REVISIÓN

BIOLOGY AND FISHERY OF THE SOUTHERN HAKE (*Merluccius australis*) IN THE SOUTHWEST ATLANTIC OCEAN*

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SUMMARY. Southern hake (*Merluccius australis*) is distributed mainly south of 50° S around South America, occurring in cold temperate waters of subantarctic origin. In the Southwest Atlantic Ocean (SAO) only adults are abundant. This species is ichthyophagous and malacophagous, feeding mainly on long tail hake (*Macruronus magellanicus*) and several cephalopods (*Illex argentinus*, *Onykia ingens*, *Doryteuthis gahi*). Age and growth studies show significant sexual differences; females grow to a larger size than males. In recent years, the highest biomasses, estimated from trawl surveys using the swept area method, are about 10,000 t. Fish 4 to 8 years old usually dominate commercial landings. Only a few factory trawler vessels have southern hake as a target species. They operate over the main fishing grounds located near Tierra del Fuego and at the eastern mouth of the Beagle Channel. Average annual landings are about 5,000 t.

Key words: *Merluccius australis*, Southern hake, SAO, biology, catches, fishery.

BIOLOGÍA Y PESQUERÍA DE LA MERLUZA AUSTRAL (*Merluccius australis*) EN EL OCÉANO ATLÁNTICO SUDOCCIDENTAL

RESUMEN. La merluza austral (*Merluccius australis*) se distribuye principalmente al sur de los 50° S alrededor de América del Sur, encontrándose en aguas templado-frías de origen subantártico. En el Océano Atlántico Sudoccidental (OAS), solo los adultos son abundantes. Esta especie es ictiófaga y malacófaga, y se alimenta principalmente de la merluza de cola (*Macruronus magellanicus*) y de varias especies de cefalópodos (*Illex argentinus*, *Onykia ingens*, *Doryteuthis gahi*). Los estudios de edad y crecimiento indican la presencia de diferencias significativas entre sexos, siendo las hembras mayores que los machos. En los últimos años, las biomasas más altas estimadas por el método de área barrida, se encontraron alrededor de las 10.000 t. Las capturas se encuentran principalmente integradas por individuos de 4 a 8 años de edad y solo unos pocos buques factoría arrastreros capturan a la merluza austral como especie objetivo. Dichos buques operan en los principales caladeros, próximos a Tierra del Fuego y a la entrada este del Canal Beagle. Los desembarques promedios anuales se encuentran cercanos a las 5.000 t.

Palabras clave: *Merluccius australis*, merluza austral, OAS, biología, capturas, pesquería.

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INTRODUCTION

Representatives of Genus *Merluccius* are highly abundant in the Southwest Atlantic Ocean (SAO). The two occurring species, *M. australis* and *M. hubbsi*, show remarkable morphological similarities, making their identification difficult in areas where they occur together. While the distribution areas of the two species are contiguous, in the absence of oceanographic barriers, their separation is likely related to a combination of factors such as food availability and physiological adaptability to different water masses (Giussi *et al*., 2005).

In the Argentine Sea, the Southern hake (*M. australis*) more abundant schools are present from 52° S southwards. Population structure data suggests that these individuals could be related to the main stock that inhabits in the Pacific Ocean (Aguayo-Hernández, 1995; Bezzi *et al.*, 1995). Probably this species could be endemic to Pacific waters that colonized the SAO region in recent geologic times (Cousseau, 1993). It is likely that the ability of the species to disperse from the Pacific Ocean was somehow restricted at some point, and later it occupied an ecological niche in the Atlantic that was suitable to its requirements. Competition with other species and the absence of appropriate spawning and nursery grounds may have also limited its expansion (Aguayo-Hernández, 1995; Giussi *et al.*, 2005).

TAXONOMY

M. australis has several synonyms (Cousseau, 1993). Hutton (1872) was the first to describe the species from samples collected in New Zealand waters naming it *Gadus australis*. Günther (1887) classified individuals from the Strait of Magellan into the current genus under the name *M. gayi*. Norman (1937) compared individuals from both areas and concluded that they were the same species, giving it its present designation, *M. australis*. Some authors (Ciechomski and Weiss, 1974; Cousseau and Cotrina, 1981) referred to the species as *M. polylepis*, which at present is considered an obsolete designation.

PHYSICAL ENVIRONMENT

The water circulation over the Patagonian shelf region (Figure 1) depends on various factors such as local winds, tide wave propagation, fresh water discharge and the influence of the deep currents (Guerrero and Piola, 1997, Sabatini *et al*., 2004).

The water mass of the Patagonian shelf is influenced by the Antarctic Circumpolar Current which gives special characteristics to the region. After reaching the Drake Passage it divides into two principal branches. One branch flows between Tierra del Fuego and Isla de los Estados through the Le Maire Strait, and it is known as the Cape Horn Current (Hart, 1946; Boltovskoy, 1970). The other branch is the Malvinas Current, which divides into an eastern and western branch when it reaches the Burdwood Bank. While the waters of the western branch are diluted significantly by continental runoff and ice melting (Lusquiños and Valdés, 1971; Piola and Gordon, 1989; Piola and Rivas, 1997; Guerrero *et al*., 1999), the eastern waters are denser and move northward along the border of the continental slope, showing higher salinity and lower average temperature.

The other water mass called the Patagonian Current flows northward along the coast. This includes the contribution from continental rivers and also diluted water from the Strait of Magellan. Local precipitation in the Southwest Pacific (with annual means greater than 5,000 mm) and the seasonal melting of glaciers reduce salinity in this region (Sabatini *et al*., 2004).

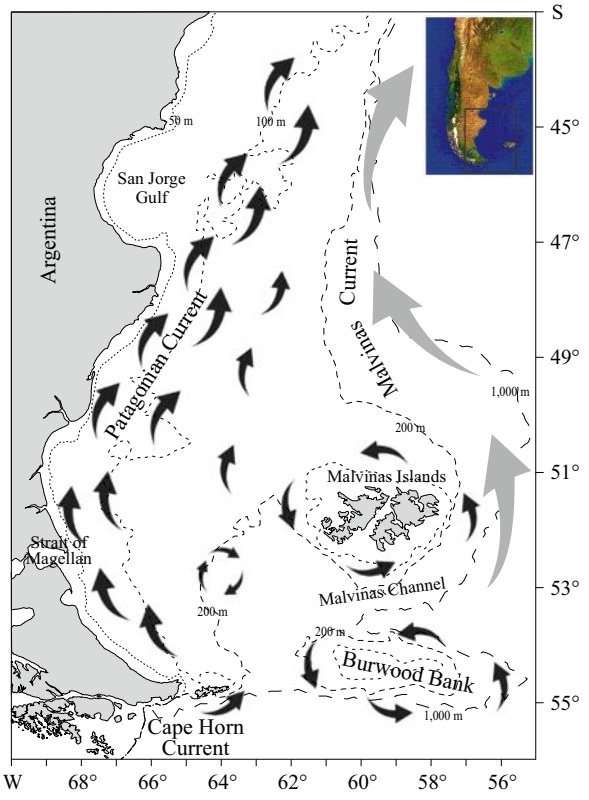

Figure 1. General scheme of the water masses and current circulation on the Patagonian shelf. Taken and modified from Sabatini *et al*. (2004).

