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## Spatial variations of the Argentine hake (*Merluccius hubbsi* (Marini, 1933)) spawning shoals in the Patagonian area during a reproductive season

Variaciones espaciales de los cardúmenes desovantes de merluza común (*Merluccius hubbsi* (Marini, 1933)) en el área de Patagonia durante una estación reproductiva

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**Resumen.-** Se analizaron los desplazamientos de los cardúmenes de merluza común *Merluccius hubbsi* en el área de desove de Patagonia antes del comienzo de la puesta y durante una temporada reproductiva. Se describieron los cambios de abundancia, composición de sexos, estructura de tallas y localización de los desoves. Durante octubre y noviembre, los cardúmenes de merluza migraron desde aguas más profundas hacia la costa, aproximadamente a los 44°S, donde tiene lugar la puesta en diciembre. Durante enero las principales agregaciones reproductivas permanecieron cerca de la costa (50 m de profundidad) pero desplazadas hacia el sur (45°S); en febrero la intensidad del desove disminuyó y las hembras en post-puesta comenzaron a retornar a aguas más profundas. En general, este proceso fue completado primeramente por los desovantes más jóvenes (35–45 cm LT), los cuales tienen una temporada reproductiva más corta que las hembras de mayor edad. Los machos arribaron más temprano al área de puesta y permanecieron durante más tiempo que las hembras. Durante el período reproductivo se observaron variaciones espaciales en la proporción de sexos, que fueron atribuidas a: 1) segregación local producida por el comportamiento reproductivo de la merluza, donde varios machos se agrupan con una hembra al momento de la puesta, y 2) migración de hembras en post-puesta hacia aguas más profundas, lo cual origina mayor proporción de machos en las áreas costeras.

Palabras clave: Merlucciidae, Océano Atlántico sudoccidental, reproducción, migración

**Abstract.-** Displacements of Argentine hake *Merluccius hubbsi* shoals in the spawning area of Patagonia before and during a reproductive season were analyzed. In particular, monthly changes in fish density, sex composition, size structure and spawning location were described for this stock. During October–November, hake shoals moved from deeper waters to the coast at about 44°S, where spawning took place in December. During January the main reproductive aggregations stayed near the coast (50 m depth) but displaced to the southern area (45°S); in February spawning activity diminished and spent females began to return to deeper waters. In general, this process was first completed by young spawners (35–45 cm TL), which have a breeding season shorter than the old females. We observed that males arrived at the spawning area first and remained there for a longer period than females. During the reproductive period skewed sex ratios in different sampling sites were observed. These differences in sex composition were attributable to: 1) local segregation produced by the reproductive behavior of hake, in which males form groups with a single female, and 2) migration of spent females to deeper waters, which causes male-biased samplings in coastal areas.

Key words: Merlucciidae, southwest Atlantic Ocean, reproduction, migration

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## Introduction

The reproductive activity of the Patagonian stock of Argentine hake (*Merluccius hubbsi*) occurs during spring and summer with a main peak in January (Macchi *et al.* 2004). Historically, spawning has taken place mainly in coastal waters off the Chubut province, in the area known as Isla Escondida (43°30'–44°S),

where this species formed large schools (Ciechomski *et al.* 1983, Macchi *et al.* 2005). Since 1998, changes in the spatial pattern of hake spawning aggregations were observed, which were characterized by a decrease in the density of shoals and a movement of fish to deeper water, with a more scattered distribution. This variation was associated with high levels of fishing exploitation applied mainly in the early 1990s (Ehrlich *et al.* 2000).

However, recent studies showed that changes in spatial location of spawners did not appear to negatively affect the recruitment of the Patagonian hake stock, at least during 2001 and 2002 (Macchi *et al.* 2005).

