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Spatial distribution of *Illex argentinus* in San Matias Gulf (Northern Patagonia, Argentina) in relation to environmental variables: a contribution to the new interpretation of the population structuring

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Abstract

Traditionally, it was assumed that major spawning activity of *Illex argentinus* occurs in discrete pulses along the outer-shelf/slope off Argentina/southern Brazil during late-fall/winter and that early life stages develop near the Brazil-Malvinas Confluence (BMC). However, a novel hypothesis of the population structuring of the species was proposed that states that coastal waters may be important as spawning and feeding grounds. Here, we analyzed the spatial distribution of *Illex argentinus* inside San Matias Gulf based on the position of the CPUE of jiggers in order to improve the knowledge of the population structuring in coastal regions. Squids were mainly concentrated on the northern region of the gulf where favorable oceanographic conditions (e.g. water stratification, chlorophyll-a concentration peaks) to feeding and spawning are present. These results provided empirical evidences that individuals of *I. argentinus* use Argentinean coastal waters, particularly San Matias Gulf, as permanent feeding and spawning grounds which supports the new hypothesis.

Running title: Spatial distribution of *Illex argentinus* in coastal waters

Key words: spatial distribution, coastal fishery, San Matias Gulf, *Illex argentinus*, jigging fishery

1. Introduction

The biology of cephalopods presents particular problems for traditional fishery assessment and management (Arnold, 1979; Caddy, 1983; Voss, 1983; Bravo de Laguna, 1989; Rosenberg et al., 1990; Pierce and Guerra, 1994) making them particularly vulnerable to overfishing (Rosenberg et al., 1990). The most frequent methods used for stock assessment in cephalopods were categorized in two groups (Pierce and Guerra, 1994): in-season or post-season assessment. The first is based on incomplete real-time data obtained during the fishing season and may be used to adjust levels of fishing activity during the exploitation, while the second is based on complete data sets of the fishing season and can be used to determine the relationship between variables and capture, and to establish management goals for the following season. Regardless the method used, it is necessary to know the distribution and migration patterns of the exploited stocks for a successful assessment and management of the fishery (Pierce and Guerra, 1994).

The Argentinean short-fin squid, *Illex argentinus* (Castellanos, 1960), is a neritic-oceanic species (Haimovici et al., 1998) and sustains the most important cephalopod fishery of the world in terms of landed tons (FAO, 2010). In Argentina, this species is mainly fished by jiggers with federal fishing license on the mid/outer shelf and slope from 38°S to 52°S (Haimovici et al., 1998; Walluda et al., 1999). These vessels are not allowed to fish in coastal regions (from the continent to 12-nautical-miles offshore) because these regions are under provincial jurisdiction and a provincial fishing license is required. Thus, the low fishing effort directed to *I. argentinus* on coastal regions leads to low catches and to underestimate the real availability of the resource. Recently, new researches have drawn the attention to the importance of coastal regions in *I. argentinus* population dynamics (Vidal et al., 2010; Crespi-Abril et al., 2012; Schwarz and Perez, 2012). New evidences have been provided on the presence of squids' aggregations year round in these areas in Northern Patagonia to feed, to mate and to spawn (Crespi-Abril et al., 2008, 2010; Crespi-Abril and Trivellini, 2011). Based on these newly data and on an extensive analysis of the sea surface temperature (SST) and chlorophyll-a (Chl-a) concentration estimates over the distribution area of *I. argentinus*, Crespi-Abril and Baron (2012) suggested the hypothesis that coastal regions play a key role as spawning and nursery grounds and they proposed a new interpretation of the population structuring. However, the access to biological data of squids inhabiting coastal regions to contrast this new hypothesis is a difficult task since there is not a direct source of specimens such as a fishery targeted to squids or surveys to assess squid's populations. In this context, the most important sources of information are the vessels that operate in coastal waters fishing upon Argentinean common hake (*Merluccius hubbsi*) or Argentinean shrimp (*Pleoticus muelleri*), where squids are a by-catch component. San Matias Gulf (SMG, 41º-42ºS and 64°-65° W) is an exception since a small jigging fleet was allowed to fish *I. argentinus* (Morsan and Gonzalez, 1996; Morsan et al., 1999) in a period of seven years between 1994 and 2003. Thus, the gulf offers a unique scenario to obtain information on abundance, spatial distribution of squid in a coastal region, and environmental factors that could affect them.

In this work, we analyze the historical data of *I. argentinus*' captures corresponding to the jigging and bottom trawl fleets that operated inside San Matias Gulf in order to determine the yearly variation and the seasonality of the catches in the gulf. Additionally, we describe the spatial distribution of the yield of the jigging fleet between years and within fishing seasons in relation to sea water temperature and chlorophyll-a concentration to contribute to the knowledge on the role that the gulf plays on the life cycle of *I. argentinus*.

2. Materials and methods

2.1 *Study area*

The San Matías Gulf (SMG) is located between 40°47´ S and 42°13´ S (Figure 1). The gulf is a semi-enclosed basin and its mouth opens to the adjacent continental shelf through a shallow sill (60 m depth) (Rivas and Beier, 1990). The gulf has a surface of 19,700 km2, a maximum depth of 180 m and approximately 45% of the gulf is less than 100 m depth (Piola and Scasso, 1988). two depressions of 160 m of depth are located symmetrically respect the parallel 41° 40´S (Figure 1). Two water masses with different oceanographic conditions are present in the gulf each one located near a depression (Piola and Scasso, 1988). One of these water masses is characterized by relatively cold–fresh water, similar to the shelf waters, and is placed in the southern region of the gulf. The other water mass is characterized by warm–salty water and is located on the northern region (Piola and Scasso, 1988).

2.2 *Sea Surface Temperature and chlorophyll-a concentration*

2.2.1 Remote-sensed data

Sea Surface Temperature (SST) and the chlorophyll-a concentration (Chl-a) were estimated from remote-sensed data. The data acquired correspond to daily Level-1B local area coverage (LAC) of the Advanced Very High Resolution Radiometer (AVHRR, on-board of the polar-orbiting satellites of the series NOAA-N) and Sea-Viewing Wide Field of view Sensor (SeaWiFS, on-board of OrbView-2 satellite).The data was obtained through the Argentine National Commission of Space Activities (CONAE) for the periods 2000–2008 for AVHRR and 2000-2006 for SeaWiFS (SeaWiFS images were available only up to 22 December 2006). Scenes with low cloud coverage of AVHRR and SeaWiFS were selected. The AVHRR data were processed applying the MultiChannel Sea Surface Temperature (MCSST) algorithm and five-day SST composite images were obtained from daily images using only the maximum value of each pixel (McClain et al., 1985). Afterward, monthly composite images were produced by averaging the value of temperature at each pixel of the five-day SST composites corresponding to each month. The SeaWiFS data were processed applying OC4v4 algorithm (O'Reilly et al., 1998). In this case, monthly composite images were built by averaging all the daily available scenes corresponding to each month on a pixel-by-pixel basis. Data from both sensors were processed using Erdas Imagine and SeaWiFS Data Analysis System (SeaDAS, v5.2#4) software (Baith et al., 2000). The products of SST and Chl-a obtained were mapped using the WGS84 reference system (datum WGS84, ellipsoid WGS84) and represented at 1.1 km of spatial resolution at nadir. The mean images of SST and Chl-a of the SMG were calculated from the monthly composite images according to the following equation:

$$V_{sat}(t_i) = \frac{1}{N}\sum_j V_{sat}(x_j, y_i)$$

Where Vsat (t_i): SST/Chl-a spatial mean, Vsat(x_j,t_i): SST/Chl-a from pixel "j" on the image of the month "i", N: number of valid pixels in SMG area.

In order to establish a limit between the water mass of the northern part of the SMG from that present on the southern part, isotherms (ºC) and thermal gradients (°C km^{-1}) from the mean temporal image of SST were used. Isotherms (ºC) were calculated by applying a low-pass gaussian filter in a 3x3-pixels area and thermal gradients (°C km^{-1}) were calculated using the Sobel operator in a 5x5-pixels area (Simpson, 1990). The limit between both water masses was defined as the isotherm that passes through the pixels of maximum thermal gradient.

