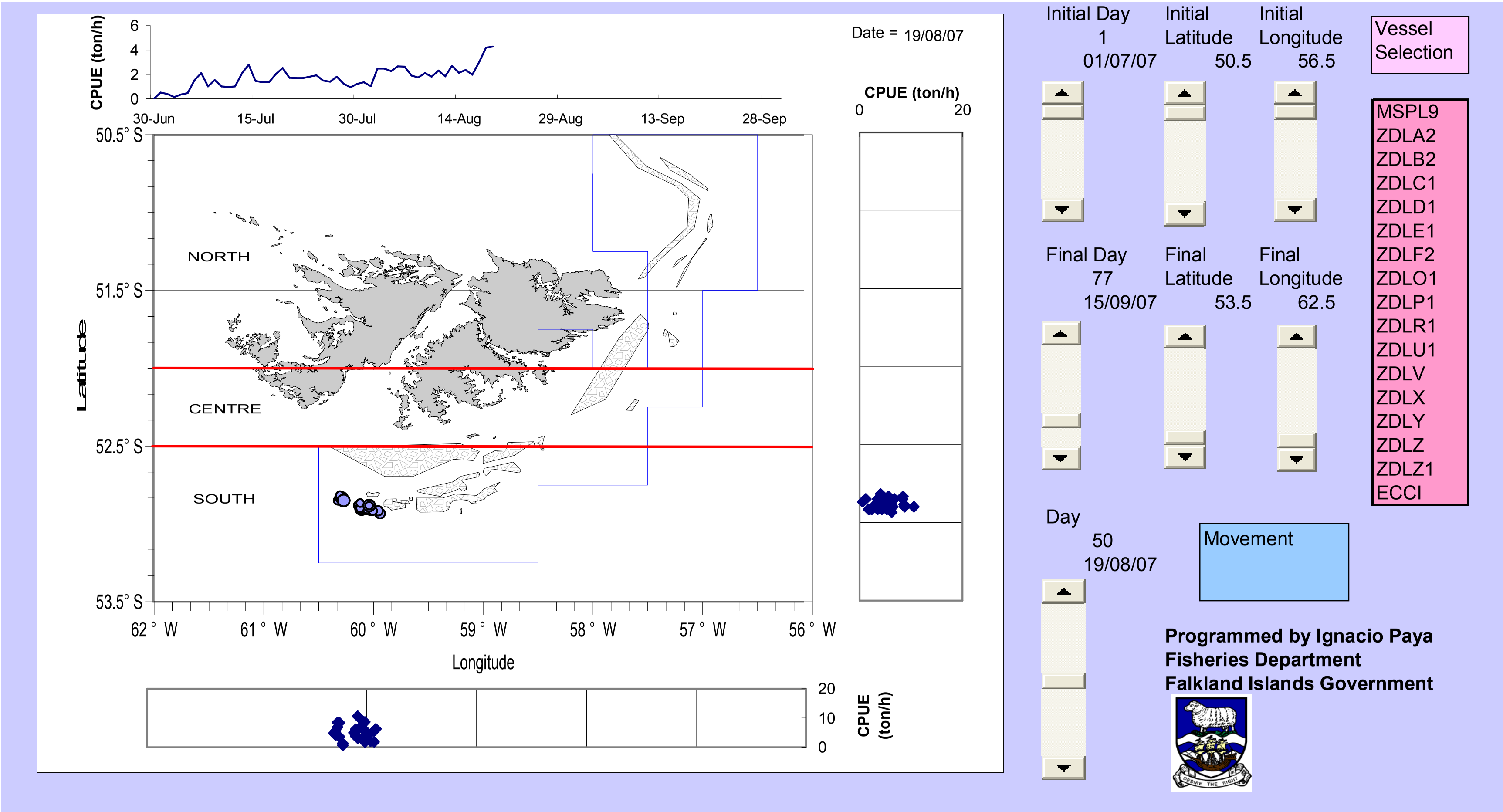


Fig. 8.- On the 19th of July the fleet was highly concentrated in the southern area, where it had the maximum catch rate of the season .

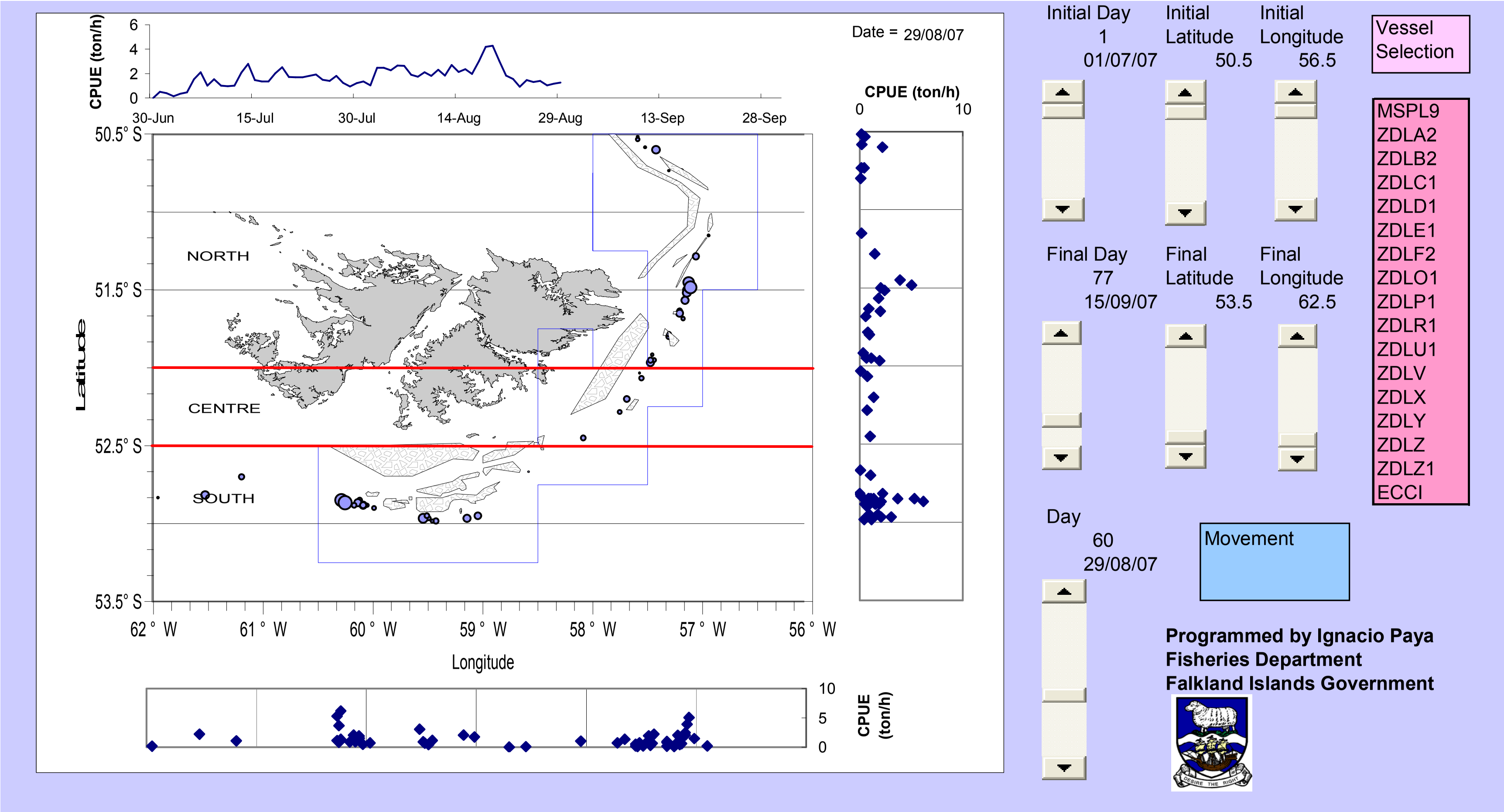


Fig. 9.- On the 29th of August the fleet searched again along the whole area and found one fishing ground with high catch rates in the northern and other in the southern area.

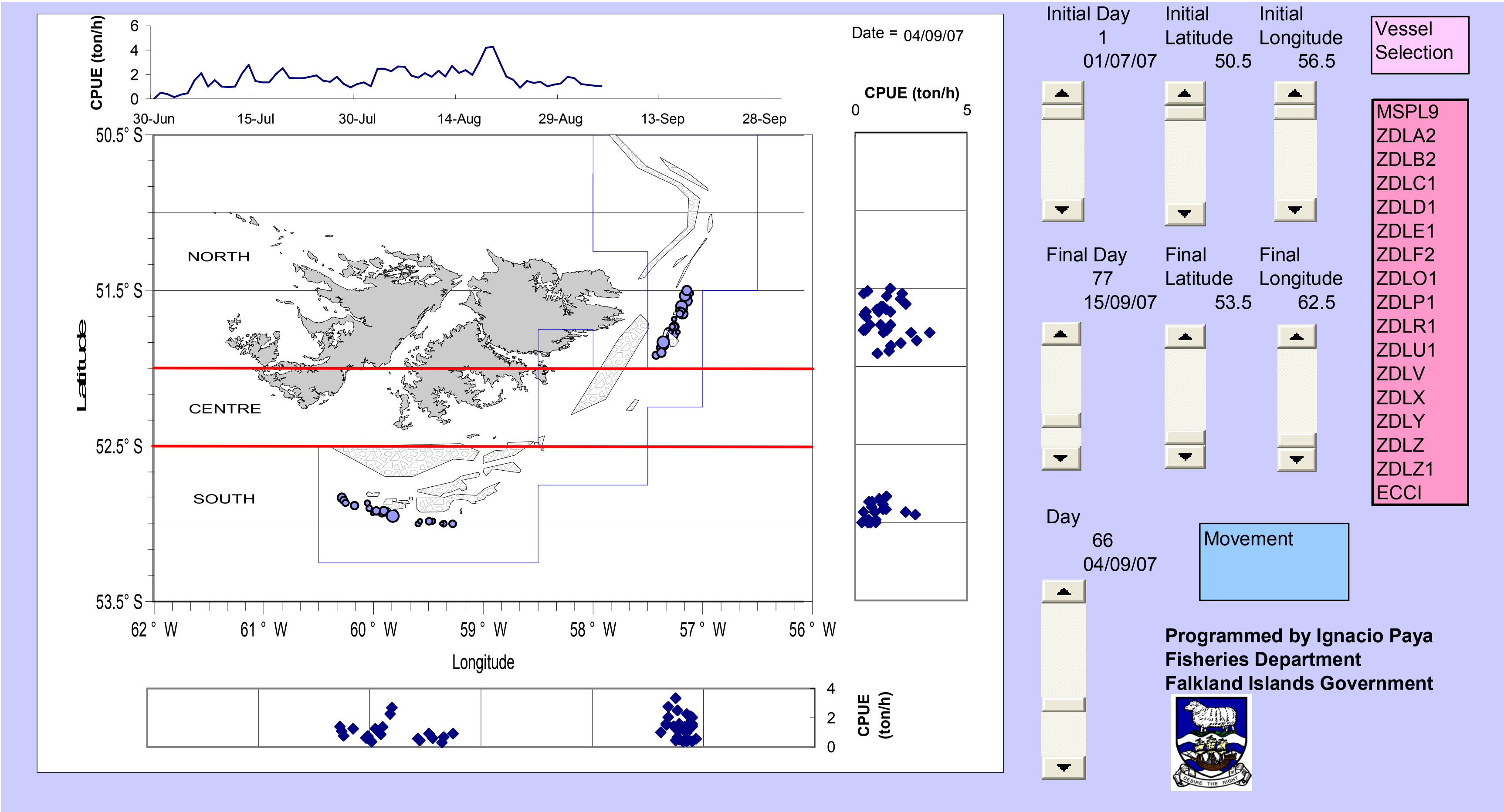


Fig. 10.- On the 4th of September the fleet was concentrated in the northern and the southern area.

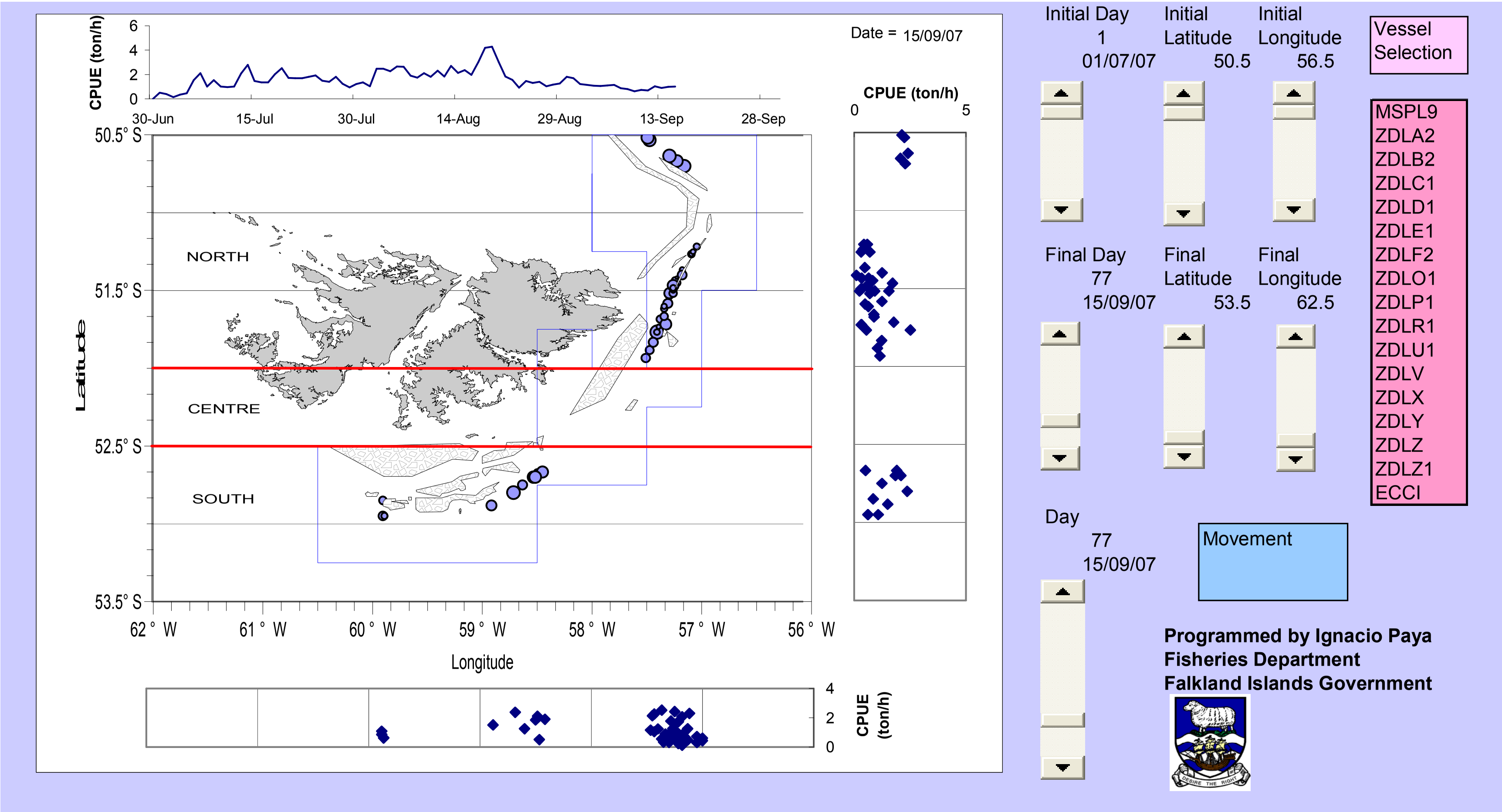


Fig. 11.- On the 15th of September, the last fishing day, the fleet was dispersed along the whole area.

