Falkland Island Fisheries Department

Fishery Report

Loligo gahi, First Season 2008

Fishery Statistics, Biological Trends, Stock Assessment and Risk Analysis

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- May 2008 -

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I. SUMMARY

Loligo catch during the first season (February/24-Arpil/14, 2008) was 24752 tonnes, which was 44% greater than in 2007 first season and 34% greater than the average of the last 5 years first seasons. The catch increased because of higher CPUE, while fishing effort (8658 trawling hours) was similar than in previous years. The 56% of *Loligo* catch was fished in Beauchene area, 37% in central area and 7% in northern area. The fleet started fishing in Beauchene area, where it had high CPUE (40 tonnes/vessel-day) during the first week. After two weeks, CPUE dropped (14 tonnes/vessel-day), and the fleet moved to explore the central and northern areas. In the central area the initial CPUE were also high (40 tonnes/vessel-day) and therefore the fleet remained fishing there most of the time, with some excursions to the southern area and in less extent to the northern area. Biological trends in proportion of mature individuals and proportion of females were similar to previous first seasons. The average mantle length was 12.1 cm, which was similar than 2007 and 2 cm larger than in 2006. Two squid groups arrived sequentially to the Beauchene area and one group to the central area. *Loligo* was also present in the northern area but it was not included in the biomass estimations because there was not enough data from that area. In-season stock assessment did not show any significant risk that projected spawning biomass could be lower than 10000 tonnes and therefore the season had the normal end. After-season stock assessment was made using eight *Loligo* survey biomasses as prior information in the Bayesian depletion model. The relative fishing powers

estimated by the model were more related with HP than GRT, because there were two vessels that had higher HP/GRT ratio than the rest of the fleet. The whole biomass that arrived to the fishing grounds was estimated at 96753 tonnes, the survival spawning biomass was estimated at 43673 tonnes and the risk of leaving less than 10000 tonnes was estimated at zero.

II. INTRODUCTION

The first season of 2008 started on the 24th of February and lasted until the 14th of April. This fishing season began the day after the *Loligo* survey, which estimated the biomass at 8709 tonnes in the whole *Loligo* box, but highly concentrated in Beauchene area (Payá 2008). The fleet started fishing in the same place where the survey had found the best *Loligo* concentrations and had similar CPUE than the *Loligo* survey. After three weeks of fishing for *Loligo*, the Beauchene area started to deplete and the fleet moved to central and northern areas. The rest of the season the fleet remained fishing in the central area with sporadic excursions to the southern area and in less extent to the northern area. The catches were supported by two squid groups in the southern area, one in the central area and another in the northern area.

Daily fishery statistics and biological data covered the whole fishing season, except for a two-day interruption of biological sampling. During this season a new area was opened to the fishery, this was restricted to the depth range of the natural northward continuity of trawling tracks that come from the central area. For the analysis this area was added to the central area and therefore the boundary between the central and northern area was moved northward (Fig. 1).

In-season stock assessment was made using the last FIFD's implementation of the stock depletion model with includes several sequential depletion events by area (Payá 2007c). In order to warn the fishing industry with two weeks in advance of any chance of early fishery closure the catch during these two weeks and the spawning biomass were projected and the risk of leaving less than 10000 tonnes was calculated.

In-season stock assessment did not show any significant risk that projected spawning biomass could be lower than 10000 tonnes and therefore the season had a normal end. After-season stock assessment was made using the biomasses estimated by eight *Loligo* surveys as prior information in the Bayesian depletion model. The relative fishing powers estimated by the model were related to HP rather than GRT. The whole biomass that arrived to the fishing grounds was estimated at 96753 tonnes and the risk of leaving less than 10000 tonnes of spawning biomass was estimated at zero.

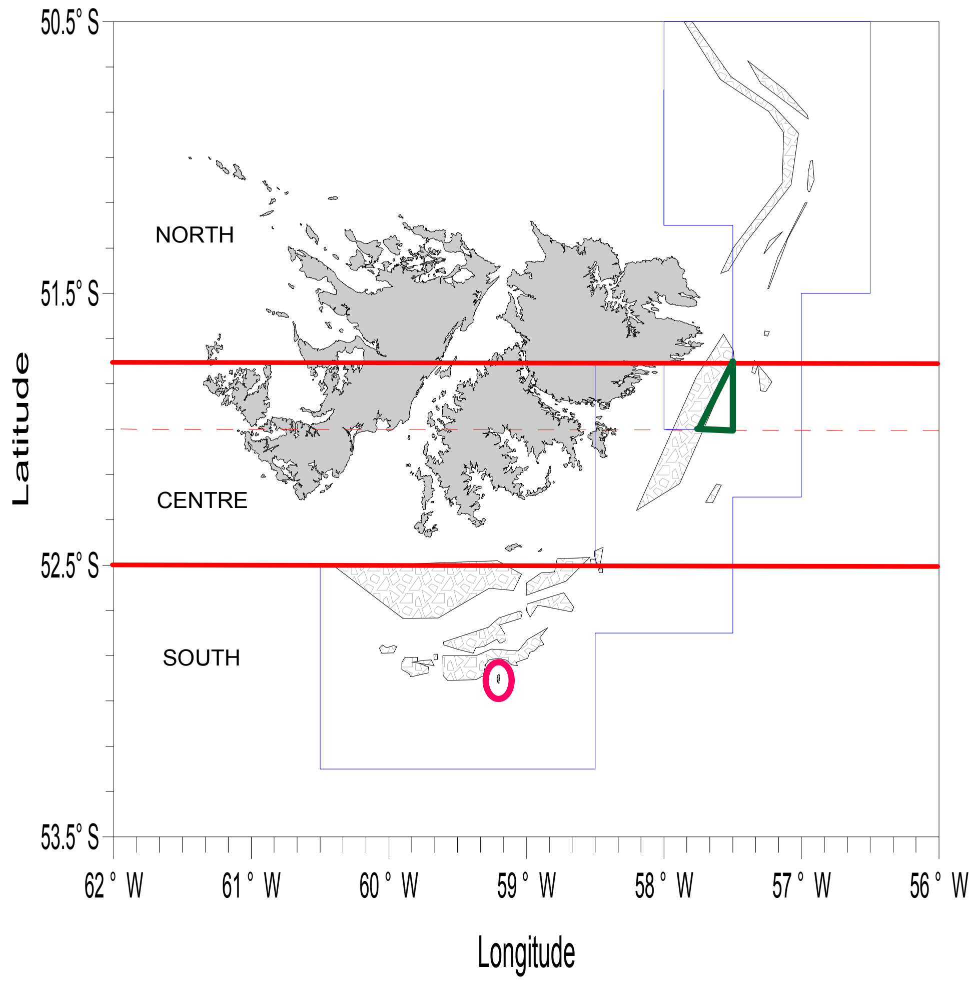


Fig. 1.- Fishing grounds and rocky bottom around the Falkland Islands. In blue, the *Loligo* box, in green, the new fishing area opened in 2008, and in magenta, the three-nm exclusion area around Beauchene Island. The border between the northern and central area was moved northward according to the new opened area, the previous border is shown by a broken red line

III. FISHERY STATISTICS

1. Total Catch and Total Effort in Historical Perspective

The whole catch in the first season was 24752 tonnes, which was 44% greater than 2007 first season and 34% greater than the average of the last 5 years first seasons. In a historical perspective the decreasing trend stopped in 2004 and in the last 4 years the catches have been fluctuated around 20000 tonnes (**Fig. 2 and Table 1**). The fishing effort has been relatively constant since 2003 (**Fig. 2 and Table 1**).

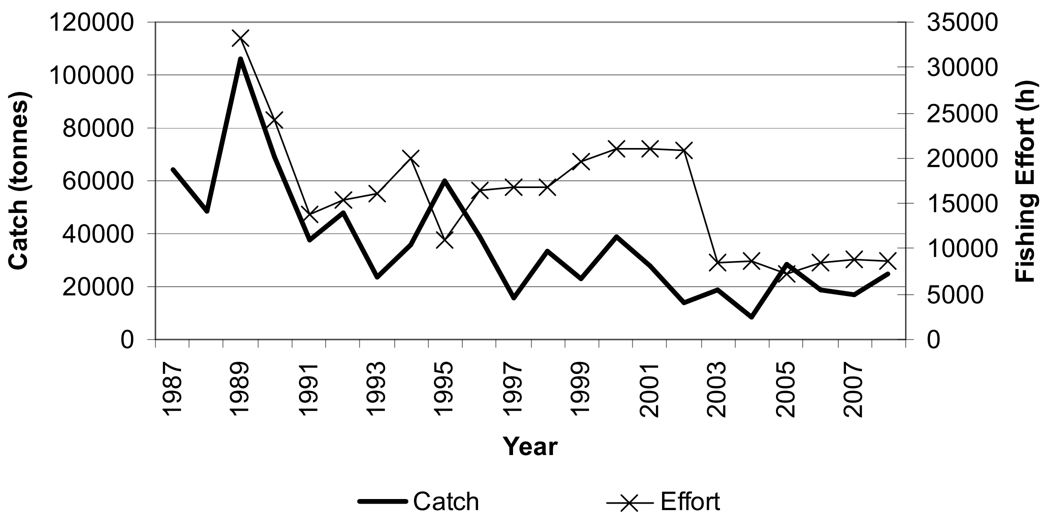
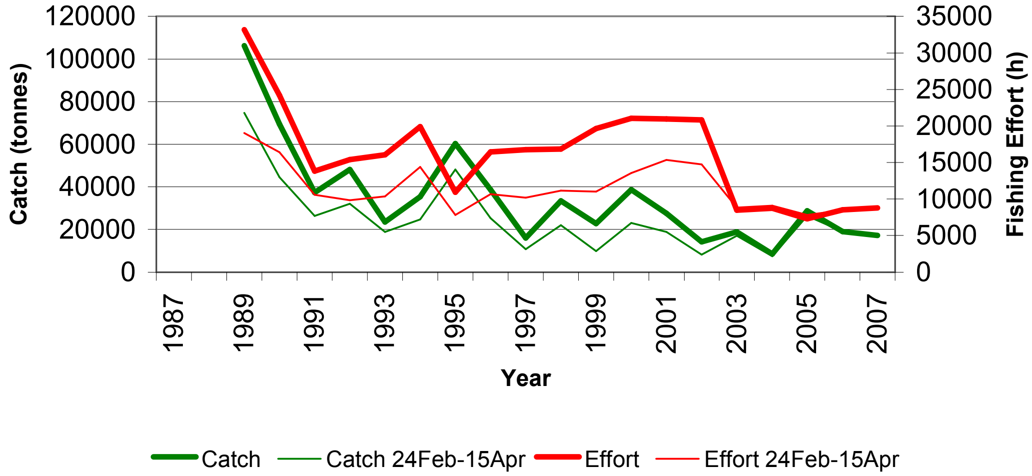


Fig. 2.- Historical catches and fishing effort of the first season.

In order to do historical comparisons, the catches, the fishing efforts and the CPUEs were calculated for the period from 24 February to 15 April, which corresponds to the length of the first seasons since 2003. The statistics of the vessels that had annual catches less than 100 tonnes were not included. The catches and fishing efforts during this period represented most of the total figures and therefore the CPUE trend for this period was similar than the CPUE trend for the whole first seasons (**Fig. 3**). The 2008 CPUE was 46% greater than 2007 and 26% greater than the last 5 years average. As the fishing effort was similar than in 2007, the increase in catch is explained by the increase in CPUE. There is a strong historical relationship between initial biomass and CPUE, although there have been methodological changes since the second season of 2004 and a reduction of the length of fishing seasons since 2003. The historical decreasing trend of CPUE stopped in 2002 and since then there has been an increasing trend, but variable.



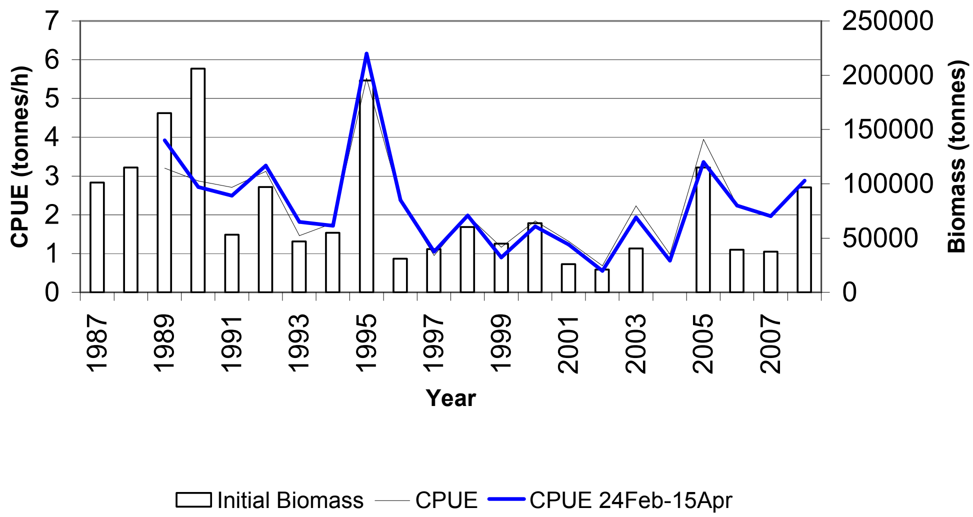


Fig. 3.- Historical catch and fishing effort (upper plot) and CPUE and initial biomass (down plot) of the first season. For comparisons the catch, effort and CPUE for the period 24 February to 15 April are also shown. For 2007 and 2008 the biomass is the sum of the biomass at the beginning of the season and the biomass of the squid groups that arrived during the 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). For 2007 and 2008 the initial biomass is the sum of the biomass at the beginning of the season and the biomass of the squid groups that arrived during the season.

	First Fishing Season			Second Fishing Season			Annual
Year	Catch (tonnes)	Effort (h)	Initial Biomass (tonnes)	Catch (tonnes)	Effort (h)	Initial Biomass (tonnes)	Catch (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
2008	24752	8657	***96753***				

2. Catch and Effort per Fishing Ground and Cumulative Catch

The 56% of the squid were caught in Beauchene area, 37% in the central area and 7% in the northern area (**Table 2**). The catch rates (2.86-2.62 tonnes/h) were high in all the areas, although the highest rates were achieved in Beauchene area and the lowest one in the northern area. The percentages of fishing effort by area were similar to the catch percentage per area.

Table 2.- Effort and catch statistics of *Loligo* first season 2008 by fishing ground.

Fishing Ground	Total Catch (tonnes)	Effort (Vessel-Days)	Effort (Hours)	CPUE (tonnes/V-D)	CPUE (tonnes/h)
Beauchene	13756	416	4756	33.067	2.893
Central	9197	289	3215	31.822	2.861
North	1799	66	686	27.265	2.622
Total	24752	771	8657	32.104	2.859

The daily cumulative catch was at medium level compared with the highest and lowest historical figures (**Fig. 4**). The fleet achieved a sustained increase in its cumulated catches by changing fishing areas.

