Falkland Island Fisheries Department

Fishery Report

Loligo gahi, First Season 2007

Fishery Statistics, Biological Trends, Stock Assessment and Risk Analysis

Author: Ignacio Paya

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SUMMARY

Total catch by the *Loligo* fleet during the first season (February/25-Arpil/15, 2007) was 17229 tonnes, an intermediate catch level compared to the catch of the first seasons in the last five years. Total effort was 8780 hours of trawling, a level similar to that of the last four years but much lower than years before 2003. Most of the catch was taken from the Beauchene (94%) and Northern areas (5%). This fishing season started with few squid in the fishing grounds but during the season the squid abundance increased because of the sequential arrivals of 5 squid groups. Because of this delay in the migration the daily catches were low (150-300 tonnes/day) during the first three weeks, but later they increased to good levels (300-570 tonnes/day). Biological trends in proportion of mature individuals and proportion of females were similar to previous first seasons, but with more variability produced by the arrivals of the different squid groups. The average mantle length was 12 cm, which was 2 cm greater than in 2006, and also fluctuated according to the sequential arrivals of squid groups. Five squid groups entered in the Beauchene area and only one in the Northern area. The FIFD stock depletion model was modified to simultaneously fitting 5 depletion events under the assumption of constant catchability during the whole season. In order to warn the industry of any possible early closure of the fishery with two weeks in advance, the catch during these weeks and the spawning biomass were projected. During the season the risk was calculated as the product of the probability of biomass depletion and the probability of leaving at the sea less than 10000 tonnes of spawning biomass by the 31^{rst} of May. The probability of biomass depletion was introduced to incorporate the probability of arrivals of new squid groups. The risk was estimated by bootstrapping techniques in the in-season stock assessment and Bayesian inference in the after-season stock assessment. The whole biomass that arrived to the fishing grounds was estimated at 37517 tonnes, and the survival spawning biomass was estimated at 12250 tonnes. The management objective of leaving 10000 tonnes of spawning biomass was met with a precautionary risk of 0.017.

INTRODUCTION

The first season of 2007 started on the 25th of February and lasted until the 15th of April. This fishing season began with few squid in the fishing grounds. The *Loligo* scientific survey that was made just before the beginning of the fishing season, between 9 and 23 February, estimated a small biomass in the fishing grounds, 2684 tonnes (Paya 2007). However, catches found by a demersal scientific survey conducted by FIFD in February showed that *Loligo* were present in shallow waters and did not yet arrive to the fishing grounds. During the fishing season 5 squid groups arrived to the Beauchene area and one to the Northern area. This produced two catch periods: the first one, from the 25th of February to the 16th March, had low total daily catches (150-300 tonnes/day); and the second one, from the 17th of March until the end of the season, had good daily catches (300-570 tonnes/day).

Our daily fishery statistics and biological data cover the whole fishing season, except for a three-day interruption of biological sampling. Most of the fishing activity was carried out in the Beauchene area, with a few operations in others areas (Fig. 1).

In-season stock assessment was made using the FIFD's implementation of the stock depletion model, as described in previous reports. However, the model was adapted to fitting five sequential depletion events simultaneously under the assumption of constant catchability throughout the fishing season.

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. The risk analysis of leaving less than 10000 tonnes was modified to incorporate the probability that other squid groups arrive to the fishing grounds.

After the season a stock assessment and risk analysis were made using Bayesian inference. Cauchy 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 tonnes of spawning biomass on the 31^{rst} of May. The fishing season finished as scheduled with a very low risk of 0.017.

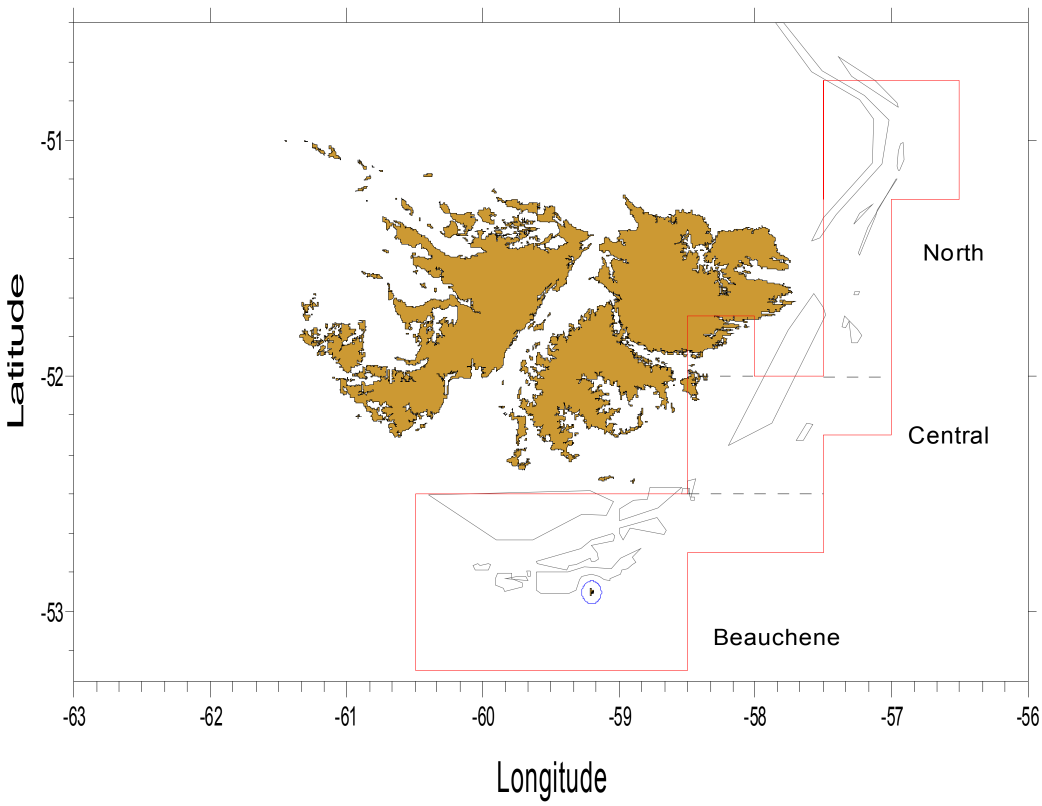


Fig. 1.- Fishing grounds and rocky bottom around the Falkland Islands. In red, the *Loligo* box, and in blue, the three-nm exclusion area around Beauchene Island.

PART 1 – FISHERY STATISTICS

Total Catch and Total Effort in Historical Perspective

The whole catch in the first season was 17229 tonnes, which was close to the average catch in the last 5 first fishing seasons, though if we consider the whole recorded history, this is a medium-low level that follows the global decreasing trend (**Fig. 2 and Table 1**). This trend not only represents squid abundance fluctuations but also the changes in management. Fishing effort was similar to the four previous years and significantly lower than the years before 2003 (**Fig. 2 and Table 1**).

CPUE was similar to the first season of 2006 and to the average in the last 5 first fishing seasons (**Fig. 3 and Table 1**). There is a strong historical relationship between initial biomass and CPUE (**Fig.3**), although there have been methodological changes since the second season of 2004 and a reduction of the length of fishing seasons since 2003. Therefore it is necessary to carry out a re-analysis of the old data.

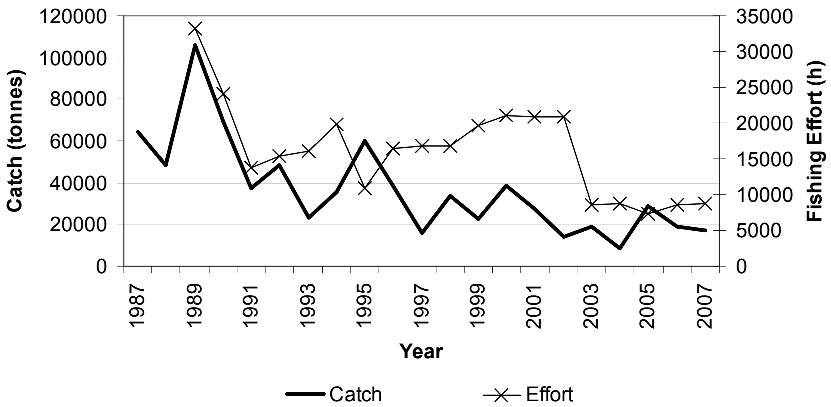


Fig. 2.- Historical catches and fishing effort of the first season.

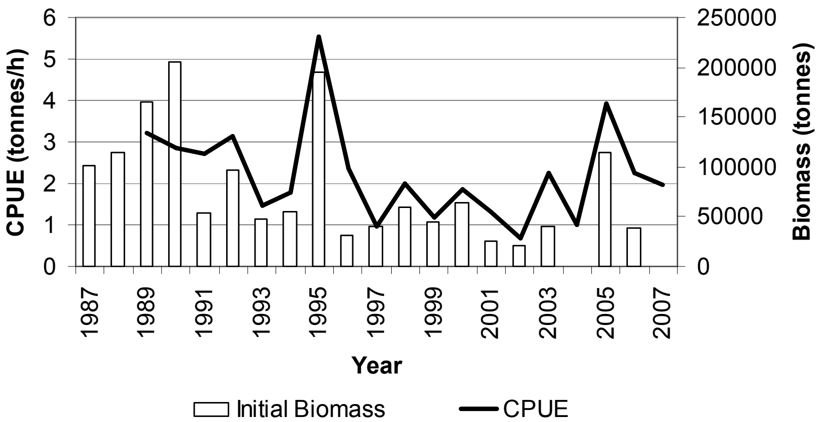


Fig. 3.- Historical CPUE and initial biomass of the first season. The first season 2007 biomass is the sum of the biomass at the beginning of the season and the biomass of the 4 squid groups that arrived during the season.

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). (*) The first season 2007 biomass is the sum of the biomass at the beginning of the season and the biomass of the 4 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	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
2007	17229	8780	37517*				

Catch and Effort per Fishing Ground and Cumulative Catch

Most of squid (94%) were caught in Beauchene area, where the fishing effort was concentrated. The catch in the north area was 5% of the whole catch and in the central area was only 1% (**Table 2**).

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

Fishing Ground	Total Catch (tonnes)	Effort (Vessel-Days)	Effort (Hours)	CPUE (tonnes/V-D)	CPUE (tonnes/h)
Beauchene	16233	691	7823	23.492	2.075
Central	171	22	239	7.793	0.719
North	825	63	718	13.088	1.148
Total	17229	776	8780	22.202	1.962

The daily cumulative catch was very close to the worst year during the first three weeks but later it increased (**Fig. 4**). The catches increased from 17th of March when new *Loligo* groups arrived to the fishing grounds.

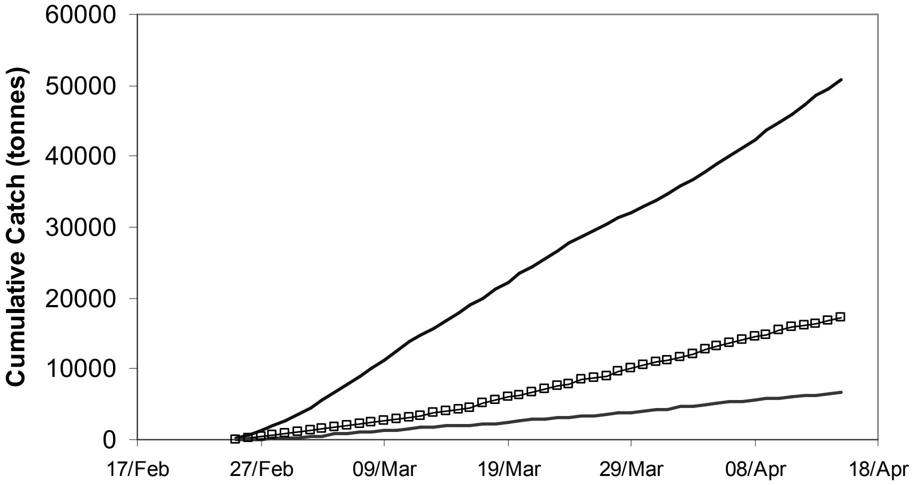


Fig. 4.- Cumulative catch versus date in the first season of 2007 (line with squares) compared with the cumulative catch of the first seasons that yielded the highest (year 1989) and lowest (year 2004) historical catches on exactly the same date range.

Fleet Movement Dynamics, Catch and Catch Rate

During the first two days the fleet fished mainly in the Beauchene area, but had poor results, the third day the fleet dispersed and searched throughout the *Loligo* Box displaying similar trawling hours by fishing area (**Fig. 5a**). The fleet found the best CPUE in the Beauchene area and remained fishing there for the rest of the season with some explorations to the northern area in the middle of March (**Fig. 5b**). In the Beauchene area the average daily catch before 17th of March was 183 tonnes and after that date was 419 tonnes (**Fig. 5b**), this corresponds to 16 tonnes/vessel-day and 28 tonnes/vessel-day, respectively (**Fig. 5c**). The CPUE fluctuated with suddenly increasing values and then decreasing periods, these combined with the biological information were interpreted as several depletion episodes.

The analysis of the fleet movement based on the e-logbook data provided by the e-logbook system implemented by Wetjens Dimmlich of FIFD, shows the sequential arrivals of five *Loligo* groups in the Beauchene 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, but catches were very poor (**Fig. 6**). During the third day the fleet made an extensive searching for the resource along the shallower border of the *Loligo* box and found the best CPUE in the southern area (**Fig. 7**). This confirmed the idea that *Loligo* had not completely arrived to the fishing grounds. On the 12th of March a second group of squids entered in the same location, where part of the fleet was fishing while the other part was operating in the shallower border of the northern area (**Fig. 8**). On the 17th of March a third squid group arrived to south-east of Beauchene Island, which generated a big CPUE increase and concentration of the fleet in that place (**Fig. 9**). On the 28th of March a fourth group of squid arrived to the south and south-east of Beauchene Island, where most of the fleet was concentrated, the rest of the vessels were exploring shallow grounds in the southern and northern areas (**Fig. 10**). On the 3rd of April the fifth and last group of squid arrived to the south-west and south-east of Beauchene Island, where most of the fleet was fishing (**Fig.11**). In the last day of the season the whole fleet fished from the west of Beauchene Island to the west border of *Loligo* box, suggesting that another squid group could have been arriving (**Fig.12**).

