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INFLUENCE OF SHELF-BREAK FRONTS ON SHELLFISH AND FISH STOCKS OFF ARGENTINA

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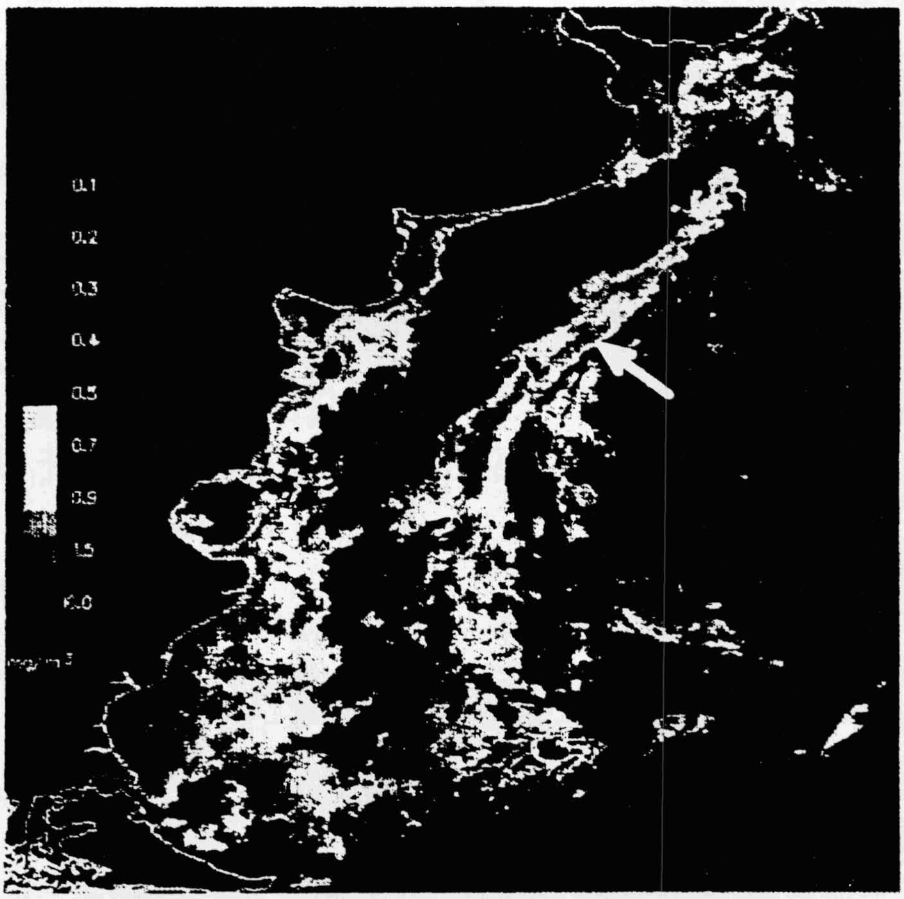

Pigment concentration.
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The general circulation pattern in the western boundary of the SW Atlantic is dominated by the opposite flows of Malvinas (=Falkland) and Brazil Current. In the Confluence region both currents separate from the continental slope and flow offshore creating an area of strong contrasts and complex dynamics. The shelf-break fronts off Argentina mark the transition between shelf waters of mixed origin and nutrient rich Malvinas waters. Two areas deserve special attention due to the steep gradients introduced by the outflow of important sources of continental waters: the Rio de la Plata and the Magellan Strait to the north and south of the study area. Characteristic of the front is the high primary and secondary production, and the presence of important invertebrate and fish stocks that concentrate along the front to feed or spawn. An analysis is presented on the linkage between the front and the reproductive strategies of semelparous marine invertebrates and iteroparous teleost fish. An assessment of the importance of the external shelf and slope fisheries on domestic (national and coastal states) economies and its share on total exports is analyzed. The area comprises nearly 30% (333 million U$S in 1995) of all Argentine catches of fish and squid. Resources in the area, beyond the EEZ limits, support international fisheries mainly of Russia, Poland and Spain.

Keywords: SW Atlantic, shelf-edge, continental slope, reproductive strategies, feeding strategies, economic assessment.

INTRODUCTION

The shelf-break off Argentina conforms a remarkable ecosystem from the point of view of its physical and dynamic characteristics and by the nature of the fishery resources associated to it. The region which comprises the outer continental shelf, continental slope and adjacent waters, supports several Argentine and international fisheries, since due to its extension the Argentine shelf expands in some regions beyond the EEZ. The objective of this presentation is to describe the hydrological characteristics of this feature, its production cycles, its influence on the life cycles of fish and shellfish, analyze the principal fishery resources and asses their incidence on Argentine economy.

THE STUDY AREA

1. Topography

The continental shelf off Argentina, extending over an area of about of 1.000.000 Km^2 shows some distinctive features. The mean distance from shore of the 200 m isobath is 270 km in the northern area and 800 km in the southern Patagonian region. Characteristics of its topography are a shallow depth gradient in contrast to a steep continental slope of up to 4° (SHN, 1966). The Malvinas plateau makes the shelf-break less abrupt to the north and east of the Malvinas Islands, while forming a steep at 200 m between 48°S and 49°S and a channel between the Islands and the Burdwood Bank. To the south of the Bank, the shelf-break is steeper in some parts than to the north of the Malvinas plateau. Details on the topography and major geographical features of the study area are presented in Figure 1.

2. Hydrography and primary production

The circulation in the offshore region is dominated by the opposite flow of the Brazil and Malvinas currents (Fig. 1). The warm Brazil Current -the western boundary current associated with the subtropical gyre in the South Atlantic Ocean-, flows along the continental margin of South America to a point off Argentina and Uruguay where, in average, it separates from the coast at 36° S (Legeckis and Gordon, 1982; Garzoli and Garraffo, 1989; Olson *et al.*, 1988; Bianchi *et al.*, 1993; Matano, 1993). The cooler nutrient rich waters of the Malvinas Current originates as a branch of the Antartic Circumpolar Current (ACC) in the Drake Passage. At its origin, this subantartic waters flows out of the Scotia Basin through two major openings in the Scotia Ridge, west and east to the Burdwood Bank. Due to its shallowness, the western channel allows the passage of waters from the upper layer with lower salinities due to the contribution of mainland waters (Piola and Gordon, 1989). This branch known as Western Malvinas Current flows along the continental shelf towards the N and NE reaching in winter the Rio de la Plata region (Severov, 1990).

In its trajectory the northern branch of the ACC encircles Burdwood Bank, conforming an anticyclonic circulation pattern (Severov, 1990), and then divides into a main flow turning to the west and the Eastern branch of Malvinas Current. After entering the Malvinas Channel, it surrounds the east flank of the Malvinas Islands, following the edge of the Argentine Continental Shelf. To the north of the islands, it flows northwards along the continental slope until it meets the Brazil Current. In this area, referred to as the Brazil/Malvinas Confluence, the two flows turn offshore in a series of large amplitude meanders.

The eddy-rich Brazil-Malvinas Confluence dominates the upper layer in the Argentine Basin, with deeper meridional flow involving North Atlantic Deep water, Circumpolar Deep water and bottom water from the Weddell Sea (Gordon,1988). The mean latitudes of separation from the shelf-break are 36°S for the Brazil Current and 39°S for the Malvinas Current. Observed temporal variability suggests cyclical excursion of the currents along the coast at semi-annual and annual periods, although there are considerable interannual variations in the signal (Olson *et al.*, 1988; Fedulov *et al.*, 1990; Garzoli and Garrafo , 1989; Matano, 1993). Short-term variations in the location of the Malvinas Current axis, with a 45 kmwestwards displacement from its average position, have been reported. (Fedulov *et al.*,1990) The Malvinas Current separation from the shelf-break is not usually coincident with that of the Brazil Current, but typically a band of intermediate temperature surface waters separating the two strong thermal front associated with the two boundary currents, may be observed. This transition zone is generally filled with eddies (Olson *et al.*, 1988; Provost, 1993; Gayoso and Podesta, 1995).

Contrary to what may be expected the phytoplankton biomass in this transition zone does not seem to be very high. Although initial studies (Hentschel,1932) reported very poor phytoplankton densities, more recent reports (Hubold, 1980a, 1980b; Provost *et al.*, 1995) indicate the existence of moderate concentrations of chlorophyll *a* (0.6 - 1.8 mg m^{-3}). Provost *et al.* (1995) pointed out that the hightest concentrations of chlorophyll *a* observed in the Confluence in summer (0.9 mg m^{-3}) were related to the return flow of Malvinas Current. Recently Gayoso and Podesta (1996) have reported an intense diatom bloom (5.5 $.10^5$ cel.l^{-1}) associated to a cyclonic eddy near the meeting of both currents. As current velocities in the Confluence region are very high (Gordon and Greengrove, 1986) the authors concluded that the bloom could be determined by the retention of phytoplankton induced by the cyclonic eddy.

This may be the reason for the high spatial heterogeneity in the distribution of chlorophyll that has been observed during *in situ* surveys and by the satellite images of the Coastal Zone Color Scanner (CZCS) (Cover Figure). In these images, the majority of open ocean blooms appeared to be meanders and filaments originating from the shelf-break blooms, manily in the Confluence region (Brown and Podestá,1996).

