Falkland Island Fisheries Department

Fishery Report

Loligo gahi, Second Season 2004

Fishing Statistics, Biological Trends and Stock Assessment

SUMMARY

Second season (July/15-Sept/30, 2004) total catch by the *Loligo* fleet was 17559 tons. This was well within the range of a moderately good season. Biological trends (proportion of mature individuals, proportion of females, and body size) were similar to recent seasons. In order to represent the spatial and temporal dynamics, as well as the fishing behaviour of the fleet, we introduced a division of fishing statistics and stock assessment per major fishing grounds (Beauchene, Central, and North). In addition, we used the vessel-day unit of effort rather than hours of trawling. Stock assessment was undertaken using a new implementation of De Lury depletion model and an additional method based on a biomass projection model from results of the Argos Vigo survey of May. Total biomass at the start of the season was estimated as 19697 tons (De Lury) or 17009 tons (biomass projection) in the Beauchene area, and 17523 tons (De Lury) or 17223 tons (biomass projection) in the Central + North. This biomass changed during the season because of individual growth, natural mortality and fishing catch. The balance at the end of the season was about 17415 tons of squid left in the sea (biomass projection). As such the management objective of leaving 10 thousand tons of spawning stock in the sea after the season was met.

INTRODUCTION

The first *Loligo* season of 2004 yielded catch and effort data that did not accord with the assumptions of De Lury depletion model, the usual method of stock assessment for this fishery. In previous seasons there have been occasions too when the catch-effort data did not yield to stock assessment analysis, using the program MSquid of RRAG in London (**Table 1**). In the present work we have carried out some basic changes in the manner in which the data are analysed. These changes have been brought about by closer examination of the real fishing and biological dynamics by biologists and stock assessment scientists. Specifically, we have observed that the *Loligo* box contains at least three separate fishing grounds, one around the Beauchene Island (Beauchene), another off Shag Rock and Lively Island (Central), and another one in the northern part of the *Loligo* box, off Stanley (North, see **Fig. 1**). This observation is very important because the stock assessment model currently used for the *Loligo* stock cannot cope with a fleet that switches between fishing grounds. The simple solution is to perform separate assessments for each fishing ground with the current model. The complicated solution is to generalise the model to account for a fleet that switches fishing grounds. We have applied the simple solution. Accordingly, the fishery statistics part has also been organised in reference to the three fishing grounds.

Another important change is in the use of the unit of fishing effort. So far, the number of hours of trawling per day has been used. However, we have observed that some vessels trawl at night for many hours for a small catch of squid (are they targeting finfish?). Squid at night are thought to go up the water column and thus are mostly inaccessible to the trawling gear. Of course this creates the problem that CPUEs are artificially reduced, seriously affecting the stock assessment model. Thus we have decided to use the vessel-day unit of effort, which is not affected by the decision to trawl at night. In addition, captains seem to measure their performance (which ultimately determines the catchability parameter in De Lury model) in terms of catch per day rather than per hour.

Finally, we have introduced a new approach to stock assessment based on projecting the biomass observed previously in a research survey onboard the commercial fishing vessel Argos Vigo. This method is mathematically different and utilises data other than that used in the De Lury depletion method mentioned above. For this reason it serves as an independent test of how reliable our methods are. If the biomass projected from the Argos Vigo survey and the biomass estimated from De Lury model are close to each other, then our assessment is more reliable.

The second season of 2004 started on the 15th of July and lasted until the 30th of September. All our fishery statistics and biological trends cover this period.

PART 1 – FISHERY STATISTICS

Fishery statistics are based on a complete census of relevant activities and results by the fleet.

Total Catch and Total Effort in Historical Perspective

Total catch and total effort were well within the range of historical results for the fishery in the second season (**Table 1**). The biomass of the stock at the start of the season was about double as much as the catch. It is not possible to compare the current biomass estimate with previous seasons' estimates because the stock assessment methodology has changed significantly. In previous seasons no distinction was made among fishing grounds, so it is possible that different depletion processes (one for each fishing ground) had been pooled into one. It may be necessary to re-analyse the data from previous seasons.

Fishing Grounds

Results of the research survey of May 2004 (Doc. 563) and previous biological and fisheries knowledge suggested that the *Loligo* box be divided into three areas, or fishing grounds, as shown in **Fig. 1**. In terms of grid squares the Beauchene area is composed of all squares (inside the *Loligo* box) in the latitudinal range XU-XW, the Central area of squares XS-XT, and the North are of squares XM-XR. Though these three areas may capture most of the dynamics of fleet movement and local depletion of the stock, it must be noted that captains identify smaller fishing grounds (like "El Seco" in the Beauchene area or the "Mar de Macaroni" in the North area).

Table 1.- Fishery statistics and initial biomass for the known history of the *Loligo gahi* fishery of the Falkland Islands. RRAG is the Renewable Resource Assessment Group of the Imperial College, London. FIFD is the Falkland Islands Fisheries Department. 'Failure' indicates that De Lury depletion model could not produce a reasonable estimate of initial biomass. Current figures in bold font.