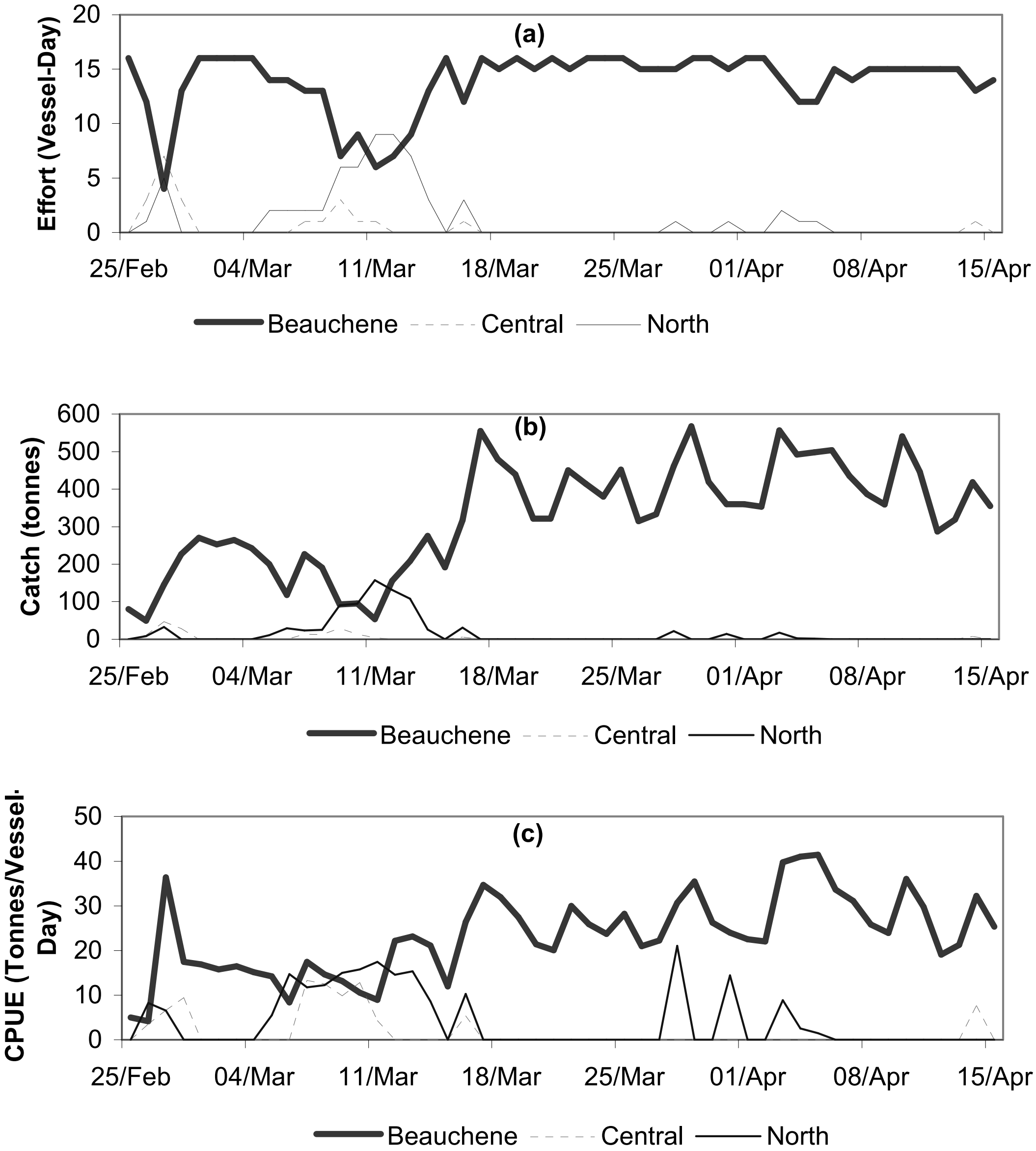


Fig. 5.- Daily evolution of effort (a), catch (b), and average catch per unit of effort (c) in the *Loligo* fishery during the first season of 2007.

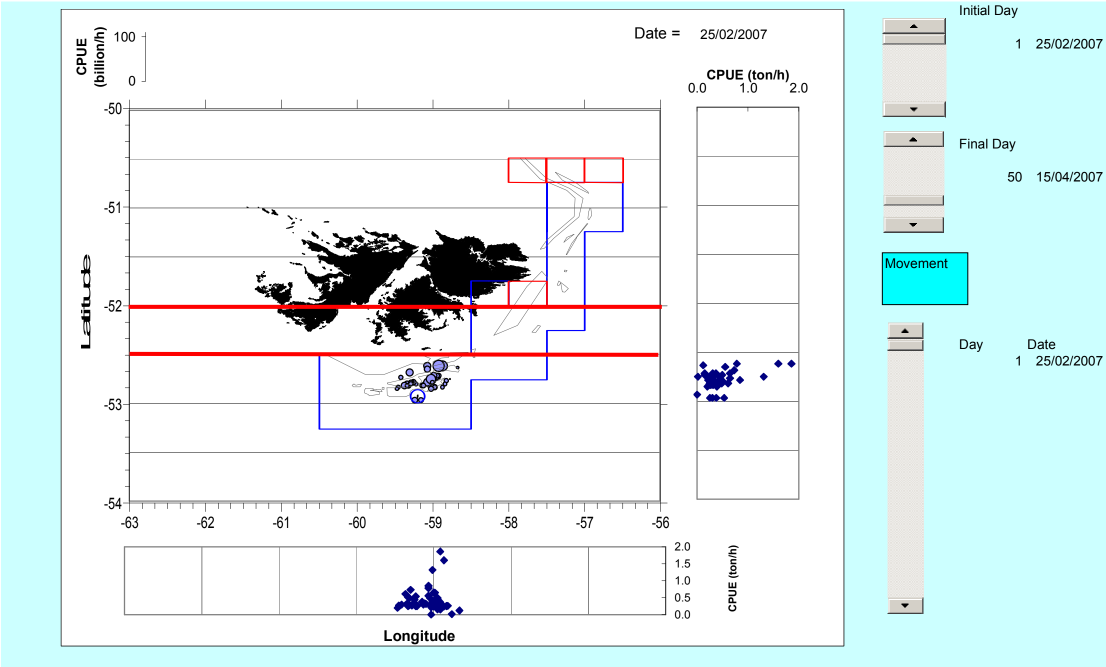


Fig. 6.- On the 25th of February, the first fishing day, the fleet concentrated in the southern area, where the *Loligo* trawl survey had found the best aggregation. This figure shows the graphical interface used to display the fleet movements and catch rates. The central plot shows the Loligo box (blue); 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 (tonnes/h) of each haul (blue circles size proportional to CPUE value). For a better understanding of the CPUE values the right plot shows the CPUE by latitude and the bottom plot the CPUE by longitude. The upper left plot shows the average CPUE (billion/h) of the fleet from the beginning of the season until the date that is displayed in the right upper corner of the frame. The upper left plot shows the CPUE in terms of billions of individuals per trawling hour to see the depletion of the number of individuals that is used in the fitting of depletion model. Before run the macro "Movement" (light blue square button) the initial and final day must be entered in the two upper scroll controls. The third scroll control allows selecting which day is to be displayed.

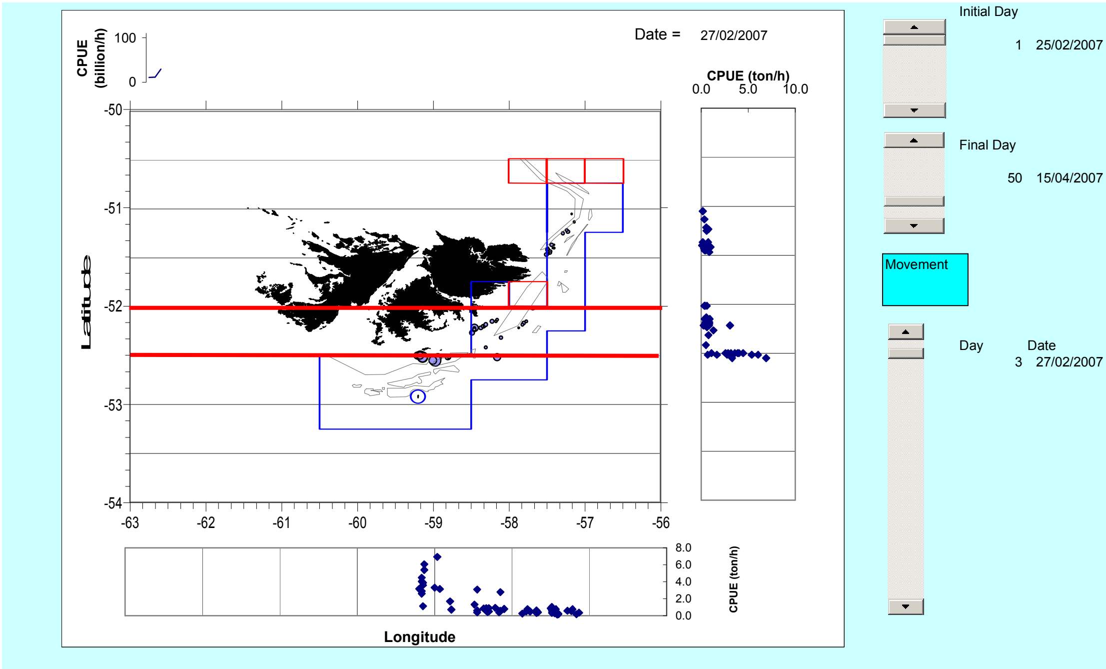


Fig. 7.- On 27th of February, the fleet explored the shallower border of the Loligo box along the three areas. After this the fleet concentrated in the southern area close to the shallower border of the Loligo box.

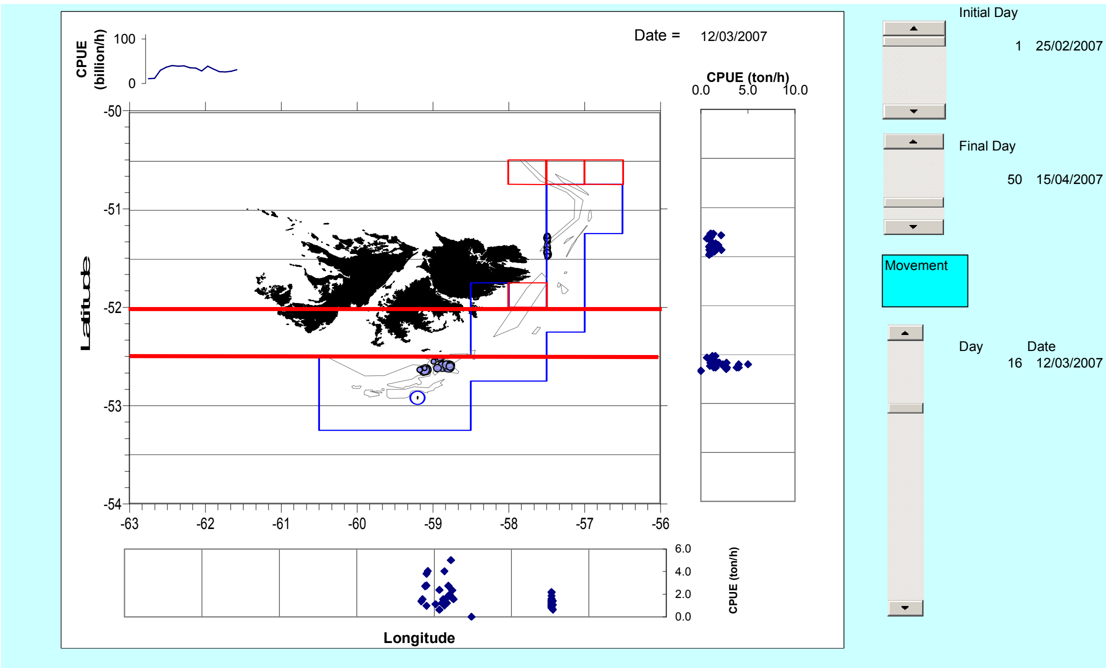


Fig. 8.- On the 12th of March a second group of squid arrived to the southern area. Most of the fleet was concentrated in the southern area, but also some vessels were fishing in the shallow border of the *Loligo* box in the northern area.