In addition to the Confluence, a strong halocline front is always found along the shelf-break. The location of this halocline is a compromise between two competing effects: the extention at the surface of the more fresh and light shelf water over the deeper ocean and the boundary currents which follow the slope. In the northern region, shelf waters are formed as a result of mixing between subantartic waters, the coastal waters off El Rincon and the Río de La Plata runoff. Although the main flow of Rio de la Plata has a NNE direction along the Uruguayan coastline, its trajectory is variable, and its influence may be detected in the coastal region to the south, and in mid-shelf waters. Occasionally its area of influence may extend to the continental slope (Fig. 1), where this estuarine waters get in contact with Brazil Current water (Lusquiños, 1968; Provost *et al.*,1995), Malvinas Current water (Negri *et al.*,1992) or it may be found between both currents and be carried offshore by the return flow of the Malvinas Current (Provost *et al.*,1995). The time and intensity of the occurence of these events may be dependent on the discharge of the river (Provost *et al.*,1995) and on the meteorological conditions (Lusquiños, 1968; Carreto *et al.*,1986; Guerrero *et al.*1996, Glorioso and Flather, 1995). Its occurrence by the end of winter when Malvinas Current shows its maiximum latitudingal extention (Olson *et al.*, 1988), creates a strong haline front , with a nutrient rich surface picnocline where intense dynoflagellate blooms, causing extended water discoloring (35°S-40°S) have been reported Negri *et al.*(1992).

When the main flow of the river follows the coastline NNEwards, in addition to the estuarine front another discontinuity is conformed between shelf waters and Malvinas Current. During spring both frontal systems show high concentrations (up to 7 mg.m^{-3}) of chlorophyll *a* (Carreto *et al.*, 1986; Carreto and Benavides, 1990). By the end of spring the shelf-break is displaced southwards (39°S-40°S) due to a relaxation of the western branch of Malvinas Current, while horizontal gradiantes, in particular the nutricline, intensify in the slope region comprised between 39°S and 47°S (Fig. 2). At the average latitude which marks the detachment of Malvinas Current (39°S) the location of the front varies seasonally, moving towards the outer region during summer and towards the continental shelf during spring and autumn. In winter the frontal system is much less developed and horizontal gradients are weaker (Carreto *et al.*,1995).

The high productivity of this front is well documented on the basis of remote sensing and *in situ* measurements (Brandhorst and Castello, 1971, Carreto *et al.*, 1981, 1995; Podesta and Esaias, 1988). A seasonal study of primary productivity of the shelf-break front at 39°S (Negri,1993) indicated values ranging between 0.1 and 2.7 gC m^{-2} day^{-1}, and a yearly regional production of about 350 gC m^{-2}. Satellite images collected by the CZCS in summer and autumn, show an almost permanent lighter band along the edge of the shelf from 39°S to 47 °S (Cover Figure), contrasting markedly with the imagery corresponding to shelf waters, the core of Malvinas Current, and the adjacent offshore region (Podesta and Esaias, 1988). Recently Brown and Podestá (1996) have indicated the existence of high reflectance patches with the spectral signature of coccolithophorid blooms during the late spring and summer in visible imagery (CZCS) along the shelf-break and slope from off the Río de La Plata to south the Malvinas Islands. As the high reflectance underestimates satellite-derived pigment concentration using CZCS algorithms (Brown and Podesta, 1996), values reported for this area could be somewhat lower than real.

In this temperate region, the shelf waters are characterized by the typical development and break down cycle of seasonal thermocline. Two well defined chlorophyll maxima are observed, with a main peak during spring and a secondary one during autumn (Carreto *et al.*, 1995). During summer surface chlorophyll and nitrate concentrations are low over the continental shelf (Figure 2 and Cover Figure). The highest chlorophyll values are associated to the depth of the pycnocline. However in relation with the surface nitrate increase, chlorophyll values higher than 2 mg m^{-3} are recorded at the shelf-break front (Carreto *et al.*, 1995, and Carreto unpublished results). This front, therefore, possibly represents one of the few areas where primary production is high during summer.

The development and maintenance of phytoplankton blooms in the shelf-break during summer seems to the result of two concurrent processes: enhanced supply of nutrient-rich Malvinas waters in the euphotic zone and increased vertical stability by the interleaving of water masses, that retain phytoplankton cells in the euphotic zone. According to Podestá (1987), the upwelling of waters in the slope region may be accounted for by the occurrence of several physical processes: small scales eddies along the edge of the Malvinas Current; interaction between coastally trapped waves propagating along the slope and bottom topography at the shelf break; and the generation of internal tides at the shelf-break coupled with episodic wind stress. According to Fedulov *et al* (1990) this upwelling, is mainly determined by short-time fluctuations in the lateral displacement of Malvinas Current. When the flow of Malvinas is intensified, the core of the current approaches the slope, causing the sinking of slope waters. The opposite dynamic situation results in the nucleus of the current displacing offshore, slope waters rising and upwelling taking place.

South of 45°S shelf waters are formed as a result of mixing between subantartic waters of the Malvinas Current and coastal waters highly diluted by run offs from the Beagle Channel and mainly from the Magellan Strait, originating a lower salinity tonge flowing along the Patagonian coast to the south of San Jorge Gulf (Bianchi *et al.*, 1982). Due to other combined effect of wind stress, light regime (Bakun and Parrish,1991) and the intrusion of rich waters of the western branch of Malvinas in this region of the shelf, nutrient concentration is high throughout the year (Fig. 2). The main factor regulating the growth of phytoplankton is light penetration, which is dependent on water column stability. The available information on the primary production of the area is scarce, although a single seasonal peak during late spring and summer has been reported (Brandhorts and Castello,1971) with chlorophyll concentrations between 2.3 and 2.7 mg m^{-3}. However, observations of pigment distribution carried out by the CZCS, show very high chlorophyll concentrations mainly related to the lower salinity tonge originating in the Magellan Strait (Cover Figure).

The slope region must be considered as a highly dynamic area., characterized by complex and strong horizontal and vertical currents. The ingress of the westem branch of Malvinas Current on the continental shelf causes the upwelling of these waters (Severov,1992) and the development of an almost permanent haline front to east of Isla de los Estados (Brandhorst and Castello, 1971; Guerrero *et al.*, 1996). This front follows the topography on its way, maintaining a line of sharp horizontal gradients at the south west border of the Malvinas Channel. A much weaker front is formed by the isopicnal convergence south of the Malvinas Islands (Guerrero *et al.*, 1996). It is interesting to point out that in this frontal system, chlorophyll *a* concentrations higher than 1,0 mg m^{-3} have been observed during winter (Guerrero,*et al.*,1966), in contrast with the seasonal values reported as typical for the region (0,25 mg m^{-3}) by Brandhorst and Castello (1971). Severov (1992) reported on the existence of cyclonic eddies to the NE of Malvinas Islands, which induce the rising of the discontinuity layer to the surface, reaching depths between 5-17 m in winter and 10-17 m in summer. Primary production values attained around the islands (1.3 gC m^{-2} day^{-1})) are among the highest reported for the sea off Argentine Sea (Angelescu and Prenski, 1987).

3. Zooplankton abundance

The distribution and composition of zooplankton in the Sea off Argentina has been analyzed in terms of three characteristic ecosystems: coastal, mid-shelf, and outer-shelf/slope (Ramírez *et al.*, 1990). The displacement of subantarctic waters to deeper layers as they progress northwards induces the presence of species which are typical of inner and mid-shelf waters in southern Patagonia , in the vicinity of the shelf-break to the north of the study area.. As examples of this shift in species distribution Ramírez *et al.* (1990) mentioned the copepods *Aetideus armatus*, *Rhincalanus gigas*, *Clausocalanus laticeps*, *Haloptilus oxicephalus*, *Eucalanus elongatus*, the polycaetes *Tomopteris septentrionalis*, the amphipod *Primno macropa*, the euphausiids *Euphausia similis*, *E. vallentine*, *Thysanoesa gregaria*, and the scyphomedusae *Desmonema chierchianun* and *Phacellopora camtschatica*. Also characteristic of theregion is the presence of oceanic species, such as the *copepods Rhincalanus nasutus*, *Metridia sp.*, *Scolecithricela sp.* and the ostracod *Conchoecia serrulata*. The copepods, *Calanus propinquus*, *Clausocalanus brevipes*, the euphausiid *Euphausia lucens* and the amphipod *Themisto gaudichaudii*, are widely distributed in the three mentioned ecosystems.

As with phytoplankton, the zooplankton production cycle in this area confoms the typical pattern for cold-temperate seas. Zooplankton production follows the advance of the spring phytoplankton bloom from the coast to the slope and from north to south, according to the progressive abundance of nutrients and the stabilization of the water column (Carreto *et al.*, 1981). To the north of the study area zooplankton production reaches a main peak in spring and a secondary one in autumn. In the southern region there is a single production peak during summer (Ciechomki and Sánchez, 1983).

Ramírez *et al.* (1990) reported average biomass values lower than 500 mg/m² (dry weight) on the Argentine shelf. Occasional high values of 2,000 mg/m² found on the continental shelf are due to the intrusion of sutantarctic waters typically containing larger organisms. As a result of the spring bloom, the numbers of copepods increase 30-fold, and dry weights up to 13 mg/m² have been recorded. Maximum zooplankton abundance occurs at the end of spring, with highest densities (1.300 ml/m³) registered on the shelf-break (Ciechomski and Sánchez, 1983; Ramírez *et al.*, 1990). According to Ciechomski and Sánchez high values of zooplankton biomass with (densities between 0.101-1.000 ml/m³) occur during summer over most of the continental shelf to the south of 48°S with peak abundance over the slope to the north of Malvinas Islands (Fig.3).

