Working Document for the ICES WGCEPH on Cephalopod Fisheries and Life History. Lisbon, Portugal, 16-19 June 2014.

Analysis of the relationship between Argentine short-finned squid (*Illex argentinus*) abundance and environmental parameters in the SW Atlantic Ocean using GIS tools.

Martinez, R.[1], Portela J.[2] and Fernandes, W.[2,3]

[1] Alfred Wegener Institute (AWI)
Bremerhaven, Germany
e-mail: Roi.Martinez@awi.de

[2] Instituto Español de Oceanografía (IEO)
Centro Oceanográfico de Vigo
Cabo Estay-Canido. 36200 Vigo, Spain
e-mail: julio.portela@vi.ieo.es

[3] University of Aberdeen, Main Street,
Newburgh, Aberdeenshire, AB41 6AA, UK
e-mail: w.fernandes@live.co.uk

ABSTRACT

The Argentine short-finned squid *Illex argentinus* is the main cephalopod species which occurs in the Southwest Atlantic Ocean. It is the most highly fished species in terms of catches and is the major target of large-scale directed fishing carried out by ñjiggersò, and to a lesser extent, by trawlers. The variability of main current systems in the region (Brazil and Falkland/Malvinas Currents) has been suggested to influence the abundance and distribution of *I. argentinus*, thus largely affecting profitability and sustainability of the fisheries. In this working document we analyse the environmental, geographical, temporal and physical factors affecting the distribution (abundance) of *I. argentinus* in two areas of highest distribution, using geographic information systems tools. Strong correlation was found between *Illex* abundance and the season of the year, as well as with latitude, confirming our knowledge of the fishery and the literature on this species.

Keywords: cephalopods, *Illex argentinus*, fisheries, Southwest Atlantic, environmental parameters, GIS

INTRODUCTION

Squid fisheries in the Southwest Atlantic Ocean (SWAO) are dominated by *Illex argentinus* (Pierce and Portela, 2014), a neritic-oceanic species widely distributed along the Patagonian shelf between 22ºS and 54ºS, undertaking large migrations between their feeding grounds in the south Patagonian shelf (Hatfield and Rodhouse, 1994; Arkhipkin et al., 2003) and spawning/nursery grounds in southern Brazil (Arkhipkin, 1993, Arkhipkin et al., 2003, 2006; Waluda et al., 1999, 2005).

Migrations and concentrations of this species may be affected by several oceanographic features, for example the Brazil and the Falkland/Malvinas Currents, the major ones in the SWAO. *I. argentinus* is associated with the Brazilï Falkland confluence front during the early life stages (Hatanaka, 1988; Leta, 1992; Rodhouse et al., 1995; Haimovici et al., 1998; Waluda et al., 1999, 2001a,b), whereas during maturation, growth, and feeding stages, it is mostly associated with the Falkland/Malvinas Current (Rodhouse et al., 1995; Laptikhovsky and Remeslo, 2001). The cold Falkland/Malvinas Current originates from the Antarctic Circumpolar Current and moves northwards along the edge of the Patagonian Shelf (Peterson and Whitworth III, 1989; Arkhipkin at el., 2006); the Brazil Current (warm) is a branch of the trans-Atlantic South Equatorial Current (SEC) that moves southward along the edge of South America. Migrations of *I. argentinus* are represented in Figure 1.

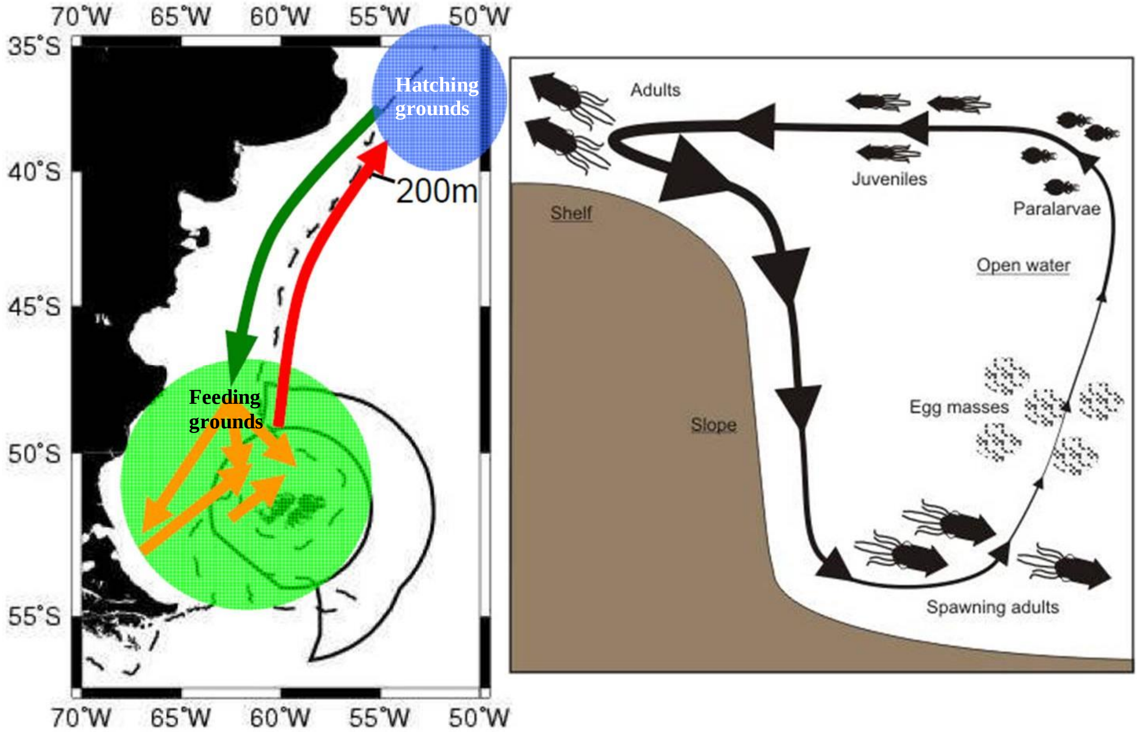

Figure 1.- Spatial and vertical migrations of *I. argentinus* in the Patagonian shelf (by courtesy of Dr. A. Arkhipkin, FIFD)

Several previous research studies have suggested links between squid abundance and oceanographic parameters such as sea surface temperature (SST). Waluda et al., (1999) revealed that variation in SST during the early life stages appears to be important factor influencing the recruitment of *I. argentinus*. SST in the northern Patagonian shelf during the period of hatching was negatively correlated with catches in the fishery in the following season. However, comparisons were made between SST anomaly data from positions in the Pacific and Southwest Atlantic to examine teleconnections between these areas. Predicting cold events via teleconnections between SST anomalies in the Pacific and Atlantic would appear to have the potential to predict the recruitment strength of *I. argentinus* in the Southwest Atlantic.

MATERIALS AND METHODS

Study Area

Two main geographical areas were defined for the study accordingly to the location of commercial hauls reported by skippers of Spanish trawlers operating in the SWAO:

1. The high seas of the Patagonian Shelf roughly between 44º50ôS and 47º10ôS
2. The waters around the Falkland/Malvinas Islands

Data

Data analysis took into account the season of the year and included:

- Commercial fishery data on catches from logbooks filled in by skippers of Spanish bottom trawlers operating in the study areas (2010-2012). These data were provided to us by the Spanish General Secretariat for Fisheries
- Environmental and physical data: Sea Surface Temperature (SST), bathymetry, latitude, and longitude (2010-2012)

Seasonality

The analysis included time comparisons of CPUE by quarter, roughly coinciding with the seasons of the year in the southern hemisphere:

- First quarter: summer
- Second quarter: autumn
- Third quarter: winter
- Fourth quarter: spring

The environmental and physical data used in the analyses originated from the following sources:

Atlantic SST: large-scale SST data was made available from the website of the Physical Sciences Division, Earth System Research Laboratory, NOAA, Boulder, Colorado, USA (http://www.esrl.noaa.gov/psd/) on a monthly basis for the period January 2010 to December 2012. Previous research has shown SST data to be comparable with near-surface data derived from in situ expendable bathy-thermograph (XBT) profiles in the southern Patagonian shelf.

Bathymetry data: high resolution bathymetry data in high seas collected via several research cruises conducted by the Spanish R/V ñMiguel Oliverò between 2007 and 2010, and low resolution bathymetry data (GEBCO) around the Falkland/Malvinas Islands. The main objective of these cruises was the study of Vulnerable Marine Ecosystems (VMEs) on the high seas of the Patagonian shelf and possible interactions of bottom trawl activities in this area.

Geographical data: daily positions (latitude, longitude) recorded at noon by skippers were extracted from logbooks and integrated into a 5ô*10ô grid.

RESULTS

Logbooksô positions were located between 40ºS-53ºS and 42ºW-64ºW within the UTM20S and UTM21S zones, and were split in two geographical areas: the northern area, north of parallel 48ºS (contained by FAO Division 41.3.1) and the southern area, south of parallel 48ºS (contained by FAO Division 41.3.2), both divisions (Figure 2, left) within the FAO Major Fishing Area 41.

A total of 2384 hauls were located in the northern area (53%), whereas 2130 were recorded in the southern area. The northern correspond to high seas of the SW Atlantic Ocean (international waters in the external Patagonian shelf and slope), where no fishing regulatory measures are currently in force. The southern area match with the Falkland/Malvinas waters which are divided in terms of fishery management in two separate zones: FICZ (Falkland Islands Conservation Zone) and FOCZ (Falkland Outer Conservation Zone) (Figure 2, right).

