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The spatio-temporal pattern of Argentine shortfin squid *Illex argentinus* abundance in the Spanish bottom-trawl fishery in the southwest Atlantic

M. Sacau, J. Wang, A. I. Arkhipkin, J. Portela, G. J. Pierce, P. Brickle, M.B. Santos and X. Cardoso

M. Sacau, J. Portela, M.B. Santos and X. Cardoso: Instituto Español de Oceanografía, PO Box 1552, 36200, Vigo, Spain [Tel: +34 986 492111, Fax: +34 986 492351, e-mail: mar.sacau@vi.ieo.es].
J. Wang, G. Pierce and M.B. Santos: Department of Zoology, Aberdeen University, Tillydrone Avenue, Aberdeen, AB24 2TZ, UK. [tel: +44 1224 272459, fax: +44 1224 272396, e-mail: j.wang@abdn.ac.uk]. A. I. Arkhipkin and P. Brickle: Fisheries Department, Falkland Islands Government, P.O. Box598, Stanley, Falkland Islands [tel: +500 27260, fax: +500 27265, e-mail: aarkhipkin@fisheries.gov.fk]

ABSTRACT

The Argentine shortfin squid (*Illex argentinus*) is a common neritic species occurring in waters off Brazil, Uruguay, Argentina, and the Falkland/Malvinas Islands in the southwest Atlantic. Illex is the most important cephalopod species in the area and plays a significant role in the ecosystem. It is object of major fisheries using both trawlers (mostly from European countries) and jigging vessels (mainly from Asian countries) and the actual total annual catch could reach up to 700 thousand tons. Fishery and biological information collected by scientific observers aboard commercial trawlers between 1988 and 2003 was analysed in relation to physical and environmental factors to establish the spatio-temporal pattern of the species distribution. The data included 26 168 fishing haul records, of which 11103 were positive. CPUE (Catch Per Unit Effort, kg·hr-1) was used as abundance index. The analyses of the general spatio-temporal pattern of fish abundance, and the influence of environmental factors, such as SST, SBT and depth on squid abundance and distribution, was based on correlation, variograms, and time-series maps created using GIS. The areas of the highest densities were found in deep waters of the High Seas between 44.5º S – 47.0º S outside the Argentinean EEZ and to the north-west of the Islands in February–May. The correlations between squid abundance and cloud index at different moon phases were also analyzed.

Keywords: Argentine shortfin squid, *Illex argentinus*, GIS, environment, spatio-temporal pattern

INTRODUCTION

The fishing grounds of the Patagonian Shelf support some of the most important fisheries in the world. The great abundance of marine resources between parallels 35º and 54º South, is associated with the Subtropical Convergence formed by the Brazil and Falkland/Malvinas currents. The mixing of the flow of La Plata River and the western branch of the Falkland/Malvinas Current generates areas of high plankton production on the shelf (Portela *et al*., 2002).

The Argentine shortfin squid (*Illex argentinus*) is a common neritic species occurring in waters off Brazil, Uruguay, Argentina, and the Falkland/Malvinas Islands in the southwest Atlantic (Nesis, 1987; Arkhipkin, 2000), where it is the most important cephalopod species playing a significant role in the ecosystem. Like many other cephalopod species it has an annual life cycle (Hatanaka, 1986) and is migratory (Caddy, 1983). Concentrations of shortfin squid are found 45-46º S in January or February and the animals gradually migrate southward towards the Falkland Islands while growing rapidly. Peak concentrations are found around the Falkland Islands between March and May. Toward the end of this period, animals start migrating northward to spawn and die around July or August (Basson *et al*. 1996).

In the South-west Atlantic, the life-cycle of *Illex argentinus* is associated with the subtropical confluence of the Brazil and Falkland (Malvinas) Currents (Fig. 1) during reproduction and the early life stages (Hatanaka, 1988; Brunetti and Ivanovic, 1992; Rodhouse *et al*., 1995; Haimovici *et al*., 1998) and with the Falkland (Malvinas) Current over the Southern Patagonian shelf during maturation, feeding and growth (Rodhouse *et al*., 1995).

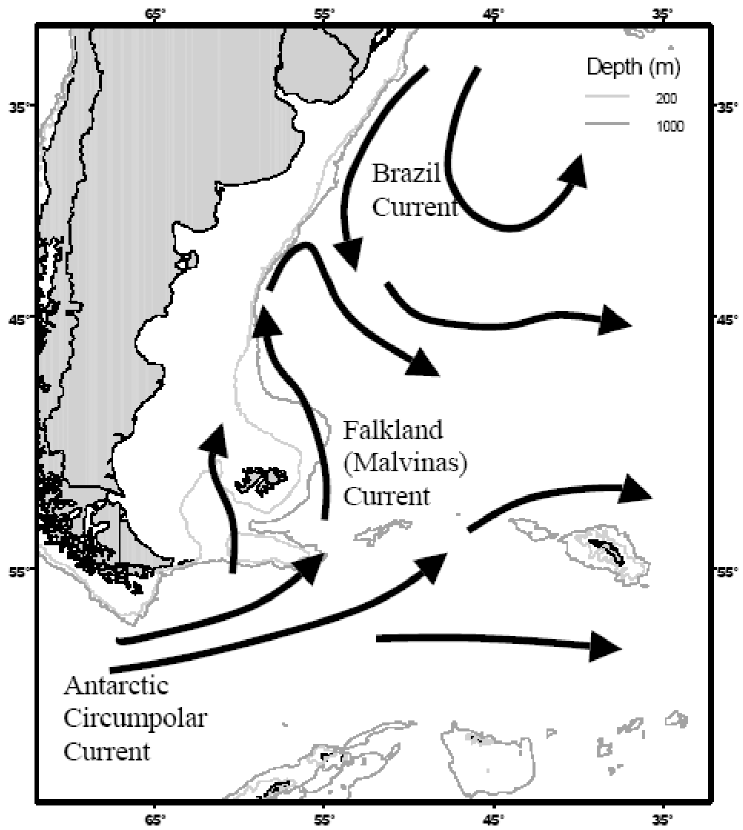


Figure 1. Brazil and Falkland/Malvinas currents

Physical oceanographic processes play a major role in influencing the distribution of ommastrephid squid, and the life cycles of a number of commercially important ommastrephid populations are linked with large-scale permanent current systems (Coelho, 1985; Hatanaka *et al*., 1985; Bakun and Csirke, 1998; Anderson and Rodhouse, in press). The influence of mesoscale processes at fronts, such as the formation of rings, meanders and streamers arising or breaking off from these dynamic current systems, has also been shown to be important in influencing the distribution of ommastrephid squid. An understanding of the influence of physical oceanographic processes on species distribution is integral to the further understanding and possible forecasting of many pelagic fisheries. The use of remote sensing methods to examine physical oceanography is becoming increasingly important within marine fisheries oceanography (Waluda *et al*., 2001).

The marine environment off austral South America is rich in coastal fronts, having various forcing, and temporal and spatial scales. Spawning of the squid *I. argentinus* is associated with these fronts. The shelf-break front is a permanent feature that characterizes the border of the shelf. The inner boundary lies between the 90 and 100 m isobath. During summer the front presents mild gradients in the density and thermal fields but is weak in the salinity field. During winter only salinity controls the density gradient. The gradients are strongest during autumn (Martos and Piccolo, 1988). The geographical location of the front may vary according to the dynamics of the Falkland (Malvinas) Current, for which cyclical variations - including semi-annual, annual and biannual periods - have been reported (Acha *et al*., 2004).

I. argentinus is fished throughout the Patagonian shelf (Haimovici *et al*., 1998), and the shelf-break region to the south of the Falkland Islands represents the most southerly extent of the species' distribution (Csirke, 1987; Basson *et al*., 1996). In Falkland Islands waters, the fishery operates between February and June (Rodhouse *et al*., 1995) and the fished population consists almost exclusively of winter spawners (Csirke, 1987; Basson *et al*., 1996) migrating south from the spawning and hatching grounds of the northern Patagonian shelf (Haimovici *et al*., 1998).

Since the early 1980s, Argentine shortfin squid have been caught by Spanish bottom trawlers as a bycatch in the hake fishery. Nowadays, this squid species is considered as one of the target species for the Spanish fleet operating in the Southwest Atlantic, with mean annual catches of about 35,000 tons. As an annual species, its catches fluctuate markedly from year to year depending on environmental conditions.

The fishing grounds in the Patagonian Shelf in which vessels flying Spanish flag are operating can be divided in two main fishing zones, one of them around the Falkland/Malvinas Islands in what are known as Falkland Interim and Outer Conservation Zones (FICZ and FOCZ respectively), and the second one in the High Seas (Fig. 2).

The activity of Spanish vessels in the High Seas is restricted to those portions of the continental shelf and slope which fall outside the Argentinean EEZ, i.e. a small patch around 42º S and a bigger area between parallels 43º 30' and 48º S, namely "Area 42 and 46" respectively. The fishing grounds around the isles have been divided in three sub-areas Malvinas North (MN), Malvinas West (MW) and Malvinas South (MS).

