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Influence of oceanographic variability on recruitment in the *Illex argentinus* (Cephalopoda: Ommastrephidae) fishery in the South Atlantic

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ABSTRACT: The fishery for *Illex argentinus* in the Southwest Atlantic is subject to large inter-annual variability in recruitment strength. In this paper we attempt to build a predictive model using sea surface temperature (SST) to examine links between recruitment to the Falkland Islands fishery and environmental variability during the juvenile and adult life history stages. SST data from the National Center for Atmospheric Research (NCAR) were found to be comparable with near-surface data derived from *in situ* expendable bathy-thermograph (XBT) profiles in the southern Patagonian shelf. Variation in SST during the early life stages appears to be important in determining recruitment of *I. argentinus*. SST in the hatching grounds of the northern Patagonian shelf during the period of hatching (particularly June and July) was negatively correlated with catches in the fishery in the following season. SST anomaly data from positions in the Pacific and Southwest Atlantic were used to examine teleconnections between these areas. Links were seen at a lag of 2 yr between the Pacific and southern Patagonian shelf, and at about 5 yr between the Pacific and northern Patagonian shelf. This is consistent with SST anomalies associated with El Niño in the Pacific propagating around the globe via the Antarctic Circumpolar Wave (ACW). 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.

KEY WORDS: Squid fishery · South Atlantic · *Illex argentinus* · Oceanography · Recruitment · El Niño · Teleconnections

INTRODUCTION

The Southwest Atlantic squid fishery is dominated by *Illex argentinus*, a neritic-oceanic species widely distributed along the Patagonian shelf between 22° and 54° S (Hatanaka 1988, Rodhouse et al. 1995, Haimovici et al. 1998).

The Patagonian shelf is a region of complex oceanography (Legeckis & Gordon 1982, Olson et al. 1988, Peterson & Whitworth 1989), where the upper level circulation is dominated by the opposing flows of the Brazil and Falkland (Malvinas) Currents (Peterson 1992). The Brazil Current flows polewards along the continental margin of South America as part of the western boundary current of the South Atlantic subtropical gyre (Olson et al. 1988). The Falkland Current originates from the Antarctic Circumpolar Current and flows equatorward in 2 branches; the eastern branch flows over the continental slope to the east of the Falkland Islands, and the western branch, sometimes termed the Patagonian Current (see Fedulov et al. 1990), flows over the shelf between the 100 to 200 m isobaths northwards to nearly 38° S. The Brazil Current exhibits high mesoscale variability with the intermittent formation of meanders and anticyclonic warm core eddies (Legeckis & Gordon 1982, Gordon & Greengrove 1986). The southern limit of the Brazil

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Current fluctuates between 38° and 46° S, and variability in the Falkland Current is related to variability in the Brazil Current (Legeckis & Gordon 1982).

The life cycle of *Illex argentinus* is associated with the subtropical confluence of the Brazil Current and the Falkland Current (Fig. 1) (Brunetti & Ivanovic 1992, Leta 1992, Haimovici et al. 1998) and from this region 3 or 4 spawning stocks have been identified (see Haimovici et al. 1998). The Bonarensis-northpatagonic stock (BNS) spawn in waters off Brazil (north of 44° S) with the southern Brazil stock (SBS) representing either a separate stock or a northward continuation of the BNS. The summer spawning stock (SSS) spend their entire life cycle in continental shelf waters, with juveniles present during the austral summer (Haimovici et al. 1998). The south Patagonic stock (SPS) spawns during the austral winter (Haimovici et al. 1998) and are thought to spawn in waters off the coast of Southern Brazil, where post-hatching paralarvae have been found between autumn and spring (Vidal pers. comm.). The Falkland Islands fishery consists almost exclusively of winter spawners (Csirke 1987, Basson et al. 1996) and it is assumed that the fishery targets a single stock (the SPS) south of 45° S (Basson et al. 1996).

