Falkland Island Fisheries Department

Fishery Report

Loligo gahi, Second Season 2006

Fishery Statistics, Biological Trends, Stock Assessment and Risk Analysis

Author: Ignacio Paya

- October 2006 -

SUMMARY

Total catch by the *Loligo* fleet during the second season (July/15-September/5, 2006) was 23238 tons, an intermediate catch level in relation to the catch of the second seasons for the last 10 years. Total effort was 13150 hours of trawling, a low level similar to the last four years. Most of the catch was taken from the Beauchene (76%) and Central area (17%). Biological trends in proportion of mature individuals and proportion of females were similar to previous second seasons, but squids were 2 cm smaller than in 2005, with an average mantle length of 13 cm. In-season stock assessment was undertaken using FIFD implementation of the stock depletion. In order to warn the industry of any possible early closure of the fishery with two weeks in advance, a new model was implemented to project the catch during this warning period and then project the spawning biomass up to 15th of October. Three depletion events were identified and monitored, the biggest one was located in the Beauchene area and the two others small sequential events in the Central-North area. Because of the quick stock depletion the Beauchene area was closed to fishery on the 29th of August and the rest of Loligo box on the 5th of September. After-season stock assessment and risk analysis was made using Bayesian inference. The risk was defined as the probability of leaving in the sea less than 10000 tons of spawning biomass on the 15th of October. Biomass at the start of the season was estimated at 26000 tons, whereas biomass at the end of the season was estimated at 13500 tons. The management objective of leaving 10000 tons of spawning biomass was met with a precautionary risk of 0.01.

INTRODUCTION

During this second fishery season an e-logbook system was implemented on board of the Loligo fleet. This system provides daily logbook information by haul and allows to make real time analysis of the fleet movement, catch rates and depletion events.

The second season of 2006 started on the 15th of July and lasted until the 5th of September. Our daily fishery statistics and biological data cover all this period, except for a three-day interruption of biological sampling. Most of the fishing activity was carried out in the Beauchene and Central area, with scarce operations in the North (Fig. 1).

During the fishing season, in-season stock assessment was made using the FIFD's implementation of the stock depletion model, as described in previous reports. In order to warn the fishing industry with two weeks in advance of any chance of early fishery closure a new catch projection model was implemented. This model projects the catch based on the numbers of individuals, individual growth, fishing effort and catchability coefficient.

Fishing industry was warned, with two weeks in advance, of the early fishery closure to meet the 10000 tons spawning biomass limit. After three FIFD-industry meetings, where stock assessment and biomass projection results were discussed, the fishery was closed early.

After the season a stock assessment and risk analysis were made using Bayesian inference. Uninformative log-uniform distributions were used as parameter priors. The posterior parameter and marginal distributions were estimated using Metropolis-Hastings Markov Chain Monte Carlo (MCMC). The risk was defined as the probability, which takes values form 0 to 1, of leaving in the sea less than 10000 tons of spawning biomass on the 15th of October.

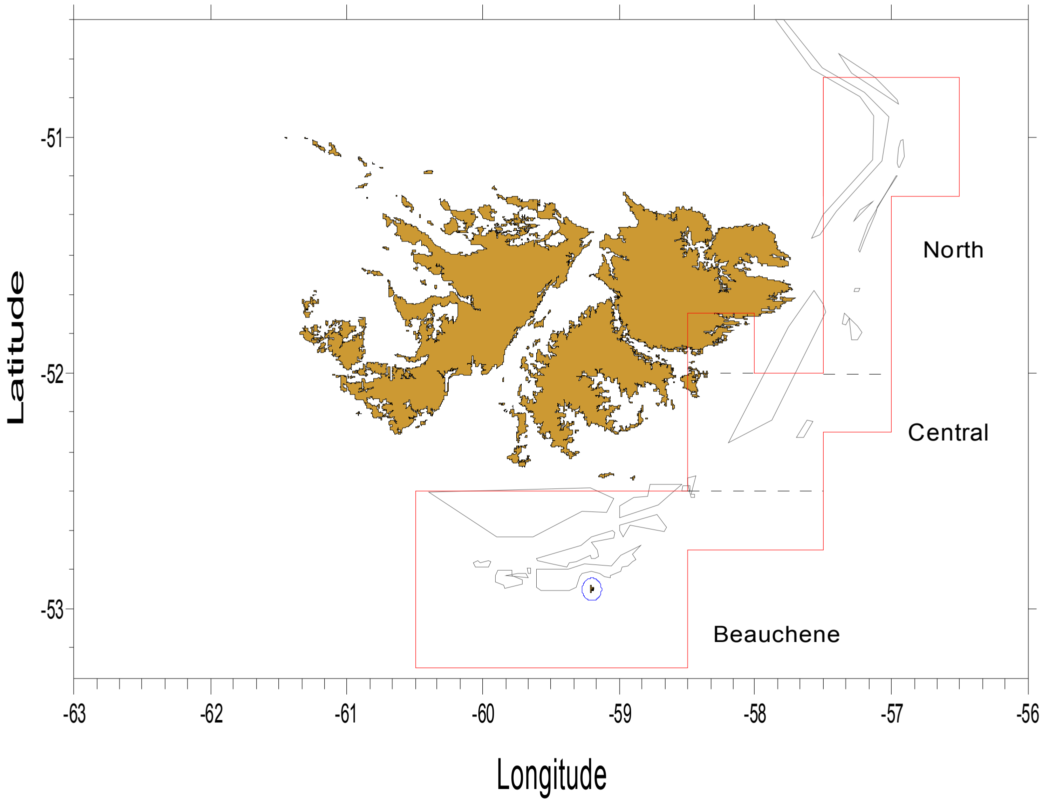


Fig. 1.- Fishing grounds and rocky bottom around the Falkland Islands. In red, the *Loligo* box, and in blue, the three-nm exclusion area around Beauchene Island.

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, lower than 2005 but greater than 2004 (**Fig. 2 and Table 1**). Historically, second season catches have an increasing trend since 1997 while the fishing efforts have a decreasing one. Consequently CPUE have an increasing trend during this period which 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.

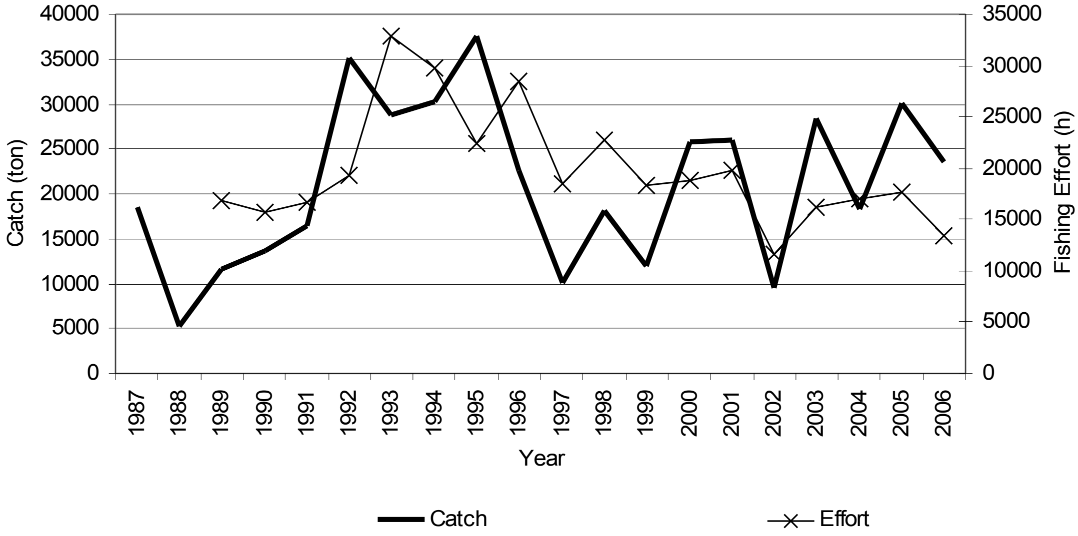


Fig. 2.- Historical catches and fishing effort of the second season.

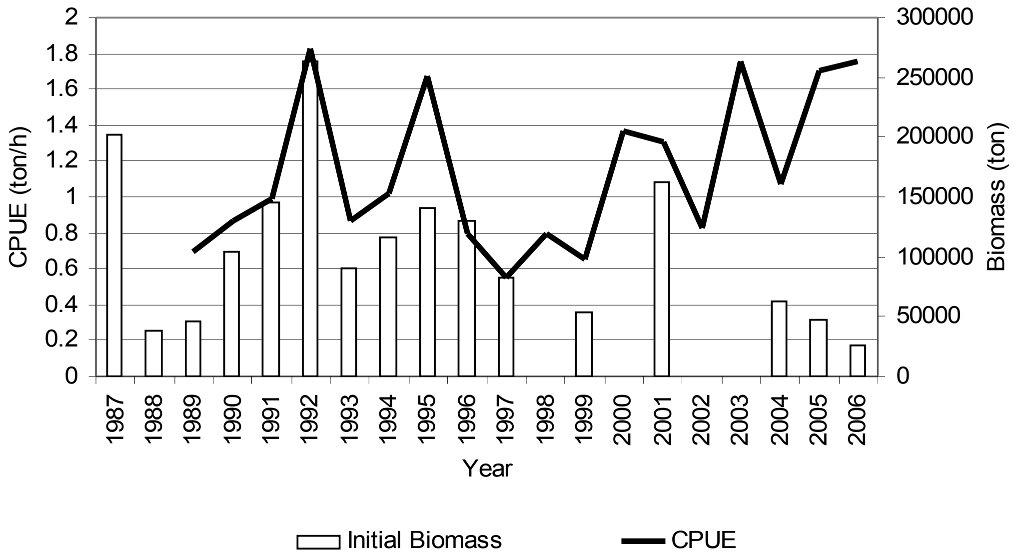


Fig. 3.- Historical CPUE and initial biomass of the second season.

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).

	First Fishing Season			Second Fishing Season			Annual
Year	Catch (ton)	Effort (h)	Initial Biomass (ton)	Catch (ton)	Effort (h)	Initial Biomass (ton)	Catch (ton)
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	98409
1996	38679	16438	31000	22694	28420	130000	61373
1997	15962	16766	40000	10159	18486	82000	26121
1998	33379	16835	60000	18178	22762	Failure	51557
1999	22863	19642	44826	12008	18266	53737	34871
2000	38713	21034	63683	25781	18869	Failure	64494
2001	27624	20955	26000	25935	19841	162234	53559
2002	14198	20824	21000	9513	11570	Failure	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	26000	42294

Catch and Effort per Fishing Ground and Cumulative Catch

Most of squid (76%) were caught in Beauchene area, where the fishing effort was concentrated. The catch in the central area was 17% of the whole catch and in the north area was only 7% (**Table 2**).

Table 2.- Effort and catch statistics of *Loligo* second season 2006 by fishing ground.

Fishing Ground	Catch (tons)	Effort (Vessel-Days)	Effort (hour)	Average CPUE (ton/V-D)	Average CPUE (ton/h)
Beauchene	17738	577	9703	30.742	1.828
Central	3836	155	2479	24.751	1.548
North	1664	86	968	19.347	1.719
Total	23238	818	13150	28.409	1.767

The daily cumulative catch was very close to the best year during the first weeks but later started to separate each other (**Fig. 4**). Like in the previous season, 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.

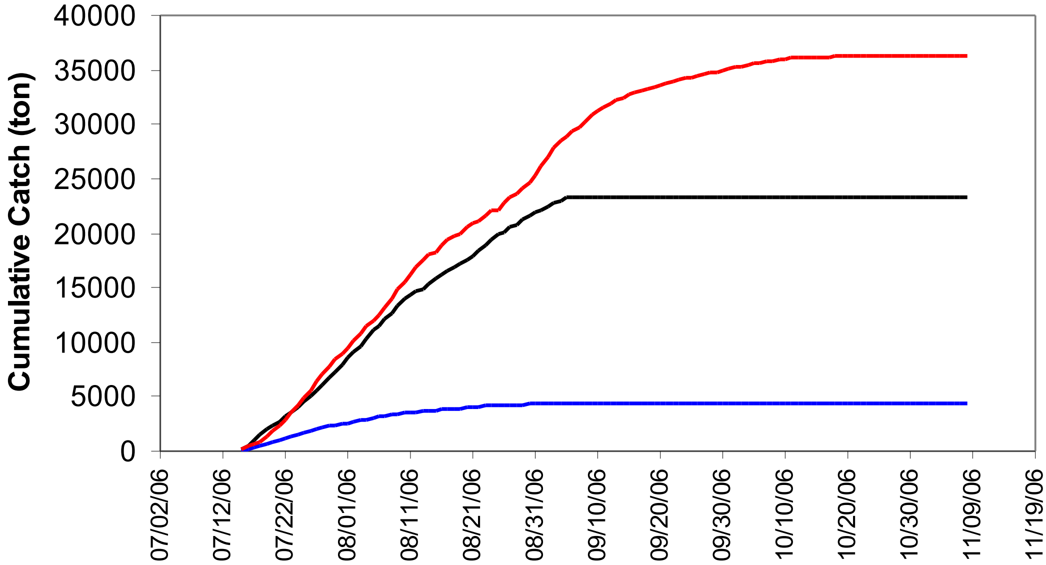


Fig. 4.- Cumulative catch versus date (mo/day/yr) in the second season of 2006 compared with the cumulative catch of the second seasons that yielded the highest and lowest historical catches on exactly the same date range (displaced back 15 days to cover the same period of time).

Fleet Movement Dynamics, Catch and Catch Rate

Before the Beauchene area was closed, the fleet remained in this area most of the time with occasional operations in the other areas (**Fig. 5a**). The small effort applied in central and north area had poor results and most of the catch was made in the Beauchene area (**Fig. 5b**). In the Beauchene area the CPUE was increasing (20-48 ton/vessel-day) during the first three weeks and reached its maximum value on the 4th of August (48 ton/vessel-day) and then it declined until the end of the season (**Fig. 5c**). The CPUE in the Central and the North area were similar to the CPUE in

Beauchene at the beginning and at the end of the fishing season, but they were lower in the middle of the season. In central area the CPUE reached a very high value (58 ton/vessel-day) on the 22nd of August, but then it swiftly declined.

A more detailed analysis of the fleet movement and depletion events is now possible based on the e-logbook information. A graphical interface was developed for Excel spreadsheet using VisualBasic Macros. This interface allows to display movements of the vessels and catch rates by haul and day and also the average CPUE by day (**Fig. 6**). During the first week the fleet operated close to the western-south boundary of Loligo box and even outside it under a FIFD authorization (**Fig. 6**). At this time squid immigration from the west was expected by the captains, but finally it was not so important, then the fleet moved to fish to the east of Beauchene Island and made some exploration of the Central-North area. The highest CPUE were obtained on the 4th of August to the east of Beauchene Island, where the fleet was concentrated during most of the season and where the main depletion event was observed (**Fig. 7**). After the Beauchene depletion the fleet had the highest CPUE on the 23rd of August in Central Area (**Fig. 8**). The Beauchene area was closed on the 29th of August when the CPUE were much lower than in the Central area (**Fig. 9**). The rest of Loligo box was finally closed on the 5Th of September when the fleet was fishing dispersed along the Central area and in the southern zone of the North area (**Fig. 10**).