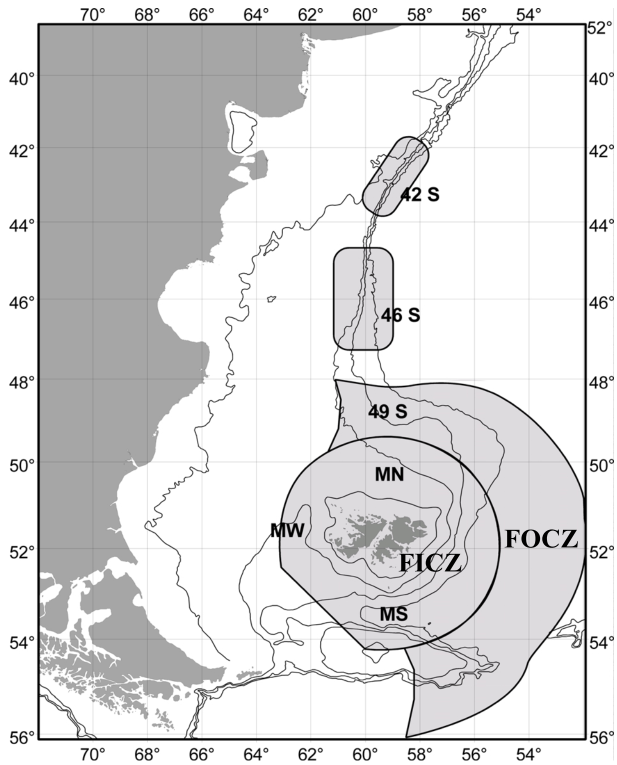


Figure 2. Main fishing areas in the Patagonian Self for the Spanish fleet

DATA AND METHODS

Data used into the GIS

Spatially referenced commercial fishery data, as well as bathymetric data were examined using Geographic Information System (GIS) techniques in order to map and represent information about the distribution and the abundance of commercial catches of *Illex argentinus* recorded by IEO scientific observers (Fig. 3) in the Falkland Islands and in the High Seas from 1988 to 2003.

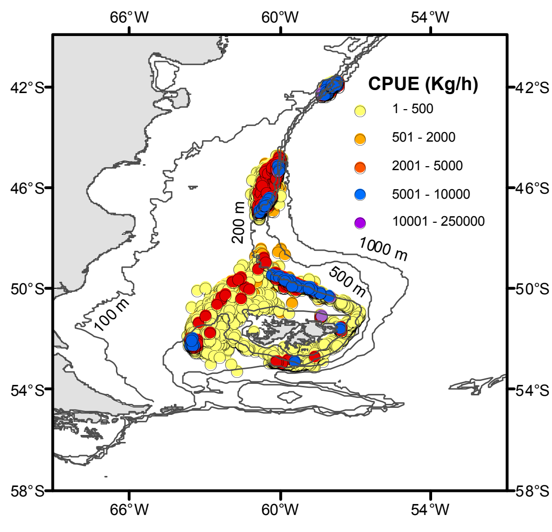


Figure 3. Locations of hauls for *Illex* 1988-2003.

Fishery, bathymetric and SST data were integrated within the GIS (ArcGIS version 8.2). This process allows a visual analysis and also the extraction of more information about the parameters that are having an influence on the catch distribution.

1- Bathymetry data

Bathymetry contours of the Patagonian shelf were extracted from the GEBCO (General Bathymetric Chart of the Oceans) Digital Atlas and entered into the GIS. Bathymetric contours represented here are 0 m, 200 m, 500 m and 1000 m.

2- Fishery data- FIFD and Spanish data

Daily fishery data for the present study were collected by observers working for the IEO (Instituto Español de Oceanografía, Vigo, Spain) and FIGFD (Falkland Islands Government Fisheries Department, Stanley) on board commercial vessels for the 17-year period 1988-2003. All data were integrated into a MS Access database and used in analysis and modelling.

Fishery data were imported and integrated into the GIS as monthly time-series grids at a spatial resolution of 0.5 degrees. CPUE (catches per unit effort, kg/hr) was used as an index of abundance in the fishery (Waluda *et al*. 1999). This index reflects squid abundance and accounts for changes in fleet activity over the 17-year period. Maps were visually analysed in order to find relations between bathymetry, SST and fisheries data for the same month.

Geographical Information System methods

GIS maps

Raster data sets of *Illex* CPUE were created with the GIS on a monthly basis. Each cell in the map is a square of 0.5^{o} longitude by 0.5^{o} latitude. The cells in a raster dataset can be any size, but they should be small enough to accomplish a detailed analysis of the temporal evolution of the features represented in the maps (CPUE , ratio of catches to the total catches and modal length).

Density surface maps

Density surfaces of *Illex* CPUE were created in the GIS as monthly raster layers. Each cell in every layer is assigned a density value based on the number of features (hauls with CPUE > 0 kg/h, assuming that CPUE = 0 refers to hauls targeting other species) within a radius of 1.5 degrees. To create a density surface we have used the Kernel method, which uses a mathematical function to give more importance to features closer to the centre of the cell. With this method, maps with patterns that are easier to interpret were obtained. The GIS defines a neighbourhood (based on the search radius specified, in this case 1.5 degrees) around each cell centre. It then totals the number of features that fall within that neighbourhood and divides that number by the area of the neighbourhood. That value is assigned to the cell. The GIS moves on to the next cell and repeats the same procedure, resulting in the creation of a smoothed surface. Mapping density shows, in a coloured graduated scale, concentrations of *Illex argentinus* on a monthly basis.

Besides the visual analysis of the maps, the Spearman´s rank correlation was carried out between *Illex argentinus* abundance and other variables (month, latitude, longitude, average depth, SST, lunar cycle and sky pattern) in order to quantify the correlations between them.

Statistical analysis and modelling

Spearman´s rank correlations

The relationship between CPUE for *Illex argentinus* and all the variables (SST, average depth, latitude, longitude, month, lunar cycle and sky pattern) was investigated by calculating Spearman's rank correlations on quarterly data. The Spearman's rank correlation coefficient was used as a measure of linear relationship between paired sets of data (CPUE being one of them). The statistical calculation was carried out using the Statsoft version 5.1. Applying Spearman's rank correlations involves linearity between variables, and this assumption was not always true in this work. For this reason, Generalized Additive Models were applied to the data set.

Generalized additive models (GAMs)

Generalized Additive Models (GAMs) are able to deal with non-linear relationships between an independent variable and multiple predictors and are particularly appropriate to our study.

GAMs were first proposed by Hastie & Tibshirani (1990) and some of the first applications to fishery data were by Swartzman *et al*. (1992, 1994, 1995). A GAM is a non-parametric regression method with less strict assumptions of normality and linearity than linear regression. This method is an extension of the generalized linear models (GLMs; McCullagh & Nelder, 1989). The principal strength of additive models is their ability to fit complex smooth functions (smooths) in the predictor rather than being constrained by the linearity implicit in GLMs. A GAM, the generalized version of an additive model, is expressed as:

$$g(E[y]) = \beta_0 + \sum_k S_k(x_k)$$

The right-hand side of the equation is the additive predictor. β_0 is an intercept term and S_k is a one-dimensional smoothing function for the k^{th} spatial covariate, x_k. The degree of smoothing is determined by the degrees of freedom (d.f.) associated with the smoothing function. The larger the degrees of freedom, the less the smoothing performed and more flexible the function obtained.

In order to model variation in *Illex argentinus* abundance we fitted GAMs using the "gam" command in S-Plus and using cubic smoothing splines to smooth covariates. Spline smoothers are popular smoothers because they have a theoretical justification that can be used to determine the appropriate smoothness for the fit. Smoothing splines are locally cubic splines that minimize a penalized residual sum of squares, drawing a smoothed curve through the data points.

In our model, the expected value of *Illex argentinus* abundance is expressed as a sum of smooth functions of the covariates (month, latitude, longitude, SST and average depth). All data were imported into S-Plus from excel files and configured as data objects. Data were screened to reveal characteristics of data sets and scatter plots were made for each pair of variables. The error distribution used was the Gaussian distribution, which is normally appropriate for describing spatial heterogeneity and abundance data (see Maravelias, 1997; Swatzman *et al*., 1994).

To measure the goodness of fit of the model, a pseudo-coefficient of residual determination, PCf, is estimated (Swartzman *et al*., 1992):

$$PCf = 1 - \frac{RD}{ND}$$

where RD is the residual deviance, i.e. the deviance of the full model, similar to the residual sum of squares in a linear model, and ND the null deviance, i.e. the deviance of the model with only the intercept term. PCf values obtained are listed in Table 1.

Table 1. Summary of GAM results for weighted and unweighted models

Unweighted model		
ND	**RD**	**PCf**
1,3961E+10 (9902 d.f.)	1,0973E+10 (9882 d.f.)	0,21
Weighted model		
ND	**RD**	**PCf**
4,3271E+10 (9902 d.f.)	3,3122E+10 (9882 d.f.)	0,23

Unweighted model		**Weighted model**	
Variable	Pr(F)	Variable	Pr(F)
Month	0	Month	0
Latitude	0	Latitude	0
Longitude	0	Longitude	0
AvgDepth	0	AvgDepth	1.22 e^{-009}
SST	3.33 e^{-008}	SST	5.8 $e^{-0.10}$

In this work, the fishing effort variable was used as a weighting factor. The amount of fishing effort can be considered as an index of the quality of the sampling, and more effort probably implies more reliability in the data. Therefore, in the weighted model, less importance is assigned to data with low fishing effort and more importance to data with high fishing effort. An unweighted model was also fitted for comparison. Scatter plots and GAM plots are shown in figures 13 and 14 respectively.

Analysis of biological data

Data on length were collected by observers by measuring dorsal mantle length (DML) of at least 75 individuals in each sample when possible. Maturity in the Argentine shortfin squid was recorded on a scale of six and five maturity stages for females and males respectively, based on differences in the appearance and size of the gonads and accessory glands, described in detail on the observers' handbook.

Data on modal lengths in each haul were mapped using GIS.

Length weight relationships were calculated.