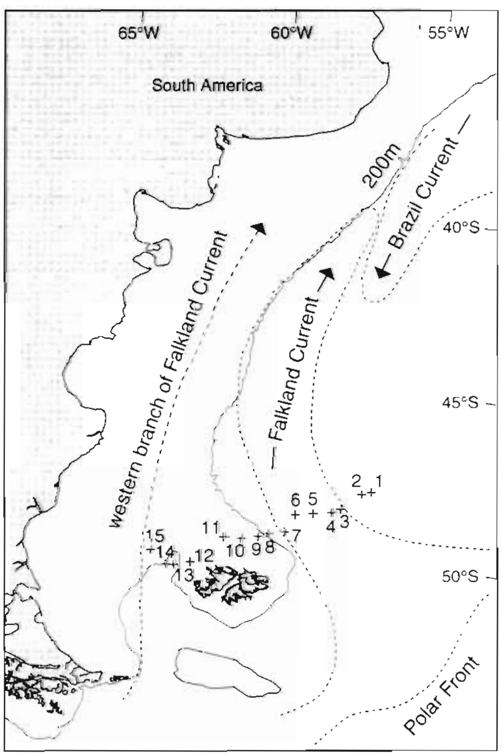

Fig. 1. Major oceanographic features of the Southwest Atlantic Ocean including location of the monthly expendable bathythermograph (XBT) transects, January to November 1993. (—) 200 m contour, (+) Stns 1 - 15

Illex argentinus migrates between spawning grounds in the northern Patagonian shelf and feeding grounds in the south. The SPS is thought to spawn in the austral winter in the waters of either the Falkland Current (Brunetti & Ivanovic 1992, Leta 1992, Rodhouse et al. 1995) or the Brazil Current (Hatanaka 1988). The eggs are carried towards the subtropical confluence (Hatanaka 1986, 1988, Haimovici et al. 1998) and are thought to develop in the waters of the Brazil Current. By early spring (September and October), juveniles are found across most of the northern Patagonian shelf, and are associated with frontal waters between warmer coastal and cooler offshore waters (Hatanaka 1988). In the austral summer, squid disperse southward and spread across the entire continental shelf as they feed, grow and mature (Hatanaka 1988, Rodhouse et al. 1995). Feeding concentrations of squid are present during January and February in waters to the north of the Falkland Islands (between 46° and 49° S) (Haimovici et al. 1998) and in Falkland Islands waters during February to June (Rodhouse et al. 1995). The spawning migration northward from Falkland Island waters is completed by June (Rodhouse et al. 1995).

Illex argentinus has a lifespan of approximately 1 yr (Hatanaka 1986, Rodhouse & Hatfield 1990, Uozumi & Shiba 1993) and is fished in several regions throughout its distributional range by a multinational fleet of jiggers and trawlers (see Haimovici et al. 1998). The species does not exhibit a clear stock recruitment relationship and estimates suggest that spawning stock biomass can vary by a factor of 10 between successive years (Csirke 1987). For a given size of spawning stock the adult population can vary enormously (Csirke 1987, Beddington et al. 1990, Basson et al. 1996). The short lifespan completed within a complex oceanographic environment means that catches exhibit considerable inter-annual variability. As is the case in the majority of cephalopod fisheries, catches are notoriously difficult to predict (see Boyle 1990, Pierce & Guerra 1994, Boyle & Boletzky 1996). A number of authors have suggested links between squid abundance and ocean temperature (e.g. Coelho & Rosenberg 1984, González et al. 1997, Pierce et al. 1998, Waluda & Pierce 1998), and this paper examines the possibility of using variability in sea surface temperature (SST) as an aid to forecasting recruitment in the *I. argentinus* fishery.

SST data were compared with data on annual squid catches from Falkland Islands waters (1987 to 1998) to test the hypothesis that recruitment variability is related to environmental variability during the juvenile and/or adult life history stages. SST data from the western Pacific were also compared with data from the Patagonian shelf to examine whether teleconnections existed between the SST anomalies of these areas.

Such teleconnections represent links between distant regions, where events in one area may have related affects that are spatially or temporally lagged.

MATERIAL AND METHODS

Data sources. ***XBT transect:*** Expendable bathy-thermograph (XBT) profiles were run over 15 stations across the southern Patagonian shelf (Fig 1) within a 2 d period each month, between January and November 1993. These transects provided an estimate of water structure across this region. Temperature data from each of the XBTs were averaged over 5 readings between 3.2 and 5.8 m; this was done to reduce the effect of variability seen in the top few readings due to stabilisation of the sensor at the surface.

Atlantic SST: Large-scale SST data are available from the National Center for Atmospheric Research (NCAR Data Center, Boulder, Colorado, USA) on both a weekly and monthly basis for the period November 1981 to July 1998 (updated regularly). These data are available globally with a spatial resolution of 1° latitude by 1° longitude and are derived from satellite and *in situ* data using optimum interpolation techniques (Reynolds & Smith 1994). Monthly SST data (November 1981 to December 1997) were extracted from the NCAR database for each of the 33 positions shown in Fig. 2. Weekly SST data were extracted from the NCAR database for comparison with XBT data.