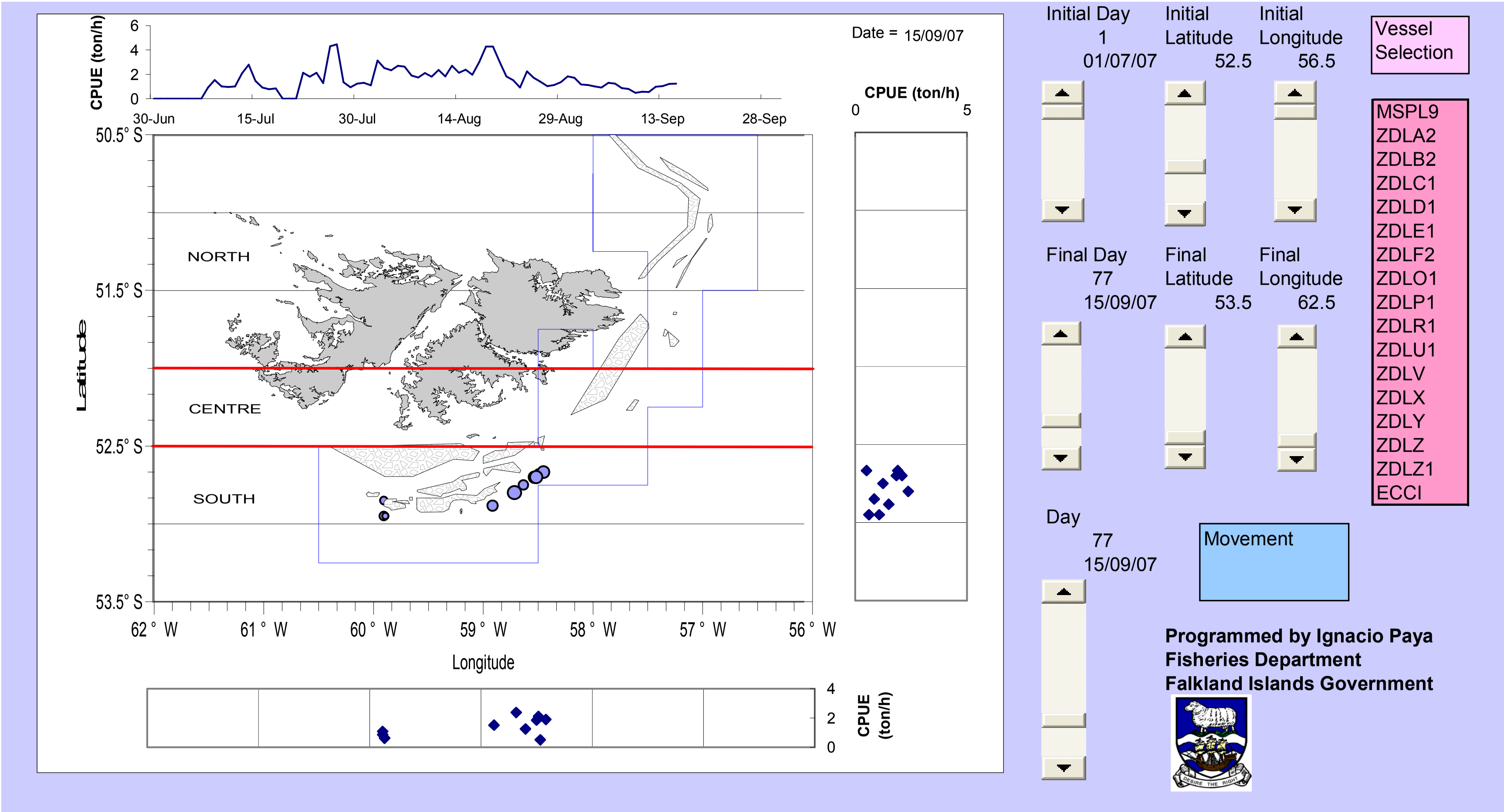


Fig. 12.- Last fishing day in the southern area. The upper graph shows the average CPUE along the fishing season for the southern area only.

PART 2 – BIOLOGICAL TRENDS

Biological trends of the stock were based on samples of animals taken by scientific observers onboard of commercial vessels. One observer was onboard during the first 25 days of the fishing season, and then two observers continued until the end of the season. Each observer takes a sample of approximately 400 animals per day. There were 4 days without observer data.

Comparison of Daily Mean Biological Characteristics with Recent Years

The proportion of sexually mature squid in the catch closely followed trends observed in the second seasons of the previous six years (**Fig. 13**). Most of the females were immature or maturing during the whole season. Conversely, the males showed a decreasing trend of immature or maturing stages. The female ratio also showed a decreasing trend, approximately from 0.5 to 0.25 (**Fig. 14**).

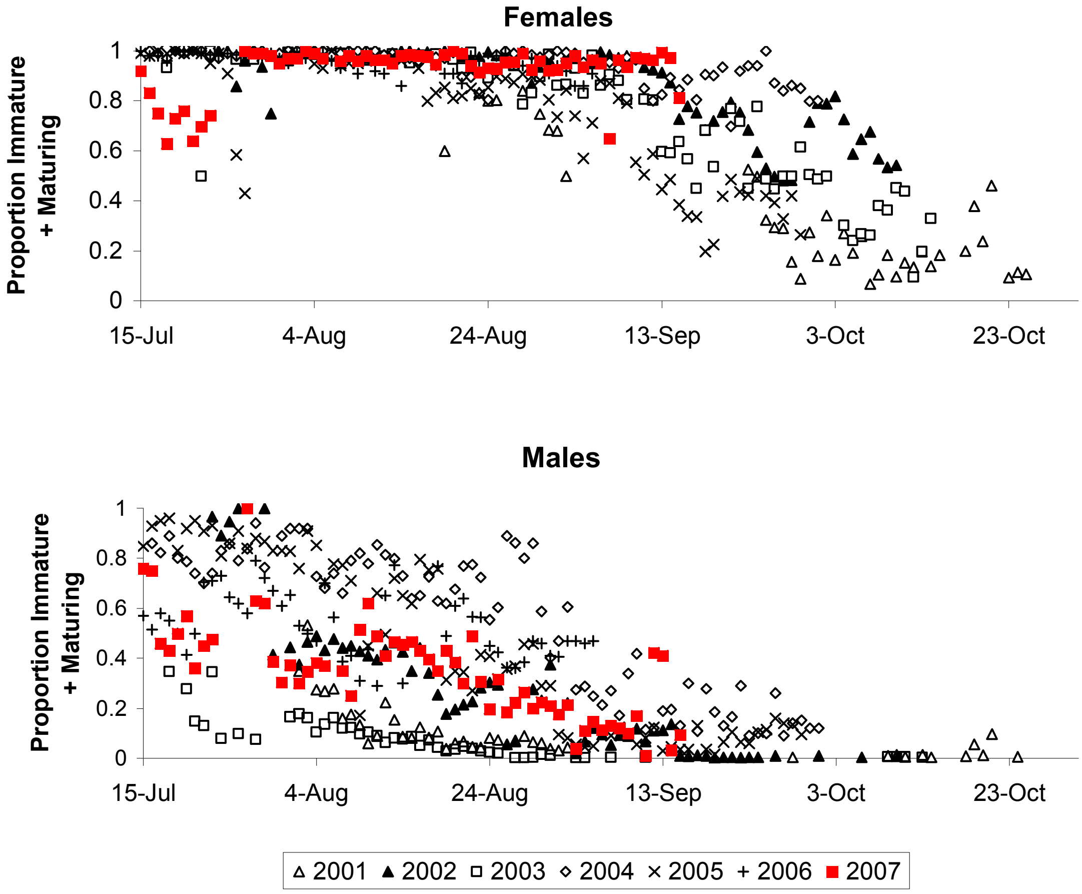


Fig. 13.- Current year trends in the proportion of sexually immature squids in the catch, compared with six previous years.

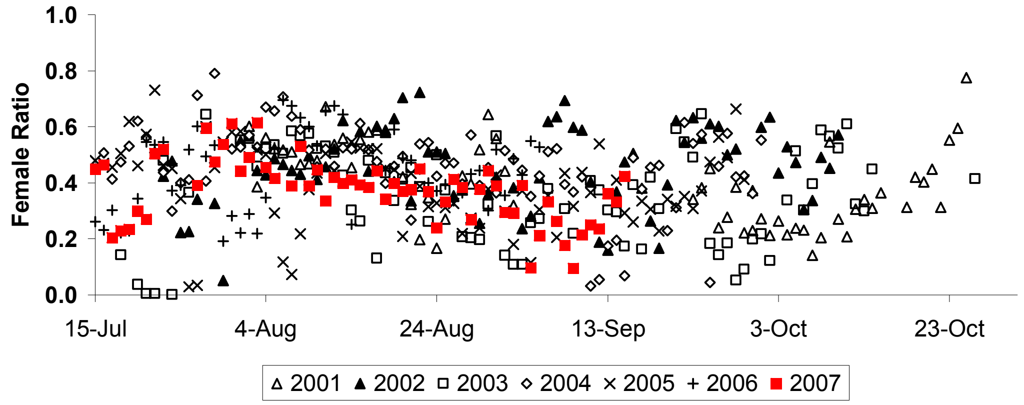


Fig. 14.- Current year trends in the daily evolution of the proportion of female squids in the catch, compared with six previous years.

The average dorsal mantle length, in both sexes, slowly increased with the days and suddenly decreased at the last week of the season. The average mantle length was 13.3 cm in females and 14.7 cm in males. These figures are approximately 1 cm greater than in 2006 and 1 cm smaller than in 2005 (**Fig. 15**).

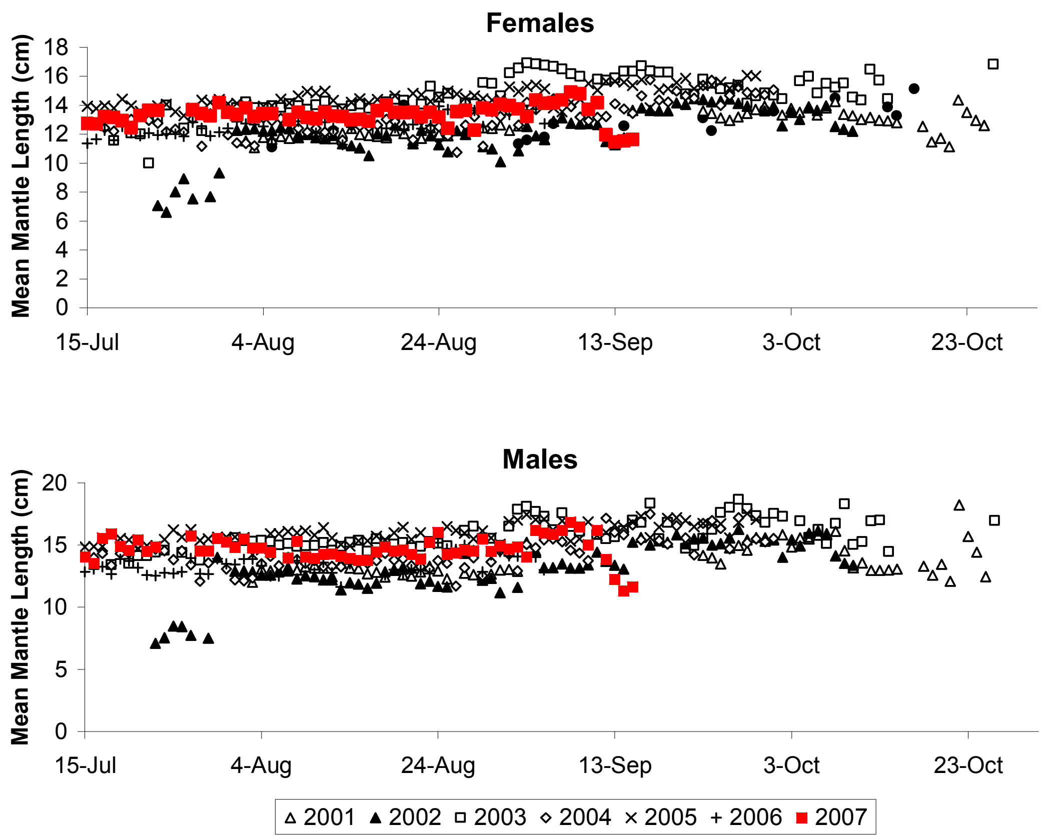


Fig. 15.- Current year trends in the mantle size by sexes, compared with six previous years.

The dorsal mantle length distributions were uni-modal (**Fig. 16**). There were four days without biological sampling that are shown on **Fig 16.**

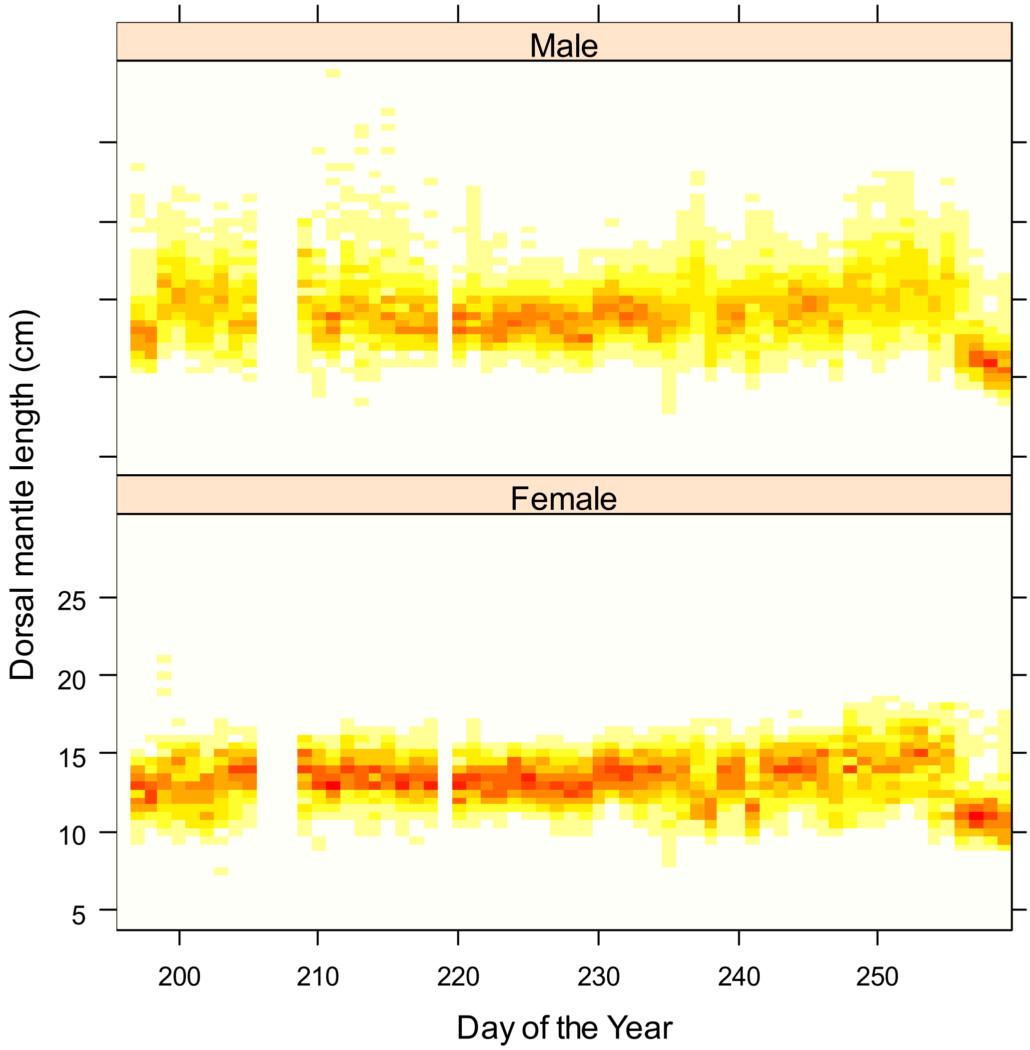
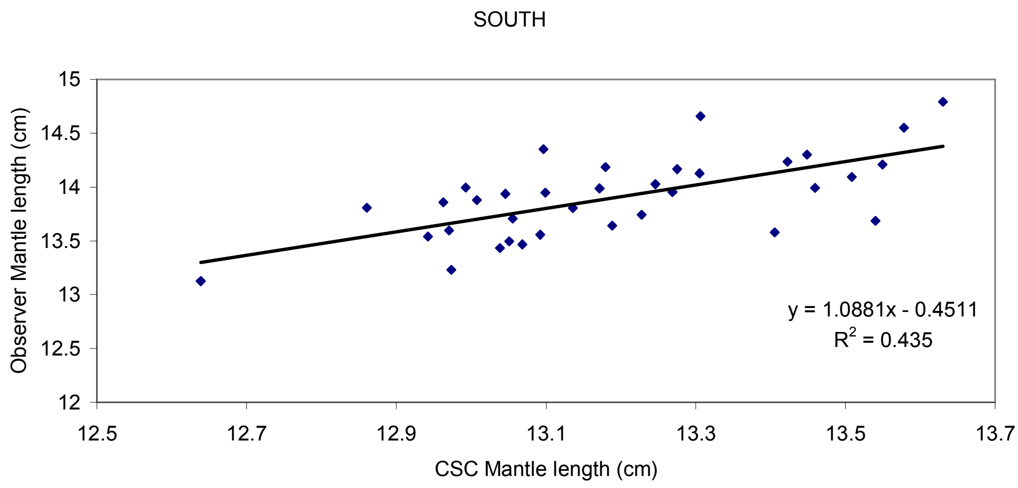


Fig. 16.- Time series of proportions (increases from yellow to red) of dorsal mantle length of squid in the catch during the second season, 2007.

The mantle size was also estimated based on the e-logbook records of production by ***C***ommercial ***S***ize ***C***ategory (***CSC***) by haul and vessel. The procedure for estimation was the one described in the 2006 second season fishery and stock assessment report (Payá 2006). During 2007 season the scientific observers were no able to cover simultaneously the two fishing areas because the vessels with observers onboard remained in the same area. To estimate the average mantle lengths in the non sampled area, the CSC were analyzed by area and then linear relations between mantle size recorded by observers and CSC were fitted, and finally used to estimate the missing observer data (**Fig. 17**).