Figura 1. Esquema general de las masas de agua y circulación de las corrientes marinas en la plataforma patagónica. Tomado y modificado de Sabatini et al. (2004).

GEOGRAPHIC DISTRIBUTION

Like other merluccid hake, Southern hake has a wide distribution. It occurs in both the Atlantic and Pacific Oceans surrounding the southern tip of South America, and it is also present in New Zealand waters (Aguayo-Hernández, 1995; Bezzi *et al*., 1995; Horn, 2015). In the Atlantic Ocean (Figure 2) it is distributed south of 50° S down to the Cape Horn (56° S), extending into the Pacific Ocean through the Drake Passage (García de la Rosa *et al*., 1997). Cotrina (1981) and Otero *et al*.

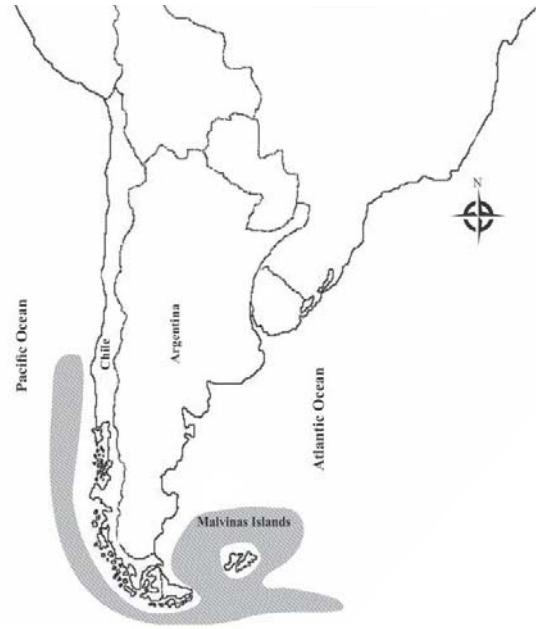

Figure 2. The geographical distribution of *Merluccius australis* around Southern South America.

Figura 2. Área de distribución geográfica de Merluccius australis *en el extremo sur de América del Sur.*

(1982) have reported lower latitudes for the northernmost limit of its distribution. However, because the species was only sporadically reported from these northern latitudes, it is likely that large-sized individuals of its congener *M. hubbsi* might have been misidentified.

Its vertical distribution is related to its demersal habits, and thus it is found near the seabed in depths from 100 m to > 1,000 m in cold waters of the Malvinas Current (Otero and Simonazzi, 1980), mainly at low temperature (3 to 9.5 °C) and high salinities (32.8 to 34.18) depending on the season (Wöhler, 1987; García de la Rosa *et al*., 1997; Giussi *et al*., 2005).

Relatively high densities have been found in waters at 52° S and > 150 m depth, with salinity ranging 33.5-33.8 and temperature values close to 8 °C (Figure 3). However, it also occurs frequently in slope waters at 34.0 salinity and 6 °C average temperature. Waters of the Patagonian Current and those related to the continental slope

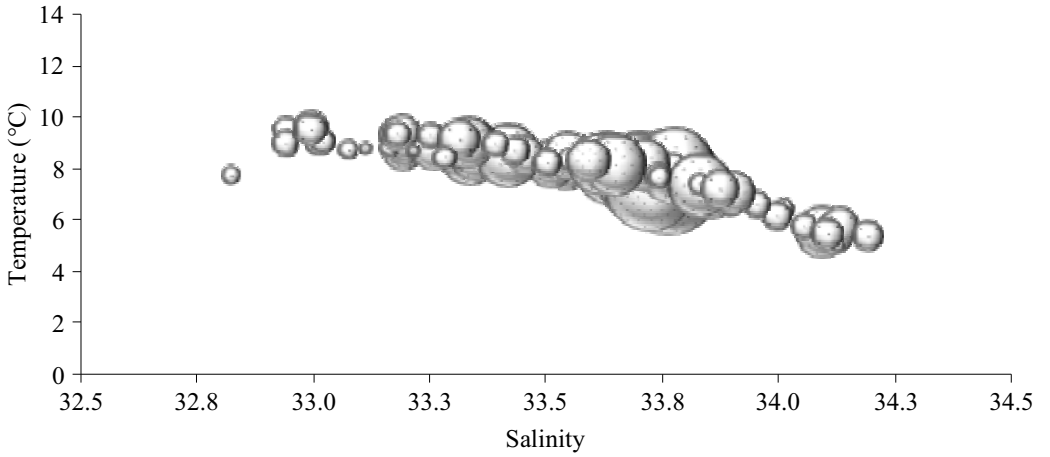

Figure 3. Density (t nm^{-2}) of *Merluccius australis* in relation to both bottom temperature and salinity. Redrawn from Giussi *et al*. (2005).

Figura 3. Densidad (t nm^{-2}) de Merluccius australis *en relación con la temperatura y la salinidad de fondo. Redibujado de Giussi et al. (2005).*

are both suitable habitats for the southern hake from their perspective of salinity and temperature, but they are sporadically visited by the species, probably related to the availability of preys (Marí and Sánchez, 2002; Sánchez and Marí, 2005; Giussi *et al*., 2005).

BIOLOGY AND LIFE HISTORY

Age and growth

Age is derived from counts of zones in the *sagittae* otoliths. These otoliths are thin and oblong, with a prominent rostrum and toothed edges on the dorsal and ventral borders. In the ventral zone there is a longitudinal depression flanked by an inferior and a superior crest, which extends parallel to the main axis of the structure; this is called the *sulcus acusticus* (Figure 4).

Otoliths are processed using standard techniques widely used for merluccids and other species (Christensen, 1964), although slightly modified by Gorini *et al.* (2010). Otoliths are first baked to enhance growth zones, then embedded in resin and transversally cut with a diamond-tipped saw. This method enables more precise sectioning through the nucleus, resulting in less bias in counts and the best definition of the marginal increments (Figure 5). The maximum ages recorded for males and females were 14 and 18 years, respectively, while the minimum was 3 years old (Gorini *et al.*, 2010).