Fishery data: Yearly catch (tonnes) and effort (number of vessels licenced to fish for *Illex argentinus*) data from Falkland Islands waters were obtained from the Falkland Islands Government Fisheries Department on a yearly basis for the 12 yr period, 1987 to 1998. The number of licences issued per year was used as a measure of effort and catch per unit effort was calculated as tonnes of squid per vessel per year for this period. The fishery is effort limited and operates by issuing a limited number of licenses that allow fishing for a fixed period of time (see Beddington et al. 1990, Basson et al. 1996). Using licenced vessels as a measure of effort is in accordance with the way in which the fishery is managed.

Pacific SST: Monthly data on SST anomalies (deviation from monthly mean SST; January 1950 to December 1997) from the western Pacific (referred to as El Niño area 4; i.e. between 5° N and 5° S, 160° E and 150° W) were taken for the period November 1981 to December 1997 from the NOAA NCEP (National Oceanic and Atmospheric Administration; National Centers for Environmental Prediction) climate prediction center website: http://nic.fb4.noaa.gov/data/cddb/cddb/sstoi.indices.

Analyses. XBT transect data were compared with data from the NCAR database using regression analyses in Minitab (Version 10, Minitab Inc.). For this analysis data were selected from the weekly NCAR database for each of the 15 cells corresponding to positions at which XBT profiles were taken (Fig. 1). Weekly NCAR data were taken for the week incorporating the day on which XBT profiles were run. Each NCAR station position was taken as the midpoint of a cell with a spatial resolution of 1° latitude by 1° longitude. Each pair of data (XBT and NCAR) were compared in order to examine relationships between the 2 datasets and the degree to which NCAR data reflected the Southwest Atlantic region.

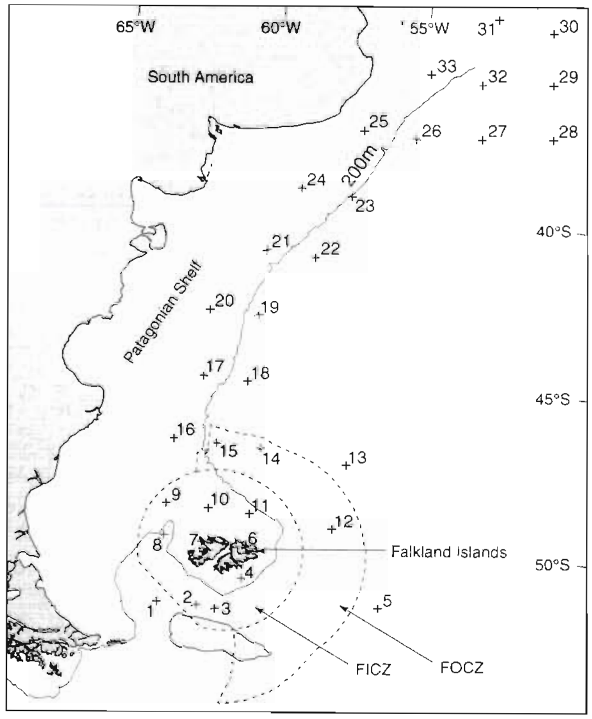

Fig. 2. Distribution of positions from which SST data (NCAR Data Center, Boulder, Colorado) were extracted and compared; (---) Falkland Islands Interim Conservation and Management Zone (FICZ) and Falkland Islands Outer Conservation Zone (FOCZ); (—) 200 m contour, (+) 33 positions from which data were obtained

Data were also extracted from the NCAR database for 33 positions over the Patagonian shelf region between longitude 62° to 50° W and latitude 34° to 53° S; this corresponds to an area covering the known range of the winter spawning stock of *Illex argentinus* (Fig. 2). SST anomalies (deviation from mean monthly SST, for the period November 1981 to December 1997) were calculated to remove the average seasonal cycle for each of the 33 positions. Monthly time series of anomalies from each position were compared to each other position in order to examine the variability in SST throughout the Patagonian shelf.

Time series analysis using S-Plus (Version 4.0, MathSoft Inc.) was used to explore possible serial dependence in the NCAR data. Data were examined from representative cells from the northern (position 32; 52.5° W, 36.5° S) and southern (position 10; 60.5° W, 50.5° S) Patagonian shelf. The presence of temporal autocorrelation was examined for both positions and cross-correlation functions were calculated in order to examine teleconnections between events in the northern and southern Patagonian shelf.