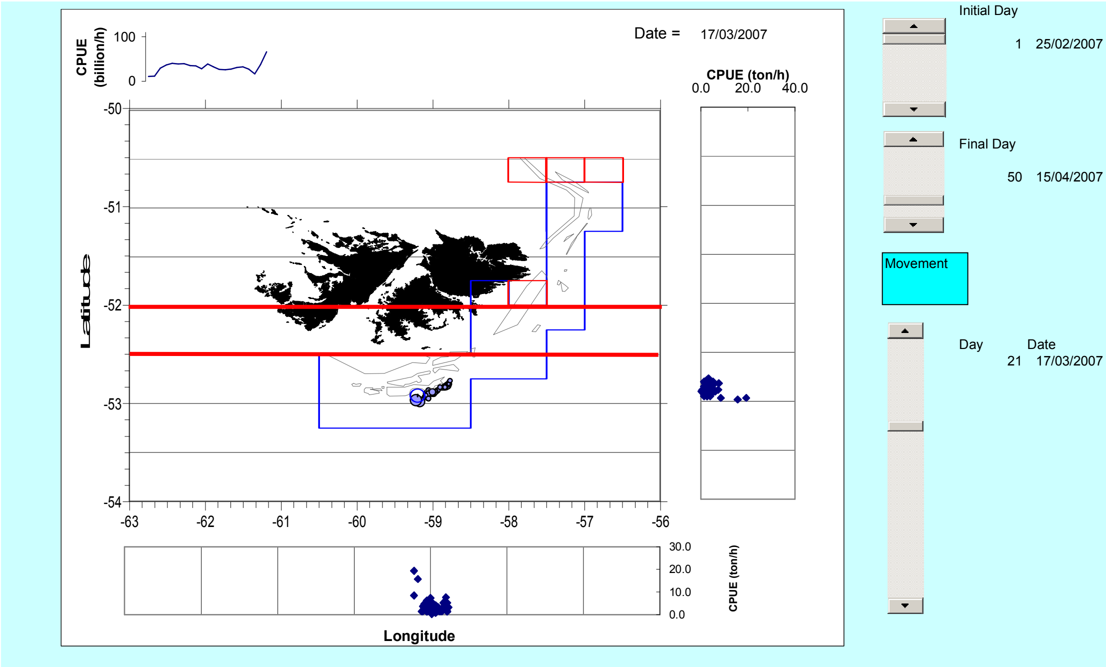


Fig. 9.- On the 17th of March a third group of squid arrived to the south-east of Beauchene Island and all the vessels fished in that location.

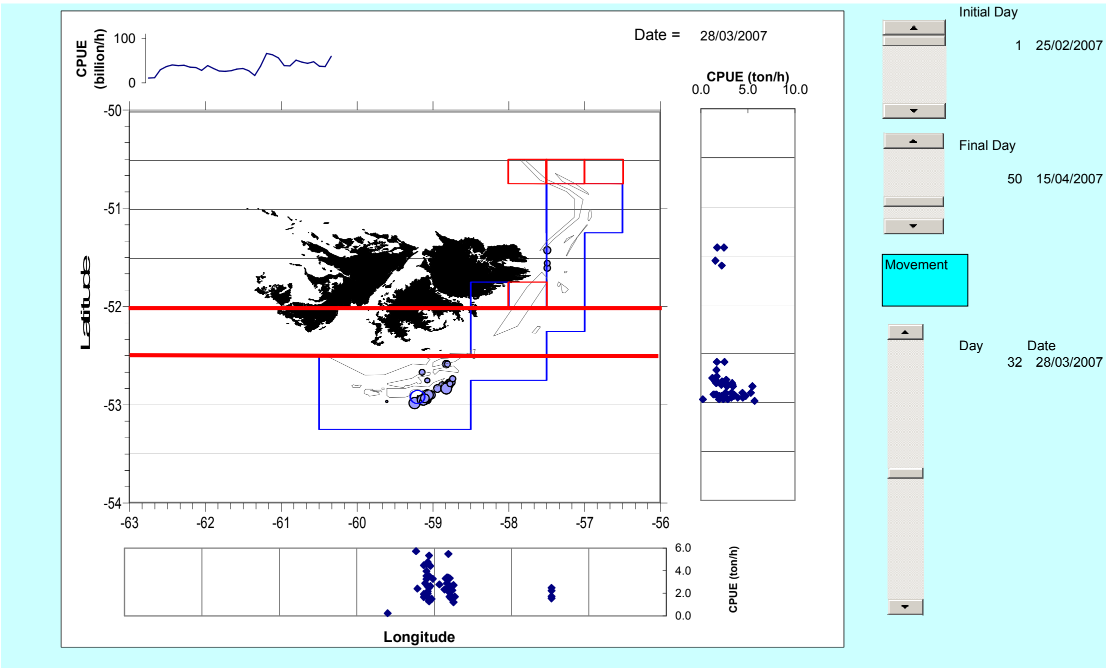


Fig. 10.- On the 28th of March a fourth group of squid arrived to the south and south-east of Beauchene Island. Most of the fleet fished in that location and some vessels explored other locations in the southern and northern area.

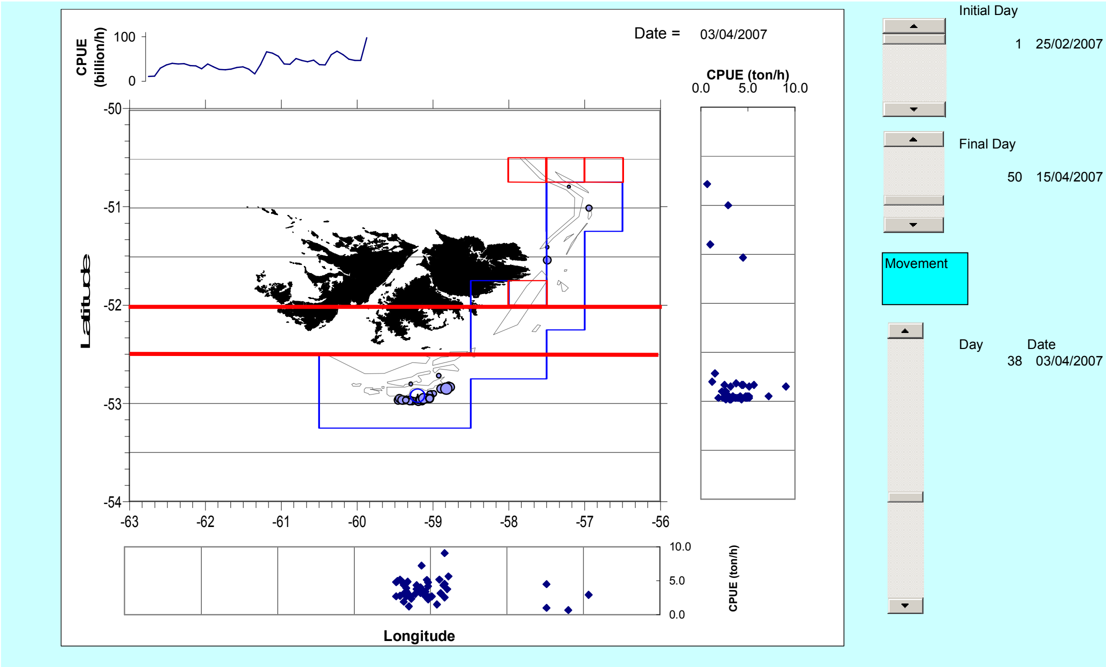


Fig. 11.- On the 3rd of April a fifth group of squid arrived to the south-west and south-east of Beauchene Island. Most of the fleet fished in these locations and some vessels explored others locations in the southern and northern area.

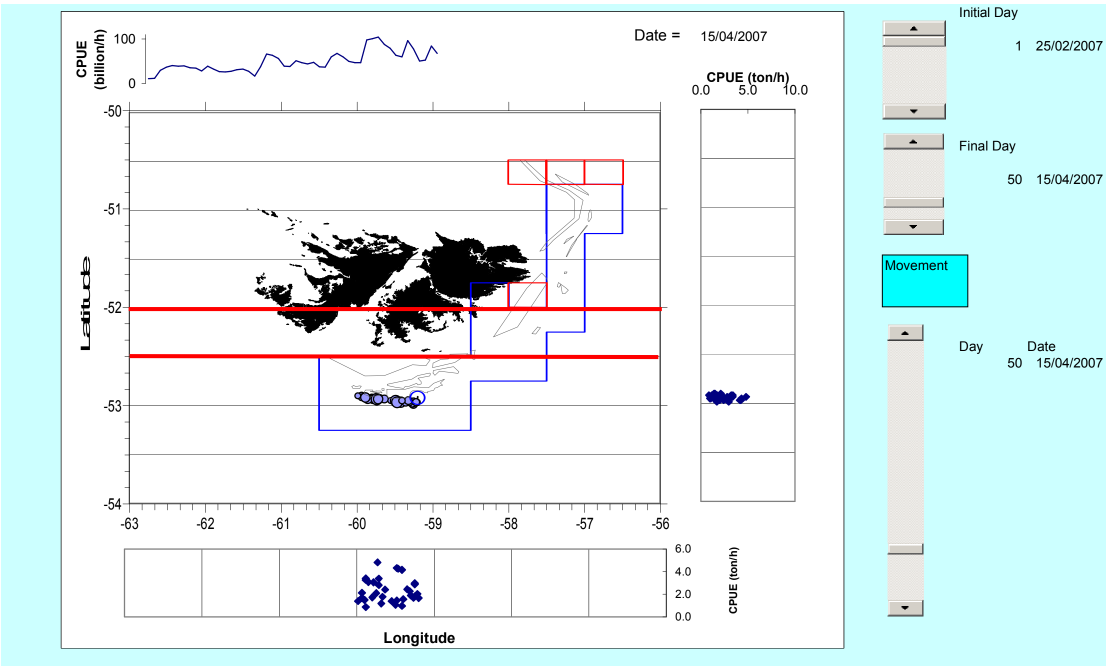


Fig. 12.- During the last day of the fishing season, 15th of April, all the vessels fished in the west and south-west of Beauchene Island.

PART 2 – BIOLOGICAL TRENDS

Biological trends of the stock were based on sampling taken by two scientific observers onboard of commercial vessels during the first twelve days and by one observer for the rest of the season. 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 immature squid in the catch followed trends observed in the first seasons of the previous six years (**Fig. 13**). Both females and males were mostly immature or maturing, but males showed a small decrease of immature proportion during the second week of the season. The sex ratio showed high variability, the female proportion was about 0.4-0.7 most of the time except during the third week when it dropped to less than 0.1 (**Fig. 14**). The average dorsal mantle length for the whole season was 11.9 cm (11.1 cm for females and 12.7 cm for males), which was 2 cm larger than in 2006. The average dorsal mantle length of females remained stable most of the season, but decreased by 2 cm during the last two weeks. Conversely, the male size increased during the first three weeks and then decreased (**Fig. 15**). The dorsal mantle length distributions were uni-modal (**Fig. 16**).

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 (Paya 2006). The average mantle length from ***CSC*** was 1.08 times the size from the scientific observer but both show the same tendency (**Fig. 17**). The deference arises from the way that measure is actually done, scientific observers approximate 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 smaller than the ***CSC*** data**.** Although there is a good relation between average mantle lengths this is not the case for mantle length distributions (**Fig. 18**).

The arrivals of five sequential groups of squid were identified combining the CPUE depletion periods and the biological information (**Fig. 19**). 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 (40 g). The second group arrived on 12th of March and was composed mainly by males (90%) of bigger mean weight (50-60 g). The third group arrived on 17th of March and had a very variable female proportion (70-30%) and a smaller mean weight (45 g). The fourth group had a higher proportion of females (70%) and a mean weight similar to the first group (40 g). The fifth and last group had also greater proportion of females (70-50%) but much smaller mean weight of 35 g.

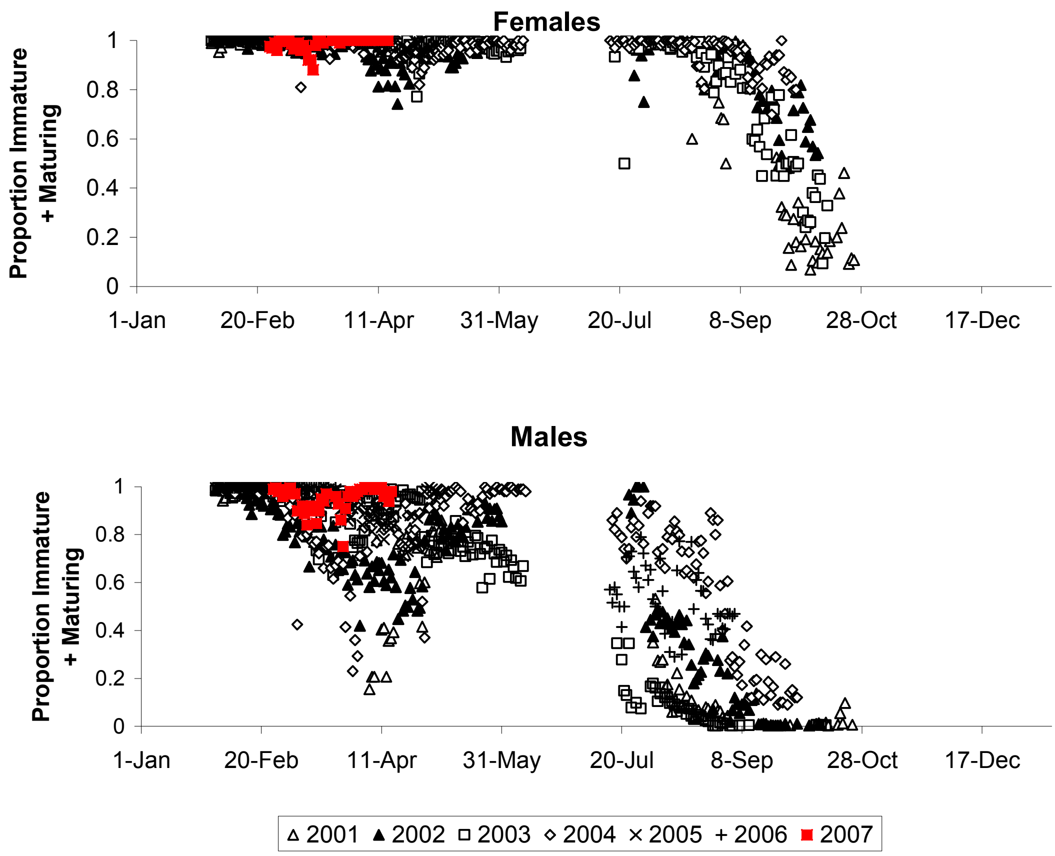


Fig. 13.- Current year trends in the proportion of sexually immature squids in the catch, compared with six previous years.