As regards the Malvinas-Brazil Confluence the region shows a wide variation in productivity according to the relative predominance of the two major currents. Areas under dominant influence of Brazil Current show low chlorophyll *a* concentrations (0.02-0.20 mg/m³) and zooplankton densities (0.01-0.10 ml/m³), whereas rich Malvinas waters have higher chlorophyll *a* and zooplankton concentrations (0.20-2.25 mg/m³ and 0.31-0.78 ml/m³, respectively) (Hubold, 1980). Strong horizontal temperature gradients and enhanced vertical circulation in the frontal region favour moderately high production values (up to 1.67 mg/m³ of chlorophyll-a and 0.76 ml/m³ of zooplankton).

INFLUENCE OF THE SHELF-BREAK ON FISH AND SHELLFISH REPRODUCTION

The shelf-break front combines the triad of processes that favour reproduction in the marine environment (Bakun and Parrish, 1991): nutrient enrichment, water column stability and a pattern of circulation that secures the dispersal/retention of early life history stages. Semelparous invertebrates and iteroparous finfish have adapted their reproductive strategies to actively exploit the characteristics of this hydrographic feature.

Illex argentinus, is the most abundant ommastrephid squid distributed in the southwest Atlantic. It is considered that this species, as other ommastrephid squids, shows a large potential to split itself into different spawning groups. On the basis of size structure, first maturity length and, area and time of spawning, at least four spawning stocks were identified in the area off Argentina adapted to a particular annual production cycle, which is different according to the regions.

Autumn-winter juveniles (Fig. 4) are timed to take advantage of the characteristics of the plankton production cycles off Buenos Aires and North Patagonia, with the shifts in abundance from costal to the offshore areas and from north to south. The consequence is that this squid grow larger, reproduce later and are more fecund than summer spawners (Brunetti *et al.*, 1991). The Malvinas Current System provides the opportunity that autumn-winter spawned egg masses be transported to favourable temperatures to the north where the embryonic development is acelerated and hatching occurs. As proposed by O' Dor (1992) and O'Dor and Coelho (1993), there exists a possibility that the highly productive inshore area associated with large currents provide a powerful selection regime for larger individuals.

As regards finfish, icthyoplankton collections in this area -under the predominant influence of Subantarctic waters of the Malvinas Current, at surface and subsurface layers, and a deeper flow of Intermediate Antarctic Waters-, show a marked prodomnance of southern blue whiting eggs, in the southern extreme of our study region during late winter, and a prevailance of mictophiid larvae along the entire shelf-break throughout the year. Myctophiids are also the most abundant icthyoplankton component on the Argentine Basin, a region showing the superposition of several boundary currents.(Sánchez and Ciechomski, 1995).

The breeding period of the southern blue whiting in the Argentine sea is short. Sánchez *et al.* (1986) reported higher percentages of spawning adults during late winter, although some mature specimens were encountered as late as November. Planktonic eggs were obtained only in August and September in few occasions (1969, 1978, 1981, 1994 and 1995), mostly around Malvinas Islands (Sánchez end Ciechomski, 1995; Ehrlich *et al.* 1995). Egg retention in the area may be induced by a circular anticyclonic current around the archipelago generated by the eastern and western branch of Malvinas Current, described by Severov (1990). Larvae and postlarvae of the species distribute more widely over the southern Patagonian shelf and northwards along the slope up to 49°S. The largest concentrations of juveniles occur over the slope to the north of Malvinas Islands (Perrotta, 1982).

Myctophiids are the most abundant small pelagic fish in the area. Published information on the planktonic distribution of the early life history stages of this group indicates that myctophiid larvae are distributed along the shelf-break and slope (75-900 m bottom depth) in Subantarctic waters of the Malvinas Current. Myctophiid larvae occurred throughout the year and, during winter months, dominated a generally low abundance of ichthyoplankton (Ciechomki *et al.*, 1975, 1981). Two cruises carried out during winter and spring 1988 on the Argentine Basin, showed that myctophiids were the predominant epipelagic and mesopelagic fish species in all surface water masses of that region. Three ecological groups were defined (Sánchez and Ciechomski, 1995): tropical/subtropical species (*i.e. Lepidophanes guentheri, Symbolophorus barnardi*); euribathyc species predominant in areas of high vertical mixing (*i.e. Lampanyctus australis, Protomyctophum tenisoni*); and Antarctic species, which penetrate into the Confluence region with Subantarctic waters of th Malvinas Current (*i.e. Gymnoscopelus nicholsi*). The distribution of myctophiid larvae on the Argentine shelf and slope with the addition of available information on larval occurrence in the oceanic basin is presented in Figure 5.

It is interesting to point out that other finfish species as anchovy and hake, more typically associated with shelf waters, are adapted to spawn along the shelf-break, after the peak of intense coastal spawning is completed, and conditions in those neritic areas become unfavourable, either by a decrease of water temperature below the physiological tolerance threshold, by the decline of food particles patches, or by the presence of large numbers of potential predators. In this situation the shelf/break conforms a safer scenario for the early development of these species.

Eggs and larvae of the anchovy (Fig. 5) have been detected along the shelf-break front, in different latitudes, throughout the year. Sánchez (1990) reported on the presence of metamorphosed juveniles in the region, during late summer and winter. The review on the spawning activity of the species presented by Sánchez and Ciechomski (1995) indicate important spawning activity over the shelf and slope during autumn and to a minor extent during winter. At least part of the autumn-winter born larvae seem to drift towards lower latitudes judging by the length frequencies distributions of larvae and the presence of large amounts of juveniles in winter and spring in the area. This larval advection is favoured by the higher intensity of the Subantarctic waters, as this is the period of maximum geostrophic transport of Malvinas Current (Fedulov, *et al.*, 1990). A similar situation has been described by Ehrlich and Ciechomski (1994) for the common hake. The spawning grounds of this species occupy the shelf-break region. to the north of the study area, in autumn and winter.

SHELLFISH AND FINFISH STOCKS ON THE SHELF-BREAK REGION

Several commercially important marine invertebrate and fish stocks are associated during part or the whole life cycle to the shelf-break region. This area has been in the past, and still is the object of an intense fishing activity by the fleets of Argentina and foreign countries as Russia, Bulgaria, Poland, Japan, Corea, Taiwan and Spain.

Among marine invertebrates, the most important resource is the short-finned squid *Illex argentinus*. This species inhabits the Continental shelf and along the shelf-break between 54°S and 23°S, and it is most frequently found between 52°S-35°S, from 80 to 400 m depth (Castellanos, 1964; Brunetti, 1981; 1988; Leta, 1981; Otero *et al.*, 1981; Hatanaka, 1986). The extension of the continental shelf off Argentina, produces an exceptionally large Neritic Province. As a consecuence, the Argentine short-finned squid has an essentially neritic life-cycle, unlike other ommastrephid squids, which are strongly associated with the Oceanic Province.The species distribution is restricted to the zone under the influence of Subantartic cold waters, mainly from the Malvinas Current, but, as mentioned above, it depends of warm waters for the embryonic development and hatching (Brunetti, 1988; Brunetti and Ivanovic, 1992).

During autumn high concentrations of squids are found along the outer shelf and continental slope (Otero *et al.*, 1981; Brunetti, 1981; Hatanaka, 1986; Nigmatullin, 1989) To the south of 43°S these concentrations occur from March to May, while northward they are encountered between May and July. In both cases, the individuals are adults (mantle length 18-35 cm) which are starting maturity or they are already mature (stages III to V). This is the step immediatily before spawning emigration. The distribution of the species during autumn winter is shown in Figure 6.

The lifecycle of the most important fished stock, depends on spawning during autumn and winter along the continental slope off Argentina, in the region where bottom topography, fast-flowing cold Malvinas Current and shelf waters conditions generate a permanent shelf-break front. Moreover the Brazil-Malvinas Confluence originates a series of meanders and warm core eddies, which bear an influence on the dispersion and survival at egg masses and hatchlings and the subsequent variation in abundance of yearly recruitment.(Fig. 4). From May to August the southern stock migrate towards deeper waters where mating, spawnig subsequent death take place (Koronkiewicz, 1980; 1986; Brunetti, 1981; 1988; Hatanaka, 1986; 1988; Brunetti and Perez Comas, 1989b). There is a little information about spawning locations but, it would be situated along the Malvinas Current from 48°S to 45°S (Koronkiewicz, 1986; Brunetti, 1988; Brunetti and Ivanovic, 1992; Rodhouse *et al.*, 1995). Fertilized or spent individuals were found on the slope between 36°S-37°30'S (Schuldt, 1979; Brunetti and Perez Comas, 1989a). It seems to be that the spawning grounds of in this area are close to the west side of Brazil-Malvinas Confluence.

Important finfish stocks aggregate along the front to feed or spawn (Fig. 7). Commercial fisheries have been established on two statistically defined fish assemblages: a first one corresponding to the continental shelf off Malvinas and Southern Patagonia (30-220 m depth), and a second one comprising species of the continental slope. A group of species is present in both assemblages: *Micromesistius australis, Macruronus magellanicus, Dissostichus eleginoides, Merluccius hubbsi, Merluccius australis, Salilota australis,* but differ in their relative densities and size of individuals, (Angelescu and Prenski 1987).

The first assemblage occupies the shelf from 30 to 220 m depth. It extends over the outer shelf and slope reaching the confluence region. Species typical of this assemblage are *Raja flavirrostris, Psammobatis scobina, P. extenta, Bathyraja sp, Squalus acanthias.*

The second group extends from 220 to 1200 m (the maximum depth sampled with bottom trawls, at present), with several typical families as Moridae (*Lepidion ensiferus, Antimora rostrata, Physiculos marginatus* etc) Macrouridae (*Coelorhinchus fasciatus, Macrourus whitsoni* etc) Cottunculidae, Centrolophidae (*Schaedophilus griseolineatus*), Bathirraja *sp.* and the squids (*Illex argentinus, Martialia hiadesi, Moroteutis ingens* etc).