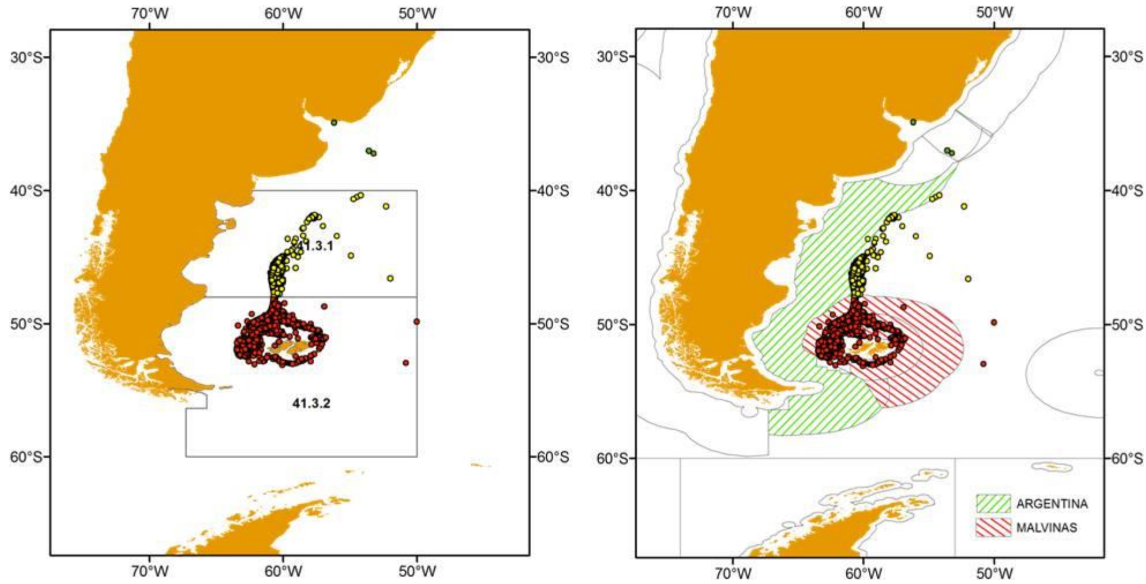

Figure 2.- Location of the hauls in relation with FAO Divisions 41.3.1 and 41.3.2 (left), and with the Argentine EEZ (green), the Falkland Conservation Zones (red) and with the high seas (colourless) (right). Hauls in yellow are located on the high seas, whereas the ones in red are within Falkland/Malvinas waters. It can be seen the presence of outliers located far east of the commercial fishing grounds, at impossible depths for trawling

In both areas respective polygons containing all the hauls selected for the study were delineated after debugging of outliers (hauls within Argentine waters or at inadequate depths). Herewith, a 5ô*10ô grid was defined and superimposed over the two polygons (Figure **3**).

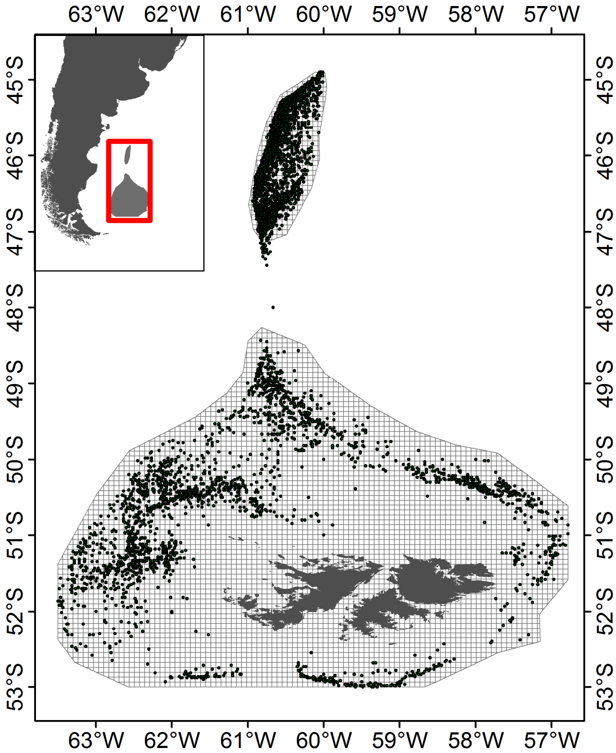

Figure 3.- Grid defined for the analysis (5ô*10ô)

The shape of the grid is based on a minimum boundaries algorithm that encompasses all locations in both the northern and southern areas/polygons. Each cell of the grid has an area of ~ 50 nm² and a statistical analysis was made based on the number of hauls per cell, thus allowing the addition of other parameter values (e.g. SST) to the corresponding cell.

3D model bathymetry

Location of the hauls in the study area: in the northern area hauls are located just within the outer shelf and upper slope of the Patagonian shelf (the high seas), beyond the 200 nm limit of the Argentine EEZ (Figure **4**). Analysis was carried out using a high resolution bathymetry (as discussed above in the methodology).

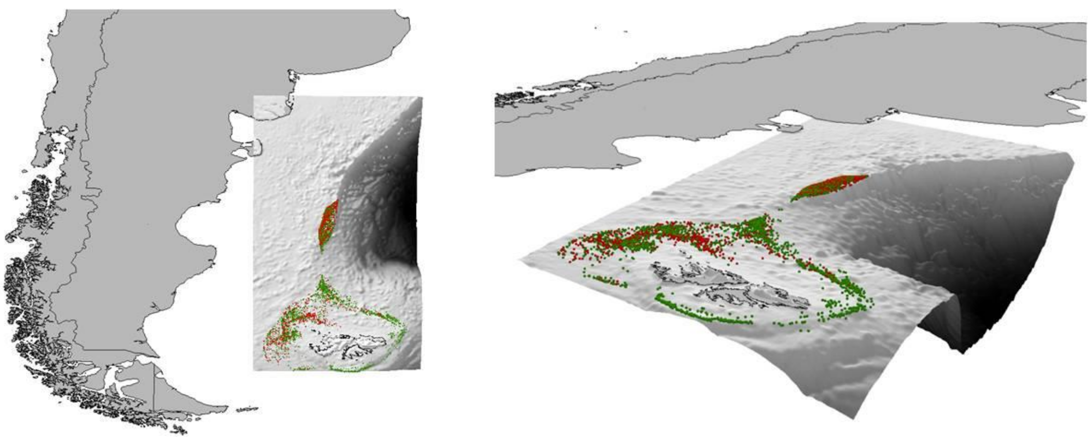

Figure 4.- 3D Bathymetry model

For the southern area, we used the low resolution bathymetry obtained from the GEBCO dataset. Opposite to the northern area, the hauls are spread all around the Falkland/Malvinas shelf where the maximum depth of the hauls is ~ 400 m.

A detailed view of the location of the hauls in northern area can be found in Figure 5. 100% of the positions fell above 400 m isobath. This result from the analysis is consistent with the findings of the study carried out by the IEO in 2007-2010 on board the R/V ñMiguel Oliverò. The Argentine EEZ is represented in green, whereas the northern part of the Falklands Outer Conservation Zone (FOCZ) is depicted in pink colour.

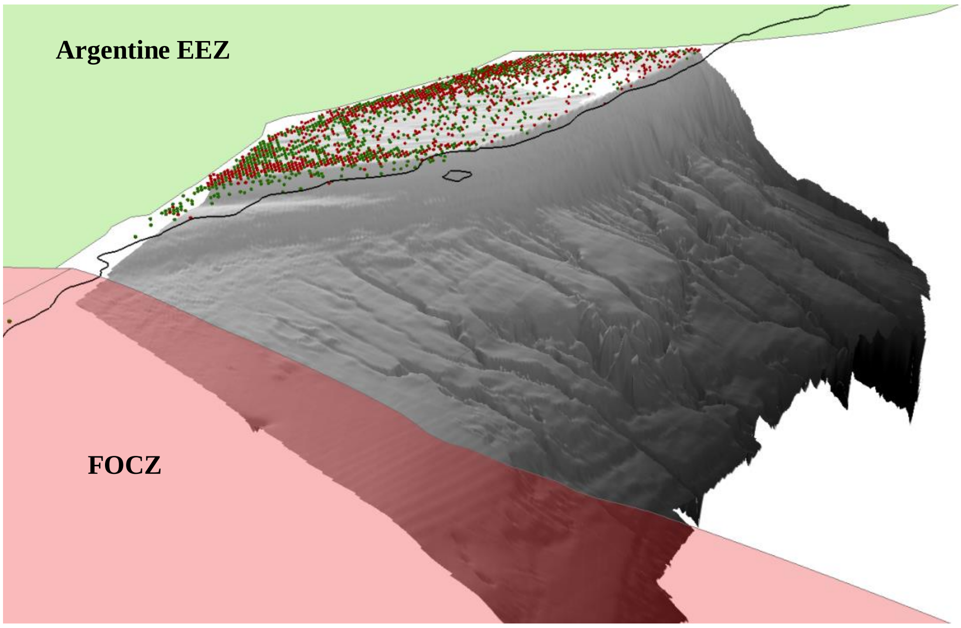

Figure **5**.- A detailed view of the hauls reported from northern area. It can be seen that hauls to the north of this area fall within the shelf, whereas some falls to the south (close to the FOCZ), are located in the slope of the Patagonian shelf

CPUE and SST Spatial Analysis

In this section we describe the relationship between the abundance of *Illex argentinus* and the SST in northern and southern areas by season of the year. We used CPUE from logbooks filled in by captains of Spanish fishing vessels between January 2010 and December 2012 as an index of abundance. To differentiate vessels targeting Argentine squid from those targeting other species such as hake, we established a threshold of 500 kg/h.