	Season 1			Season 2			Year Total	
Year	Catch (ton)	Effort (h)	Biomass (ton)	Catch (ton)	Effort (h)	Biomass (ton)	Catch (ton)	Source
1970							200	Csirke 1986
1971							100	Csirke 1986
1972							100	Csirke 1986
1973							250	Csirke 1986
1974							200	Csirke 1986
1975							140	Csirke 1986
1976							129	Csirke 1986
1977							354	Csirke 1986
1978							911	Csirke 1986
1979							925	Csirke 1986
1980							1111	Csirke 1986
1981							631	Csirke 1986
1982							18452	Csirke 1986
1983							38256	Csirke 1986
1984							36450	Csirke 1986
1985							36430	Csirke 1986
1986								
1987	64063		101000	18484		202000	82547	
1988	48664		115000	5267		39000	53931	
1989	106186	33159	165000	11671	16881	46000	117857	RRAG-FIFD
1990	69078	24177	206000	13589	15713	104000	82667	RRAG-FIFD
1991	37336	13808	53000	16293	16610	146000	53629	RRAG-FIFD
1992	47407	15406	97000	35100	19291	264000	82507	RRAG-FIFD
1993	21814	16065	47000	28650	32950	90000	50464	RRAG-FIFD
1994	34741	19891	55000	30226	29687	116000	64967	RRAG-FIFD
1995	60759	10913	195000	37251	22365	141000	98009	RRAG-FIFD
1996	38729	16438	31000	22662	28420	130000	61392	RRAG-FIFD
1997	15973	16766	40000	10159	18486	82000	26131	RRAG-FIFD
1998	32774	16835	60000	17287	22762	Failure	50061	RRAG-FIFD
1999	22189	19642	44826	11596	18266	53737	33785	RRAG-FIFD
2000	38697	21034	63683	25723	18869	Failure	64420	RRAG-FIFD
2001	27611	20955	26000	25888	19841	162234	53499	RRAG-FIFD
2002	14194	20824	21000	9459	11570	Failure	23653	RRAG-FIFD
2003	15966	8494	40350	28301	16166	Failure	44267	RRAG-FIFD
2004	6669	8740	Failure	**17559**	**17024**	**37220**	24228	FIFD

An additional area only for fishery statistics has been defined at grid squares XHAL, XKAG, and XKAN, which are north and north-west of the *Loligo* box. Three vessels visited this area from 10 to 13th based on data provided by the R/V Dorada.

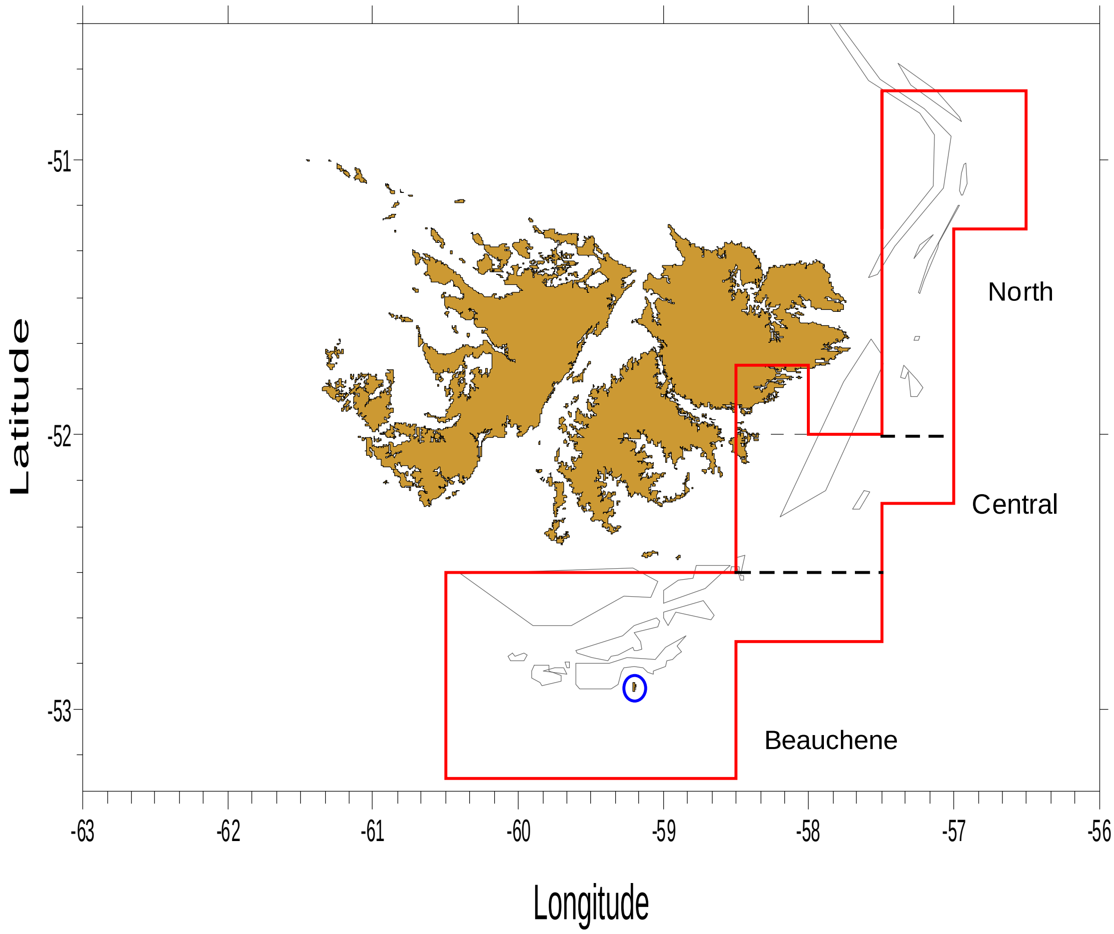

Fig. 1.- Fishing grounds and rocky bottoms around the Falkland Islands. In red, the *Loligo* box, and in blue, the three-nm exclusion area around Beauchene Island.

Catch and Effort per Fishing Ground and Cumulative Catch

In terms of total catch and total effort the Beauchene area was the most important one this season (**Table 2**). This area also yielded the highest average catch per unit vessel-day, though not the highest average catch per unit of hour trawling. It appears that the Beauchene area is most often used for nocturnal trawling.

The daily cumulative catch varied approximately half-way between the best and worst recorded second seasons (**Fig. 2**).