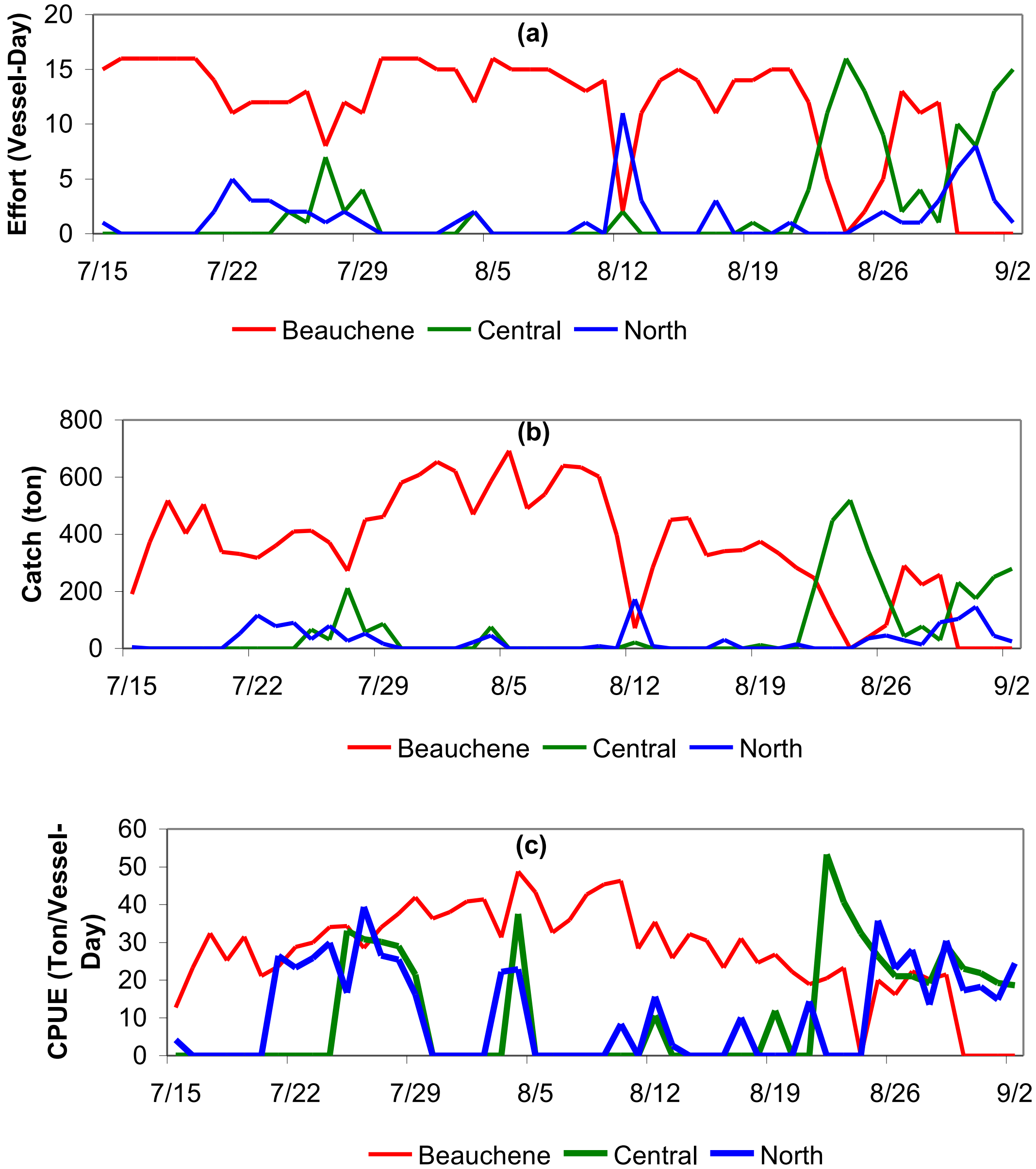


Fig. 5.- Daily evolution of effort (a), catch (b), and average catch per unit of effort (c) in the *Loligo* fishery during the second season of 2006.

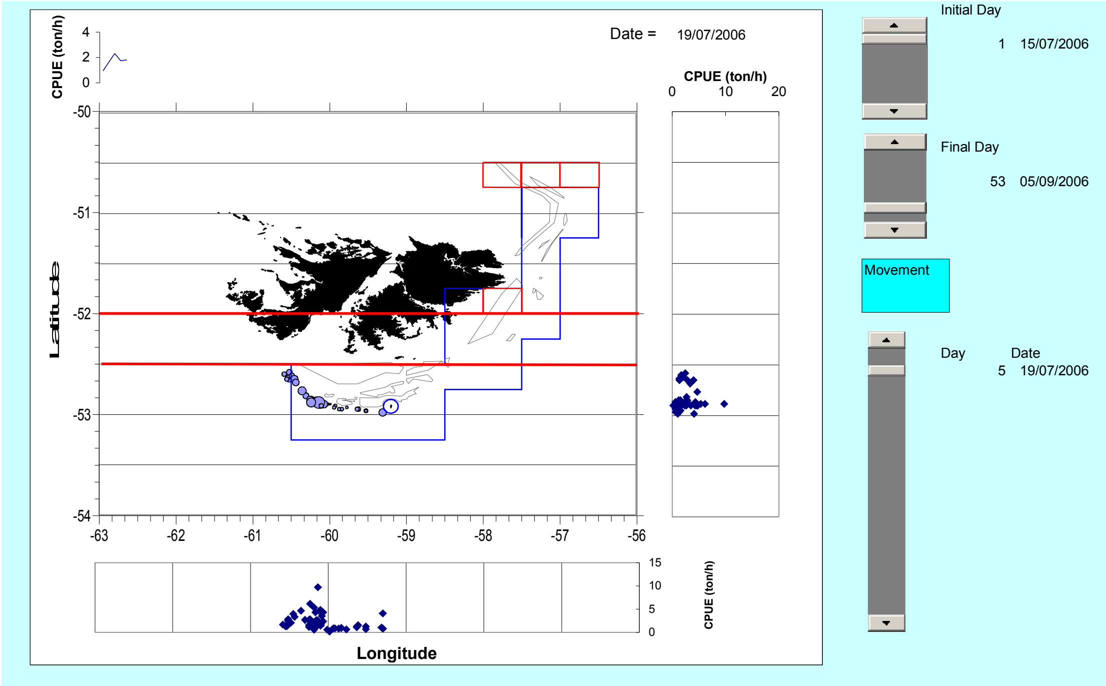


Fig. 6.- Graphical interface to display fleet movements and catch rates. The central plot shows the Loligo box (blue); the squares opened during the Loligo survey (red squares), the boundaries of the fishing areas (red lines); the rocky bottoms (white polygons); the three-nm exclusion area around Beauchene Island (blue); and the CPUE (ton/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 fleet from the beginning of the season until the date that is displayed in the right upper corner of the frame. Before run the macro “Movement” (light blue square button) the initial and final day must be entering in the two upper scroll controls. The third scroll control allows selecting which day is to be displayed.

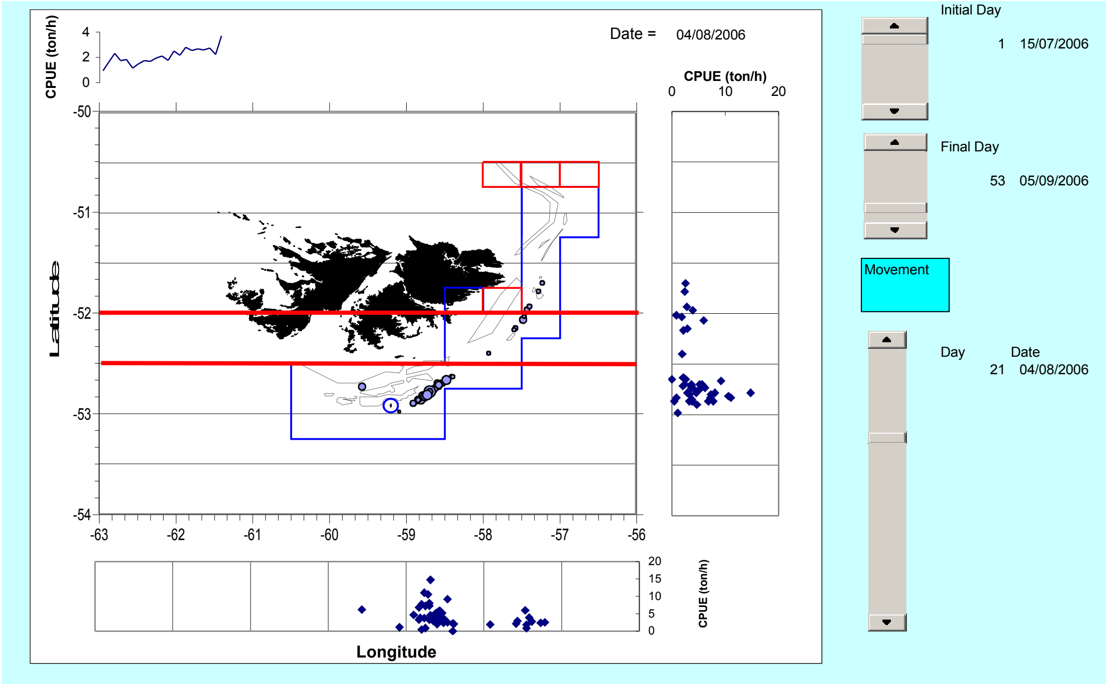


Fig. 7.- The highest CPUE was obtained in the east of Beauchene area on 4th of August. On this day part of the fleet was fishing in the Central-North area and a vessel was exploring shallow water in the west.

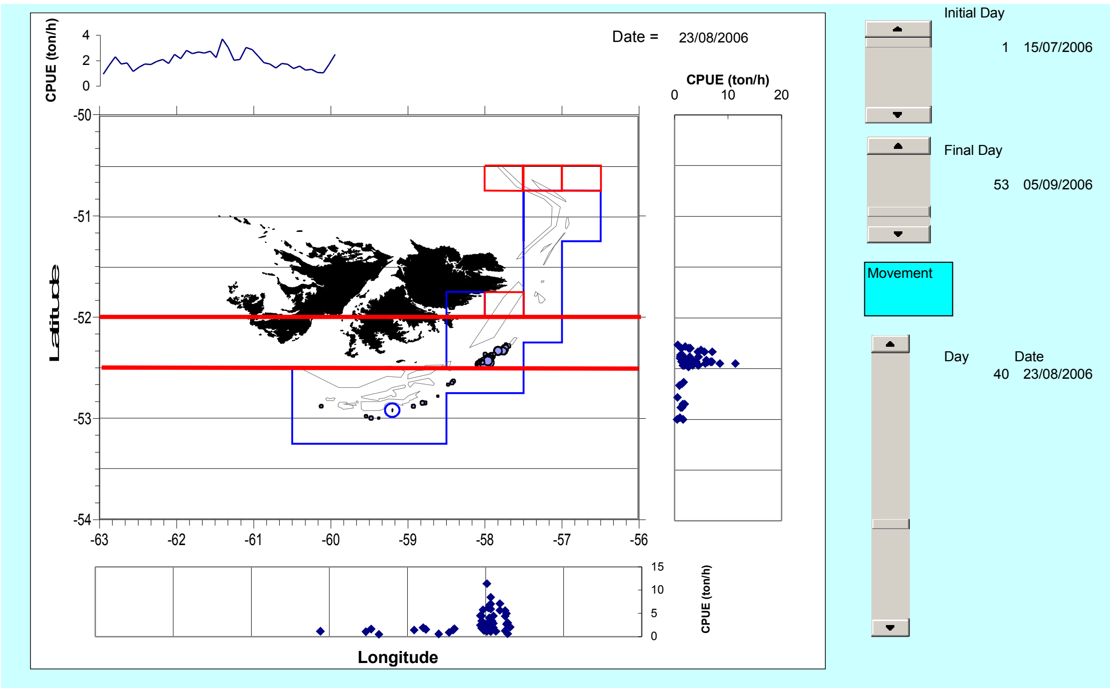


Fig. 8.- The highest CPUE was obtained in Central area on 23rd of August after the depletion of east of Beauchene Island.

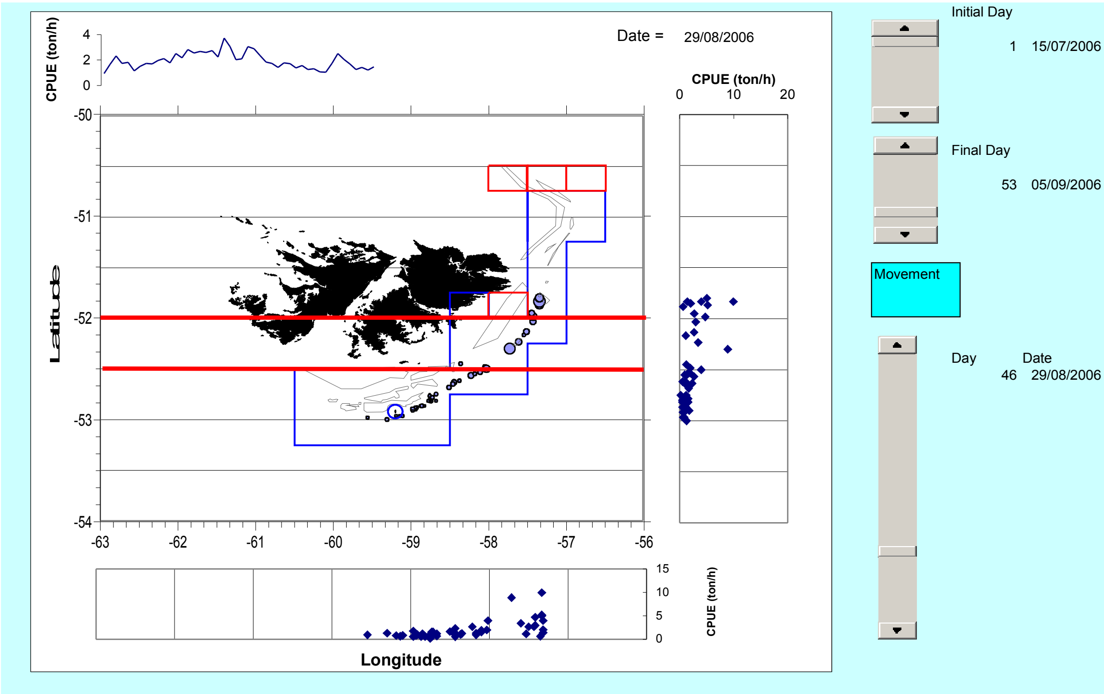


Fig. 9.- Last fishing day in the Beauchene area on the 29th of August.