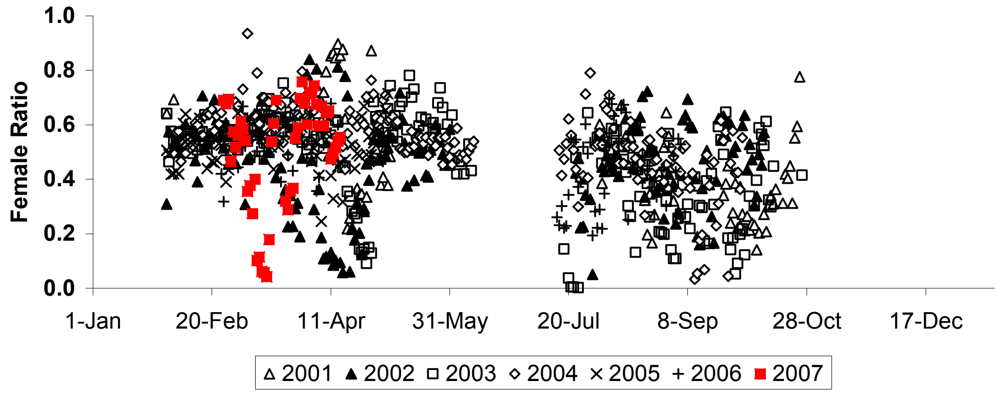


Fig. 14.- Current year trends in the daily evolution of the proportion of female squids in the catch, compared with six previous years.

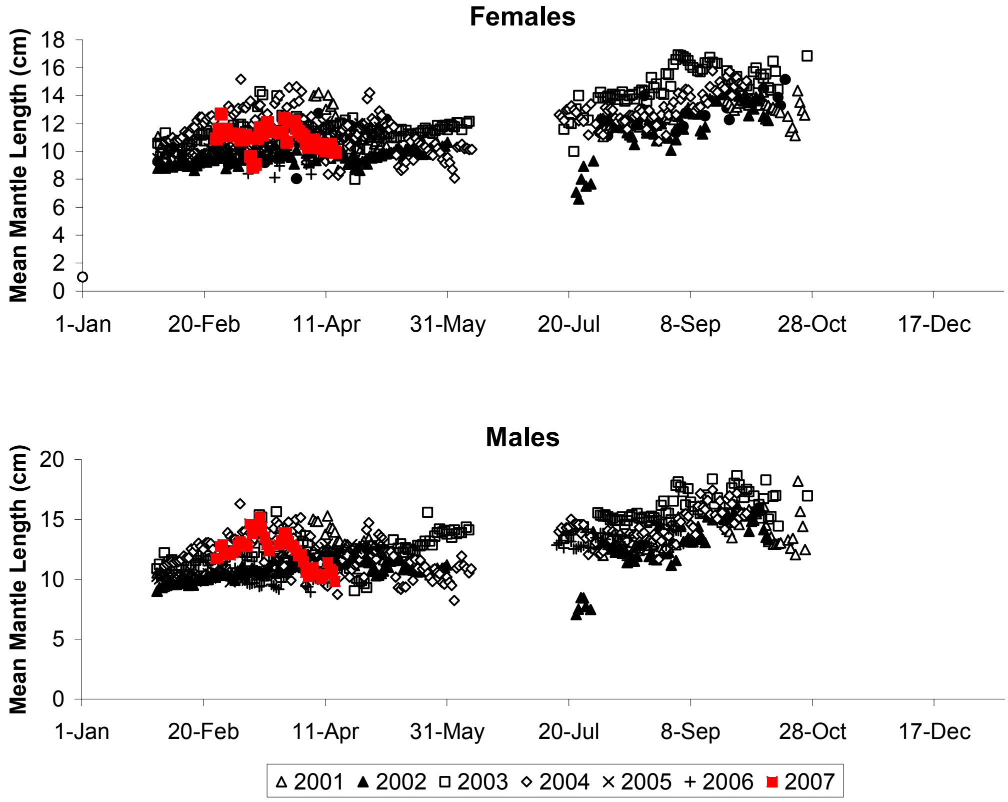


Fig. 15.- Current year trends in the mantle size by sexes, compared with six previous years.

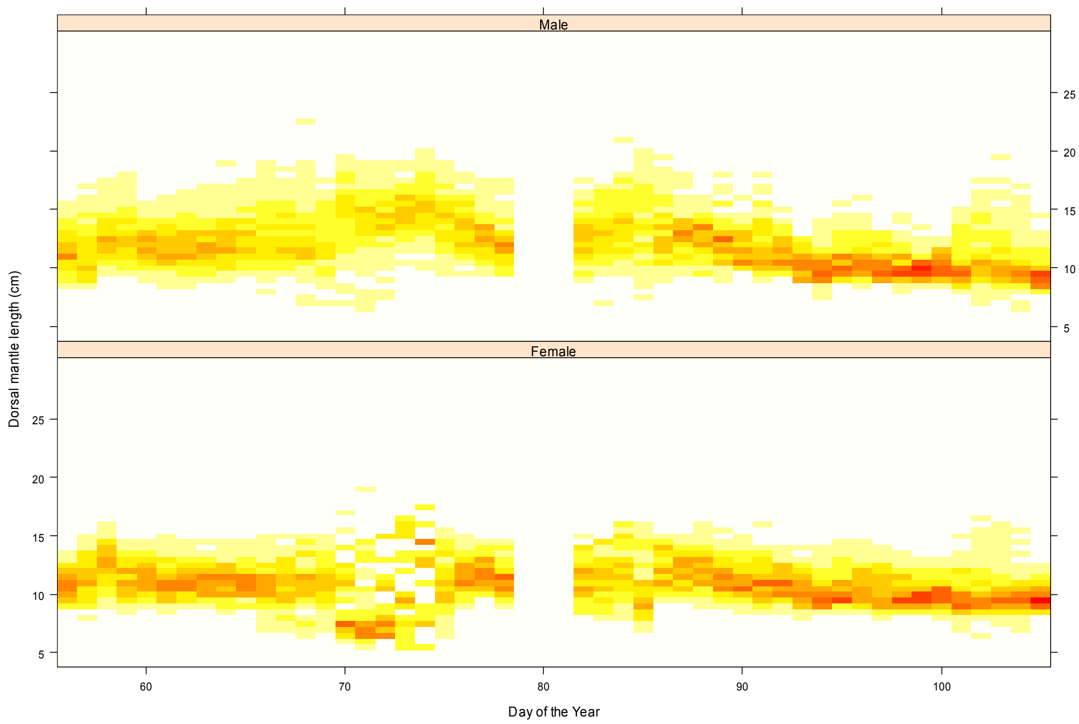


Fig. 16.- Time series of proportions (increases from yellow to red) of dorsal mantle length of squid in the catch during the first season, 2007.

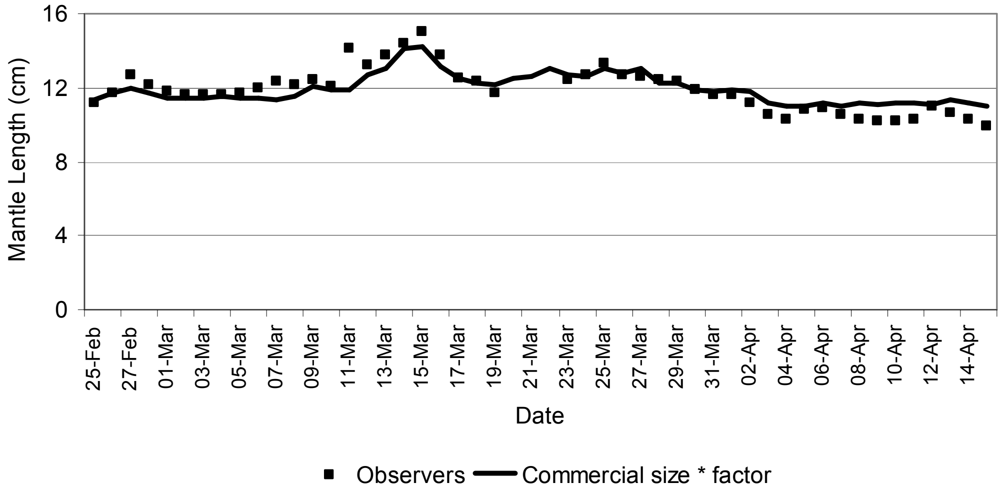


Fig. 17.- Average mantle length estimated from the scientific observers onboard and from the commercial size categories.

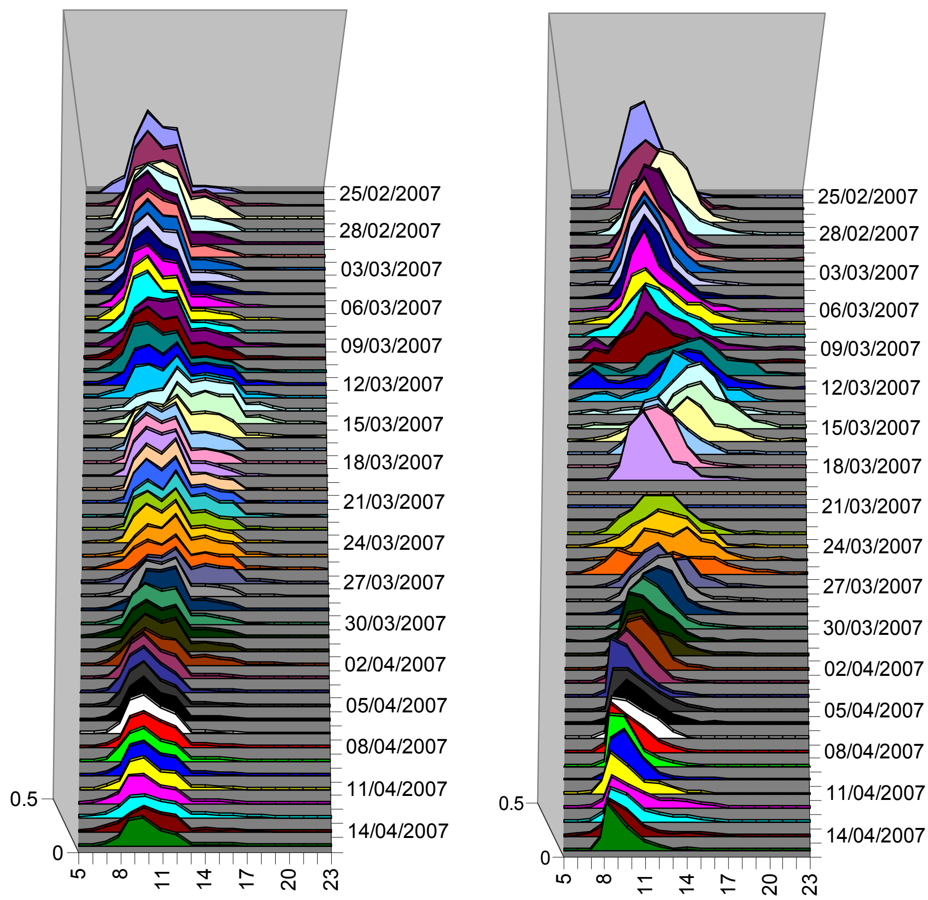
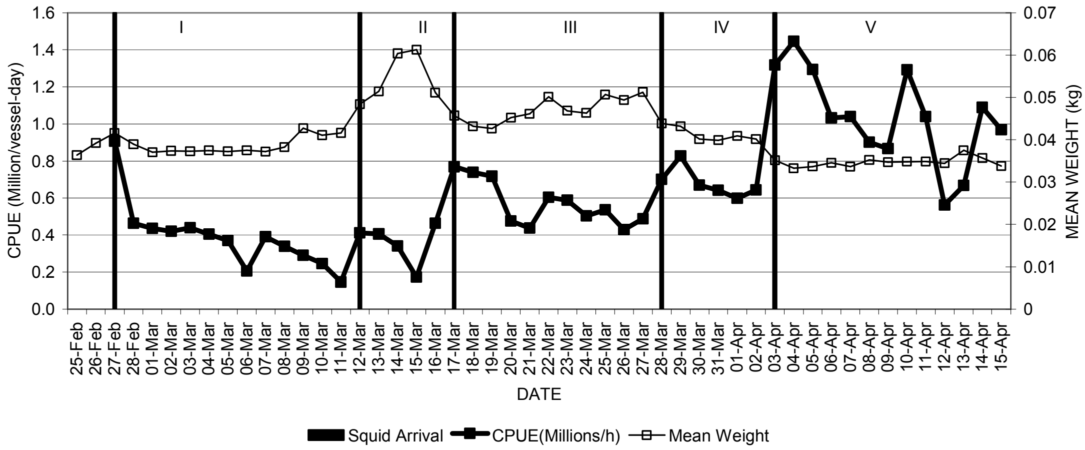


Fig. 18.- Mantle length distribution by day estimated from commercial size categories (left plot) and from scientific observers onboard (right plot).