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

Fishing Ground (Area)	Total Catch (ton)	Effort (Vessel-Day)	Effort (hour)	Average CPUE kg/V-D	Average CPUE kg/h
Beauchene	8544	533	8875	16.029	0.963
Central	3038	226	3483	13.442	0.872
North	5956	376	4584	15.841	1.299
North Extra	21	6	82	3.461	0.255
Total	17559	1141	17024	15.389	1.031

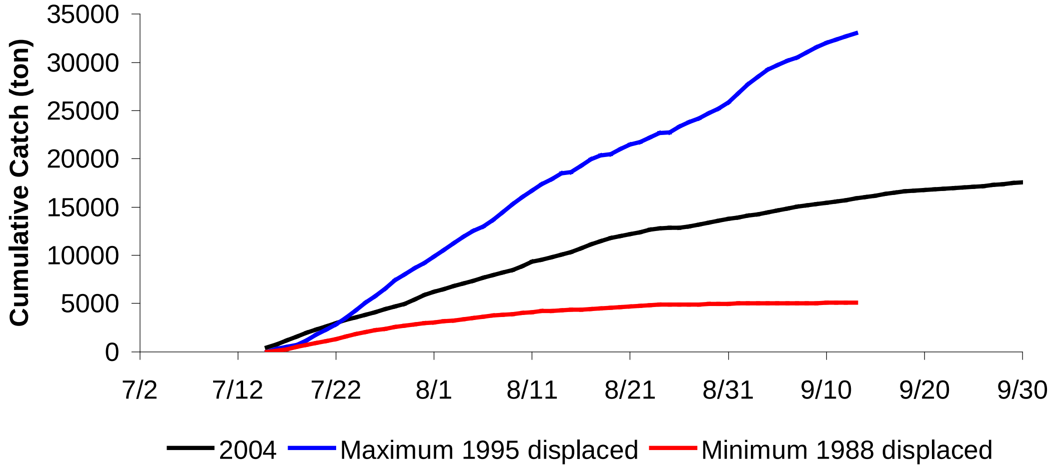

Fig. 2.- Cumulative catch versus date (month/day) in the second season of 2004 compared with the cumulative catch of the second seasons that yielded the highest and lowest historical catches (displaced as if they had started at the same date as the 2004 second season).

Fleet Movement Dynamics

During the first few days of the season (up to July/27) the whole fleet worked in the Beauchene area (**Fig. 3a**). After that date the situation changed as different captains decided to switch to the central or northern fishing grounds while some decided to stay in Beauchene (**Fig. 3a**). This dynamic situation in which different captains changed grounds remained until the end of the season (**Fig. 3a**). Despite this, at any given day during the season the North or Beauchene fishing grounds had most of the vessels. One plausible explanation for this pattern is that while most of the vessels were fishing in the currently best area, others were exploring the other grounds. If these grounds were more productive the other would move there when information was passed along from vessel to vessel.

Total daily catch showed a steady decrease over the season in the Beauchene and North areas (**Fig. 3b**). The decreasing trend was less marked in the CPUE (as catch per vessel-day) for all the three areas (**Fig. 3c**). Thus it appears that vessels switched fishing grounds in order to maintain the catch per day as close to the initial value as possible. In other words, fleet movement dynamics had a stabilising effect on catch per vessel-day.