The growth in length of the Southern hake has been adequately fitted using the von Bertalanffy (1938) model, and revealed differences between sexes (Gorini *et al*., 2010). Males have a growth rate parameter (K) notably higher than females, although their asymptotic length (L_∞) is lower:

$$\text{Males TL} = 82.05 \text{ cm } (1 - e^{-0.277\,(t - 0.9929)})$$

$$\text{Females TL} = 100.19 \text{ cm } (1 - e^{-0.137\,(t + 1.137)})$$

Length-weight relationship

The relationship between total length and weight was estimated as:

$$W = 0.0029 * TL^{3.2007} \qquad R^2 = 0.9478$$

Due to the incomplete population structure of southern hake in the SAO, data from several years were used to fit this equation. But first, linear regressions between length and weight were estimated for each year, and their slopes were compared by multiple Tukey-Kramer tests (Zar, 1999). There were no statistically significant between-year differences, thus allowing the estimation of a single equation.

Natural mortality

Instantaneous rate of natural mortality (M) was estimated using different equations that consider growth parameters as well as abiotic variables (Pauly, 1980; Jensen, 1996). The M values for both sexes pooled were 0.19 and 0.18 year^{-1}, depending on the methodology applied:

- Pauly (1980):

$$\log M = -0.0066 - 0.279 \log 102.03 + 0.6543 \log 0.12 + 0.4634 \log 9$$

- Jensen (1996):

$$M = 1.5*0.12$$

These values were similar to the ones compiled by Horn (2015), for the New Zealand stock and those obtained by Quiroz *et al*. (2014) for the Chilean stock.

Feeding

M. australis is part of the demersal community acting as a macrophagous predator (Angelescu and Prenski, 1987). Being primary ichthyofagous and secondarily malacophagous, its trophic level is 4.50 (Wöhler *et al.*, 1999; Marí and Sánchez, 2002; Sánchez and Marí, 2005). Although the most important food items are gadiform species, especially long tail hake (*Macruronus magellanicus*, 55% frequency) and Southern blue whiting

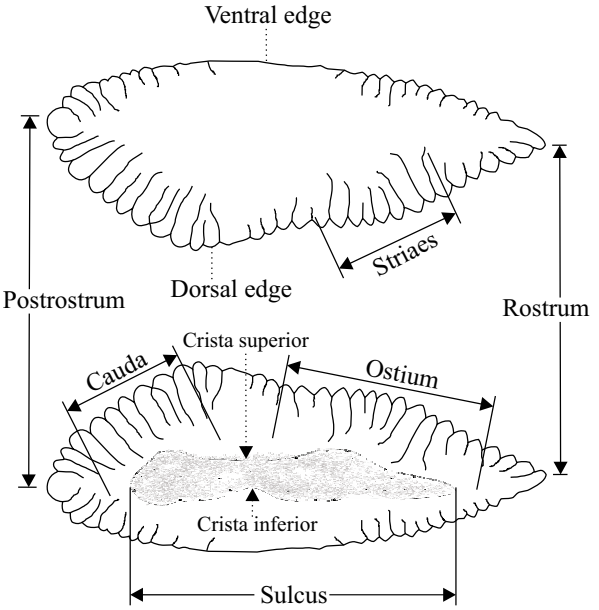

Figure 4. *Sagitta* otolith of *Merluccius australis*.
Figura 4. *Otolito sagitta de* Merluccius australis.

(*Micromesistius australis*, 18% frequency), other fishes are also ingested sporadically depending on their seasonal availability in the area. Cephalopods such as *Illex argentinus*, *Doryteuthis gahi*, *Onykia ingens* and *Eledone* sp. (6-12% frequency) are secondary prey, while macrocrustaceans such as *Austropandalus grayi* and *Eufausia lucens* (Marí and Sánchez, 2002; Sánchez and Marí, 2005) and the salp, *Ihlea magalhanica* (Thaliaceae), are occasional items in the diet. Both sexes have a similar diet (Table 1; Figure 6).

Parasitism

Both myxosporids and cestodes parasitize Southern hake in the Atlantic Ocean. Among the former, *Alatospora merluccii* n. sp. and *Myxidium baueri* Kovaleva and Gaevskaya 1982 have been found in the gall bladders (Kalavati *et al*., 1995), while the cestode *Clestobothrium splendidum* sp. n. (Gil de Pertierra *et al*., 2011) has been found in the intestine.

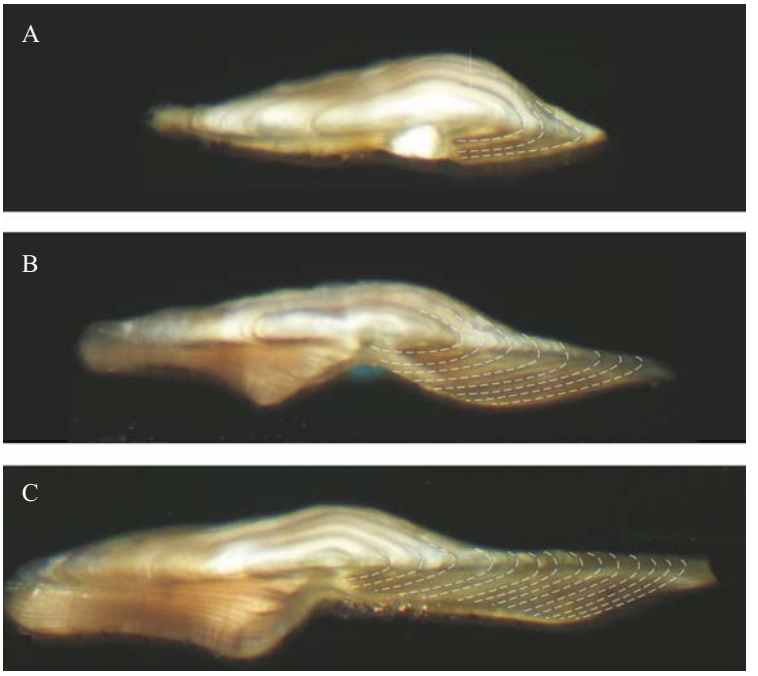

Figure 5. *Merluccius australis* otolith transverse sections, observed with stereoscopic microscopic at 10X magnification, showing the translucent zones. A) 44 cm total length (TL), 3 zones. B) 69 cm TL, 8 zones. C) 83 cm TL, 14 zones. Taken and modified from Gorini *et al*. (2010).