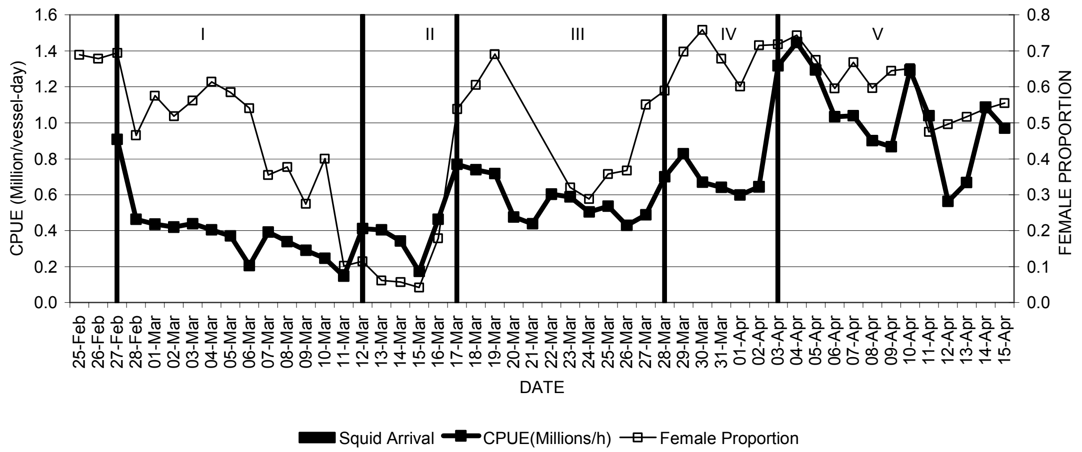


Fig. 19.- The arrivals of five different groups of squid to the southern area was identified based on the behaviour of the CPUE (million/vessel-day), the female proportion (upper plot) and the mean weight (down plot). The arrival dates are represented by the vertical bars.

PART 3 – STOCK ASSESSMENT AND RISK ANALYSIS

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 20**.

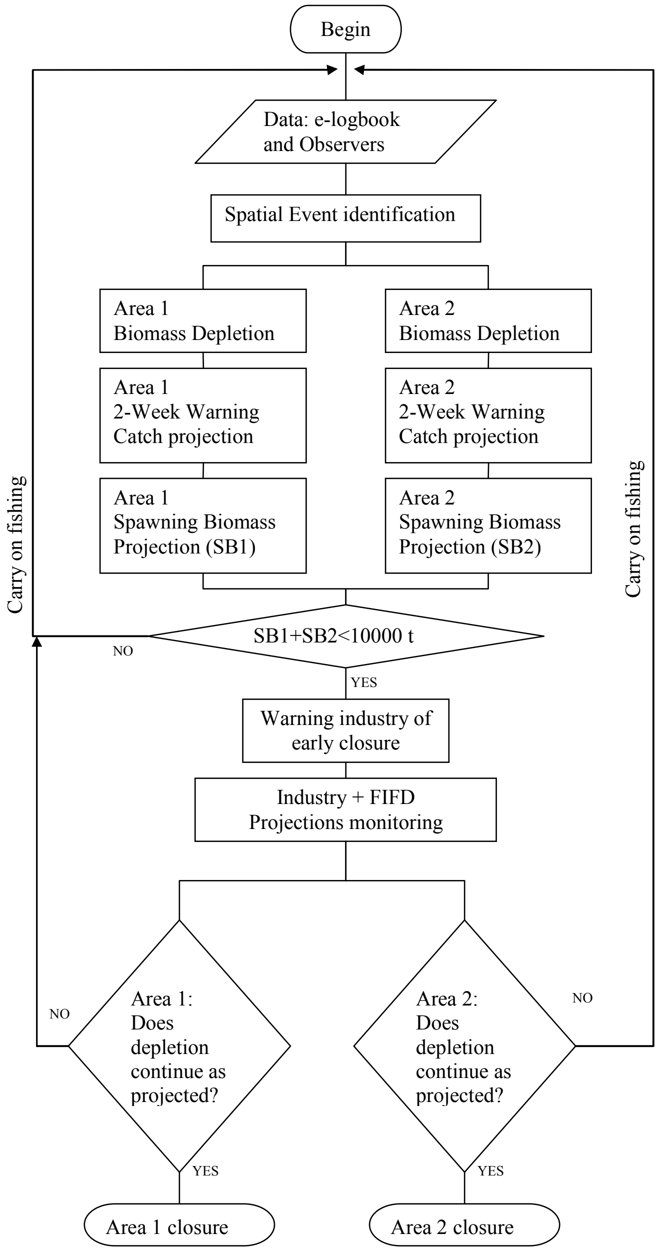


Fig. 20.- Flowchart of spatial management procedure for the early fishery closure decision. For simplicity only two depletion events are shown.

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

The equations for the stock assessment and risk analysis have been previously described in the 2006 second fishery report (Paya 2006), and therefore are not presented here again. However the depletion model was modified to estimate several depletion episodes together in one likelihood maximization process. It was assumed that the catchability, ***q***, was the same for the different squid groups. The different squid groups arrived to the same area and it was not possible to discriminate them in the catch statistics, therefore when a new group arrived the whole number of individuals (new group and survivals of previous groups) was estimated as a model parameter. Hence the abundance of the new group was calculated subtracting the survivals of previous groups from the whole abundance.

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

$$ {}^{G}B_{t=a} = B_{t=a} - {}^{S}B_{t=a} \, ,$$

$$ B_{t=a} = N_{t=a} W_{t=a} \, ,$$

$$ {}^{S}B_{t=a} = \mathrm{W}_{t=a} \left[\left(\mathrm{N}_{t=a-1} e^{-M/2} \right) - \mathrm{C}_{t=a-1} \right] e^{-M/2} $$

where:

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

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

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 tonnes of spawning biomass on the 31rst of May. During the first weeks of the season it was evident that *Loligo* migration to the fishing grounds was delayed and therefore there was a probability that new squid groups will arrive during the rest of the season. To incorporate this probability into the risk analysis a combined risk (*CR*) was defined as:

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

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

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

Biomass depletion probability was calculated by visual inspection of historical data of CPUE by day for the remaining time of the season. This probability was the proportion of all years in which the CPUE did not show any other depletion event that could be generated by the arrival of additional squid groups.

The uncertainty of the biomass estimations and projected biomass was estimated by bootstrapping techniques. The probability of leaving at sea less than 10000 tonnes of spawning biomass was calculated as the proportion of 1000 bootstrapping samples in which the projected biomass were lower than 10000 tonnes.

The assessment with data up to 27Th of March showed the projected catch for the two-week warning period lead the spawning biomass below 10000 tonnes (**Fig. 21**). The probability that spawning biomass were below 10000 tonnes was calculated at 0.72 (**Fig. 22**) and the probability of CPUE depletion was estimated at 0.75 (**Fig. 23**), resulting in a combined risk of 0.54. This analysis was presented to the fishery industry and it was agree to wait 4 days to see if another squid group could arrives. On the 28th another squid group arrived and then the fishery continued.

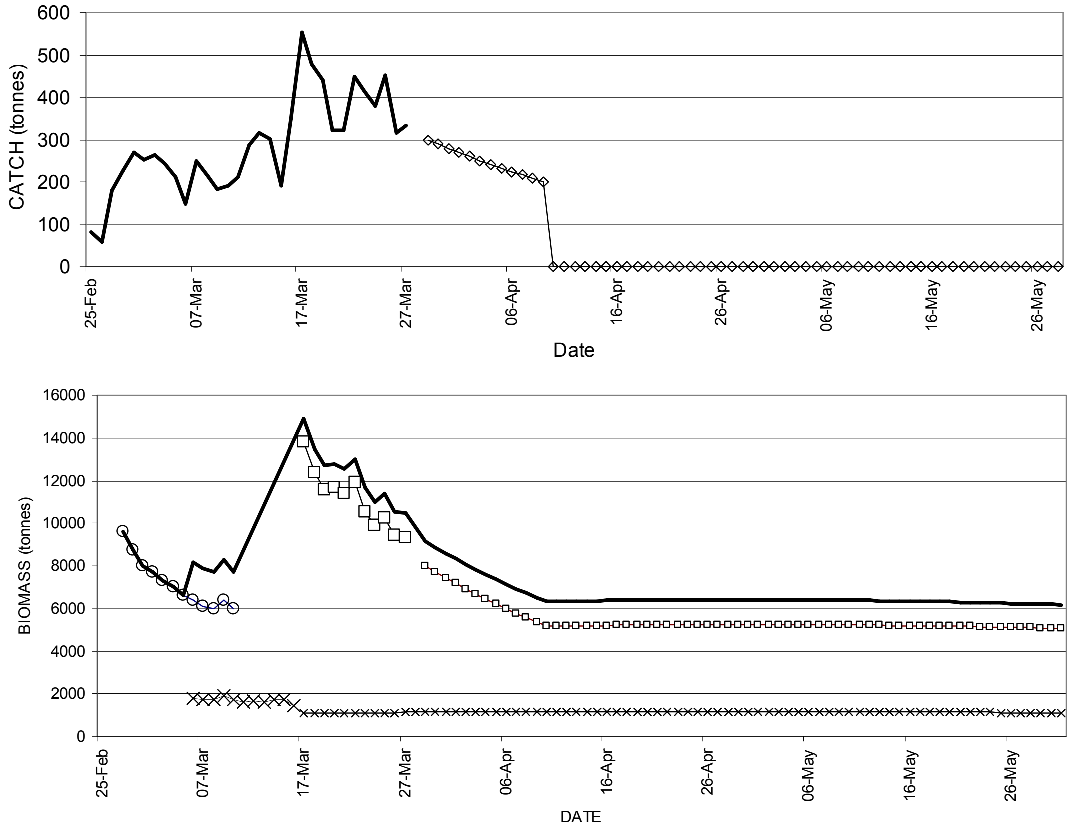


Fig. 21.- In-season stock assessment with data up to 27th of March. The upper plot shows the actual (bold line) and projected (line with squares) catches. The lower plot shows the total biomass (bold line) and Beauchene (lines with circles and squares) and the northern (lines with X) biomass.

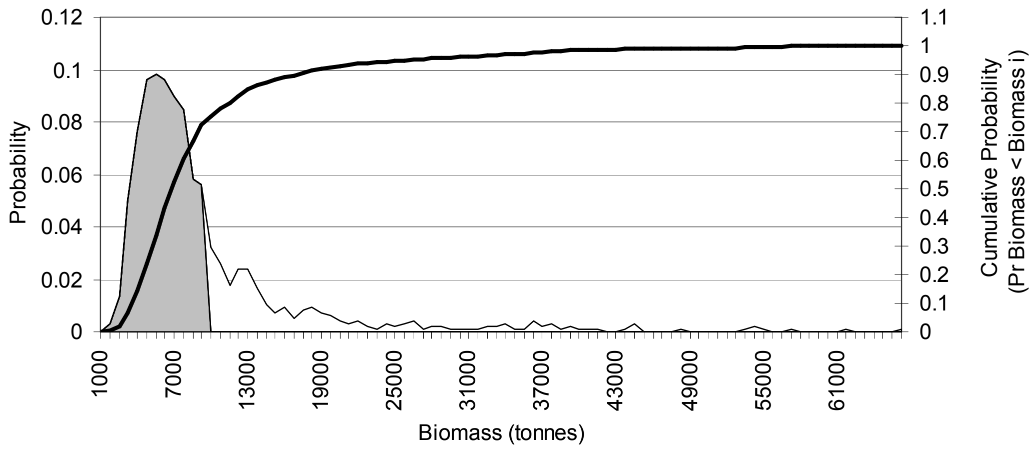


Fig. 22.- In-season stock assessment with data up to 27th of March. Probability distribution of projected spawning biomass and its cumulative probability. The risk of SB<10000 was 0.72 (proportion of grey area in the total area under the curve).

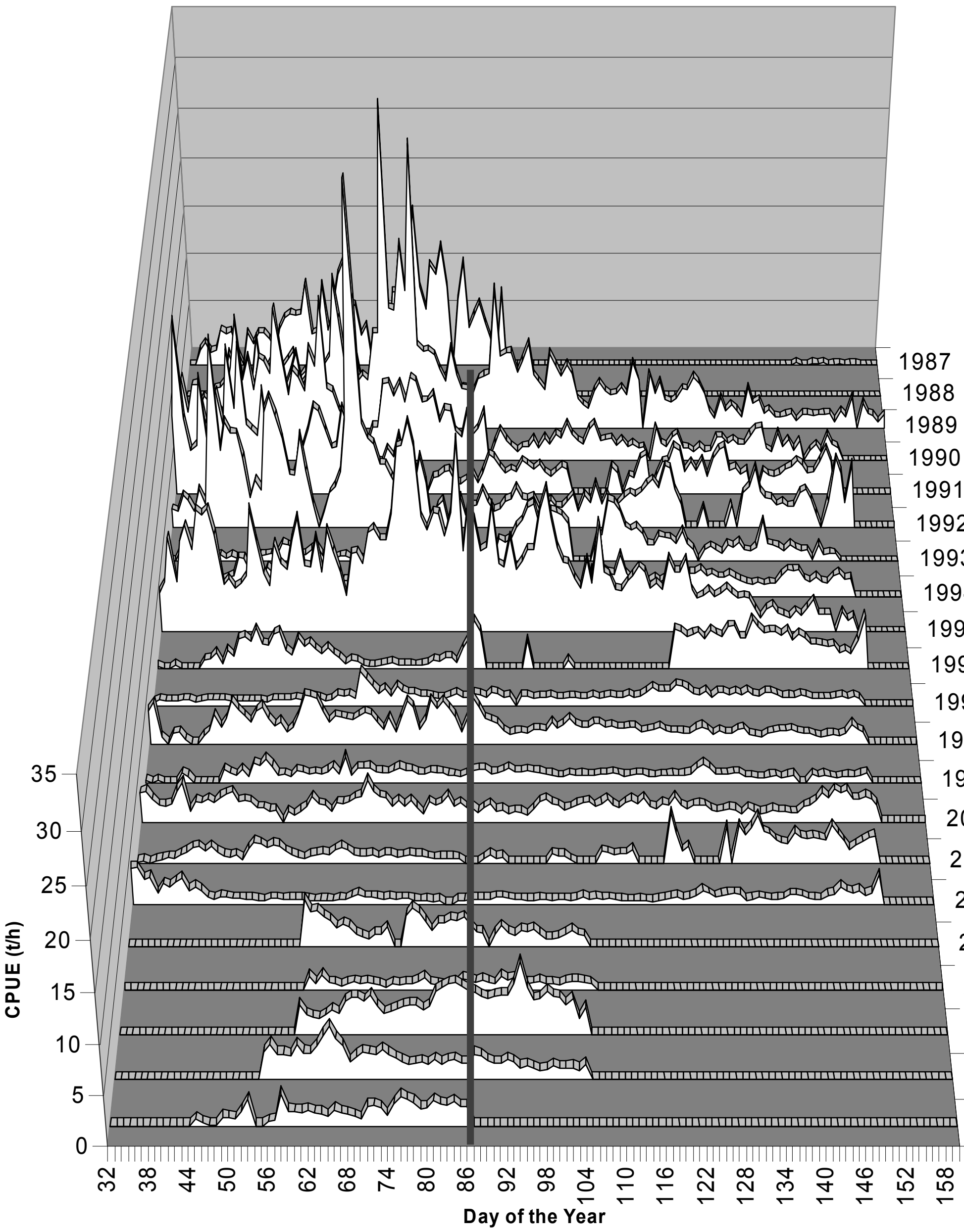


Fig. 23.- In-season stock assessment with data up to 27th of March. The CPUE is shown by day of the year and year. The bold line is the 27th of March, at this date there was 0.75 probability of CPUE depletion for the remaining days of the season.