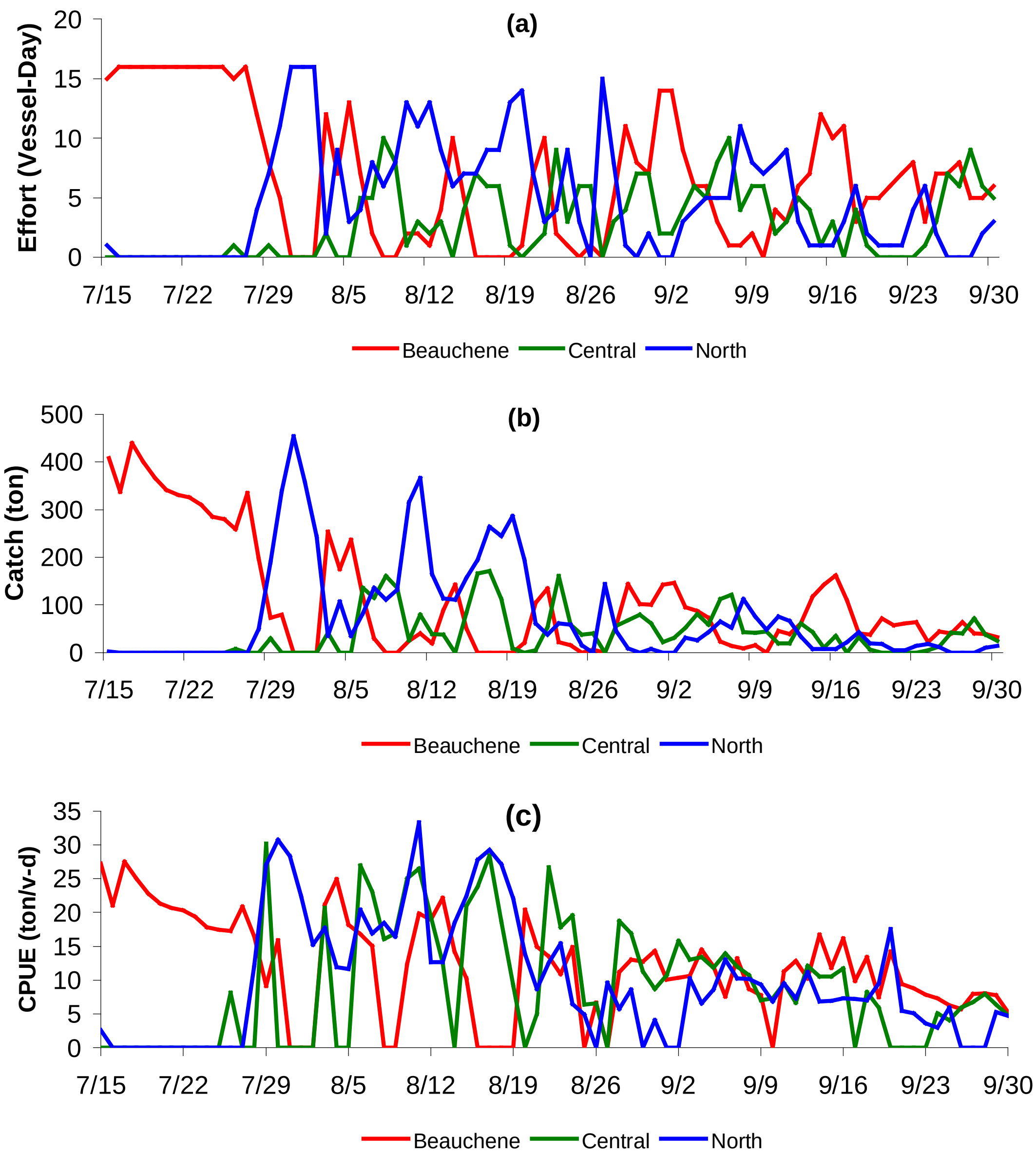

Fig. 3.- Daily evolution of effort, catch, and average catch per unit of effort (CPUE) in the *Loligo* fishery during the second season of 2004 (July/15 to Sept/30).

PART 2 – BIOLOGICAL TRENDS

Biological trends of the stock were based on a sample of animals taken from the catch of a few vessels. Typically there was an observer on one vessel taking a sample of 200 animals from every other trawl, though sometimes this effort was doubled by the presence of another observer on a second vessel. Thus our results in this part are affected by sampling variation.

Comparison with Recent Years

The proportion of sexually mature squid in the catch closely followed trends observed in the previous five years (**Fig. 4**). In the second season, most females were immature or maturing by the end of the season, though the process of sexual maturation started during the first week of September. For males there was a constant and strong trend towards sexual maturation right from the start of the season. By the end of the season, most males were sexually mature.

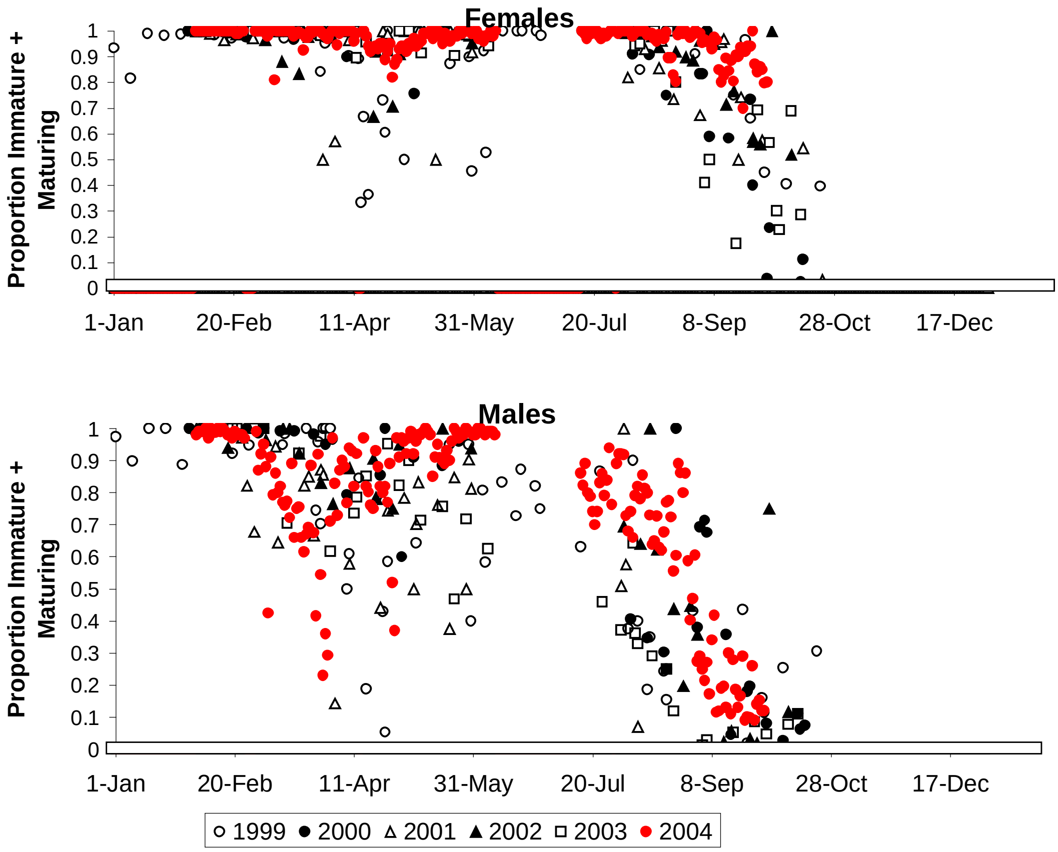

Fig. 4.- Current year trends in the proportion of sexually mature squids in the catch, compared with five previous years.

There is a constant and weak decrease in the proportion of females in the catch as the season progresses (**Fig. 5**). On any given day the proportion of females is often very different from 50% (**Fig. 5**) indicating that squids usually tend to form groups of individuals of the same sex. This latter observation applies to all six recent years (**Fig. 5**) and it is a known feature of Loligo population ecology (Arkhipkin and Middleton 2002).

For both sexes there was a period of stability in mean mantle length in the catch and then in the last month of the season (September) the mean body size of squids grew, with a more marked tendency in females (**Fig. 6**). This result does not differ from observations of previous years (**Fig. 6**).