The intraannual thermal cycles of the northern and southern regions of the SMG were described using monthly SST data. For each region, SST monthly data were fitted by least-square nonlinear regression (Beron-Vera and Ripa, 2000) to the function:

$$SST(x,t) = SST_0(x) + T_1(x)\cos[w(t - t_0)]$$

SST(t) is the estimated mean SST for month 't', SST_0(x) is the annual mean temperature, T1 is the amplitude of the seasonal cycle, $w = 2\pi/12$ month-1, t is the month (starting from January) and t_0 is the phase that coincides with the month of the year in which temperature is maximum.

The validation of remote-sensed data of sea surface temperature and chlorophyll-a concentration with *in situ* data of was conducted previously by Williams (2011). There is a marked correlation between remote-sensed and *in situ* observations for both variables

(Williams, 2011) that allow the use of satellite information to estimate environmental variables without bias.

2.2.2 Oceanographic surveys

In order to analyze the vertical profile of the water masses, three oceanographic cruises were conducted by the “Centro Nacional Patagónico (CENPAT)” and the “Instituto de Biología Marina y Pesquera Almirante. Storni (IBMPAS)” to measure *in-situ* sea temperature at different depths in the San Matías Gulf (Table 1). Data of sea temperature and depths were obtained using a CTD-YSI 6600v2 (±0.15 °C). The vertical profiles were constructed based on stations located along a north-south transect. The method used to estimate the profiles was a kriging interpolation (Journel and Huiybnegts, 1978).

2.3 *Fishery data*

Statistical data from vessels belonging to jiggers and bottom trawlers that operate in San Matias Gulf are regularly collected by On Board Observers Program of the “Instituto de Biología Marina y Pesquera Almirante Storni” (IBMPAS) and by fishing slips filled by fishermen in each fishing trip. Jiggers fished between 1994 and 2003 from June to September (Table 2) and the target species were *I. argentinus*. For each jigger, real-time data of catches in weight, fishing effort in hours and number of jigging lines, and geographical position (latitude and longitude) data were registered and transmitted to the IBMPAS by the onboard observer everyday. Thus, all the fleet was aware of the position and the fishing success of each vessel. The information obtained of each jigger was used to estimate the catch per unit effort (CPUE) as kg hour^{-1} line^{-1}. The daily position of each vessel was integrated into a geographical information system tools (GIS) to describe the interannual spatial-patterns of the vessels inside the gulf using the information of the seven years and to describe on a week-basis the intrannual spatial-patterns of the fleet during the years 2001 and 2003). Bottom trawlers have license to fish year round and the target species is *M. hubbsi*. *I. argentinus* is only captured as by-catch. Information of monthly capture in Kg of squids and fishing effort in number of fishing trips was recorded by onboard observers from 1982 to 2010.

In 2001 and 2003, random samplings of squids were taken from the captures of the jiggers by on-board observers to analyze the composition of the capture. The mantle length (ML), total weight (W) and sex was recorded for each individual. Length-to-weight linear relationships were estimated to weight and mantle length data for males and females. Comparisons of the models between sexes were by an ANCOVA.

3. Results

3.1 *Sea Surface Temperature and chlorophyll-a concentration*

3.1.1 Remote-sensed data

The mean map of isotherms and thermal gradients for the period January 2000-December 2008 shows that the water mass present on the northern region of the SMG is thermally different from the water mass of the southern region of the gulf and from the water of the adjacent continental shelf (Figure 2A). The water mass of the southern region is thermally similar with that of the adjacent shelf (Figure 2A). A marked thermal front separates the waters of northern region of the gulf from the southern region and adjacent shelf. The maximum values of the thermal gradient (~0.1 ° C.km^{-1}) were used to define the limit of the two water masses which coincides with the isotherm of 16°C (Figure 2A). The mean map of Chl-a concentration for the period January 2000-December 2006 shows that the northern region of the gulf is characterized by relatively low mean concentrations of Chl-a (below 1.0 mg.m^{-3}), while the southern region presents higher mean concentrations of chlorophyll-a (2.0-3.0 mg.m^{-3}) (Figure 2B).

Two different models of thermal annual cycle fitted to SST (Figure 3a): one for the southern region and other for the northern region (Table 1). The monthly variation of the mean SST showed a clear seasonal cycle in both regions. The annual cycle of the northern region had greater thermal amplitude (~7.5°C) than the cycle of the southern region (~6°C) (Table 2). Also, cycles of both regions were in different phases (t_0): the northern region reaches the maximum temperature earlier (early February, t_0=1.99) than the southern region (early March, t_0=2.38).

The monthly cycle of Chl-a concentration in the northern and southern regions showed a similar pattern with two major peaks (one in autumn and other in spring) and a minor one (in winter) (Figure 3b). The main difference between both regions was that during the summer (from December to March) the southern region had higher values of Chl-a concentration (>1.00 mg m^{-3}) than the northern region (<0.80 mg m^{-3}) (Figure 3b).

3.1.2 Oceanographic surveys

In February 2008, both water masses of San Matias Gulf were clearly identified. The water of the northern region of the gulf presented a marked thermal stratification (Figure 4), while the southern region was more homogeneous (Figure 4). In June of 2008, the waters of both regions of the gulf were completely homogeneous and indistinguishable (Figure 4). In October 2009, the northern region of the gulf was starting to stratify and the southern region remained homogeneous (Figure 4).

3.2 Fishery data

3.2.1 Jigging Fleet

The size of the jigging fleet that operated in waters of San Matias Gulf was variable, but it never exceeded 7 vessels (Table 3). The annual captures of the fleet were higher than 700 tons except in 1996 and 1998 that it did not surpass 200 tons (Table 3). The duration of the fishing season measured in effective fishing days was variable between years (Table 3). The longest fishing season was in 2003 (Table 3). The fishing season started mainly in end of July and lasted up to the end of September, except in 2003 that the fleet started fishing earlier in June (Figure 5). The mean fishing hours per day and per vessel invested by jiggers was similar between years (Table 3, Kruskal-Wallis test P>0.05). The temporal trend of the CPUE was very variable within each year reaching its maximum value of 52.8 Kg h^{-1} $line^{-1}$ in 2003 (Table 3).

The spatial distribution pattern shows that the fishing operations were mainly on the Northern region of the SMG but with some differences between years (Figure 5). Years with high CPUE values the fleet clumped in the areas with the highest yield in the central and northern part of the gulf (i.e. 1997, 2001), while years with low CPUE values (i.e. 1996, 1998), jiggers were dispersed over the gulf (Figure 5). Particularly, the year 2003 presented high values of CPUE and the vessels fished over a wider area in the gulf compared with previous years (Figure 5).

The analysis of the intrannual spatial-dynamics of the fleet in 2001 and 2003 showed an alternating pattern of gathering and scattering depending on the fishing success. When the daily production, evidenced by CPUE values, increased the fleet was concentrated in zones with higher yields (i.e. week 38 in 2001, Figure 6; and week 29 in 2003, Figure 7), and when the production (low CPUE values) decreased, the fleet was dispersed over a wider area (i.e. week 35 in 2001, Figure 6; and week 32 in 2003, Figure 7).

Squids (664 males and 678 females) were obtained from random samplings of jiggers in 2001 and 2003. The proportion of sexes of the squids caught was 1:1 in both years (binomial test, p>0.05). The mean size of male and female was similar (ML males: 23.4 cm, standard deviation: 3.2 cm and ML females: 25.5 cm, standard deviation: 4.1 cm, Student´s t-test, p>0.05), but females were heavier than males (males: 362.7 g standard deviation: 4.3 g and females: 412.4 g standard deviation: 4.9 g, Student´s t-test, p<0.05).

There were no significant differences of the length-to-weight relationships between males and females (ANCOVA, p>0.05). The potential model was fitted using the combined data of both sexes. The model was $W=11.802*ML^{3.081}$ ($r^2=0.89$, Figure 8).