The values of mean CPUE and mean SST for each cell of the grid in summer and autumn in the northern area are shown in Figure 6. In summer we can appreciate that the higher CPUE values are located close to the 150 m isobath in the northern part of this area, whereas in the southern one, they are found between the 150 m and 400 m isobaths. We also show a decrease of the CPUE values in autumn, which is in agreement with previous research. It appears that fishery catches of *I. argentinus* decrease dramatically beyond mid-May, forcing the fleet to target other species.

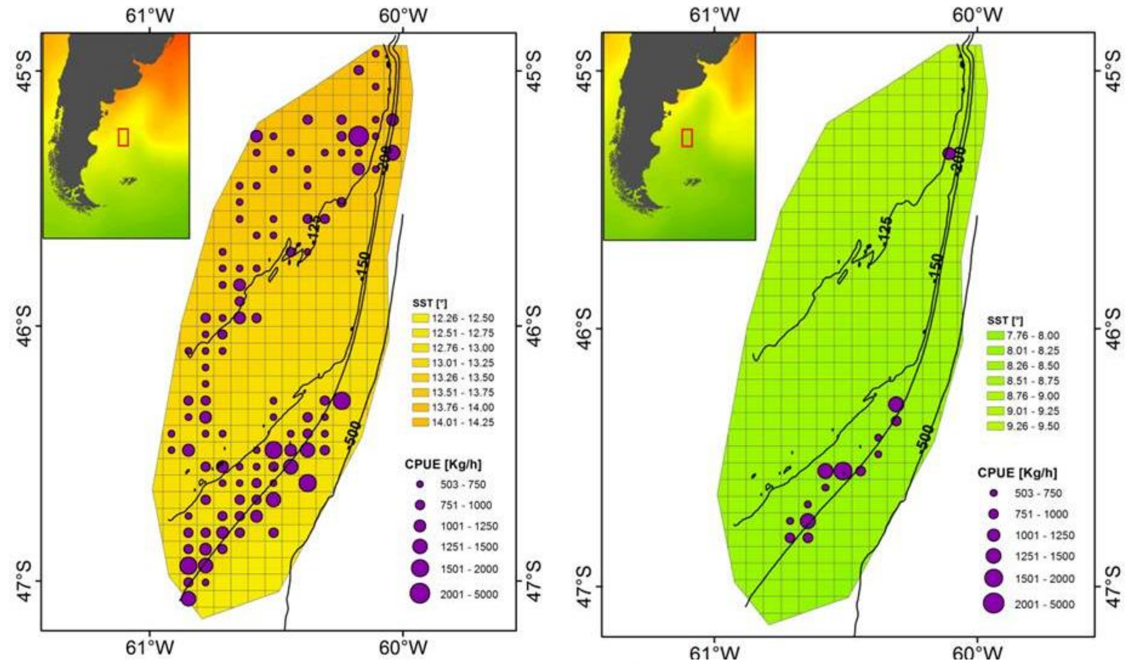

Figure 6.- Mean CPUE and mean SST in summer (left) and autumn (right) in the northern area

The same type of information is represented in Figure 7 for winter and spring. CPUE continue dropping in the following season: the presence of *I. argentinus* is negligible in winter, but seems to increase in spring, when we can see two cells with intermediate CPUE values, probably corresponding to late December, when Argentine squid starts to appear in this region as a result of its maturation/growth/ feeding migration to the southern Patagonian shelf.

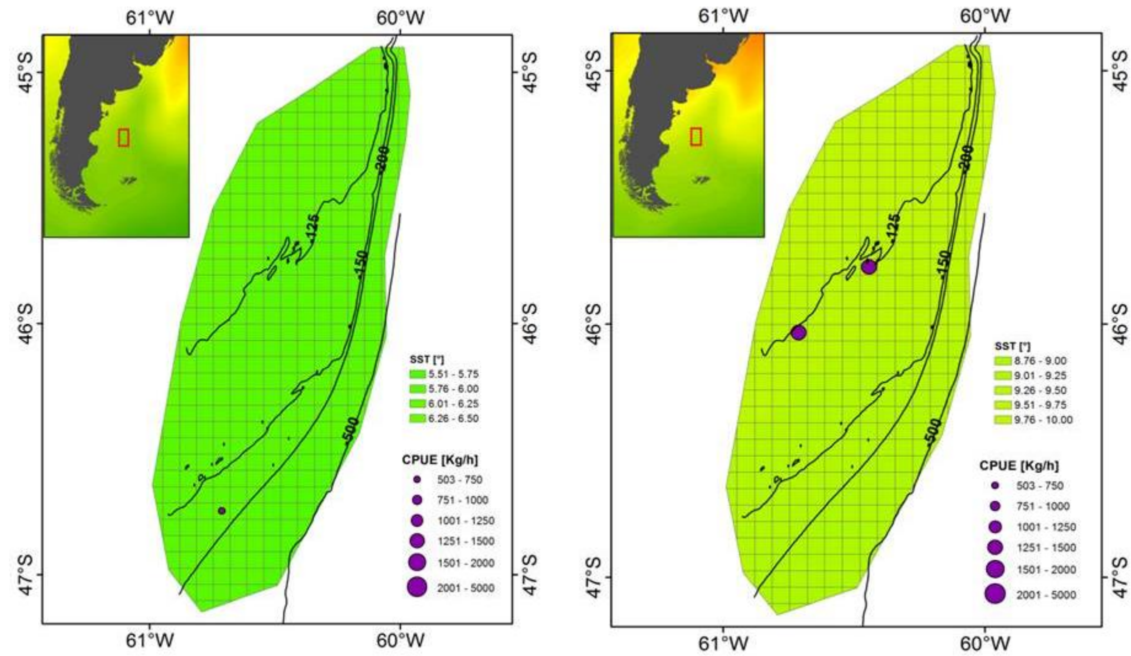

Figure 7.- Mean CPUE and SST in winter (left) and spring (right) in the northern area

In Figure 8 we can see the mean CPUE and mean SST values for each cell of the grid in the southern area during summer-autumn. It can be seen that *I. argentinus* just distributes in northern part of Falkland/Malvinas waters. *Illex* abundance looks lower than in the high seas, probably due to a lower SST induced by a stronger influence of the Falkland/Malvinas Current in higher latitudes.

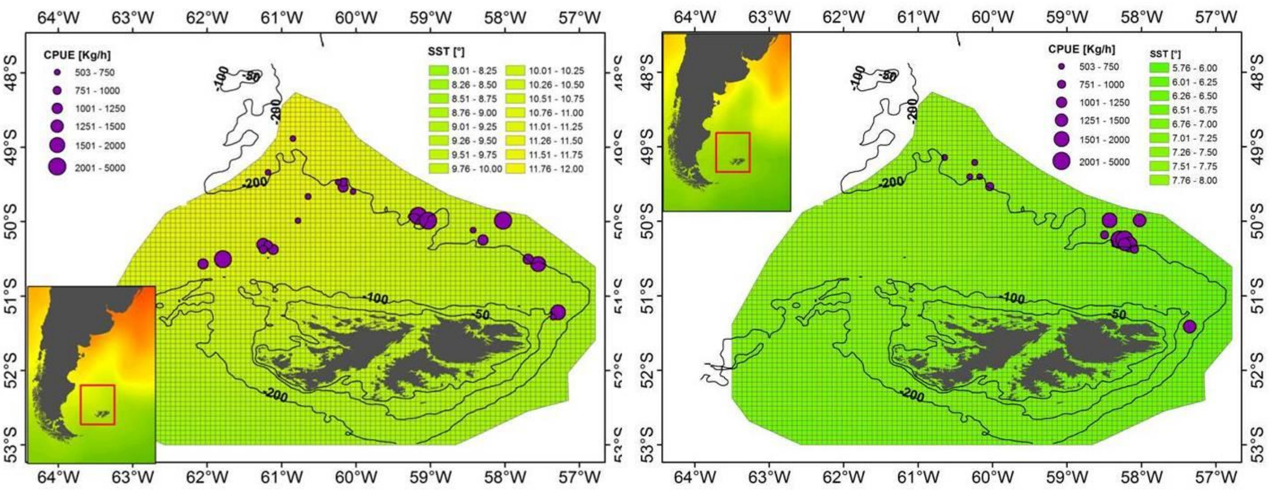

Figure 8.- Mean CPUE and SST in summer (left) and autumn (right) in the southern area

In winter-spring seasons (Figure 9), we can see that the Argentine squid has left the fishing grounds in Falkland/Malvinas waters, what is confirmed by the fact that no fishing licences are issued by the Falkland Islands Government for this part of the year.