The stock assessment with data up to 8th of April showed that after the 27th of March two other squid groups arrived and that the catch projected until the end of the season lead to biomass below 10000 tonnes (**Fig. 24**). The probability that the projected spawning biomass was less than 10000 was estimated at 0.78 (**Fig 25**) and the probability that the biomass depletion go on was estimated at 0.5, resulting in a combined risk of 0.39. Remaining only seven days to the fishing season and with an evident delay in the migration to the fishing grounds and a moderate combined risk level, it was decided to continue with the fishing operations until the scheduled end of the season.

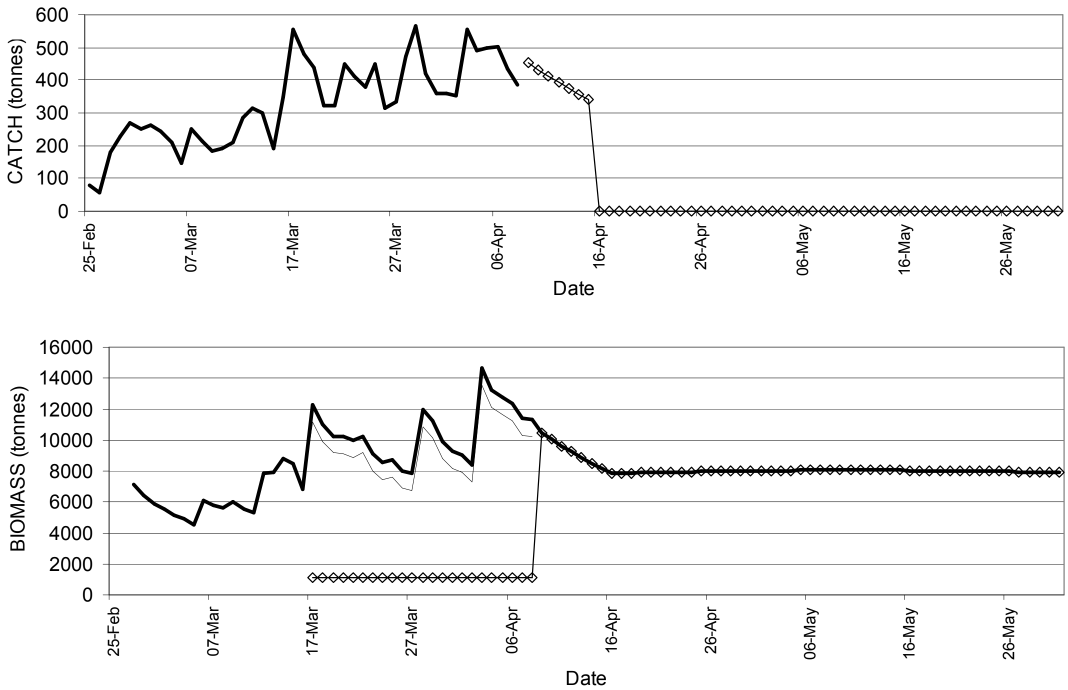


Fig. 24.- In-season stock assessment with data up to 8th of April. The upper plot shows the actual (bold line) and projected (line with squares) catches. The lower plot shows the total biomass (bold line) and Beauchene (thin lines) and the northern (lines with diamonds) biomass.

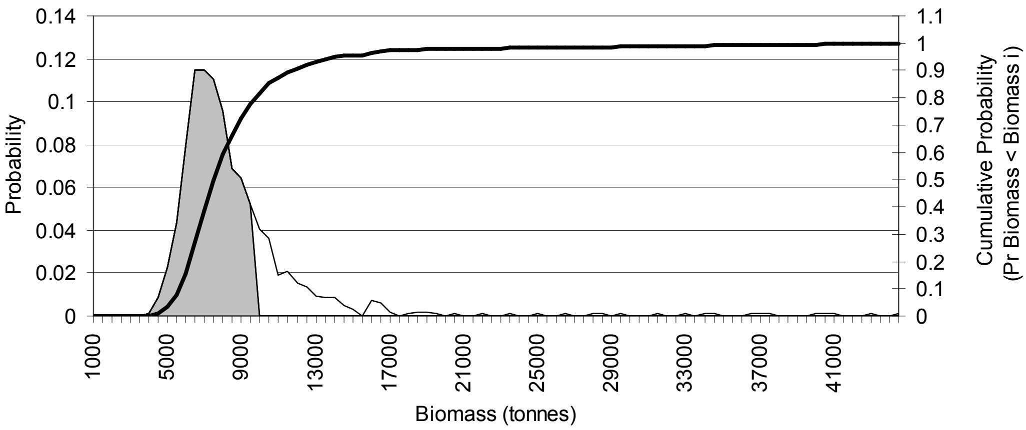


Fig. 25.- In-season stock assessment with data up to 27th of March. Probability distribution of projected spawning biomass and its cumulative probability. The risk of SB<10000 was 0.78 (proportion of grey area in the total area).

After-season stock assessment

Bootstrapping

The depletion model for the Beauchene area included five squid groups and the depletion model for the northern area just one. Both models had good fittings to the data (**Figs. 26 and 27**).

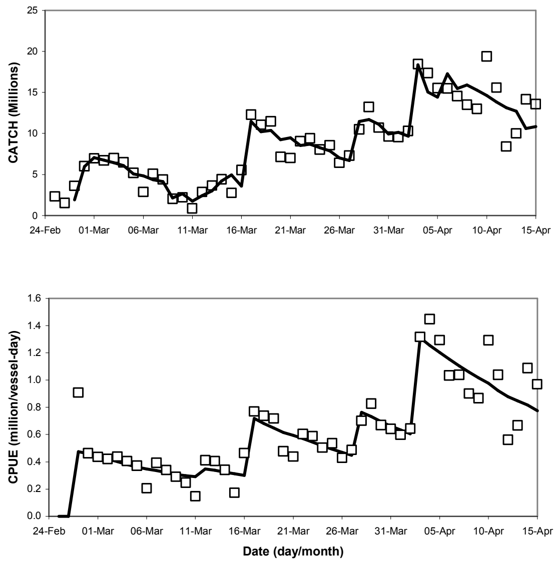


Fig. 26.- Model fitting to catch (upper plot) and CPUE (lower plot) data in the Beauchene area. The line is the predicted value and the squares are the data.

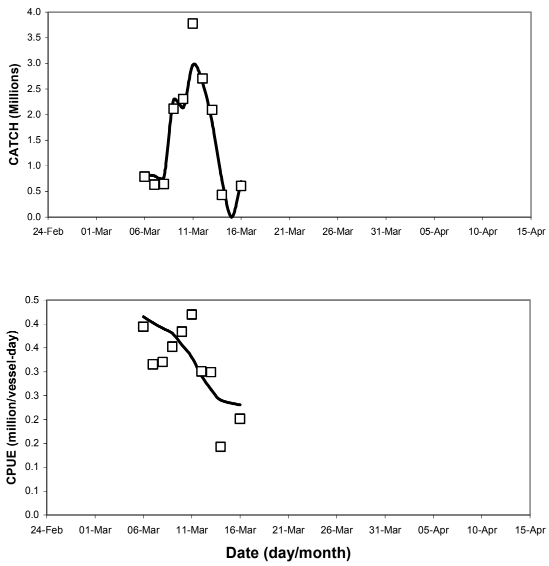
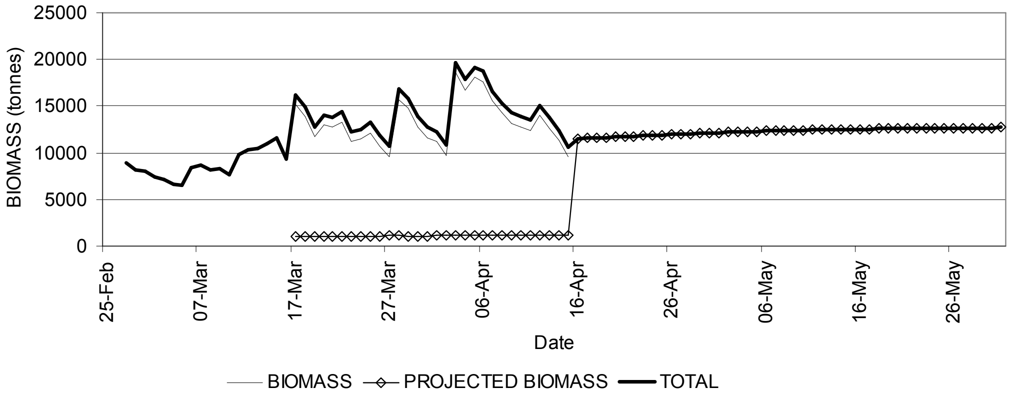


Fig. 27.- Model fitting to catch (upper plot) and CPUE (lower plot) data in the Northern area. The line is the predicted value and the squares are the data.

The whole biomass at the beginning of the season was estimated at 8923 tonnes then it increased with the arrivals of the new squid groups; the maximum biomass was estimated at 19686 tonnes on the 3rd of April and the biomass at the end of the season at 10626 tonnes (**Fig. 28**). The whole biomass in the fishing season was estimated in 37926 tonnes and corresponds to the sum of the biomass at the start of the season and the biomasses of the squid groups that arrived during the season. The spawning biomass on the 31rst of May was estimated at 12693 tonnes, and it is the result of the surviving squids and the growth of their body weight (**Fig. 28**).



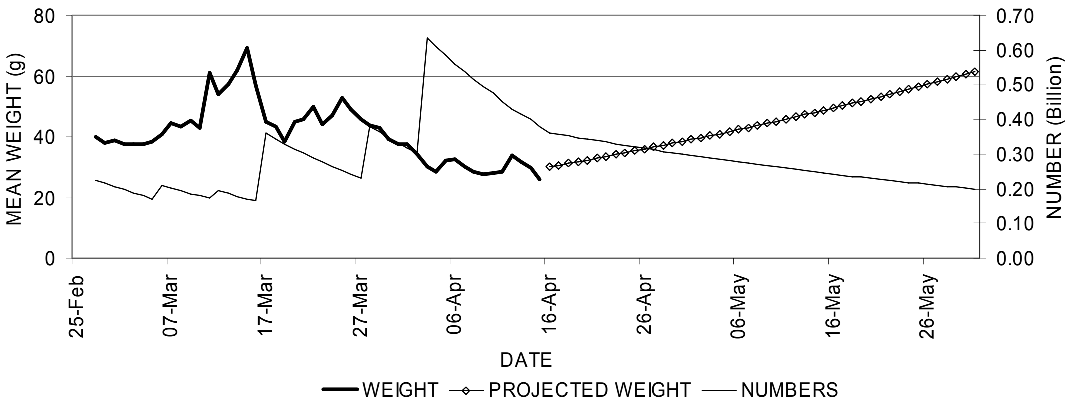


Fig. 28.- Biomass estimated by the depletion model and projected biomass (upper plot) based on the surviving squid number and on their growth in body weight (lower plot). The projected biomass before 15th April is based on the biomass in the northern area.

The uncertainty analysis by bootstrapping showed strong linear correlations between the natural logarithm of the catchability coefficient and the number of individuals parameters (**Fig. 29**). The density probability distributions of the biomasses were asymmetrical; with the maximum likelihood estimation closer to the 10% percentile than to the 90% percentile (**Fig. 30**). The projected spawning biomass was distributed from 6000 to 66000 tonnes and the risk that the spawning biomass could be less than 10000 tonnes was estimated at 0.08 (**Fig. 31**).