3.2.2 Bottom trawl fleet

The total catch of *I. argentinus* was variable during the years studied (Figure 9). The highest catches were obtained in 2001 and 2003 reaching more than 400 tons while the lowest catches were recorded in 1984 and 2002 (less than 10 tons, Figure 9).

The CPUE of the bottom trawlers was variable between years alternating high values with low ones (Figure 10). The maximum value was observed in 1990 (2.5 tons per fishing trip) and the minimum values was observed in 2002 (0.26 tons per fishing trip).

There was a significant positive correlation between the CPUE estimated from the bottom trawlers data and the total catches of the jiggers (Spearman Correlation, $r=0.807$, $p<0.05$). Years when the CPUE was higher the jiggers' catches were higher (Figure 10).

The seasonal variation of the mean CPUE estimated from the bottom trawlers data started to increase in May and achieving the maximum in August (Figure 11). Afterward, the mean CPUE decreased suddenly reaching the minimum value in December (Figure 11). The maximum yield of squids occurred during the period with coldest waters (~12.0ºC) and intermediate Chl-a concentration (~0.8 mg m-3) (Figure 11).

4. Discussion

The hypothesis that sustains that coastal regions are important habitats for *I. argentinus*, since individuals use them as spawning and feeding grounds, is a novel approach that provides a new interpretation on the population structuring of the species. This idea was addressed recently in southern Brazil waters (Vidal et al., 2010; Schwarz and Perez, 2012) and was further expanded by Crespi-Abril and Baron (2012) based on a model accounting for embryonic and paralarvae development suitability over its complete geographic distribution, considering both thermal conditions and food availability. The present work is an advance over previous studies since we provided evidences that squid's life cycle is coupled to certain oceanographic processes (e.g. water column stratification, primary productivity peaks) of a particular coastal region (San Matias Gulf) that may ensure the reproductive success of the species.

In waters of San Matias Gulf, two mayor cohorts of *I. argentinus* are present (Crespi-Abril et al., 2009): a major one characterized by bigger individuals (males of 30 cm of ML and females of 34 cm ML) that reach the maximum size and maturity between July and September (winter - early spring) and presumably spawn in September and November, and a minor one characterized by smaller individuals (males of 20 cm of ML and females of 24 cm ML) that reach maximum size and maturity in February and March (late summer) and presumably spawn in March and April (Crespi-Abril et al., 2008). The increase in CPUE of *I. argentinus* of bottom trawlers in San Matias Gulf from May to August is consequence of the growth of squids belonging to the first cohort and the subsequence decrease from September onward is a consequence of the massive adult mortality after spawning typical of ommastrephid squids (Rocha et al., 2001). In January and February, the CPUE increases again due to the presence of adult individuals of the second cohort, but it did not reach the same magnitude achieved in August. The life cycle of both cohorts are synchronized to the seasonal variation of chlorophyll-a in the SMG. Individuals of both groups reach the maximum maturity before an important peak of chlorophill-a concentration (Figure 11). This synchrony ensures food availability for paralarvae. The increase in chlorophyll-a concentration leads to an increase in the number of microalgae, bacteria and protozoans that constitute the first food during the rhynchoteuthion phase of *I. argentinus* (Vidal and Haimovici, 1998). Also these microorganisms give trophic support to the meso-zooplankton that is preyed upon during the rest of the planktonic phase of *I. argentinus* (Vidal and Haimovici, 1998).

Jiggers usually fish at night whereas during the day operations are mainly focused on searching for concentration of squids using acoustic devices. Vessels can move over a huge area while the searching task is conducted. Considering the potential movement of jiggers and the relatively small area of San Matias Gulf, it can be assumed, that the vessels can detect the highest concentration of squids in the gulf and fish upon them in relatively short time. Additionally, the daily open-communication system with research group managers to transmit information of catches, effort and position, for management purposes, provided more data to each vessel about the yields and location of the rest of the fleet. Thus, the position of the fleet during the fishing operation can be used to infer the spatial distribution of squids inside the gulf. The analysis of the spatial distribution of jiggers' CPUE showed that individuals of *I. argentinus* concentrate mainly in the northern part of the gulf. This region presents adequate oceanographic conditions for spawning and feeding ground for *I. argentinus*. It is characterized by a cyclonic gyre (~70 Km diameter) that retains an important mass of water in the gulf (Piola and Scasso, 1988; Tonini et al., 2006; Tonini et al., 2007). This retention leads to a marked thermal stratification during austral spring and summer generating a strong thermocline due to the heating of the superficial water layer. The oceanographic condition produces a stable water column that could be favorable to the spawning of *I. argentinus*. It is known that females of ommastrephid squids lay egg masses over the thermocline and the neutral buoyancy of the masses keep them in the water column (Sakurai et al., 2000) avoiding their collapse against the bottom with the consequent mortality of the embryos. Additionally, the seasonal thermal stratification produces two major peaks of chlorophyll-a concentration. These peaks of primary productivity are a direct source of food for rhynchoteuthion of *I. argentinus* and also sustains an important stock of anchovy (*Engraulis anchoita*) (~0.7 million tons of spawning biomass, Sánchez and Ciechomski 1995, Pájaro 1998, Pájaro et al. 2008) which is an important prey of adult squids (Crespi-Abril and Trivellini, 2011). The oceanographic characteristics of San Matias Gulf together with the presence of squids in advanced maturation year round (Crespi-Abril et al., 2008) and the presence of paralarvae

(Crespi-Abril and Barón, 2012) are conclusive evidence that the gulf is a coastal spawning and feeding grounds for *I. argentinus*.

The fishery of *I. argentinus* on the continental shelf is managed by the application of modified depletion methods (Rosemberg et al, 1990) usually linked to a harvest rate. These methods assume that catchability is constant during the fishing season and, therefore, CPUE reflects the population abundance (Hilborn and Walters, 1992). However, fishery-dependent data are influenced by increasing improvements in technology and by human decisions (Hilborn, 1985; Hilborn and Walters, 1992) which might lead to the violation some assumptions of the depletion models. Technological advances, such as gear or fish-finding devices improvements, can modify the catchability in a long term period (mostly from one fishing season to another). Human decisions implies the fishermen's behavior of actively seek outer areas with greater squid concentrations, and operate on them until the yield decreases to a level that enforce fishermen to move to another area (Hilborn, 1985). These short-term changes of the fishing areas (that might occur several times during the same fishing season) could have as consequence a hyper-stability of the relationship of CPUE and population abundance (CPUE remains stable or even increases in the face of a declining stock), since catchability is not constant (Hilborn and Walters, 1992; Prince and Hilborn, 1998; Walters and Martell, 2004). The case of *I. argentinus* fishery inside the gulf represents an example that fleet spatial dynamics is fueled by the short term decisions of fishermen. Then, the fishing effort is rapidly concentrated in areas with high yields. When the CPUE in those areas decreases, the vessels disperse inside gulf searching new squid concentrations. Once a school of squid is found the fleet clumps again to fish over it. At an interannual scale, the global pattern of an entire season reflects the short-term temporal scale: the fleet is dispersed over a great area when the global abundance is low indicating a huge seeking effort, and it is clumped in years when the abundance is high. Further studies should be conducted to determine if the fleet dynamics modify the catchability coefficient with the consequent misuse of depletion models as assessment in the gulf.

During an entire fishing season, catch per vessel of the jigging fleet that operates in the outer continental shelf and slope varies between 400 and 1600 tons, while in the SMG, it varied from 22 to 705 tons. However, the fishing season inside the gulf is significantly shorter than the fishing season on the shelf and slope: the fishery in the shelf and slope remain open six months approximately (Basson et al., 1996; Brunetti et al., 1999), whereas in SMG is about 40 days. A simple estimation suggests that, even when the yield inside the gulf can be smaller than the obtained on the outer shelf, it is not negligible in terms of daily production. Such observation is supported by CPUE of jigging fleet, which is highly variable between years but, occasionally, higher than the CPUE of the fleet operating outside the gulf (Basson et al., 1996; Brunetti et al., 1999).