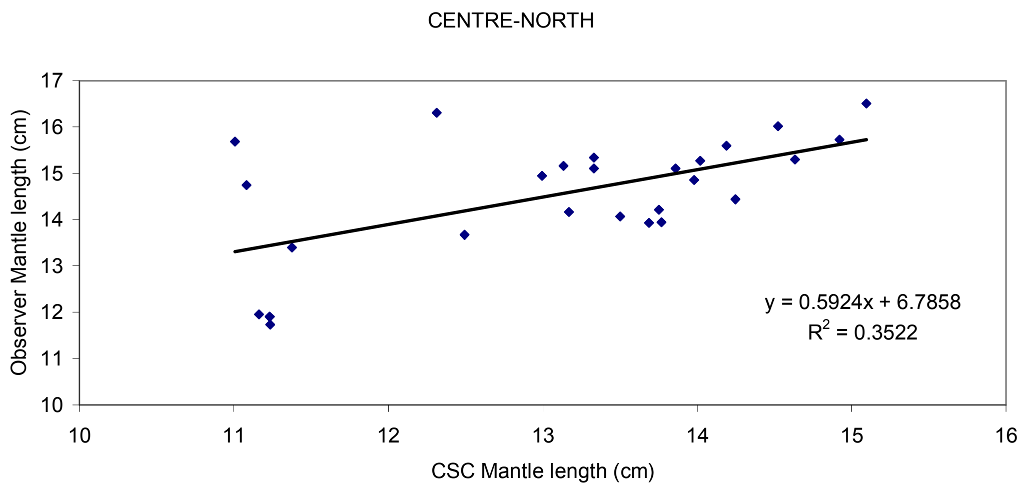


Fig. 17.- Relations between observer mantle length and commercial size categories (CSC) mantle length for the southern and central-northern areas.

The average mantle length was similar along the season, except during the last week when the length decreased, this was observed in the central-northern area only, where observers were present and did not happened in the southern area, according to the CSC data (**Fig. 18**).

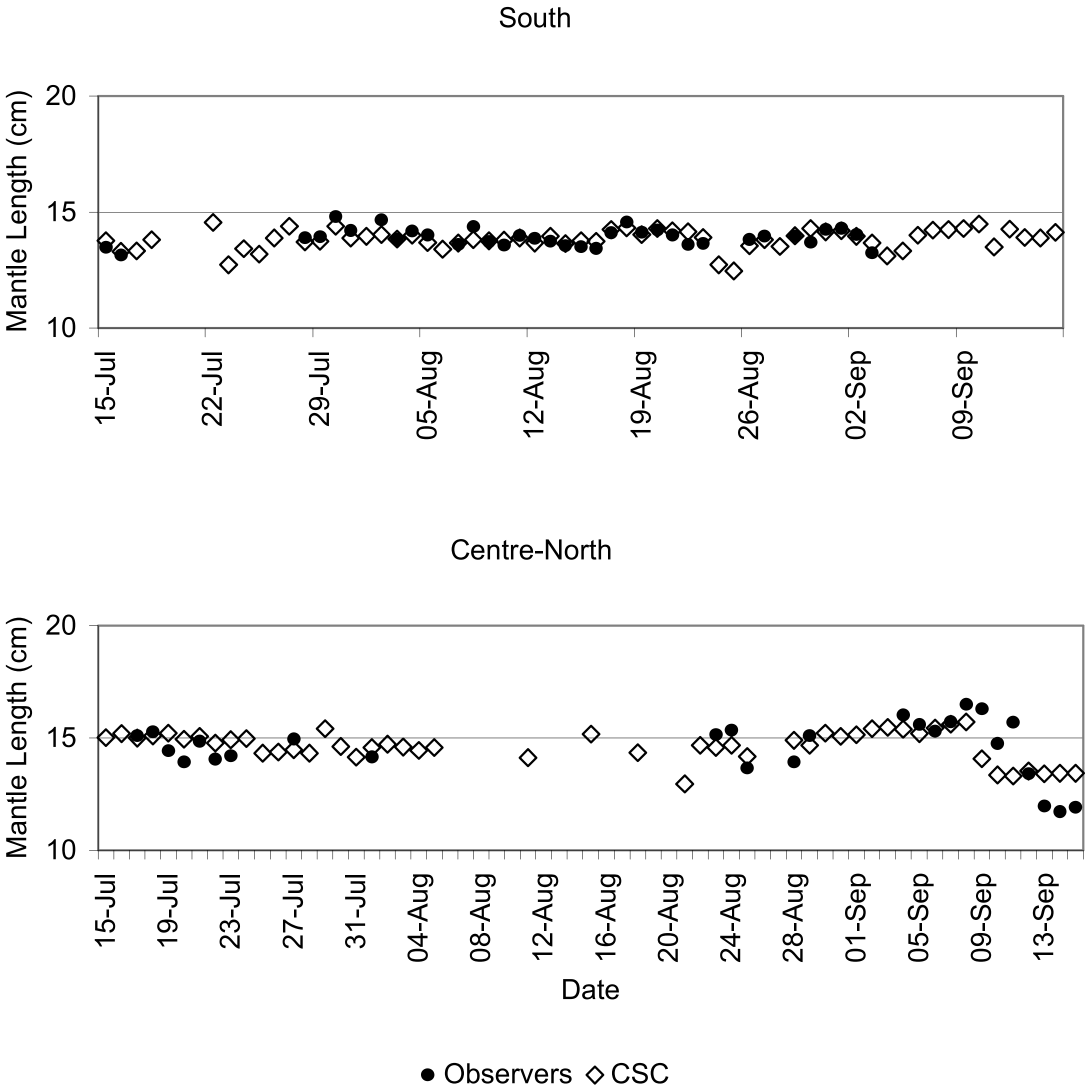


Fig. 18.- Average mantle length by area. Data from scientific observers onboard and estimations base on the commercial size categories (CSC).

The CSC length distributions were less precise than the observer length distributions because uniform length distributions were assumed inside each CSC (**Figs. 19 and 20**). The best way to improve this estimation is to ask the captains to provide the data of their own samples of CSC; they do these samples frequently to check the sorting by CSC in the vessel factory. Nevertheless, the CSC and observer length distribution have the same general pattern, as it is observed at the last week of the season in the northern area (**Fig. 20**).

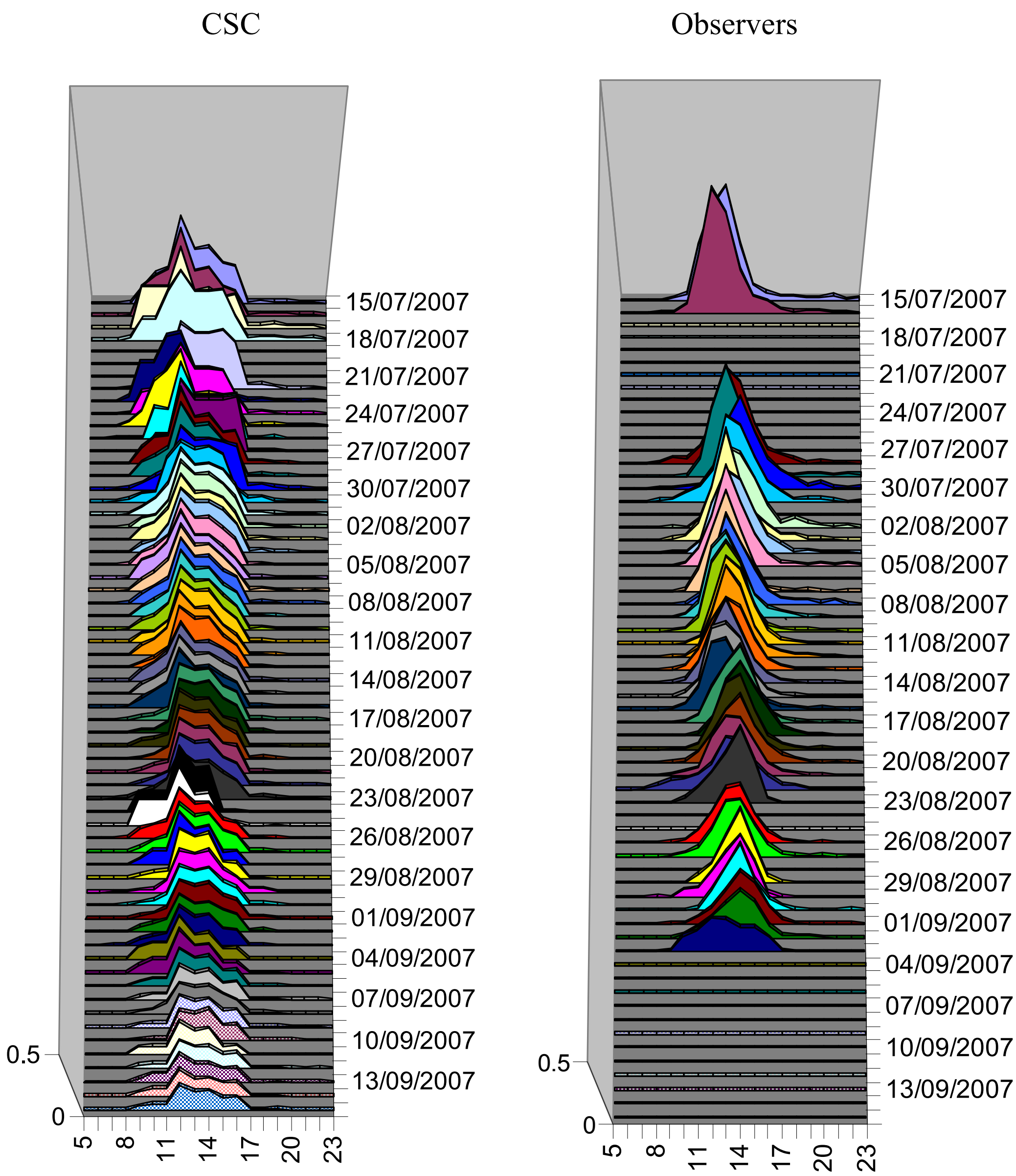


Fig. 19.- Mantle length (cm) distribution by day in the southern area. The sizes were estimated from commercial size categories (left plot) and from scientific observers onboard (right plot).

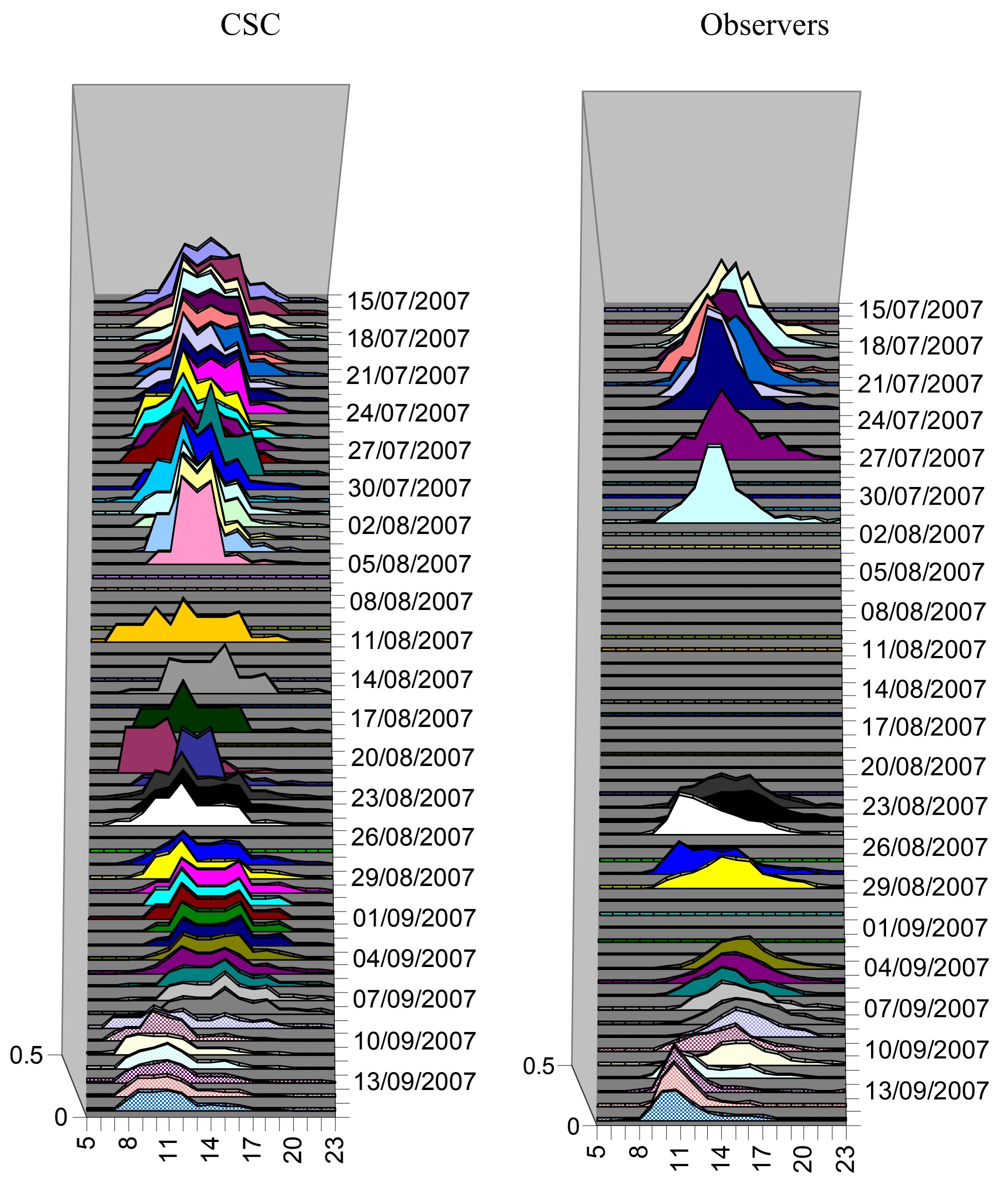


Fig. 20.- Mantle length distribution by day in the central-northern area estimated from commercial size categories (left plot) and from scientific observers onboard (right plot).

To identify different squid groups the CPUE, the mean weight and the female proportion were analyzed by area. Three groups were identified in the southern area based mainly on the CPUE depletions, because the mantle length remained similar and female proportions were very variable (**Fig. 21**). Two squid groups were identified in the central-northern area based on the strong mantle length decrease; female proportion increase and CPUE increase observed during the last week (**Fig. 22**).

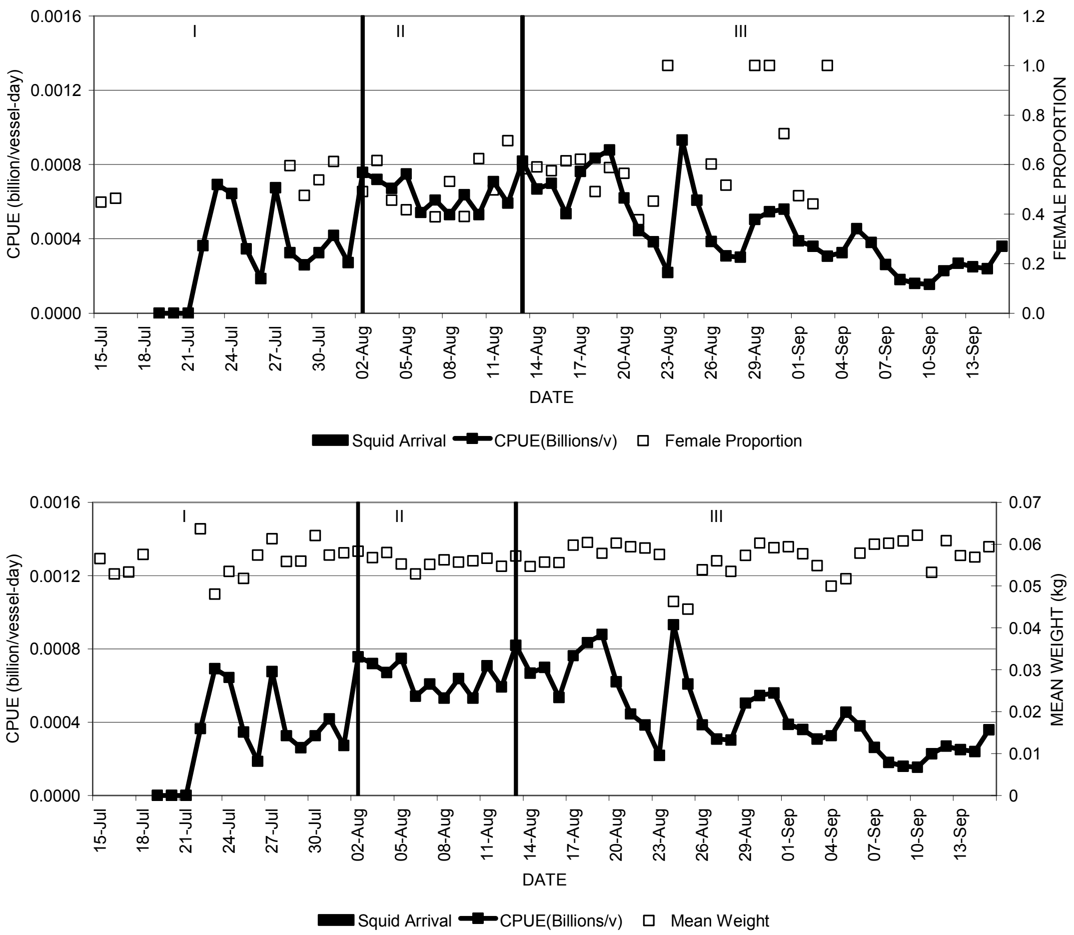
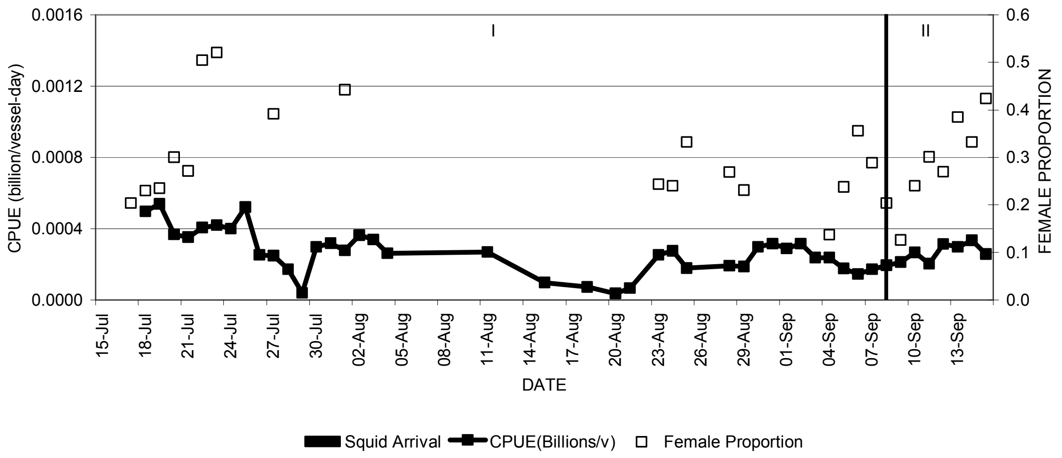


Fig. 21.- The arrivals of three squid groups to the southern area were identified based on the behaviour of CPUE (billion/vessel-day), female proportion (upper plot) and mean weight (down plot). The arrival dates are represented by vertical bars.