Figura 5. Secciones transversales del otolito de Merluccius australis*, observadas con microscopio estereoscópico y un aumento de 10X. Se identifican los anillos hialinos. A) 44 cm de longitud total (LT), 3 anillos. B) 69 cm LT, 8 anillos. C) 83 cm LT, 14 anillos. Tomado y modificado de Gorini et al. (2010).*

Table 1. Food items found in stomach contents of *Merluccius australis*.
Tabla 1. Ítems presa encontrados en los contenidos estomacales de Merluccius australis*.*

Phylum	Class	Family	Species/genus	Common name
Vertebrata	Osteichthyes	Macruridae	*Macruronus magellanicus*	Long tail hake
		Gadidae	*Micromesistius australis*	Southern blue whiting
		Notothenidae	*Patagonotothen ramsayi*	Nototheniids
		Moridae	*Salilota australis*	Red cod
		Merlucciidae	*Merluccius hubbsi*	Argentine hake
Mollusca	Cephalopoda	Ommastrephidae	*Illex argentinus*	Argentine shortfin squid
		Loliginidae	*Dorytheutis gahi*	Patagonian squid
		Onychoteuthidae	*Onykia ingens*	Greater hooked squid
		Eledonidae	*Eledone* sp.	Musky octopus
Crustacea	Malacostraca	Pandalidae	*Austropandalus grayi*	
		Eufausiidae	*Eufausia lucens*	Krill
Tunicata	Thaliacea	Salpidae	*Ihlea magalhanica*	Salps

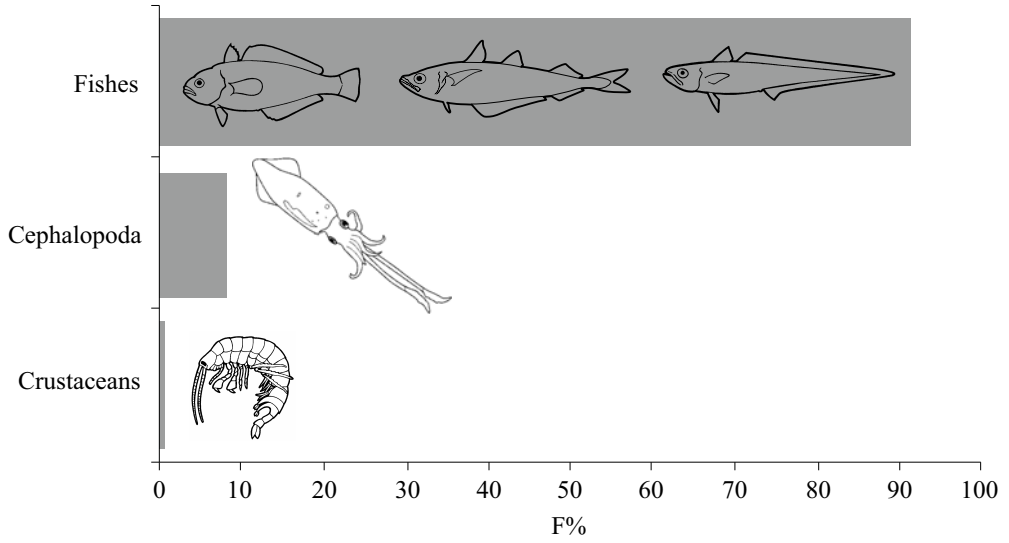

Figure 6. *Merluccius australis* trophic spectrum (%F) in the Southwest Atlantic Ocean.
Figura 6. Espectro trófico (%F) de Merluccius australis *en el Océano Atlántico Sudoccidental.*

Reproduction

There is little information about the southern hake reproductive biology in the Southwest Atlantic. This is mainly due to the relatively low abundance of this species in this region –particularly of juveniles–, and the lack of evidence for a well-defined spawning season and area.

Some histological studies suggest that spawning may occur between July and September over the continental shelf (Cotrina, 1981). However, Ciechomski *et al*. (1975), using postlarvae length and histological methods, concluded that spawning would take place between October and November near the Malvinas Islands.

Ciechomski and Weiss (1974) described the larvae and postlarvae of the species from specimens caught over the shelf off Tierra del Fuego and the southwestern coast of the Malvinas Islands. These authors emphasized the morphological similarity observed with its congener *M. hubbsi* in many aspects. Differences between the two species were found in the pigmentation, body proportions, ossification rate, and formation of the caudal fin (Figure 7).

The length at sexual maturity ($TL_{50\%}$) estimated for the two sexes combined is 59.5 cm total length (TL) (Figure 8), corresponding to an age of 4.5 years old (Gorini *et al*., 2012). These estimates were obtained from the macroscopic observation of the gonads, using the same 5 stages maturity scale as applied in reproductive studies of *M. hubbsi* (Macchi and Pájaro, 2003). When ovaries become opaque and show evidence of spawning but with many yolked oocytes (from stage 2 onward) individuals were considered mature.

FISHERY

Yields and abundance estimates

An abundance index for the Southern hake in the Southwestern Atlantic was obtained directly from trawl surveys using the swept area method (Alverson and Pereyra, 1969) during the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP) annual assessment cruises in the region (Wöhler *et al*., 1999), carried out in summertime