Considering the results of the present study, we believe that *I. argentinus* is a permanent resource in the gulf and can sustain a fishery with regional relevance. The abundance of *I. argentinus* in other coastal regions and their potential as fishing grounds remain unknown. However, the CPUE of squids estimated from landings of the bottom trawlers in other coastal fishery can be used as an indicator of its abundance since there is a positive correlation between de CPUE on this fleet and the total catches of jiggers.

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Figure captions

Figure 1. Location of San Matias Gulf. Isobaths are expressed in meters.

Figure 2. Mean isotherms (ºC) and thermal gradients (ºC.km-2) for the period 2000-2008 estimated by remote-sensed data (AVHRR) (A), mean isotherms (ºC) mean chlorophyll-a concentration for the period 2000-2006 estimated by remote-sensed data (SeaWiFS) (B), Mean isotherms (ºC) and depth (m) (C). The 16°C isotherm indicates the limit between the Northern and Southern water masses.

Figure 3. Monthly variation of the mean sea surface temperature and chlorophyll-a concentration in the northern area (NA) and southern area of San Matias Gulf (SA) with the standard error.

Figure 4. Vertical profiles of sea temperature in Celsius degree (ºC) in a north-south transect in February 2008, June 2008 and October 2009 in San Matias Gulf.

Figure 5. Spatial and temporal variation of the CPUE (capture per unit of effort expressed as Kg h^{-1} $line^{-1}$) of the jigging fleet in San Matias Gulf in different years. The black line (16°C isotherm) represents the division of the southern and northern waters masses in the gulf.

Figure 6. Spatial variation of the CPUE (capture per unit of effort expressed as Kg h^{-1} $line^{-1}$) of the jigging fleet in San Matias Gulf of 2001. The numbers on the maps represent the number of the week counted continuously from the first week of the year in January.

Figure 7. Spatial variation of the CPUE (catch per unit of effort expressed as Kg h^{-1} $line^{-1}$) of the jigging fleet in San Matias Gulf of 2003. The numbers on the maps represent the number of the week counted continuously from the first week of the year in January.

Figure 8. Mantle length (ML) versus total weight (W) relationship for *Illex argentinus*.

Figure 9. Historical catches of *Illex argentinus* of the bottom trawlers that operate in San Matias Gulf.

Figure 10. Historical variation of the CPUE (tons per fishing trip per vessel) of *Illex argentinus* of the bottom trawlers is shown in line and historical catches of *Illex argentinus* of the jiggers that operated in San Matias Gulf is shown in bars.

Figure 11. Seasonal variation of the mean CPUE (tons per fishing trip per vessel) and standard error of the bottom trawlers in San Matias Gulf (Black line). Monthly cycle of sea surface temperature (dark gray) and chlorophyll-a concentration (light gray) in San Matias Gulf.

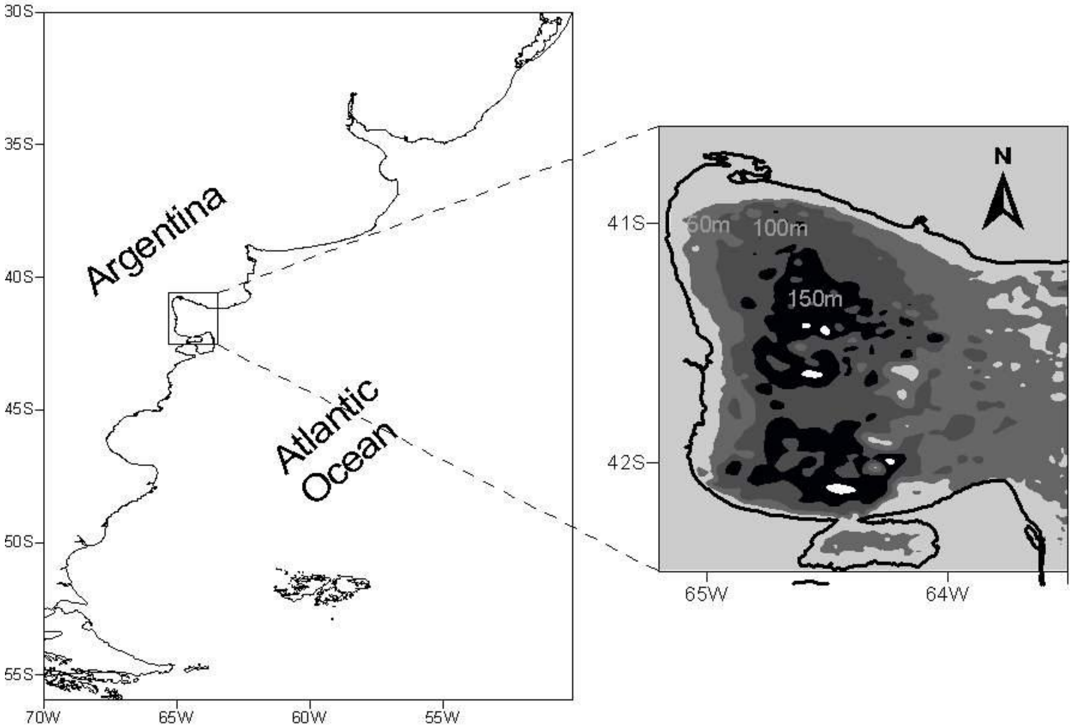
30S
35S
40S
45S
50S
55S
70W
65W
60W
55W
Argentina
Atlantic Ocean
41S
42S
65W
64W
N
50m
100m
150m

Fig. 2

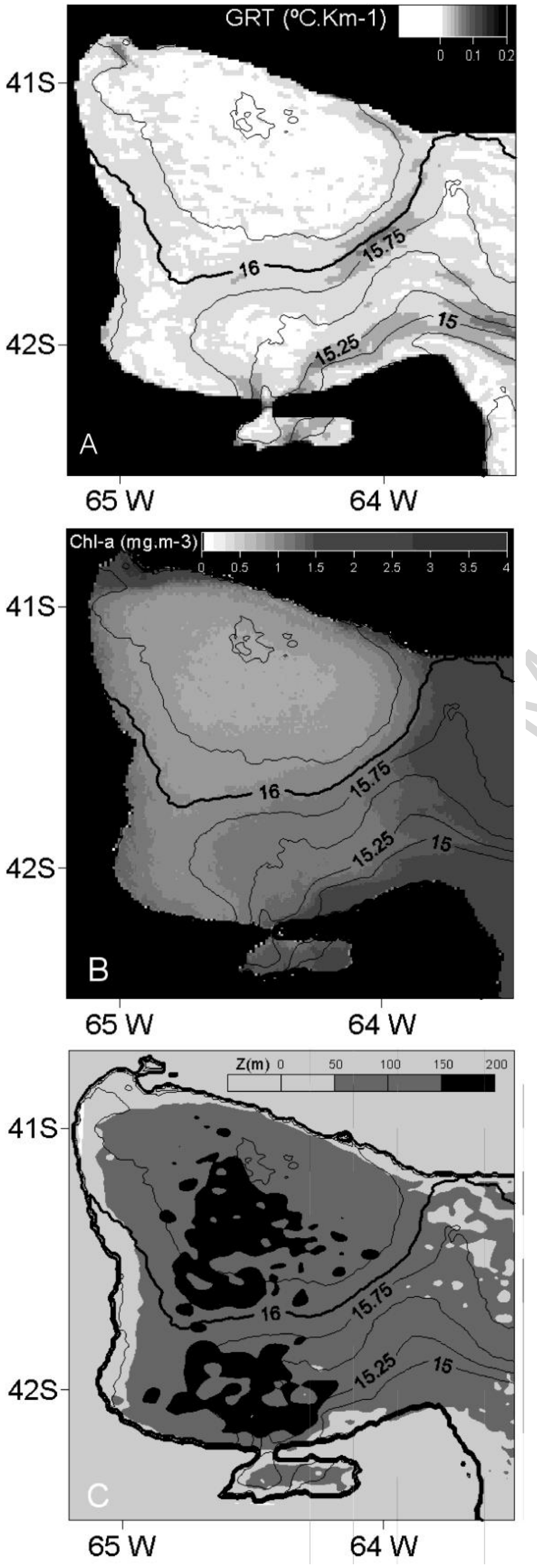
GRT (ºC.Km-1)
0
0.1
0.2
41S
42S
16
15.75
15
15.25
A
65 W
64 W
Chl-a (mg.m-3)
0
0.5
1
1.5
2
2.5
3
3.5
4
B
Z(m)
50
100
150
200
C