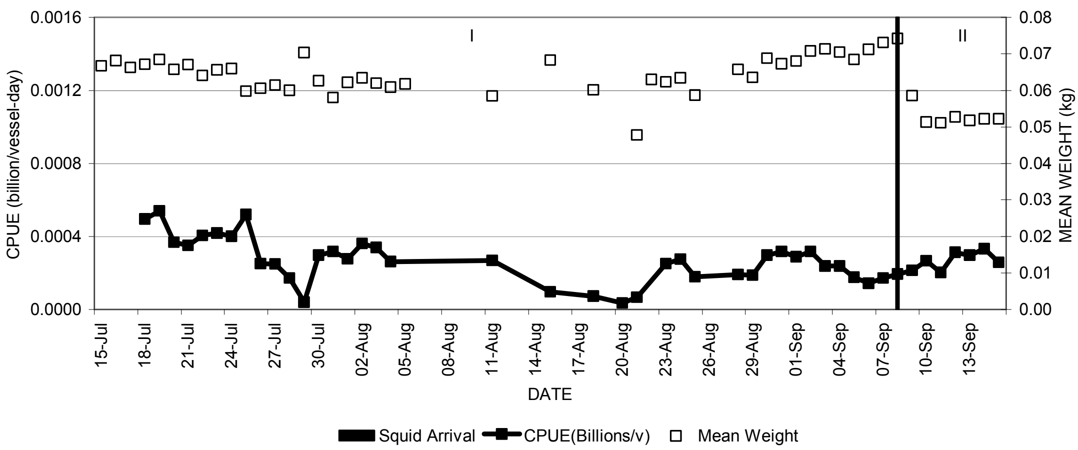


Fig. 22.- The arrivals of two squid groups to the central-northern area were identified based on the behaviour of CPUE (million/vessel-day), female proportion (upper plot) and mean weight (down plot). The arrival dates are represented by vertical bars.

PART 3 – STOCK ASSESSMENT AND RISK ANALYSIS

In-season assessment and catch projection

In-season stock assessment was used to apply the decision rule to close the fishery if the projected spawning biomass is below 10000 tonnes, under the restriction to warn the industry with two weeks in advance of the expected closing date. A flowchart of the *Loligo* management procedure is presented in **Figure 23**.

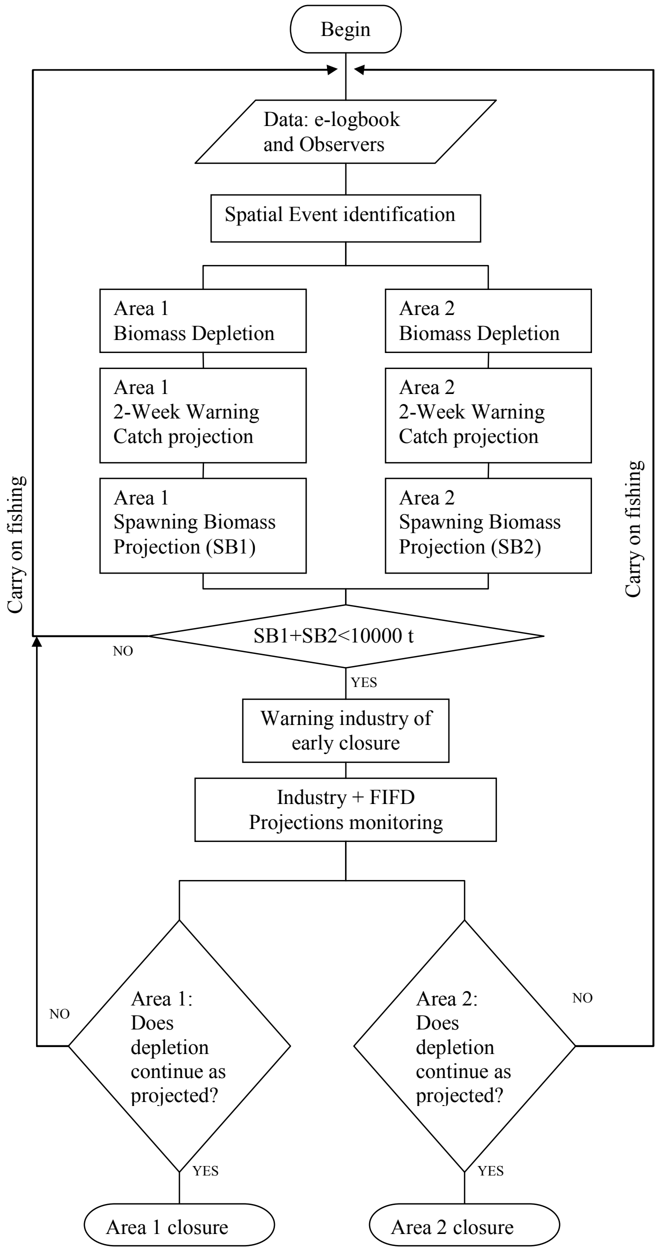


Fig. 23.- Flowchart of spatial management procedure for the early fishery closure decision. For simplicity only two depletion events are shown.

The fishery data was collected by daily catch reports and e-logbook and biological data by scientific observers onboard. Depletion events were located spatially and temporally by means of the graphical interface. Current biomass in each area was estimated by depletion models, then the catches and biomass during 2-week warning period were projected and finally the surviving spawning biomass was estimated. If the projected spawning biomass is lower than 10000 tonnes then a warning of an early fishery closure is sent to the industry. During the warning period the FIFD daily updates the stock assessment and biomass projections, which are shown to the fishery entrepreneurs for discussion. Real time fleet movements and possible new areas of good catches are also discussed. If the biomass depletion follows the projection and no other new squid aggregations appear then the area will be closed.

The equations for the depletion model have been previously described (Rosemberg ***et al.*** 1990; Roa-Ureta & Arkhipkin 2007). The uncertainty and risk analysis was presented in the 2006 second season fishery report (Payá 2006). The modifications to depletion model to include several depletion episodes together in one likelihood maximization process, under the assumption of equal catchability coefficient (***q***) for the different squid groups, were described in the 2007 first season fishery report (Payá 2007b).

The aim of the risk analysis is to estimate the probability of an adverse event in a specific time. For the second season *Loligo* management the risk is the probability (takes values from 0 to 1) of leaving at the sea less than 10000 tonnes of spawning biomass on the 15th of October. As in the first seasons, during the second seasons there was also a probability that new squid groups will arrive during the rest of the season. To incorporate this probability into the risk analysis a combined risk, *CR* (Payá 2007a) was calculated as:

$$CR_{t=i} = \Pr(B_{t>i} < B_{t=i}) * \Pr(SB < 10000),$$

where ***t*** is the time, ***i*** is the current day of the season, ***B*** is the biomass and ***SB*** is the spawning biomass projected from the biomass at ***i*** day, and *Pr* is the probability. The first component is the probability that biomass continues decreasing and no other squid groups arrive during the remaining days of the season. The second component is the probability that spawning biomass, projected from the current biomass, be less than 10000 tonnes. As *CPUE= q*B* and assuming that ***q*** is constant during the whole fishing season then:

$$CR_{t=i} = \Pr(CPUE_{t>i} < CPUE_{t=i}) * \Pr(SB < 10000)$$

Biomass depletion probability corresponds to a prediction based on a binomial distribution (Gelman ***et al.*** 2004) and it is calculated as:

$$\Pr(CPUE_{t>i} < CPUE_{t=i}) = \frac{dy+1}{ny+2},$$

where ***ny*** is the total number of previous years and ***dy*** is the number of previous years in which CPUE depletion continued without any CPUE increase that could be generated by the arrival of additional squid groups. The ***dy*** was computed by visual inspection of historical CPUE trends for the remaining days of the season. The 2006 second season was not included in the calculations because it was early closed.

During 2007 second season, three depletion events were identified in the southern area and two in the central-northern area (see biological section). On the 31rst of August, the first warning of a possible early closure on the 10th of September was sent to the fishery industry. This was based on the analysis with data up to the 27th of August. The stock assessment showed that the whole biomass was composed mainly by the biomass from the southern (Beauchene) area (**Fig. 24**). The biomass projection based on a 2-week catches simulation showed that the spawning biomass would be less than the limit of 10000 tonnes.

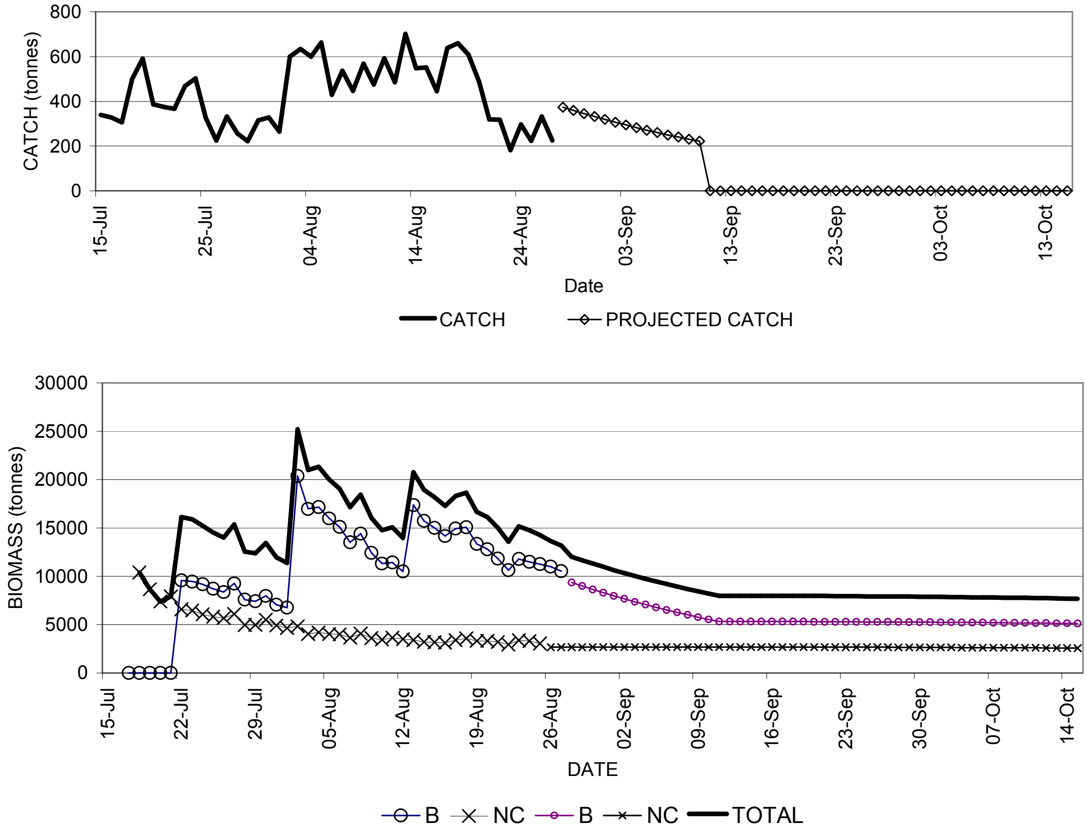


Fig. 24.- Actual and projected catch (upper plot) and biomass (down plot) with data up to 27th of August. (B= Beauchene; NC= Centre-North)

Based on the biomass uncertainty estimated by bootstrapping (**Fig. 25**), the risk of leaving less than 10000 tonnes by the 15th of October was estimated at 0.68 (**Fig. 26**).

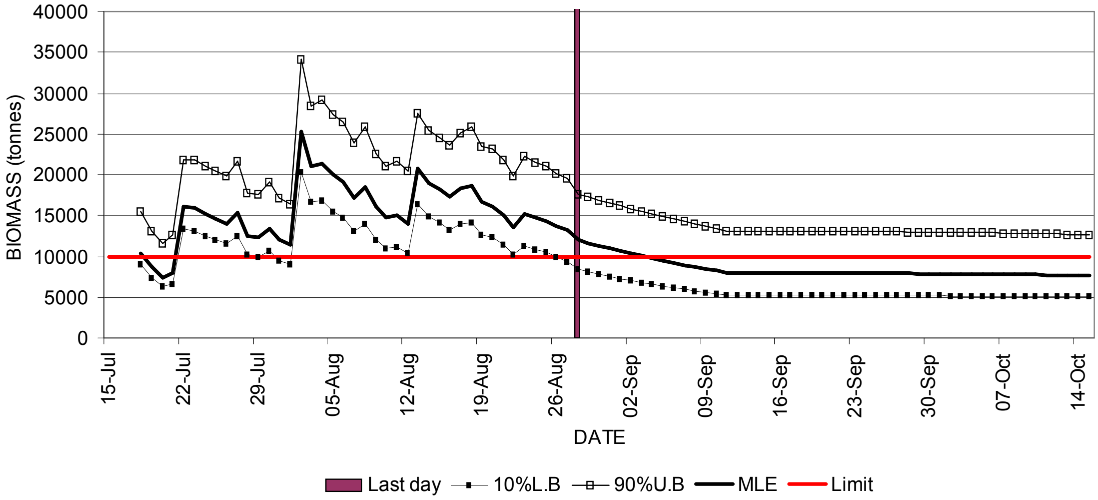


Fig. 25.- Actual and projected biomass estimations with data up to 27th of August. The uncertainty was calculated by bootstrapping technique (10%LB= 10% percentile; 90%UB= 90% percentile; MLE= Maximum Likelihood Estimate; LIMIT= 10000 tonnes spawning biomass).

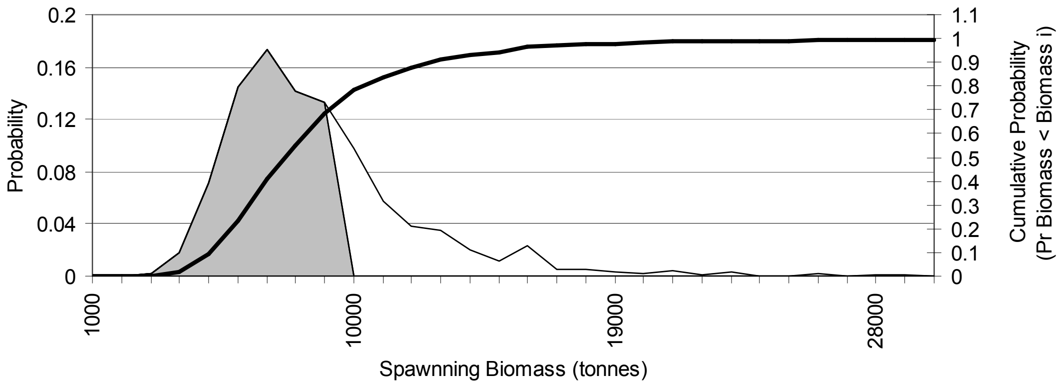


Fig. 26.- Probability distribution and cumulative probability of the spawning biomass projected to the 15th of October, based on data up to 27th of August. The dark area beneath the curve shows the values lower than 10000 tonnes. The cumulative probability at 10000 tonnes was 0.68 and it corresponds to risk of leaving less than 10000 tonnes spawning biomass.

The biomass depletion probability, i.e. probability that CPUE depletion continues during the rest of the season, was estimated at 0.63 (**Fig. 27**), which multiplied by the risk of leaving less than 10000 tonnes of spawning biomass produced a combined risk of 0.43.