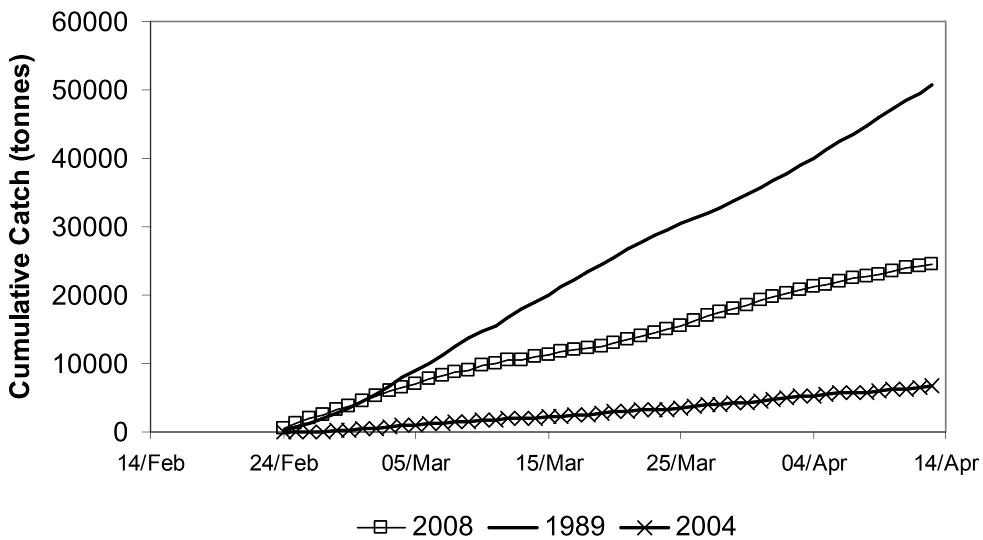


Fig. 4.- Cumulative catch versus date in the first season of 2008 compared with the cumulative catch of the first seasons that yielded the highest (year 1989) and lowest (year 2004) historical catches on exactly the same date range.

3. Fleet Movement Dynamics, Catch and Catch Rate

The fleet was fishing only in the Beauchene area during the first 19 days, and then it moved to the central area where it was fishing for 3 days before move to the northern area. Despite of the good CPUE and because of the smaller *Loligo* sizes found in the northern area (see biological parameter section) the fleet returned to the central area where it was fishing the rest of the season with some sporadic movement to the Beauchene area and in less extent to the northern area (**Fig. 5a**).

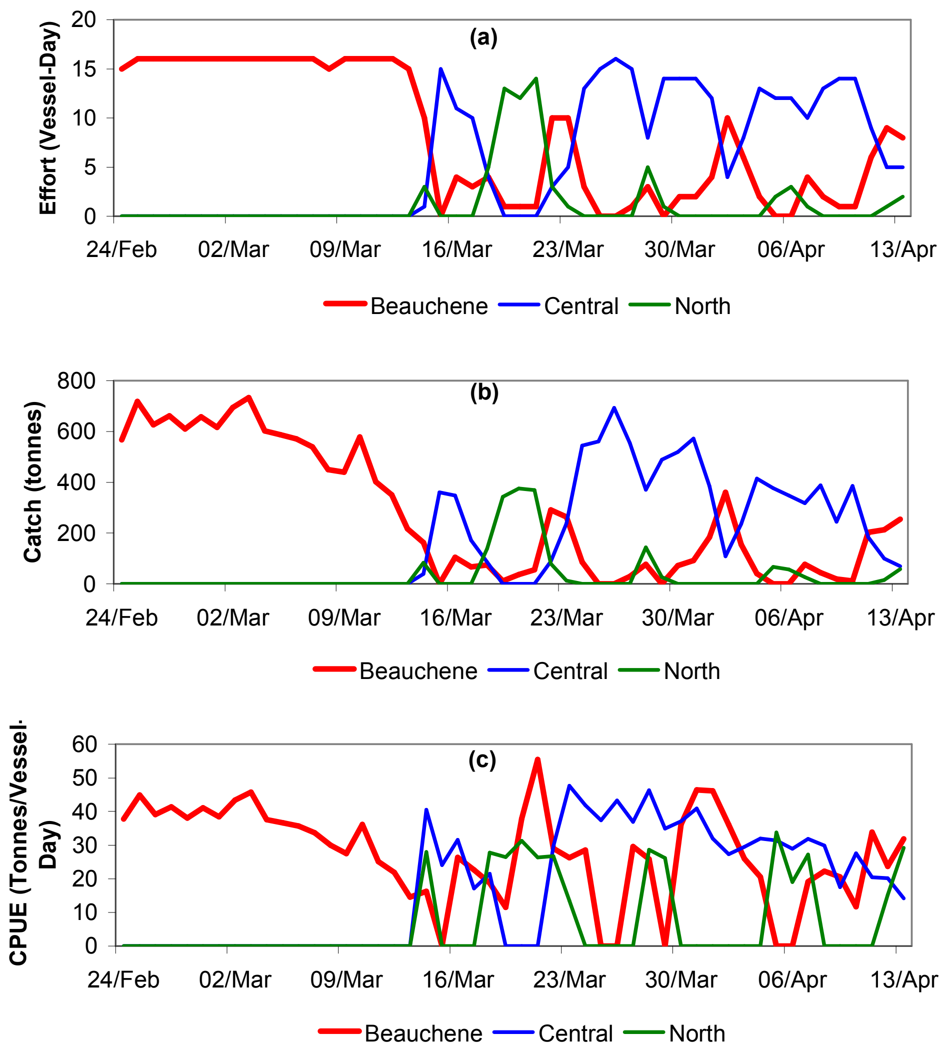


Fig. 5.- Daily evolution of effort (a), catch (b), and average catch per unit of effort (c) in the *Loligo* fishery during the first season of 2008.

The daily fleet catches were high (600-700 tonnes) during the first week and then rapidly decreased during the next two weeks (**Fig. 5b**). The initial daily catches in the central area were about a half of the initial catches of the Beauchene area and similar to the daily catches later achieved in the northern area. The daily catches in central area reached the highest levels (600-700 tonnes) in the last week of March, and then decreased until the end of the season. The CPUE were high, 40 tonnes/ vessel-day, during the first week, but decreased at 14 tonnes/vessel-day after two weeks (**Fig. 5c**). Later in the same Beauchene area, the CPUE increased again and their highest figures were achieved on the 21^{rst} of March and 1^{rst} and 12th of April. In the central area, the initial CPUE was high, 40 tonnes/ vessel-day, but quickly decreased in 4 days at 21 tonnes/ vessel-day. Four days later the highest CPUE were observed in the central area and then after a steady depletion occurred until the end of the season. In the northern area the CPUE was relatively stable at around 25 tonnes/ vessel-day. Because the absent of CPUE depletion and low fishing effort in the north, this area was not included in the depletion model estimations (see stock assessment section).

The analysis of the fleet movement based on e-logbooks, shows the sequential arrivals of two *Loligo* groups in the Beauchene area, one in the central area and one in the northern area. In the first day the fleet fished in the Beauchene area in locations where the *Loligo* survey had found the squid concentrations (**Fig. 6**). After the depletion in Beauchene area the fleet explored almost the whole *Loligo* box and found *Loligo* concentrated in the central and northern areas, with similar levels of CPUE, while in the southern area its abundance decreased (**Fig. 7**). The highest CPUE in the central area was achieved on the 26th of March at the border with the southern area (**Fig. 8**). The appearance of the second wave of squid in the southern area was evident on the 2nd of April, when the CPUE were very high and were located in a very small fishing ground called " El semaforo" (the traffic light) (**Fig. 9**). In this day the CPUE was very small in rest of the southern area and in the central area. After the depletion observed in the central area, the fleet searched along the whole *Loligo* box and found the best CPUE in the southern area (**Fig. 10)**, where at the end of the fishing season the CPUE increased again (**Fig. 11**).

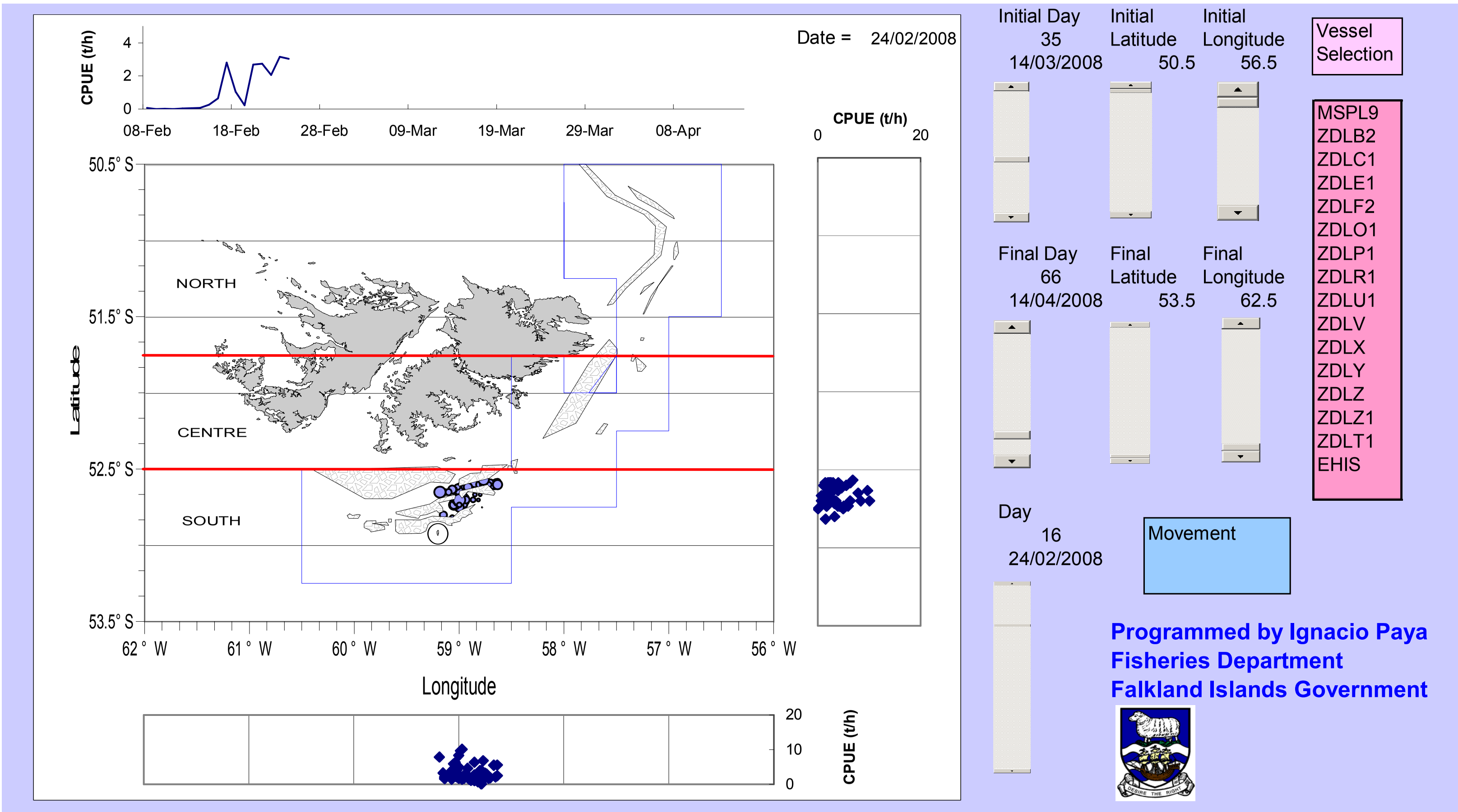


Fig. 6.- On the 24th of February, the first fishing day, the fleet was concentrated in the southern area, where *Loligo* trawl survey had found the best aggregation. The graphical interface displays the fleet movement and CPUE (tonnes/h) and has been described in previous reports.

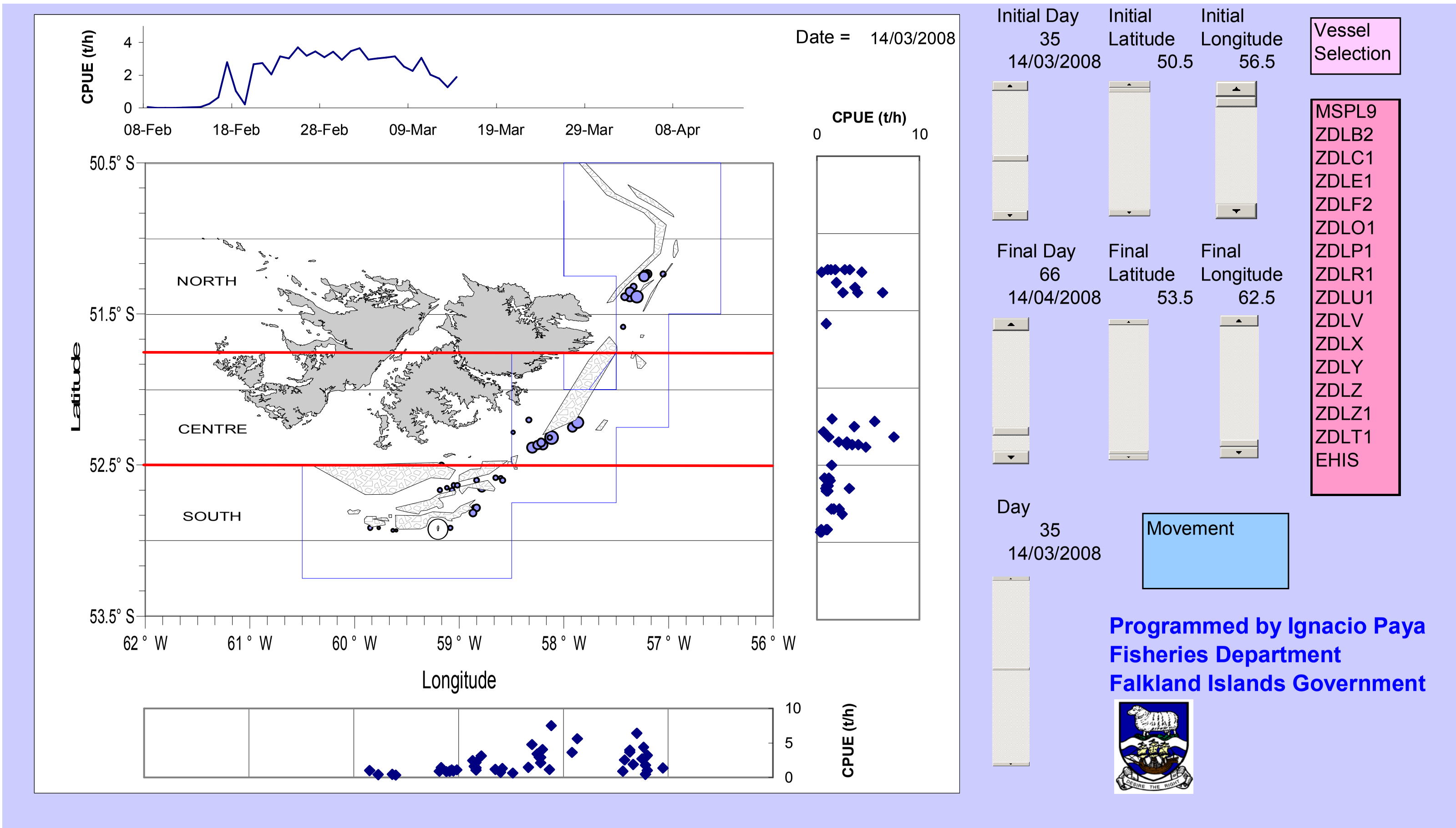


Fig. 7.- On 14th of March, after the depletion in Beauchene area the fleet explored almost the whole *Loligo* box. After this the fleet was concentrated in the central and sporadically in the southern area.