Fishery data (average annual catch per vessel; 1987 to 1998) from Falkland Islands waters were compared using regression analyses (in Minitab) with SST data (by month; January to December) from the NCAR database for the region of: (1) the spawning/hatching grounds over the northern Patagonian shelf in the season prior to recruitment, and (2) the fishing grounds of the Falkland Islands Interim Conservation and Management Zone (FICZ) and Falkland Islands Outer Conservation Zone (FOCZ) (Fig. 2) during the fishing season. These analyses examined the influence of environment during the early life stages and the period of recruitment into the fishery. The hatching area was defined as described by Vidal (pers. comm.) and Haimovici et al. (1998), and covered the area between 50° and 52° W, 34° and 38° S (positions 27 to 32; Fig. 2). The fishing area comprised waters north of 51° S within the FICZ and FOCZ, (see Rodhouse et al. 1995; positions 6 to 11 and 14 to 15; Fig. 2).

Data from the western Pacific (El Niño area 4; 5° N to 5° S, 160° E to 150° W) extracted from the NOAA website were examined for the presence of temporal autocorrelation. Cross-correlation functions were calculated between the Pacific (El Niño area 4) and positions in the northern (position 32; hatching grounds) and southern (position 10; fishing grounds) Southwest Atlantic (Fig. 2). Teleconnections between events in the western Pacific and Southwest Atlantic were examined. The occurrence and timing of significant positive and negative SST anomalies were examined to compare oceanographic variability in the northern and southern Patagonian shelf and the western Pacific.

RESULTS

SST data recorded using XBTs were consistent with data extracted from the NCAR database. When all available data were compared (Fig. 3) a linear relationship was observed between XBT and NCAR data (n = 130, $F_{1,129} = 510.72$, $R^2 = 80.0$, $p < 0.001$). SST data recorded using XBTs were found to be generally higher (XBT = 0.297 + 1.01 × NCAR) than those given by NCAR data.

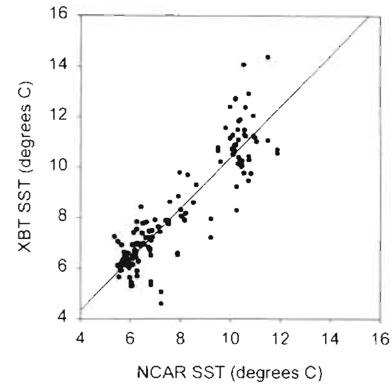

Fig. 3. Relationship between *in situ* XBT temperature data and large-scale SST (NCAR) data (pooled over all months for each sampling location; n = 130) for the transect shown in Fig. 1

Examination of correlations between NCAR SST anomaly data for pairs of positions (1 to 33; Fig. 2) suggested a dissimilar environment in the region of the northern and southern Patagonian shelf.

Autocorrelation functions calculated for positions in the northern and southern Patagonian shelf (Fig. 4a,b) indicate the absence of serial dependence, i.e. the lack of any regular cycling in the data. When data from the southern Patagonian shelf are compared by cross-correlation with data from the northern shelf a weak

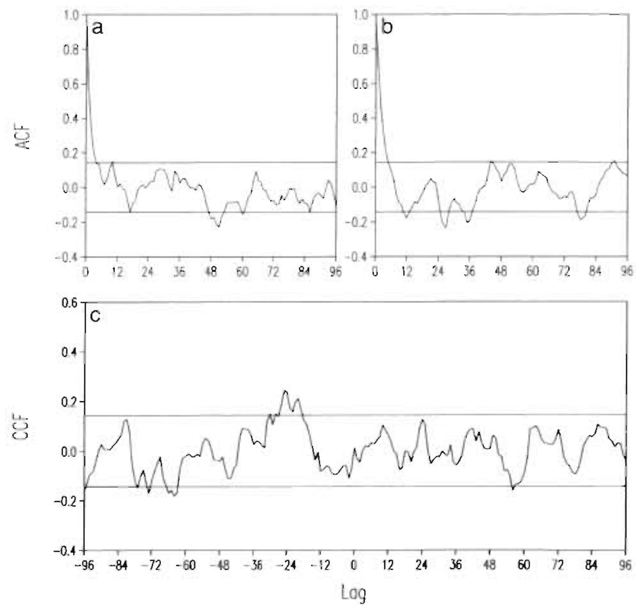

Fig. 4. Time series analyses between the northern and southern Patagonian shelf. Autocorrelation function (ACF) for (a) northern Patagonian shelf (b) southern Patagonian shelf. Cross-correlation function (CCF) for (c) northern Patagonian shelf leading southern shelf (positive lag, 0 to 96) and southern Patagonian shelf leading northern shelf (negative lag 0 to -96); horizontal lines are 95% confidence intervals at $\pm 2\sqrt{n}$