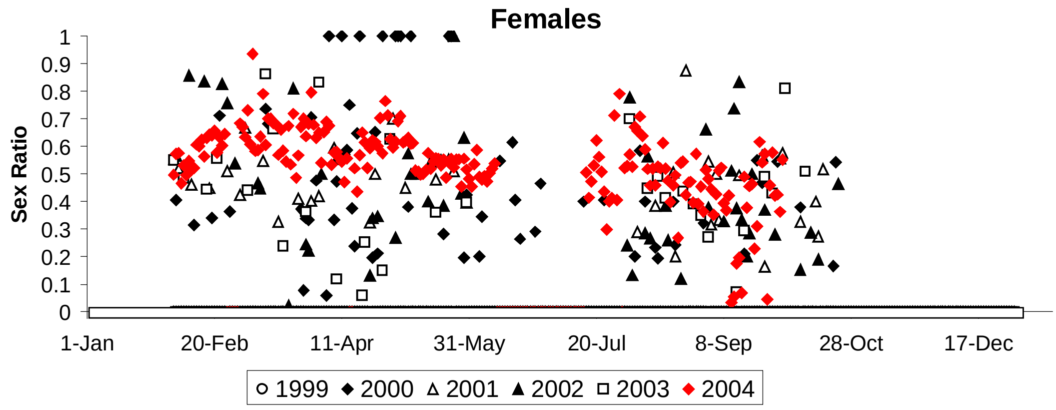

Fig. 5.- This year's trends in the proportion of female squids in the catch, compared with five previous years.

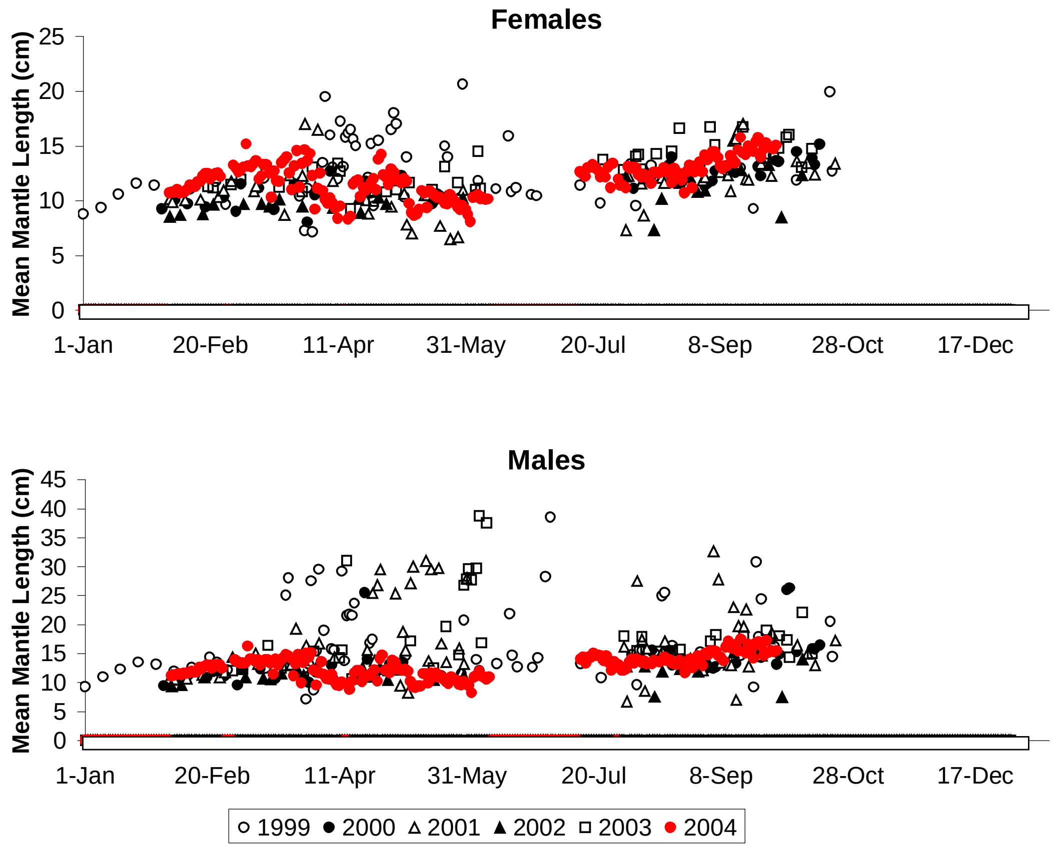

Fig. 6.- This year's trends in mean mantle length (body size) of squids in the catch, compared with 5 previous years.

Plotting a time series of histograms for each sex for all days in the season provides a more detailed view of the body size of squids in the catch. **Fig. 7** shows the information from every single squid measured by observers for the whole season (20143 females and 20214 males) without any form of interpolation, only raw day by day data connected to form a sequence in time. **Fig. 7** shows relative frequencies so the variation in sampling effort (mostly the presence of one or two observers on any given day) is lost. The most notable feature is the stability of the body size distribution along the season, even though the vessels started to switch from one to another fishing ground since the end of July. It appears that the stock is biologically quite homogeneous in the *Loligo* box. Some jumps in the most frequent body size categories (indicated by 'redder' colour) can possibly be explained by a switch of fishing ground by the vessel in which the observer was recording the data.