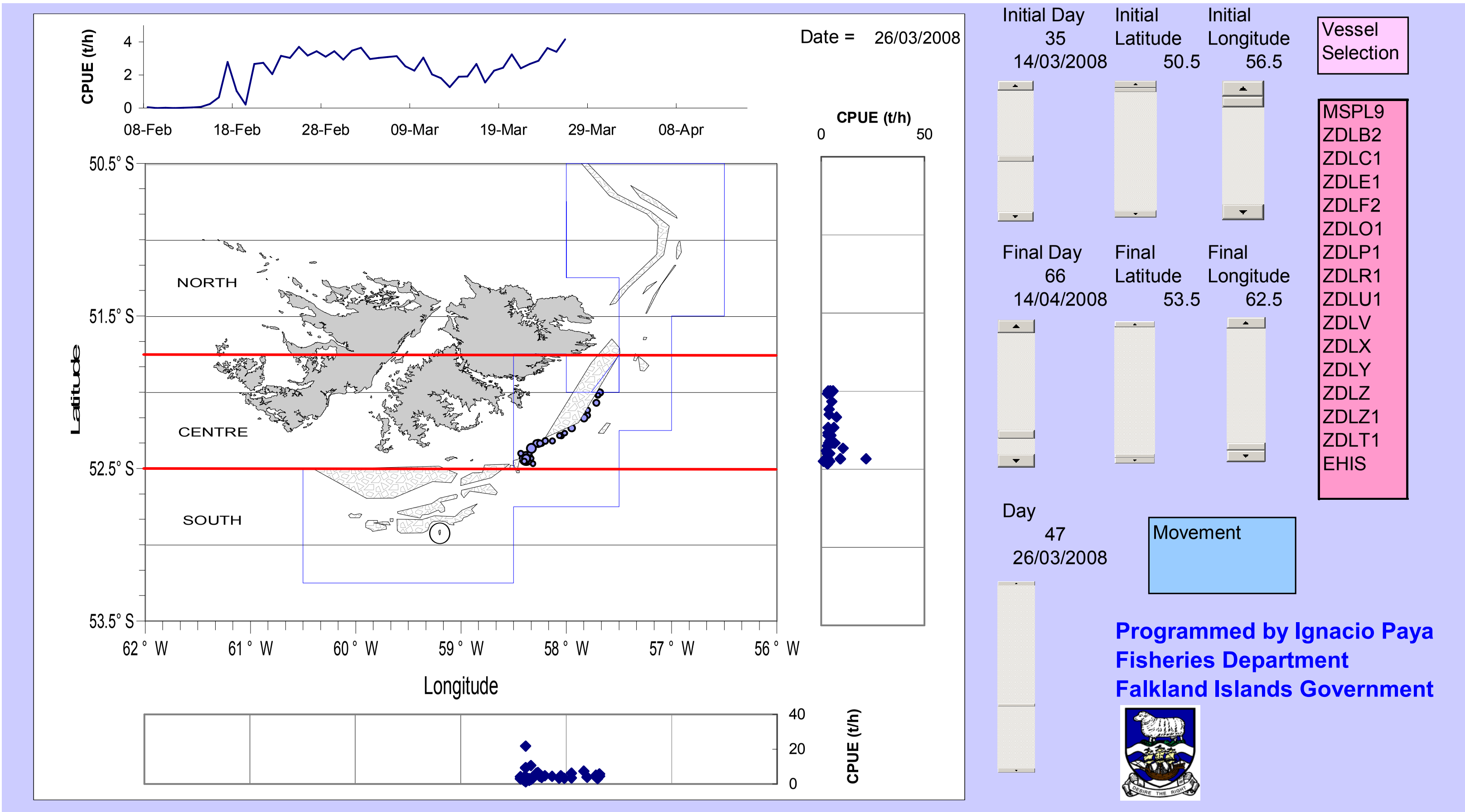


Fig. 8.- On the 26th of March the fleet achieved the highest CPUE in the central area, with the best CPUE located close to the border with southern area.

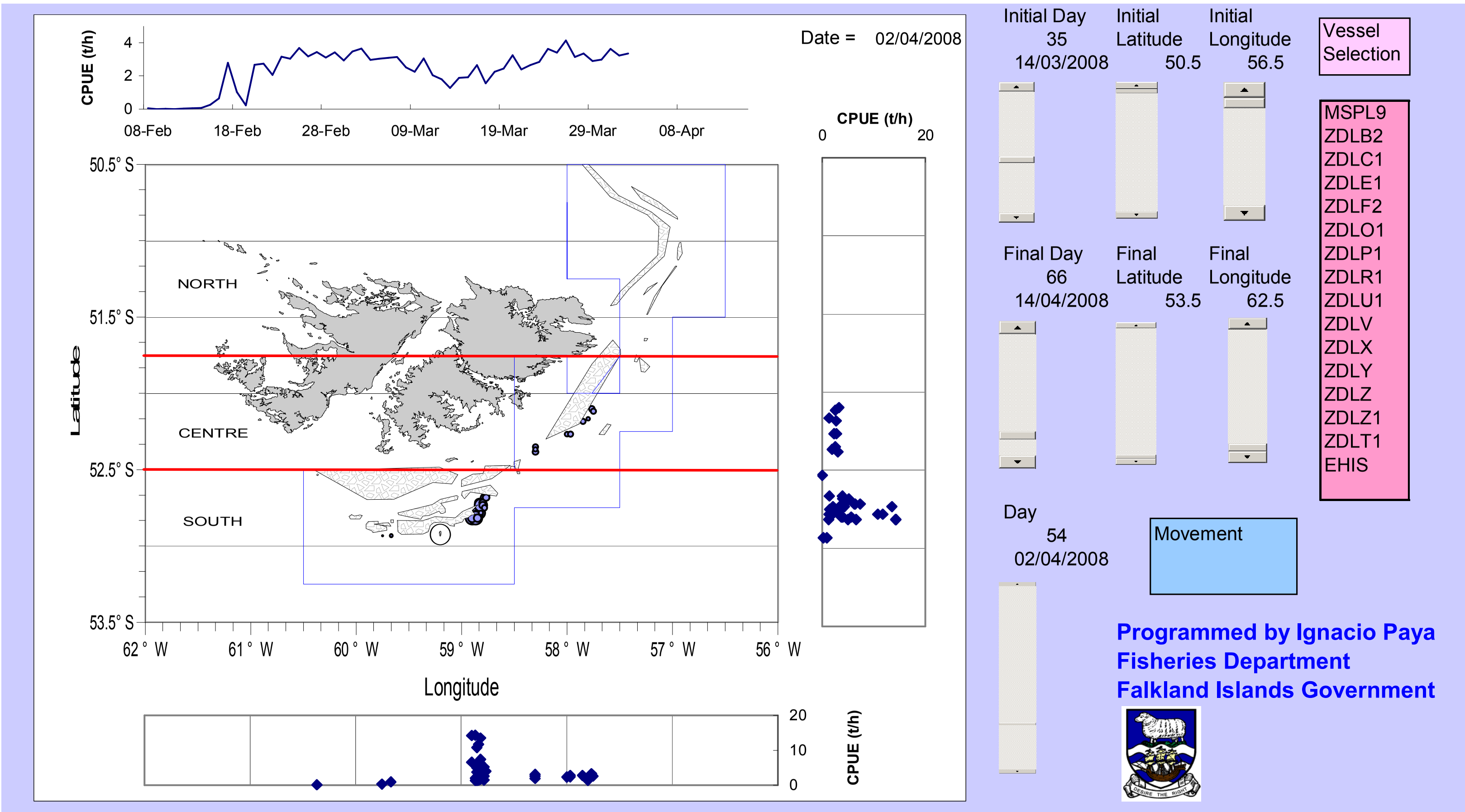


Fig. 9.- On the 2nd of April the fleet had high CPUE in the southern area in a very small place called “El semaforo”.

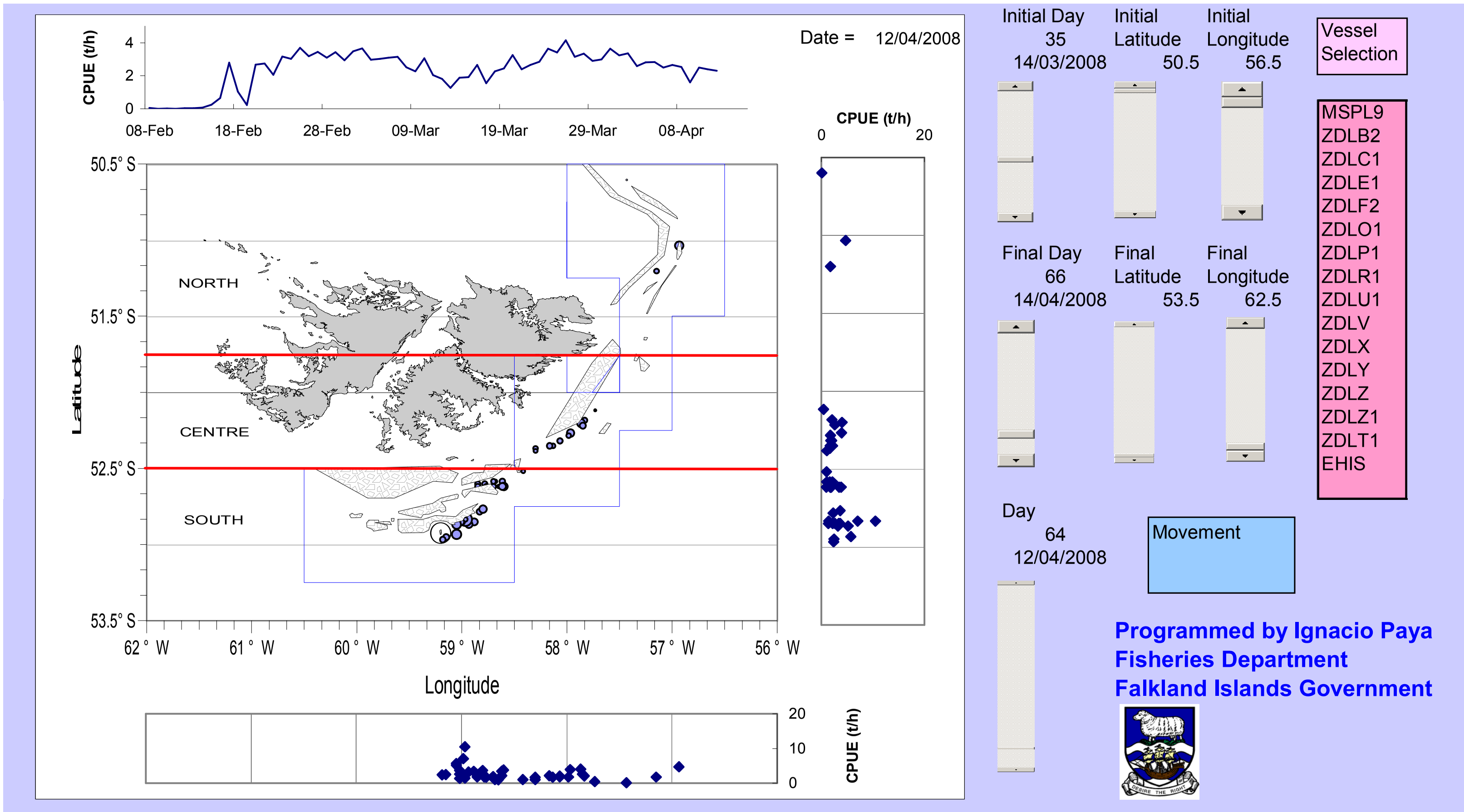


Fig. 10.- On the 12th of April, after the depletion observed in the central area, the fleet searched along the whole Loligo box and found the best CPUE in the southern area.

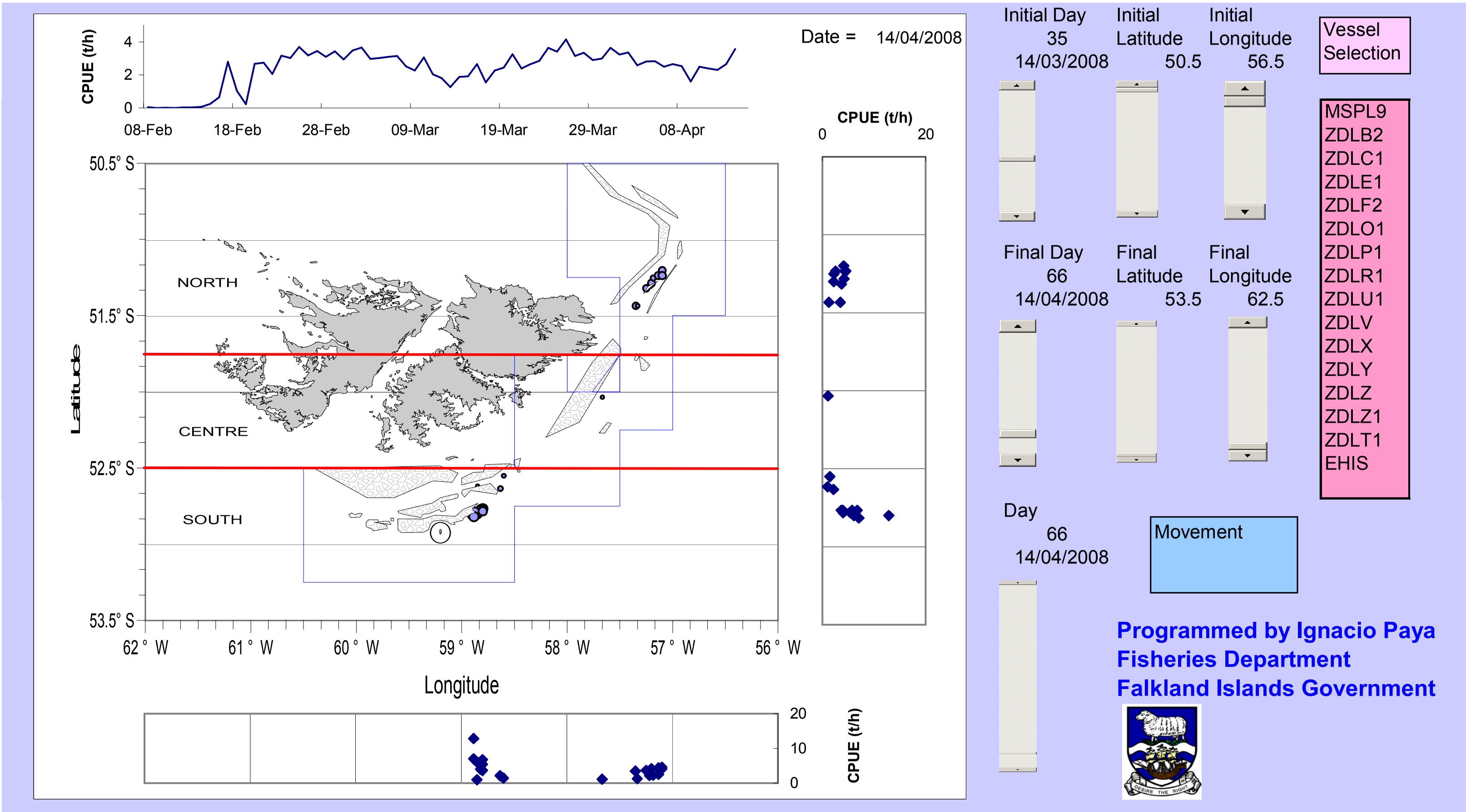


Fig. 11.- On the last day, 14th of April, the CPUE increased again at " El Semaforo" in the southern area.