Fig. 2

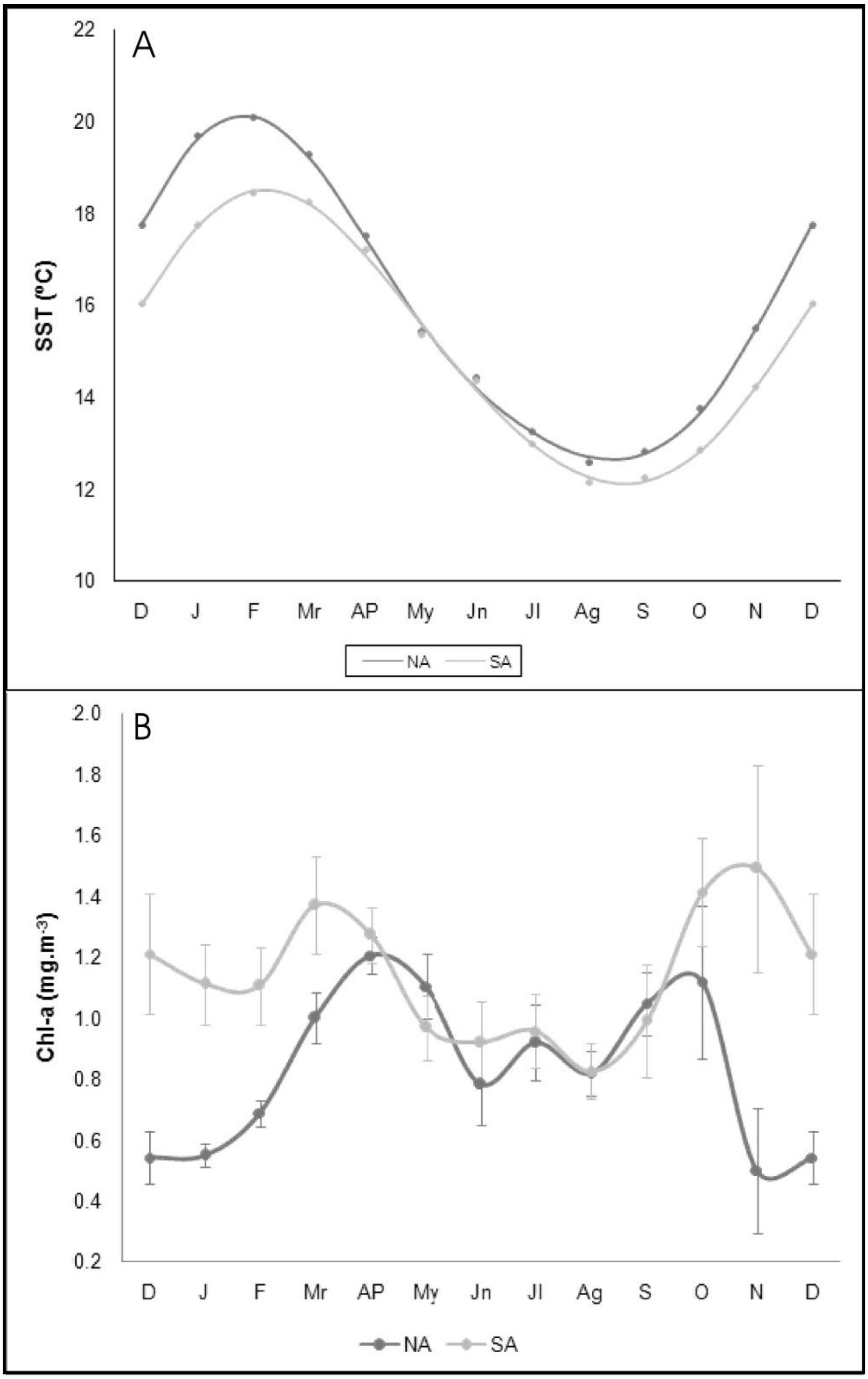
A
SST (ºC)
22
20
18
16
14
12
10
D
J
F
Mr
AP
My
Jn
Jl
Ag
S
O
N
D
NA
SA
B
Chl-a (mg.m-3)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
D
J
F
Mr
AP
My
Jn
Jl
Ag
S
O
N
D
NA
SA

Fig. 3

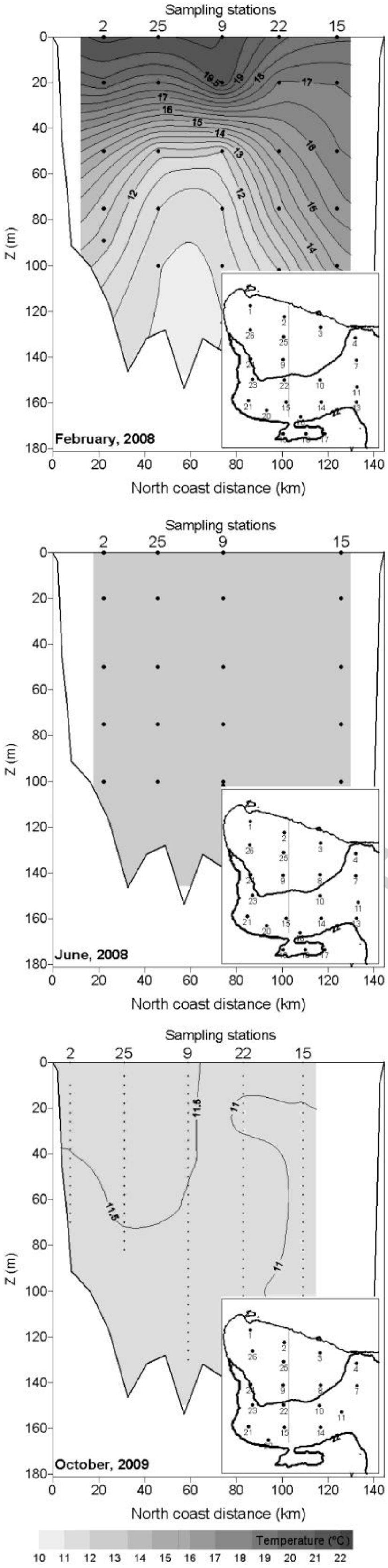
Sampling stations
2
25
9
22
15
Z (m)
North coast distance (km)
February, 2008
June, 2008
October, 2009
11.5
11
Temperature (ºC)
10
11
12
13
14
15
16
17
18
19
20
21
22