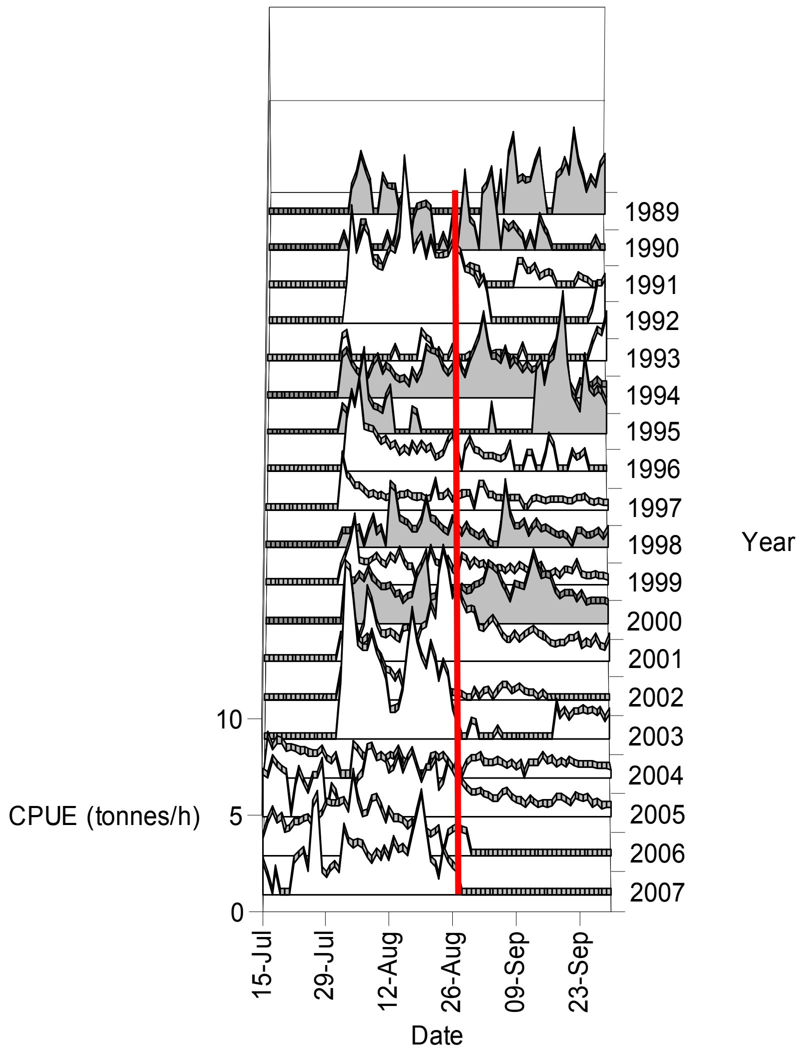


Fig. 27.- Historical second season CPUE trends. The red line shows the 27th of August, the years with increasing CPUE after this date are shown in grey colour. There was a 0.63 probability that CPUE depletion continues during the rest of the season.

During the warning period the assessment and risk analysis were updated according to the new data and assumptions about number of vessels fishing by area (**Table 3**). On the 7th of September the early closure day was moved from 10th to 15th of September, because the results with data up to the 2nd of September showed a decrease of the projected risks (**Table 3**). The last analysis made with data up to the 10th of September showed that the biomass continued decreasing (**Fig. 28**); the projected risk that SB<10000 tonnes increased to 0.33 (**Fig. 29**); the biomass depletion probability increases to 0.79 (**Fig. 30**); and the combined risk increased to 0.26 (**Table 3**). Based on these figures the fishery was early closed on the 15th of September.

Table 3.- Evolution of projection assumptions (number of vessels by area) and risk results through the warning period.

	Data up to			
	27-Aug	29-Aug	02-Sep	10-Sep
Projection assumptions				
N# of vessels in Southern Area	16	9	13	9
N# of vessels in Central-Northern Area	0	7	3	7
Risk results				
Pr(SB<10000 tonnes)	0.68	0.44	0.20	0.33
Depletion Probabilty	0.63	0.63	0.63	0.79
Combined Risk	0.43	0.28	0.13	0.26

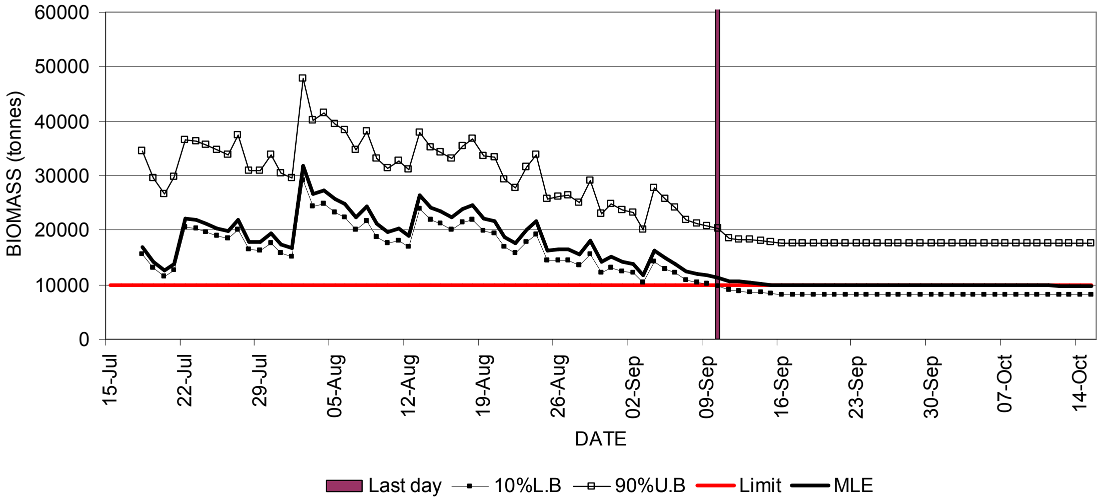


Fig. 28.- Actual and projected biomass estimations with data up to 10th of September. The uncertainty was calculated by bootstrapping technique (10%LB= 10% percentile; 90%UB= 90% percentile; MLE= Maximum Likelihood Estimate).

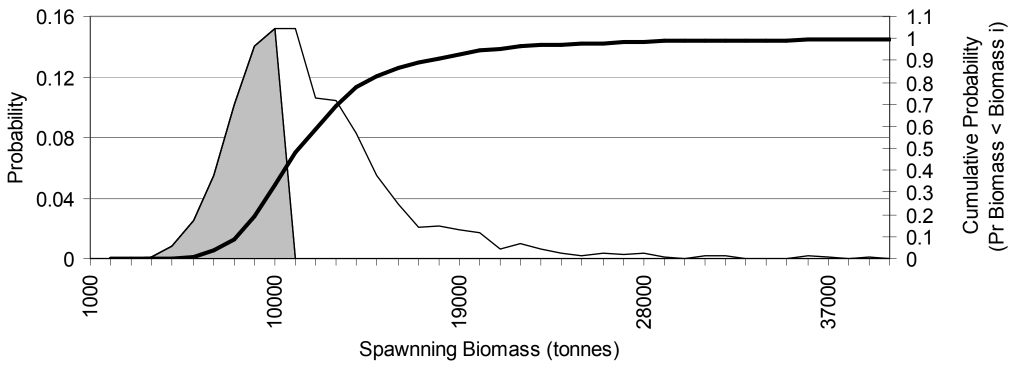


Fig. 29.- Probability distribution and cumulative probability of the spawning biomass projected to the 15th of October, based on data up to 10th of September.

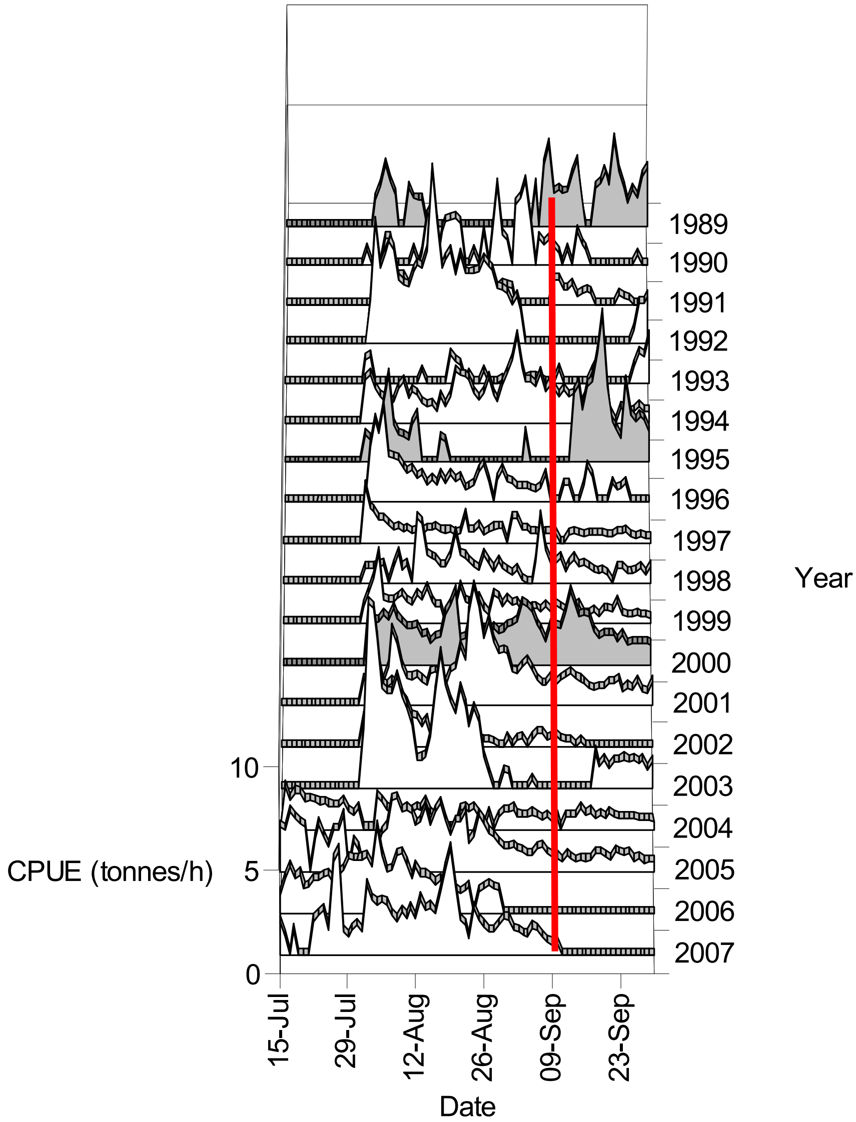


Fig. 30.- Historical second season CPUE trends in the southern area. The red line shows the 10th of September, the years with increasing CPUE after this date are shown in grey colour. There was a 0.79 probability that CPUE depletion continues during the rest of the season.

After-season stock assessment

Bootstrapping

The depletion model for the southern area included three squid groups and the depletion model for the central-northern area just one. The second squid group that appeared during the last week in the central-northern area was not included in the depletion model because CPUE data had an increasing trend (see biological section). Both depletion models fitted well to the data (**Figs. 31 and 32**).

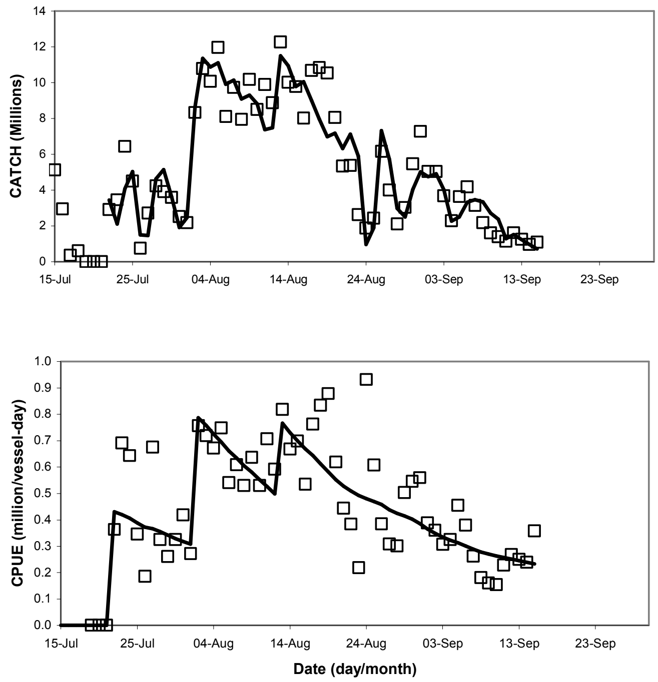


Fig. 31.- Model fitting to catch (upper plot) and CPUE (lower plot) data in the Beauchene area. The line is the predicted value and the squares are the data.

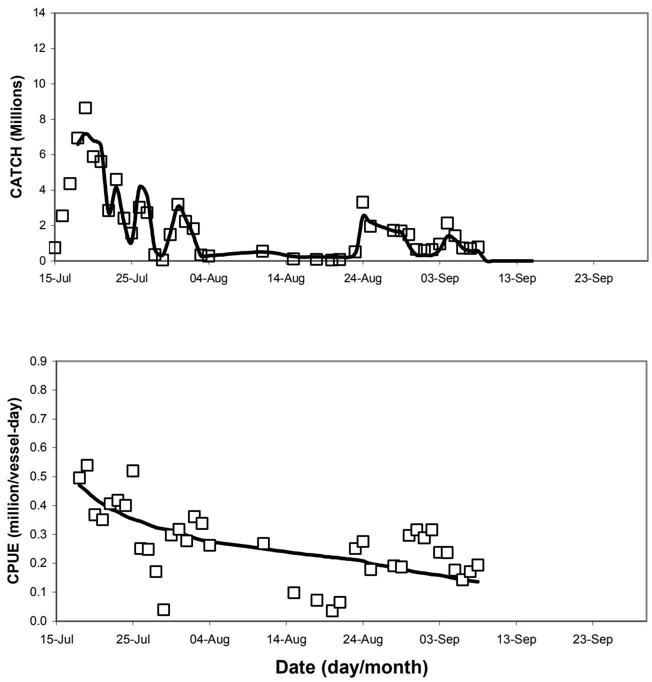


Fig. 32.- Model fitting to catch (upper plot) and CPUE (lower plot) data in the central-northern area. The line is the predicted value and the squares are the data.

The initial biomass in the central-northern area on the 17th of July was estimated at 15000 tonnes (**Fig. 33**). The initial biomass in the southern area on the 22nd of July was estimated at 12957 tonnes. The biomass of the second squid group, that entered the southern area on the 2nd of August, was estimated at 13404 tonnes, which was added to the survival biomass of the previous group and totalled 21644 tonnes. The biomass of the third squid pulse on the 13th of August was estimated at 7898 tonnes and added to the survival biomass of previous pulses totalled 20681 tonnes.

The initial biomass in the whole area was estimated at 24602 tonnes on the 22nd of July (**Fig. 33**). As a result of the southern biomass variations, the second whole biomass peak was estimated at 30182 tonnes on the 2nd of August, and the third one at 27673 tonnes on the 13th of August. At the end to the season the whole biomass was estimated at 10580 tonnes. The whole biomass that arrived to fishing grounds during the season was estimated at 50334 tonnes and corresponds to the sum of the biomass at the start of the season and the biomasses of the squid groups that arrived during the season. The spawning biomass on the 15th of October was estimated at 11019 tonnes, and it is the result of the surviving squids and the growth of their body weight (**Fig. 33**).

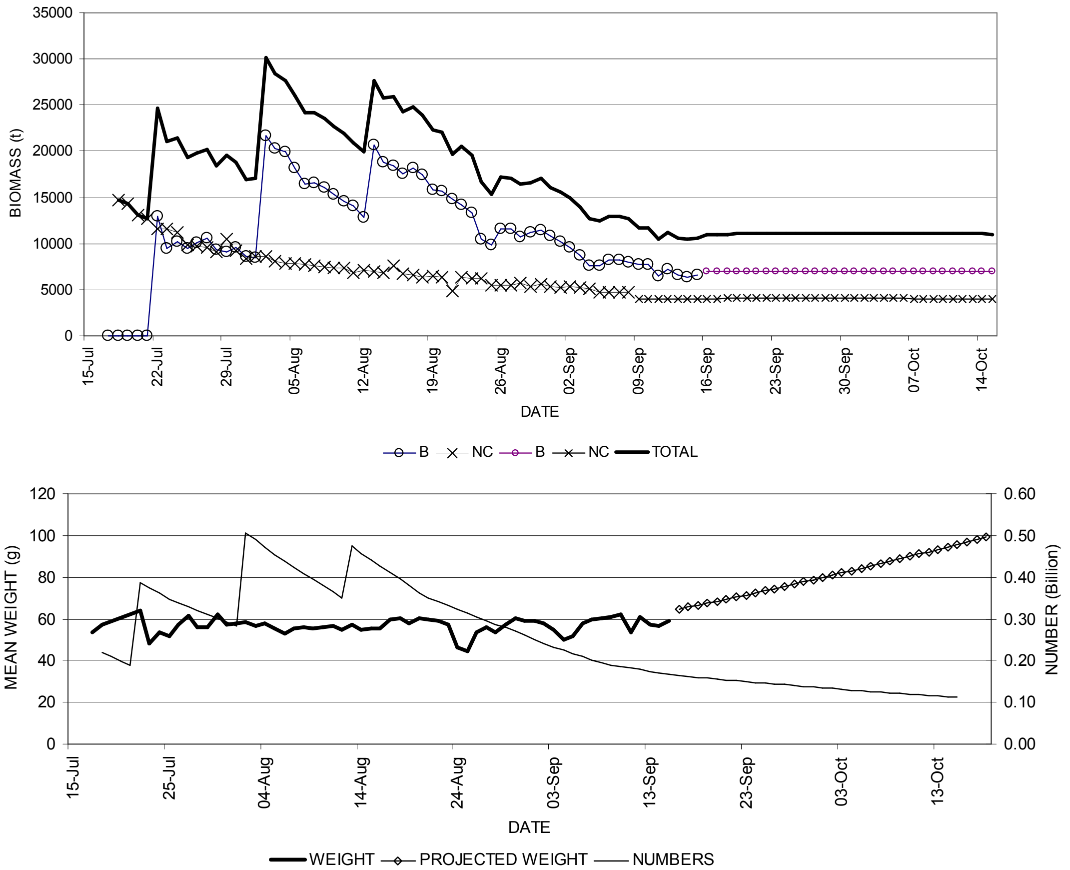


Fig. 33.- Biomass estimated by the depletion model and projected biomass (upper plot) based on the surviving squid number and on their growth in body weight (lower plot). (B= Beauchene; NC= central-northern).