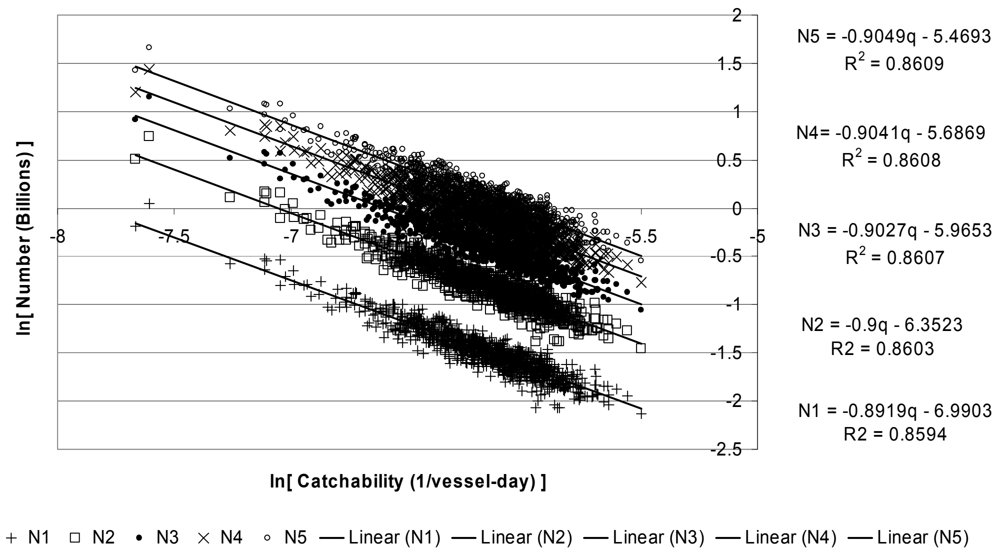


Fig. 29. Linear regressions between the natural logarithm of the catchability coefficient and the initial number parameters of the depletion model fitted to the Beauchene data.

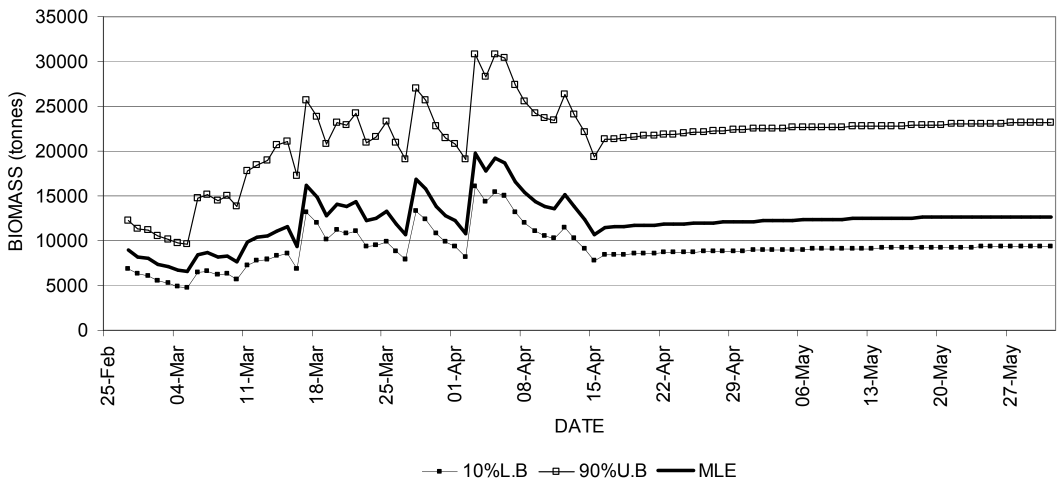


Fig. 30.- Maximum likelihood estimations of biomass and their 10% and 90% percentiles estimated using bootstrapping.

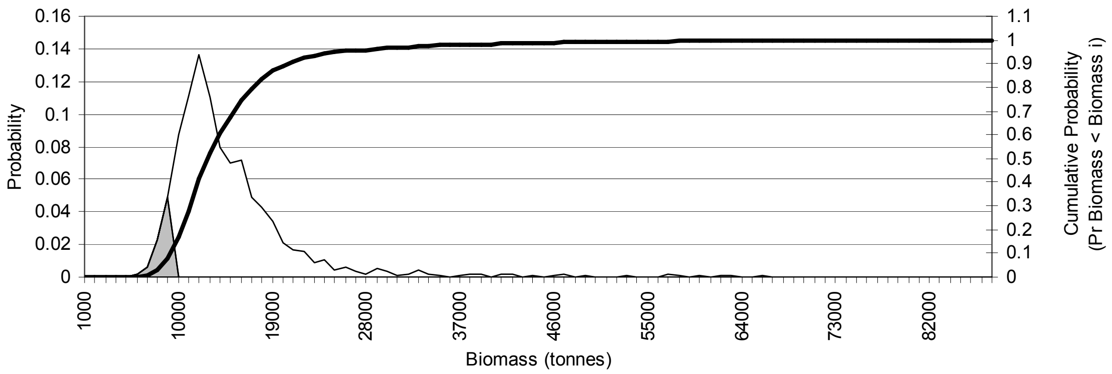


Fig. 31.- Probability distribution of projected spawning biomass and its cumulative probability estimated by bootstrapping. The risk that the spawning biomass could be less than 10000 tonnes is 0.08 (proportion of grey area in the total area).

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 analysis.

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. 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 Cauchy distributions, because their heavy tails allow higher probability for extreme values (Johnson ***et al.*** 1994). The Cauchy density function is

$$(\pi\lambda)^{-1}\left[1+\left\{\frac{x-\phi}{\lambda}\right\}^2\right]^{-1}$$

This distribution does not possess finite moments of order greater than or equal to 1, and so does not posses a finite expected value or standard deviation, however the locations parameters ϕ and λ may be regarded as being analogous to mean and standard deviation (Johnson *et al.* 1994). For each parameter the average of the 1000 bootstrapping were used as ϕ and a standard deviation that generates a coefficient of variation of 150% was used as λ.

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. Three chains of 20000 iterations were generated using a normal distribution as a local jumping rule, in each iteration the mean is equal to the value of the parameter in the previous iteration and the coefficient of variation is 1.5 (Gelman ***et al.*** 2004). The first 8000 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 36000-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.

After the burning section, the chains reached the convergence criterion at iteration 15000 for Northern area model (**Fig. 32**) and at iteration 8000 for Beauchene model (**Fig.33**).

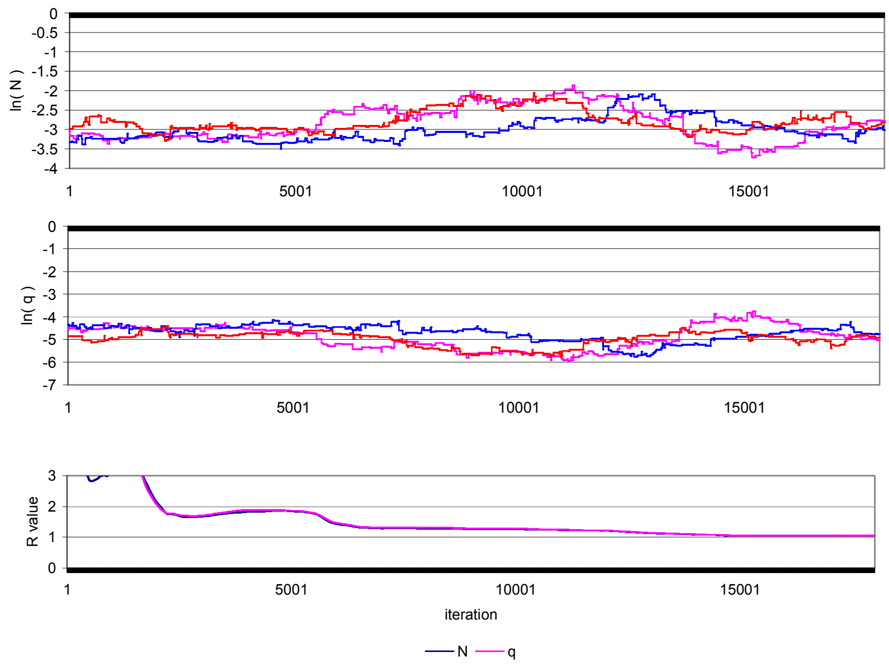


Fig. 32.- MCMC results for Northern area. Three chains for each parameter and the convergence index (***R***), which must be lower than 1.1.

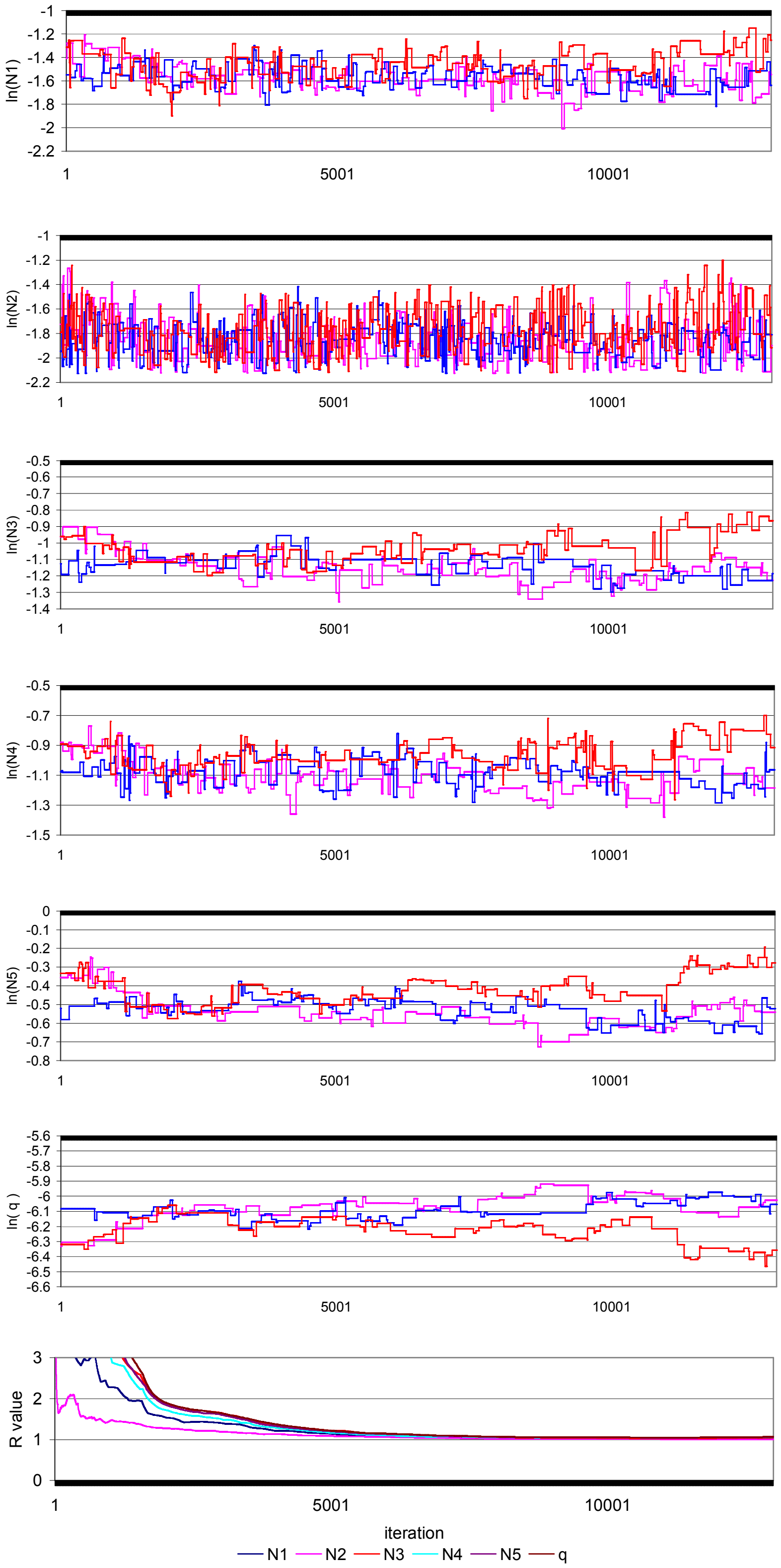


Fig. 33.- MCMC results for Beauchene area. Three chains for each parameter and the convergence index (***R***), which must be lower than 1.1.

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. 34 and 35**). The numbers of individual (N) parameters were highly correlated with the catchability parameters, and they had strong log-linear relationship (**Fig. 36**).

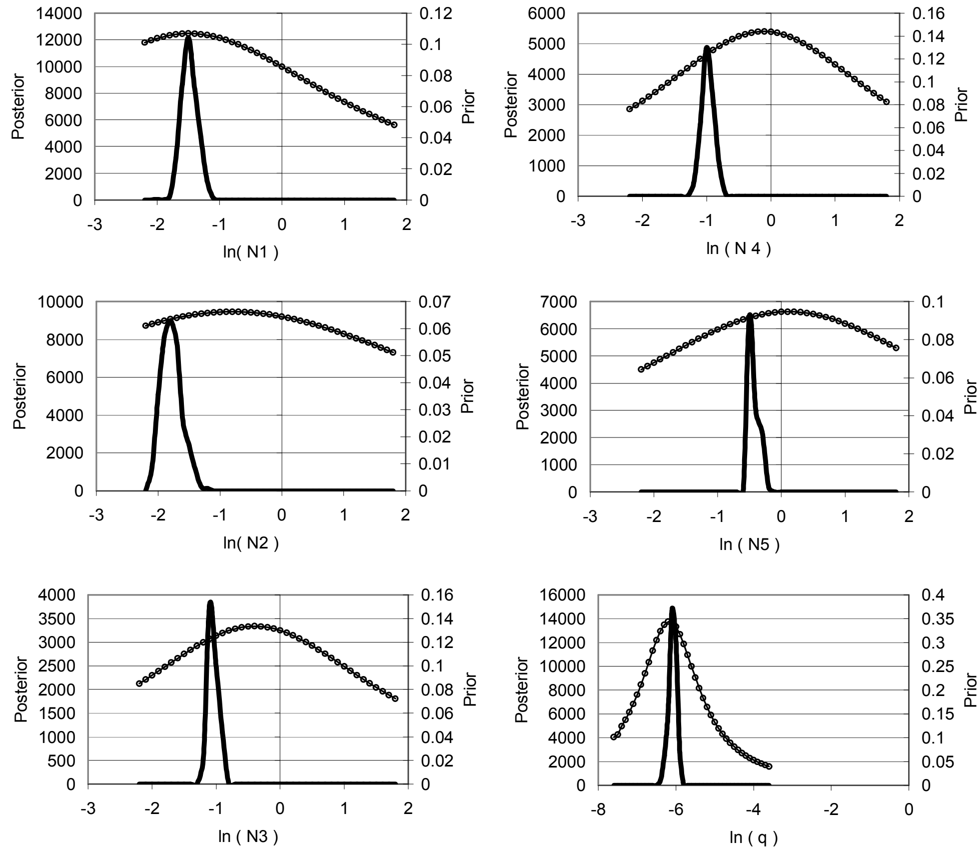


Fig. 34.- Prior (line with circles) and posterior (bold line) distribution of initial numbers (N) and catchability coefficient (q) parameters of the Beauchene depletion model.