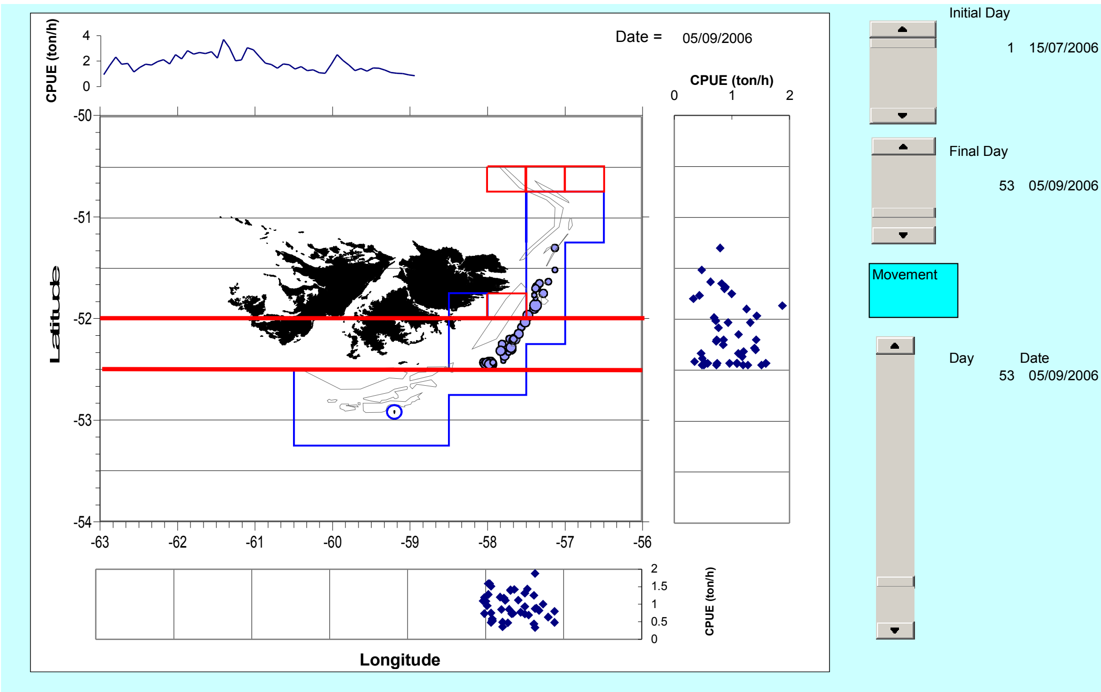


Fig. 10.- Last season day on the 5th of September.

PART 2 – BIOLOGICAL TRENDS

Biological trends of the stock were based on a sample of animals taken by one scientific observer onboard of commercial vessels. The observer takes a sample of approximately 400 animals per day. Unfortunately, during this season there were 3 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 five years (**Fig. 11**). Most of the females were immature or maturing during first weeks and then this proportion slowly decreased. Conversely, about half of the males showed immature or maturing stages, with an increasing tendency of mature stages through the season. The sex ratio showed high variability but remained around the 0.4 value, as in most previous seasons and according with sexual segregation by depth (**Fig. 12**) (Arkhipkin & Middleton 2002). The average dorsal mantle length, in both sexes, slowly increased with the days and was about 2 cm smaller than in 2005 (**Fig. 13**). Males were on average 0,77 cm greater than females. The dorsal mantle length distributions were uni-modal (**Fig. 14**). There was a three-day interruption of the biological sampling that is shown on **Fig 14.**

A new estimation of mantle size is now available based on the e-logbook records of production by ***C***ommercial ***S***ize ***C***ategory (***CSC***) by haul and vessel. The mantle size was calculated by the following steps: 1) to compute ***CSC***-mantle size keys for each vessel, at this point a uniform distribution restricted by the range of each ***CSC*** was used, a further development is required to compute the actual size distribution inside each ***CSC***; 2) to compute the mean squid weight for each ***CSC*** from the key; 3) to compute production by ***CSC***, vessel and day; 4) to compute the number of squid produced by ***CSC,*** vessel and day, this is made dividing the ***CSC*** production by the corresponding mean squid weight; 5) to compute the number of squid produced by mantle size by vessel and day, that is multiplying the number of squid produced by ***CSC*** by the respective key; and 5) to sum all over the vessels the number of squid produced by mantle size. This procedure generates a mantle size distribution completely independent of the scientific observer, from which the mean and variance are directly calculated.

The average mantle length from ***CSC*** was on average 1.048 cm greater than the size from the scientific observer but both show the same tendency (**Fig. 15**). The deference arises from the way that measure is actually done, scientific observers approximates to the lower 0.5 cm and fisherman to the upper cm. The average mantle length from scientific observers was more variable than the ***CSC,*** because the sample size is much lower than the ***CSC*** data**.** Although there is a good relation between average mantle lengths this is not the case for mantle length distributions (**Fig. 16**).

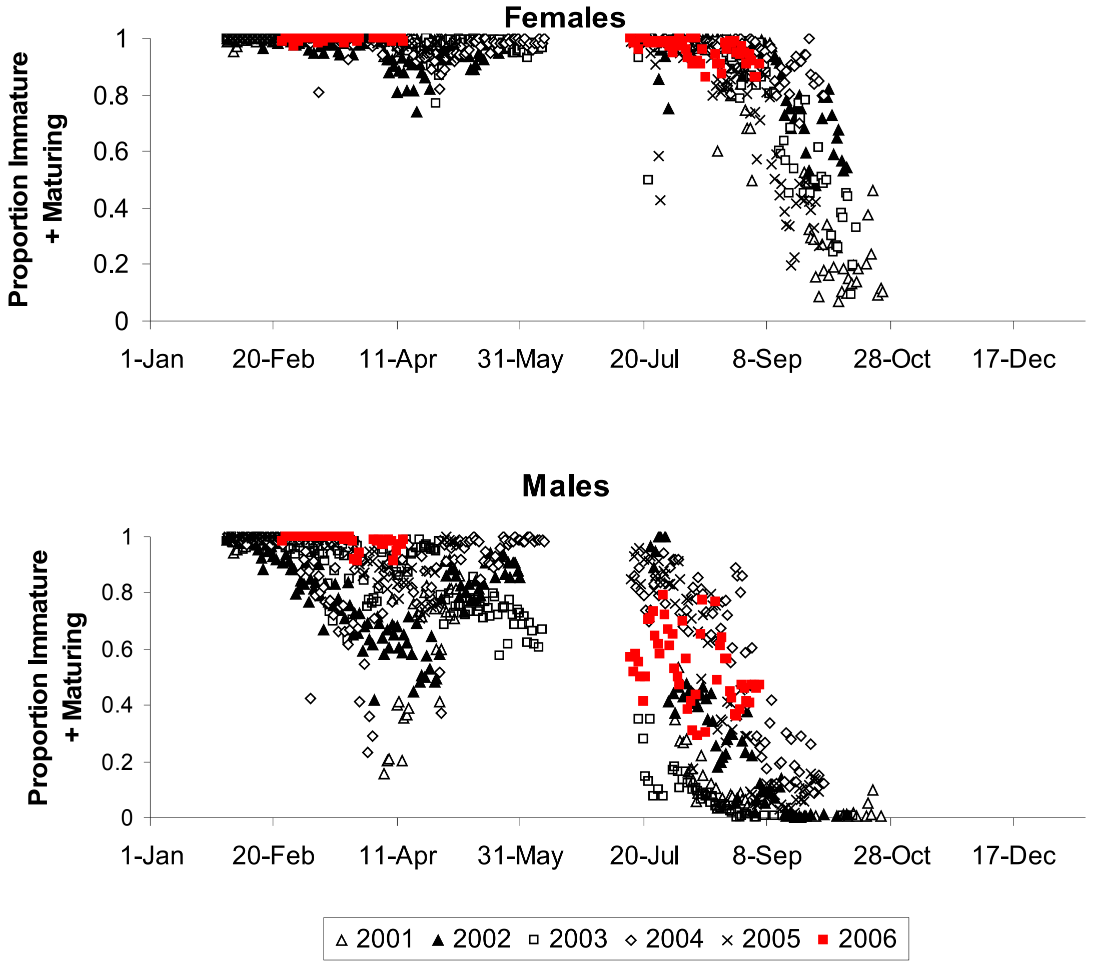


Fig. 11.- Current year trends in the proportion of sexually immature squids in the catch, compared with five previous years.

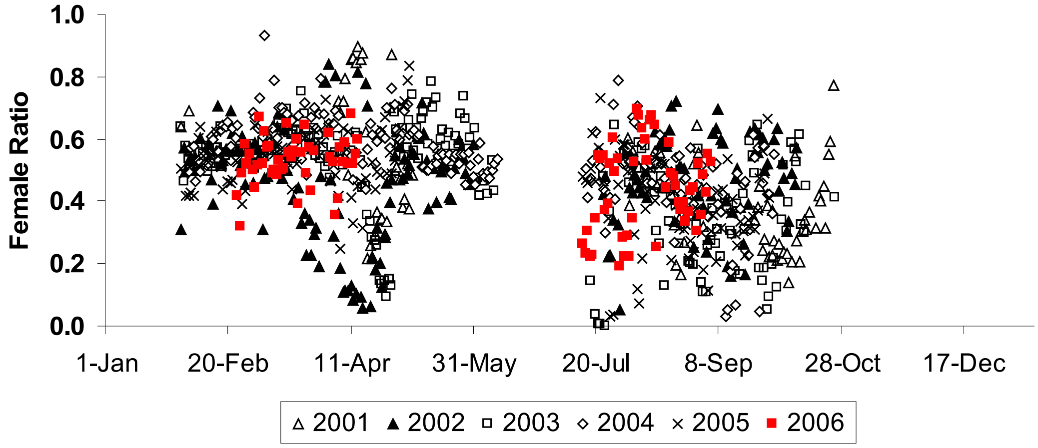


Fig. 12.- Current year trends in the daily evolution of the proportion of female squids in the catch, compared with five previous years.

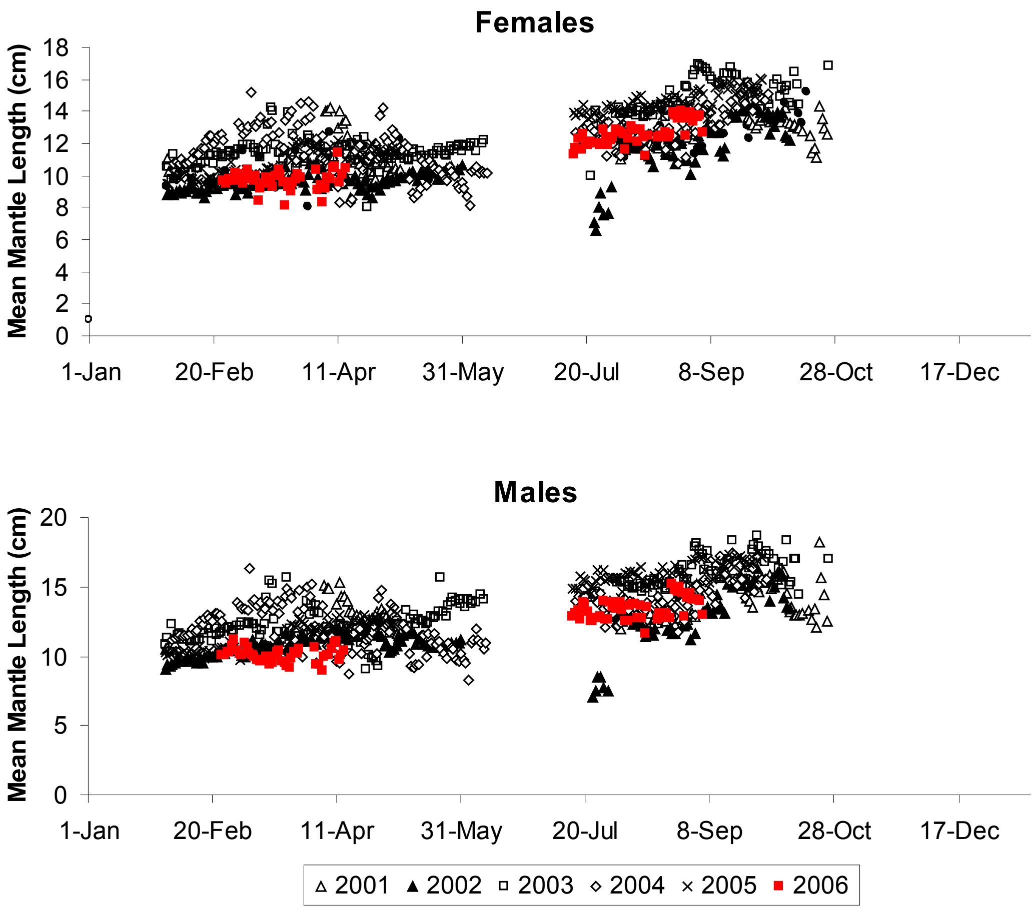


Fig. 13.- Current year trends in the mantle size by sexes, compared with five previous years.

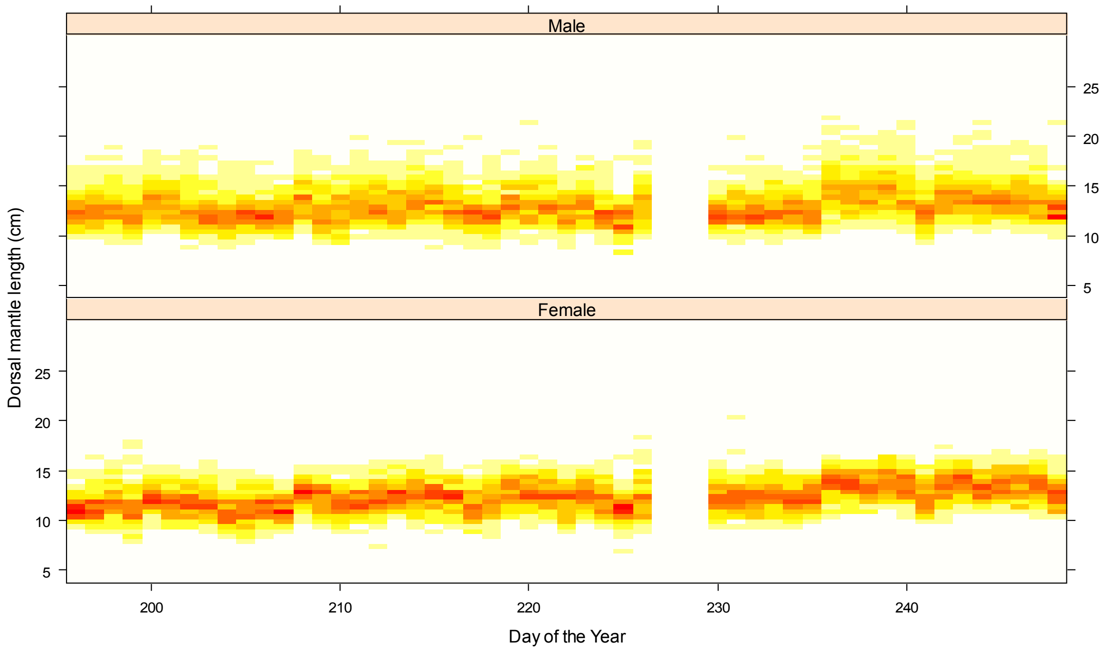


Fig. 14.- Time series of proportions (increases from yellow to red) of dorsal mantle length of squid in the catch during the second season, 2006.