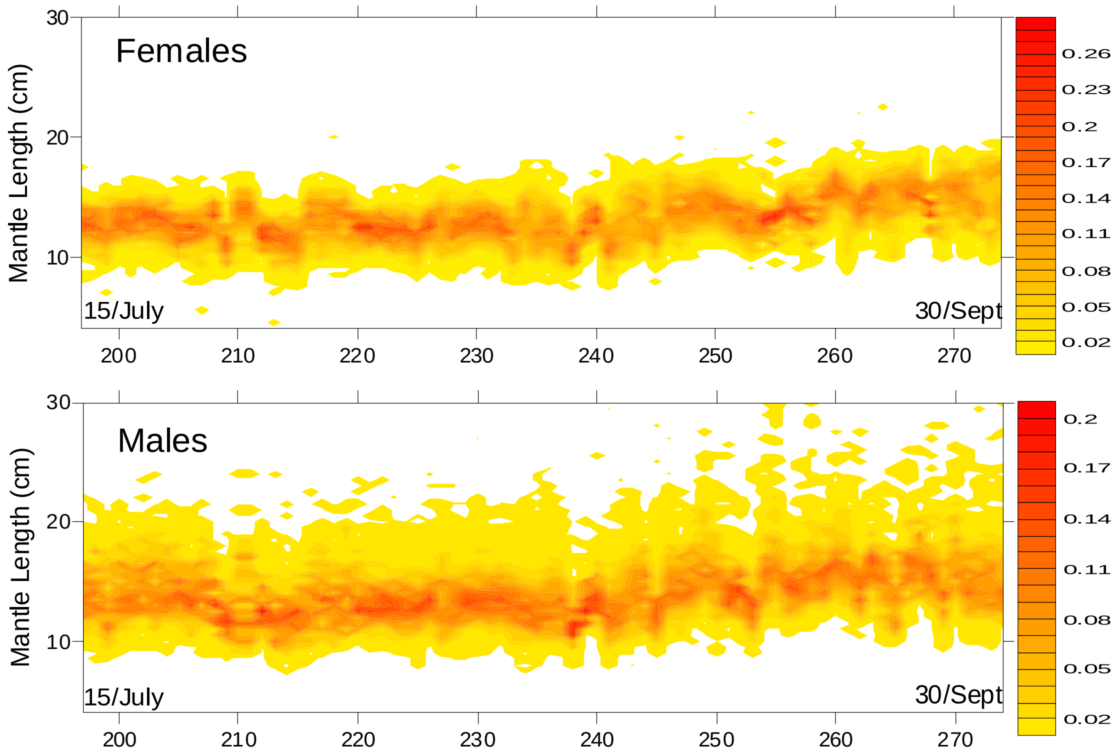

Fig. 7.- Time series of histograms of body size distribution of squid in the catch during the second season.

PART 3 – STOCK ASSESSMENT

Two mathematically different methods based on different data converge on the same results (**Table 3**). The first method is a Biomass Projection model that uses the biomass estimated during a research cruise performed on the Argos Vigo vessel during the first 10 days of May. This model also utilises an individual growth model of the Schnute type and an exponential decay cohort model with natural mortality rate of 0.009 per day (code written in MATLAB, available on request). The second method is the classic De Lury depletion model applied to data from the North and Beauchene areas separately, with the likelihood maximised over both initial population size and catchability (code written in ADMB, available on request). The Biomass Projection model predicts 17 thousand tons in each of Beauchene and Central + North areas while De Lury model estimates two thousand tones more in Beauchene and three hundred tons more in Central + North (**Table 3**). The coincidence is striking considering that the two methods are mathematically different and are based on different data.

Table 2.- Results of stock assessment of Beauchene and North areas using De Lury method implemented in ADMB (**App.1**), and projected biomass in MATLAB (**App. 1**), both for the date indicated as Starting Date (percentage coefficients of variations in parentheses for estimated parameters). mle: maximum likelihood estimator. Parameters M: natural mortality rate, N_0: initial abundance in numbers, q: catchability, B_0: initial biomass.

Parameter	Status	**Beauchene** Value	**Central (C)** Value	**North (N)** Value	**C+N**
M (1/day)	Known	0.009	0.009	0.009	
N_0 (billions)	Estimated	0.3960 (45.7)	0.0675 (18.5)	0.2786 (97.5)	0.3461
q (1/vessel-day)	Estimated	0.0013 (31.4)	0.0142 (10.2)	0.0027 (10.5)	
Starting Date	Known	15 of July	16 of August	29 of July	
Starting day	Known	197	229	211	
Last day	Known	218	244	236	
Number of days	Known	14	4	7	
Period Length	Known	22	16	26	
Min. Fleet Size	Known	13	5	13	
σ Fleet 1 (billions/√day)	Nuisance (mle function)	0.0009	0.0006	0.0023	
B_0 (tons) De Lury	Functional Invariance mle	19697	3359	14164	17523
B_0 (tons) Projection		17009			17223
Catch Up to 30^{th} September (ton)		8544	3038	5956	

The De Lury model provided reasonably good statistical results in terms of the coefficient of variation (CV) of estimates (N_0 and q, see **Table 3**), though the percentage CV for the N_0 parameter for North is somewhat high. Fortunately, the confirmation of a similar estimate with the Biomass Projection model compensates for the rather high CV. The correlations between N_0 and q parameters for the three areas were very low (<0.007) indicating that the maximisation of the (Gaussian) likelihood occurs over two nearly orthogonal dimensions. The predictions of De Lury model and the data are presented in **Fig. 8**. These predictions are presented in two units, total catch by the fleet per day in billions of individual squids (left-hand side column of graphs) and catch rate or CPUE, that is catch in millions of individual squids per vessel-day. It must be noted that the model was fitted to the data in catch rate units. The best fit of for the Central area, followed by the Beauchene area (**Fig. 8**). This is also appreciated in the CVs for model parameters in **Table 3**.