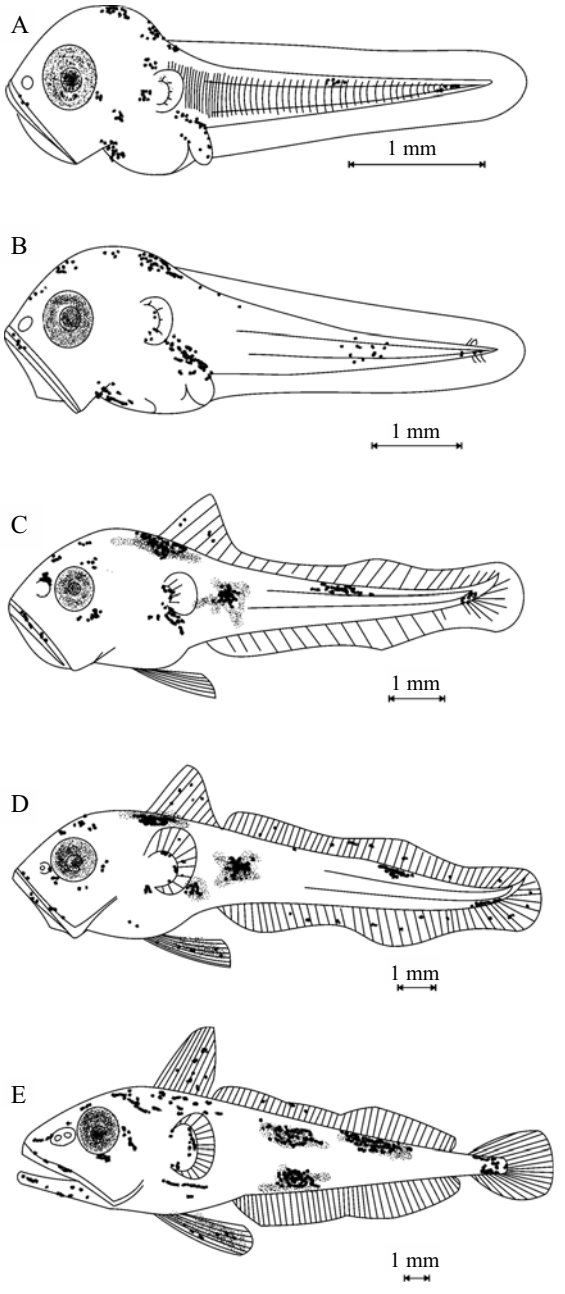

Figure 7. *Merluccius australis* postlarvae pigmentation. A) 4 mm. B) 6 mm. C) 10 mm. D) 17 mm. E) 25 mm. Taken and modified from Ciechomski and Weiss (1974).

Figura 7. Pigmentación de las postlarvas de Merluccius australis. *A) 4 mm; B) 6 mm; C) 10 mm; D) 17 mm; E) 25 mm. Tomado y modificado de Ciechomski y Weiss (1974).*

from 1992 to 2009. These estimates may be biased however, because of the surveys cover only a part of the total distribution area (Figure 9), and do not include the higher latitudes where the largest fishing yields are obtained. In view of these difficulties, the catches per unit effort (CPUE) were used to produce an alternative series of relative abundance indices. Both abundance series showed a clear tendency of decreasing biomass through the period 1997-2010, although some variability was observed, particularly from 1997 to 2001. The trend shown by the CPUE index was similar to the one obtained from data collected during the assessment surveys (Figure 10).

The stock assessment was performed using a statistical catch-at-age model (Giussi and Zavatteri, 2016) implemented in the AD Model Builder platform (Fournier *et al*., 2012). The model was tuned with the annual catch data, catch-at-age compositions and the abundance index (CPUE) derived using data obtained from the commercial fleet in the period 1992-2015. The assessment comprised 30 years, from 1986 to 2015 and two models were evaluated considering two different values of M due to the stock dynamic of Southern hake in SAO is not completely understood. Both models denoted spawning stock is currently over 30% SB_0, considering SB_0 as the first year of diagnosis (1986) nearly to the unfished status. A strong decrease in abundance was observed at the beginning of the period, probably related to the fishing pressure over the stock (Figure 11).

Although a similar trend was observed in the stock distributed in the Pacific Ocean (Quiroz *et al*., 2013), the absolute abundance of the SAO stock was estimated to be only arround one-tenth of the Pacific stock (Giussi *et al*., 2016).

Commercial catches

Historically, commercial catches of *M. australis* have been low in comparison to other finfish species occurring in the same area. Because

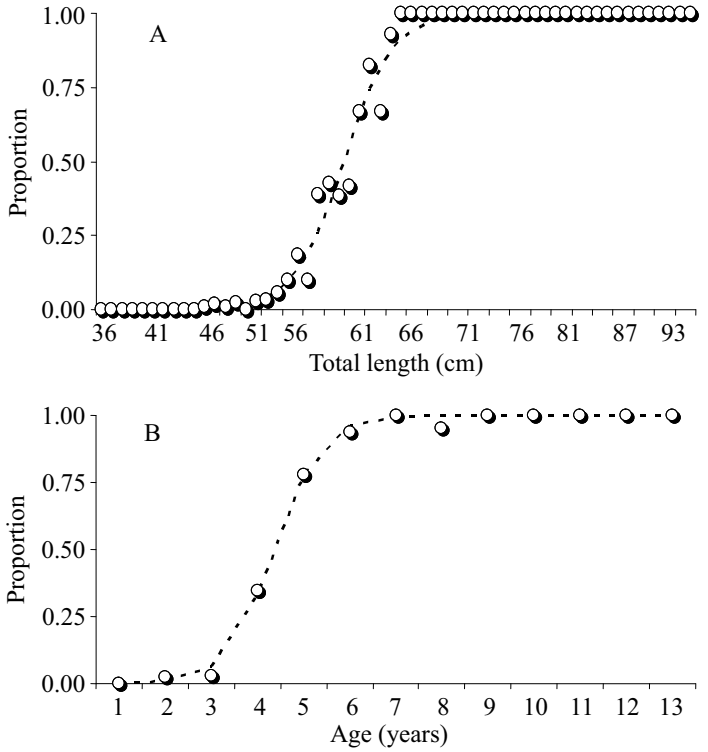

Figure 8. Proportion of mature *Merluccius australis* in relation to total length (A) and age (B).
Figura 8. Proporción de individuos maduros de Merluccius australis*, en relación a la longitud total (A) y a la edad (B).*

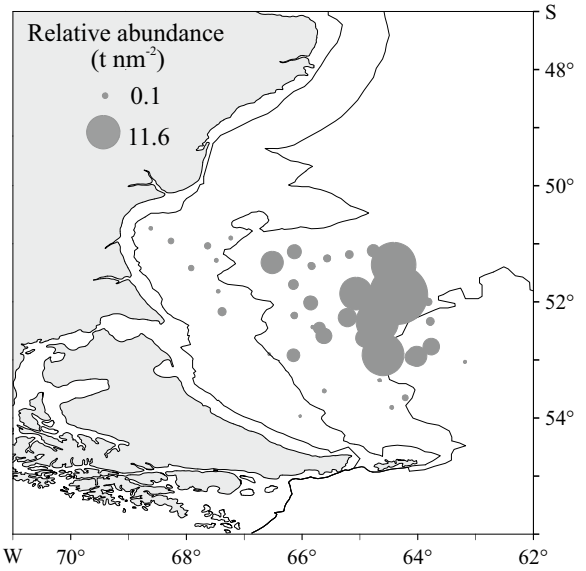

Figure 9. Relative concentrations of *Merluccius australis* estimated during summer cruises.
Figura 9. Concentraciones relativas de Merluccius australis *estimadas durante los cruceros de verano.*