negative relationship is seen at a lag of around 56 mo, but there is no evidence of a strong systematic correlation (Fig. 4c; positive lag 0 to 96). In contrast, when events in the northern shelf are compared to the southern shelf a positive relationship is seen at a lag of −20 to −30 mo, and a negative correlation at a lag of −63 to −68 mo, suggesting that events in the south precede those in the north with a lag lead of around 2.5 yr (Fig. 4c; negative lag, 0 to −96).

The fishery for *Illex argentinus* in Falkland Islands waters is subject to large inter-annual variability in overall catch (Fig. 5). Catch per vessel appears to follow a similar pattern (Fig. 5) and was used as an index of abundance. When catch per vessel data were compared with SST from the northern Patagonian shelf (positions 27 to 32) a relationship was observed between SST in the austral winter and squid catches in the Falkland Islands fishery in the following season (Fig. 6a). Correlation coefficients were found to be statistically significant during June (n = 12, $F_{1,11}$ = 5.98, b = −262, t_{10} = −2.45, p < 0.05,) and July (n = 12, $F_{1,11}$ = 7.03, b = −300, t_{10} = −2.65, p < 0.05). It appears that

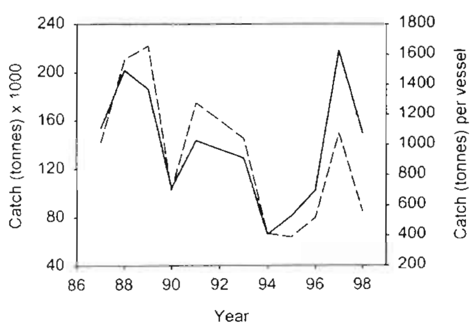

Fig. 5. Catch (tonnes × 1000; - - -; left axis) and catch per vessel (tonnes; ——; right axis); of *Illex argentinus* from Falkland Islands waters (FICZ and FOCZ) 1987 to 1998

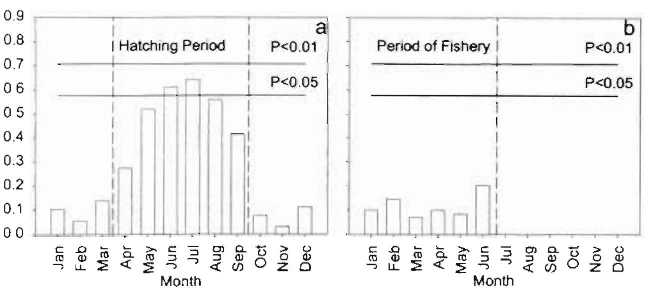

Fig. 6. Correlation (r values) between catches of *Illex argentinus* and SST in (a) the previous year in the northern Patagonian shelf and (b) the southern Patagonian shelf during the period of the fishery. Probability levels of p < 0.01 and p < 0.05 (n = 12) are indicated. 'Hatching period' was estimated by back calculation from statolith increments (Rodhouse & Hatfield 1990, Uozumi & Shiba 1993)

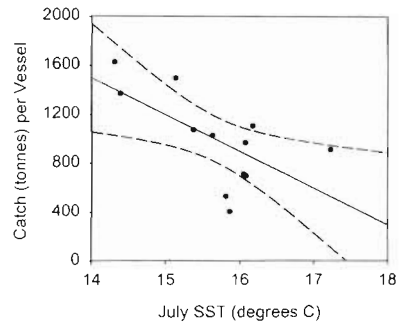

Fig. 7. Catch (tonnes) per vessel of *Illex argentinus* in Falkland Islands waters (1987 to 1998) versus SST in the northern Patagonian shelf from July in the season prior to the fishery; (——) regression line [R^2 = 41.3%]; (- - -) 95% confidence intervals

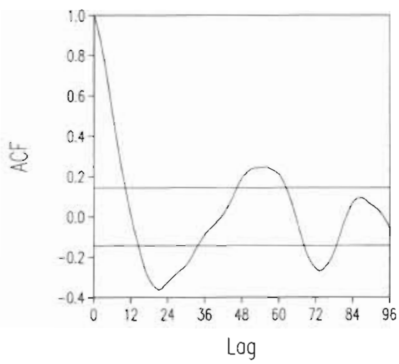

Fig. 8. Autocorrelation function for the western Pacific (El Niño area 4); horizontal lines are 95% confidence intervals at $\pm 2\sqrt{n}$

when temperatures are colder in the hatching area of the northern Patagonian shelf better catches arise in the following year's fishery (Fig. 7). In comparison, no significant correlations between squid catches and SST were observed in the southern region (positions 6 to 11 and 14 to 15) during the period of the fishery (Fig. 6b).