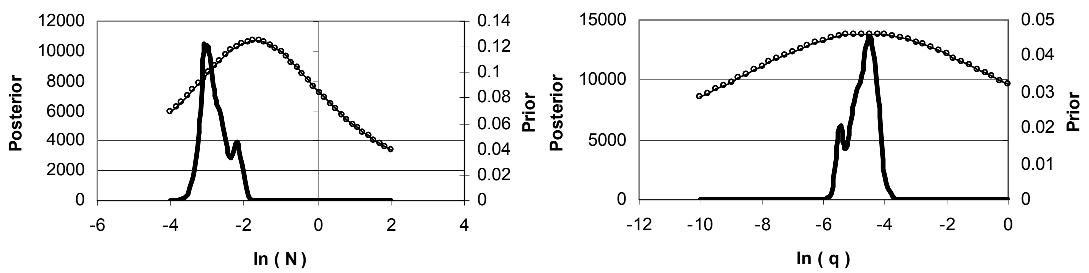


Fig. 35.- Prior (line with circles) and Posterior (bold line) distribution of initial number (left plot) and catchability coefficient (right plot) parameters of the depletion model of the Northern area.

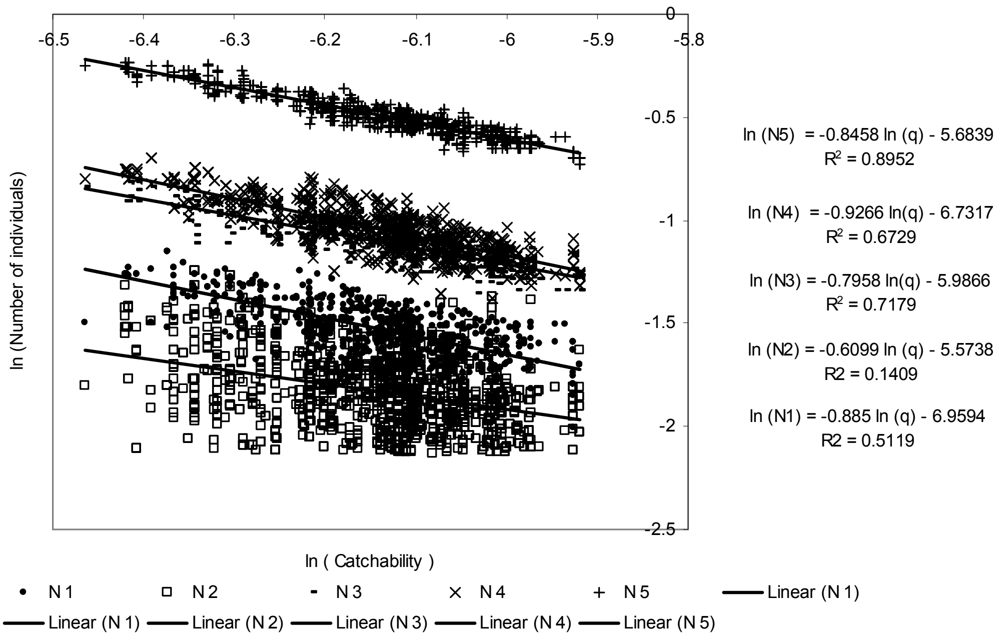


Fig. 36.- Log-linear regression of abundance (N) parameters and catchability (q) parameter for the Beauchene depletion model.

The whole biomass at the beginning of the season was estimated at 8250 tonnes then it increased with the arrivals of the new squid groups; the maximum biomass was estimated at 19250 tonnes on the 3rd of April and the biomass at the end of the season at 10500 tonnes (**Fig. 37 and Table 3**). The whole biomass in the fishing season was estimated at 37517 tonnes and corresponds to the sum of the biomass at the start of the season and biomasses of the squid groups that arrived during the season (**Fig. 38 and Table 3**). The spawning biomass on the 31rst of May was estimated at 12250 tonnes (**Table 4**). All these estimations are quite similar to those made with likelihood maximization without any prior distribution (see bootstrapping section).

The risk of surpassing the 10000 tonnes spawning biomass limit was 0.017. This risk corresponds to the cumulative probability of the biomass values lower than 10000 tonnes (**Fig. 39**).

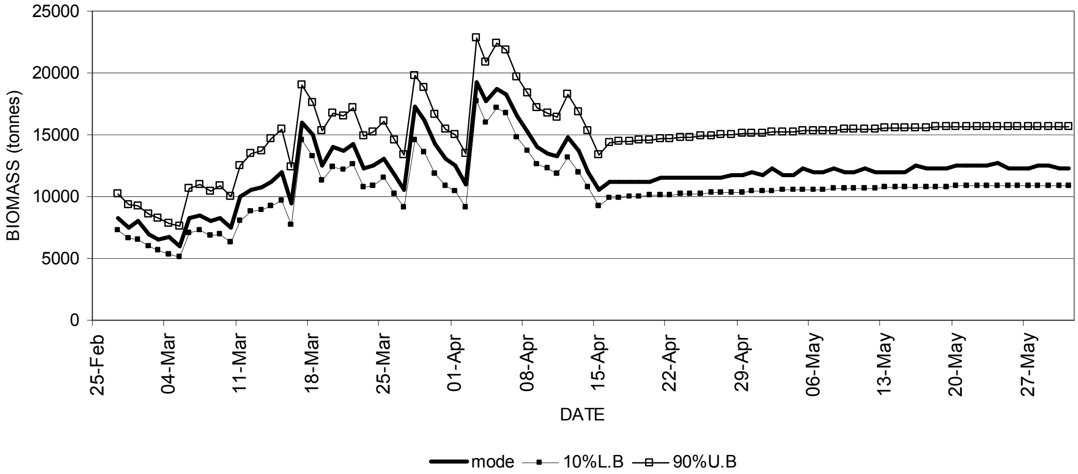


Fig. 37.- Biomass depletion and projection estimated by Bayesian inference (10%L.B= 10% percentile lower boundary; 90%U.B= 90% percentile upper boundary).

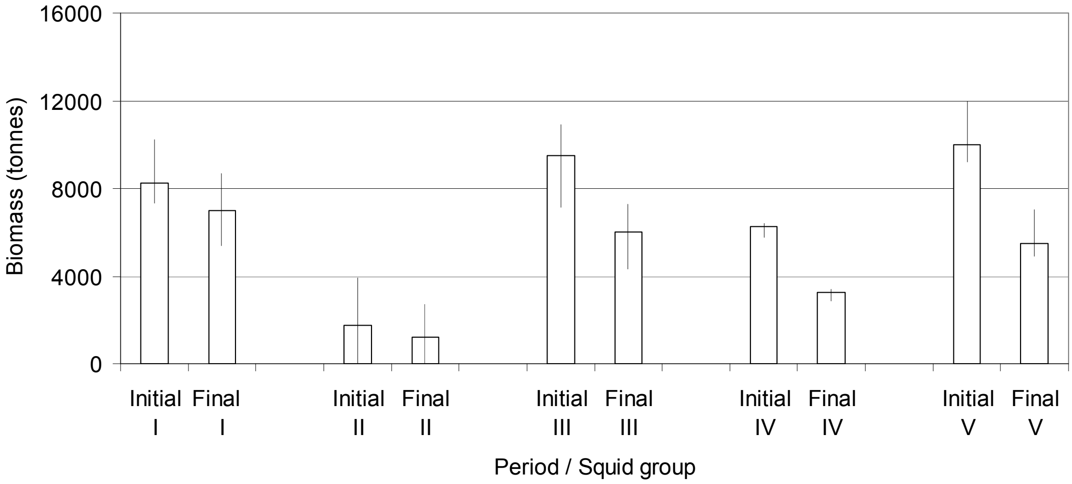


Fig. 38.- Initial and final biomass of the squid groups in Beauchene area estimated by Bayesian inference (vertical bars represent the 80% confident intervals). These biomasses correspond to the biomasses presented at the start and at the end of each depletion episode.

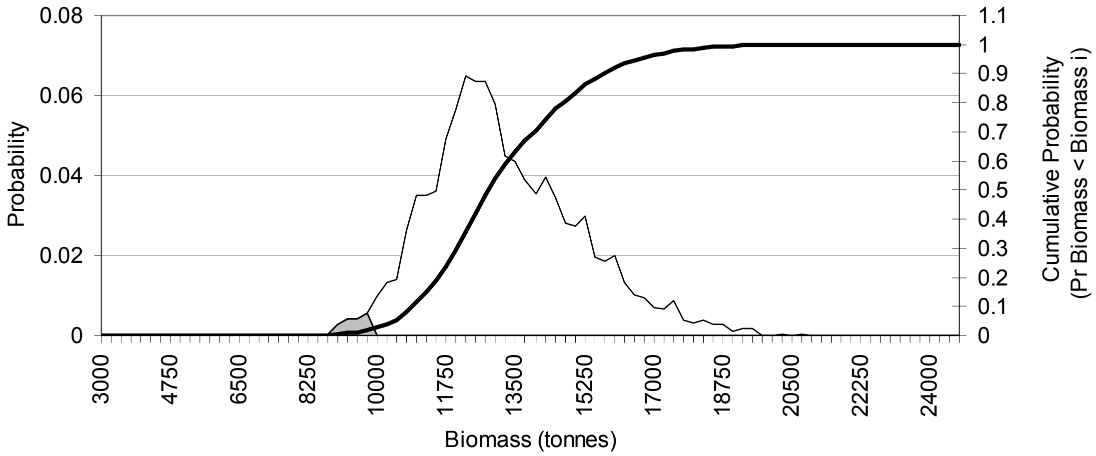


Fig. 39.- Probability distribution and cumulative probability of the spawning biomass projected to the 31[rst] of May. The dark area beneath the curve shows the values lower than 10000 tonnes. The cumulative probability at 10000 tonnes was 0.017 and it corresponds to risk of surpass the limit of 10000 tonnes spawning biomass.

DISCUSSION

The 3-week delay in migrations to the fishing grounds is likely related with the negative anomalies of the sea temperature observed during February, which constrained the *Loligo* distribution to shallow waters (A. Arkhipkin. Pers. Com.). The 5.5°C isotherm marks the limit of squid distribution into deeper waters (Arkhipkin ***et al.*** 2004).

The greater *Loligo* sizes during this season, 2 cm larger than in 2006 first season, is likely related with positive anomaly in water temperature in December. This increase in water temperature should positively affected *Loligo* growth (A. Arkhipkin. Pers. Com.).

The quick dynamics of migrations to the fishing grounds showed that the arrival of the squid groups must be observed in a daily basis, because this is obscured in a weekly basis. There was also evident the high dynamics of sexual rations that could be incorporated in further models.

The depletion model with several squid groups is based on the assumption that the catchability is constant during the whole fishing season. This allows to fit the model to depletion events of short duration, that otherwise could be very difficult to do. However, it is also possible that some variability exist in the catchability coefficient related with environmental conditions or some reactions of the squid to the fishing activities in a particular place. In the current depletion model, this variability is considered as part of the random error that is included in the residuals.

Table 3.- 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 (tonnes)	21816	82247	38212	8250	1767	9500	6250	10000	1750
	(53.0)	(55.6)	(53.1)	(11.0)	(98.0)	(16.0)	(3.9)	(10.9)	(23.3)
Final Numbers N_T	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.- 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)

[1]Inshore Beauchene and [2]Offshore Beauchene

This fishing season showed that when there is a delay in the immigration to the fishing grounds the risk analysis must include not only the projection of the biomass presents in the fishing grounds but also the probability of the arrivals of new squid groups. The computation of arrival probability was made counting these events in the historical data, but further studies on the arrivals of squid to the fishing grounds are needed to improve this probability estimation.

The bootstrapping uncertainty estimations were similar to the Bayesian estimations. Therefore the bootstrapping provides a quick option to estimate the uncertainty during the in-season stock assessment. However, if more informative priors could be generated from historical analysis, the Bayesian estimation could produce different results than the bootstrapping technique.

CONCLUSIONS

1) Total catch (17229 tonnes) reached an intermediate catch level compared to the last 5-yrs first seasons, while total effort (8780 hours of trawling) was similar to the last 4-yrs first seasons.
2) This fishing season started with few squid in the fishing ground (8924 tonnes) due to a 3-week delay in the *Loligo* immigration to the fishing grounds.
3) Five squid groups arrived sequentially to the Beauchene area and one group to the Northern area.
4) The whole biomass, the one that was present at the start of the season plus the ones that arrived during the season, was estimated at 37517 tonnes.
5) The biomass at the end of the fishing season was estimated at 10500 tonnes.
6) When the immigration is delayed the risk analysis should incorporate the probability that new squid groups arrive to the fishing grounds and not only the projection of the biomass presents in the fishing grounds.
7) The fishing season ended at the scheduled date with a projected spawning biomass of 12250 tonnes and a risk of leaving less than 10000 tonnes of 0.017.

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