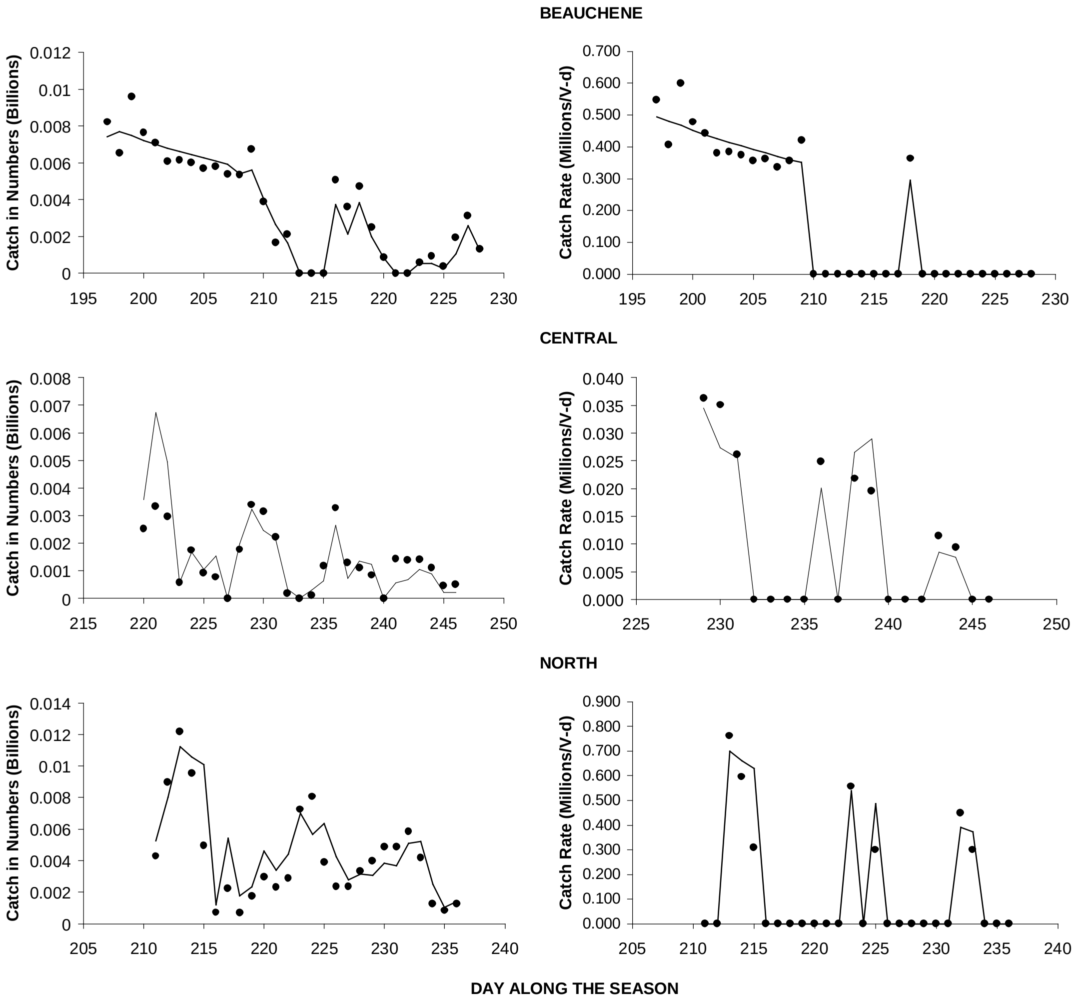

Fig. 8.- Graphical presentation of results of De Lury model (lines) fitted to fisheries data (black dots) for the three fishing grounds, in two units: total catch in billions (left column) and catch rate in millions per vessel-day).

In **Fig. 9** we show the biomass for each area and for the whole *Loligo* box discounted for catch up to the 30th of September, using the Biomass Projection model. It must be noted that this model is complete as a deterministic working model but that it remains to develop the statistical model accounting for the sampling variation in some of the data that are used. We will develop this in the next few months using a hierarchical model under the direct-likelihood school of statistical inference. The exploitation rate (catch over biomass) was very nearly 50% for all areas, slightly higher than 50% in the north (Central + North areas), and a little lower than 50% in Beauchene (**Fig. 9**). It was estimated that about 17415 tons of squid were left in the sea, which is quite above the established management target of 10000 tons.

.

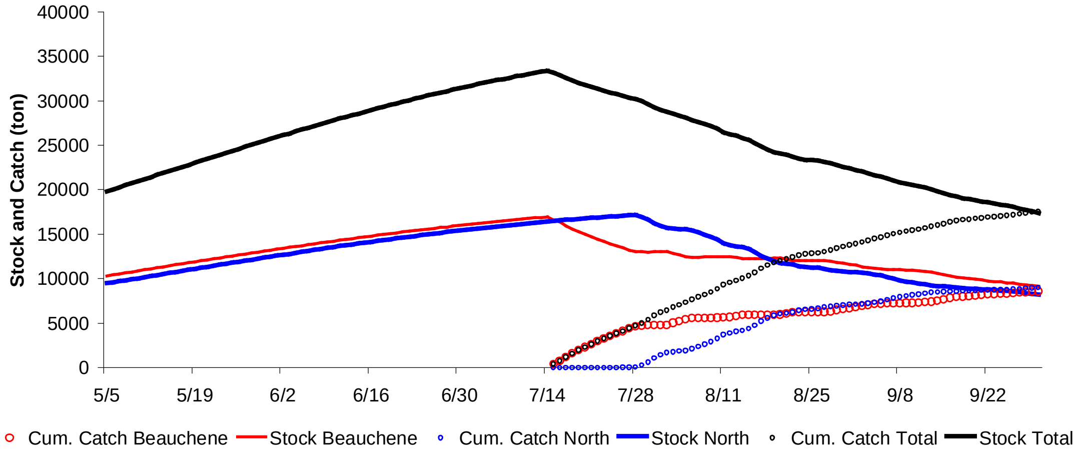

Fig. 9.- Projected *Loligo* total biomass and for two major areas in the *Loligo* box**,** discounted for catch, versus date (Month/Day), from the date of the Argos Vigo survey (Doc. 563) up to the final day of the season (Sept/30).