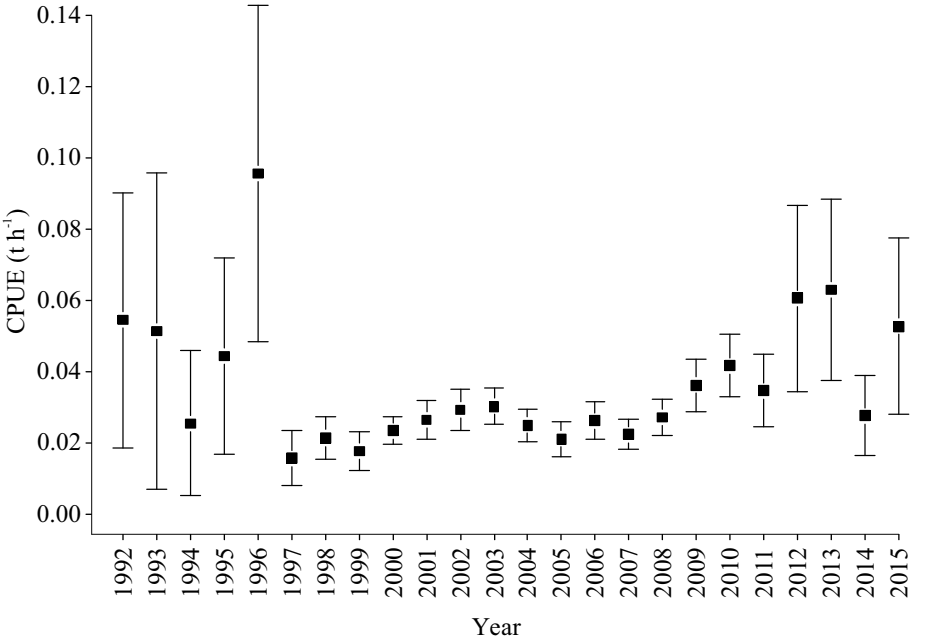

Figure 10. Catch per unit effort (CPUE) from the Argentine fleet. Period 1992-2015.
Figura 10. Captura por Unidad de Esfuerzo (CPUE) de la flota argentina. Período 1992-2015.

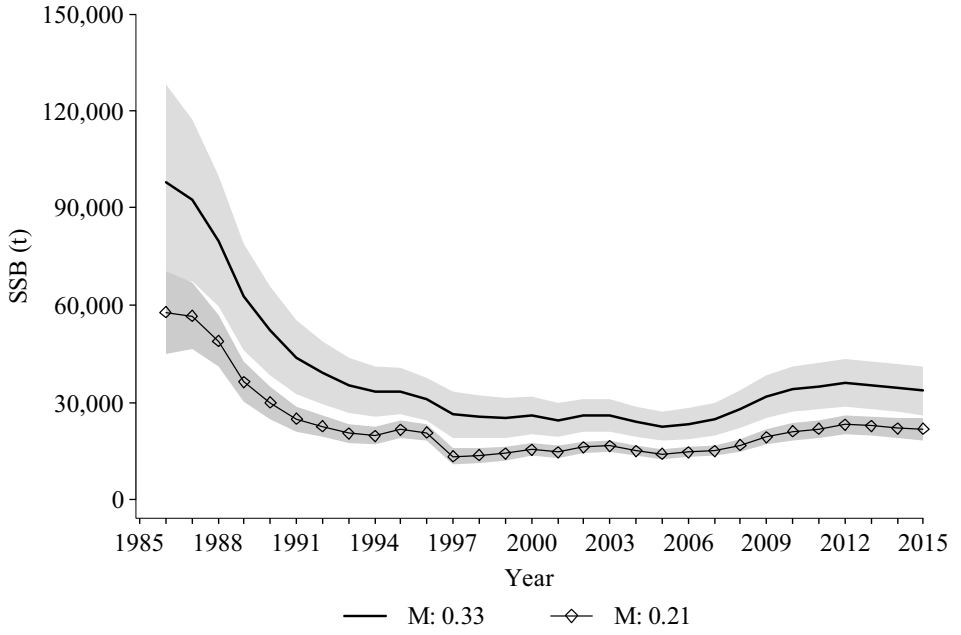

Figure 11. Estimated stock spawning biomass (SSB) trajectory as a result of the stock assessment, during the period 1986-2015, considering two natural mortality values.
Figura 11. Evolución de la biomasa desovante (SSB) como resultado de la evaluación de abundancia correspondiente al período 1986-2015, considerando dos valores de mortalidad natural.

of this relatively low abundance (Marí and Giussi, 2003), Southern hake is primarily a bycatch of the long tail hake fishery, which is the major target species within the main fishing grounds in the region (Gorini *et al*., 2014).

The species is caught south of 47° S, the main fishing grounds being located between 54° S and 55° S (Figures 12 and 13), where relatively higher yields are obtained between 200 and 400 m and between 700 and 800 m depth (Figure 14). Captures and yields show a similar tendency when they are analyzed monthly (Figure 15). Lowest values of both are recorded between June and October. At this time of the year, *M. australis* occurs in low numbers in Argentine waters, probably because a large proportion of the population is in Chilean waters for spawning during winter (Aguayo and Zuleta, 1988; Aguayo-Hernández, 1995). Catches increase later in summer, likely because of the larger availability of long tail hake schools, which is the main prey of Southern hake (Wöhler *et al.*, 1999; Marí and Sánchez, 2002; Giussi *et al.*, 2004; Sánchez and Marí, 2005). Annual migration of Southern hake between the Southeast Pacific Ocean and SAO appears likely.

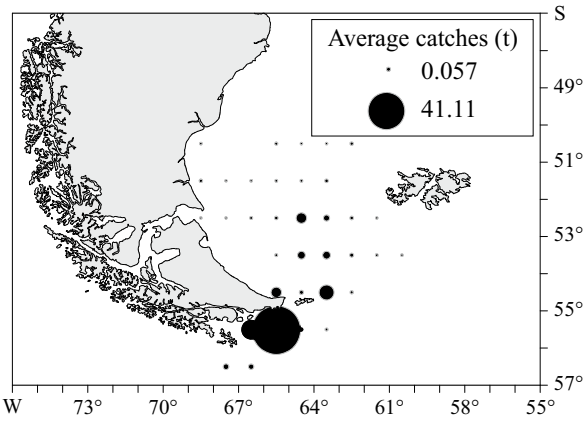

Figure 12. *Merluccius australis* fishing grounds in the Southwest Atlantic Ocean, indicated by locations of catches summed into 1° squares of latitude/longitude over the years 2006 to 2012.