Table 1 shows the biomass estimates of the most important species, with reference to the percentages corresponding to the continental slope and adjacen areas. We shall briefly refer to some characteristics of the biology and population dynamics of these species.

The Argentine hake *(Merluccius hubbsi)* has an extended distribution on the continental shelf and slope covering an area of more than 370,000 km² and up to a depth of 800 m. The hake fishery is the most important in Argentina. Two stocks (northern and southern) have been identified, with characteristic annual spawning migratory cycles. The northern stock spawn in winter at 35-37°S, mostly in mid and outer shelf, and in summer in coastal and mid-shelf waters, at 42-44°S together with the southern stock (Ehrlich and Ciechomski, 1994). In autumn both stocks migrate following the squid spawning migration and spread to the south of 46°S (Angelescu and Prenski,1987). The main food items of hake diet included species of crustaceans (meso-macrozoo-plankton), anchovies, squids and other fishes. The total biomass rises at about 2,000,000 t.

The southern blue whiting (*Micromesistius australis*) is a mesopelagic species typically associated with Subantarctic Waters, occurring off Chile, Argentina and New Zealand. In the Southwest Atlantic, between 38° and 47°S, the species is confined to the shelf-break and slope, at bottom depths ranging between 100 and 500 m. In the southern end of our study region (47°-55°S) the blue whiting is distributed more widely over the continental shelf and slope, over bottom depths of 78-800m. The species extends south to the southern end of the Sea of Scotia, east to South Georgia and west to the Shetland Islands (Otero, 1976). The species has supported directed fisheries both natioanal and international. Over the period 1978-1994, the total biomass of the species has shown a declining tendency. It is at present estimated at about 1,200,000 t.

Hoki (*Macruronus magellanicus*) distributes from 36°S to 55°S, although the largest concentrations occur to the south of 47°S, at bottom depths ranging from 100 to 200 m (Fig. 19). The species may live up to 16 years, although specimens caught at present seldom surpass 12 years of age and 110 cm in total length. First reproduction occurs when specimens are 3 years old and about 60 cm long. Spawning takes place in winter and spring, in Gulfs San Matías and San Jorge, to the east of Malvinas Islands and over the continental shelf. Recent research is indicative that massive spawning could take place to the south of Tierra del Fuego, between 400 and 600 m depths, the larvae being passively transported into the shelf. The hoki is a crab eating species, although adults also prey on several fish species, such as sprat, myctophids and notothenids. Some sharks and rays, the hake and abadejo are the hoki main predators. The species biomass has been estimated at 1,400,000 t in 1995. Commercial yields are mainly based upon 4-8 year old individuals. Results of a VPA run over the catch data from 1985-1995 were used to identify the biological reference points $F_{0.1}$ and to give indications of biological risk associated with different management options. The Total Allowable Catch for 1986 was estimated at180,000 tons (Prenski et al 1996)

The Patagonian toothfish (*Dissostichus eleginoides*) distributes between 36°30' S and 55°S, at depth ranging between 80 and 1800 m (Fig. 7). Greatest concentrations areas are located to the South and NE of Malvinas Islands, East of Burdword Bank and on the continental slope off Buenos Aires, with bottom temperatures ranging between 2°C and 12°C. Most of the specimens of sizes over 80 cm (the length of first maturity) are found at depths over 1000 m. Spawning seems to take place in deep waters. The main food items of adult specimens are also deep-water fish as granadier fish and blue whiting, and squid.

The kinglip (*Genypterus blacodes*) is distributed over the continental shelf and slope between 34°S to 55°S and bottom depths between 45 and 300 m .During winter and spring large concentrations have been registered between 40° and 48° S, mostly over the continental slope. In summer, they occur between 44° and 48°S, with a coastwards shift in relation to previous seasons. Reported temperature and salinity ranges of the species are 4-15°C and 32-35 psu, respectively.

Age determination shows that the species can reach 23 years. It feeds on demersal and benthic fish, such as notothenids, hake, salilota and several species of benthic crustaceans. The species reaches a maximum length of 143 cm. First sexual maturity occurs at 70 cm. Spawning takes place in summer at 46°S along the 100 m depth contour. Nursery grounds are located in the area of El Rincón, to the SE of Peninsula Valdés and in Gulf San Jorge. The species biomass has been recently estimated at 156,220 t. Kinglip is caught by demersal trawlers, as by catch of the hake fisheries. Abadejo targeted fishing is carried out by the use of bottom long-line, the most adequate gear in view of bottom irregularities where adults aggregate. According to fishing statistics over the period 1990-94, highest contribution of long-liners to over all landings corresponded to 1994, when they reached 17%. The most important fishing grounds are located between 43°- 49°S latitude and 60° - 64°W longitude.

The grenadier *(Macrourus whitsoni)* is a cold-water shelf-break species that extends to greater depths, particularly in winter to the north of the study area, where the species is more abundant and covers a wider bathymetric range

Table 1 :Estimated abundances of commercial species and proportion of them corresponding to the shelf-break region and adjacent waters.

Species	TOTAL BIOMASS ESTIMATES (1994/1995) <u>Data source</u>: INIDEP internal reports	% OF RESOURCES BETWEEN 41-48° S OUTSIDE THE 200 MILES LIMIT <u>Data source</u>: Inada *et al.*, (1983) and INIDEP internal reports	% OF RESOURCES IN WATERS DEEPER THAN 200 m <u>Data source</u>: INIDEP internal reports
Micromesistius australis	1200127.	0.9-12.2%	94-98%
Disosstichus eleginoides		1.7-15.9%	94-98%
Macrourus whitsoni		11.6-57.8%	97%
Merluccius australis	21150-32500	0%	95-98%
Merluccius hubbsi	1900000	2.1-6.2%	12%
Macruronus magellanicus	1425022	0.3-5%	4-7%
Salilota australis	278932	1.6-5%	6-9%
Genypterus blacodes	156220	3.1-7%	3-8%

Table 2 gives the changes in biomass of demersal fish species off southern Patagonia, from 46° to 55° over the last fifteen years. To put the values on a comparative basis, estimates have been standardized and are expressed as percent change from values of 1979. The observed fluctuations, show a progressive increase of hoki biomass, possibly due to a decrease in the species catches, intensive fishing on the species predators (austral hake, rays and sharks), and an growth on food availability due to intensified fishing on the southern bluen whiting and accompanying species. Also evident is a rise in the biomass of the nothotenid fish *Patagonothoten ramsayi* due to a decline of predators of the species, mainly *Salilota australis, Genypterus blacodes,* and *Merluccius hubbsi.*

Table 2. The fluctuation of demersal fish species off southern Patagonia relative to 1979 estimates.

YEAR	1979	1987	1992	1993	1994	1995
SEASON	SUMMER	SUMMER	SUMMER	SUMMER	SUMMER	SUMMER
Merluccius hubbsi	1	0.90	0.26	0.21	0.53	0.80
Macruronus magellanicus	1	0.93	1.42	1.45	1.07	1.59
Genypterus blacodes	1	0.33	0.33	0.47	0.51	0.27
Illex argentinus	1	0.29	0.96	0.46	0.38	-
Loligo gahi	1	0.52	5.17	13.20	21.88	-
Micromesistius australis	1	0.02	0.1	0.07	0.03	0.06
Salilota australis	1	0.82	0.28	0.89	0.25	0.25
Merluccius australis	1	0.82	0.28	0.89	0.25	0.25
Dissostichus eleginoides	1	0.59	0.68	0.48	0.29	-
Stromateus brasiliensis	1	2.16	0.72	1.26	0.96	-
Squalus acanthias	1	4.91	4.04	2.74	6.57	3.79
Schroedericthys bivius	1	0.55	0.36	0.65	1.75	-
Congiopodus peruvianus	1	1.82	0.79	1.45	1.36	-
Cottoperca gobio	1	0.91	2.44	2.39	5.76	-
Sebastes oculatus	1	2.38	2.03	6.68	13.68	-
Patagonothoten ramsayi	1	2.41	27.68	27.58	35.70	-

ECONOMIC INCIDENCE OF OUTER SHELF AND CONTINENTAL SLOPE FISHERIES

In 1995, the total catches of Argentina exceeded one million tons. Of the species analyzed, eight (Table 3, Fig. 8) show commercial catches (*Genypterus blacodes, Salilota australis, Merluccius hubssi, M. australis, Macruronus magellanicus, Dissostichus eleginoides, Micromesistius australis* and *Illex argentinus*). This group contributed to 86.6 of total catches in 1993, 81.4% in 1994 and 82.3% in 1995. Over 69% of all catches were conducted on the continental shelf and 30.3% on the slope region (Table 3)

The sustained increase (108%) of Argentine catches over the period 1990-1995, was the result of an expansion of the investments on the industrial fleet, particularly with the incorporation of twenty-five long-liners designed to catch kingklip and Patagonian tooth fish, 88 jiggers incorporated to the squid fishery, and 5 vessels that catch and process blue whiting, hoki and accompanying species to produce surimi. This type of vessel, with a gross tonnage of 71,363, did not exist prior to 1989.