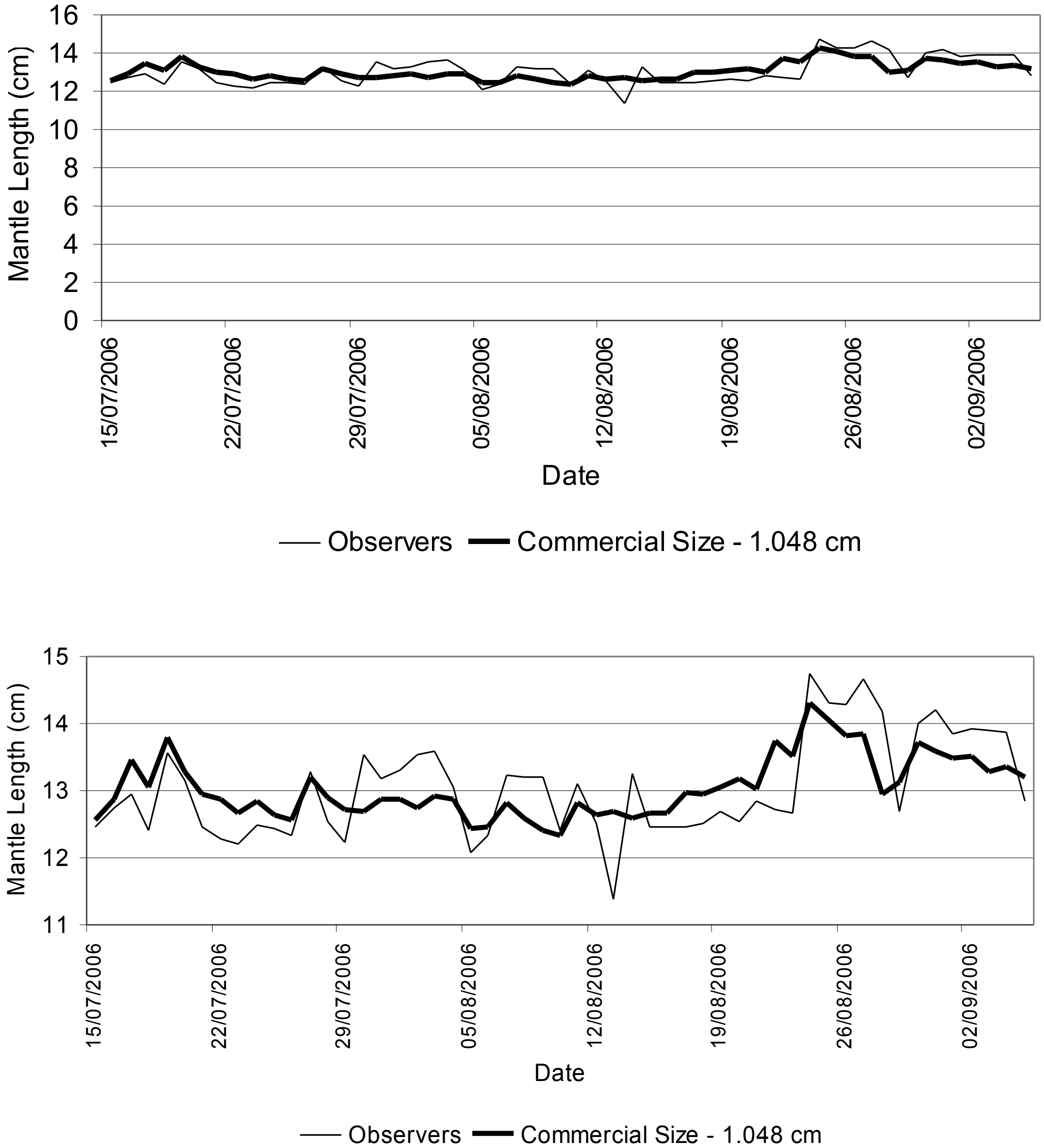


Fig. 15.- Average mantle length estimated from the scientific observers onboard and from the commercial size categories. Both plots show the same information, the down plot is a zoom in of the upper plot.

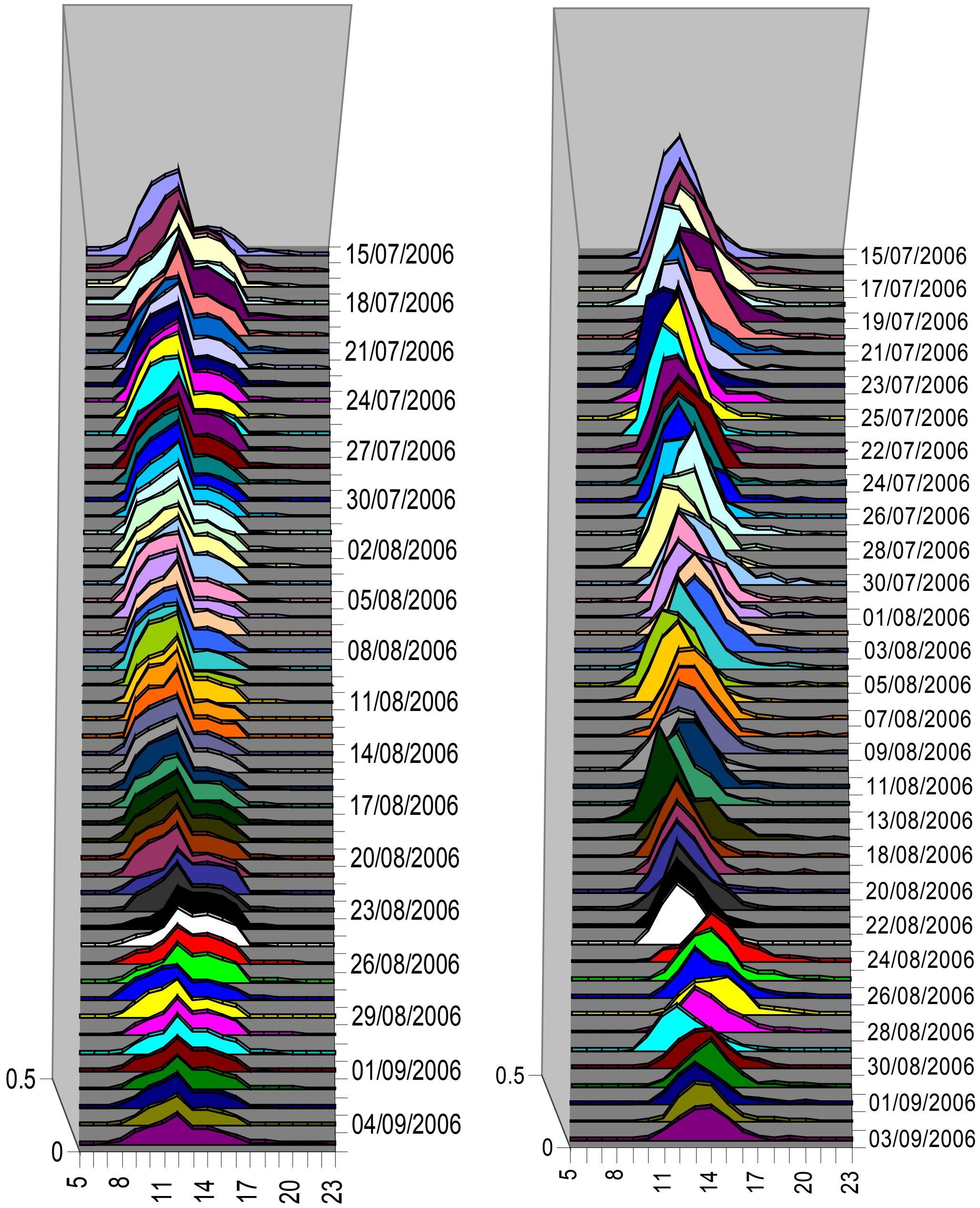


Fig. 16.- Mantle length distribution by day estimated from commercial size categories (left plot) and from scientific observers onboard (right plot).

PART 3 – STOCK ASSESSMENT

In-season assessment and catch projection

In-season stock assessment was used to apply the decision rule of close the fishery if the spawning biomass is below 10000 tons biomass on the 15th of October, under the restriction to warn the industry with two weeks in advance of the expected closing date. To apply the decision rule a catch projection model was developed to predict the catch that would be taken during the two weeks after the warning. The catch projection is made using the same formulation of the depletion model but adding the fishing effort as number of vessel in the following equation:

$$Y = N * W * V * q$$

where ***Y*** is the catch: ***N*** is the number of individuals; ***W*** is the mean weight: ***V*** is the number of vessel and ***q*** is the catchability coefficient. After the two-week catch projection the biomass projection model was used to estimate the spawning biomass on the 15th of October. In catch and biomass projections the mean weight was calculated projecting the growing of the squid sampled in the last week based on the growth model of Arkhipkin & Roa-Ureta (2005).

Three depletion events were spatially identified using the new graphical interface. The first and main depletion event occurred in the Beauchene Area. The second depletion was located along the Central area and southern part of North area, without any clear boundary between these areas; therefore it was named Central-North area. The third depletion event occurred also in the Central-North area.

The first warning of a possible early closure was sent to industry based on analysis with data up to the 22nd of August. The current biomass was closed to 10000 tons and projected spawning biomass was below the 10000 tons limit (**Fig. 17**). Most of catch had been taken in the Beauchene area and therefore the biomass estimations were mainly for this area. In the first FIFD-Industry meeting the analysis were discussed and it was agreed to wait another week to see more fishing activity in the Central and North area. After a week, in the second FIFD-Industry meeting the analysis with data up to 27th of August showed the same situation, most of catch and biomass estimations came from Beauchene area, and biomass limit would be surpassed (**Fig. 18**). The uncertainty of the Beauchene biomass estimations were computed by bootstrapping technique, the depletion model was fitted 1000 times with data generated adding to the model estimations random samples of the residuals (**Table 3 and Fig. 19**).

Finally, it was agreed to close Beauchene area at the night on the 29th of August and the rest of Loligo box on the 5th of September unless a new group of squid was found during the next days. In the last meeting with the industry, the analysis with data up to 31rst of August showed that there were no other squid group entering the area and the current biomass was 10993 tons and projected spawning biomass was close to 10000 tons limit (**Fig. 20 and 21**).

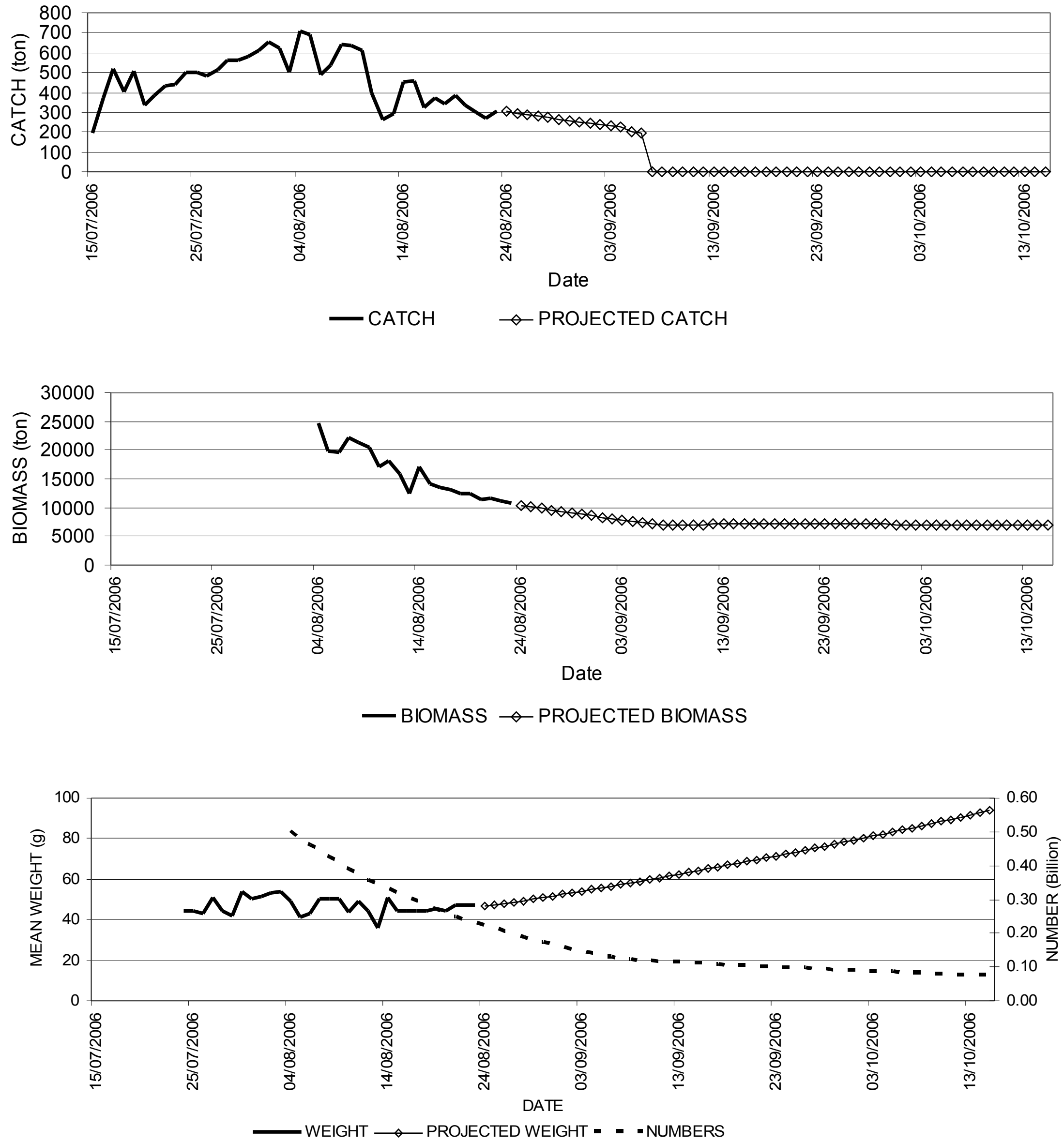


Fig. 17.- Actual and projected catch (upper plot), biomass (middle plot), mean weight and number (down plot) with data up to 22nd of August. Mean weight

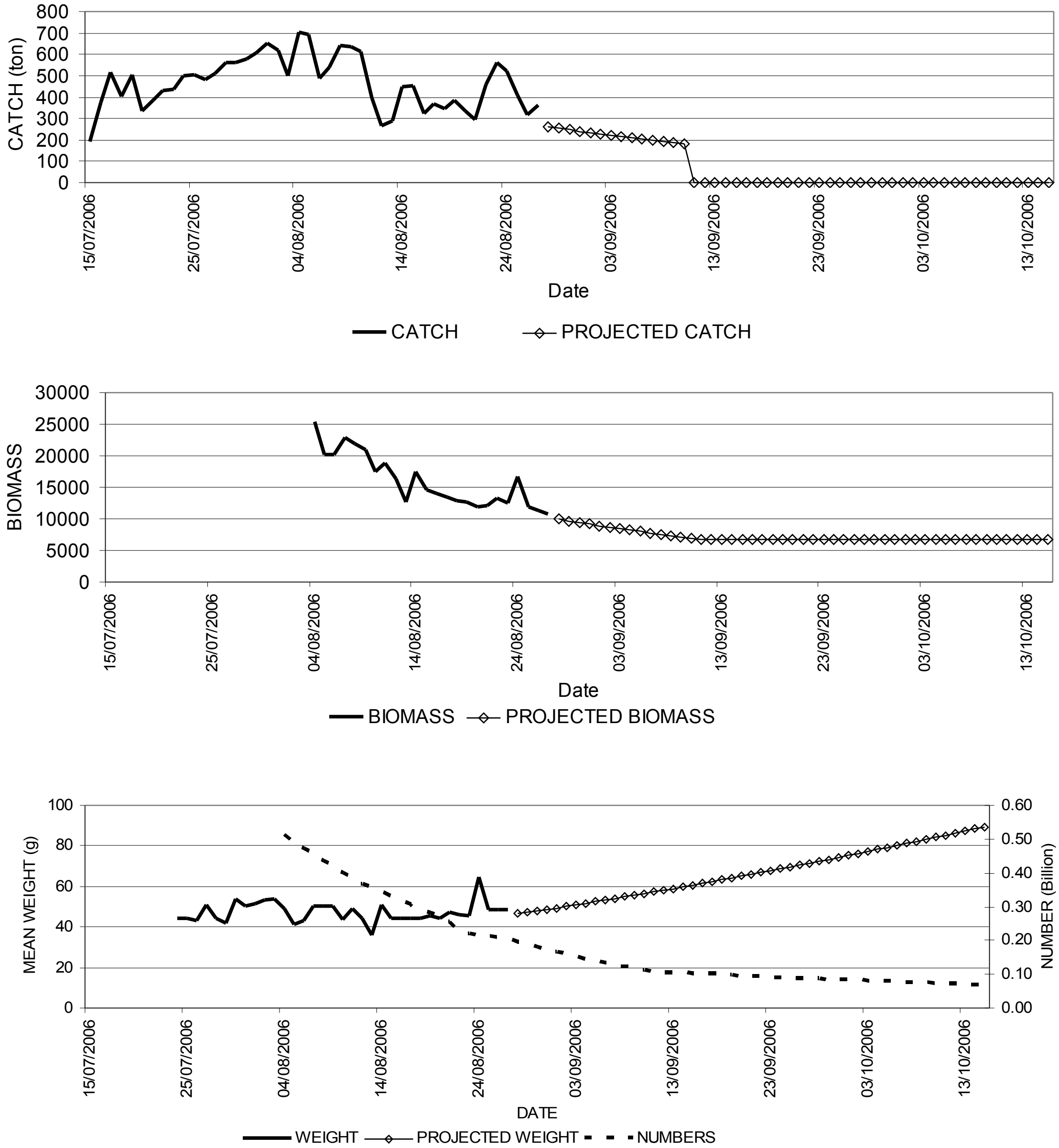


Fig. 18.- Actual and projected catch (upper plot), biomass (middle plot), mean weight and numbers in the stock (down plot) with data up to 27th of August. The biomass is sum of Beauchene and Central-North biomasses.