IV. BIOLOGICAL TRENDS

Biological trends of the stock were based on sampling taken by one scientific observer onboard of one commercial vessel, except for 3 days when two observers overlapped onboard of two different vessels. The observers took a sample of approximately 400 animals per day. There were only two days without biological samples because of transhipping activities.

1. Comparison of Daily Mean Biological Characteristics with Recent Years

The proportion of sexually immature squid in the catch followed trends observed in the first seasons of the previous five years. Both females and males were mostly immature or maturing (**Fig. 12**). The sex ratio was variable but without any trend; the female proportion was about 0.4-0.7 (**Fig. 13**). The average dorsal mantle length for the whole season was 12.1 cm (11.3 cm for females and 12.0 cm for males), which was similar than 2007 and 2 cm larger than in 2006. The average dorsal mantle length remained stable most of the season, but it decreased by 2 cm when the samples were taken in the northern area (**Fig. 14**). The variation of length by day was similar between sexes. The dorsal mantle length distributions were uni-modals, except for some days during the last two weeks of the season (**Fig. 15**).

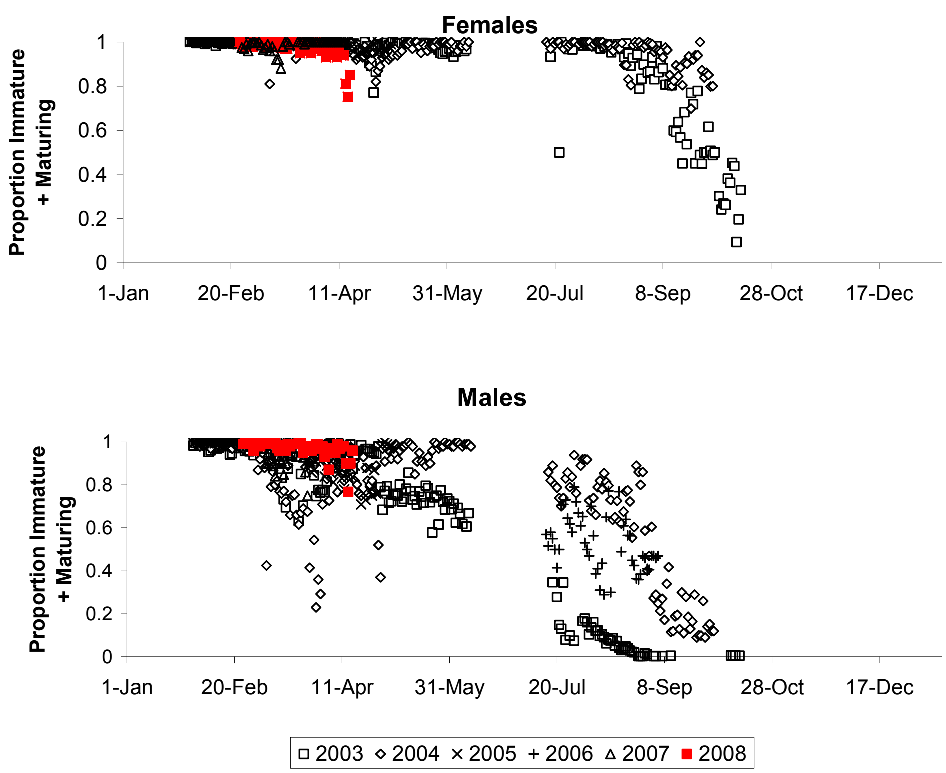


Fig. 12.- Current year trends in the proportion of sexually immature squids in the catch, compared with five previous years.

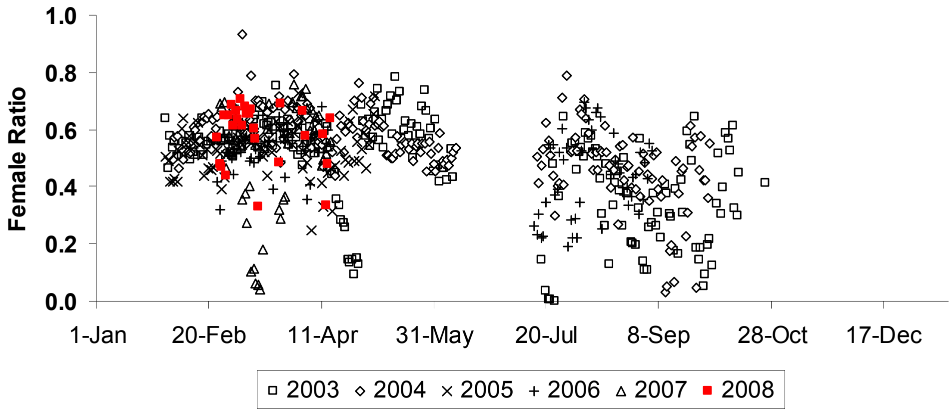


Fig. 13.- Current year trends in the daily evolution of the proportion of female squids in the catch, compared with five previous years.

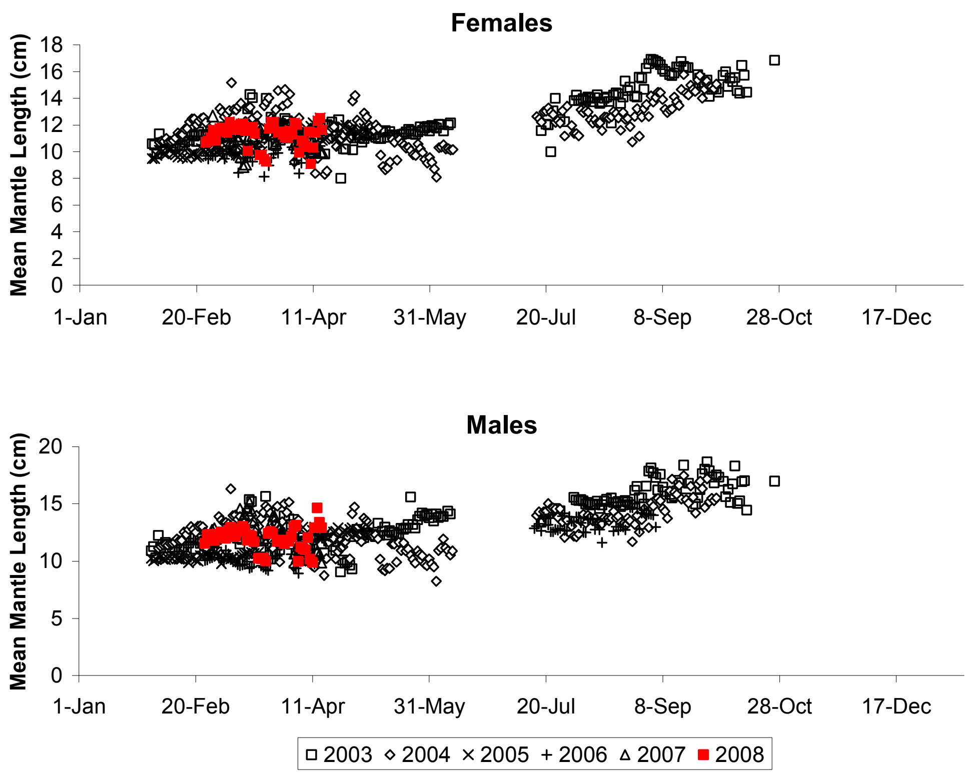


Fig. 14.- Current year trends in the mantle size by sexes, compared with five previous years.

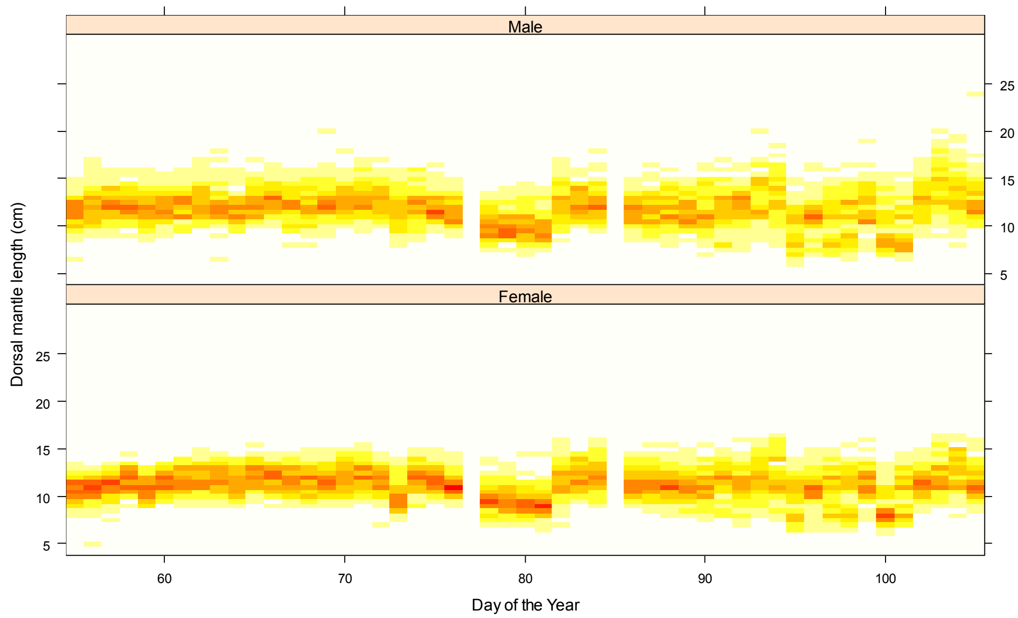


Fig. 15.- Time series of proportions (increases from yellow to red) of dorsal mantle length of squid in the catch during the first season, 2008.

2. Mean Mantle Length and Commercial Size Categories

During 2008, with only one scientific observer onboard, it was no possible to take samples from all the areas where the fleet fished. Therefore 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). 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. 16**). The size by CSC for the northern area was not estimated because this area was not included in the depletion models. The average mantle length was similar along the season, except during the last two weeks when the length decreased in the central area (**Fig. 17**).

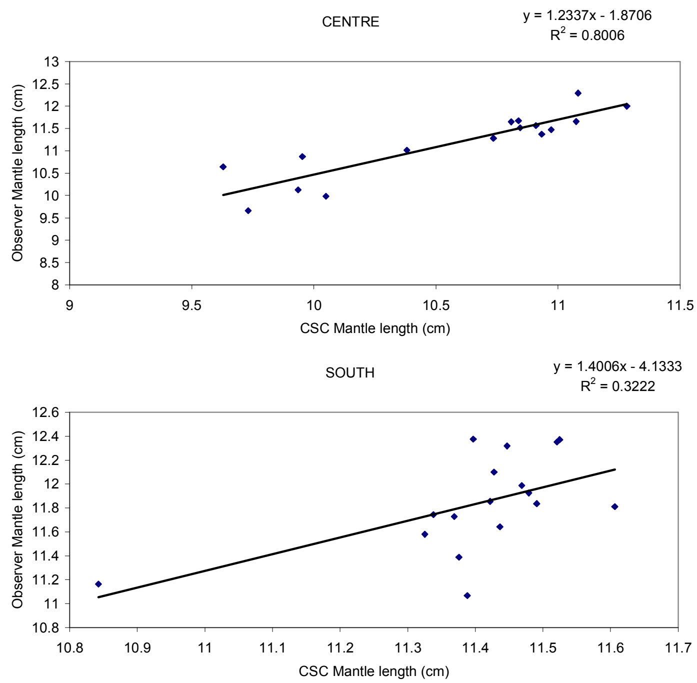


Fig. 16.- Relations between observer mantle length and commercial size categories (CSC) mantle length for the central and southern areas.

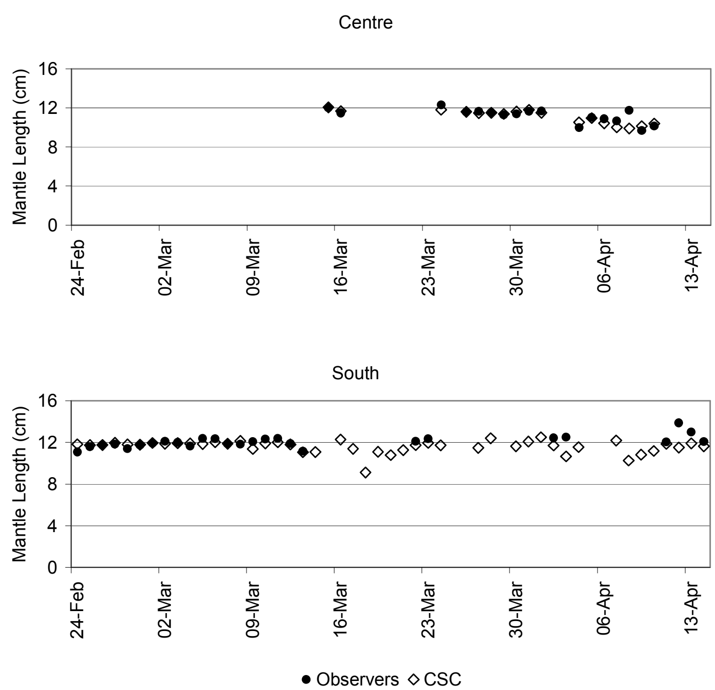


Fig. 17.- Average mantle length by area. Data from scientific observers onboard and estimations based on the commercial size categories (CSC).

The CSC length distributions were less precise than the observer length distributions because uniform length distributions were assumed inside each CSC (**Figs. 18 and 19**). 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.

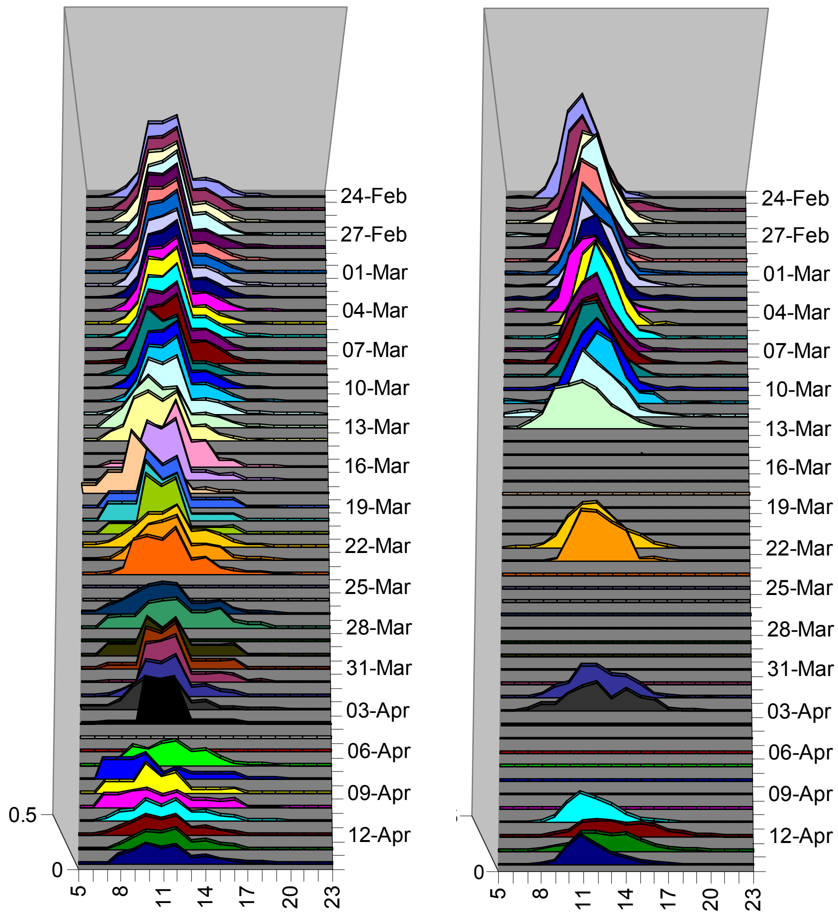


Fig. 18.- Mantle length (cm) distribution by day in the southern area. The sizes were estimated from commercial size categories (left plot) and from scientific observers onboard (right plot).