Fig. 4

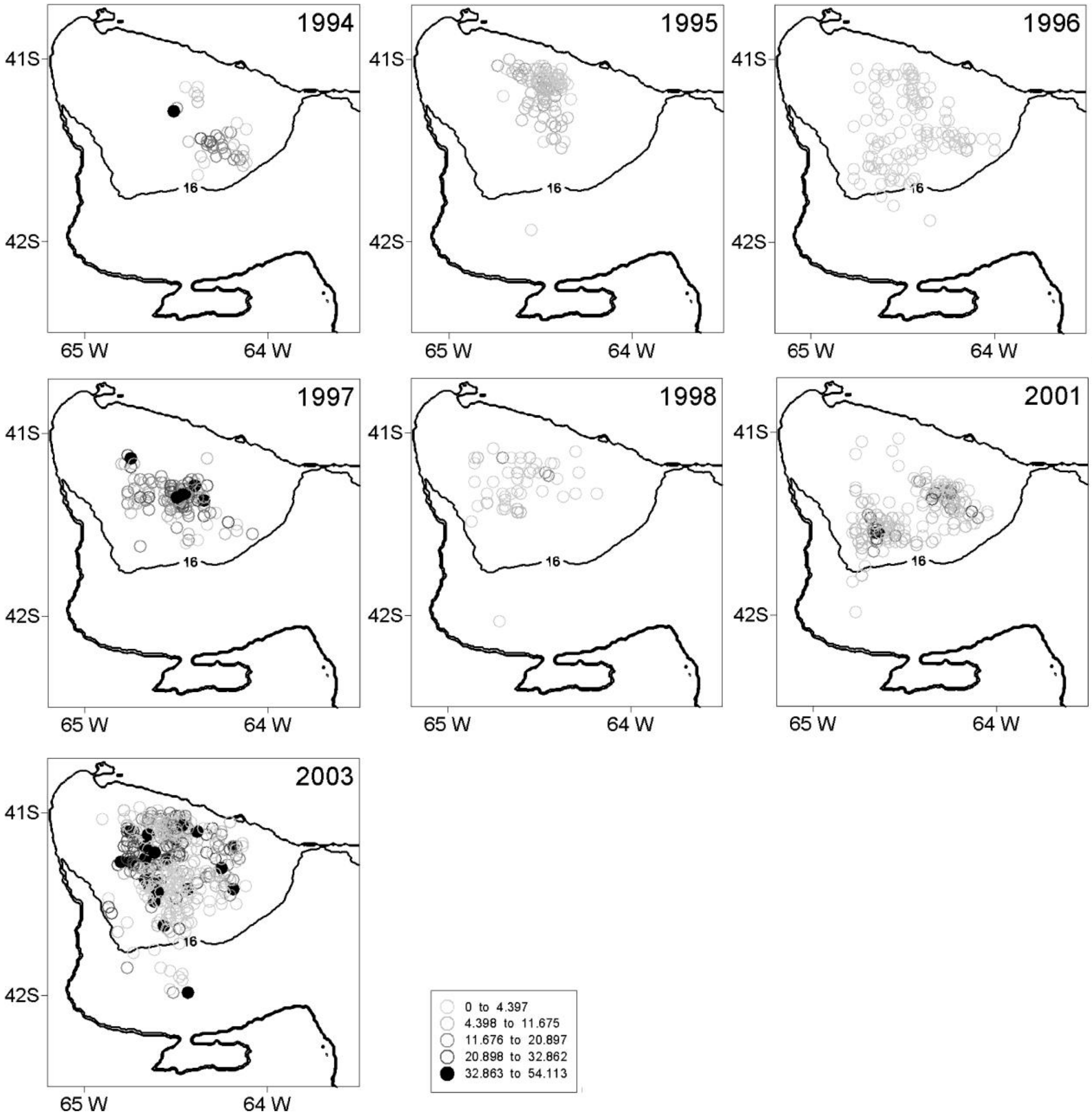
1994
1995
1996
1997
1998
2001
2003
41S
42S
65 W
64 W
16
○ 0 to 4.397
○ 4.398 to 11.675
○ 11.676 to 20.897
○ 20.898 to 32.862
● 32.863 to 54.113

Fig. 5

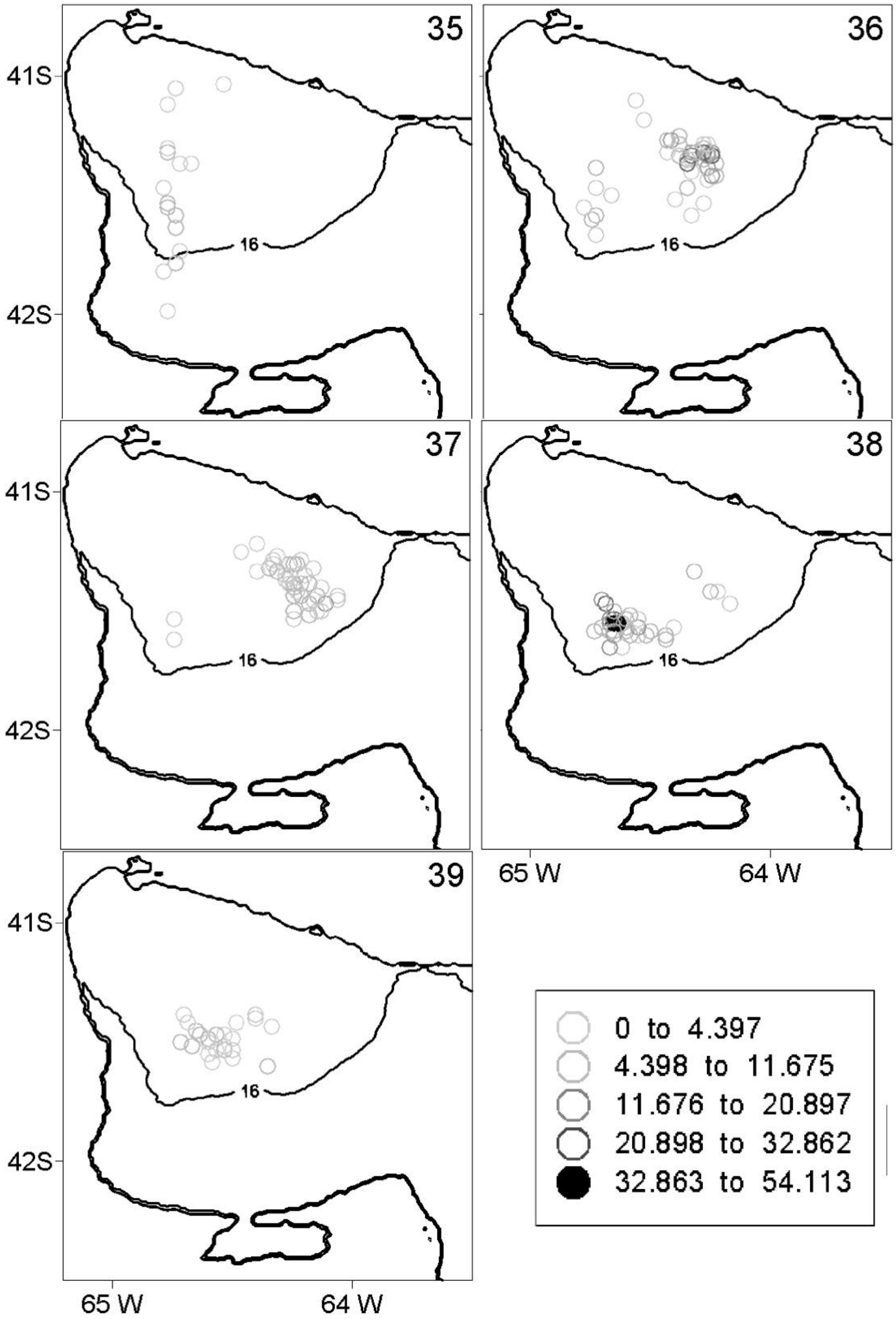
35
36
37
38
39
41S
42S
16
65 W
64 W
0 to 4.397
4.398 to 11.675
11.676 to 20.897
20.898 to 32.862
32.863 to 54.113