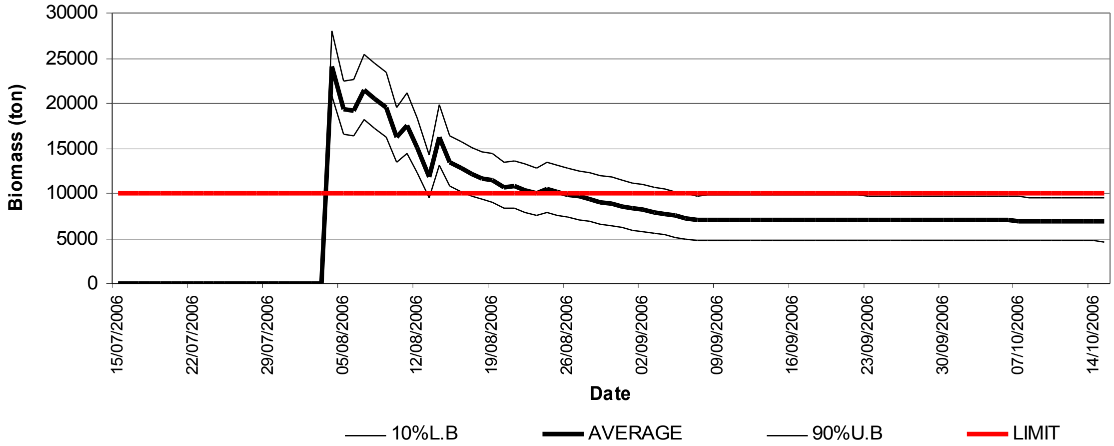
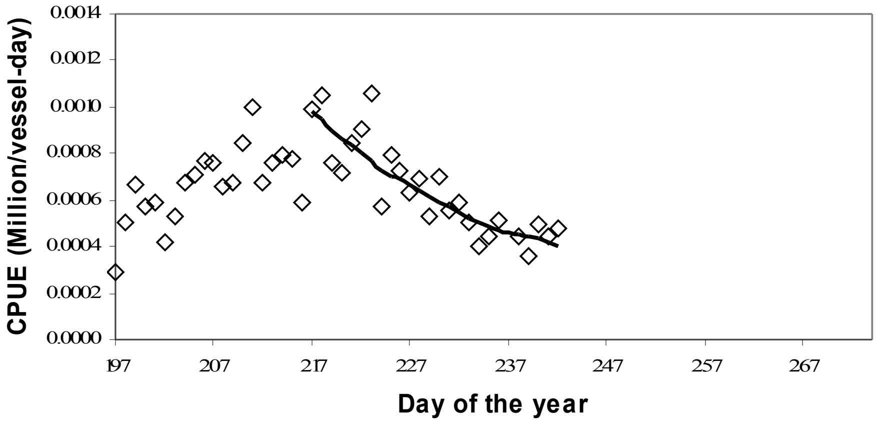
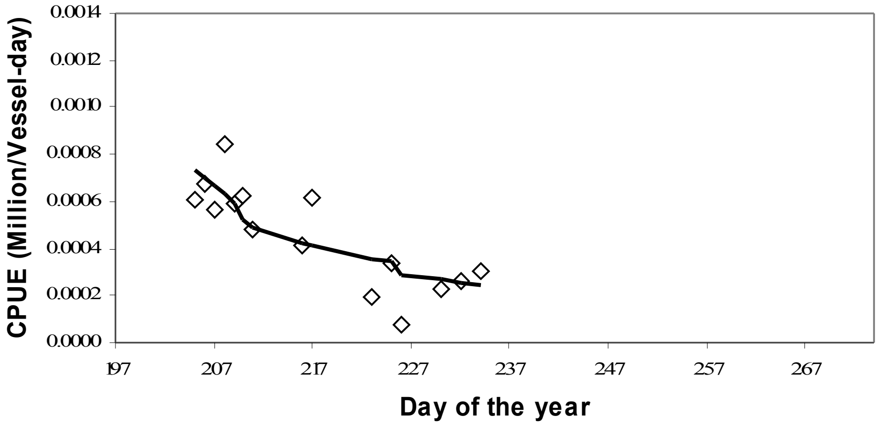


Fig. 19.- Actual and projected biomass estimations for Beauchene area with data up to 27th of August. The uncertainty was calculated by bootstrapping technique (10%LB= 10% percentile; 90%UB= 90% percentile; LIMIT= 10000 tons spawning biomass).

Table 3.- Beauchene biomass estimations with data up to 27th of August. The uncertainty was calculated by bootstrapping (10%LB= 10% percentile; 90%UB= 90% percentile; Std: Standard deviation; CV= coefficient of variation).

	Biomass		
	Initial 04/08/2006	Current 27/08/2006	Spawning 15/10/2006
10%L.B	21561	7600	4915
AVERAGE	**24743**	**9806**	**6960**
90%U.B	28302	12239	9306
Std	2685	1906	1808
C.V.	11	19	26





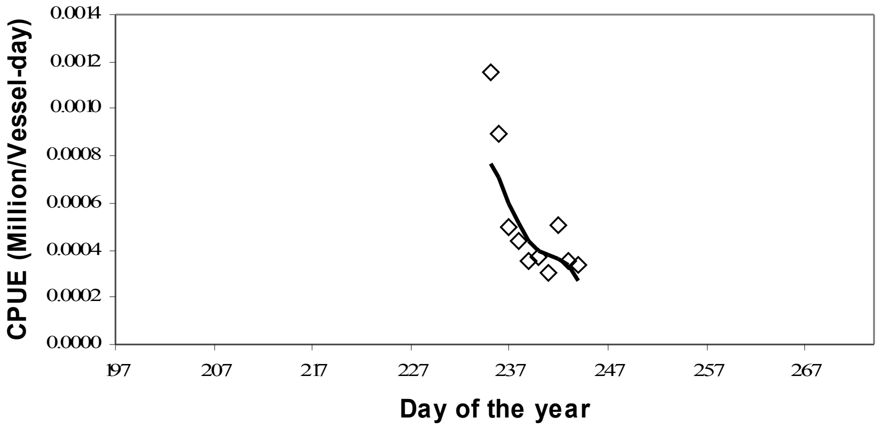


Fig. 20.- Observed and predicted (lines) CPUE for the Beauchene area (upper plot), first depletion in Central-North area (middle plot) and second depletion in Central-North area (down plot), with data up to 31rst of August.

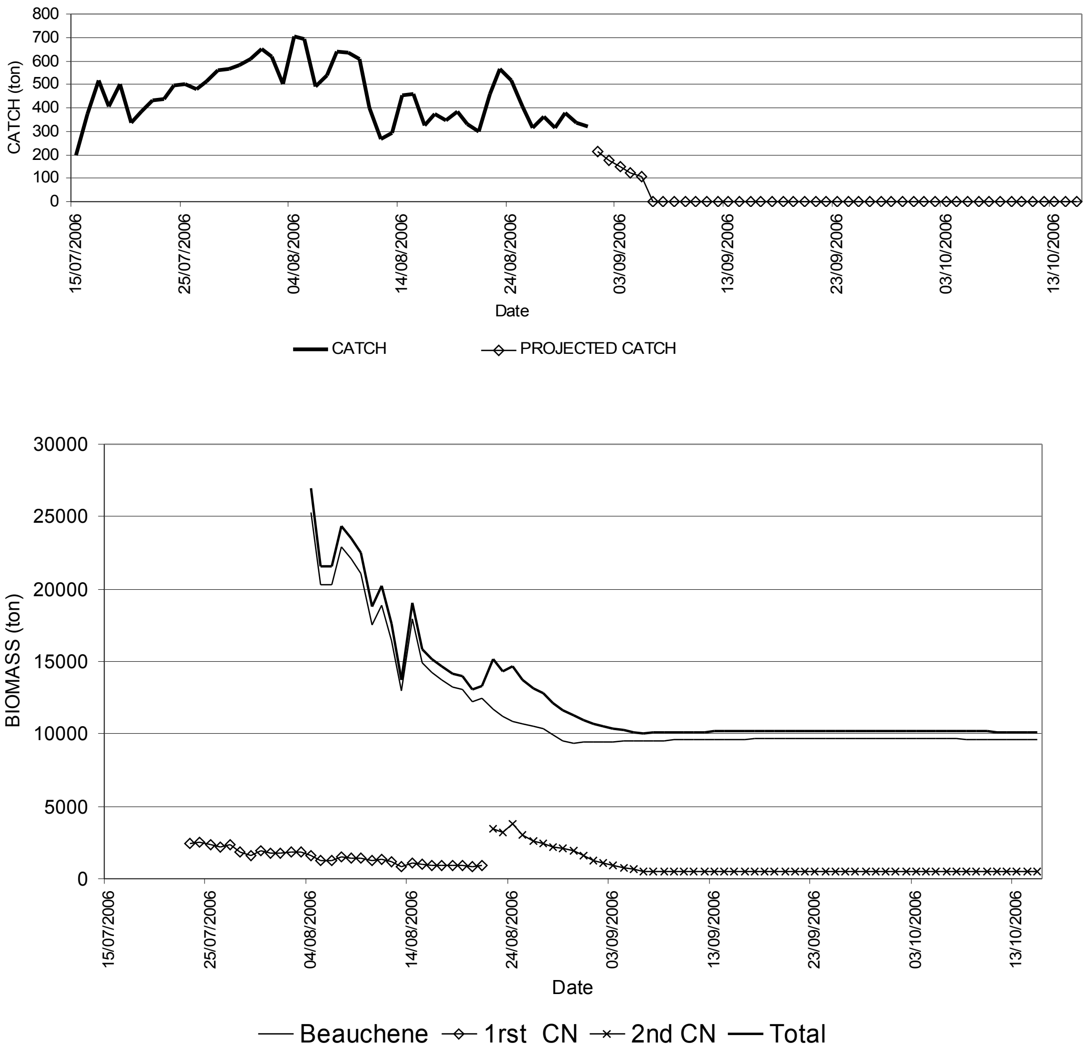


Fig. 21.- Actual and projected catch (upper plot) and biomass (down plot) with data up to 31rst of August. The biomass plot shows the biomass for each depletion events (CN= Central-North Area) and the total biomass.

After-season stock assessment

Having all collected and sampled data and more time to uncertainty analysis, a risk Bayesian analysis was implemented. The bootstrapping technique was used during the in-season stock assessment because it is easier and faster to compute than Bayesian analysis, but Bayesian analysis is more appropriate for a long history fishery as Loligo fishery, which has a lot of information that could be useful as prior information for the inference and uncertainty analysis.

The aim of the risk analysis is to estimate the probability of an adverse event in a specific time. For Loligo management the risk is the probability (takes values from 0 to 1) of leaving at the sea less than 10000 tons of spawning biomass on the 15th of October.

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

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

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 uninformative log-uniform distributions, $-\ln(\theta_i)$.

The maximum posterior density was found by Solver maximization algorithm. To compute the posterior distribution a Metropolis-Hastings Markov Chain Monte Carlo algorithm (MCMC) was programmed in VisualBasic. Five chains of 10000 iterations were generated using a Cauchy distribution as a jumping rule (Johnson ***et al.*** 1994 and Gelman ***et al.*** 2004). The first 5000 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. The five chains were pulled together in a 25000-iteration chain that was used to compute the posterior densities. To estimate the biomass distribution (marginal density) 3000 parameters where taken from the posterior distributions. This sampling was made thinning the 25000-iteration chain, that is taken parameters every 8 iterations.

The Bayesian analysis was made in each of the three depletion events and the biomass results were summed. As an example the Cauchy distribution, the five chains and R indices for the parameters in the Beauchene area are presented in the figures 22 to 24.

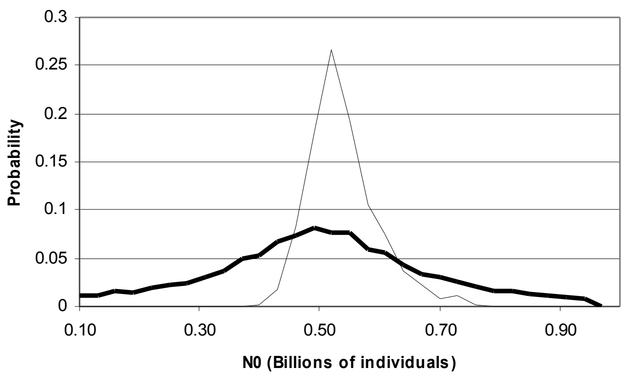


Fig. 22.- Posterior distribution (thin line) of initial number parameter (N0) and Cauchy distribution (bold line) uses in the global jumping rule for Beauchene area.