RESULTS AND DISCUSSION

The shortfin squid, *Illex argentinus*, is the main cephalopod species targeted by the international fleets in the SW Atlantic. One of its distinguishing characteristics is that during its life-cycle, Illex migrates clockwise from the spawning grounds off northern Argentina, Uruguay, and Brazil southwards to the Patagonian and Falkland Islands shelves (Arkhipkin, 2000). Concentrations of shortfin squid are found at 45-46º S in January or February, and the animals gradually migrate southward towards the Falkland Islands while growing rapidly.. Peak concentrations are found around the Falkland Islands between March and May. Toward the end of this period *Illex argentinus* returns to the north where they spawn and die around July or August (Basson *et al*., 1996). The basic pattern of migration is described in Hatanaka (1988).

Results obtained in this study show very clearly the migration pattern described above.

Spatial distribution of catches of *Illex argentinus*

Illex argentinus is fished in Falkland Island waters and International Waters (Fig. 3). Most of the fishing activity takes place on the shelf and close to the shelf-break region. Of all these areas, the Patagonian Shelf north of 52º S was the major fishing site with CPUE >2000 kg /hour. Fishing effort over the 17-year period (1988-2003) was highest along the shelf break (200 m isobath) and to the north-west of the region. Fishing intensity decreases as depth increases.

Figure 4 shows position of hauls and CPUE values for *Illex* over the period 1988-1999 in a monthly basis. The highest CPUE values were recorded during the first four months of the year, with peak values higher than 5000 kg/hr mainly located within 42º S, 46º S and MN areas. From May to October there was a clear drop in the number of hauls which contained *Illex*. During this period, CPUE values showed a marked decrease, especially in Falklands waters where CPUE, in general terms, do not exceed 20 kg/h. The decrease was also pronounced in the High Seas regions where CPUE values did not exceed 1000 kg/h.

Mean November and December CPUE reached values higher than 1000 kg/hr. These high-yield hauls were recorded in the 46º S region. During the last three months of the year, hauls with catches of *Illex argentinus* were mainly located within the 46º S region, although the absence from area 42º S is probably due to the lack of data.

The displays of the monthly averaged CPUE shows that the higher catches of *Illex argentinus* occurred during the first four-month period of the year (Fig. 5). The geographical and temporal distribution of the catches showed clear fluctuations related to the fleet following the migration of *Illex*. CPUE peaks in the first fourth month period were distributed mainly in the High Seas. Moreover, it is necessary to notice from the observation of the maps that catches of *Illex* around Falkland/Malvinas waters were also very significant (occasionally 80 to 100% of the total catches). From May to June percentages of *Illex* catches suffer a clear drop except in 42º S region where they maintain high proportions. During July to October, the drop in

Illex catches to the total catches was very remarkable within all areas, reaching proportions ranging between 0-20 %. November and December were characterised by a sharp fall in the hauls positive for *Illex* that in the last month of the year were restricted to the 46º S region. The spatial distribution of the ratio of *Illex argentinus* catches to the total catches of all species (Fig. 6) follows a similar temporal pattern with highest ratios of catches concentrated in the first four months and within the same areas.

Density maps

Illex argentinus was present in a large number of trawls (11103) in the area located along the Patagonian shelf and Falkland islands. Density surface maps show that high concentrations of *Illex* were found at 45 - 46º S from January to February (Fig. 7). Density around the Falkland Islands reached the maximum value in March and April where the highest abundances are found in MW and MN regions. Density maps depict very clearly the basic pattern of *Illex* migration (high concentrations found at 45-46º S in January and February, followed by high abundances around the Falkland Islands between March and May and final migration northwards to spawn and die around July or August).

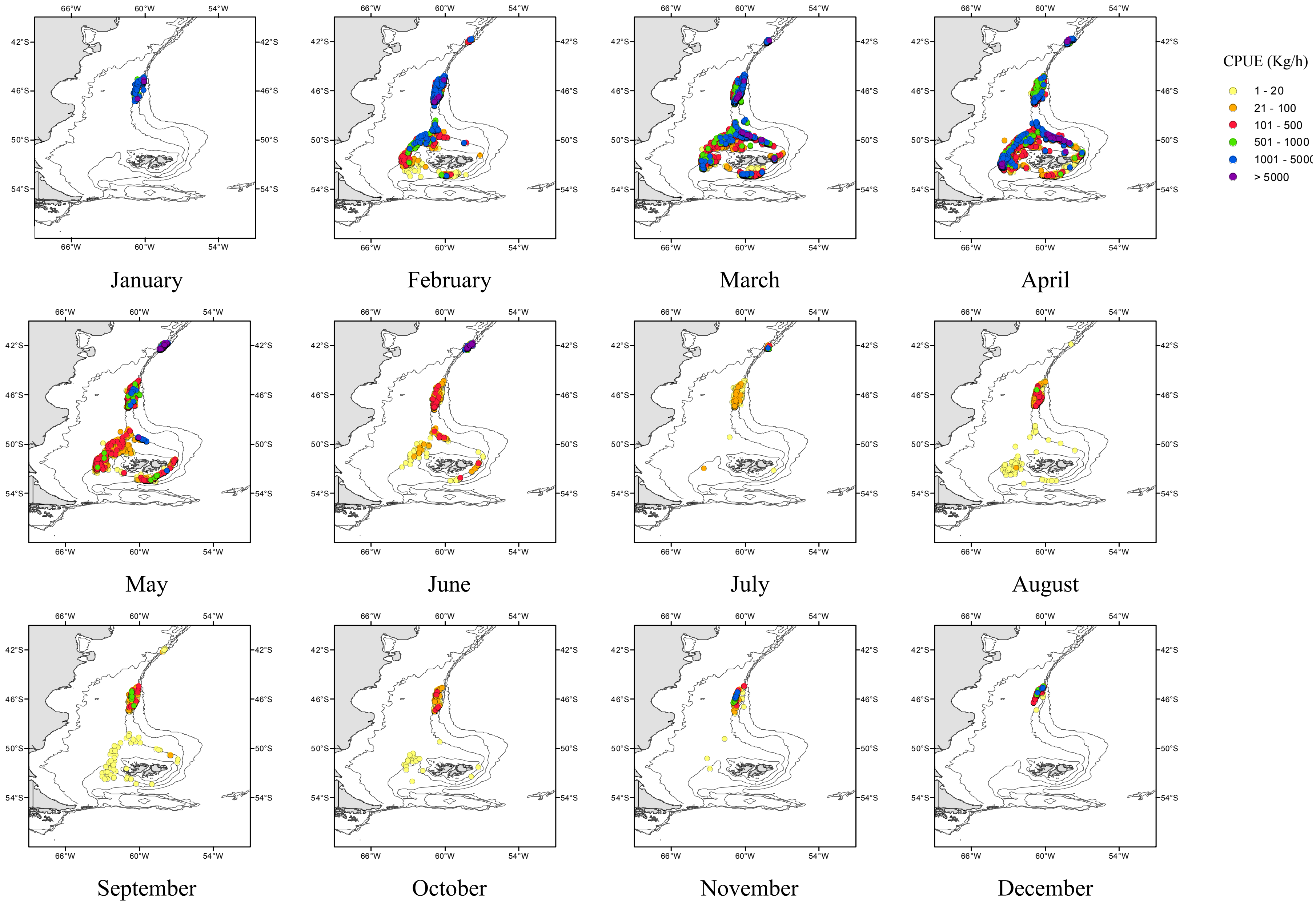


Figure 4. Location of hauls where *Illex* was recorded and CPUE in different months over the period 1988-1999.

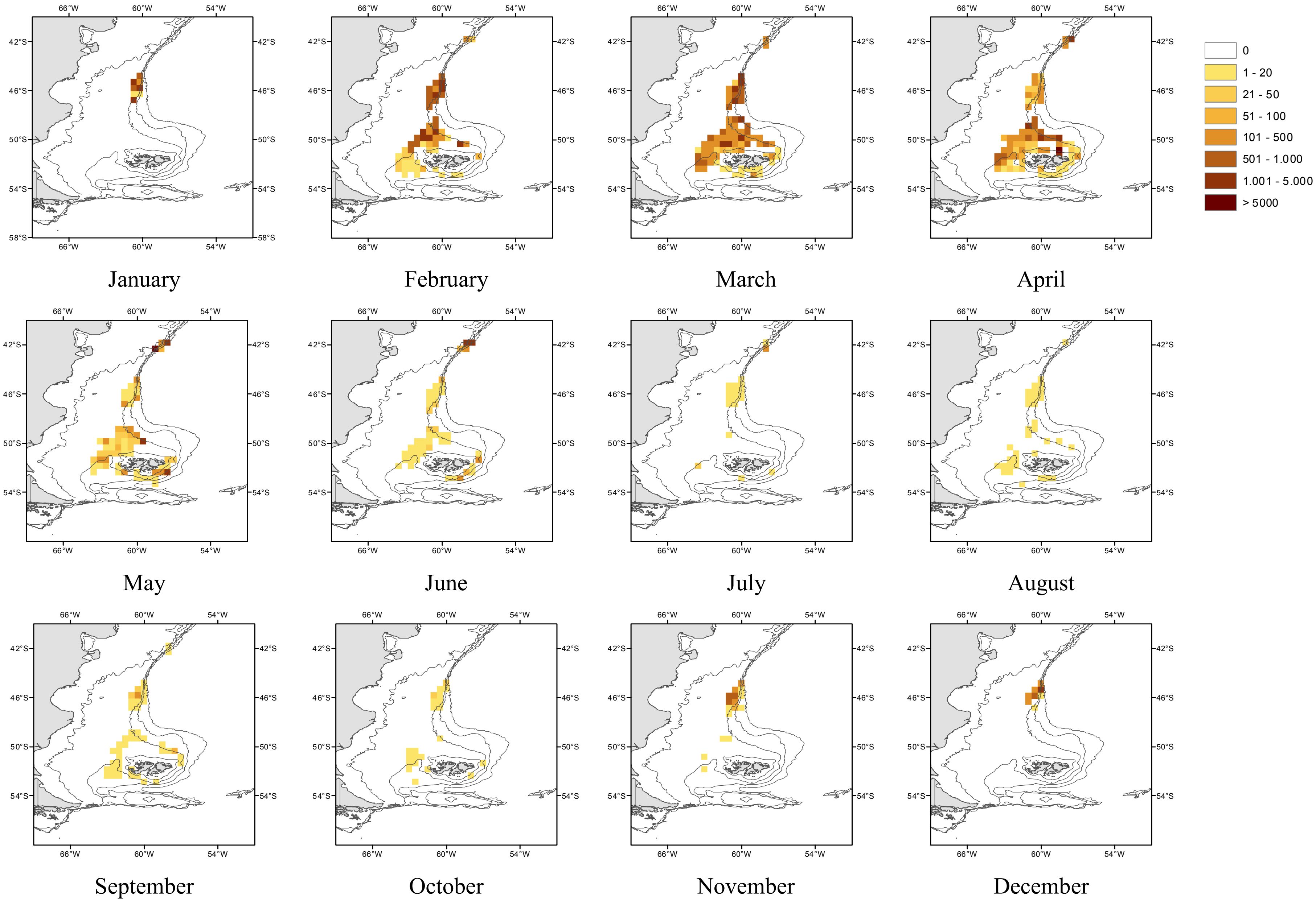


Figure 5. Distribution of monthly averaged CPUE (kg/hr) at 0.5 by 0.5 degree resolution.