Fig. 6

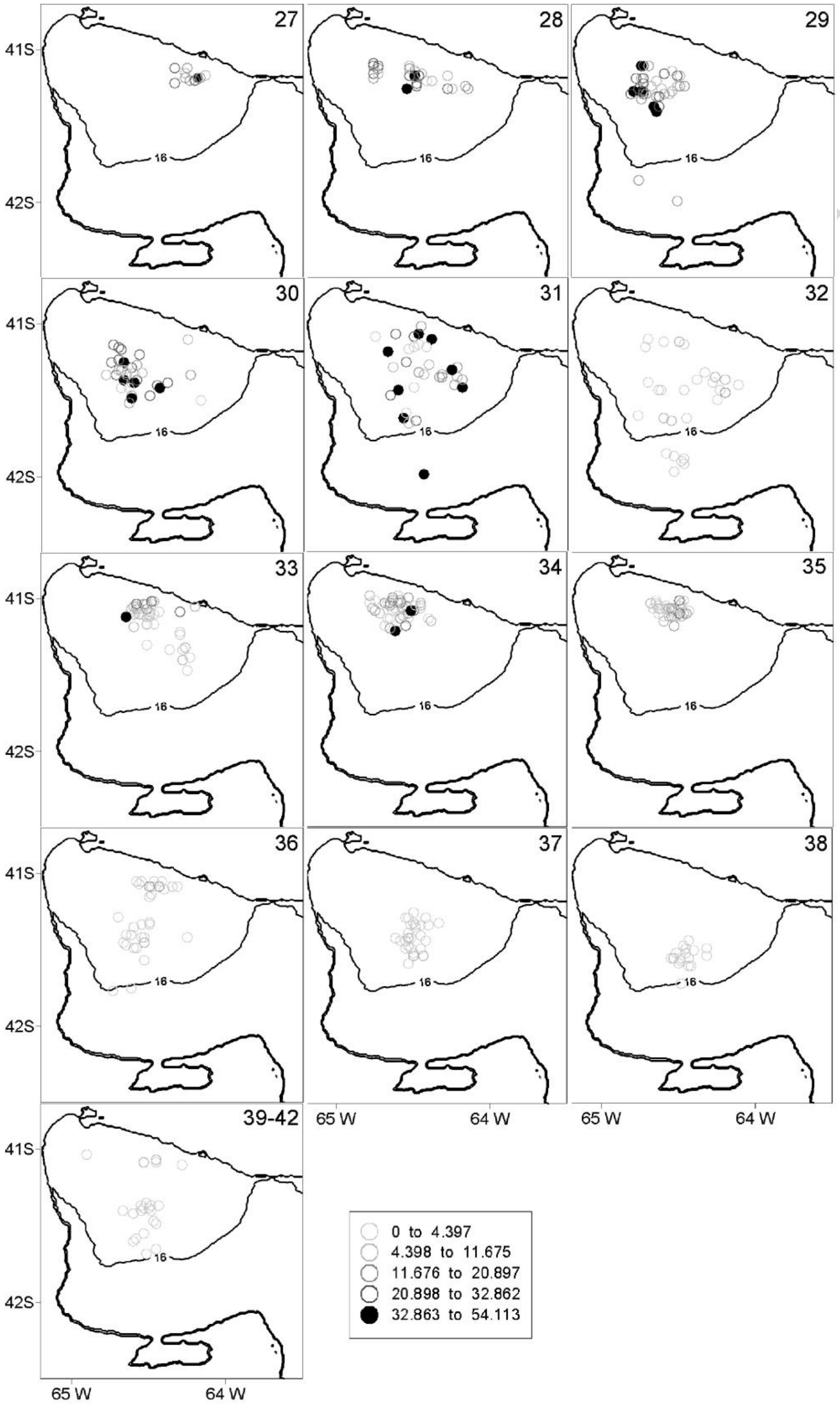
27
28
29
30
31
32
33
34
35
36
37
38
39-42
41S
42S
16
65 W
64 W
0 to 4.397
4.398 to 11.675
11.676 to 20.897
20.898 to 32.862
32.863 to 54.113

Fig. 7

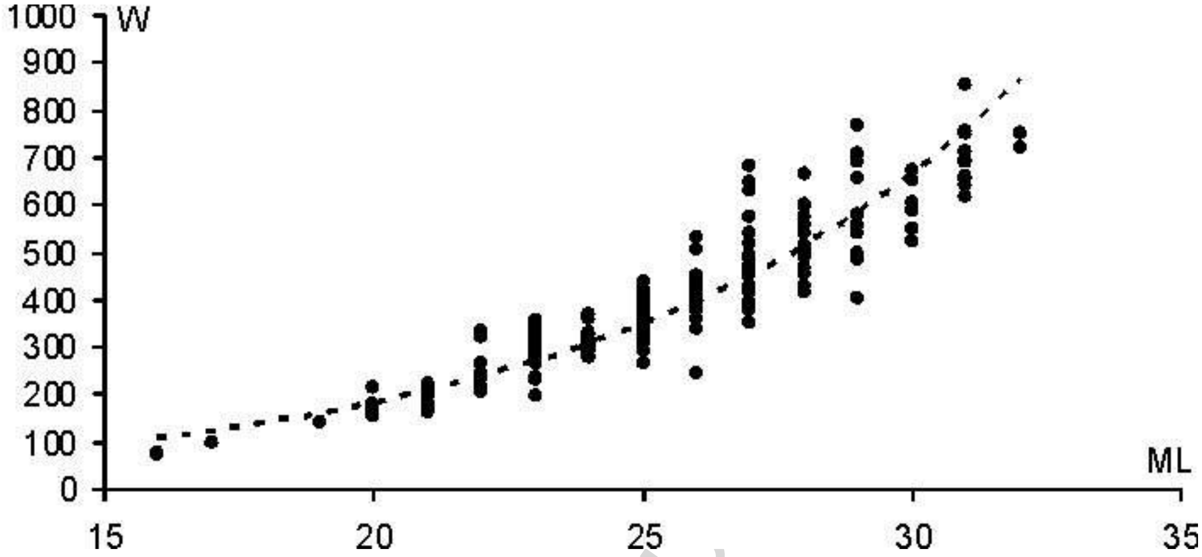

Fig. 8

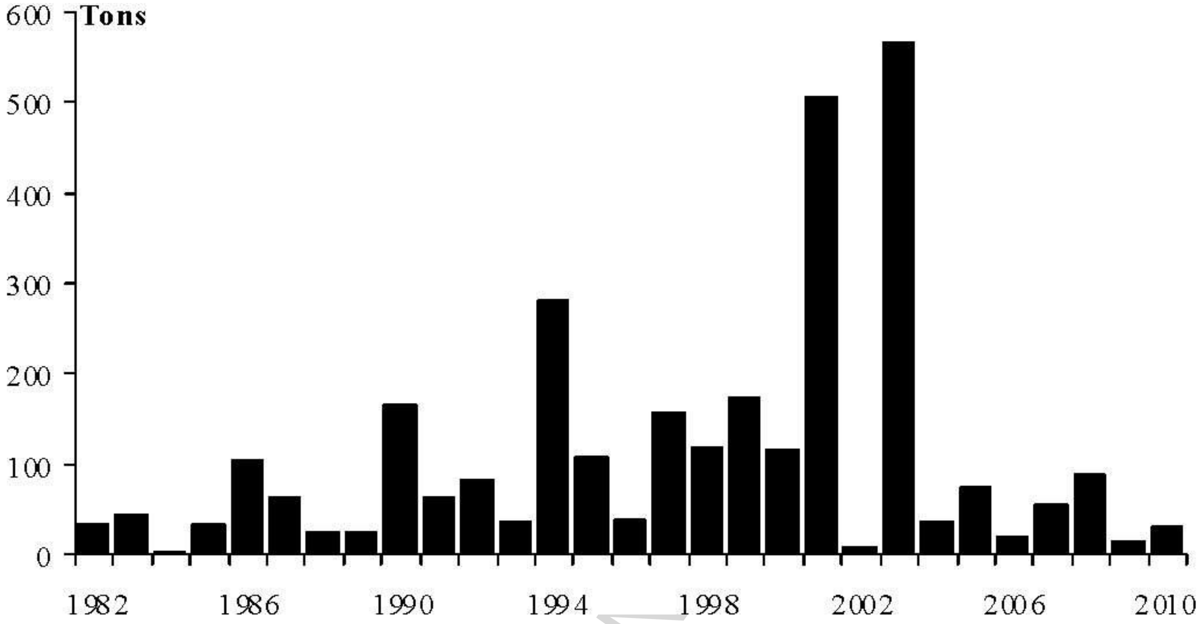
Tons
600
500
400
300
200
100
0
1982
1986
1990
1994
1998
2002
2006
2010