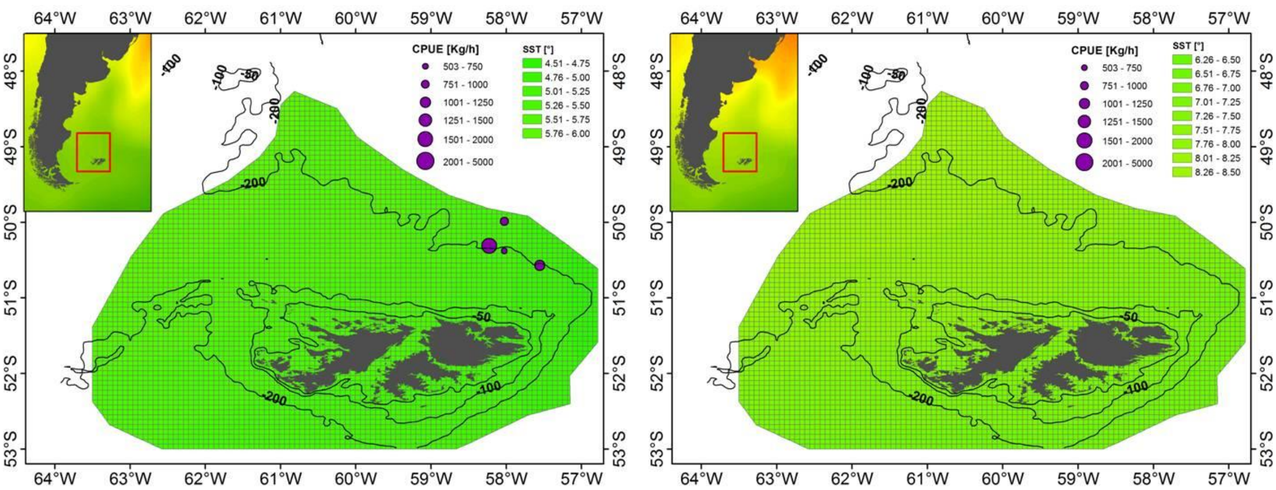

Figure 9.- Mean CPUE and SST in winter (left) and spring (right) in the southern area

Data exploration

Data exploration was made by using box plots. Analysis showed that the majority of the catches of *Illex* reported in the log books corresponded to the austral summer and autumn months (January- March; April-May); therefore, we carried out the data exploration over the CPUE values matching these periods of the year, comparing them against several oceanographic, geographical and physical parameters (SST, latitude, longitude and depth). To discriminate vessels targeting *I. argentinus* from vessels fishing for other species, a threshold of 500 Kg/h was defined in the northern area, whereas in the southern area the threshold was 10kg/h. We analyzed separately the northern and the southern areas.

Northern Area

Table 1.- Statistical values of the explanatory variables

	lat	long	CPUE	SST	depth
Minimum	-47.05	-60.90	501.5	7.643	-384.58
1st Quartile	-46.65	-60.75	685.9	13.083	-152.96
Median	-46.05	-60.65	910.2	13.603	-132.80
Mean	-46.09	-60.61	1048.9	13.224	-141.42
3rd Quartile	-45.58	-60.53	1228.4	13.603	-118.40
Maximum	-44.83	-60.00	3609.6	15.273	-38.67

The statistical values of the explanatory variables for *I. argentinus* in the northern area are presented in Table 1. In Figure **10** we can see the evolution of the data over time.

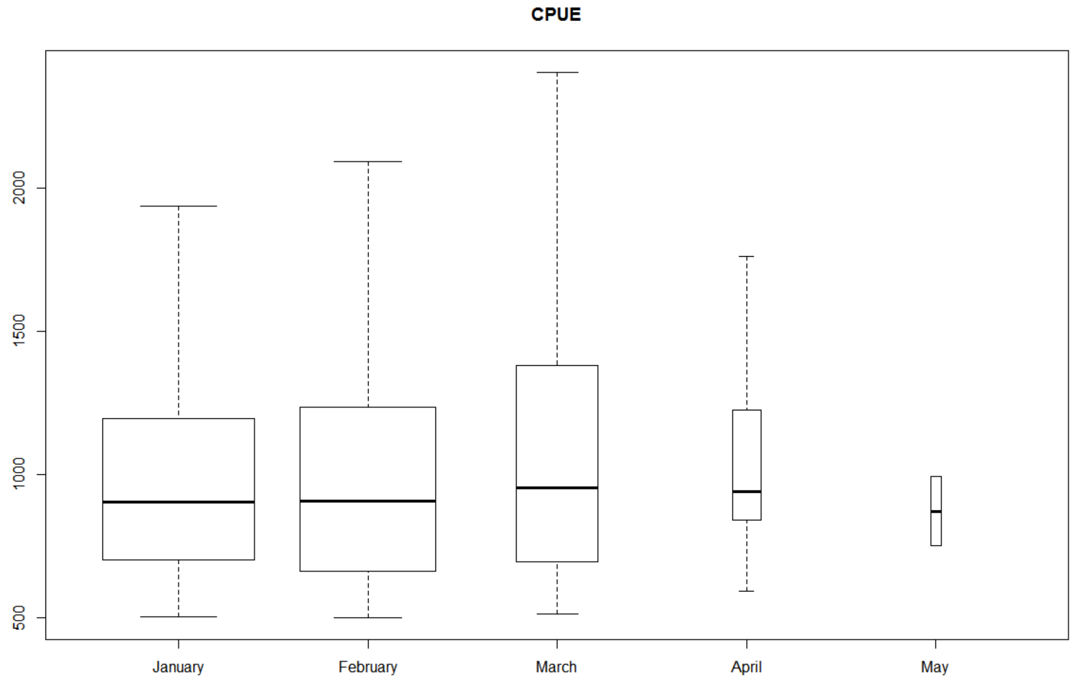

Figure 10.- Monthly CPUE values (kg/h)

Table 2.- CPUE statistical values

	Min	1st Quartile	Median	Mean	3rd Quartile	Maximum	Count
January	502.7	702.7	903.4	1034	1196	3389	458
February	501.5	662.4	906.2	1026	1236	3220	368
March	511.9	694.6	955.4	1155	1382	3610	133
April	594.4	852.8	939.2	1135	1226	2225	16
May	751.6	811.9	872.2	872.2	932.5	992.7	2

Figure 10, shows a slight increase of the median CPUE between January and March (austral summer), together with the increase of the maximum CPUE value (over 3600 kg/h in March, Table 2). A marked reduction in both, the maximum CPUE values and the number of hauls/month can be appreciated during April and May -austral autumn- (¡Error! No se encuentra el origen de la referencia.).

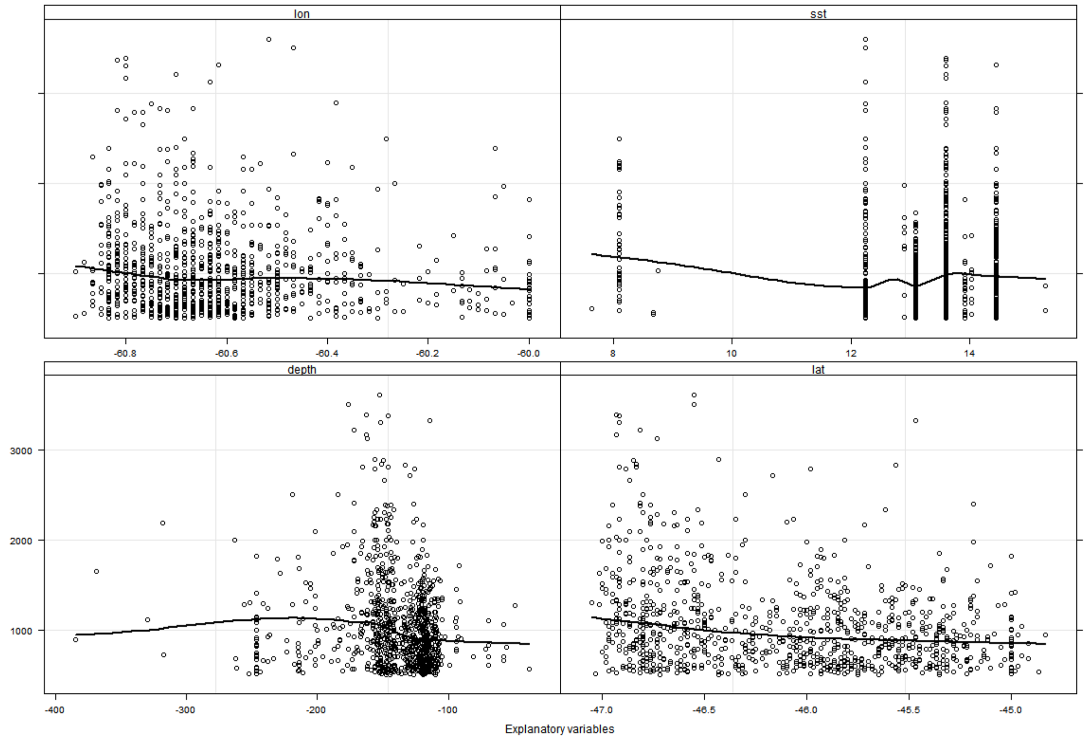

Figure 11.- Relationships between CPUE and selected variables

In Figure 11, a moderate correlation can be seen between CPUE and longitude, SST, and depth: most of the hauls are located at longitudes above 60.25W, the most important CPUE values are between 12ºC and 14.5ºC and amid 100 m and 175 m depth. Also a weak correlation with latitude can be observed (higher CPUEs are found at latitudes further south).