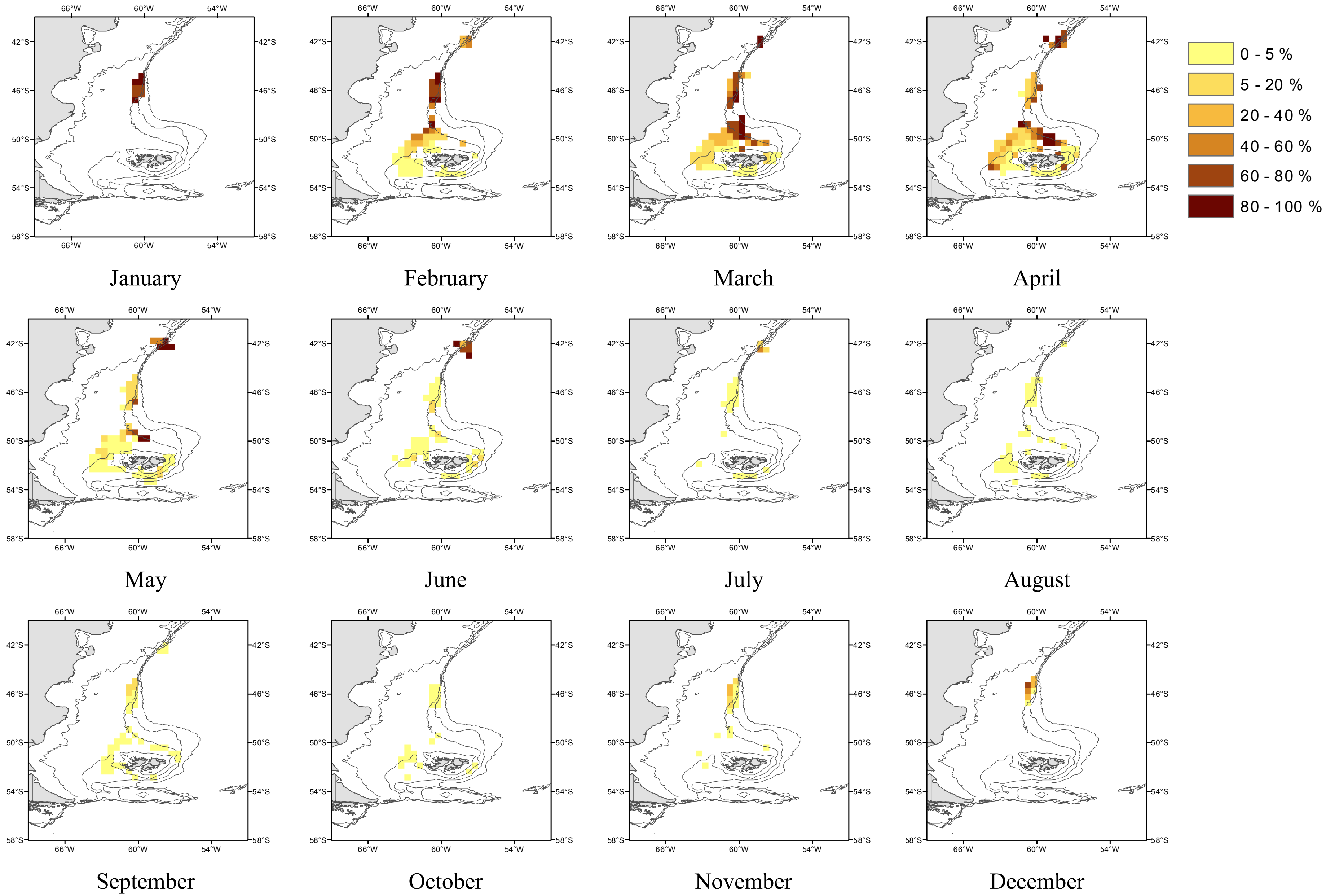


Figure 6. Monthly ratio of catches of *Illex argentinus* to the total catches of all species at 0.5 by 0.5 degree resolution

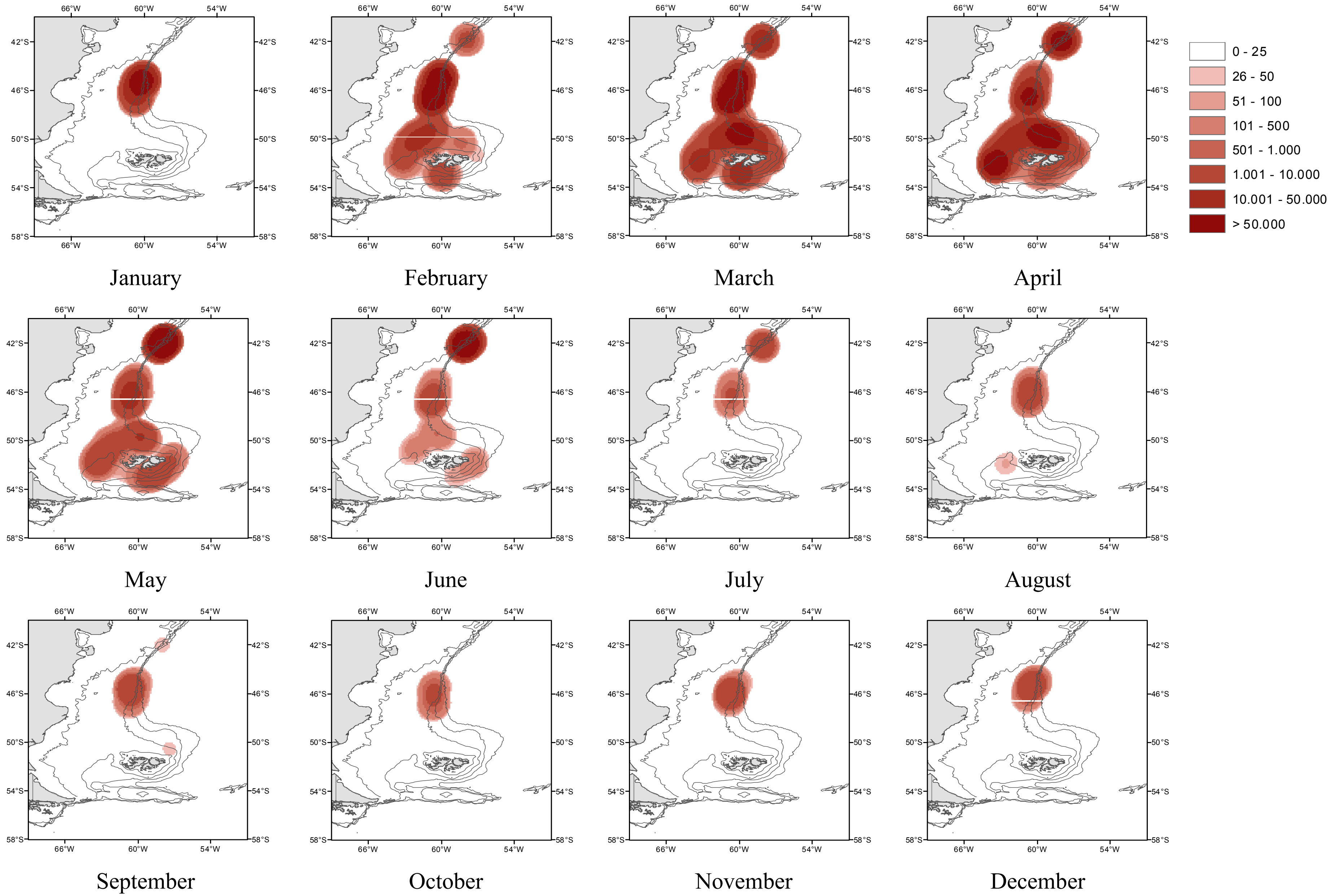


Figure 7. Monthly density of *Illex argentinus* (kg/hr per 0.125 x 0.125 degree resolution)

Biological data

Monthly modal length

Illex argentinus modal length distribution is consistent with the basic migration pattern of the species (Figure 8). Length distributions founded at 45-46º S during January ranged between 25 and 35 cm. During the following months (February, March and April), *Illex* migrates towards the south and grow rapidly. In general terms, during that period, modal length increases its value, from 20-25 cm (registered in MS on February) to 25-30 cm (registered in March and April at the same area) and from 25-30 cm in MW (during February) to 30-35 cm (during March and April). Besides, maps show clearly how during April, proportion of 35-40 cm *Illex* specimens were much higher than during the previous month.. After this period, squid start their migration to the north to spawn and die later. During May to July period, modal lengths ranged between 30-40 cm. August and September were characterised by the presence of 18-30 cm individuals mainly registered within 42º S and 46º S areas. Length distributions in October could suggest the presence of a second *Illex* generation in 46º S area (summer-spawning population). From November to December there is an evident increase in the lengths that might be explained by the growth of the second cohort that continues its annual cycle.