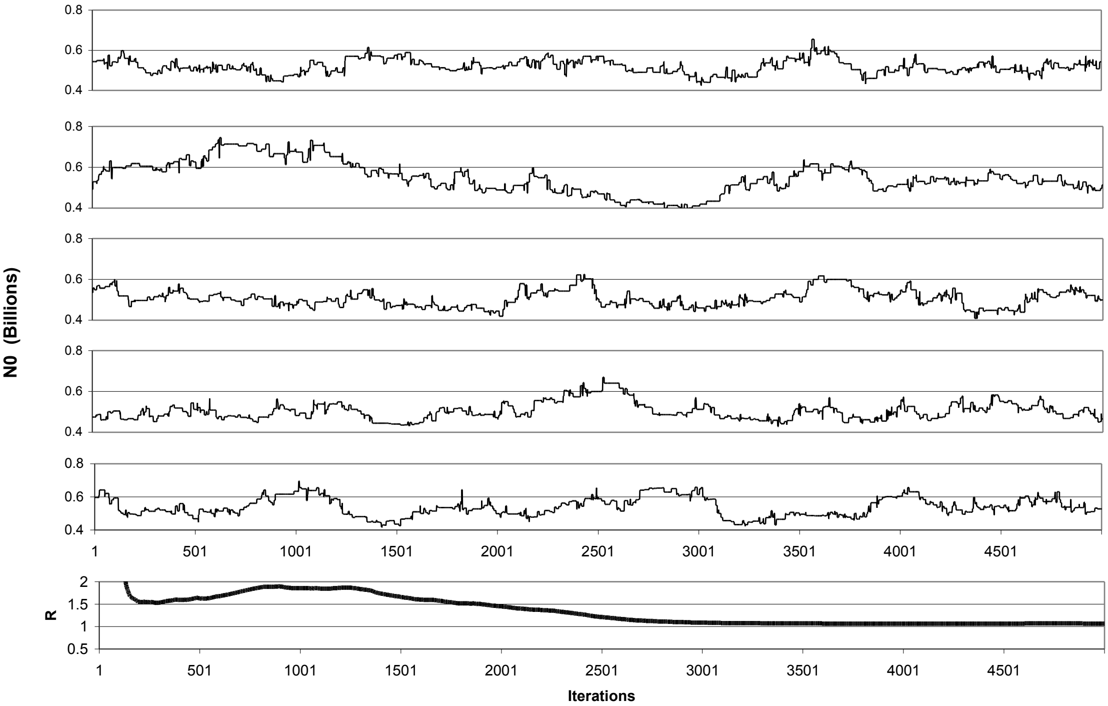


Fig. 23.- MCMC results for Beauchene area. Five chains for the initial number parameter (***N0***) and the convergence index (***R***), which must be lower than 1.1.

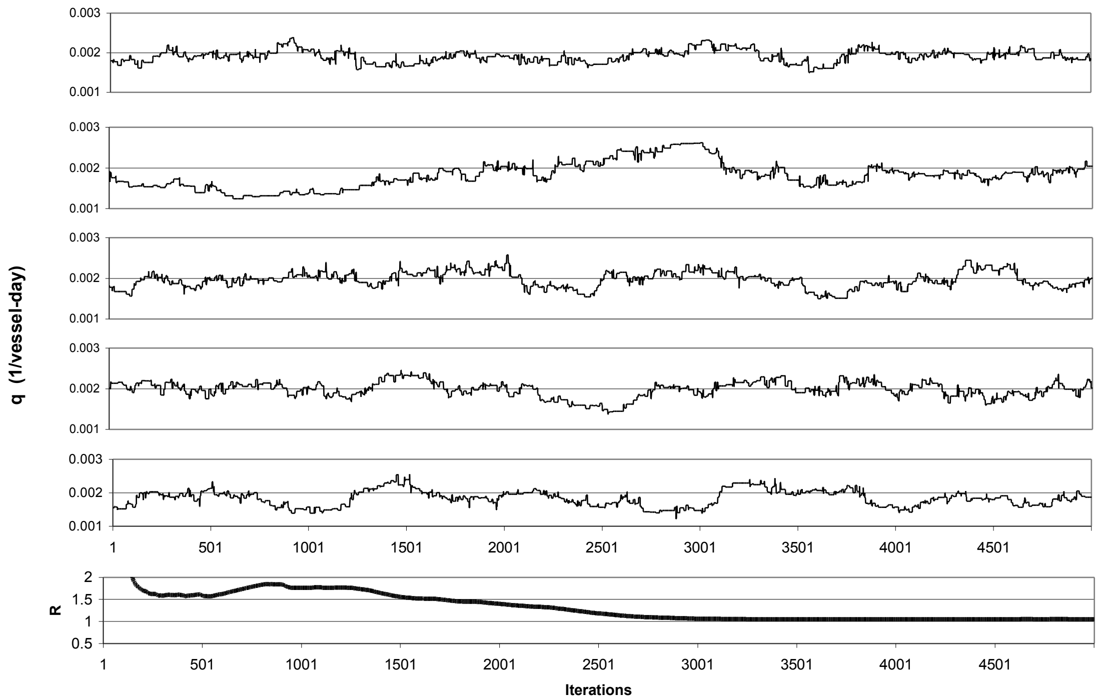


Fig. 24.- MCMC results for Beauchene area. Five chains for the catchability parameter (***q***) and the convergence index (***R***), which must be lower than 1.1.

The prior and posterior distributions are shown in figures 25 to 27.

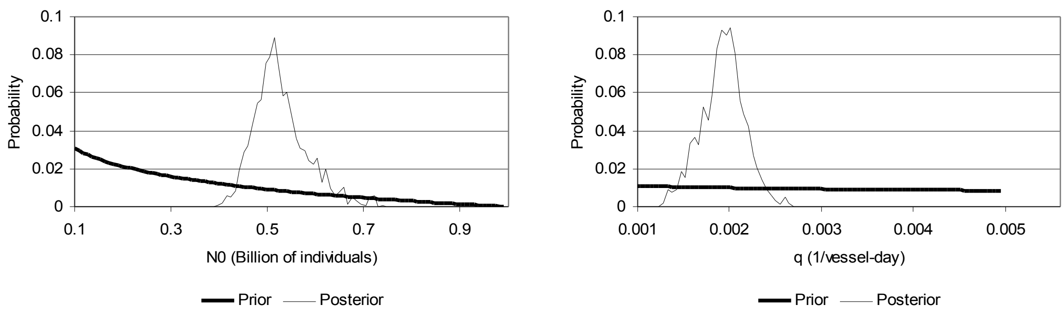


Fig. 25.- Prior and Posterior distribution of initial number (left plot) and catchability coefficient (right plot) parameters of the Beauchene depletion model.

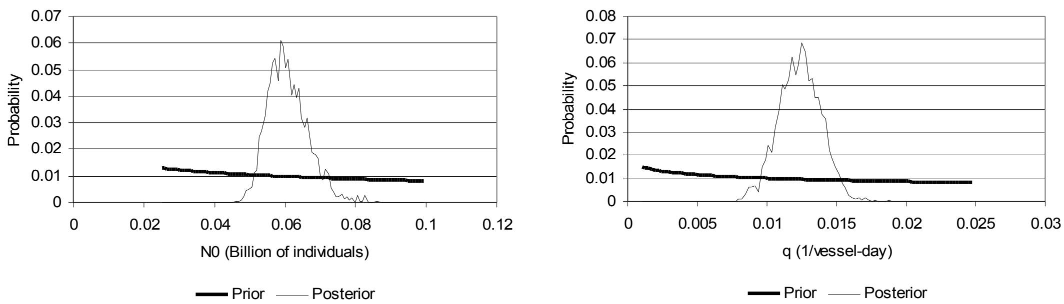


Fig. 26.- Prior and Posterior distribution of initial number (left plot) and catchability coefficient (right plot) parameters of the first depletion model of Central-North area.

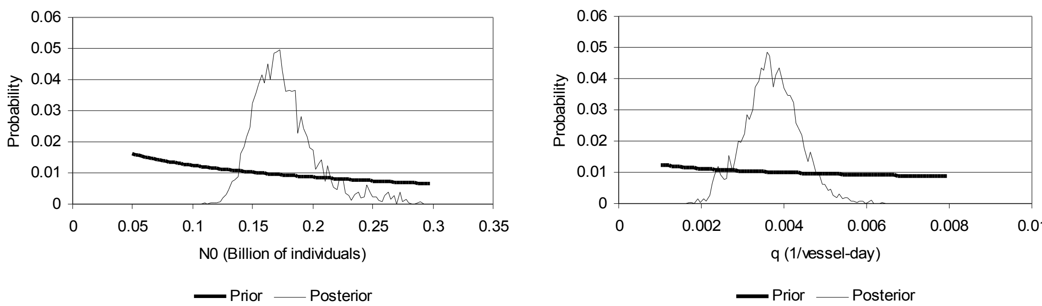


Fig. 27.- Prior and Posterior distribution of initial number (left plot) and catchability coefficient (right plot) parameters of the second depletion model of Central-North area.

Biomasses estimated and projected up to the 15th of October, for each depletion event, are shown in figures 28 to 30. The initial biomass in Beauchene area on the 4th of August was 25500 tons. The initial biomass of the first depletion event in Central-

North area on the 23rd of July was 2600 tons, while the initial biomass of the second depletion event on the 22nd of August was 7900 tons (**Table 4**).

The initial biomass in the whole Loligo box on 4th of August was estimated at 26000 tons, with a 10% percentile lower boundary of 24300 tons and a 90% percentile upper boundary of 31213 tons (**Fig. 31 y 32**). The biomass at the end of the fishing season was 13200 tons with a 10% percentile lower boundary of 11347 tons and a 90% percentile upper boundary of 16899 tons.

The projected spawning biomass on the 15th of October was 13500 tons with a 10% percentile lower boundary of 11348 tons and a 90% percentile upper boundary of 16897 tons (**Figs. 31 to 32 and Table 5**).

The risk of surpass the 10000 tons spawning biomass limit was 0.01. This risk corresponds to the cumulative probability of the biomass values lower than 10000 tons (**Fig. 33**).

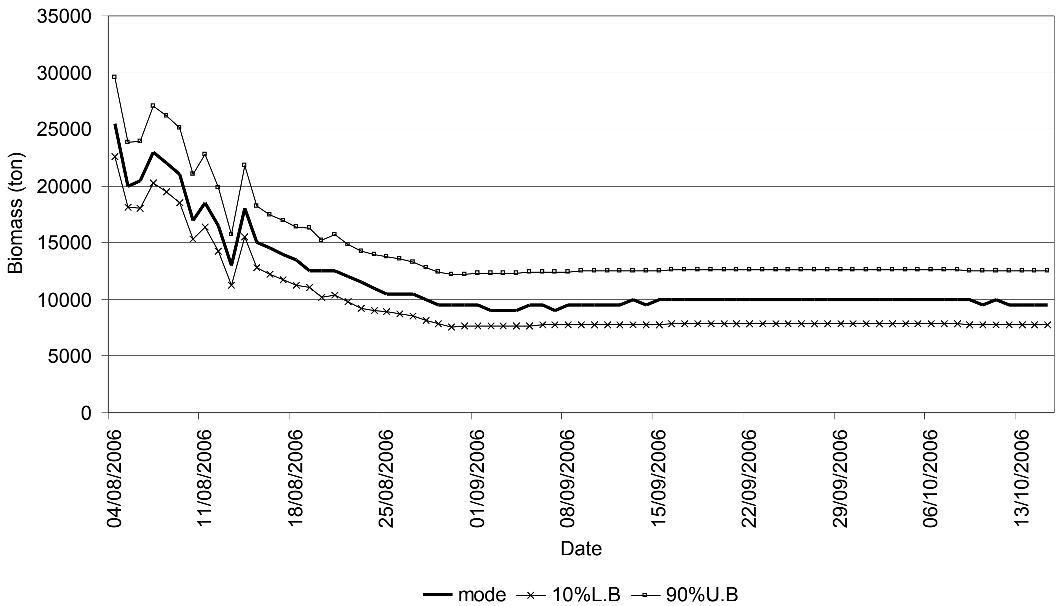


Fig. 28.- Biomass depletion and projection in the Beauchene area (10%L.B = 10% percentile lower boundary; 90%U.B= 90% percentile upper boundary).

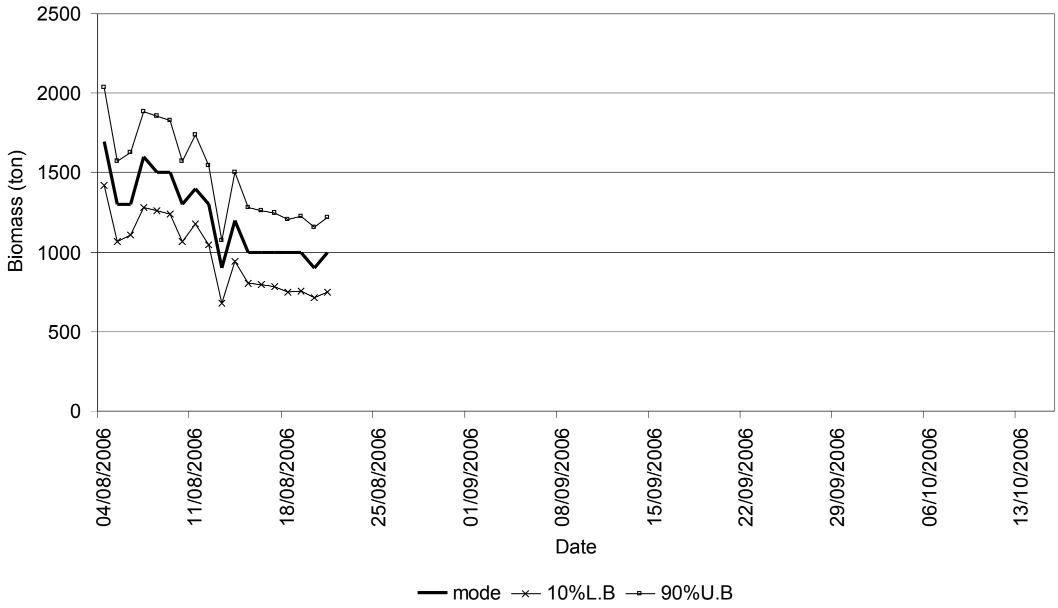


Fig. 29.- Biomass depletion of the first depletion in the Central-North area (10%L.B = 10% percentile lower boundary; 90%U.B= 90% percentile upper boundary). There is no biomass projection because this biomass is incorporated in the second depletion event (next figure).

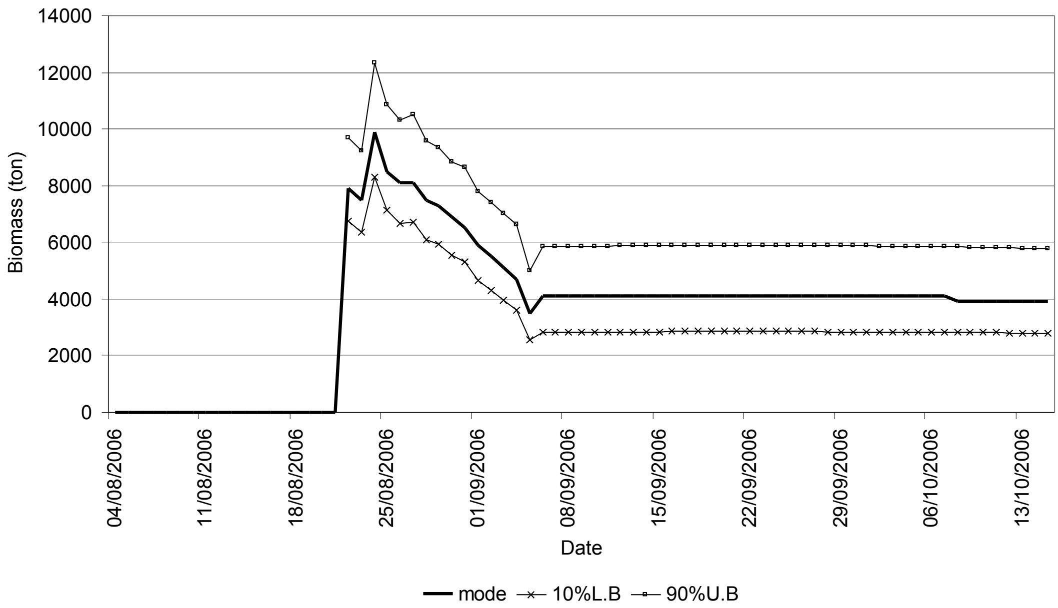


Fig. 30.- Biomass depletion and projection of the second depletion in the Central-North area (10%L.B = 10% percentile lower boundary; 90%U.B= 90% percentile upper boundary).