Autocorrelation functions calculated for data from the western Pacific (Fig. 8) show a cyclical pattern, with negative correlations at a lag of 15 to 34 and 70 to 80 mo and positive correlations at a lag of 46 to 62 mo. Cross-correlations calculated between data from the western Pacific and northern Patagonian shelf (Fig. 9a; positive lag, 0 to 96) indicate a positive correlation at a lag of between 52 to 60 mo (4.5 to 5 yr). No significant correlations are seen in the opposite direction, where events in the northern Patagonian shelf precede events in the western Pacific (Fig. 9a; negative lag, 0 to −96).

In the southern Patagonian shelf, positive correlations are observed at lags of 15 to 40 and 76 to 86 mo, with negative correlations at 6 to 14 and 46 to 60 mo. This indicates a lag of approximately 2 yr, with events

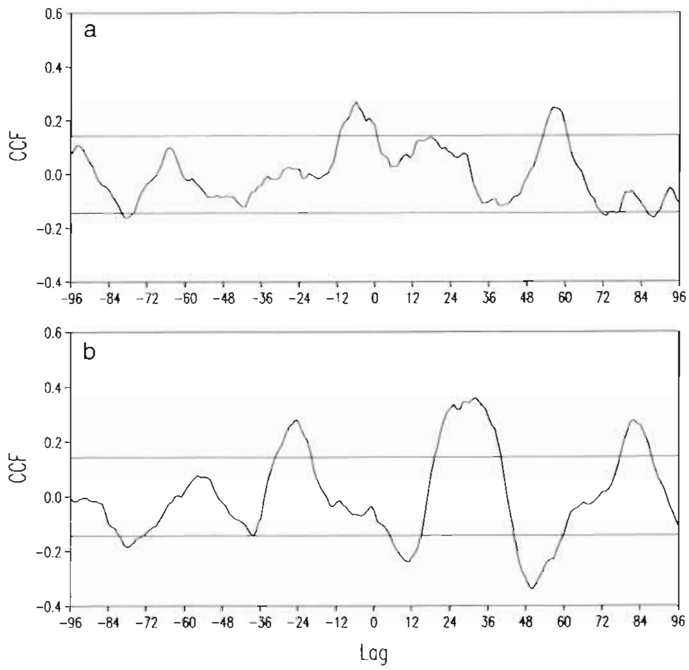

Fig. 9. Time series analyses between the Pacific and Atlantic. Cross-correlation function for (a) Pacific and northern Patagonian shelf. Positive lag (0 to 96) indicates Pacific leading northern Patagonian shelf. Negative lag (0 to −96) indicates northern Patagonian shelf leading Pacific. (b) Pacific and southern Patagonian shelf. Positive lag (0 to 96) indicates Pacific leading southern Patagonian shelf. Negative lag (0 to −96) indicates southern Patagonian shelf leading Pacific; horizontal lines are 95% confidence intervals at $\pm 2\sqrt{n}$

in the Pacific preceding those in the southern Patagonian shelf (Fig. 9b; positive lag 0 to 96). Correlations in the opposite direction (Fig. 9b; negative lag, 0 to −96), where the southern Patagonian shelf leads the western Pacific indicate a positive correlation at a lag of between −20 and −32 mo. The 2 yr lag between the western Pacific and southern Patagonian shelf, and the 4.5 to 5 yr lag between the Pacific and northern Patagonian shelf data is in accord with the 2.5 yr lag in the correlation between the southern and northern Patagonian shelf (Fig. 4c).