Table 3. The contribution of the continental slope to catch volumes of different species

	1993		1994		1995		January- June 1996	
	TOTAL CATCH (kg)	SLOPE CATCH (kg)	TOTAL CATCH (kg)	SLOPE CATCH (kg)	TOTAL CATCH (kg)	SLOPE CATCH (kg)	TOTAL CATCH (kg)	SLOPE CATCH (kg)
Micromesistius australis	109829228	102454668	86084323	83220338	104208094	101980870	23849482	22373066
Dissostichus eleginoides	3650826	3575617	10840181	9217396	20005795	11889474	8242217	5824789
Merluccius australis	3026071	2228967	1649628	1075605	3899018	2603342	1728280	1129558
Macruronus magellanicus	39373248	27972747	17251074	7412987	22796268	10876507	11475345	4003483
Illex argentinus	194031852	70926391	191757334	33212468	186807899	109252700	146028216	89368158
Merluccius hubbsi	422194604	44222765	435788234	30264776	574313880	70049698	209738165	23338543
Genypterus blacodes	23787969	4558846	20337681	2526073	23264942	4921799	16806768	1767894
Salilota australis	0	0	0	0	0	0	377948	80364
8 major commercial spp.	795893798	255940001	763708455	166929643	935295896	311574390	418246421	147885855
TOTAL CATCH	919503200		938601900		1136898700			

The incorporation of these vessels was preceded by the elaboration of a body of legislation for the appoval of projects and the regulation of the granting of fishing licenses. The basic principles for resource exploitation were established, determining the access to the fishing grounds, quotas and measurements to secure the preservation of the species. The expansion was also accompanied by investment on fish plants, development of market infrastructure, communication and transport.

Argentine fish products reached in 1995 a value of 1055 million U$S. Argentina is a typically exporting country. The domestic market absorbs only 15% of total production. The eight species analyzed represented, as an average during 1993-1996, 69.4% of total fish production. The contribution of the slope region to the total production of Argentina, may be estimated at 15.8% to 39.8% (Table 4, Fig. 9). This variation is associated to the abundance and catches of squid on the continental slope.

Table 4. Economic incidence of catches on the shelf-break

U$S	1993	1994	1995	January- June 1996
Total value of fishery products	725.086.072	827.471.183	1.055.877.544	648.640.835
Contribution of 8 major commercial spp.	488.749.937	560.761.834	792.214.096	419.432.363
Continental Slope contribution	146.649.105	130.769.258	333.239.817	257.952.134

The presence of international fleeets operating in the slope region has a two-fold influence on Argentine economy: It affects directly by exerting an enhanced fishing pressure on the fishery, and indirectly by increasing the offer, in the international markets, of the same products exported by Argentina.

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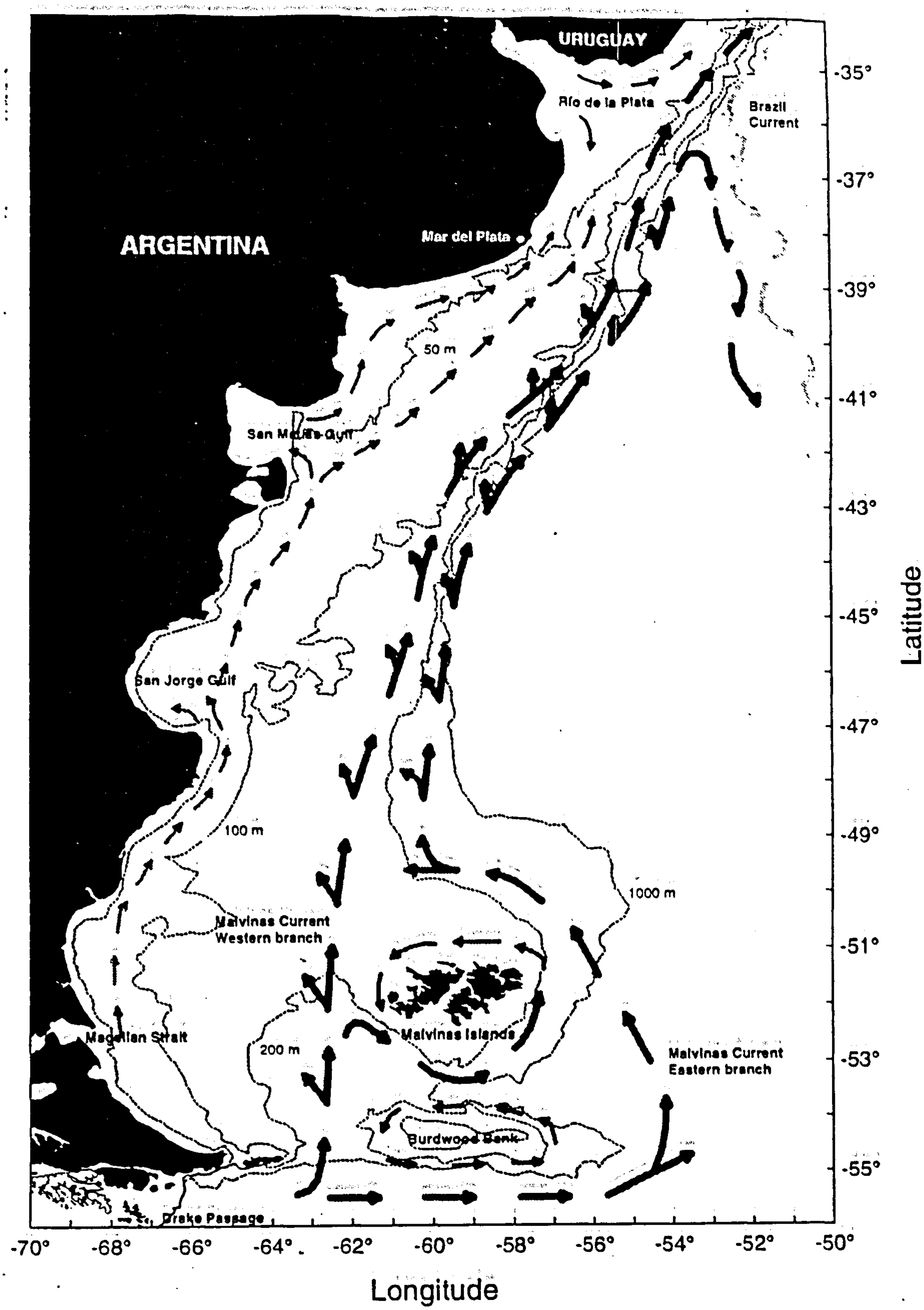


Figure 1. Water masses circulation on the Argentine shelf and shelf break regions

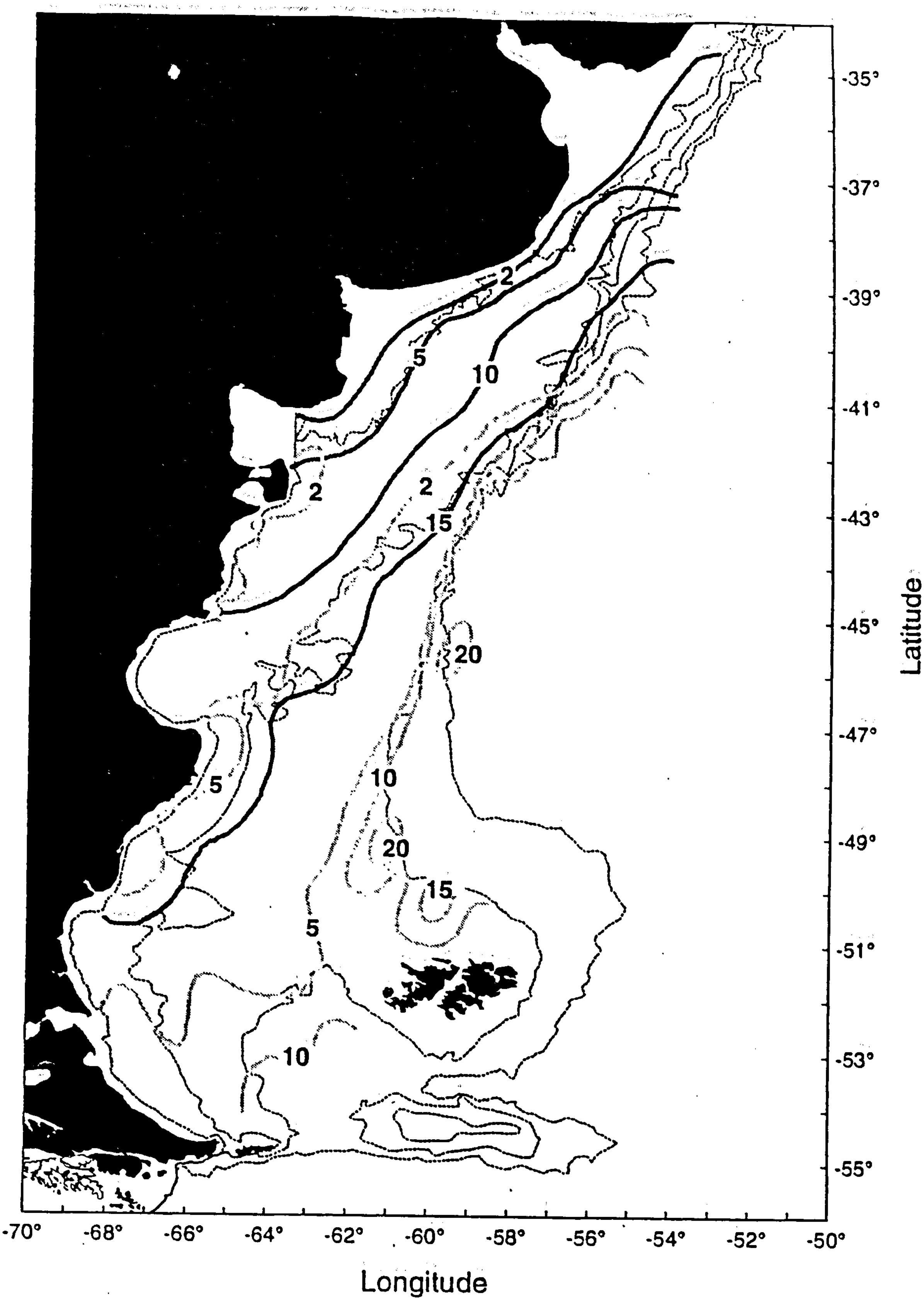


Figure 2. Surface nitrate distribution (μM) during summer (······) and winter (———). (Redrawn from Brandhorst and Castello, 1971)