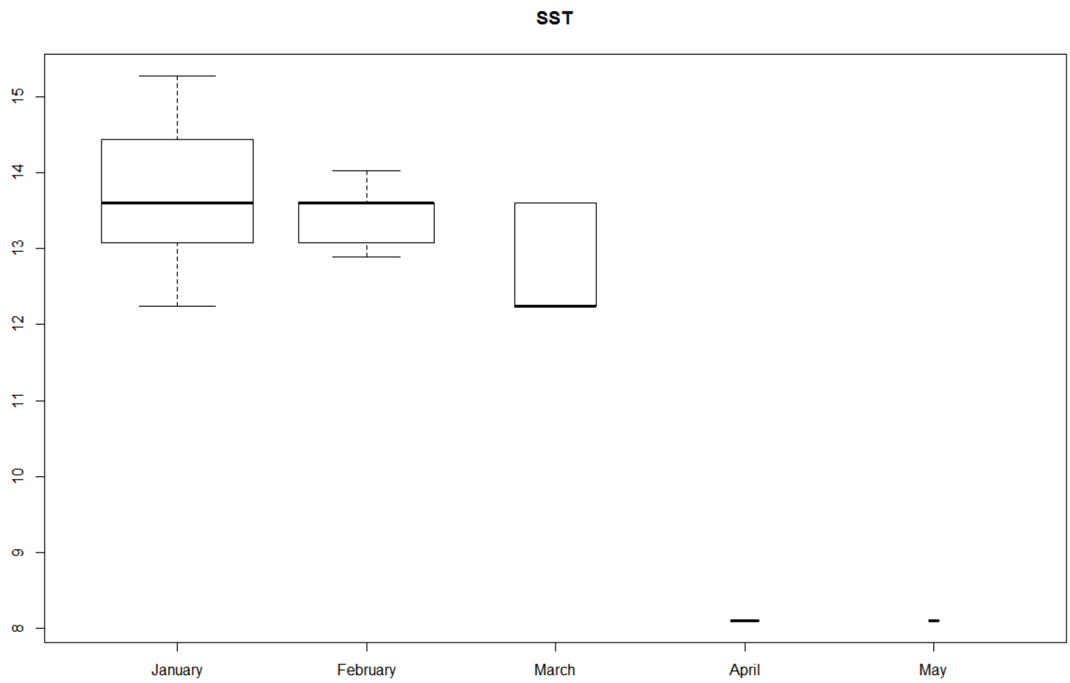

Figure 12.- Monthly SST values (ºC)

As expected, remotely sensed SST is higher during austral summer (mean SST 13.5ºC), when the Brazil Current has more influence in this area. From Figure 12, we may conclude that SST behaves similarly to CPUE: in March, the month with the uppermost CPUEs, SST decreased until 12ºC, whereas in April and May, SST drops dramatically until mean values around 8ºC (Table 3).

Table 3.- SST statistical values

	Min	1st Quartile	Median	Mean	3rd Quartile	Maximum	Count
January	12.24	13.08	13.6	13.64	14.44	15.27	458
February	12.24	13.08	13.6	13.38	13.6	15.27	368
March	7.643	12.24	12.24	12.06	13.6	13.6	133
April	8.103	8.103	8.103	8.103	8.103	8.103	16
May	8.103	8.103	8.103	8.103	8.103	8.103	2

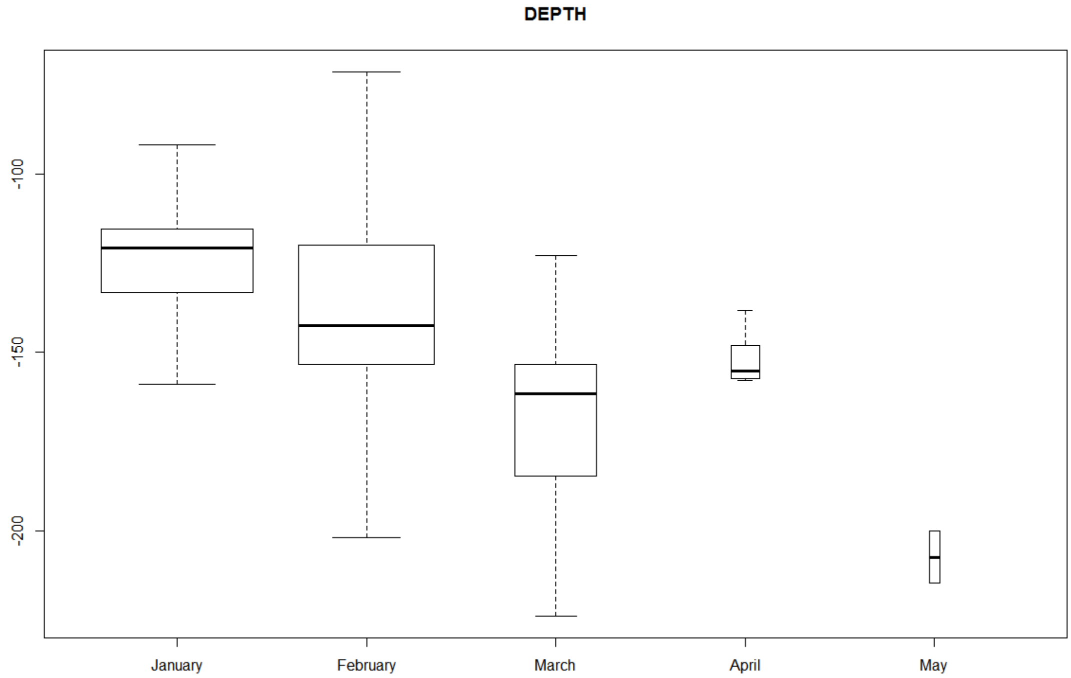

Figure 13.- Monthly depth values (m)

Table 4.- Depth statistical values

	Min	1st Quartile	Median	Mean	3rd Quartile	Maximum	Count
January	-384.6	-133.3	-120.7	-128	-115.6	-48.99	458
February	-318	-153.3	-142.5	-144.7	-120.1	-38.67	368
March	-368.9	-184.6	-161.6	-175.8	-153.3	-122.8	133
April	-186.9	-157.2	-155.3	-156.4	-148.4	-138.2	16
May	-214.6	-211	-207.3	-207.3	-203.7	-200	2

Figure 13 shows that depth increases from January to March, suggesting that the fleet moves to deeper and meridional waters (see Figure 15) in the outer Patagonian shelf (high seas) close to the upper slope, following *Illex* in its migration to the Falkland/Malvinas shelf. The wider bathymetric range (~ 40 m - 385 m) takes place in January- February, indicating a broader spatial distribution of the resource, and the mean depth increases from January (128 m) to May (204 m) (Table 4); this being an additional indicator of its migration to the south (depth is higher in the southern part of the high seas area).

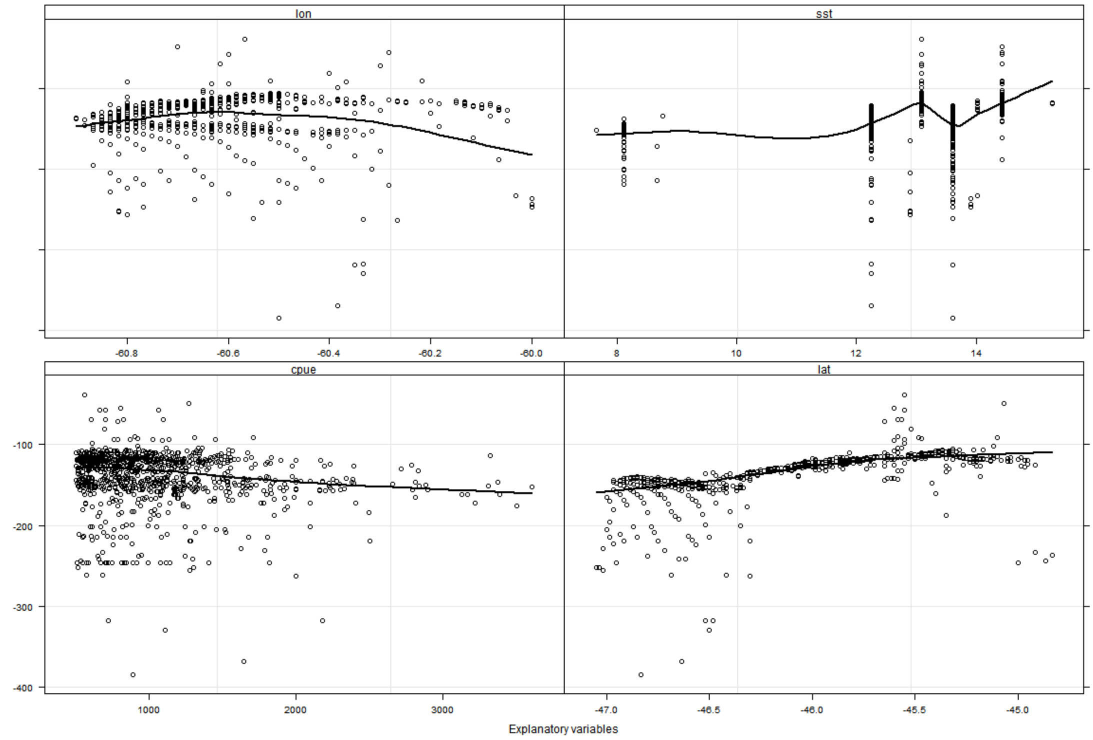

Figure 14.- Relationships between depth and selected variables

In Figure 14 we show a weak correlation between depth and CPUE, as well as with latitude, greater CPUEs being recorded at higher depths, which are located at higher latitudes.