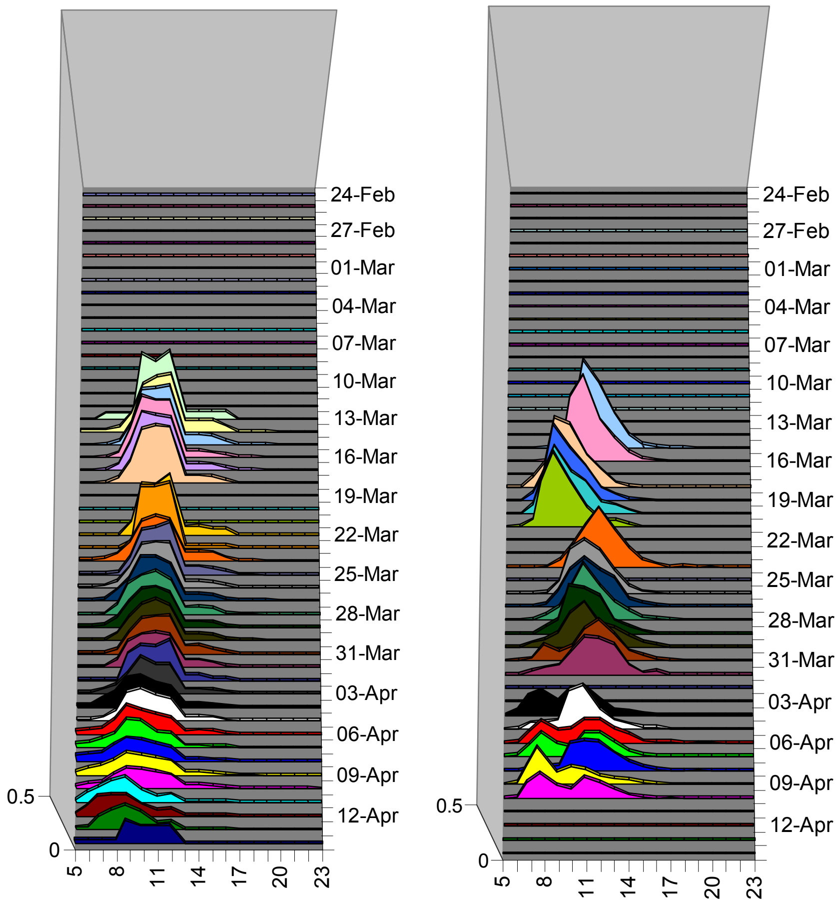
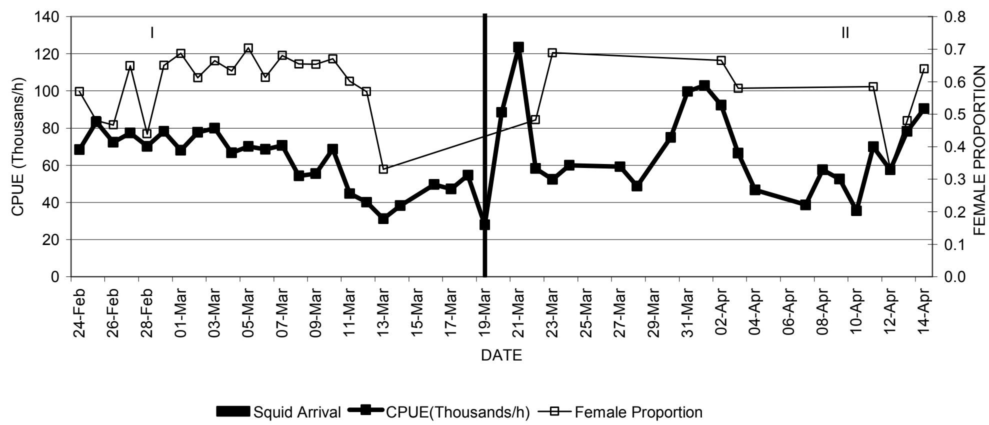


Fig. 19.- Mantle length distribution by day in the central area estimated from commercial size categories (left plot) and from scientific observers onboard (right plot).

3. Arrivals of squid waves by area.

In the southern area, the arrivals of two sequential groups of squid were identified combining the CPUE depletion periods and the biological information (**Fig. 20**). The first group was present at the start of the season and it was composed mainly (60-70%) by females and had a stable mean weight (45 g). The second group arrived on 20th of March and had higher and more variable CPUE and also more variable mean weights than the first group. In the central area there was only one group in terms of CPUE but the mean weight had a decreasing trend (**Fig. 21**).



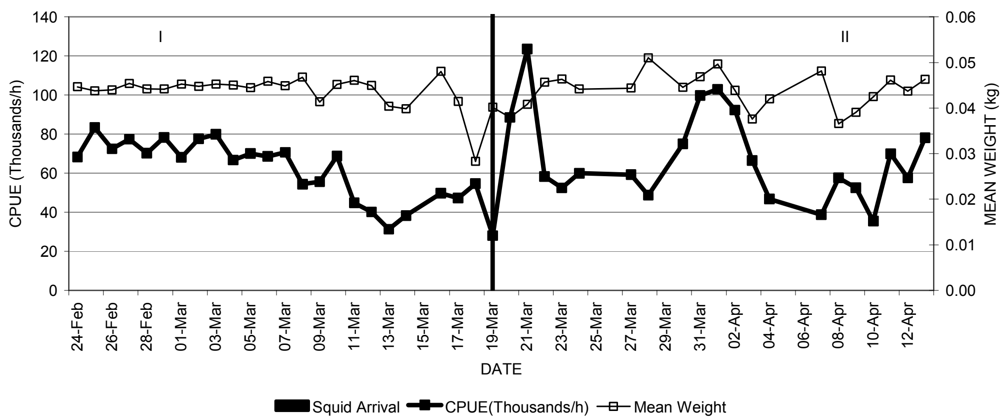
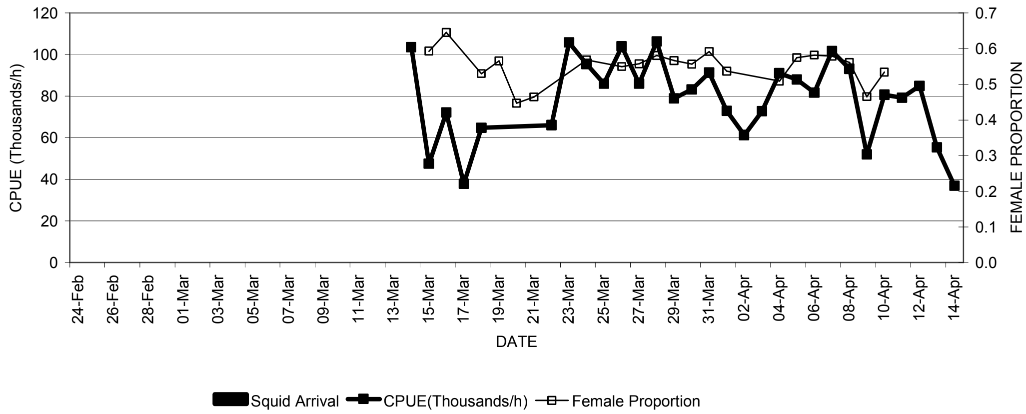


Fig. 20.- The arrivals of two different groups of squid to the southern area was identified based on the behaviour of the CPUE (Thousands/h), the female proportion (upper plot) and the mean weight (down plot). The arrival date is represented by the vertical bar.



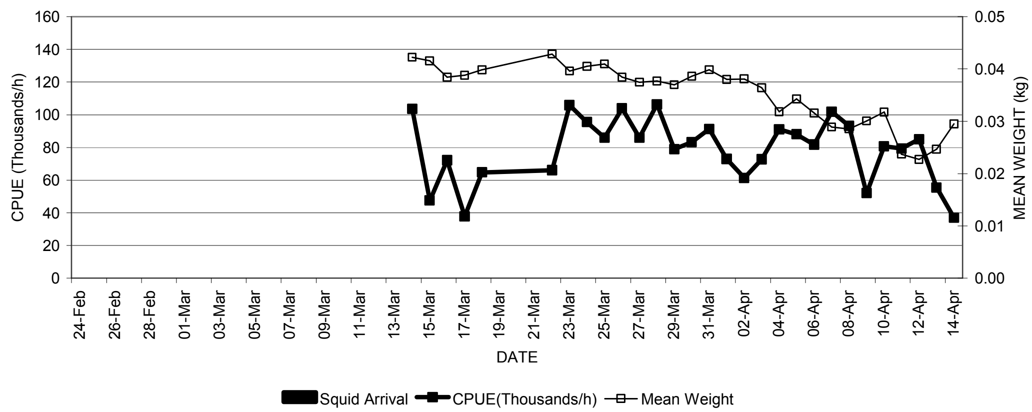


Fig. 21.- The arrivals of only one group of squid to the central area was identified based on the behaviour of the CPUE (Thousands/h), the female proportion (upper plot) and the mean weight (down plot).

V. STOCK ASSESSMENT AND RISK ANALYSIS

1. In-Season Stock Assessment and Risk Analysis

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 22**.

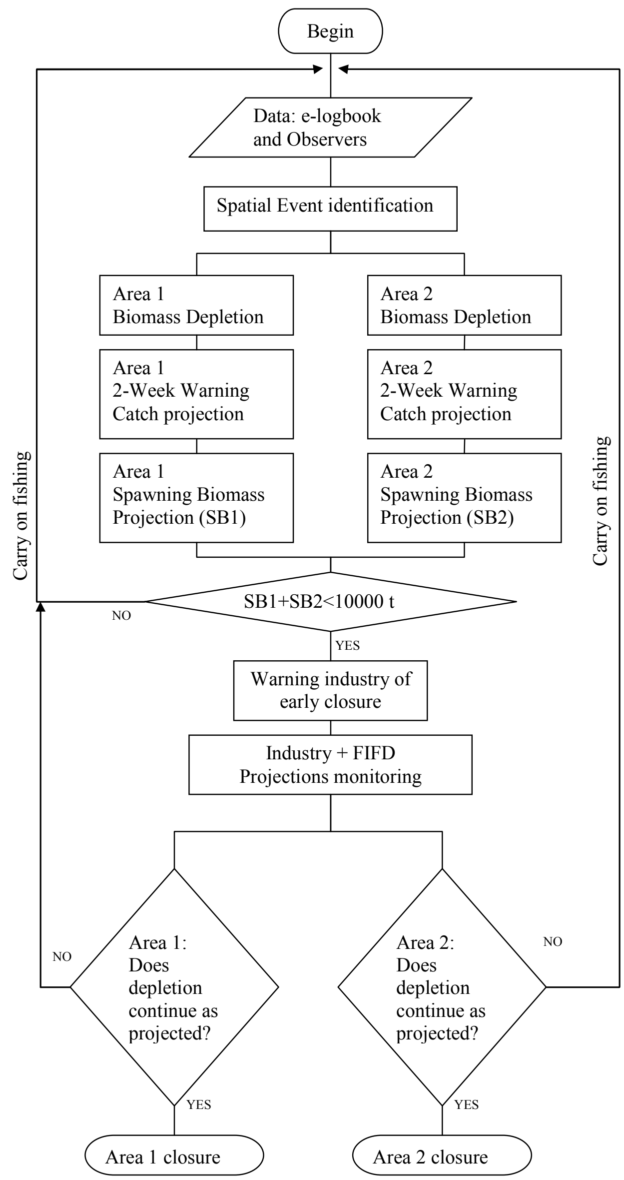


Fig. 22.- Flowchart of spatial management procedure for the early fishery closure decision. For simplicity only two depletion events are shown.

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 the 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 appear then the area will be closed.

The stock assessment was done using the depletion model with several recruitment pulses and vessel catchability coefficients estimations by area. The equations for the stock assessment and risk analysis have been previously described in the 2007 second fishery report (Payá 2007c), and therefore are not presented here.

The assessment with data up to 19th of March showed the projected catch for the two-week warning period lead the spawning biomass below 10000 tonnes (**Fig. 23**). However the probability of arrivals of new groups was 0.74 (**Fig. 24**), this was later confirmed with the arrival of the second wave in Beauchene area and another in the central area, which allowed a normal ending of the fishing season.

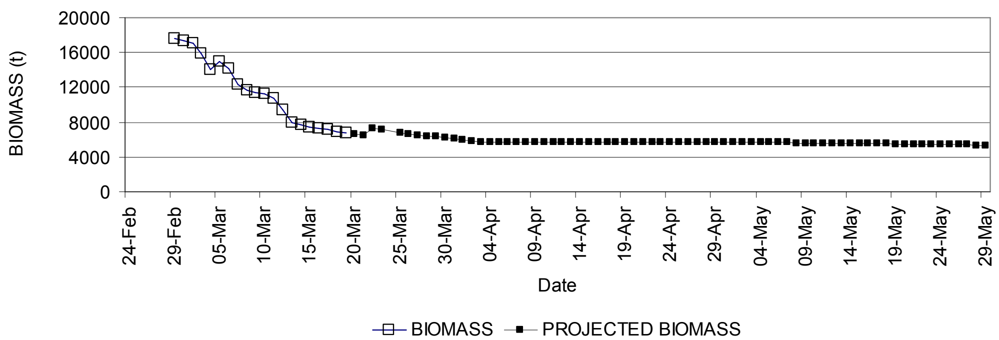


Fig. 23.- In-season stock assessment with data up to 19th of March. Estimated (open squares) and projected (black squares) biomass in Beauchene area.