The uncertainty analysis by bootstrapping showed that the density probability distributions of the biomasses were asymmetrical; with the maximum likelihood estimation closer to the 10% percentile than to the 90% percentile (**Fig. 34**). The projected spawning biomass was distributed from 5000 to 30000 tonnes and the risk that the spawning biomass could be less than 10000 tonnes was estimated at 0.08 (**Fig. 35**). The probability that CPUE continues decreasing after the 15th of September was estimated in 0.84. The combined risk was estimated at 0.07.

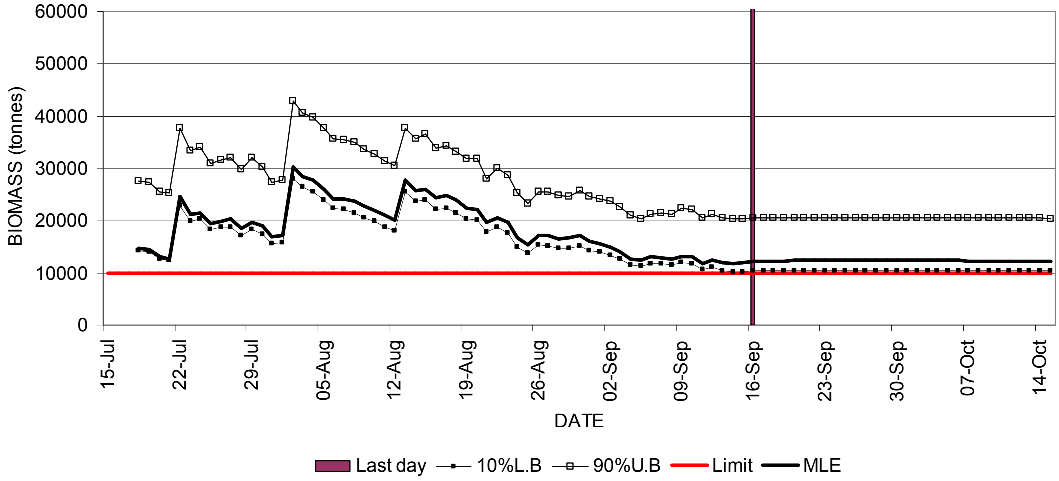


Fig. 34.- Maximum likelihood estimations (MLE) of biomass and their 10% and 90% percentiles estimated using bootstrapping.

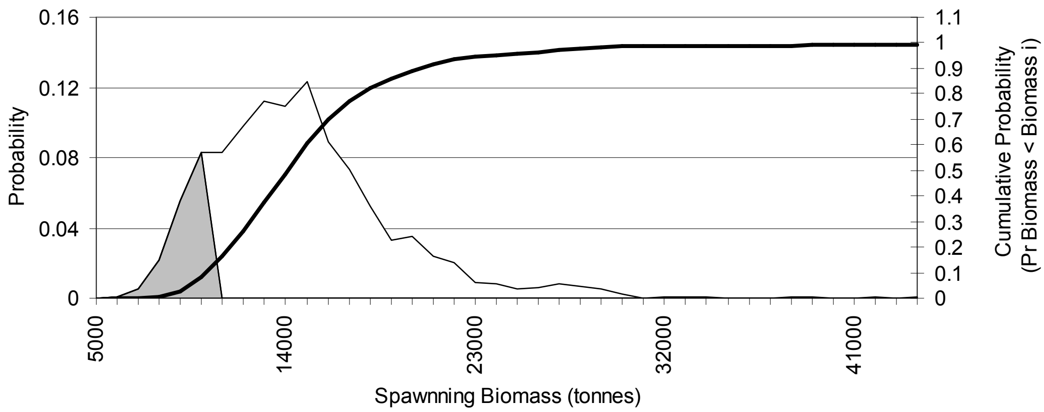


Fig. 35.- Probability distribution of projected spawning biomass and its cumulative probability estimated by bootstrapping. The projected risk that spawning biomass could be less than 10000 tonnes was estimated at 0.08 (proportion of grey area in the total area).

Bayesian analysis

In Bayesian inference, the posterior probability of the θ_i parameters, $P(\theta_i|X)$ is calculated as:

$$P(\theta_i \mid X) = \frac{P(X \mid \theta_i) * p(\theta_i)}{\sum_i P(X \mid \theta_i) * p(\theta_i)}$$

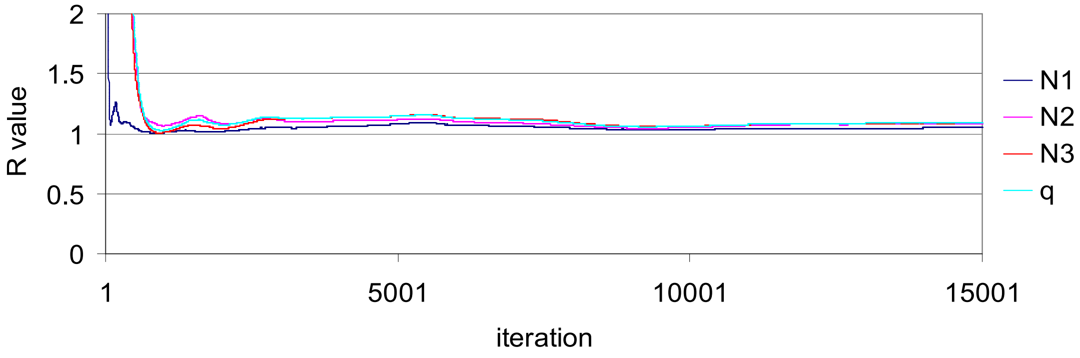
where X is the data; $P(X|\theta_i)$ is the Likelihood and $p(\theta_i)$ is the prior distribution of θ_i parameter. For the depletion model the log Likelihood is computed as:

$$\log(P(\theta_i \mid X)) = -\frac{n}{2} \ln(\sum (o-p)^2)$$

where n is the number of observations, o is the observed data and p is the predicted data. The priors were noninformative Cauchy distribution of the $\ln(\theta_i)$ (Johnson ***et al.*** 1994).

The maximum posterior density was found by Solver maximization algorithm. To compute the posterior distribution the Metropolis-Hastings Markov Chain Monte Carlo algorithm (MCMC) programmed by Payá (2006) was used. Five chains of 20000 iterations were generated using a normal distribution as a jumping rule (Gelman ***et al.*** 2004). The first 1000 iterations of each chain were discarded as a burning section. The number of iterations was determined using the convergence index R, which is the ratio between the variances within and between chains (Gelman ***et al.*** 2004). The convergence is achieved when R is lower than 1.1. To estimate the biomass distribution (marginal density) 3000 parameters where taken randomly from the posterior distributions.

The convergence of MCMC chains was achieved at 8000 iterations in both areas (**Fig. 36**). The biomasses estimated by MCMC were closed to the biomass estimated by the bootstrapping, and the uncertainty estimated by MCMC (CV=18%) was lower than one estimated by bootstrapping (CV=47%)(**Fig. 37**). The risk that SB<10000 tonnes was estimated at 0.12 (**Fig. 36**), the probability of CPUE depletion at 0.84, and the combined risk at 0.10.



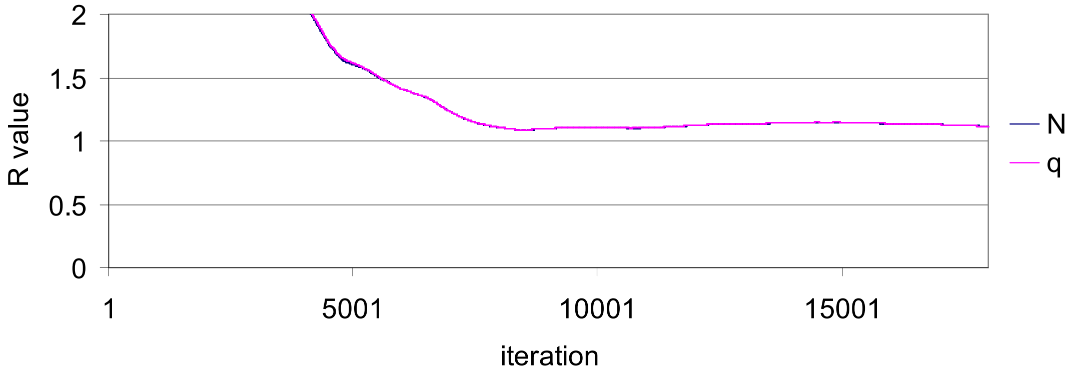


Fig. 36.- MCMC results for the southern (upper plot) and central-northern area (down plot). Convergence index (***R***) for each parameter, which must be lower than 1.1.

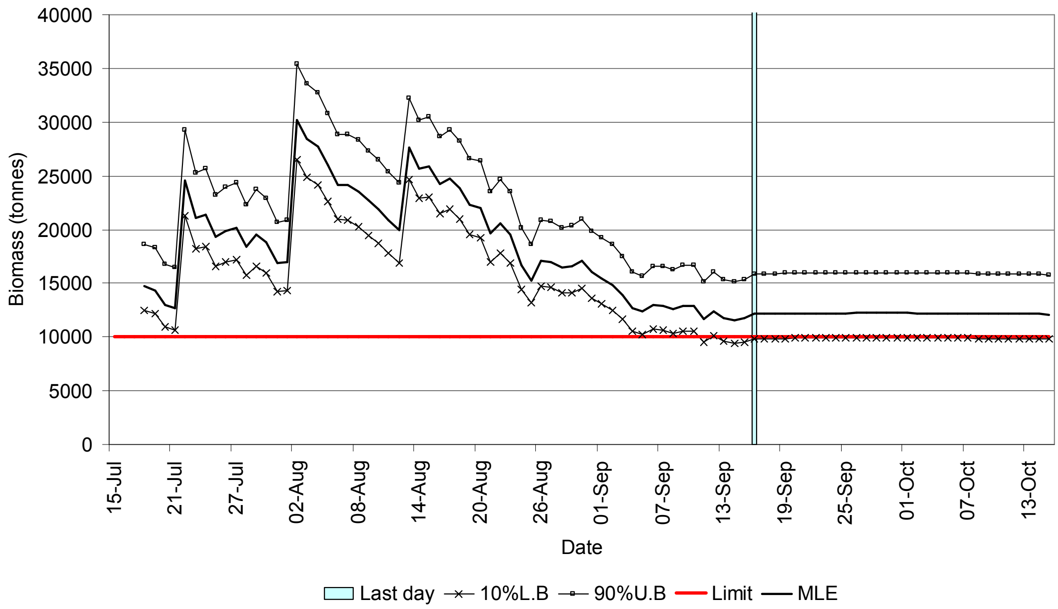


Fig. 37.- Biomass depletion and projection in the whole *Loligo* box (10%L.B = 10% percentile lower boundary; 90%U.B= 90% percentile upper boundary).

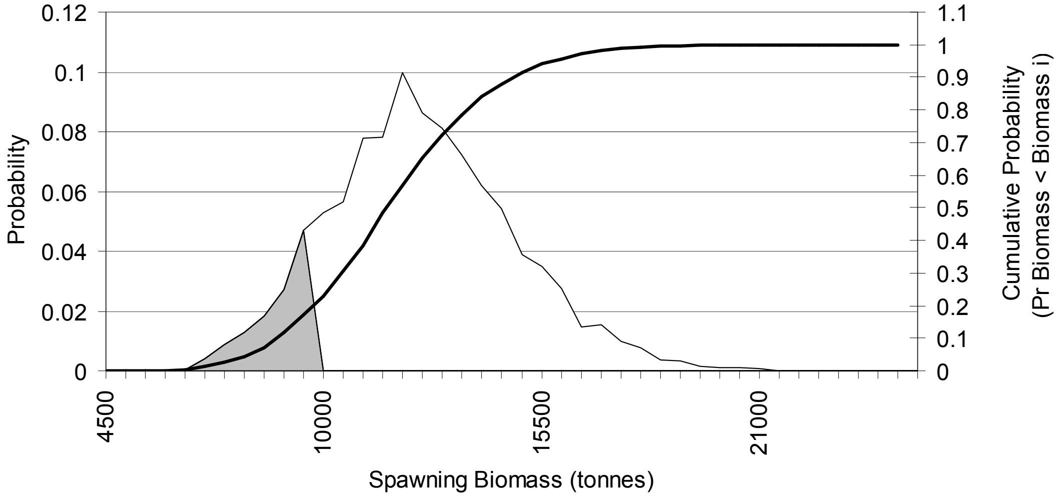


Fig. 38.- Probability distribution and cumulative probability of the spawning biomass projected to the 15th of October. The dark area beneath the curve shows the values lower than 10000 tonnes. The cumulative probability at 10000 tonnes was 0.12 and it corresponds to risk of surpass the limit of 10000 tonnes spawning biomass.

Integrated depletion model with recruitment pulses and vessel catchability coefficients estimations by area.

This model integrates the last development that includes the estimations of several pulses in a depletion model; a procedure to calculate catchability coefficients for each vessel inside the depletion model; and a simultaneous estimation of biomasses and catchability coefficients by area. To integrate several depletion models from different areas it was assumed that the vessel catchability coefficients should be similar between areas. The model uses a loss function that includes the maximum likelihood by area and a penalty function to make the catchability coefficients similar between areas. This model is fully presented in the **ANNEX**.

The integrated model was fitted by Bayesian inference, using the same MCMC procedures previously described. The priors of the natural logarithm of the parameters were Cauchy distributions with high dispersion parameters and with central value and limit values estimated from the bootstrapping results of the previous model. The posteriors distributions were narrow than the priors and were far from the limit values; therefore the priors did not restrict the range of the posteriors (**Fig. 39**). The MCMC algorithm achieved the convergence criterion ($R<1.1$) at 10000 iterations (**Fig. 40**).

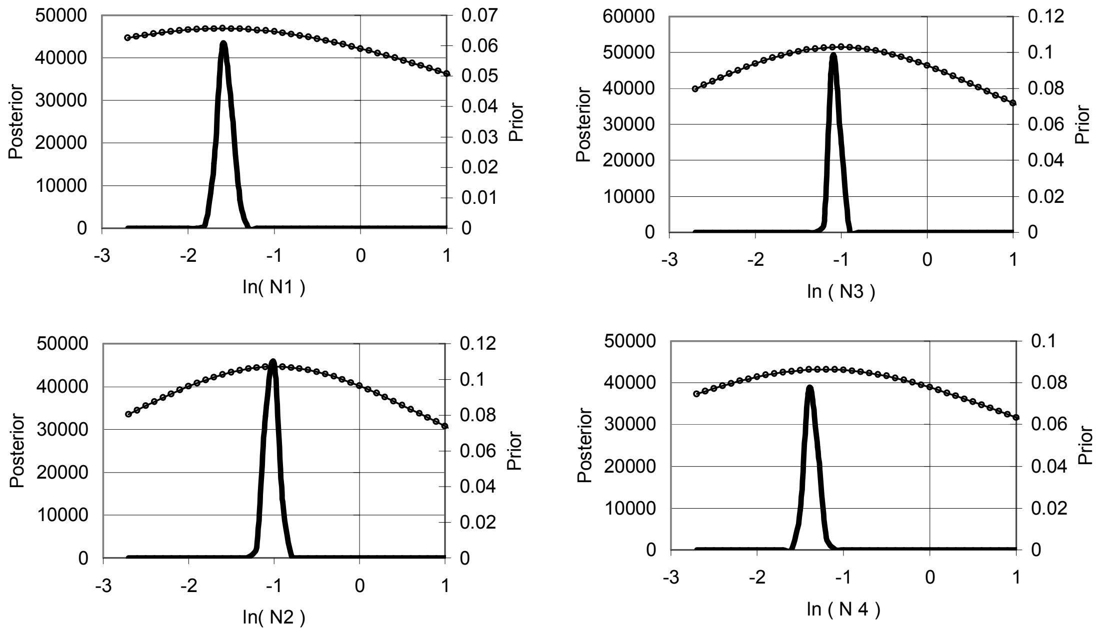


Fig. 39.- Prior (line with circles) and posterior (bold line) probabilities for the parameters of the integrated depletion model.

The fitting of the model was good and the residuals had lognormal distributions in both areas (**Fig. 41**). In figure 41 the model fittings to one vessel in each area are shown as examples, the total of 32 plots (16 vessels by 2 areas), are not presented only for space reasons. The residuals were evenly distributed and they did not show any trend in time or by vessel (**Fig. 42**). Only two data points from the southern area were excluded as outliers (extremely high values).

The catchability coefficients by vessel were similar by area, although in two vessels their values were greater in the southern area than in the central-northern area (**Fig. 43**). The relative fishing powers (vessel catchability / reference vessel catchability) had the best relationship (R^2=0.45) with the main engine horse power (HP), then (R^2=0.35) with the gross registered tonnage (GRT) and finally (R^2=0.29) with the overall length (LOA) (**Fig. 44**). Further studies are required to model the relationship between fishing powers and other operational and morphological vessel variables.