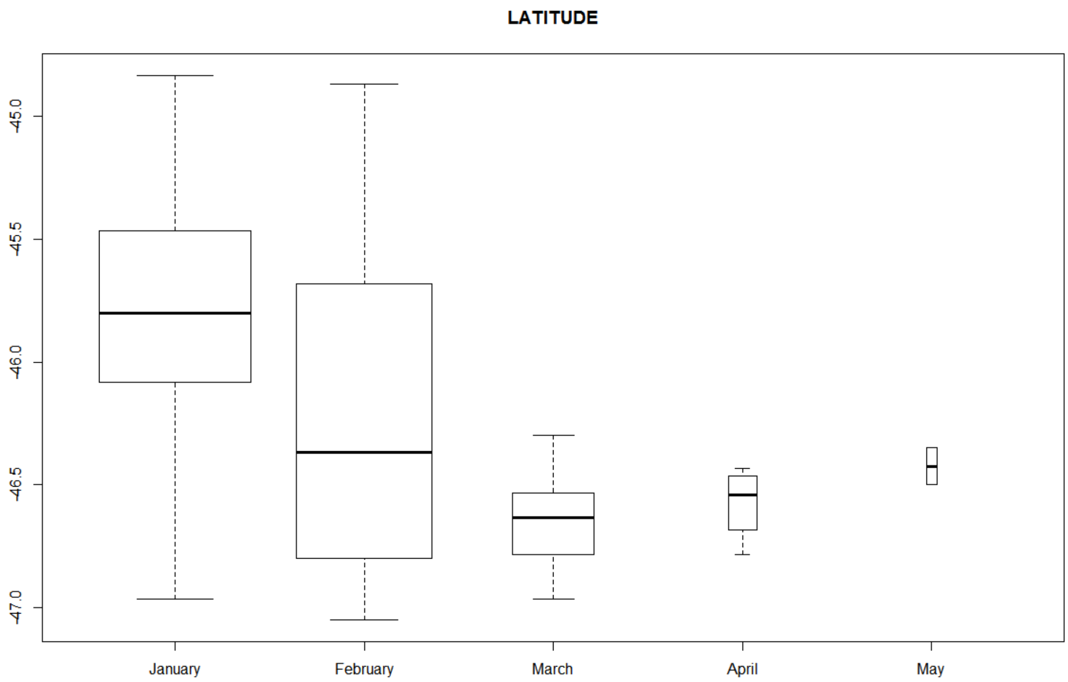

Figure 15.- Monthly latitude values

Figure 15 confirms our comment regarding the strategy of the fleet in relation to depth (Figure 13) and shows that the fleet moves to higher latitudes with time, following the resource in its migration to the south, reaching the most meridional mean latitude in March (late summer).

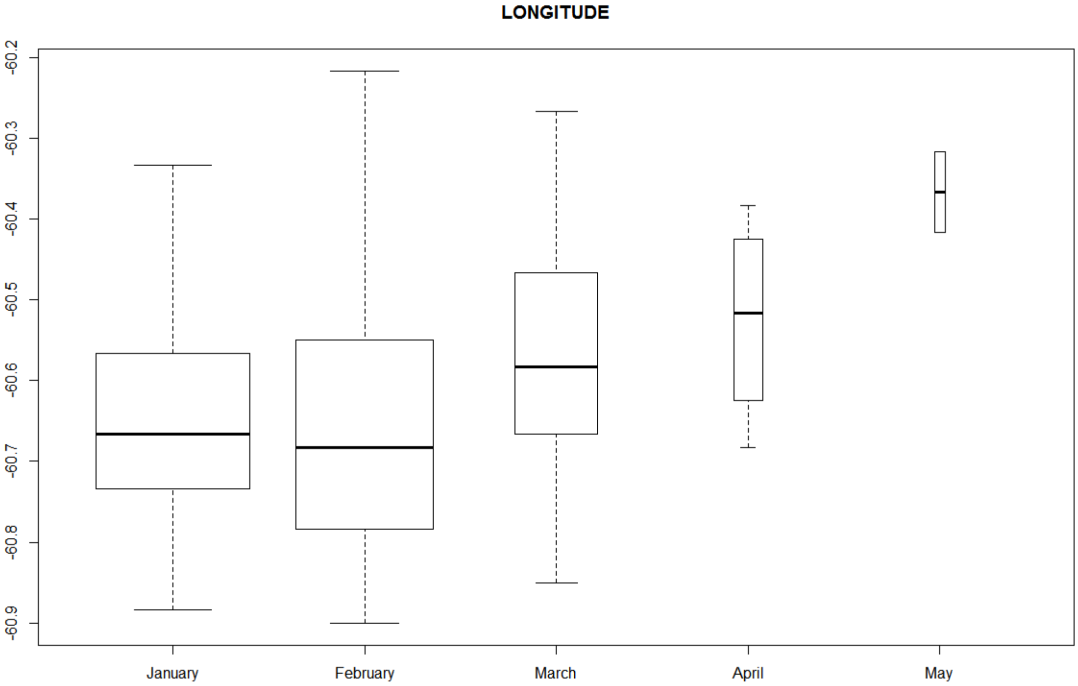

Figure 16.- Monthly longitude values

The same pattern is shown regarding longitude (Figure 16): the fleet moves eastwards searching for higher concentrations of *Illex* at higher depths in the southern part of the study area (see Figure 13 and Figure **15**).

Southern Area

Table 5.- Statistical values of the explanatory variables

	lat	long	CPUE	SST	depth
Minimum	-52.3	-63.43	10.21	4.64	-352
1st Quartile	-51.16	-62.41	23.87	7.32	-209.6
Median	-50.43	-61.45	42.67	7.767	-186.4
Mean	-50.58	-61.22	245.12	8.504	-187.8
3rd Quartile	-50.12	-60.69	145.9	9.85	-163.2
Maximum	-48.8	-56.9	3188.64	12.447	-83.4

In this area, only CPUE data for February-April was available. The statistical values of the explanatory variables for *I. argentinus* in the southern area are presented in **¡Error! No se encuentra el origen de la referencia.**. In Figure 17 we can see the evolution of the data over time.

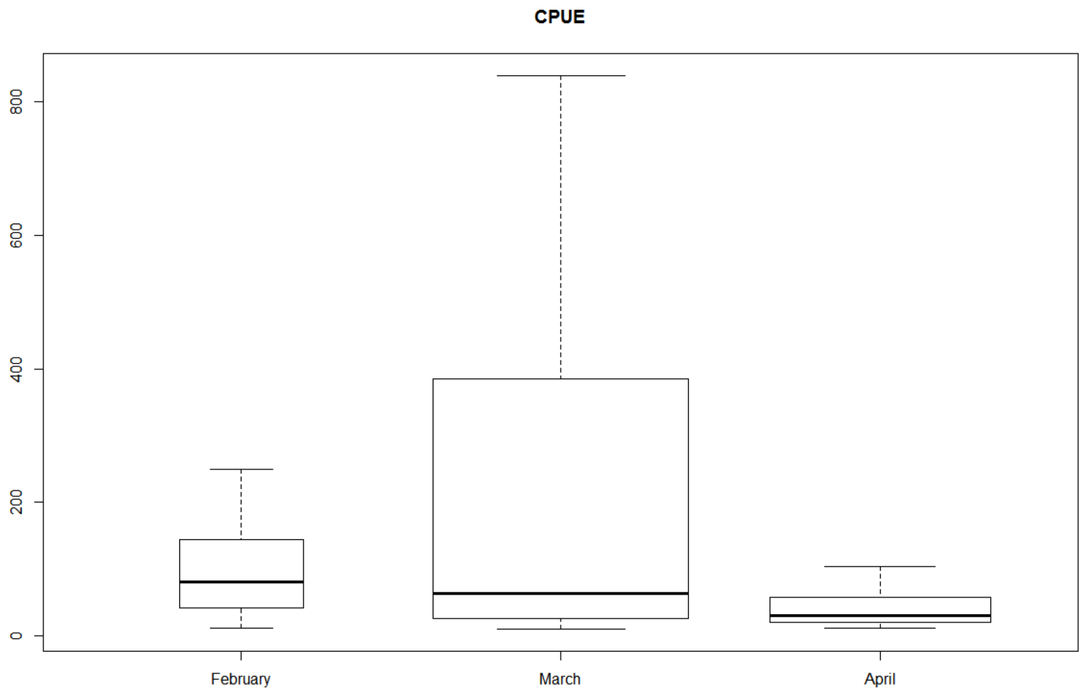

Figure 17.- Monthly CPUE values (kg/h)

Table 6.- CPUE statistical values

	Min	1st Quartile	Median	Mean	3rd Quartile	Maximum	Count
February	11	41	81	194.2	144	2423	45
March	10.21	25	62.5	365.9	385.5	3189	189
April	10.41	20.25	30.07	99.43	57	2280	141

CPUE values in the southern area are with difference much lower than in the northern area (see Table 2 and Table **6**). Figure **17** shows that the CPUE reached a high peak in March prior to a significant decrease in April and a steady decrease of the median between February and April.

.