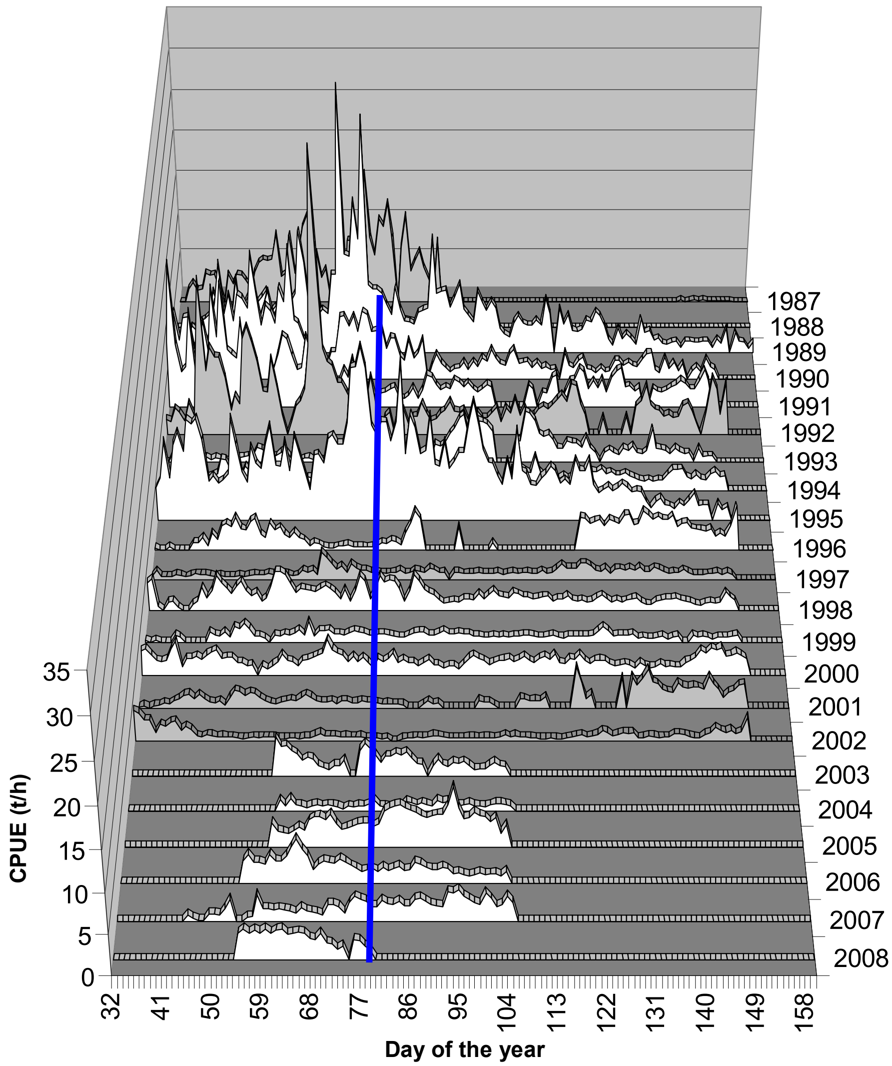


Fig. 24.- Historical first season CPUE trends in the southern area. The blue line shows the 19th of March; the grey colour years had not any increase in CPUE between this date and the end of fishing season. There was a high historical probability (0.74) of arrivals of new squid groups.

2. After-Season Stock Assessment and Risk Analysis

2.1 Bayesian inference

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.

2.1 Prior Analysis

The priors were calculated using the relationship between the biomasses estimated by the *Loligo* swept area surveys and initial biomass estimated by depletion models for each fishing season from 2004 second season until 2007 second season. Before make any relationship the survey biomass were standardized because they were done with different commercial vessels. In the last *Loligo* survey report (Payá 2008) was shown that the ratio of the swept area by hour between vessels is a good correction factor to standardize the fishing powers of the different vessels. Therefore, these correction factors were calculated from the logbooks of the *Loligo* surveys. The second problem was the difference between the dates from the survey and the initial biomass in the depletion model, which was solved by projecting the survey biomass to the initial depletion biomass date. This projection was made by transforming the biomass into number of individuals using the mean weight at the surveys and then projecting the number of individuals that survived to the natural mortality until the date of the initial depletion. The projected survey biomass was then calculated multiplying the survivals by the mean weight (sampled by the observers) at the initial of the depletion (**Table 3**).

Table 3. Projection of standardized survey biomasses to the initial depletion dates. Correction factors were used to standardize the fishing power of the different vessels.

Year	Season	Survey Date	Initial Depletion Biomass date	Time between survey and initial depletion (days)	Survey Biomass (t)	Correction factors	Standardized Survey Biomass (t)	Mean Weight at survey (g)	Standardized Survey Number (Millions)	Standardized projected Number (Millions)	Mean weight at initial depletion (g)	Projected Survey Biomass (t)
2004	2	12-May	15-Jul	63	25137	1.028	25841	46	567	522	50	25953
2005	1	14-Feb	10-Mar	26	15737	1.000	15737	29	535	517	36	18489
2005	2	15-May	21-Jul	66	15290	1.106	16907	35	488	448	64	28597
2006	1	23-Feb	08-Mar	15	11241	1.028	11556	24	488	479	26	12451
2006	2	13-Jul	04-Aug	21	22805	1.029	23455	37	631	614	49	30117
2007	1	23-Feb	27-Feb	4	2678	1.028	2753	35	79	79	41	3255
2007	2	14-Jul	22-Jul	8	19104	1.048	20022	57	353	349	66	22985
2008	1	23-Feb	23-Mar	30	7866	1.107	8709	41	214	205	38	7832

A linear regression was fitted between the projected standardized survey biomass and the initial biomass estimated by the depletions model (**Fig. 25**). Then the initial biomass for the 2008 was predicted with its prediction intervals, which were used to calculate both normal and Cauchy distribution of the predicted biomass. These distributions were left truncated at the lowest value required to support the caches of the first wave in Beauchene area (**Fig. 26**). Finally Cauchy distribution was selected for the prior, because their heavy tails allow higher probability for extreme values (Johnson ***et al.*** 1994).

As in the 2008 survey the *Loligo* was found mainly in the Beauchene area, the survey biomass can only be related with the first *Loligo* wave in this area. Therefore the priors for the second squid wave of Beauchene and the squid in the central area were estimated based on historical biomasses estimated by depletion models. For the second wave in Beauchene there were biomass estimations since 2005 and for the central area since 2004. The means and standard deviations were estimated and these were used as parameters for truncated Cauchy distributions.

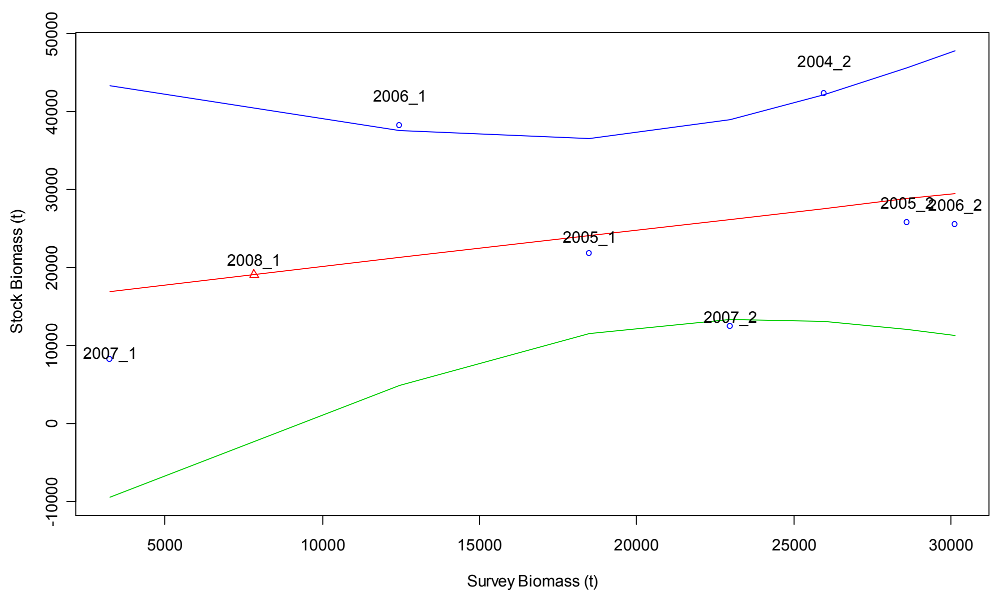


Fig. 25.- Linear regression between the projected standardized survey biomass (survey biomass) and the initial biomass estimated by depletion models (stock biomass). Red line is the fitted linear model; green and blue are the 95% confident intervals. The predicted value for the first season 2008 is also shown (2008_1).

The likelihood of the parameters was based on lognormal error distributions. To find the maximum posterior density the *LOSS* function was maximized by Solver maximization algorithm:

$$LOSS = \sum_{a=1}^{A} \ln Ld_a + \ln Lq + \ln Lp$$

where ***a*** is the area and ***A*** is the total number of areas; *Ld* is the likelihood of the lognormal errors of the depletion model; *Lq* is the penalty function that was calculated as a likelihood of lognormal distribution of the vessel catchability coefficients by area; and *Lp* is the likelihood of the prior distributions. More detailed information about the *Loss* function was presented in Payá 2007c.

2.3 MCMC results

To compute the posterior distribution a Metropolis-Hastings Markov Chain Monte Carlo algorithm (MCMC) programmed in VisualBasic was used (Payá 2007c). Three chains of 15000 iterations were generated using a Cauchy distribution as a global jumping rule, the mean was the maximum posterior density and dispersion parameter was a coefficient of variation of 1.5 (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 like the ratio between the variances within and between chains (Gelman ***et al.*** 2004). The convergence is achieved when ***R*** is lower than 1.1. The three chains were pulled together in a 42000-iteration chain that was used to compute the posterior densities. To estimate the biomass distribution (marginal density) 3000 set of parameters where randomly taken from the posterior distributions. For each of the 3000 biomass estimations the spawning biomass was projected and the risk of leaving at the sea less than 10000 tonnes of spawning biomass was computed.

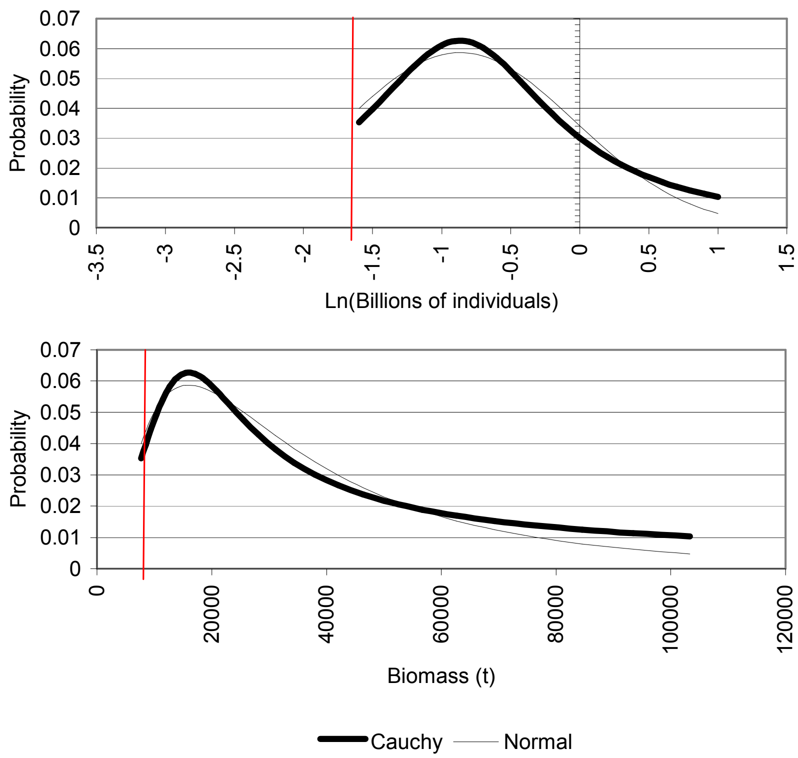


Fig. 26.- Prior distributions for the ln(Number) (upper plot) or the biomass (lower plot) at the initial of the depletion for the first squid wave in Beauchene area. The priors were left truncated at the lowest biomass required to support the caches (red line).

In MCMC, after the burning section, the chains reached the convergence criterion at iteration 3000 (**Fig. 27**).

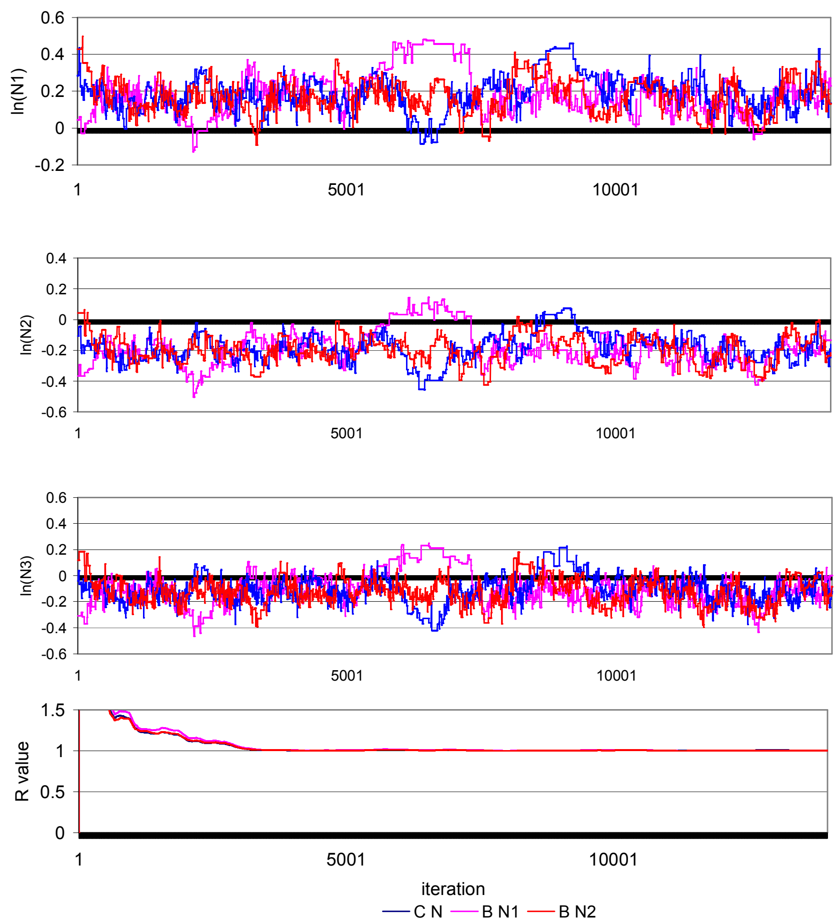


Fig. 27.- MCMC results for the three chains for each parameter (first three upper plots) and the convergence index (***R***), which must be lower than 1.1 (down plot). (C N: Number in central area; B N1: number of the first wave in Beauchene area; B N2: number of the second wave in Beauchene area)

2.4 Posterior Analysis

The lower and upper limits of the prior distribution were wide enough for covering all the possible values of the posterior distribution and the Cauchy distributions did not constrained the posterior values (**Figs. 28**).

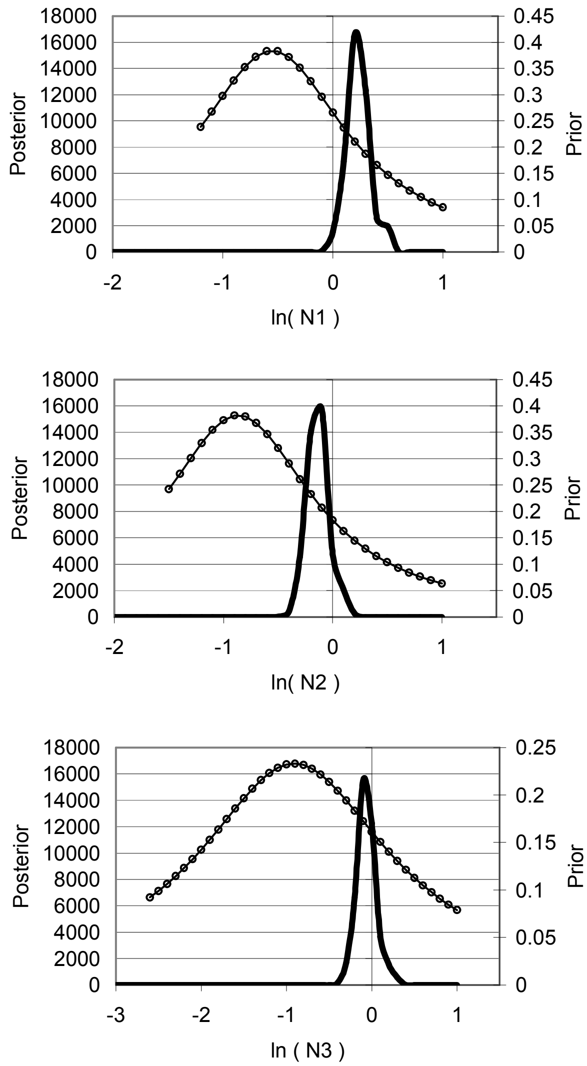


Fig. 28.- Prior (line with circles) and posterior (bold line) distribution of initial numbers (N) parameters for central (upper plot) and Beauchene (middle and down plots) areas.