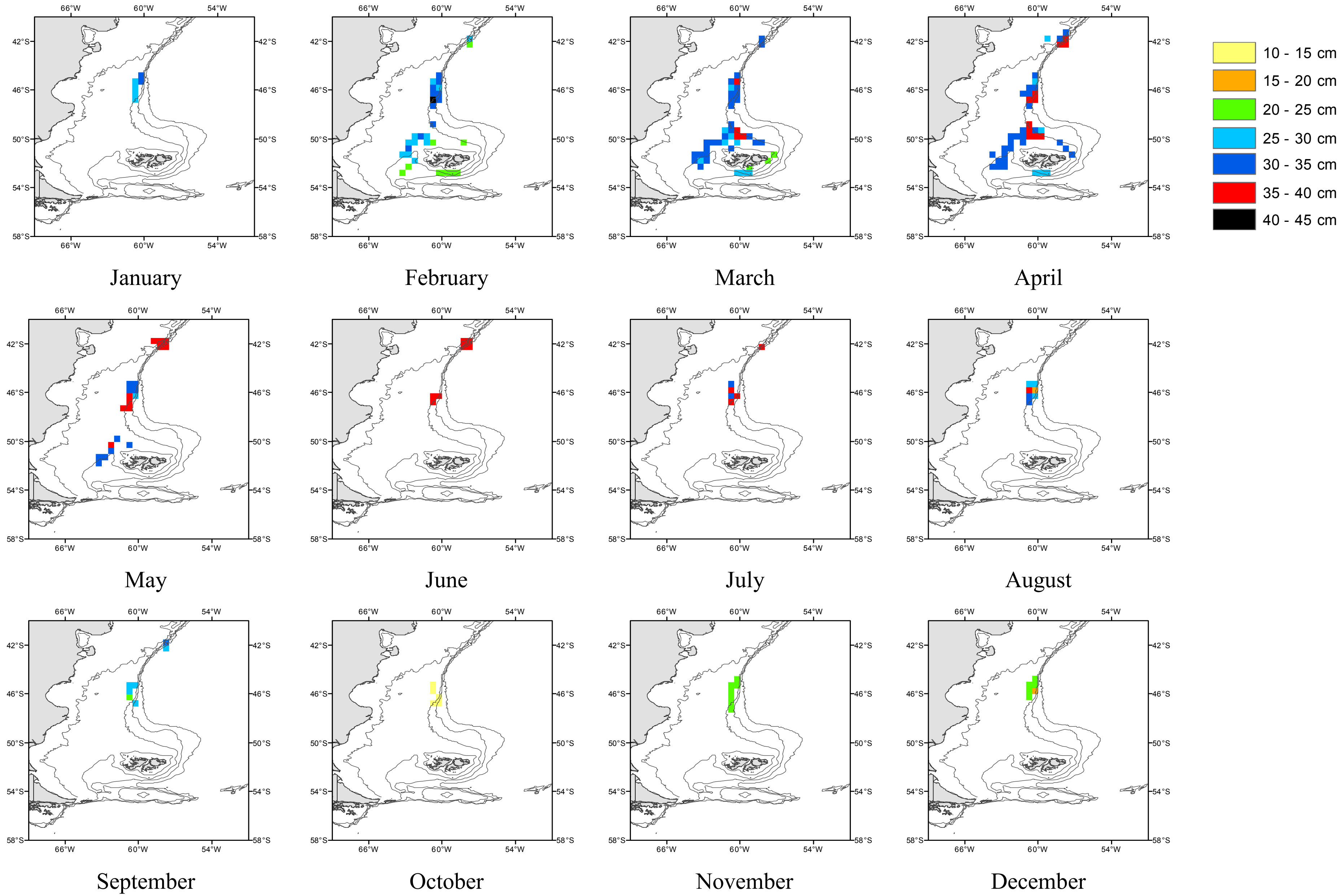
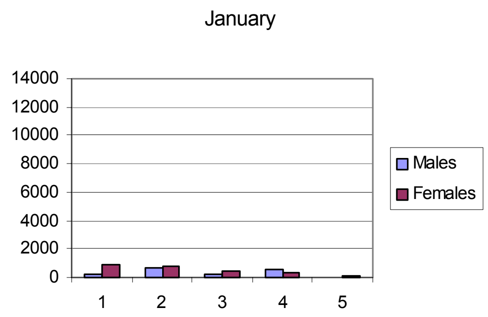
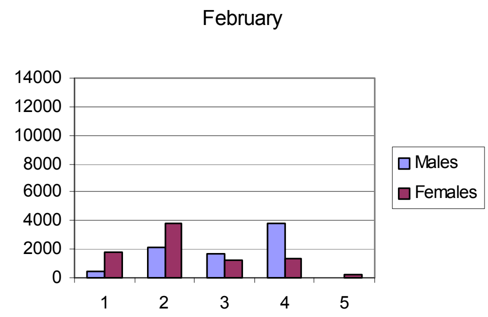


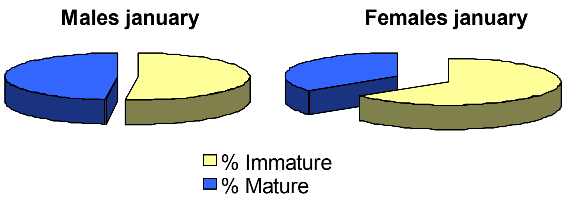
Figure 8. *Illex argentinus* monthly modal length at 0.5 x 0.5 degree resolution

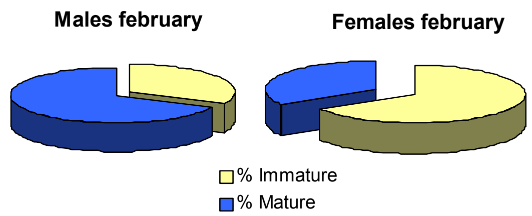
Maturity

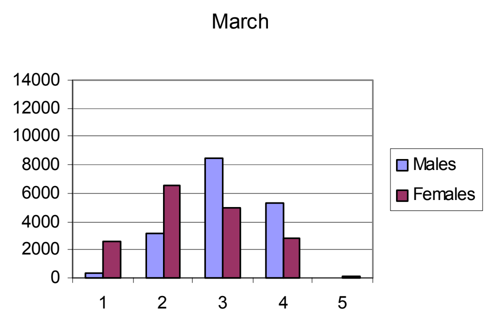
Study of maturity in the Argentine shortfin squid was made with a general scale of six and five maturity stages for females and males respectively based on differences in the appearance and size of the gonads and accessory glands.

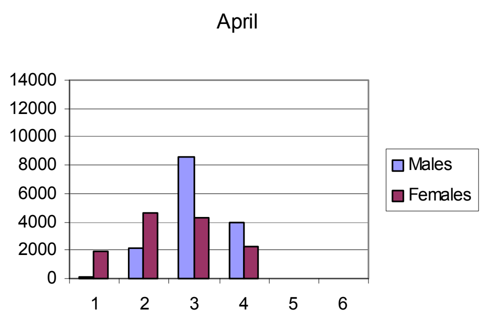


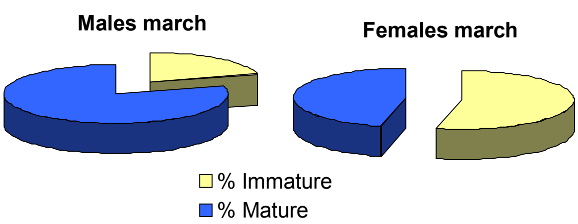


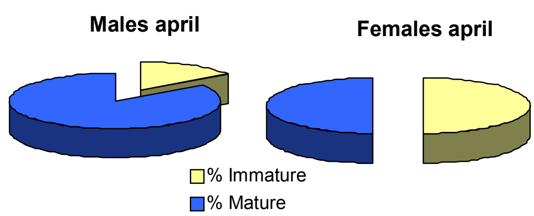












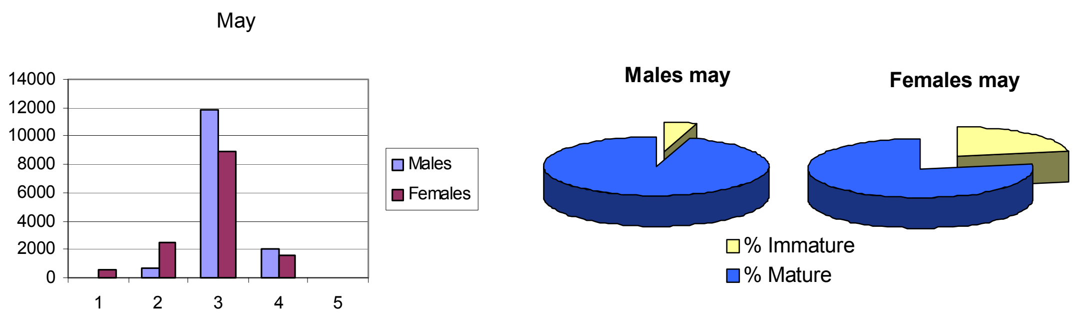


Figure 9. Maturity stage and ratio of mature and immature individuals per month

From January to May there is a general increase in the maturity for males and females (Fig. 9). For males, during the first five months mature squid dominate the sample and proportion of mature squid increases from January (48%) to May (80%). For females, during January and February the opposite is true, but the proportion of immature squid begins to decrease from March (54%) to May (22%).