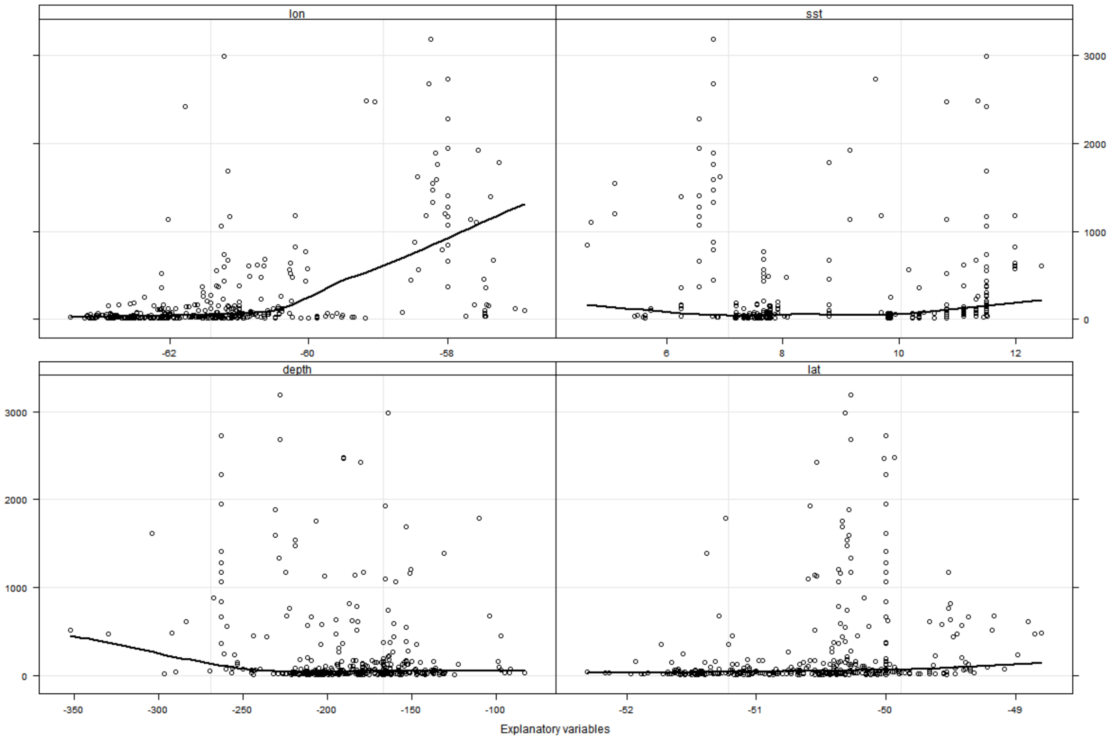

Figure 18.- Relationships between CPUE and selected variables

The only correlation that can be inferred from Figure **18** is between CPUE and longitude: CPUE values increase eastwards of 60.5ºW, suggesting that higher concentrations of the species are found in this region. This conforms with the license system in force in the Falkland Islands Conservation Zones, allowing fishing for *Illex* to the east of 60º30ôW. Most of the values in the data set are located to the west of this point and it can be explained by the fact that Spanish trawlers operating in Falkland/Malvinas waters target other species in this area.

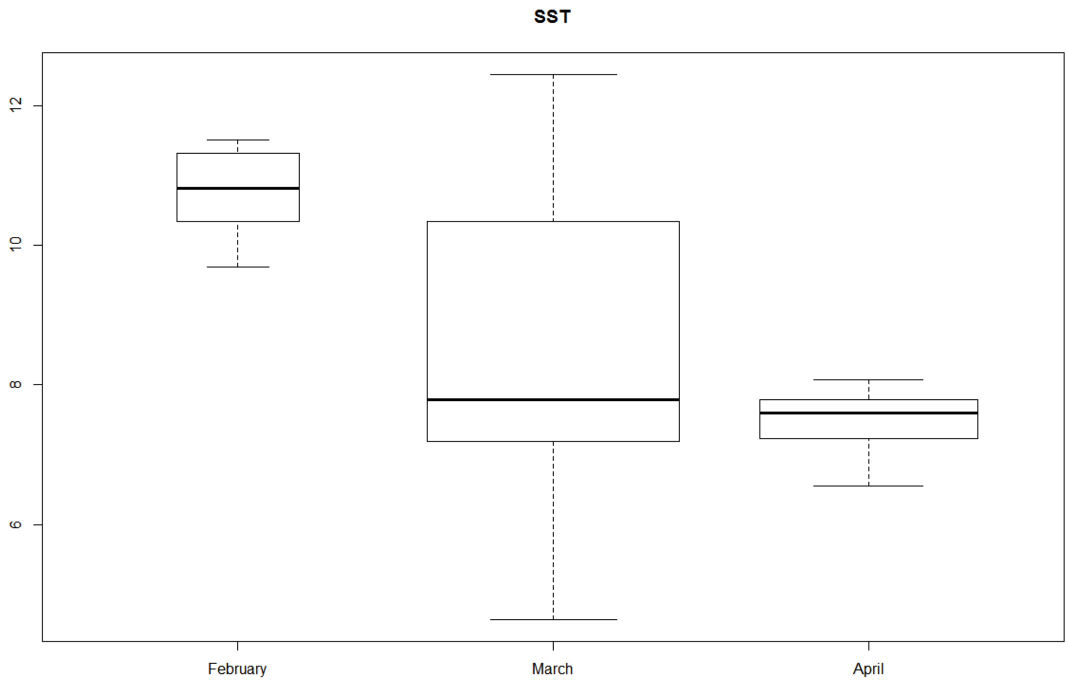

Figure 19.- Monthly SST values (ºC)

Table 7.- SST statistical values

	Min	1st Quartile	Median	Mean	3rd Quartile	Maximum	Count
February	9.697	10.34	10.82	10.8	11.33	11.52	45
March	4.64	7.187	7.787	8.7	10.34	12.45	189
April	5.723	7.237	7.6	7.506	7.787	8.077	141

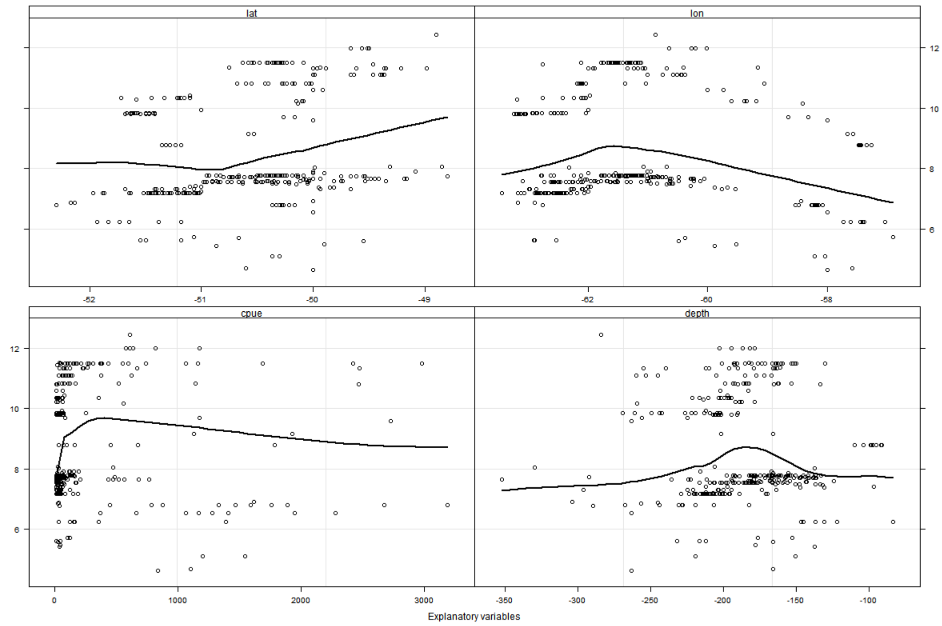

Figure 20.- Relationships between SST and selected variables

As expected, SST diminishes as early autumn approaches, and this similar pattern is found in the northern area. No correlation was found between SST and any of the other selected variables.

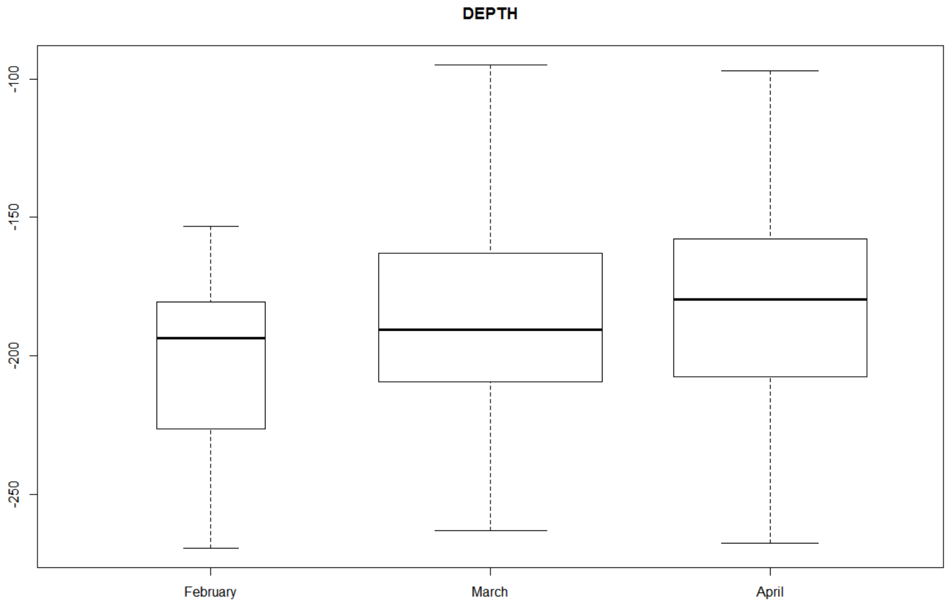

Figure 21.- Monthly depth values (m)

Table 8.- Depth statistical values

	Min	1st Quartile	Median	Mean	3rd Quartile	Maximum	Count
February	-269.3	-226.3	-193.5	-203.4	-180.5	-153.1	45
March	-352	-209.4	-190.6	-187.9	-162.8	-91.48	189
April	-329.6	-207.4	-179.5	-182.6	-157.9	-83.4	141

The mean depth of the hauls decrease with time, passing from an average depth of 203 m in February, to 182 m in April. Neither patterns, nor clear correlations were found in the data exploration between depth and the other variables (Figure 22).