2.5 Model Fittings By Area

The fitting of the model was good and the errors were lognormal distributed in both areas (**Figures 29 to 31**). The residuals were evenly distributed and they did not show any trend in time or by vessel. Only two data points from the southern area were excluded as outliers (extremely high values).

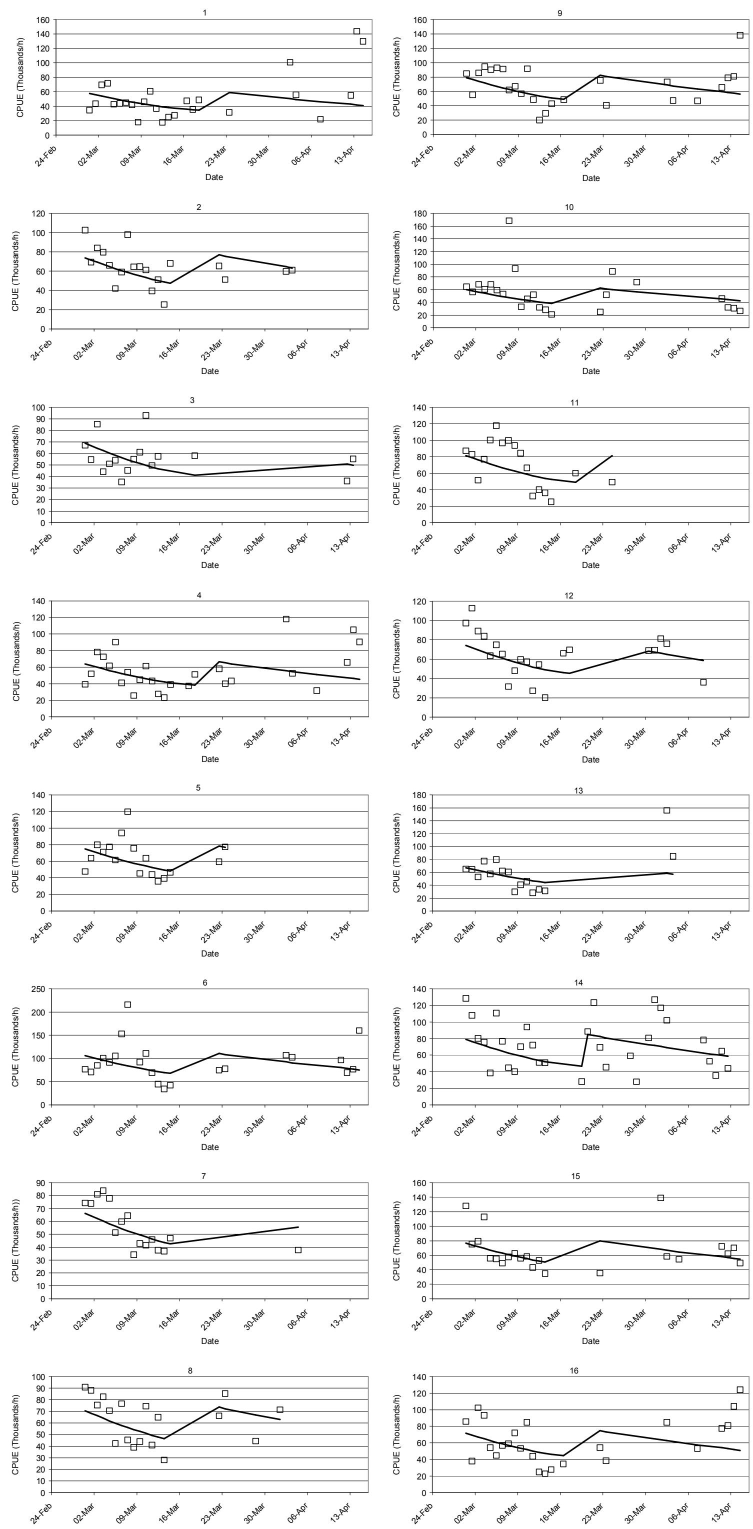


Fig. 29.- Fitting model (line) to CPUE (thousands/h) data (squares) by vessel in the Beauchene area.

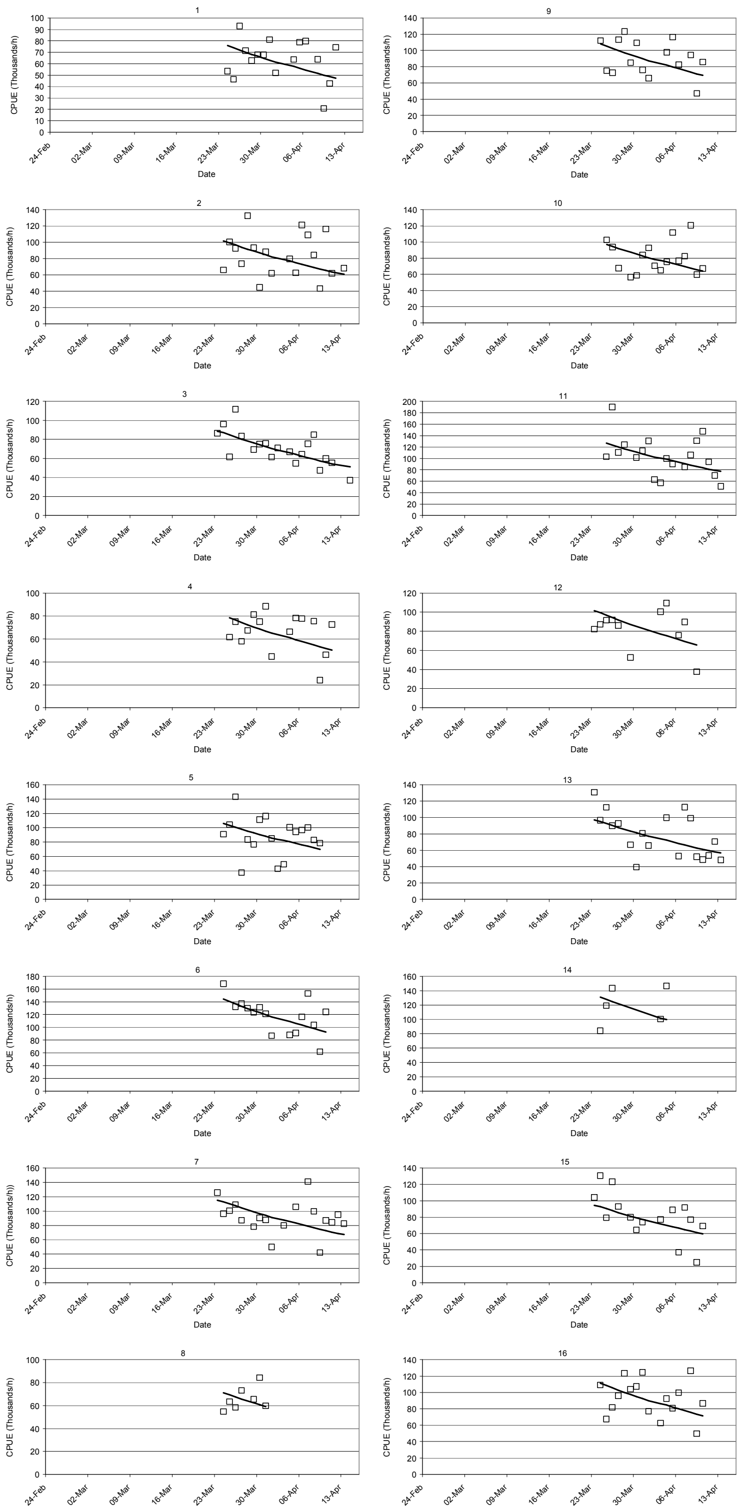


Fig. 30.- Fitting model (line) to CPUE (Thousands/h) data (squares) by vessel in central area.

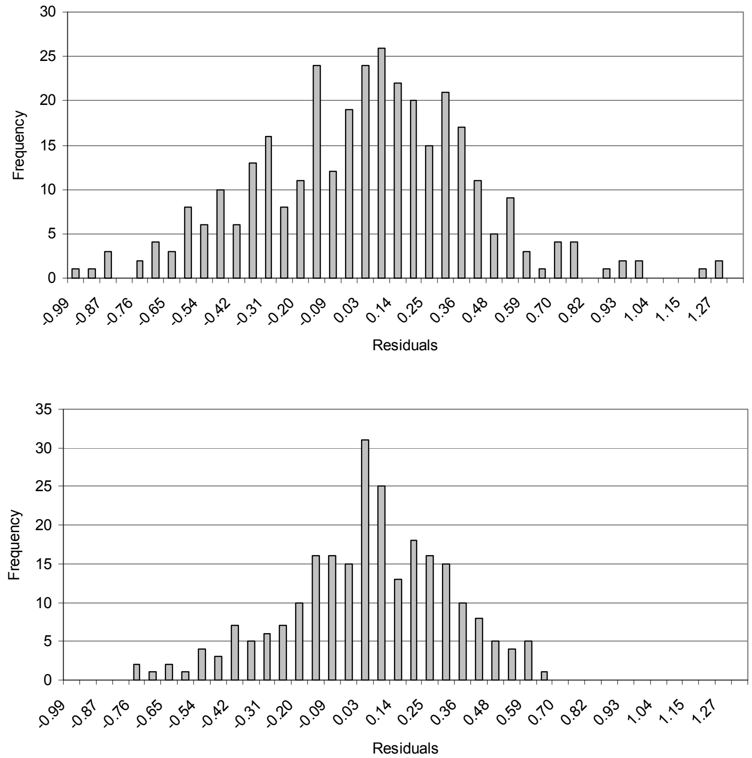


Fig. 31.- Residual distribution in Beauchene (upper plot) and central (down plot) area.

2.6 Catchability Coefficients and Fishing Powers by Vessels

The catchability coefficients by vessel were similar by area (**Fig. 32)**

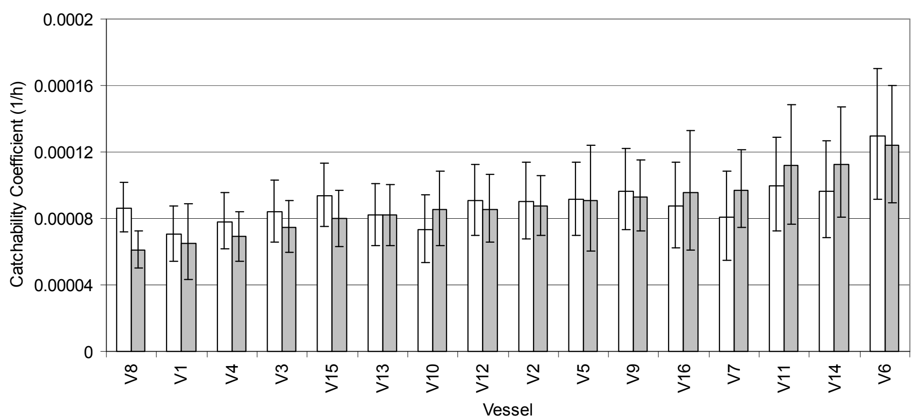


Fig. 32.- Catchability coefficients by vessel and area (white bar = southern area; grey bar = central area). The vertical bars represent the 95% confident interval.

The relative fishing powers (vessel catchability / reference vessel catchability) had the best relationship (R^2=0.46) with the main engine horse power (HP) while the relationship with the gross registered tonnage (GRT) was very low (R^2=0.17) (**Fig. 33)**.

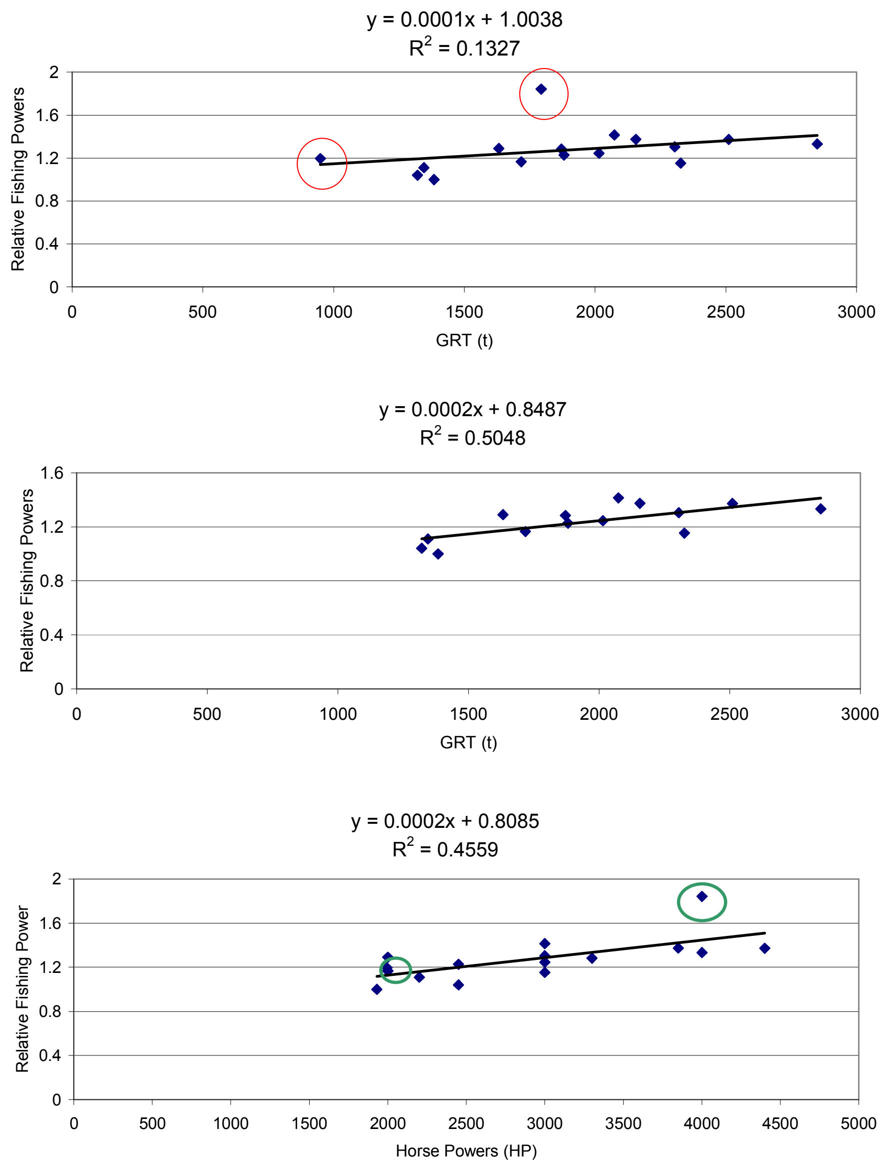


Fig. 33.- Relation between relative fishing power (relative catchability coefficients) and GRT (gross registered tonnage) (upper plot). There were two vessels that have HP/GRT ratios 40% greater than average ratio of the rest of the fleet (red circles in upper plot), if these two vessels are removed the relationship between fishing power and GRT increased notably (middle plot). Relation between relative fishing power and HP (horse power) includes those vessels with higher HP/GRT (green circles in down plot).