The timing and magnitude of SST anomalies from the northern Patagonian shelf (Fig. 10a) the southern Patagonian Shelf (Fig. 10b) and the western Pacific (Fig. 10c) are variable. Extreme positive and negative anomalies were defined as those lying outside upper and lower confidence intervals calculated, where $y = x \pm 2$ SD (where SD is the standard deviation of SST anomalies). Periods of extreme positive anomalies were seen in 1991 and 1992 in the northern Patagonian shelf region (Fig. 10a), and in 1985, 1990–91 and 1993 in the southern Patagonian shelf region (Fig. 10b). Extreme negative anomalies were seen in 1988, 1993 and 1997 (north; Fig. 10a) and 1986–87, 1990 and 1992 (south; Fig. 10b). Data from the western Pacific showed extreme positive anomalies during 1987 and 1994, and extreme negative anomalies in 1988–89 (Fig. 10c).

DISCUSSION

Data extracted from the NCAR database for stations on the Patagonian shelf are correlated with data obtained from XBTs and may be regarded as being of sufficient similarity for use in an analysis of this kind. SST as derived from XBTs generally gave higher temperatures than those extracted from the NCAR database. This was not unexpected, as the XBT data relate to the sub-surface of the water column and satellite data give temperatures for the surface skin alone. It is possible that the colder temperatures indicated by the NCAR dataset are due to the way data are derived using optimal interpolation techniques (Reynolds & Smith 1994), or related to satellite biases such as the atmospheric absorption of infra-red radiation or the influence of cloud cover (Legeckis & Gordon 1982). Data from NCAR are interpolated over a large area (1° of longitude by 1° of latitude) and are unlikely to correlate exactly with single point data from XBT profiles; however, large-scale data from the NCAR

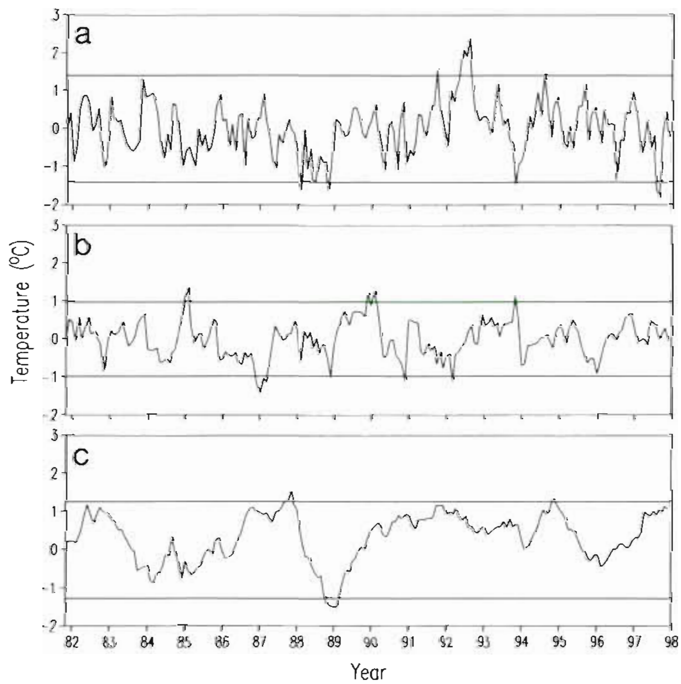

Fig. 10. Monthly SST anomalies (deviation from mean monthly SST) November 1981 to December 1997 for (a) northern Patagonian shelf (b) southern Patagonian shelf (c) western Pacific; horizontal lines areconfidence intervals where $y = x \pm 2 \times$ standard deviation

database does appear to give a reasonable approximation to SST data obtained *in situ*.

Cross-correlations calculated between the northern and southern Southwest Atlantic suggest a relationship between these areas, with conditions in the northern shelf apparently following those in the south with a lag of around 2.5 yr. No correlations are seen in the opposite direction (i.e. south following north) suggesting an equatorward transfer of SST anomalies, possibly via the anti-cyclonic circulation of the Atlantic gyre (cf. Peterson & White 1998).

Data from the Falkland Islands fishery were used as an index of abundance for *Illex argentinus* in the Southwest Atlantic. Catch per vessel was used as a simple index of abundance reflecting the variability in catches between 1987 and 1998 (Fig. 5). The highest catch rates and the bulk of the stock apparently occur within the FICZ throughout most of the fishing season (Beddington et al. 1990), particularly during April and May (Basson et al. 1996). Data from the Falkland Islands are thought to be indicative of the population within the South Atlantic, and models for estimating spawning stock biomass and recruitment suggest similar results, whether squid from within and without the FICZ are regarded as separate or mixed populations (Basson et al. 1996). Comparative data from FAO fishery statistics (FAO 1992, 1997, Table C41) indicate an upward trend in squid catches from the Southwest Atlantic from 1987 to 1995. This is possibly related to increased effort by the multinational fleet, but comparable effort data are not available at this resolution. Falkland Islands fishery data are used here in comparison with SST data as they most accurately reflect inter-annual variability in recruitment to the fished stocks of *I. argentinus*.