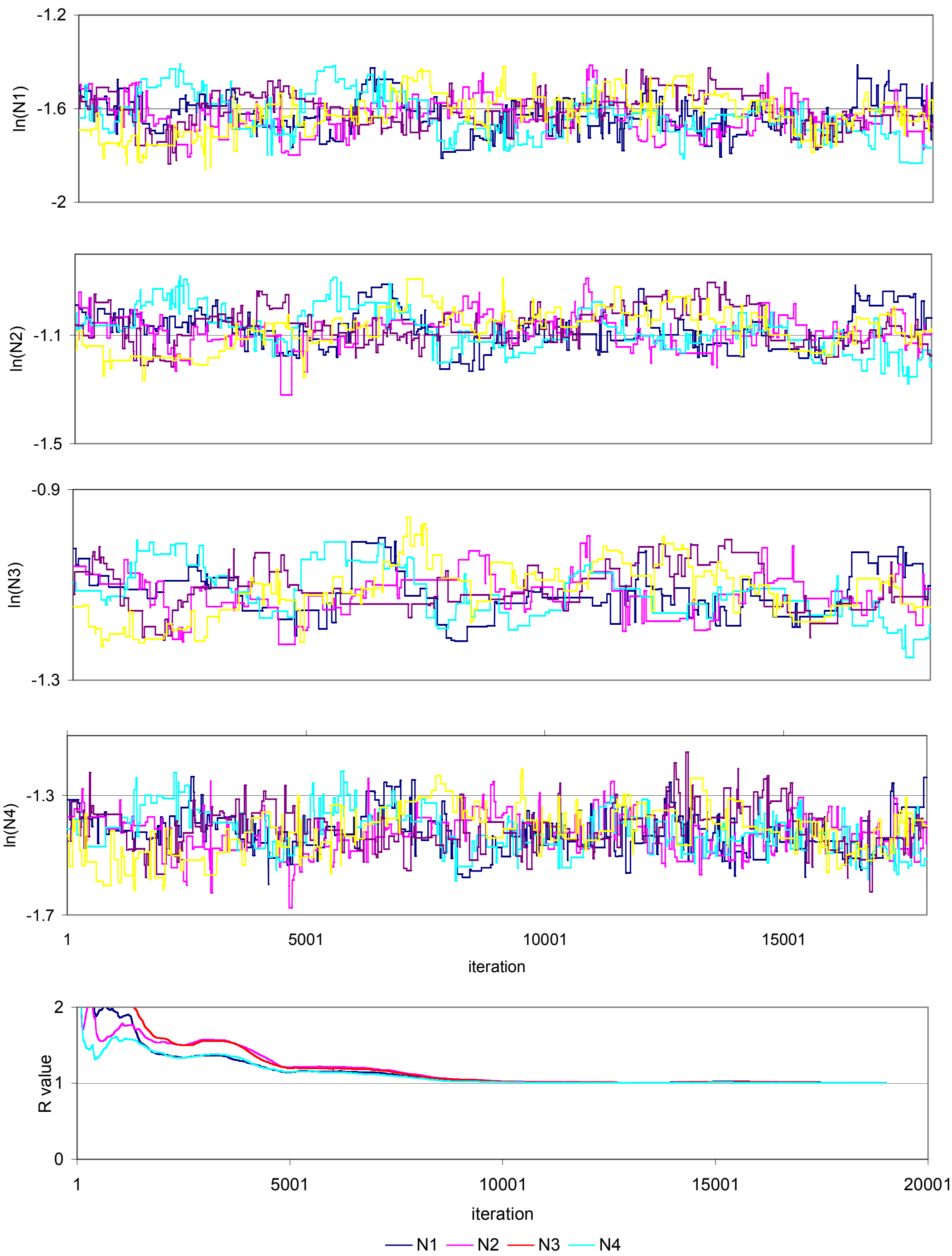


Fig. 40.- Five chains for each parameter of the integrated depletion model and the convergence index, R (bottom graph).

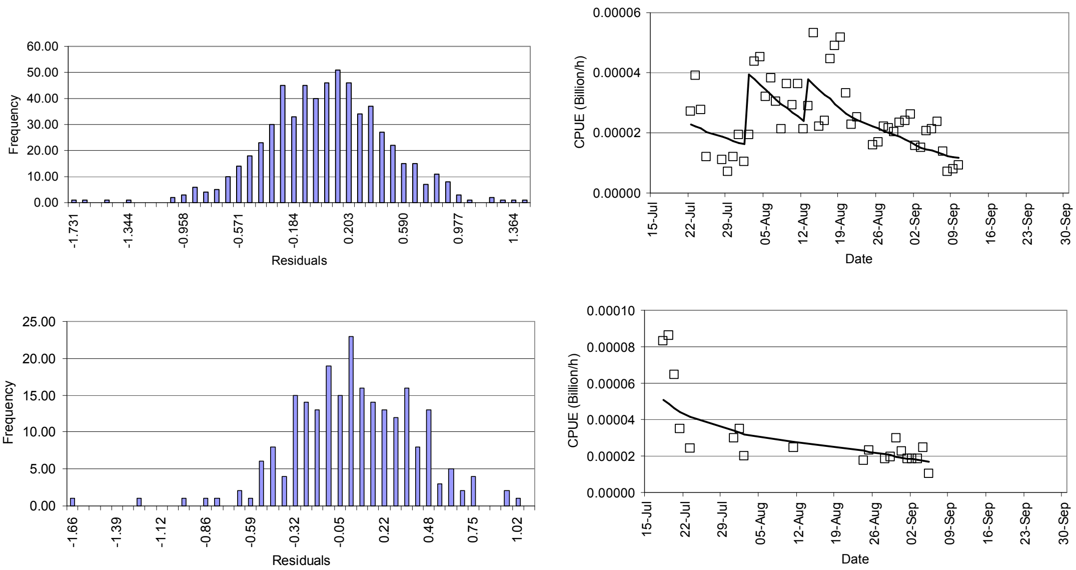


Fig. 41.- Residual distribution from the southern area (upper left plot) and central-northern area (lower left plot) and some examples of CPUE observed and predicted for one vessel in the southern (upper right plot) and another in the central-northern (lower right plot).

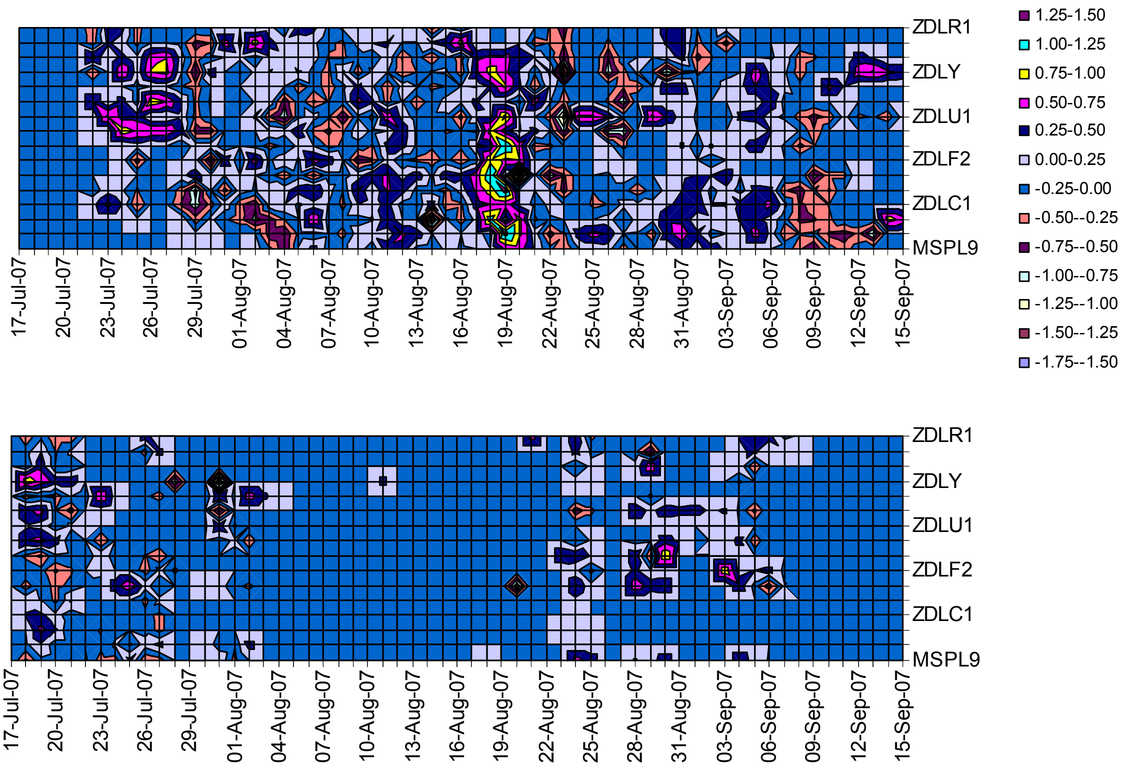


Fig. 42.- Residuals by day and vessel from the southern (upper plot) and central-northern (lower plot) areas.

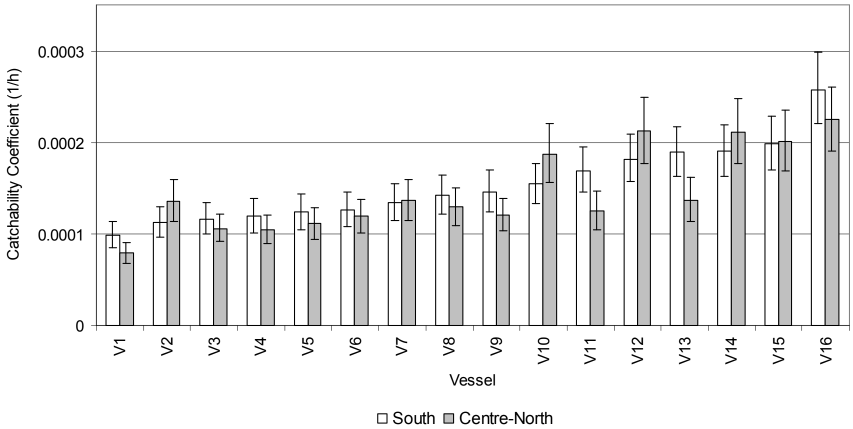


Fig. 43.- Catchability coefficients by vessel and area (white bar = southern area; grey bar = central-northern area). The vertical bars represent the 95% confident interval.

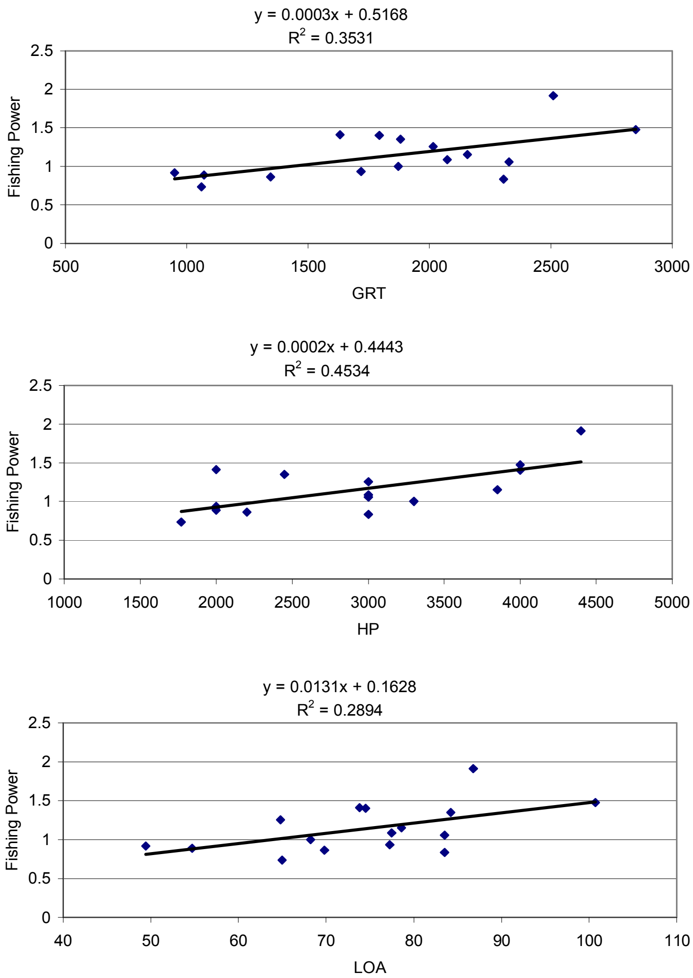


Fig. 44.- Relations between relative fishing power (relative catchability coefficients) and vessel characteristics (GRT = gross registered tonnage; HP = horse power; LOA = overall length).

The biomass in the whole *Loligo* box was estimated at 25445 tonnes on the 22nd of July; 29391 tonnes on the 2nd of August; and 26557 tonnes on the 13th of August (**Fig. 45**). The whole biomass that arrived to fishing grounds during the season was estimated in 48500 tonnes and corresponds to the sum of the biomass at the start of the season and the biomasses of the squid groups that arrived during the season (**Fig. 46 and Table 4**). The spawning biomass by the 15th of October was estimated at 11458 tonnes (**Table 5**). The integrated depletion model results were similar to the previous model in terms of biomass for the whole area, but the estimations by area were different, in the case of the southern area the integrated model estimated greater biomass than the previous model, and the opposite happened for the central-northern area (**Fig. 47**).

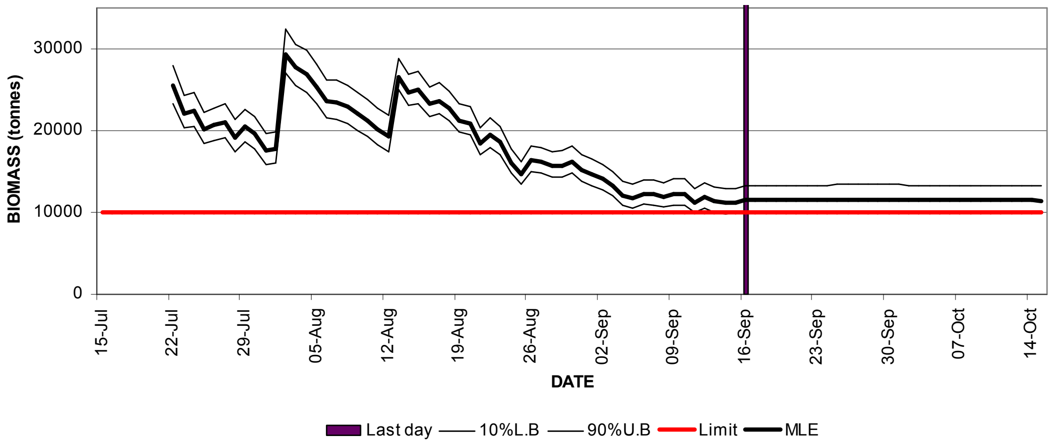


Fig. 45.- Biomass depletion and projection in the whole *Loligo* box (10%L.B = 10% percentile lower boundary; 90%U.B= 90% percentile upper boundary; MLE= Maximum Likelihood Estimate).

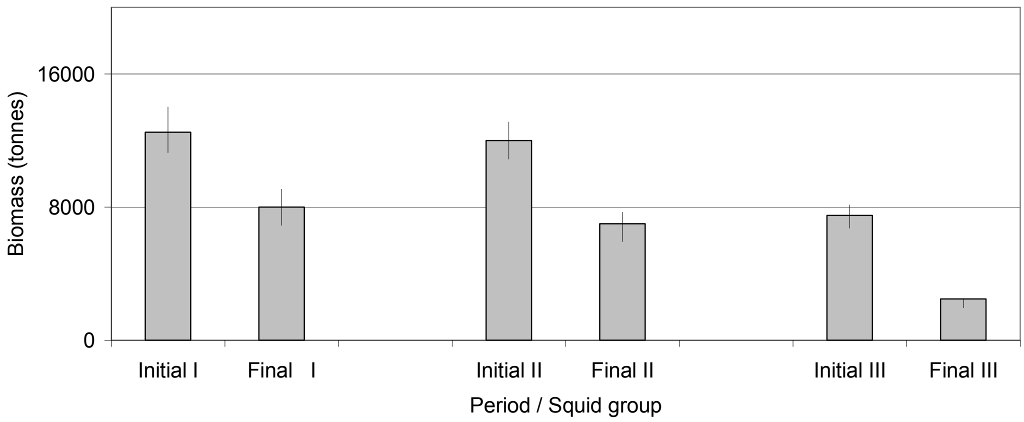


Fig. 46.- Initial and final biomass of the squid groups in southern area estimated by the integrated depletion model (vertical bars represent the 80% confident intervals). These biomasses correspond to the biomasses presented at the start and at the end of each depletion episode.

Table 4.- Stock assessment of *Loligo gahi* in the Falkland Islands by a stock depletion model. Numbers in parentheses are the measures of statistical precision (coefficients of variation). (S = southern; C = Central; N = Northern; and CN = central-northern area). (*) It is the average of catchability by vessel. (**) This biomass is the sum of all squid group biomasses.