These results are consistent with fishing power analysis of the second season of 2007 (Payá 2007c), and suggest that HP is more important than the GRT for the fishing power. There were two vessels that had HP/GRT ratios 40% greater than average HP/GRT ratio of the rest of the fleet. If these two vessels are removed the relationship between fishing power and GRT increased from R^2=0.17 to R^2=0.5.

2.7 Biomass Estimations and Risk

The biomass in the whole *Loligo* box was estimated at 35590 tonnes on the 29th of February and at 84256 tonnes on the 23rd of March (**Fig. 34 and Table 4**). The whole biomass that arrived to fishing grounds during the season was estimated in 96753 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 (**Figures 35 and 36 and Table 4**). The spawning biomass by the 31rst of May was estimated at 43673 tonnes (**Table 5**).

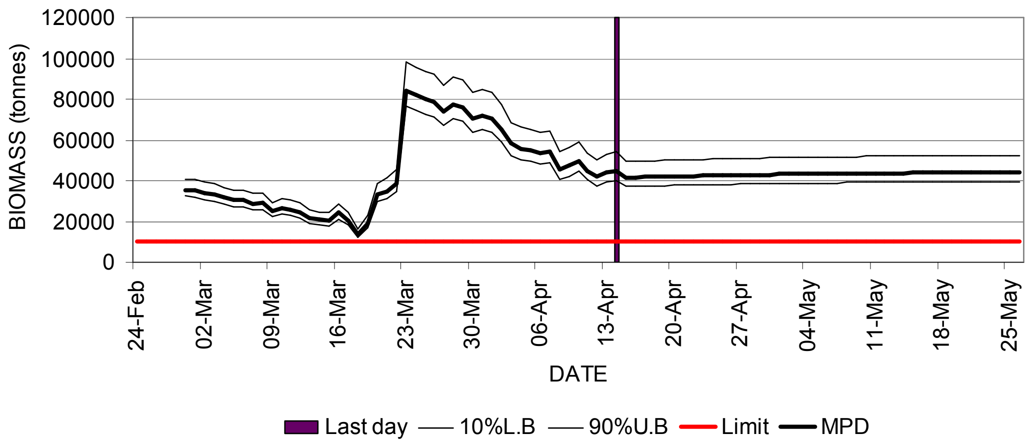


Fig. 34.- Biomass depletion and projection in the whole *Loligo* box (10%L.B = 10% percentile lower boundary; 90%U.B= 90% percentile upper boundary; MPD= Maximum Posterior Density).

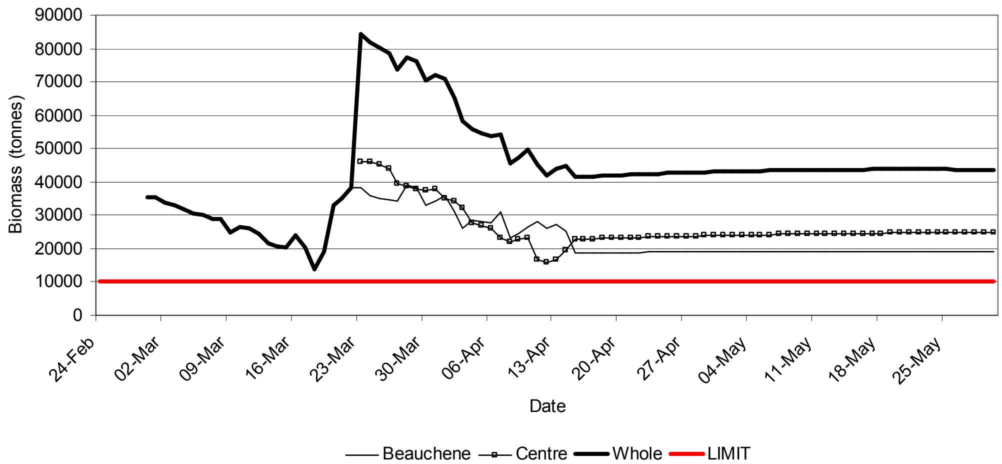


Fig. 35.- Depletion biomass and projected biomass in the whole *Loligo* box and by area. Two squid waves were observed in Beauchene area and one in central area.

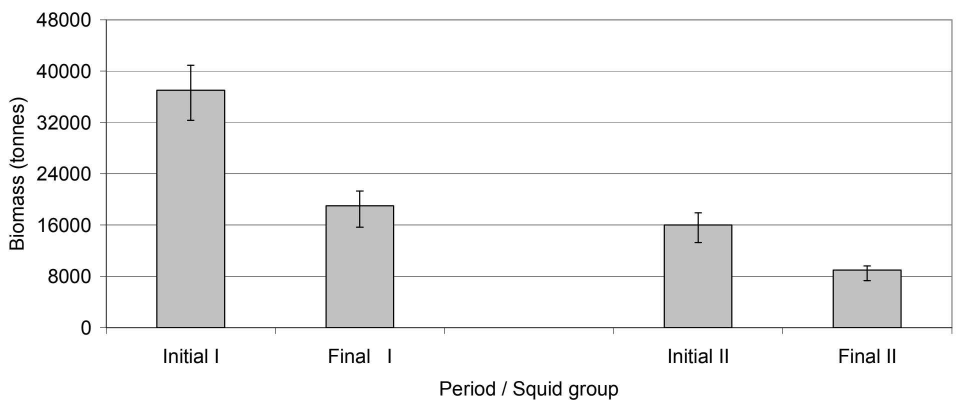


Fig. 36.- Initial and final biomass of the squid groups in Beauchene area estimated by the integrated depletion model (vertical bars represent the 80% confident intervals). These biomasses correspond to the biomasses presented at the start and at the end of each depletion episode.

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). (*) Cumulative biomass is the sum of all squid group biomasses.

	1st Season 2005		1st Season 2006	1st Season 2007					
Parameter	Beauchene Inshore	Beauchene Offshore	Beauchene	Beauchene 1rst	Beauchene 2nd	Beauchene 3rd	Beauchene 4th	Beauchene 5th	North
Starting Date	10/03	22/03	8/3	27/02	12/03	17/03	28/03	3/04	6/03
Final Date	21/03	14/04	14/4	11/03	16/03	27/03	2/04	15/4	16/03
N° of days	12	24	32	12	5	11	6	13	11
Catchability	1.7×10^{-3}	6.1×10^{-4}	9.8×10^{-4}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	3.6×10^{-3}
(1/vessel-day)	(0.6)	(10.7)	(34.2)	(8.9)	(8.9)	(8.9)	(8.9)	(8.9)	(50.4)
Initial numbers	8.5×10^{-1}	2.3	1.47	2.0×10^{-1}	3.2×10^{-2}	2.1×10^{-1}	1.4×10^{-1}	3.3×10^{-1}	4.4×10^{-2}
(billions)	(12.9)	(5.7)	(5.5)	(11.0)	(98.0)	(16.0)	(3.9)	(10.9)	(23.3)
Initial biomass	21816	82247	38212	8250	1767	9500	6250	10000	1750
(tonnes)	(53.0)	(55.6)	(53.1)	(11.0)	(98.0)	(16.0)	(3.9)	(10.9)	(23.3)
Final Numbers NT	5.4×10^{-1}	1.4	5.6×10^{-1}	1.3×10^{-1}	2.7×10^{-2}	1.4×10^{-1}	1.0×10^{-1}	2.1×10^{-1}	1.0×10^{-2}
(billions)	(54.0)	(3.6)	(2.5)	(18.2)	(99.0)	(20.1)	(6.5)	(15.2)	(28.0)
Final Biomass (tonnes)	15594	52834	16282	7000	1225	6000	3250	5500	1250
	(55.7)	(56.2)	(54.0)	(18.0)	(99.0)	(20.2)	(6.5)	(15.2)	(27.0)
Cumulative Biomass at the start of the period (tonnes)*				8250	8750	15250	16250	18250	
				(11.0)	(14.1)	(8.5)	(30.6)	(8.5)	
Cumulative Biomass at the end of the period (tonnes)*				7250	8000	9500	8150	10250	
				(14.6)	(15.2)	(13.4)	(30.6)	(11.7)	

Table 4.- Continuing….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).. (*) This biomass is the sum of all squid group biomasses. (**) It is the average of catchability by vessel.

	1st Season 2008		
Parameter	1rst Beauchene	2nd Beauchene	Centre
Starting Date	29/02	20/03	23/03
Final Date	19/03	14/04	14/04
N° of days	20	26	23
Catchability (1/h) **	9.13×10^{-5}	9.13×10^{-5}	9.8×10^{-5}
	(10.0)	(10.0)	(10.0)
Initial numbers	8.1×10^{-1}	3.9×10^{-1}	1.16
(billions)	(10.0)	(10.0)	(10.0)
Initial biomass (tonnes)	35590	17799	46061
	(10.0)	(10.0)	(10)
Final Numbers NT	1.3×10^{-1}	3.9×10^{-1}	6.6×10^{-1}
(billions)	(10.0)	(10.0)	(10.0)
Final Biomass (tonnes)	17798	8572	19748
	(10.0)	(10.0)	(10.0)
Cumulative Biomass at the	35590	32901	
start of the period	(10.0)	(10.0)	
(tonnes)**			
Cumulative Biomass at the	7250	18674	
end of the period (tonnes)**	(10.0)	(10.0)	

Table 5.- Spawning 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)
First Season 2005	21/03[1] and 14/04[2] to 30/05	70114 (9.9)
First Season 2006	14/4 to 30/5	16495 (9.1)
First Season 2007	16/4 to 31/5	12250 (14.4)
First Season 2008	15/4 to 31/5	43673 (10.0)

[1]Inshore Beauchene and [2]Offshore Beauchene

The spawning biomass projected by the 31rst of May ranged from 30000 to 65000 tonnes and had a mode at 43673 tonnes. As the biomass was far from the limit there was no risk of leaving less than 10000 tonnes of spawning biomass (**Fig. 37**).

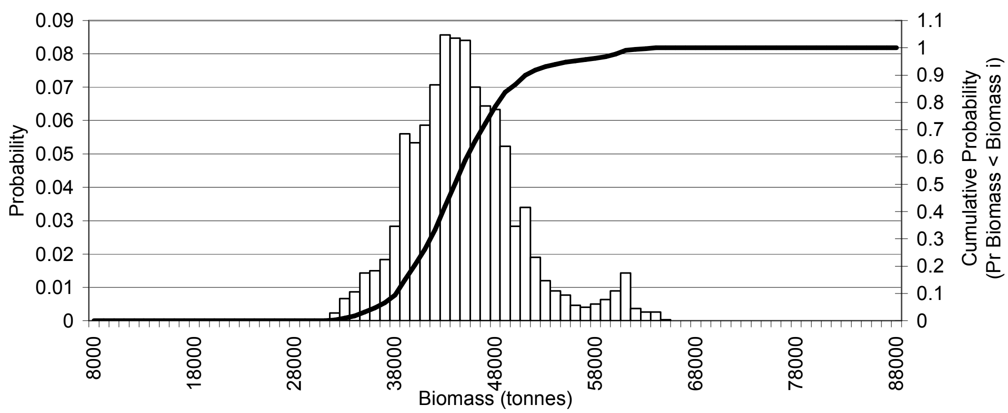


Fig. 37.- Probability distribution and cumulative probability of the spawning biomass projected to the 31rst of May. There were no values lower than lower than 10000 tonnes, so there was no risk of surpassing the limit.

VI. DISCUSSION

It is difficult to collect representative biological samples of catches by area with only one observer in the fleet. When catches are good in two areas the fleet fishes simultaneously in both areas, and when the CPUEs decrease the fleet searches in three areas of the *Loligo* box. Therefore it is recommended to have a least two observers simultaneously to increase the probability of covering at least the two main areas. Another way to increase samples sizes by area is to improve the estimation of size based on commercial size categories statistics. For this purpose it is recommended to ask the captains to report their own sampling of size by commercial categories that they normally do to control their product quality.

For first time the information of *Loligo* surveys was really included in the depletion model estimations. The eight *Loligo* surveys made from 2005 second season provided important prior information of the biomass that is present at the beginning of the fishing season. Of course they can not provide information of the biomass that could later arrive with new squid waves. The prior information that matter is the relationship between the survey biomass and the biomass in the stock estimated by the depletion model; therefore it is possible to use surveys from both first and second seasons, although the timing of migrations and depths are different by season.

The fishing powers by vessel were more related to HP rather than GRT because there were two vessels that have HP/GRT ratio greater than the rest of the fleet. This result was consisted with the fishing powers estimated in the second season of 2007 (Payá 2007). The reason for this seems to be that the fishing power is related with the swept area by trawling hour (Payá 2008), therefore a greater HP/GRT ratio increases the fishing power.

The whole biomass was underestimated because the northern biomass was not included in the depletion model estimations. Only 7% of the whole catch was caught in the northern area and the CPUE had no depletion trend. In previous years the northern data were included in the central-northern area but this time were left apart because it had an increase of CPUE in the last days that was not consistent with the depletion observed in the central area.

It seems that the shortening of fishing seasons in 2003 and the maintaining of the fishing effort level since then have allowed the recovery of the stock abundance during the last 4 years, although this recovery has been variable. If this increasing trend continues it will be necessary to analyze the biological target and limit of the management because an important surplus production could be lost. This analysis should include both the density-dependent factors, control by the fishery management, and the density-independent factors, driven by environmental fluctuations. Furthermore, the *Loligo* market dynamic should be taken into account because an increase in the catches (market supply) could lead to a decrease of market prices and not necessarily to a proportional increase of profits.

VII. CONCLUSIONS

1) The whole catch, 24752 tonnes, was 44% greater than in 2007 first season and 34% greater than the average of the last 5 years first seasons.
2) The 56% of the whole catch was caught in Beauchene area, 37% in central area and 7% in northern area
3) The catch increased because of higher CPUE since fishing effort was similar than previous years.
4) The average mantle length was 12.1 cm, which was similar than 2007 and 2 cm larger than in 2006.
5) Two squid groups arrived sequentially to the Beauchene area and one group to the Central area.
6) *Loligo* was also present in the northern area but it was not included in the biomass estimations because there not enough data from that area.
7) The eight *Loligo* surveys provided information that was used as parameter priors in the Bayesian depletion model.
8) Relative fishing powers were more related with HP than GRT, because there are two vessels that have higher HP/GRT ratio than the rest of the fleet.
9) The whole biomass presented in the central and southern areas, the one that was present at the start of the season plus the ones that arrived during the season, was estimated at 96753 tonnes.
10) Whole biomass was underestimated because northern biomass was not included in estimations.
11) The fishing season ended at the scheduled date with a projected spawning biomass of 43673 tonnes and no risk of leaving less than 10000 tonnes.

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