In the austral summer (January-February) very small numbers of individuals were found in the samples. From February to May an increase in the number of mature specimens for both sexes was observed. During March, males were predominantly mature (mainly stages III and IV) while the modal maturity stage for females was II (immature). The maximum maturity stage found within this month was V (females). The distribution of maturity stages was rather similar in April, although the maximum maturity stage found was VI (the number of squid at this stage was negligible). In May, the majority of squid of both sexes were at maturity stage III.

During the first quarter of the year, there were no significant correlations between maturity stage and the environmental parameters (Fig. 10). In the second quarter, maturity was positively correlated with latitude, longitude and SST. This correlation was stronger for females than for males in the case of latitude and longitude.

In the third quarter there was a strong negative correlation between male maturity and SST, but this was not seen for females. Latitude and longitude were also negatively correlated with maturity (as opposed to the pattern found in the 2^{nd} quarter). There were also significant positive correlations between both average depth and lunar cycle and maturity stage.

In the fourth quarter, the most significant positive correlations were between latitude, longitude and maturity stage for males. For females, there was a positive correlation with SST. Depth was negatively correlated with maturity for both sexes.

GAM plots shown in figure 11 represent the effects that latitude, longitude, average depth and sea surface temperature (SST) have on maturity of *Illex argentinus.*

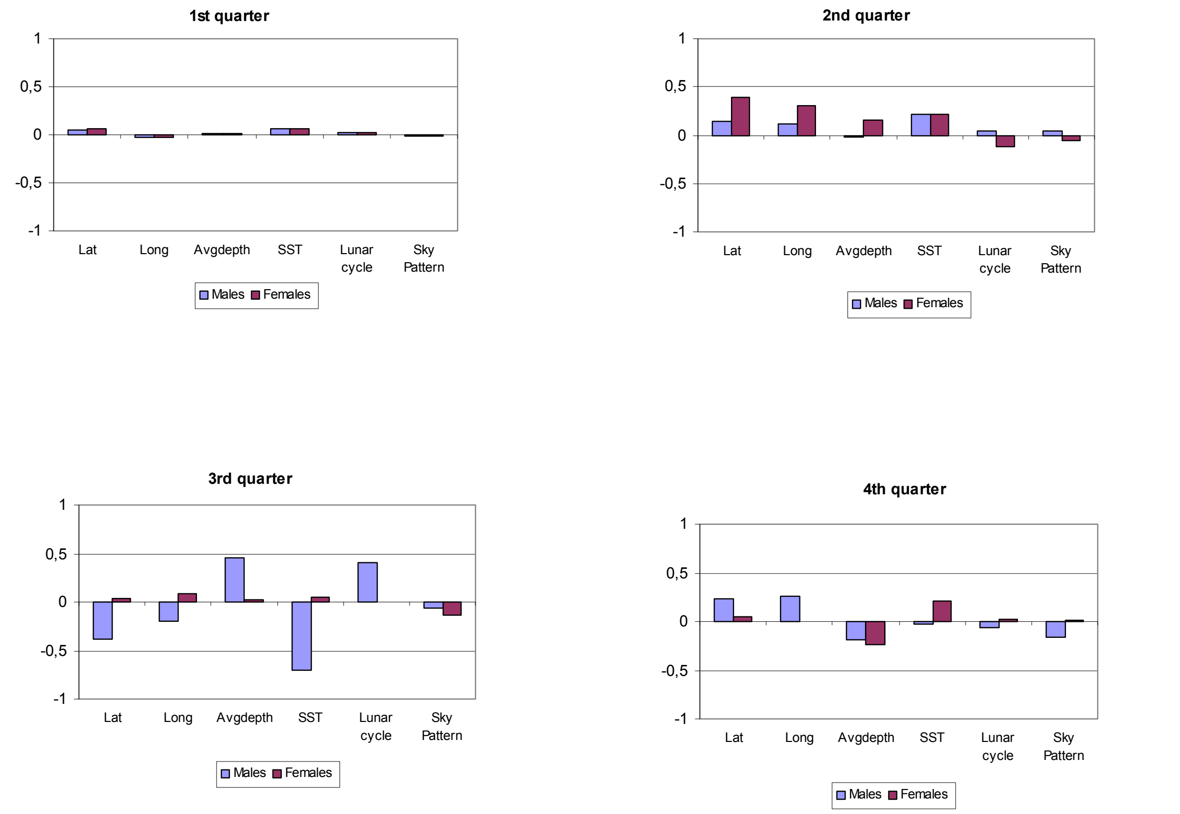


Figure 10. Spearman's rank correlation between maturity stage and all other variables

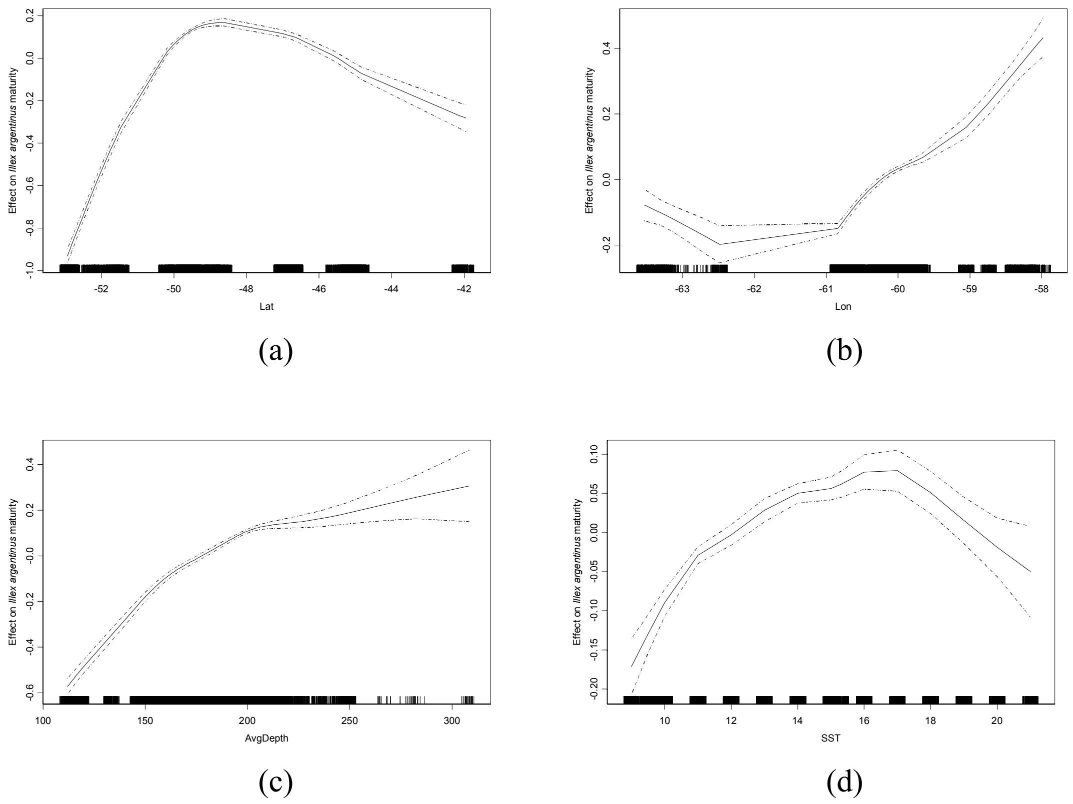
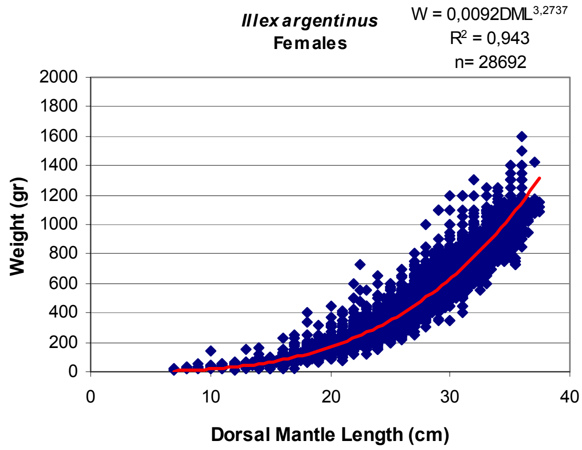
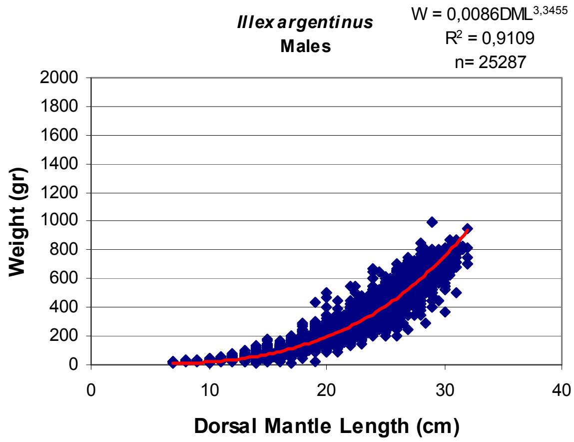


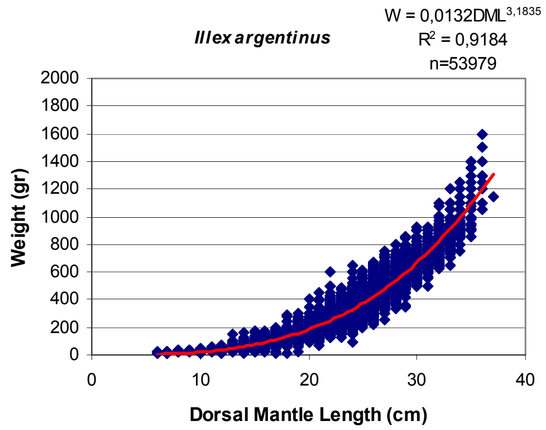
Figure 11. GAM regressions between maturity and other variables