Figura 12. Caladeros de Merluccius australis *en el Océano Atlántico Sudoccidental por rectángulo estadístico de 1º de latitud y 1° de longitud, entre los años 2006 y 2012.*

Total length in commercial catches

From the four years where data are available, the length frequency distribution of *M. australis* caught by the Argentine fleet is unimodal (Figure 16) with the peak around 60-70 cm total length (TL). Maximum length is slightly larger than 100 cm TL while average values are about 68 cm TL. Catches comprise mainly adults with a small proportion of juveniles (≤ 15%), although with some inter-annual variability. Sex ratio is close to 1:1.

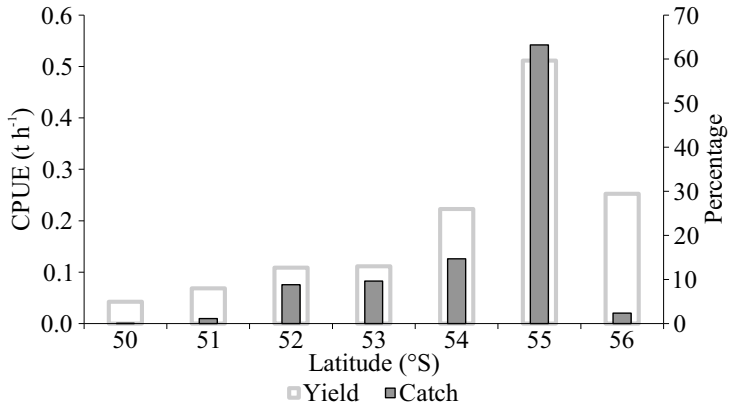

Figure 13. *Merluccius australis* average yield (CPUE) and catch obtained by latitude. Period 1997-2010.

Figura 13. Rendimiento promedio (CPUE) y captura de Merluccius australis, *en relación con la latitud. Período 1997-2010.*

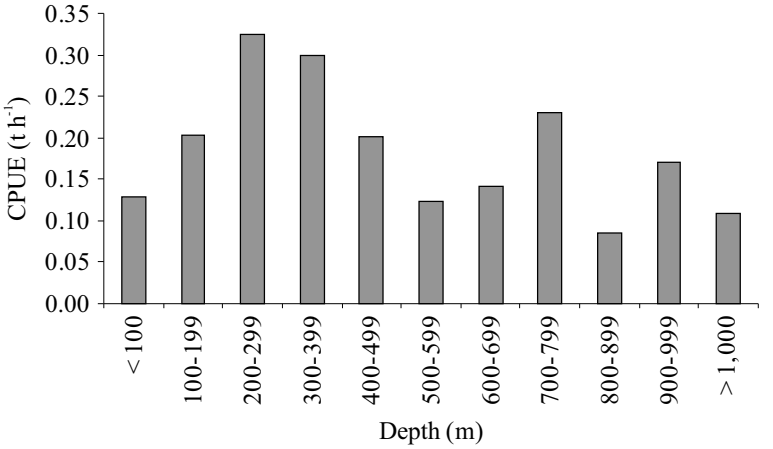

Figure 14. *Merluccius australis* average yield (CPUE) in relation to depth. Period 1997-2010.
Figura 14. Rendimiento promedio (CPUE) de Merluccius australis *en relación con la profundidad. Período 1997-2010.*

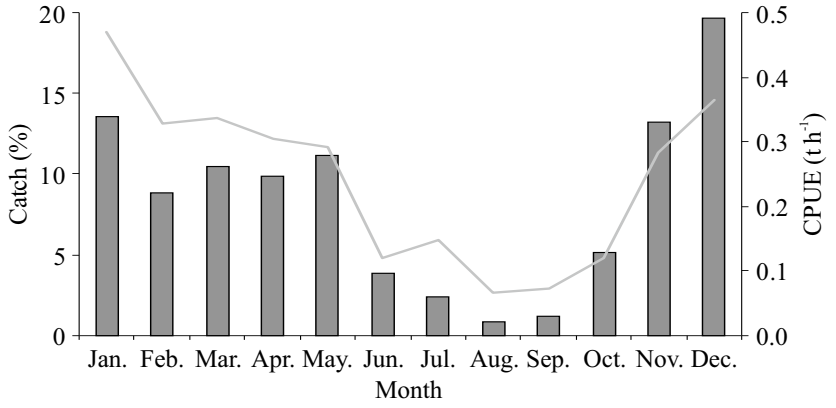

Figure 15. *Merluccius australis* average yield (CPUE) and catch per month. Period 1997-2010.
Figura 15. Rendimiento promedio (CPUE) y captura de Merluccius australis *obtenidos por mes. Período 1997-2010.*

Catch at age

The age structure of commercial catches obtained by scientific observers on board of commercial fleet has been variable through time (Figure 17) and thus annual classes or cohorts are difficult to follow. Juveniles are scarce and individuals 4 to 8 years old are the most abundant (Gorini *et al.*, 2012).

Landings and commercial aspects

Relatively larger landings occurred through the period 1987-1990 (Figure 18) mostly due to the presence of foreign fleets operating in areas close to the Argentine Exclusive Economic Zone (AEEZ) (Gorini *et al*., 2007). In those years the catches exceeded 9,000 t, thereafter decreasing markedly down to 3,000-7,000 t. In recent years (2006-2015), annual catches averaged 5,300 t (Giussi and Zavatteri, 2016).

The fishing fleets currently catching *M. australis* in the SAO include large vessels with enough autonomy to remain for a long period of time in the fishing grounds. These vessels are trawlers that use bottom or mid-water nets. Catches are processed on board and fish is maintained at temperatures