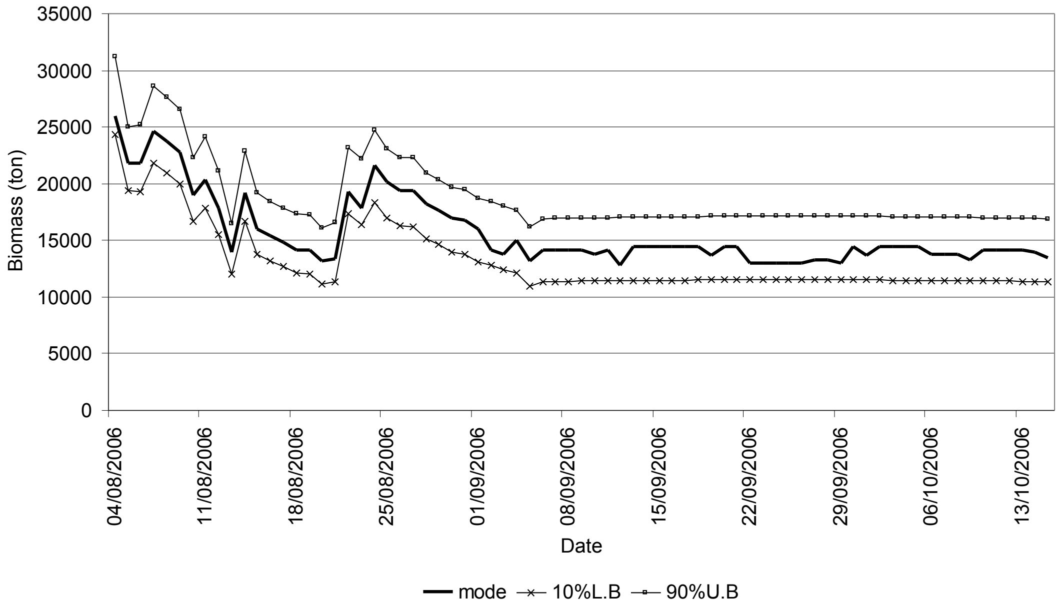


Fig. 31.- Biomass depletion and projection in the whole Loligo box (10%L.B = 10% percentile lower boundary; 90%U.B= 90% percentile upper boundary).

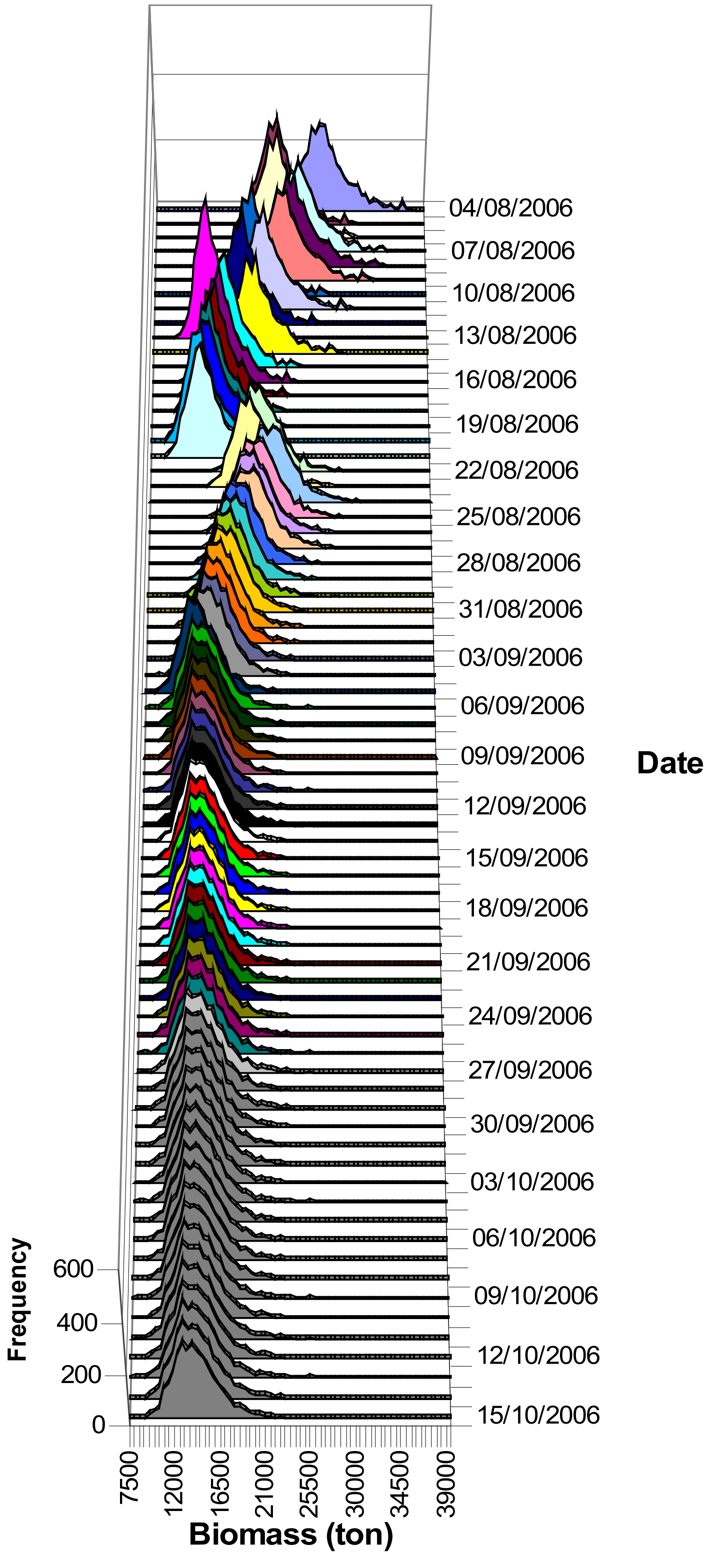


Fig. 32.- Biomass distributions by date for the whole area during depletion and projected period.

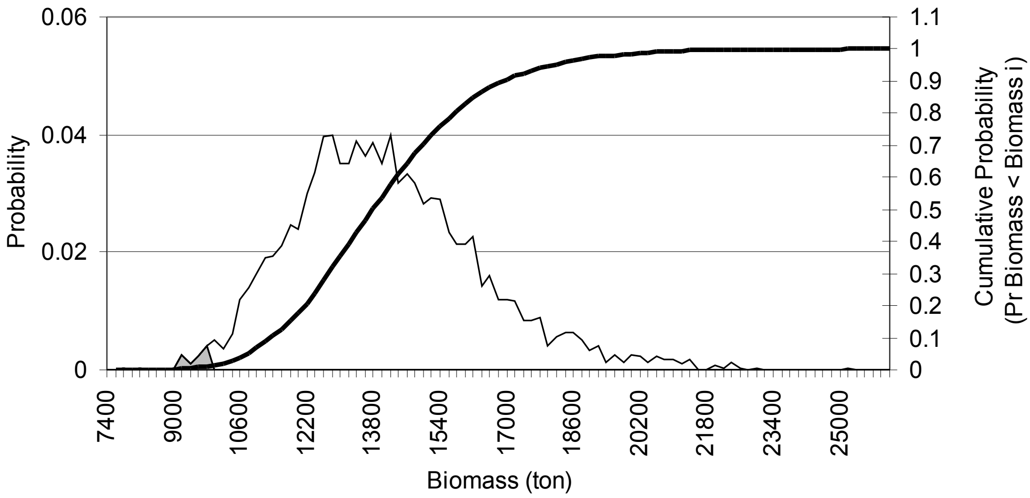


Fig. 33.- Probability distribution and cumulative probability of the spawning biomass projected to the 15th of October. The dark area beneath the curve shows the values lower than 10000 tons. The cumulative probability at 10000 ton was 0.01 and it corresponds to risk of surpass the limit of 10000 ton spawning biomass.

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).

	2nd Season 2004			2nd Season 2005			2nd Season 2006		
Parameter	Beauchene	Central	North	Beauchene	Central	North	Beauchene	1rst Depletion Central-North	2nd Depletion Central-North
Starting Date	15/07	16/08	28/07	10/08	25/07	21/07	4/08	23/07	22/8
Final Date	30/09	30/09	30/09	30/09	30/09	30/09	29/08	21/08	5/9
N° of days	66	16	58	52	25	39	25	30	15
Catchability	$5.9x10^{-4}$	$3.4x10^{-3}$	$2.7x10^{-3}$	2.3x10-3	3.7x10-2	2.1x10-3	1.9x10-3	1.2x10-2	3.7x10-3
(1/vessel-day)	(5.4)	(9.9)	(14.9)	(1.2)	(703.5)	(25.6)	(12.5)	(12.4)	(18.3)
Initial numbers	$8.5x10^{-1}$	$1.4x10^{-1}$	$2.7x10^{-1}$	3.2x10-1	1.6x10-2	4.1x10-1	5.2x10-1	5.8x10-3	1.7x10-1
(billions)	(23.0)	(50.3)	(3.0)	(5.4)	(363.5)	(8.3)	(11.1)	(9.6)	(15.4)
Initial biomass	42239	6983	13510	20417	1070	25714	25500	2600	7900
(ton)	(39.6)	(61.2)	(34.0)	(30.2)	(365.7)	(32.0)	(10.8)	(10.0)	(15.3)
Final Numbers	$2.2x10^{-1}$	$3.3x10^{-2}$	$4.4x10^{-2}$	6.2x10-2	1.4x10-3	5.6x10-2	0.21	0.02	0.08
N_T (billions)	(31.1)	(100.9)	(21.0)	(13.9)	(2778.4)	(53.5)	(18.7)	(19.5)	(18.7)
Final Biomass	15191	2229	3009	5203	112	4505	9500	1000	3500
(ton)	(49.2)	(107.8)	(43.6)	(39.8)	(2778.6)	(56.4)	(18.7)	(19.5)	(28.4)

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 (mt)
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)

Comparisons between in-season and after-season stock assessments

For the depletion in Beauchene area and the first depletion in Central-North area the in-season and after-season biomass estimations were quite similar with a large overlapping of confident intervals (**Fig. 34**). These two depletion events have the same data before and after the early fishery closure, therefore the slightly differences are due to bootstrapping (in-season) and Bayesian (after-season) methods. However for the second depletion in the Central-North area, after-season stock assessment estimated larger biomasses than in-season stock assessment. In this case after-season stock assessment included five days more than in-season stock assessment (**Fig. 35**) and therefore has less uncertainty (confident intervals).

Comparisons between FIFD and Msquid program

Biomass estimations obtained by FIFD algorithm were compared with results produced by Msquid program (version 5, 1999, RRAG, Imperial College). Msquid was applied following RRAG criteria: 1) Data by week; 2) All data of Loligo box pulled together and 3) Different fleets based on GRT stratification. However, as the natural mortality per week has an important effect in the estimates, M was set to FIFD value (M=0.09).

CPUE estimated by Msquid fitted well to the data of five GRT groups of vessels (**Fig. 36**). Msquid biomass estimations were greater than ones made by FIFD algorithm during the first three weeks of the depletion period (weeks 3 to 5 of the fishery season) but then forward they were similar, actually there were not statistically significant differences between them (**Fig. 37**). Msquid biomass at the end of the fishery season was 12660 tons while FIFD biomass was 13200 tons.

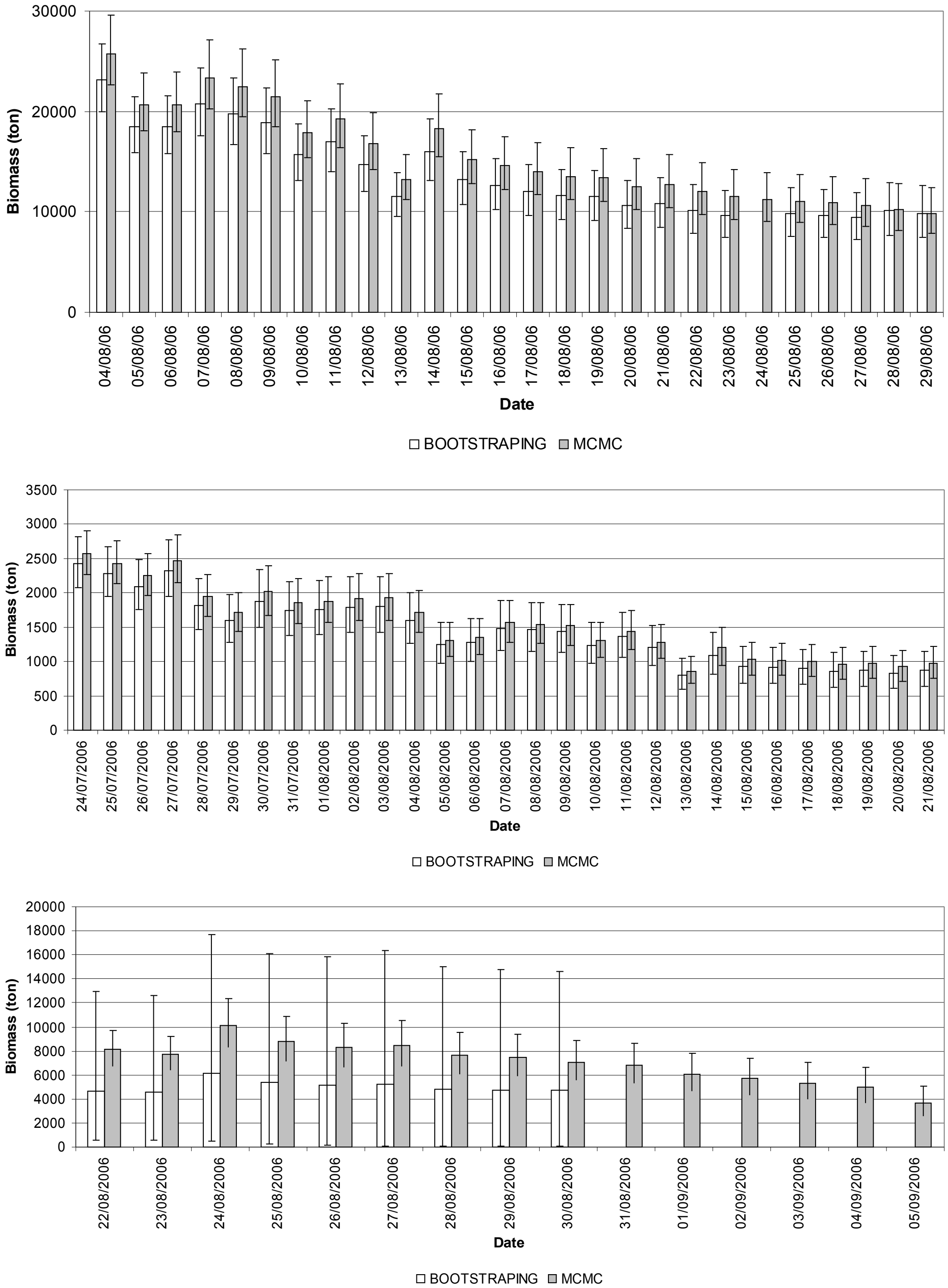
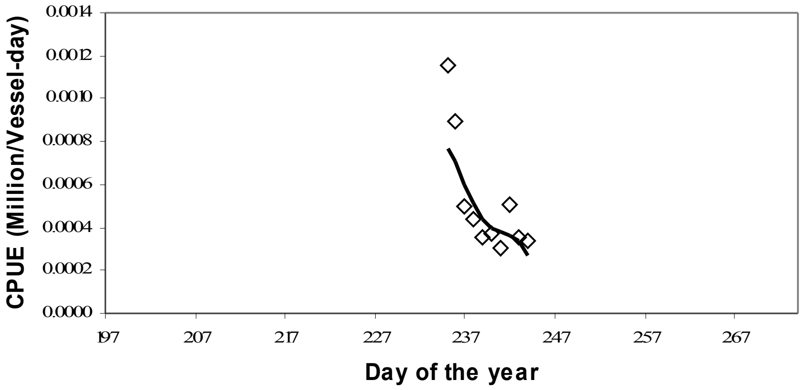


Fig. 34.- Biomass estimated by in-season stock assessment with bootstrapping (white bar) and by after-season stock assessment with MCMC (grey bar) for Beauchene (upper plot), first depletion in Central-North area (middle plot) and second depletion in Central-North area (lower plot). Vertical bar represents the 80% confident interval. Note different scales in each graph for more clearness.