Length-weight relationships

Maximum lengths recorded for *Illex argentinus* were 36 cm DML for males and 41 cm DML for females. The relationship between DML and body weight was similar for males and females as shown in figure 12.







	a	b	R^2
Male	0,0086	3,3455	0,9109
Female	0,0092	3,2737	0,943
Non sexed	0,0135	3,1777	0,917

Figure 12. Length-weight relationship for *Illex argentinus*

Scatter plots

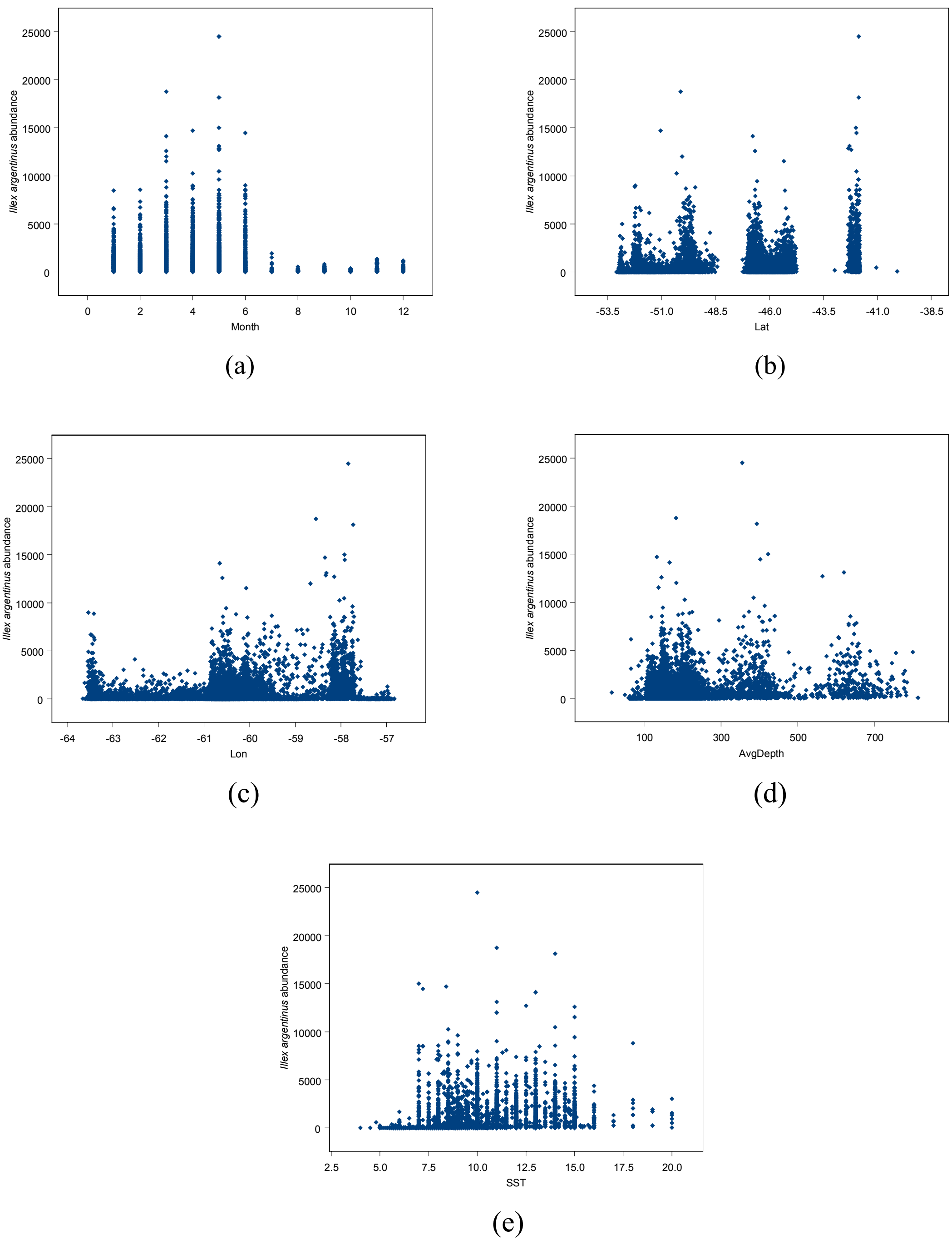


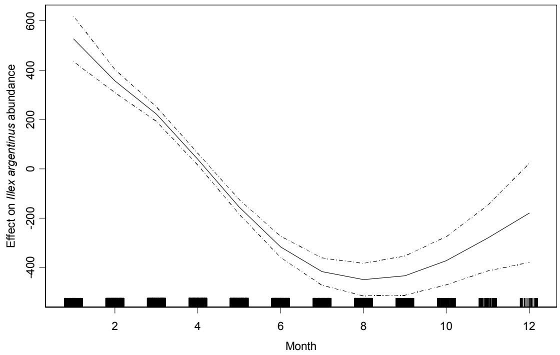
Figure 13. Scatter plots showing the relationship between *Illex argentinus* abundance (CPUE as kg/h) and month (a), latitude (b), longitude (c), average depth (d) and SST (e)

Scatter plots (Fig. 13) confirm the non-linearity of the relationships between CPUE and environmental variables. *Illex argentinus* abundance appears to be higher during the six first months of the year reaching the maximum value in May. There is a marked difference in abundances between the first and the second half of the year.

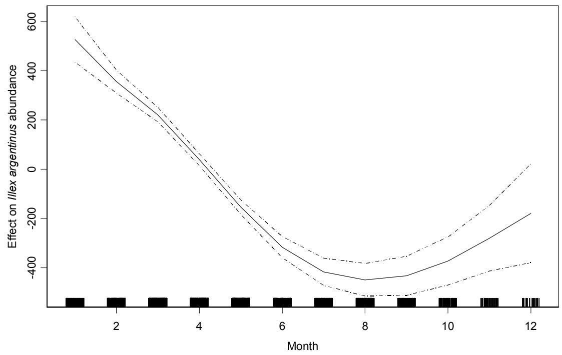
Illex argentinus abundance seems to be positively related to three depth ranges: around 200, 400 and 650 m. The highest squid abundances were associated with a wide range of SST (7º C to 15º C). The relationship of abundance (CPUE) with the geographic position (latitude and longitude) probably indicates where the vessels are fishing.

Generalized additive models

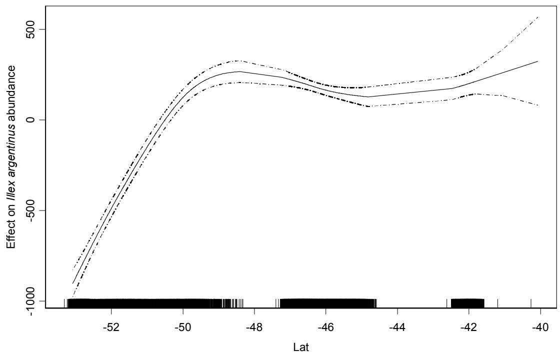
Unweighted model *Weighted model*



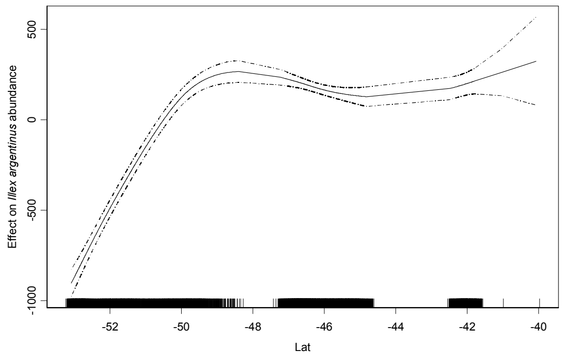
(a)



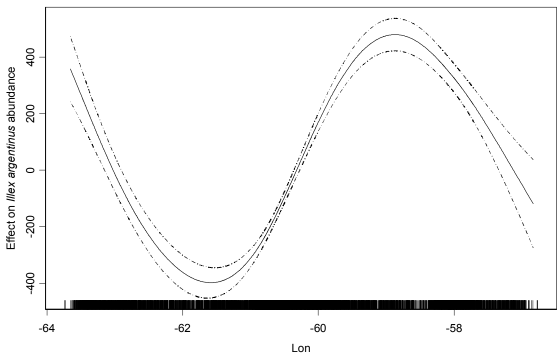
(b)



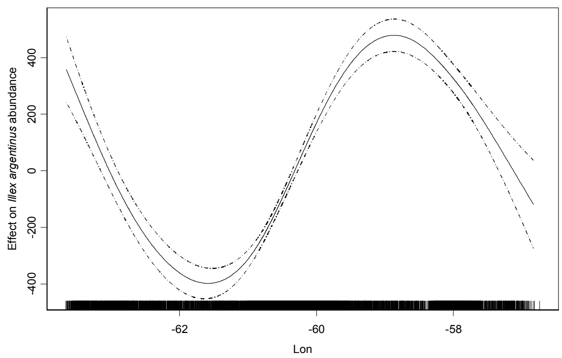
(c)