	2nd Season 2004			2nd Season 2005			2nd Season 2006			2nd Season 2007			
Parameter	S	C	N	S	C	N	S	1rst CN	2nd CN	1rst S	2nd S	3rd S	CN
Starting Date	15/07	16/08	28/07	10/08	25/07	21/07	4/08	23/07	22/8	22/07	2/08	22/8	17/7
Final Date	30/09	30/09	30/09	30/09	30/09	30/09	29/08	21/08	5/9	1/08	13/08	15/9	15/09
N° of days	66	16	58	52	25	39	25	30	15	11	11	34	60
Catchability	5.9×10^{-4}	3.4×10^{-3}	2.7×10^{-3}	2.3×10^{-3}	3.7×10^{-2}	2.1×10^{-3}	1.9×10^{-3}	1.2×10^{-2}	3.7×10^{-3}				
(1/vessel-day)	(5.4)	(9.9)	(14.9)	(1.2)	(703.5)	(25.6)	(12.5)	(12.4)	(18.3)				
Catchability (1/h) *										1.54×10^{-4}	1.54×10^{-4}	1.54×10^{-4}	1.46×10^{-4}
										(27.0)	(27.0)	(27.0)	(31.0)
Initial numbers	8.5×10^{-1}	1.4×10^{-1}	2.7×10^{-1}	3.2×10^{-1}	1.6×10^{-2}	4.1×10^{-1}	5.2×10^{-1}	5.8×10^{-3}	1.7×10^{-1}	1.9×10^{-1}	2×10^{-1}	1.3×10^{-1}	2.4×10^{-1}
(billions)	(23.0)	(50.3)	(3.0)	(5.4)	(363.5)	(8.3)	(11.1)	(9.6)	(15.4)	(8.3)	(7.2)	(7.5)	(6.1)
Initial biomass	42239	6983	13510	20417	1070	25714	25500	2600	7900	12500	12000	7500	16500
(tonnes)	(39.6)	(61.2)	(34.0)	(30.2)	(365.7)	(32.0)	(10.8)	(10.0)	(15.3)	(8.3)	(7.2)	(7.5)	(6.1)
Final Numbers N_T	2.2×10^{-1}	3.3×10^{-2}	4.4×10^{-2}	6.2×10^{-2}	1.4×10^{-3}	5.6×10^{-2}	0.21	0.02	0.08	1.4×10^{-1}	1.2×10^{-1}	4×10^{-2}	1.2×10^{-1}
(billions)	(31.1)	(100.9)	(21.0)	(13.9)	(2778.4)	(53.5)	(18.7)	(19.5)	(18.7)	(10.2)	(9.9)	(8.0)	(9.5)
Final Biomass	15191	2229	3009	5203	112	4505	9500	1000	3500	8000	7000	2500	6500
(tonnes)	(49.2)	(107.8)	(43.6)	(39.8)	(2778.6)	(56.4)	(18.7)	(19.5)	(28.4)	(10.2)	(9.9)	(28.4)	(9.5)
Initial Biomass * * (tonnes)										12500	20500	19000	
										(7.4)	(6.0)	(4.6)	
Final Biomass ** (tonnes)										8500	12000	5500	
										(8.8)	(8.6)	(10)	

Table 5.- Biomass of squid projected from the end of the season with starting numbers as estimated from the stock depletion model. The numbers in parentheses are the measures of statistical precision (percentage coefficients of variation).

	Dates	Biomass (tonnes)
Second Season 2004	30/09 to 15/10	20721 (24.3)
Second Season 2005	30/09 to 15/10	8665 (38.0)
Second Season 2006	5/9 to 15/10	13500 (15.9)
Second Season 2007	15/9 to 15/10	11458 (9.4)

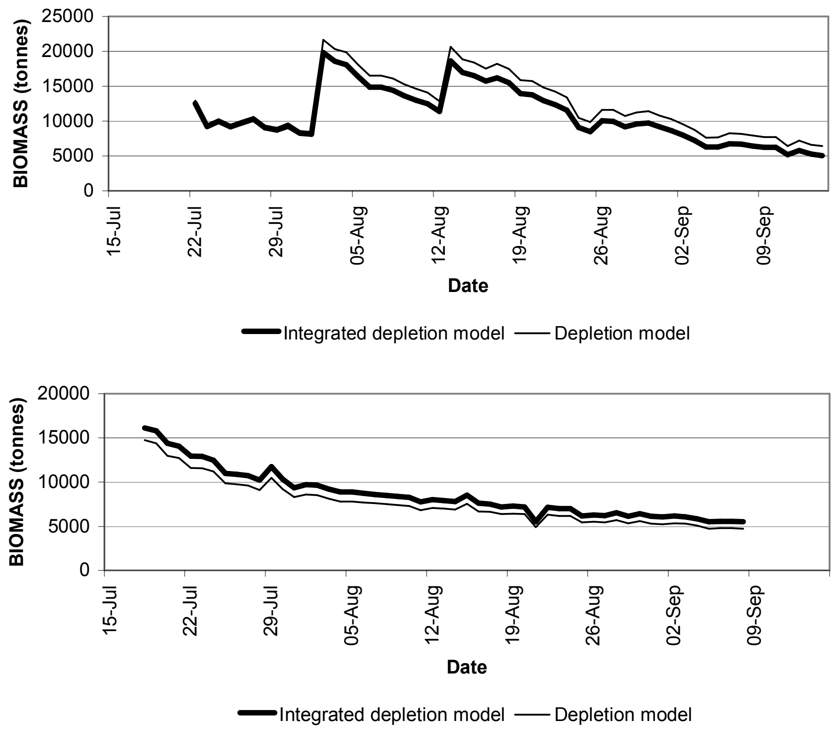


Fig. 47.- Biomass estimations made by integrated depletion model and previous depletion model for the southern (upper plot) and central-northern (down plot) area.

The spawning biomass projected by the 15th of October fluctuated from 7500 to 15500 tonnes and had a mode at 11458 tonnes. The risk that SB<10000 tonnes was estimated at 0.09 (**Fig. 48**). The probability that CPUE continues decreasing after the 15th September was estimated at 0.84 and the combined risk at 0.07.

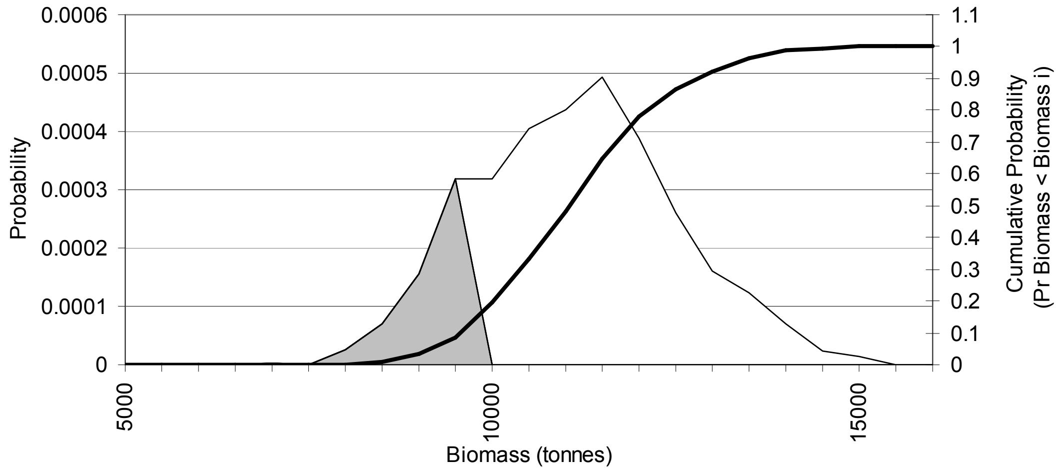


Fig. 48.- Probability distribution and cumulative probability of the spawning biomass projected to the 15th of October. The dark area beneath the curve shows the values lower than 10000 tonnes. The cumulative probability at 10000 ton was 0.09 and it corresponds to risk of surpass the limit of 10000 ton spawning biomass.

DISCUSSION

The biological sampling of the catches onboard is limited both by numbers of scientific observers and dynamics of the fishery, for example, in this season there were two observers simultaneously at sea but their vessels remained fishing in the same area, therefore other fishing areas were not sampled during several days. The solution to this problem is not easy, and a better use of the statistics of commercial size categories (CSC) could be useful. There is a good correlation between the mean squid sizes estimated from the observer data and the CSC, but the dispersion and distribution of the different sizes could be very different. To increase the quality of the size estimation it is suggested to ask the captain to share with the FIFD their own statistics of size frequency by commercial category. The officers frequently make the sampling to monitor the quality (size) of commercial size categories.

During 2007 *Loligo* behaviour had two main characteristics; the first was a 3-week delay in the arrival to the fishing grounds observed in the first season (Payá 2007b) and the second one was the sequential arrivals of different squid groups during the fishing season that happened in both the first and the second fishing seasons. The high historical variability of the CPUE by day during different fishing seasons (**Fig. 30**) suggests that sequential arrivals of different groups are not rare events. This pulse behaviour has a direct impact on the risk analysis done during the fishing season when the early closure decision is evaluated. During the last week of the season a new group of smaller squid was fished in the northern area, but it was not possible to estimate its abundance because the CPUE data did not show any depletion trend. Therefore the model underestimates the biomass and overestimates the risk in some extent that seems to be small because CPUE values were rather low.

The new integrated depletion model has several advantages over the previous model:

- It estimates the catchability coefficients by vessel then the assumption that all vessels are equal is no longer required.
- The vessel catchability coefficients are estimated separately by area but they are driven to similar values by a penalty function. As the penalty function is a likelihood function, the catchability coefficients by area could be equals or not, depending on the data.
- The biomasses of several pulses are estimated simultaneously in only one model.
- The biomasses of different areas area are estimated simultaneously and are linked by means of the similarity between the catchability coefficients by area.

The ratio between the survey biomass and the initial biomass was 0.8. The biomass estimated by the *Loligo* survey was 19198 tonnes and the first biomass estimated by the integrated depletion model was 25445 tonnes. In 2006 second season the ratio between the survey biomass and the initial biomass was 0.9 (22625/26000 tonnes). Therefore the survey biomass has been between 80 and 90% of the initial biomass estimated by the depletion model. Of course the survey biomass is unrelated with the biomass of the squid groups that arrive later during the fishing season. In the case of the first season it is not possible to compare these ratios because in the 2007 first season there was a big delay in the arrival of squids to the fishing grounds

CONCLUSIONS

1) Total catch (24171 tonnes) reached an intermediate level considering the last 10 years, while total effort (14740 hours of trawling) was of rather low level compared with the levels at the last 10 years.
2) Initial squid biomass presented on 22nd of July was estimated at 25445 tonnes.
3) Three squid groups arrived sequentially to the southern area and two groups to the central-northern area.
4) The whole biomass, the one that was present at the start of the season plus the ones that arrived during the season, was estimated at 48500 tonnes.
5) During fishing season the stock assessment projected a high risk of failure the management limit of 10000 tonnes of spawning biomass
6) Therefore, the fishery was closed 15 days before the end of fishing season in order to protect the spawning biomass.
7) After-season stock assessment estimated the spawning biomass on 15th of October at 11458 tonnes.
8) The probability that biomass continue decreasing after the 15th September was estimated at 0.84; the risk that spawning biomass could be lower than 10000 tonnes was estimated at 0.09, and the combined risk at 0.07. Therefore the management aim to preserve a minimum escaping biomass was met with a low risk.

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ANNEX

Depletion model with several recruitment pulses and vessel catchability coefficients estimations by area.

By Ignacio Payá

A new depletion model was developed which integrates the estimations of several recruitment pulses and vessel catchability coefficients by area by means of a penalized maximum likelihood. For clarity the model formulation is presented in three steps of increasing complexity:

1. Estimation of one squid pulse and vessel catchability coefficients in only one fishing area

The new integrated model is based on the DeLury model (DeLury 1947) formulation in Rosenberg *et al.* (1990). These authors estimated the catchability by fleet using weekly data, in this study catchability coefficients were estimated by vessel based on daily data. The dynamic of the abundance and the CPUE was calculated as:

$$\begin{aligned} CPUE_{v,t} &= q_v N_t e^{-M/2} \\ &= q_v e^{-M/2}\left(N_0 e^{-Mt} - e^{-M/2}\sum_{v=1}^{V}\sum_{j=0}^{t-1} C_{v,j} e^{-(t-j-1)M} \right)\cdots \quad \text{for t<=T,} \end{aligned} \tag{1}$$

where $\boldsymbol{t}$ is time in days and $\boldsymbol{T}$ is time at the end of the depletion event (t=1,2, ..,$\boldsymbol{T}$), $\boldsymbol{v}$ vessel ($\boldsymbol{v}$=1,2,…,$\boldsymbol{V}$), *CPUE* catch in numbers per unit of effort (number/trawling hour), $\boldsymbol{N}$ stock abundance in numbers, N_0 initial abundance in numbers, $\boldsymbol{q}$ catchability coefficient, and $\boldsymbol{M}$ rate of natural mortality per day. $\boldsymbol{M}$ was assumed constant and equal to 0.013, which is the value estimated by Roa-Ureta and Arkhipkin (2007) based on longevity and age information from Arkhipkin and Roa-Ureta (2005).

The cpue in numbers at t-day was calculated as

$$CPUE_t = \frac{Y_t}{\overline{w}_t} / E_t\,, \tag{2}$$

where Y is catch in grams and $\overline{w}$ the mean body weight calculated by

$$\overline{w}_t = \frac{\sum_s \sum_i f_{t,i,s}\hat{a}_s l_{t,i,s}^{\hat{b}_s}}{\sum_s \sum_i f_{t,i,s}}\,, \tag{3}$$

where $\boldsymbol{f}$ is the number of sampled squids, $\boldsymbol{l}$ mantle size, $\boldsymbol{i}$ mantle size interval, $\boldsymbol{s}$ sex, and $\hat{a}$ and $\hat{b}$ are length-weight relationship parameters.

Biomass at *t*-day was calculated as

$$\begin{aligned} B_t &= \overline{w}_t N_t \\ &= \overline{w}_t \left(N_0 e^{-Mt} - e^{-M/2} \sum_{j=0}^{t-1} C_j e^{-(t-j-1)M} \right) \end{aligned} , \tag{4}$$

This non-linear model was fitted by maximum likelihood. The initial number $\boldsymbol{N_0}$ was the parameter to be estimated and the vessel catchability coefficients, $\boldsymbol{q_v}$, were computed as nuisance parameters:

$$q_v = \exp(\sum_{t=1}^{T} \ln(CPUE_{v,t} / N_t e^{-M/2}) / T) , \tag{5}$$

The likelihood of lognormal distribution is:

$$L(q, N_0, M, \sigma^2 \mid \ln CPUE_t) \propto (\sigma^2)^{-T} \exp\left[-\frac{1}{2\sigma^2} \sum_{t=1}^{T} (\ln \hat{C}PUE_t - \ln CPUE_t)^2 \right], \tag{6}$$

and its profile likelihood function is:

$$L \propto \left(\sum_{t=1}^{T} (\ln \hat{C}PUE_t - \ln CPUE_t)^2 \right)^{-T/2} , \tag{7}$$

2. Estimation of several recruitment pulses in one area.

It was assumed that vessel catchability coefficients, $\boldsymbol{q_v}$, were the same for different squid groups. The different squid groups arrived to the same area and it was not possible to discriminate them in the catch statistics, therefore when a new group arrived the whole number of individuals (new group and survivals of previous groups) was estimated as a model parameter. Hence the abundance of the new group was calculated subtracting the survivals of previous groups from the whole abundance.

The biomass of the first squid group presented in the fishing grounds at the start of the season was estimated directly by the depletion model, but the biomasses of the squid groups that arrived during the season required some extra computation. Let make ***t*** the day of the season and ***g*** the arrival day of a new squid group, then the biomass of this new group, ${}^{G}\boldsymbol{B_{t=g}}$, was calculated as:

$${}^{G}B_{t=g} = B_{t=g} - {}^{S}B_{t=g} , \tag{8}$$

$$B_{t=g} = N_{t=g} W_{t=g} , \tag{9}$$

$$^{S}B_{t=g} = \mathrm{W}_{\mathrm{t=g}}\,[(\mathrm{N}_{\mathrm{t}=g\text{-}1}\mathrm{e}^{\text{-M/2}}) - \mathrm{C}_{\mathrm{t}=g\text{-}1}]\mathrm{e}^{\text{-M/2}}, \tag{10}$$

where:

- ***B*** is the whole biomass estimated by the depletion model.
- $^{S}\boldsymbol{B}$ is the survival biomass of previous groups.
- ***N*** is the whole number of individuals estimated by the depletion model.
- ***W*** is the mean weight.
- ***M*** is the natural mortality.
- ***C*** is the catch in numbers.

For estimating the group composition of the survival biomass ($^{S}\boldsymbol{B}$), it was assumed that biomass proportions by group at the beginning and at the end of each depletion episodes were the same. This is a corollary of assuming the same catchability for all groups.

3. Integrating estimations from several areas

To integrate several depletion models of different areas it was assumed that the vessel catchability coefficients should be similar between areas. Therefore the maximum likelihoods were integrated in a loss function with a penalty function to make these parameters similar between areas:

$$LOSS = \sum_{a=1}^{A} \ln L_a + \ln L_q\,, \tag{11}$$

where $\boldsymbol{L_a}$ is the likelihood in the area ***a*** and ***A*** is the total number of areas. $\boldsymbol{L_q}$ is the penalty function that was calculated as a likelihood of lognormal distribution of the vessel catchability coefficients:

$$L_q \propto (\sigma^2)^{-(A-1*V)} \exp\left[-\frac{1}{2\sigma^2}\sum_{a>1}^{A}\ \sum_{v=1}^{V}(\ln q^{a=1}{}_v - \ln q^{a}{}_v)^2\right], \tag{12}$$

where ***V*** is number of vessel. The profile likelihood function is:

$$L_q \propto \left[\sum_{a>1}^{A}\ \sum_{v=1}^{V}(\ln q^{a=1}{}_v - \ln q^{a}{}_v)^2\right]^{-((A-1)V)/2}, \tag{13}$$

The final parameters were found by maximization of the loss function.

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