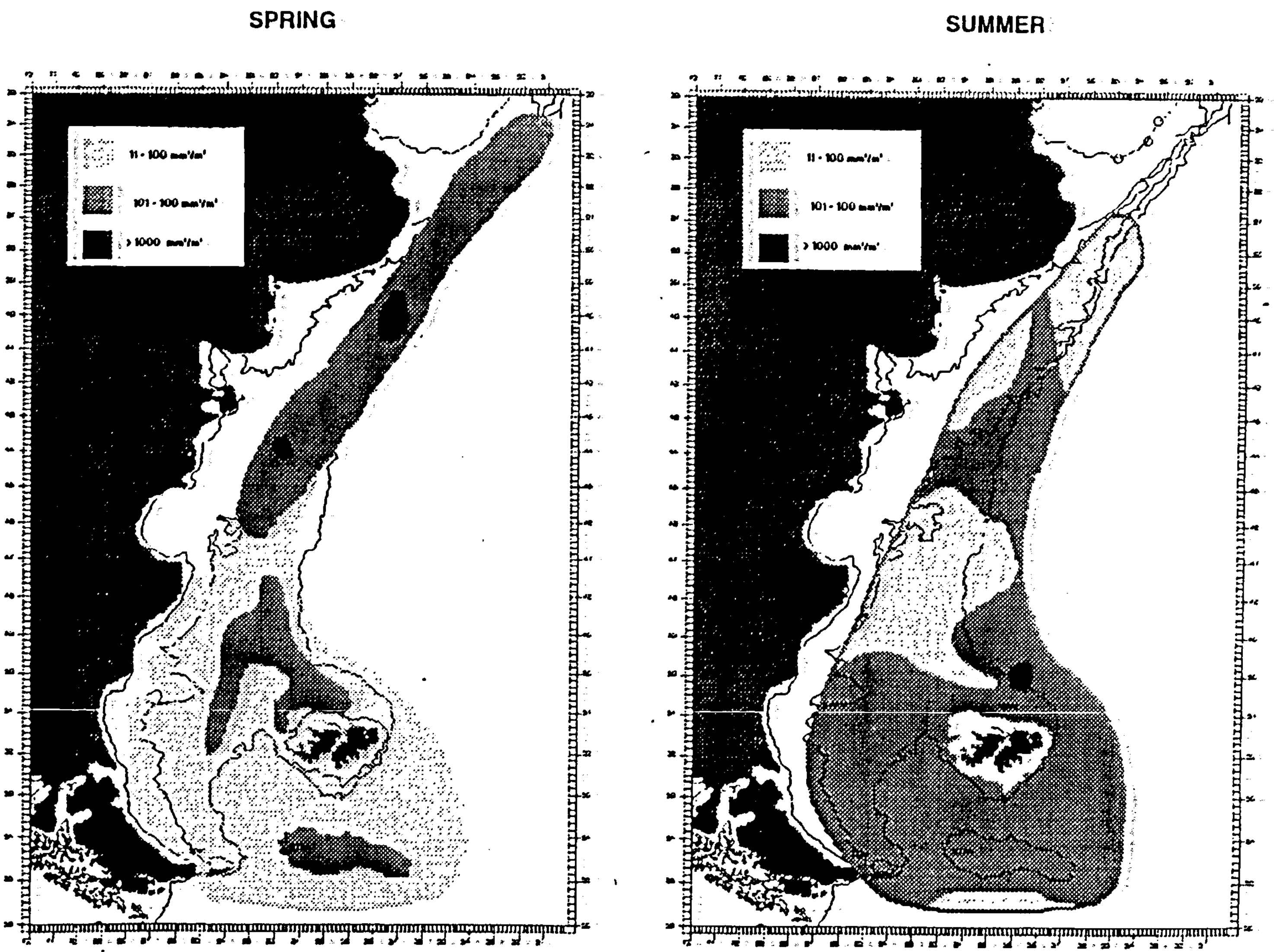


Figure 3. Zooplankton abundance in spring and summer (Redrawn from Ciechomski and Sánchez, 1983)

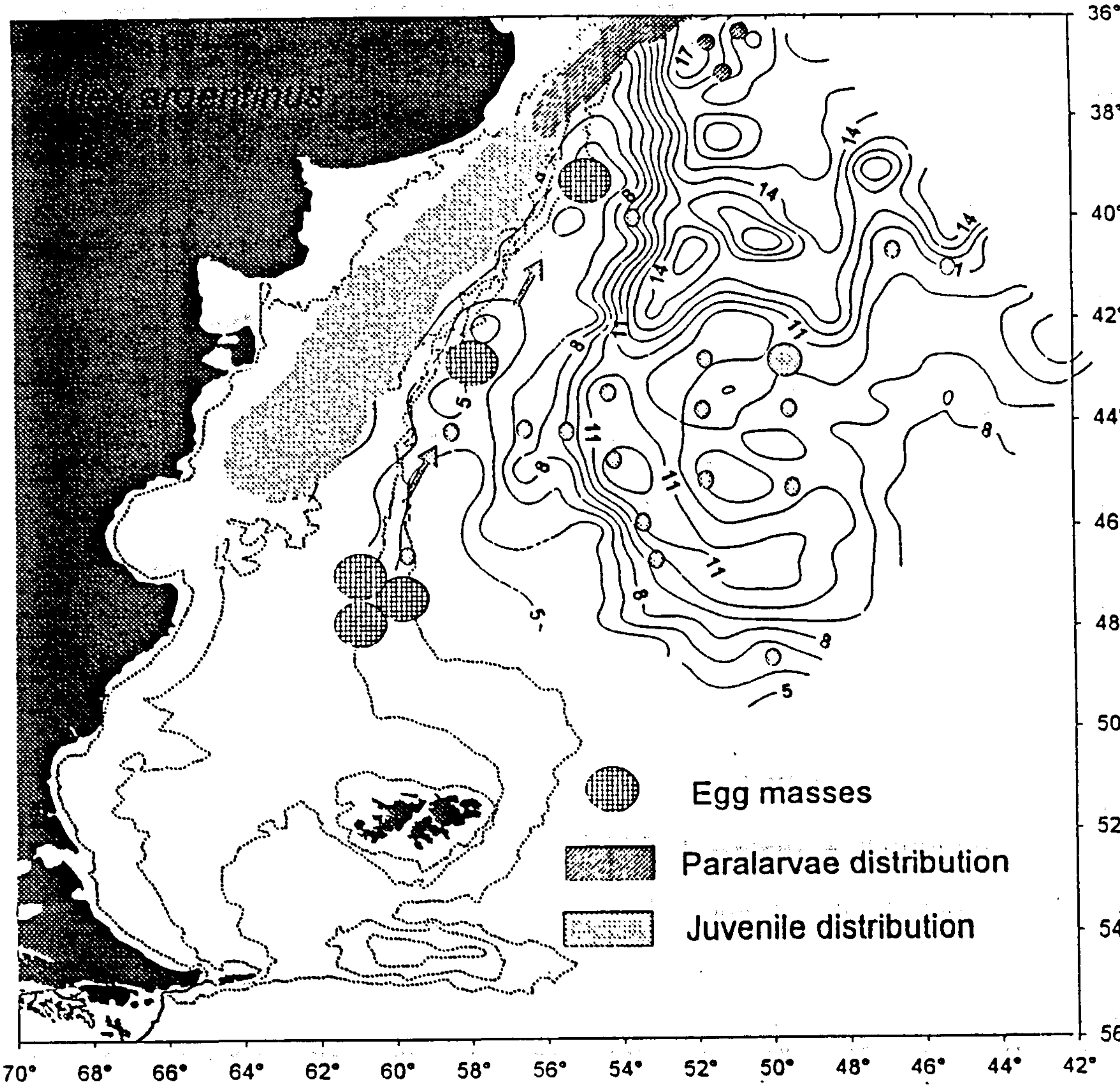


Figure 4. Distribution of egg masses, paralarvae and juveniles of *Illex argentinus* and surface temperatures.