De Lury model provides a short-term estimation of biomass in the immediate past, while the biomass projection model provides a short-term prediction of future biomass in the incoming season. Together they have shown to be useful for the *Loligo* fishery at least for the second season of 2004. Nevertheless, it would be desirable to have a long-term stock assessment model providing the ‘big picture’, the historical trend (if any) in biomass across the years, or at least connecting two consecutive years. This is because the ultimate cause of the magnitude of biomass in the current season is the magnitude of spawning biomass in the same season of the previous year. There are other factors that can disrupt or alter this ultimate causative connection but we know for sure that the spawning biomass one year ago has created the biomass that we are seeing now. Our short-term stock assessment models cannot utilise this link to improve predictability and the quality of estimates. Now we have completed our first attempt at construction and fitting of a long-term stock assessment model for the whole recorded history of the *Loligo* fishery. It is one of the simplest dynamical models available for long-term stock assessment, a biomass dynamic model (Hilborn and Walters 1992). This model relates the biomass in the previous year with the biomass in the current year through a parameter representing the capacity of the stock to grow, a maximum-attainable abundance parameter, a catchability parameter, and a mathematical symmetry parameter. We have implemented a marginal likelihood model rather than the usual process-error, observation-error, or Kalman filter approaches (mathematical formulation and statistical model available on request). Results are shown in **Fig. 10**. We have two scenarios: fit of each season separately, and fit of both seasons in the same model. For both scenarios, it can be seen that the model is unable to capture the full dynamics, though for the First Season the model predicted reasonably well the dynamics of the last seven years, including the prediction of a poor First Season for this year. We believe it is necessary to construct a more complex model that incorporates some critical environmental variable. The observation by Arkhipkin and Middleton (2003) that *Loligo* eggs are laid on inshore algae and that they become lost due to severe storms suggests that we should construct a model incorporating the frequency and intensity of storms. A mathematical formulation allowing this is the delay-difference model of Deriso (1980) and Schnute (1985), or the differential version of Horbowy (1992).

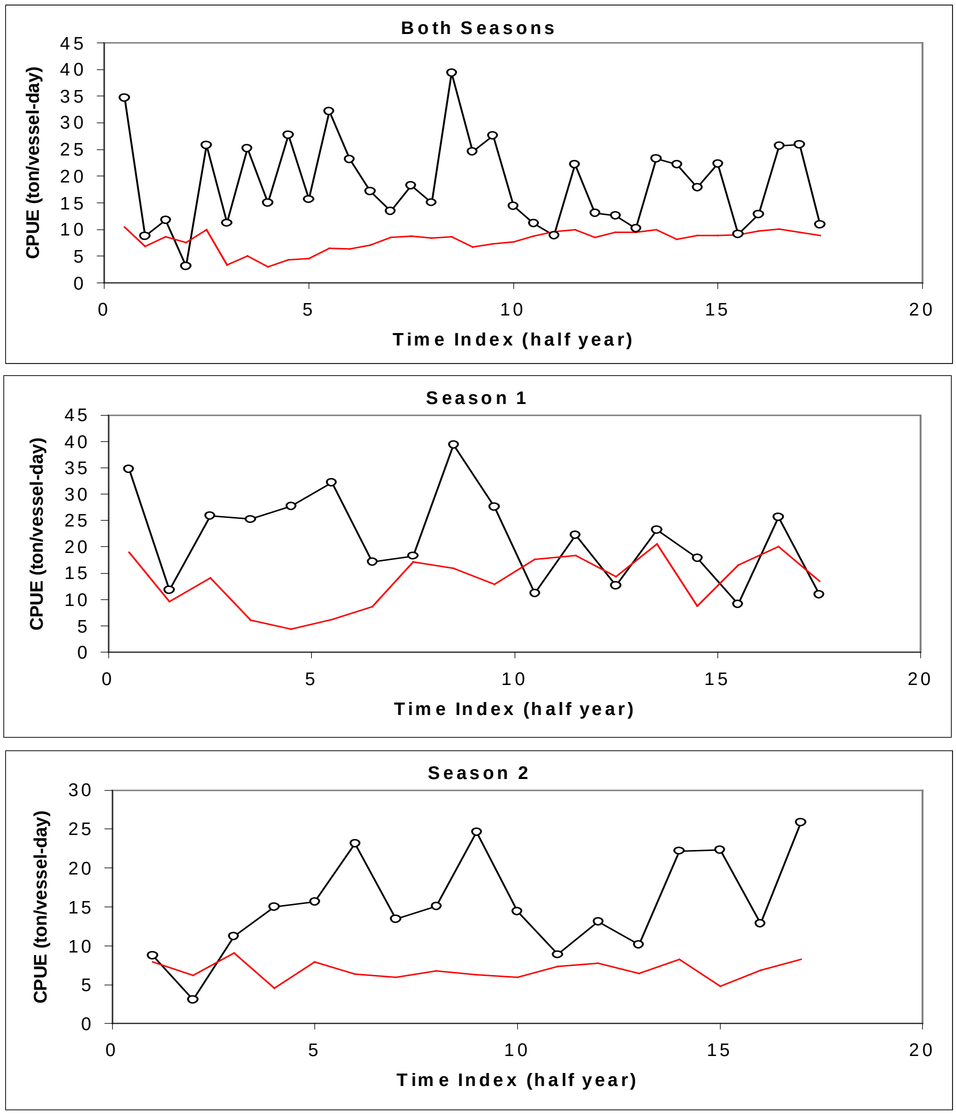

Fig. 10.- Observed historical time series of CPUE for the *Loligo gahi* fishery (black line with open circles) and predicted CPUE by a marginal-likelihood biomass-dynamic stock assessment model (red line). First season goes from 1987 to 2004, while second season goes from 1987 to 2003.

REFERENCES

Arkhipkin AI, Middleton DAJ. 2002. Sexual segregation in ontogenetic migrations by the squid *Loligo gahi* around the Falkland Islands.

Csirke J. 1986. Review of the state of the fishery resources in the south-west Atlantic with particular reference to the Patagonian offshore fisheries. Mimeo.

Deriso RB. 1980. Harvesting strategies and parameter estimation for an age-structured model. Can J. Fish. Aquat. Sci. 37:268-282.

Doc 563. 2004. Loligo stock assessment survey. Fisheries Technical Report, Falkland Island Fisheries Department.

Hilborn R, Walters CJ. 1992. Quantitative fisheries stock assessment: Choice, dynamics and uncertainty. Chapman & Hall, NY.

Horbowy J. 1992. The differential alternative to the Deriso difference production model. ICES J. Mar. Sci. 49:167-174.

Schnute J. 1985. A general theory for analysis of catch and effort data. Can. J. Fish. Aquat. Sci. 42:414-429.