Correlations between SST and squid abundance are seen in both the location (Vidal pers. comm., see also Haimovici et al. 1998) of the hatching grounds and the time at which hatching occurs (Fig. 6a). Lower SST appears to be associated with higher catch, but this relationship may possibly break down at higher temperatures (Fig. 7). The correlation is strongest during the months of June and July, corresponding with the peak of hatching as estimated by back calculation from statolith increments (Rodhouse & Hatfield 1990, Uozumi & Shiba 1993). It is possible that the relationship observed may be due to direct temperature effects or that SST may be a proxy for oceanographic conditions favouring such mechanisms as the retention of planktonic eggs and paralarvae, or for conditions which are favourable to the prey of paralarvae and juveniles. Mechanisms driving inter-annual variability are likely to be complex and the development and testing of suitable hypotheses is required to further address this issue.

No significant correlations were found between squid catches and SST on the fishing grounds during the period of the fishery (Fig. 6b), suggesting that variability in SST at the spatial and temporal scale examined here does not directly influence the recruitment of adults to the fishery. Environmental variability appears to be of more importance in driving recruitment variability during the hatching and early life history stages than during the adult phase.

In the Pacific (Fig. 8) the influence of El Niño is clearly seen, with positive and negative temperature anomalies occurring on a regular basis, with a 4 to 5 yr period. This is consistent with previous reports (White & Peterson 1996). Cross-correlation functions calculated between the Pacific and Atlantic suggest a significant link between the southern Patagonian shelf and the western Pacific (Fig. 9b), with events in the Pacific leading those in the Atlantic with a lag period of approximately 2 yr. The positive correlation seen at a lag of −20 to −32 mo (Fig. 9b) is likely to result from regularity in the ocean system. It is plausible that this pattern relates to variability within the Antarctic Circumpolar Current, which exhibits a 4 to 5 yr cycle (in anomalies of wind stress, SST, sea level pressure and sea-ice extent) known as the Antarctic Circumpolar Wave (ACW; White & Peterson 1996). The ACW travels from west to east and may be important in transferring temperature anomalies around the globe (White & Peterson 1996). The periodicity of the ACW is reflected strongly in SST data south of the Polar Front, and the signal is reduced to the north of this (Trathan & Murphy 1998). Signals consistent with the ACW are apparent in the region to the north of the Falkland Islands.

On the northern Patagonian shelf, correlations between Pacific and Atlantic temperature data are seen at a lag-period of around 4.5 to 5 yr (Fig. 9a). It is possible that this is a reflection of signals from the ACW (see Peterson & White 1998) transported via the south Atlantic gyre, though further work is required to test this hypothesis. It is also possible that anomalies observed in the northern South Atlantic may be driven in part by the atmospheric influence of El Niño anomalies, for example anomalously high rainfall (e.g. see Nobre & Shukla 1996) may result in a greater outflow of water from the Rio de la Plata, Argentina, with an increase in warmer and less saline water occurring in the region of the spawning grounds (Leta 1992).

Positive and negative SST anomalies for the northern and southern Patagonian shelf and for the western Pacific occur at irregular periods. Events in the Pacific appear to persist for longer than events in the Atlantic (Fig. 10); however, there is a high degree of spatial smoothing in the Pacific time series as the data cover a large area (10° latitude by 50° longitude). Differences between the northern and southern Patagonian shelf indicate anomalous periods are out of phase.

SST anomalies appear to be transferred from the Pacific to the Atlantic via the Antarctic Circumpolar Current and equatorward via the Atlantic circulation. Further investigation into the lag observed between the Pacific and northern Patagonian shelf is required. If SST in the northern Patagonian shelf can be accurately predicted from conditions seen previously in the Pacific or the southern Patagonian shelf, this would be of great value in the forecasting of recruitment strength in the fishery in the following season. The model already described allows the prediction of recruitment strength some 8 mo prior to the beginning of the fishing season, and links between Pacific and Atlantic anomalies could allow a significant increase in this prediction timescale.

The recruitment success of *Illex argentinus* on the southern Patagonian shelf would appear to be related to environmental conditions associated with SST in the hatching area during the early part of the life cycle. The results of this study indicate that further work to establish a mechanism driving recruitment variability should be sought in the hatching area, rather than on the feeding grounds where the stock is harvested.

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