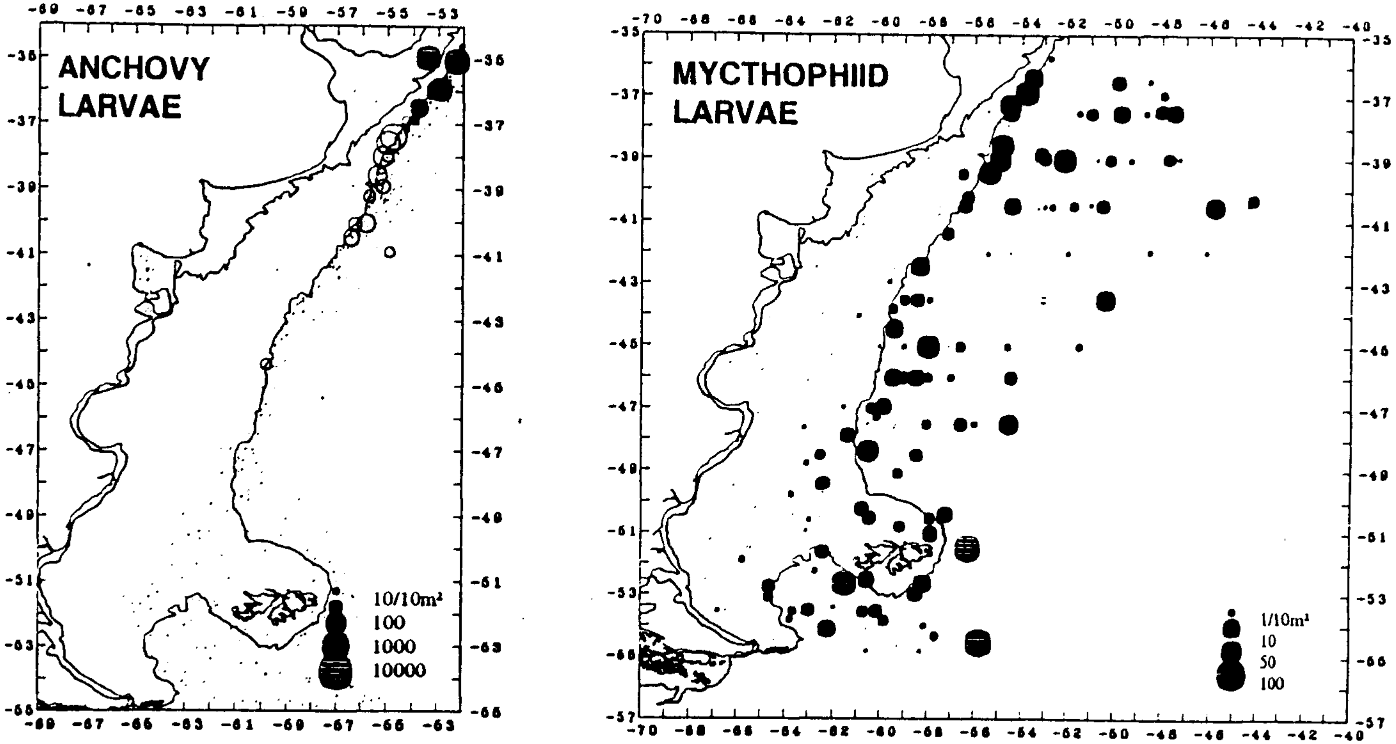


Figure 5. Occurrence of anchovy larvae on the shelf-break in Spring-Summer (open circles) and Autumn-Winter (solid circles). Occurrence of myctophiid larvae on the continental slope and Argentine Basin.

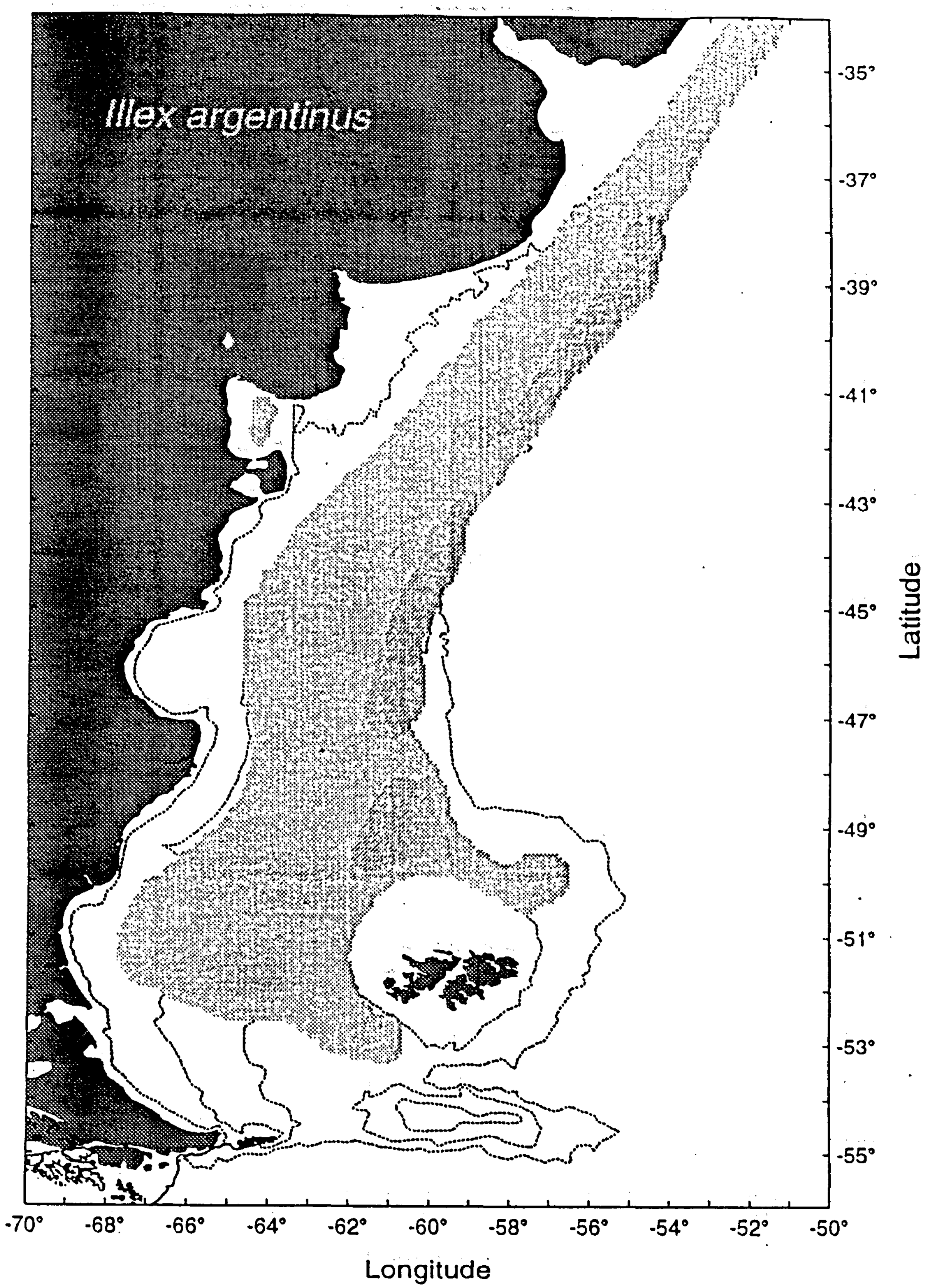
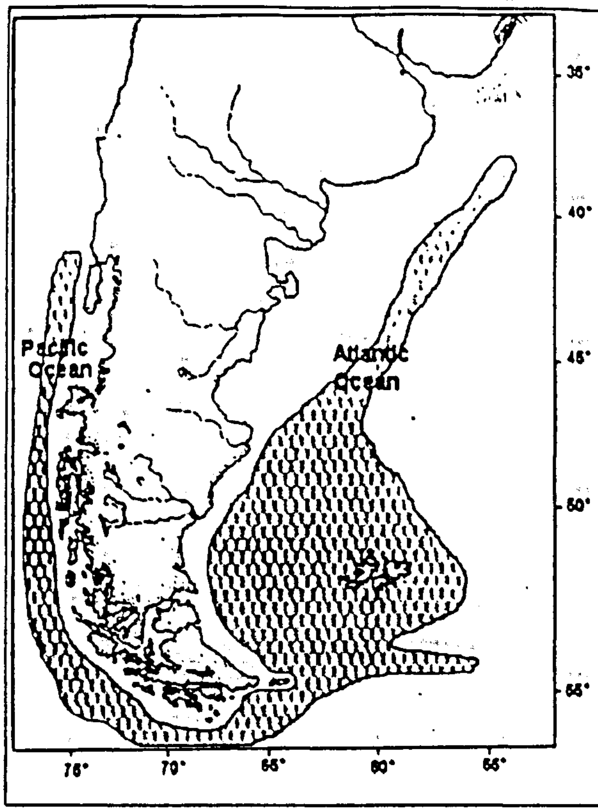
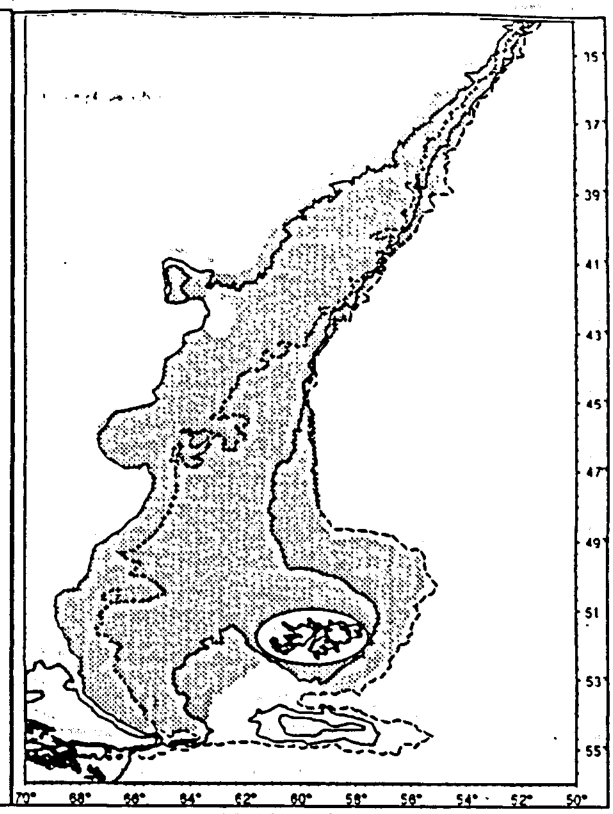