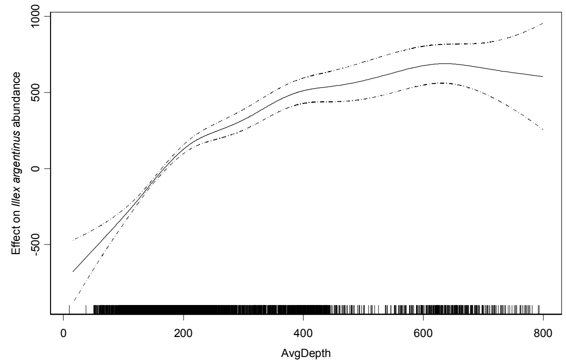
(d)



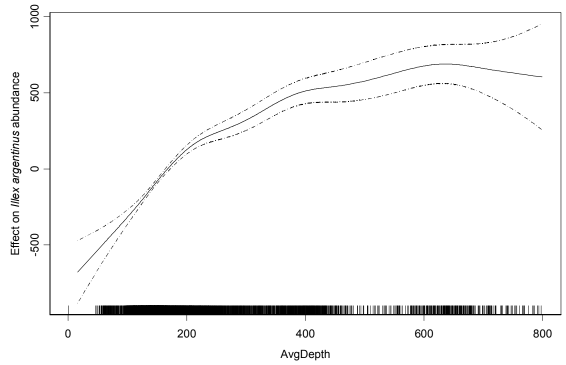
(e)



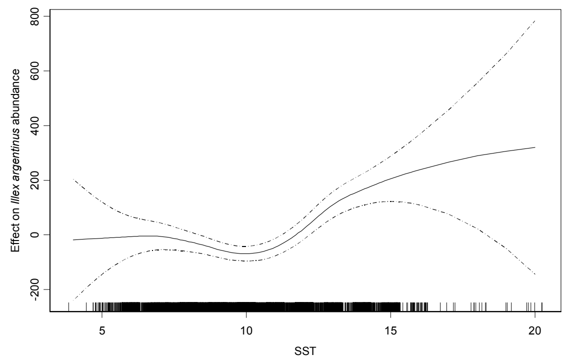
(f)



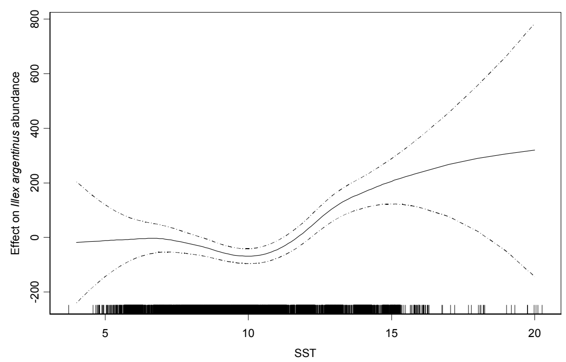
(g)



(h)



(i)



(j)

Figure 14. Results of GAM regression for unweighted and weighted model

The GAM plots show the best fitting smoothers (and 90% confidence limits) for the effects of month, latitude, longitude, average depth and SST on *Illex argentinus* abundance (CPUE) for the unweighted and weighted model. Dashed lines represent two standard error boundaries around the covariate main effects. Tick marks on the x-axis show locations of data points. The density of points for different covariate values is shown by the rug under the single covariate effect plots. Fewer points lead to larger standard error bands. The plots show the best fitting smoothers for the effect of the covariates included in the model. The partial components, as represented by the y-values on the GAM plots, express the relationship between the abundance and each of the variables included in the model (Fig. 14). The weighted and unweighted GAMs had rather similar goodness of fit values (Table 1).

The GAMs essentially confirm trends revealed by visual examination of scatter plots. There is a strong seasonal effect on the squid abundance (Fig. 14 a & b). The minimum value is in August. Regarding latitude, the GAM plots (Fig. 14 c & d) show an increasing trend in abundance from around 53^{o} S to 48º S. From this latitude northwards the abundance is quite constant. There is a clear minimum of abundance located at longitudes close to 62º W and a maximum located at 59º W (Fig. 14 e & f).

There is also here is a general increase in abundance with increasing depth (Fig. 14 g & h). *Illex argentinus* preferentially occurs in areas with SST above 10º C (Fig. 14 i & j). Even higher abundances were found at temperatures above 15º C but the trend in this SST range is not significant as indicated by the very wide confidence limits due to the low density of data points.

REFERENCES

Acha, E.M., Mianzan H.W., Guerrero, R.A., Favero. M., Bava, J., 2004. Marine fronts at the continental shelves of austral South America Physical and ecological processes. *Jour. Mar. Syst.* **44** (2004) 83– 105

Anderson, C.I.H. and Rodhouse, P.G. Life cycles, oceanography and variability: ommastrephid squid in variable oceanographic environments. *Fish. Res*. in press.

Arkhipkin, A. I., 2000. Intrapopulation structure of winter-spawned Argentine shortfin squid, *Illex argentinus* (Cephalopoda, Ommastrephidae),during its feeding period over the Patagonian Shelf. *Fish. Bull*.98:1 –13.

Bakun, A. and Csirke, J., 1998. Environmental processes and recruitment variability. In: *Squid Recruitment Dynamics*. P.G. Rodhouse, E.G. Dawe and R.K. O'Dor (eds). Rome: FAO, pp. 105-124.

Basson, M., Beddington, J.R., Crombie, J.A., Holden, S.J., Purchase, L.V. and Tingley, G.A., 1996. Assessment and management techniques for migratory annual squid stocks: the *Illex argentinus* fishery in the Southwest Atlantic as an example. *Fish. Res*. **28**:3-27.

Brunetti, N.E. and Ivanovic, M.L., 1992 Distribution and abundance of early life stages of squid (*Illex argentinus*) in the south-west Atlantic. *ICES J. Mar. Sci*. **49**:175-183.

Caddy, J.F., 1983. The Cephalopods: factors relevant to their population dynamics and to the assessment and management of the stocks. In: J.F. Caddy (Editor), Advances in Assessment of World Cephalopod Resources. *Tech. Pap*. 231, FAO, Rome, 452 pp.

Coelho, M.L., 1985 Review of the influence of oceanographic factors on cephalopod distribution and life cycles. NAFO *Sci. Coun*. Report **9**:47-57.

Haimovici, M., Brunetti, N.E., Rodhouse, P.G., Csirke, J. and Leta, R.H., 1998. *Illex argentinus*. In: *Squid Recruitment Dynamics*. P.G. Rodhouse, E.G. Dawe and R.K. O'Dor (eds). Rome: FAO, pp. 27-58.

Hastie, T. and Tibshinari R., 1990. Generalized additive models. Chapman and Hall, London.

Hatanaka, H., 1988. Feeding migration of short-finned squid *Illex argentinus* in the waters off Argentina. *Nippon Suisan Gakkaishi* **54**:1343-1349.

Hatanaka, H., 1986. Growth and life span of short-finned squid *Illex argentinus* in the waters off Argentina. *Bull. Jpn. Soc. Sci. Fish*., 52 (1):11-17.

Hatanaka, H., Kawahara, S., Uozumi, Y. and Kasahara, S., 1985 Comparison of five ommastrephid squids fished by Japan: *Todarodes pacificus*, *Illex illecebrosus*, *Illex argentinus*, *Nototodarus sloani sloani* and *Nototodarus sloani gouldi*. NAFO *Sci. Coun. Studies* **9**:59-68.

Lutz, V.A., Carreto, J.I., 1991. A new spectrofluorometric method for the determination of chlorophylls and degradation products and its application in two frontal areas of the Argentine Sea. *Cont. Shelf Res*. 11 (5), 433– 451.

Maravelias, C. D., 1997. Trends in abundance and geographic distribution of North Sea herring in relation to environmental factors. Mar. Ecol. Prog. Ser. 159, 151-164.

Martos, P., Piccolo, M.C., 1988. Hydrography of the Argentine continental shelf between 38º and 42º S. *Cont. Shelf Res*. 8 (9), 1043– 1056.

McCullagh, P. & Nelder, J. A., 1989. Generalized Linear Models. Chapman & Hall, London, UK.

Portela, J.M., Arkhipkin, A., Agnew, D., Pierce, G., Fuertes, J.R., Otero, M.G., Bellido, J.M., Middleton, D., Hill, S., Wang, J., Ulloa, E., Tato, V., Cardoso, X.A., Pompert, J., Santos, B., 2002. Overview of the Spanish fisheries in the Patagonian Shelf. ICES ASC 2002. ICES CM 2002/L: 11. Theme Session on Census of Marine Life: Turning Concept into Reality.

Rodhouse, P.G., Barton, J., Hatfield, E.M.C. and Symon, C., 1995. Illex argentinus: life cycle, population structure and fishery. *ICES Mar. Sci. Symposium* **199**:425-432.

Swartzman, G., Huang, C. P., Kaluzny, S. P. 1992. Spatial analysis of Bering Sea ground fish survey data using generalized additive models. Can. J. Fish. Aquat. Sci. 49:1366-1378

Swartzman, G., Stuetzle, W., Kulman, K., Powojowski, M., 1994. Relating the distribution of Pollock schools in the Bering Sea to environmental factors. ICES J. Mar. Sci. 51 (4), 481-492.

Swartzman, G., Silverman, E., Williamsom, N., 1995. Relating trends in walleye Pollock (*Theragra halcogramma*) abundance in the Bering Sea to environmental factors. Can. J. Fish. Aquat. Sci. 52 (2), 369-380.

Waluda, C.M., Rodhouse, P.G., Trathan, P.N. and Pierce, G.J., 2001. Remotely sensed mesoscale oceanography and the distribution of *Illex argentinus* in the South Atlantic. *Fish. Oceanogr*. 10:2, 207-216.

Waluda, C.M., Trathan P.N., Rodhouse P.G., 1999. Influence of oceanographic variability on recruitment in the *Illex argentinus* (Cephalopoda: Ommastrephidae) fishery in the South Atlantic. *Mar Ecol Prog Ser* 183:159-167