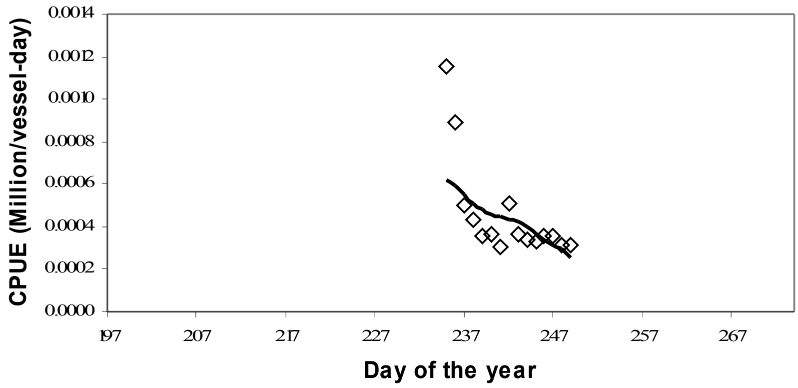


Fig. 35.- Observed and predicted (lines) CPUE for second depletion in Central-North area with data up to 31[rst] of August (upper plot) and up to 5[th] of September (down plot).

The differences in the first three weeks might arise from the areas used by each program; Msquid assumed only one big depletion event in the whole area but FIFD program took into account three different depletion events in two different areas. Furthermore, Msquid was fitted to different vessel categories whilst FIFD program was fitted to the whole fleet.

To make results of two programs more comparable, Msquid was fitted again with the following criteria: 1) Only data from Beauchene area; 2) All vessels together without any stratification and 3) Natural mortality equals to FIFD value (0.09). Msquid fitted well to these data (**Fig. 38**) and biomass estimations were closer to FIFD program estimations (**Fig. 39**). Although, there were not statistically significant differences (95% confident interval overlapped along the whole depletion period), Msquid average estimations were greater and these differences with FIFD averages increases toward the beginning of depletion period. These differences could be related with time intervals used by the programs; Msquid uses weeks while FIFD program uses days. Thus FIFD program requires more data and therefore has more degrees of freedom and shorter confident intervals, which is statistically better.

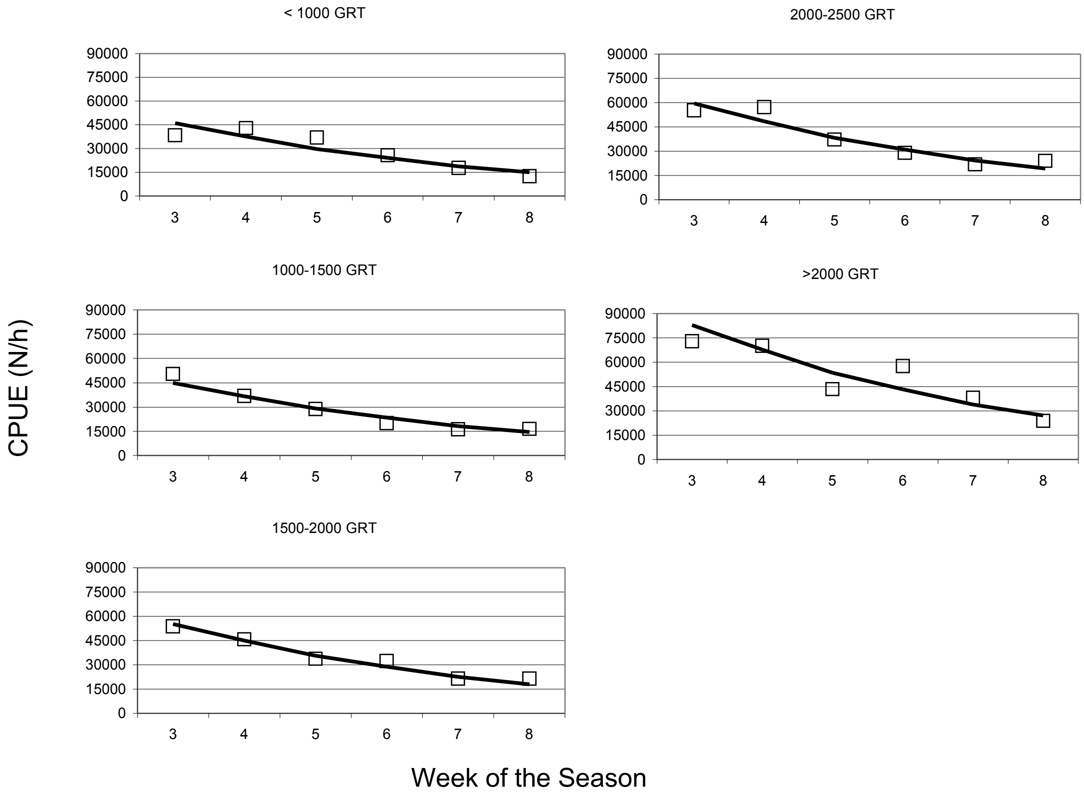


Fig. 36.- Observed (squares) and predicted (lines) CPUE by Msquid program for each vessel category (M=0.09).

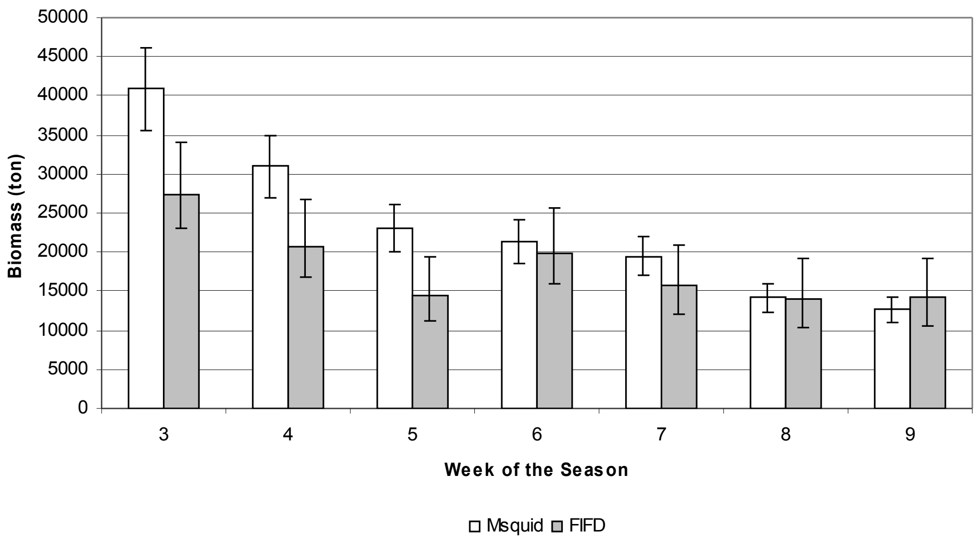


Fig. 37.- Biomass in whole Loligo Box estimated by Msquid and FIFD programs. Vertical bars are the 95% confident intervals. Msquid was run with M=0.09 and five GRT vessel categories.

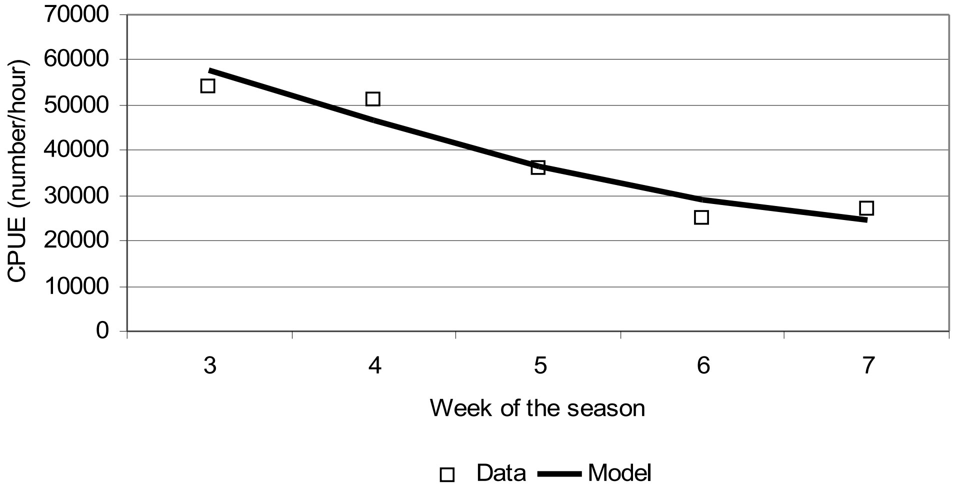


Fig. 38.- Observed and predicted CPUE by Msquid program (M=0.09 and all vessels together).

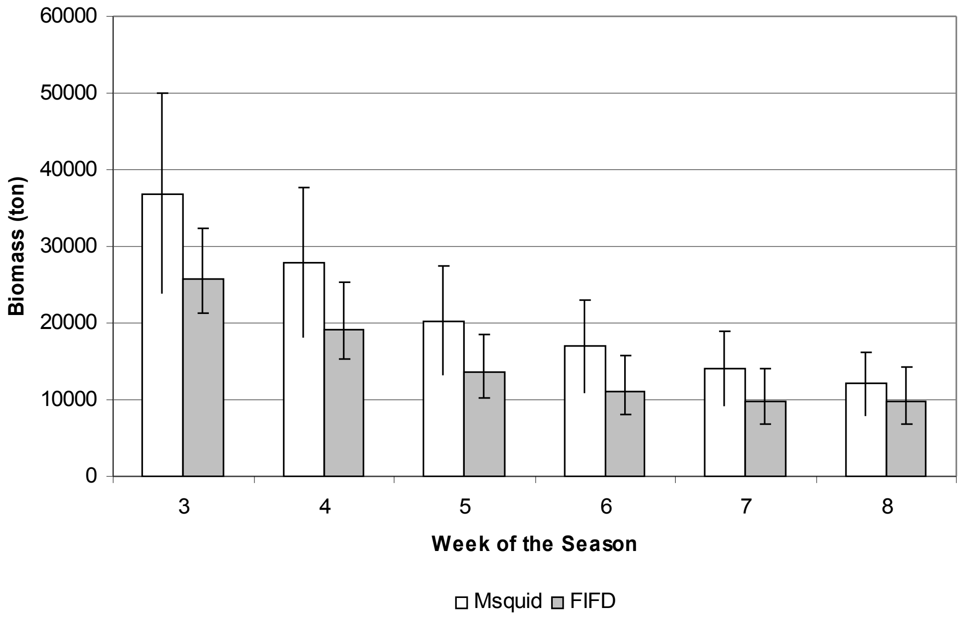


Fig. 39.- Biomass in the Beauchene Area estimated by Msquid and FIFD programs. Vertical bars are 95% confident intervals. Msquid was run with M=0.09 and with all vessel together.

DISCUSION

The current management procedure was improved incorporating an operational model and risk analysis under a precautionary management approach. Precautionary approach means to incorporate the high uncertainty of stock assessment into the management decision.

Operational model was developed to apply the decision rule: ‘To close the fishery if spawning biomass is lower than 10000 tons, under the constraint of warning fishery industry with two weeks in advance of the closing day’. Operational model includes the depletion model, catch projection and biomass projection. The catch projection module allows to projecting the catches during the warning period under different fishing effort levels (number of vessels) by fishing areas.

Risk analysis was implemented to know the probability of leaving in the sea less than 10000 tons of spawning biomass, by means of estimating the uncertainty of operational model estimations. The uncertainty is estimated during the fishing season by bootstrapping techniques and after the season by Bayesian inference.

The after-season stock assessment showed that the projected spawning biomass was 13500 tons with a risk probability of only 0.01. This biomass is greater than the 10000 tons biomass projected during the fishing season with data up to 31st August. This difference is because of the initial biomass of the second depletion event in the Central-North Area, increased from 4000 tons, in the in-season assessment, to 7900 tons in the after-season assessment.

The implementation of the e-logbook was very important to identify and monitoring the local depletion events. This new CPUE information by trawl was very useful to analyse with the industry the evolutions of the depletions events and finally to support the early closure decision. Furthermore, the production by commercial category size was very useful to validate our observer data of mantle size by day.

Biomass in the whole area on 4th of August was estimated at 26000 tons which is greater than 22625 tons at 7th of July estimated by Loligo survey (Paya 2006). However, these biomass estimations are not directly comparable because depletion model estimates total stock biomass while survey estimates biomass available to trawling net (first 4-5 metres from the bottom). Thus the biomass from the survey must be considered as an index of relative abundance.

FIFD and RRAG (Msquid) programs for depletion model produced similar results with high overlapping of the confident intervals. This is true only if the same natural mortality, same area and same vessel categorization are used. However, the FIFD program is statistically better because it uses data by day instead of week and thus it has more degrees of freedom and lower uncertainty of the estimates than Msquid program.

CONCLUSIONS

1) Total catch (23238 tons) reached an intermediate level considering the last 10 years, while total effort (13150 hours of trawling) was of rather low level compared with the levels at the last 10 years.
2) Initial squid biomass presented on 4th of August was estimated at 26000 tons.
3) The resource was mainly concentrated in the Beauchene and Central area and was quickly depleted.
4) During fishing season the stock assessment projected a high risk of fail the management target of 10000 tons of spawning biomass
5) Therefore, the fishery was closed 25 days before the end of fishing season in order to protect the spawning biomass.
6) After-season stock assessment estimated the spawning biomass on 15th of October at 13500 tons.
7) The risk that spawning biomass could be lower than 10000 tons was estimated at 0.01, so the management target was fully met.

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