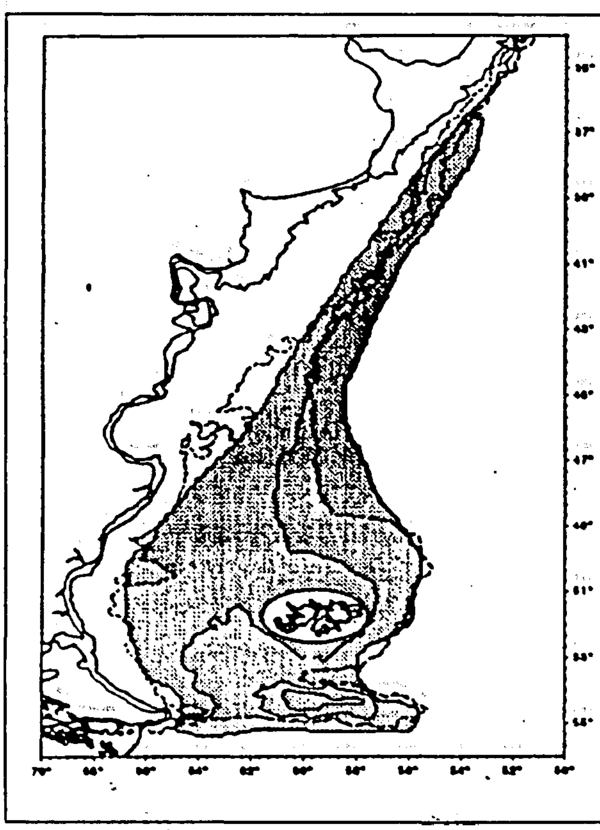
Figure 6. Autumn-winter distribution of *Illex argentinus*



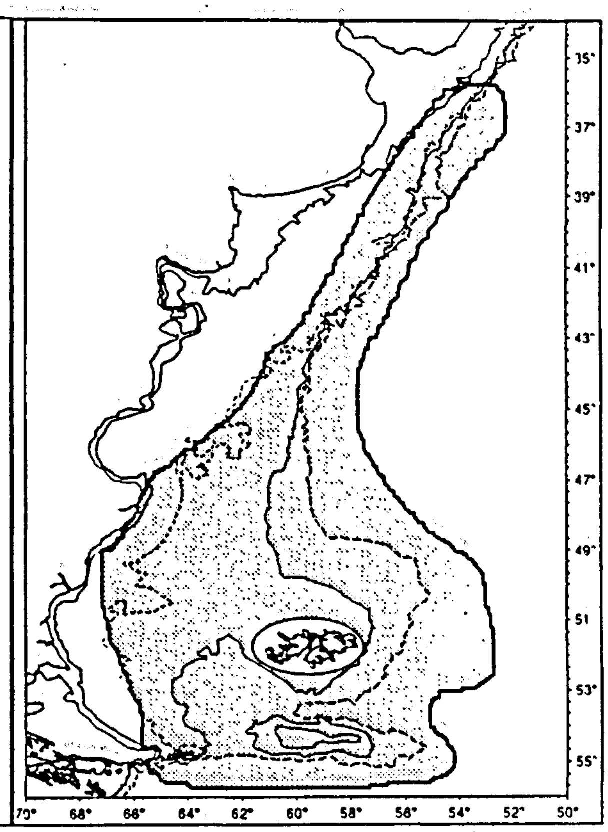
Macruronus magellanicus



Merluccius hubbsi



Micromesistius Australis



Disosstichus eleginoides

Figure 7. Distribution of important fish resources along the shelf-break and southern Patagonian shelf

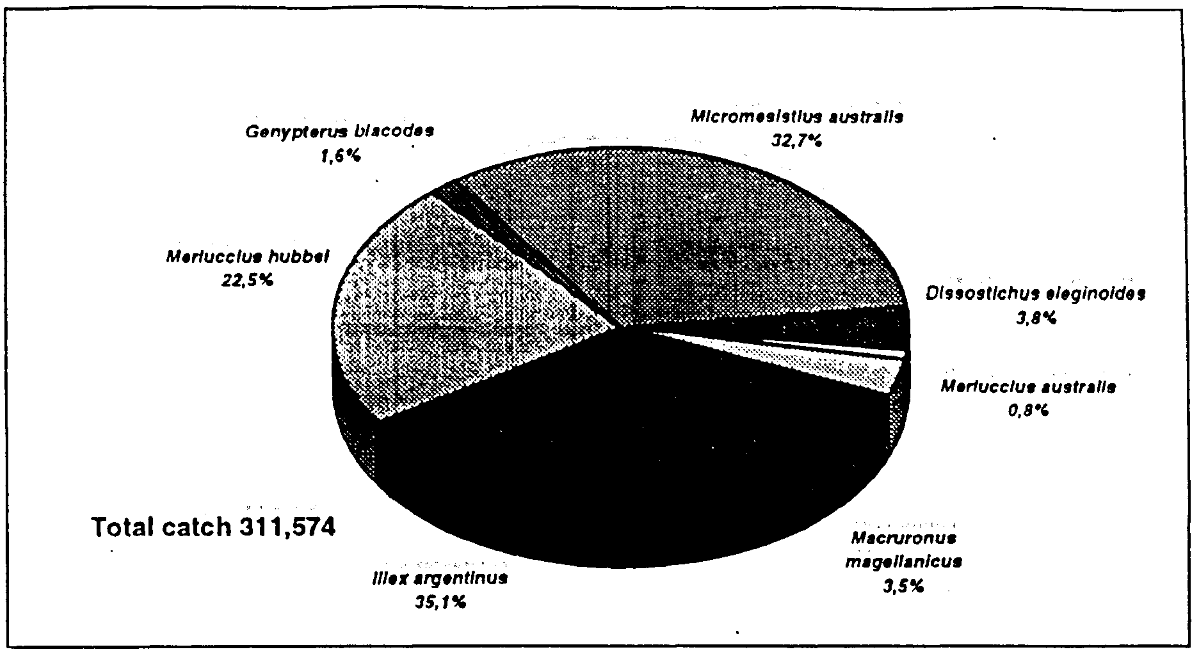


Figure 8. Percent catches of different species in the continental slope in 1995

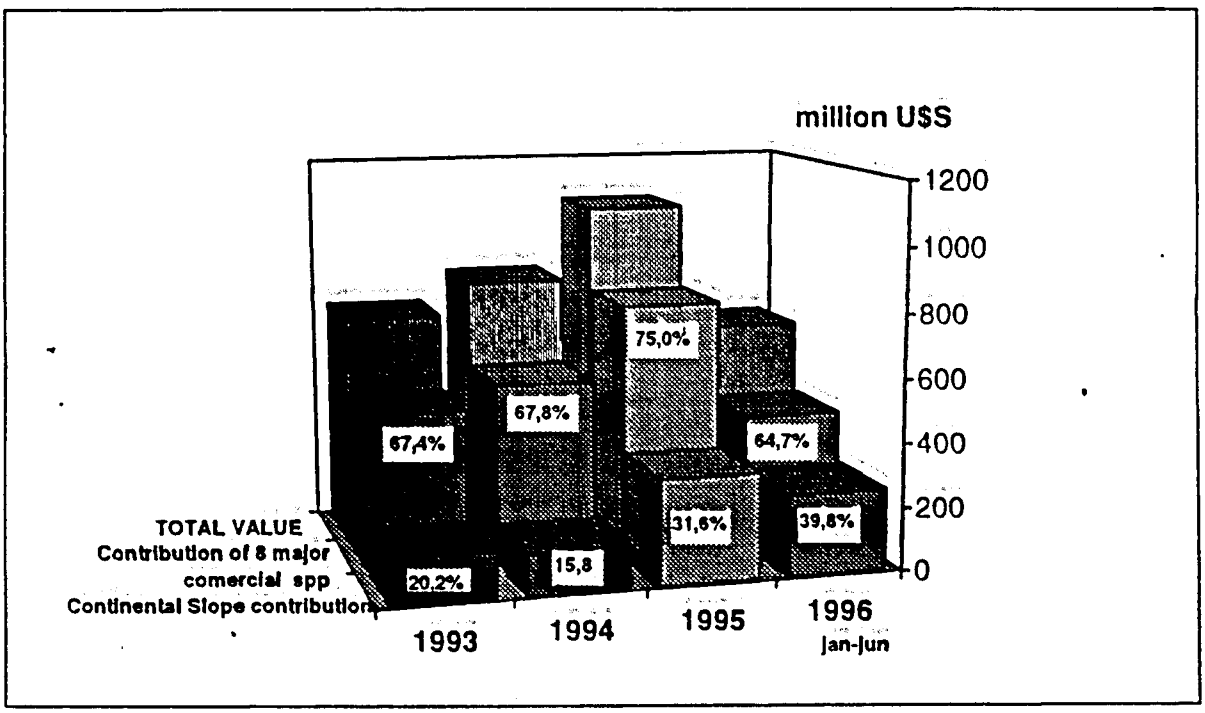


Figure 9. Total value of fishery products (in U$S).