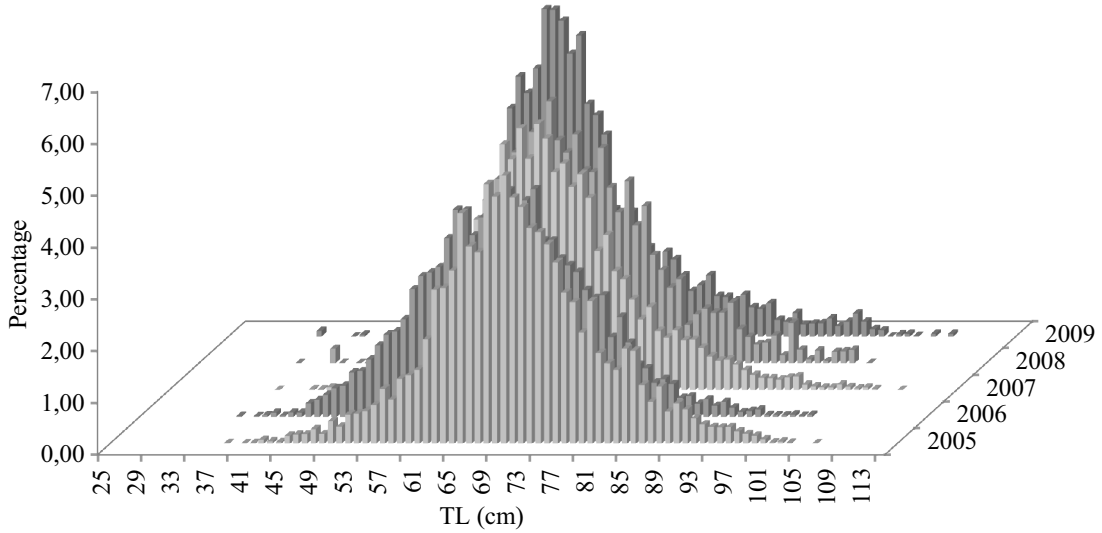

Figure 16. Percentage of total length (TL) in commercial catches of *Merluccius australis* in the Southwest Atlantic Ocean. Period 2005-2009.

Figura 16. Porcentaje de las longitudes totales (TL) de Merluccius australis *obtenidas de las capturas comerciales en el Océano Atlántico Sudoccidental. Período 2005-2009.*

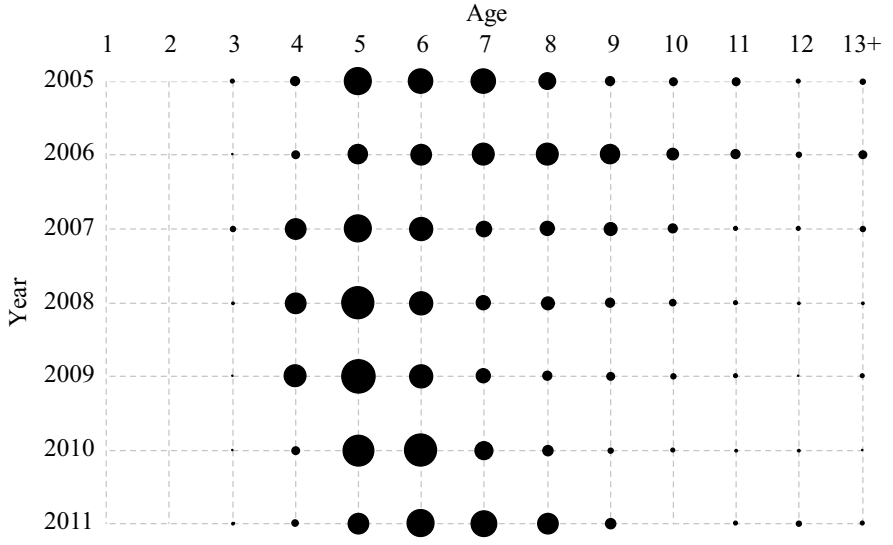

Figure 17. Catch at age of *Merluccius australis* in the Southwest Atlantic Ocean. Period 2005-2011.

Figura 17. Captura por edad de Merluccius australis *en el Océano Atlántico Sudoccidental. Período 2005-2011.*

lower than -18 °C (Bertolotti *et al.*, 2001). Factory fleets take 51% of the total catch (Figure 19). Most Southern hake caught in SAO are landed in Ushuaia, which is the most important harbor for these fleets (Gorini *et al.*, 2014).

Most Southern hake are processed as headed and gutted product (H&G), but cheeks and several meat cuts are also produced. These products are sold to Europe, with Spain being the principal market.

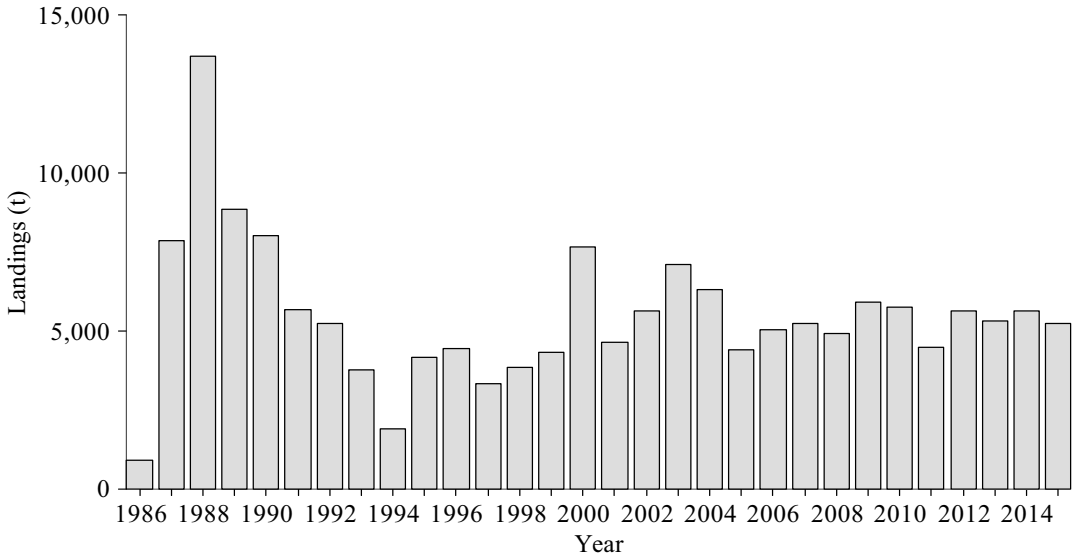

Figure 18. *Merluccius australis* annual landings in the Southwest Atlantic Ocean. Period 1986-2015.
Figura 18. Desembarques anuales de Merluccius australis *obtenidos en el Océano Atlántico Sudoccidental. Período1986-2015.*

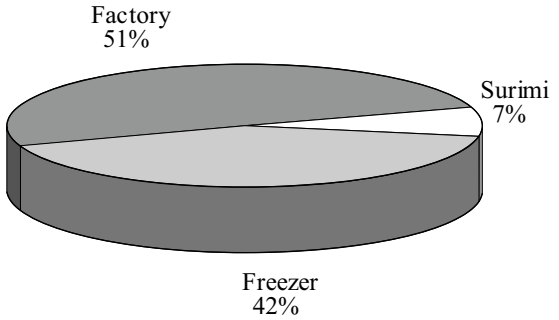

Figure 19. *Merluccius australis* catch declared per fleet. Taken and redrawn from Gorini *et al*. (2014).
Figura 19. Captura de Merluccius australis *declarada por tipo de flota. Tomado y modificado de Gorini et al. (2014).*

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