Fig. 9

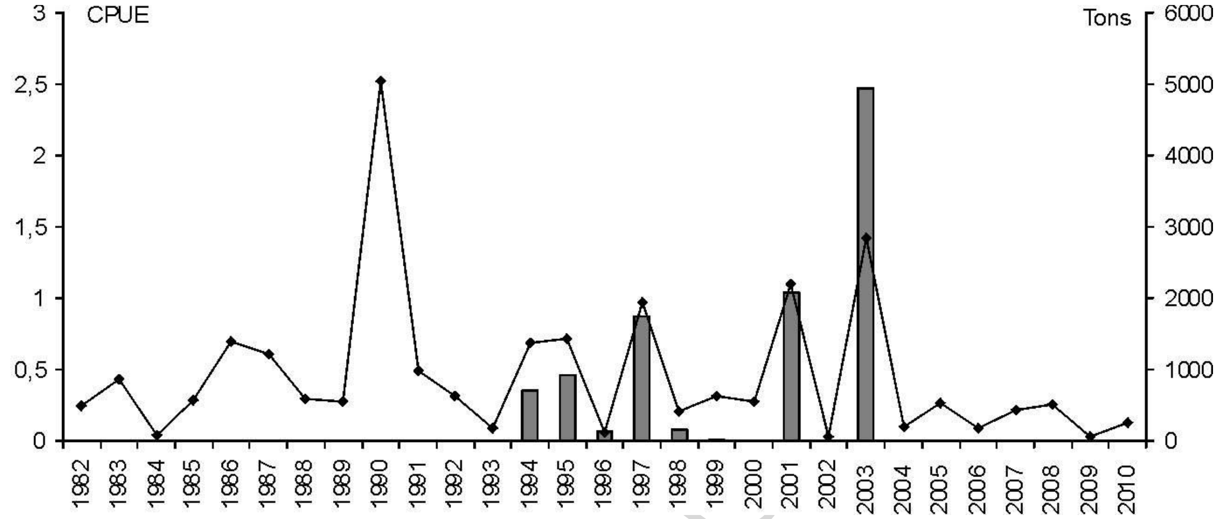
CPUE
Tons
3
2,5
2
1,5
1
0,5
0
6000
5000
4000
3000
2000
1000
0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

Fig. 10

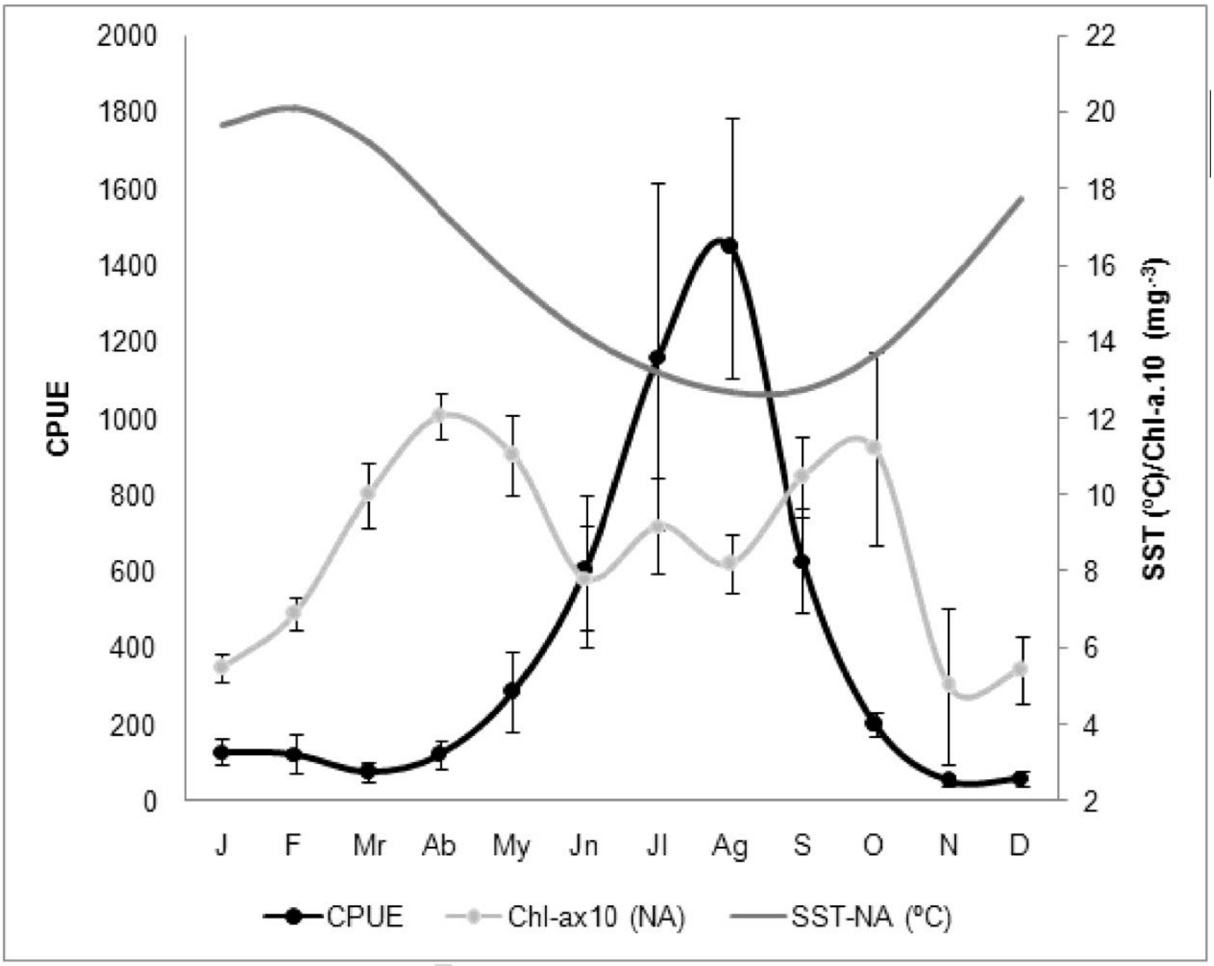
2000
1800
1600
1400
1200
1000
800
600
400
200
0
CPUE
22
20
18
16
14
12
10
8
6
4
2
SST (ºC)/Chl-a.10 (mg·$^{-3}$)
J
F
Mr
Ab
My
Jn
Jl
Ag
S
O
N
D
CPUE
Chl-ax10 (NA)
SST-NA (ºC)

Fig. 11

Table 1. *In-situ* sampling obtained in oceanographic cruises conducted in San Matias Gulf.

Cruise name	**Sampling date**	**Season**	**Number of stations**
GSM-III-08	20-23 February 2008	Summer	26
GSM-IV-08	19-21 June 2008	Autumn	25
GMS-VI-08	2-3 October 2009	Spring	17

Table 2. Parameters of the periodic model fitted to the monthly thermal cycle of San Matias Gulf. NA: northern region of the gulf, SA: southern region of the gulf.

Area	T_0	T_1	**w**	t_0	r^2_{annual}	**min**	**max**
NA	16.00	3.70	0.52	1.99	0.9913	12.59	20.07
SA	15.15	3.18	0.52	2.38	0.9963	12.15	18.45

Table 3. Fishing statistics of the jiggers that operated in San Matias Gulf. CPUE: catch per unit of effort expressed as Kg h^{-1} $line^{-1}$. SD: Standard deviation.

Year	**Number of vessels**	**Total fishing days**	**Mean fishing hours per day per vessel (SD)**	**Mean CPUE (SD)**	**Total Catches in tons**
1994	2	20	14.31 (2.81)	10.5 (8.4)	780.482
1995	5	27	14.05 (2.25)	7.4 (5.2)	914.796
1996	6	38	13.67 (1.33)	1.8 (3.02)	135.904
1997	3	52	13.02 (2.38)	15.9 (8.1)	1742.800
1998	4	14	12.32 (0.86)	4.3 (4.8)	151.987
2001	7	32	12.93 (1.57)	13.3 (12.1)	2028.912
2003	7	99	12.57 (1.74)	13.9 (12.4)	4935.257

Highlights

Coastal waters are feeding and spawning grounds for *Illex argentinus*

Individuals of *Illex argentinus* are associated to a stratified water column

The dynamics of the jigging fleet reflect the location of squids concentration