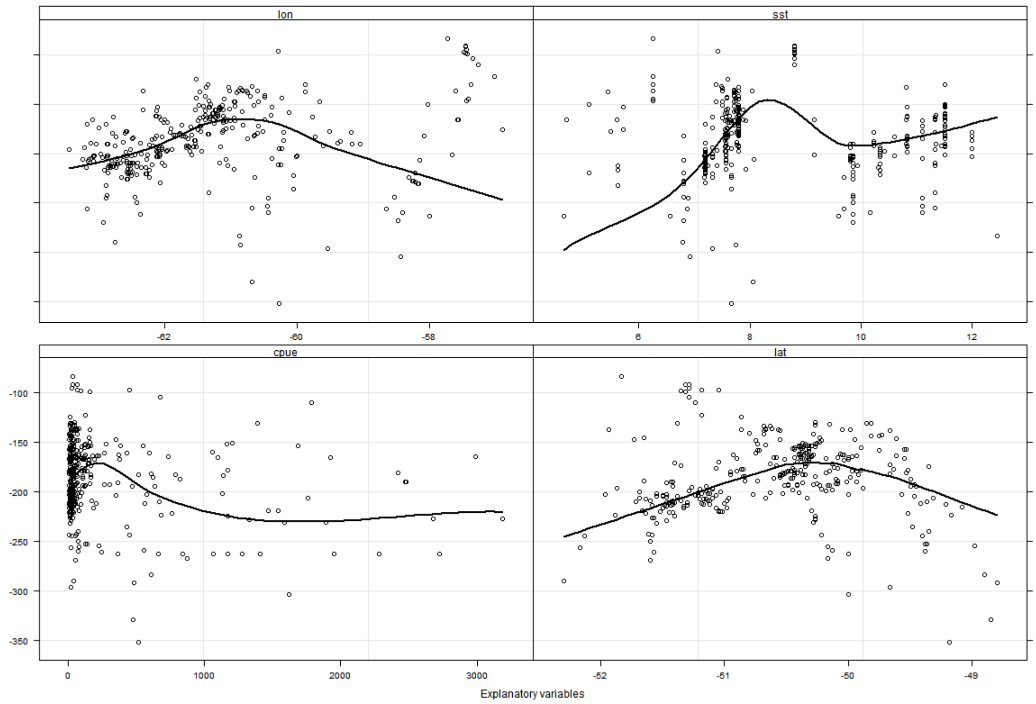

Figure 22.- Relationships between depth and selected variables

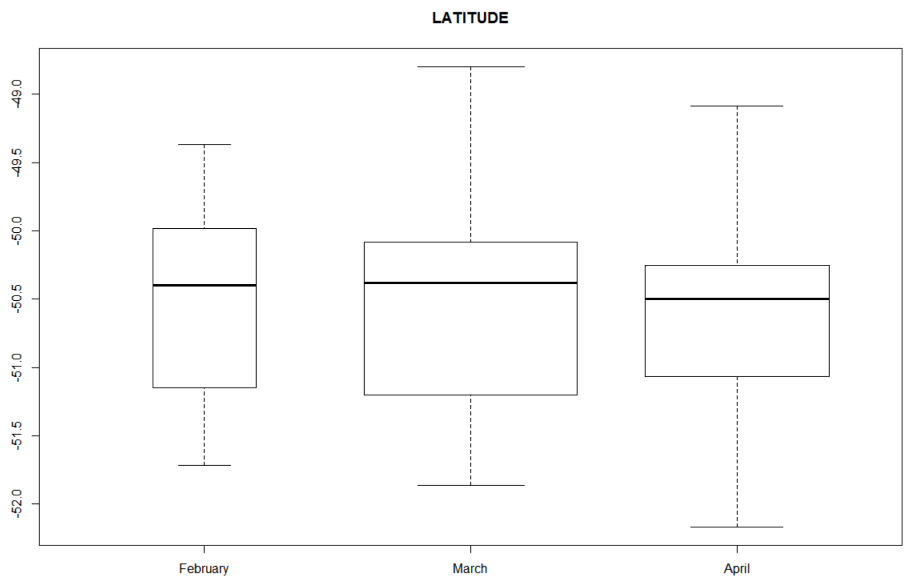

Figure 23.- Monthly latitude values

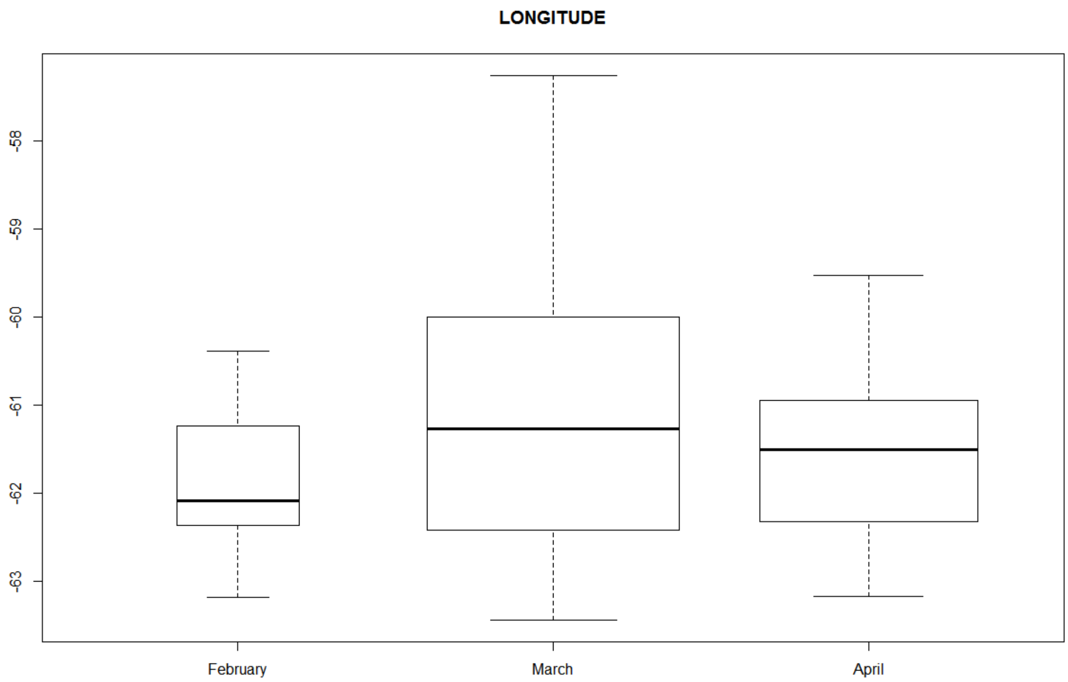

Figure 24.- Monthly longitude values

Both latitude and longitude show no evident variations along the period when *Illex* is present in Falkland/Malvinas waters.

We found no correlation between CPUE and SST, nor between CPUE and depth. Furthermore most of the hauls are located west of 60.5ºW and south of 50ºS (see Figure **18**), we may conclude that most of the fishery data we had access to in the southern area correspond to fishing vessels targeting other species other than *Illex*, such as hakes, Patagonian squid, southern, blue whiting, etc.

ACKNOWLEDGEMENTS

We thank the anonymous captains and skippers, as well as the Spanish General Secretariat for Fisheries, for providing us with commercial fishery data.

REFERENCES

Arkhipkin, A.I. (1993). Age, growth, stock structure and migratory rate of pre-spawning short-finned squid *Illex argentinus* based on statolith ageing investigations. *Fish. Res.* 16, 313-338.

Arkhipkin, A., Grzebielec, R., Sirota, A.M., Remeslo, A.V., Polishchuk, I.A. and Middleton, D.A.J. (2003). The influence of seasonal environmental changes on ontogenetic migrations of the squid *Loligo gahi* on the Falkland shelf. *Fish. Oceanogr*: 13, 1-9.

Arkhipkin, A.I., V.V. Laptikhovsky, A.M. Sirota and R. Grzebielec (2006). The role of the Falkland Current in the dispersal of the squid *Loligo gahi* along the Patagonian Shelf. *Est. Coast. Shelf Sci.* 67(1-2): 198-204.

Haimovici, M., Brunetti, N.E., Rodhouse, P.G., Csirke, J. and Leta, R.H. (1998). *Illex argentinus*. In: Rodhouse, P.G., Dawe, E.G., OÕDor, R.K. (Eds.), Squid Recruitment Dynamics. The Genus *Illex* as a Model. The Commercial Illex species. Influences on Variability, vol. 376. *FAO Fish. Tech. Pap.*, pp. 27ï 58.

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

Hatfield, E.M.C. and Rodhouse, P.G. (1994). Migration as a sort of bias in the measurement of cephalopod growth. *Antarct. Sci.* 6:179ï 184.

Laptikhovsky, V.V. and Remeslo, A.V. (2001). The Falkland Current as a governor of biological patterns in the shortfin squid, *Illex argentinus* on the high seas (45ºï 47ºS). *ICES C.M. K*:16, 8.

Leta, H.R. (1992). Abundance and distribution of *Illex argentinus* rhynchoteuthion larvae (Cephalopoda: Ommastrephidae) in the Southwestern Atlantic. *S. Afr. J. Mar. Sci.* 12, 927ï 941.

Peterson, R.G. and Whitworth III, T. (1989). The Subantarctic and Polar fronts in relation to deepwater masses through the Southwestern Atlantic. *J. Geophy. Res*: 94, 10817-10838.

Pierce, G. and Portela, J. (2014). Fisheries production and market demand. Pag. 41-58 in: Iglesias, J.; Fuentes, L.; Villanueva, R., (editors). Cephalopod Culture (494 pp.). Aquatic Sciences Unit, Springer, Dordrecht (The Netherlands).

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

Waluda, C.M., Trathan, P.N. and 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.

Waluda, C.M., Rodhouse, P.G., Podestá, G.P., Trathan, P.N. and Pierce, G.J. (2001a). Surface oceanography of the inferred hatching grounds of *Illex argentinus* (Cephalopoda: Ommastrephidae) and influences on recruitment variability. *Mar. Biol.* 139, 671ï 679.

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

Waluda, C.M., Trathan, P.N. and Rodhouse P.G. (2005). Influence of oceanographic variability on recruitment in the *Illex argentinus* (Cephalopoda: Ommastrephidae) fishery in the South Atlantic. *Mar. Ecol. Progr. Ser.*, 183: 159-167.