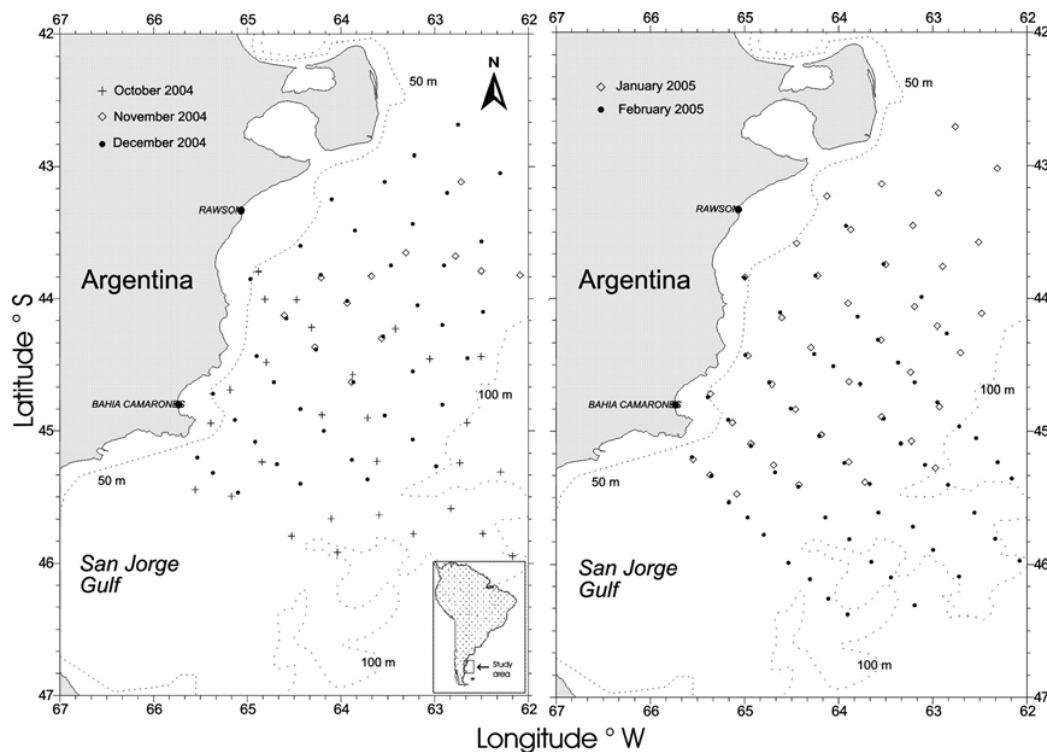
Different aspects as oocyte development, gonadal maturation, fecundity and spawning frequency of Argentine hake have been analyzed (Christiansen *et al.* 1986, Louge & Christiansen 1993, Macchi *et al.* 2004), but information about reproductive behavior of this species is scarce. *M. hubbsi* is a batch spawner with relatively high egg production compared to other members of the Merlucciidae family (Macchi *et al.* 2004). Analysis of hake aggregations showed that this species formed skewed sex ratios during the reproductive season, characterized in general by male-biased schools in areas with a high proportion of spawning females (Pájaro *et al.* 2005). This variation in sex composition was associated with a reproductive behavior that involves male-competition during

fertilization. Nevertheless, reproductive aggregations with a high proportion of females were recently observed in an offshore spawning ground (Dato 2006). For this reason, we hypothesize that differences in sex ratio within the reproductive area of Argentine hake in part may be attributable to the movement of post-spawning females to deeper waters.

In the present paper, we study the displacements of the Argentine hake shoals in the spawning area of Patagonia, before and during a reproductive season. We analyze monthly changes in fish density, sex composition, size structure and spawning location of this fishing stock.

## Material and methods

Samples of *M. hubbsi* were collected during five research surveys carried out between October 2004 and February 2005 in the north-Patagonian area (Fig. 1).



**Figure 1**

**Samples location of *Merluccius hubbsi* collected from October 2004 to February 2005 in the north Patagonian area**

Localización de las muestras de *Merluccius hubbsi* recolectadas desde octubre 2004 a febrero 2005 en el área nor-patagónica

Argentine hake specimens were captured at depths between 50 m and 110 m using a bottom net with a mouth width of about 20 m, a height of about 4 m, and with a 20 mm mesh at the inner cover of the cod end. Total length (TL), sex and maturity stage were recorded for each fish sampled (Table 1). A macroscopic maturity key of five stages designed for biological studies was employed: 1) immature, 2) developing and partially spent, 3) spawning (gravid and running), 4) spent and 5) resting (Macchi & Pájaro 2003). To validate this scale in females, 3778 paired ovaries were removed from individuals collected in different trawls (about 25-30 specimens per station) during the period analyzed (Table 1), and preserved in 10 % formalin for histological analysis.

Ovaries were weighed (GW) to the nearest 0.1 g and a portion of sample (about 2.0 g) was removed from each gonad, dehydrated in ethanol, cleared in xylol and embedded in paraffin. Sections were cut at 5- $\mu$ m thickness and stained with Harris's hematoxylin followed by eosin counterstain. Histological staging was based on the stage of oocyte development and on the occurrence of postovulatory follicles (POF) and atresia (Macchi *et al.* 2004), following the criteria previously described by Hunter & Goldberg (1980) and Hunter *et al.* (1992). Postovulatory follicles were classified as day-0 (elapsed time from spawning < 24 h) and day-1 (elapsed time from spawning > 24 h but < 48 h), according to the description reported by Hunter & Macewicz (1985a) for *Engraulis mordax*, which spawns at similar temperatures as *M. hubbsi* (Macchi & Pájaro 2003). The criteria for identification of the different atresia stages and determination of post-spawning condition of the ovary were adopted from Hunter & Macewicz (1985b), who classified females with more than 50% vitellogenic alpha atresia as being spent.

To estimate length at first maturity ( $L_{50\%}$ ) a logistic model was fitted to the proportion of mature individuals (macroscopic stage 2 or higher) by total length class using the maximum likelihood method (Kendall & Stuart 1967). Coefficients of the regression obtained for males and females, and from different months, were compared using a  $\lambda^2$ -test (Aubone & Wöhler 2000).

Sex ratio (M:F) was determined as the number of males (M) divided by the number of females (F), only considering adult fish. This variable was estimated for each trawl station sampled during the period October 2004 – February 2005.

**Table 1**

**Number of Argentine hake (*Merluccius hubbsi*) specimens sampled during the research surveys carried out in the north Patagonian area from October 2004 to February 2005**

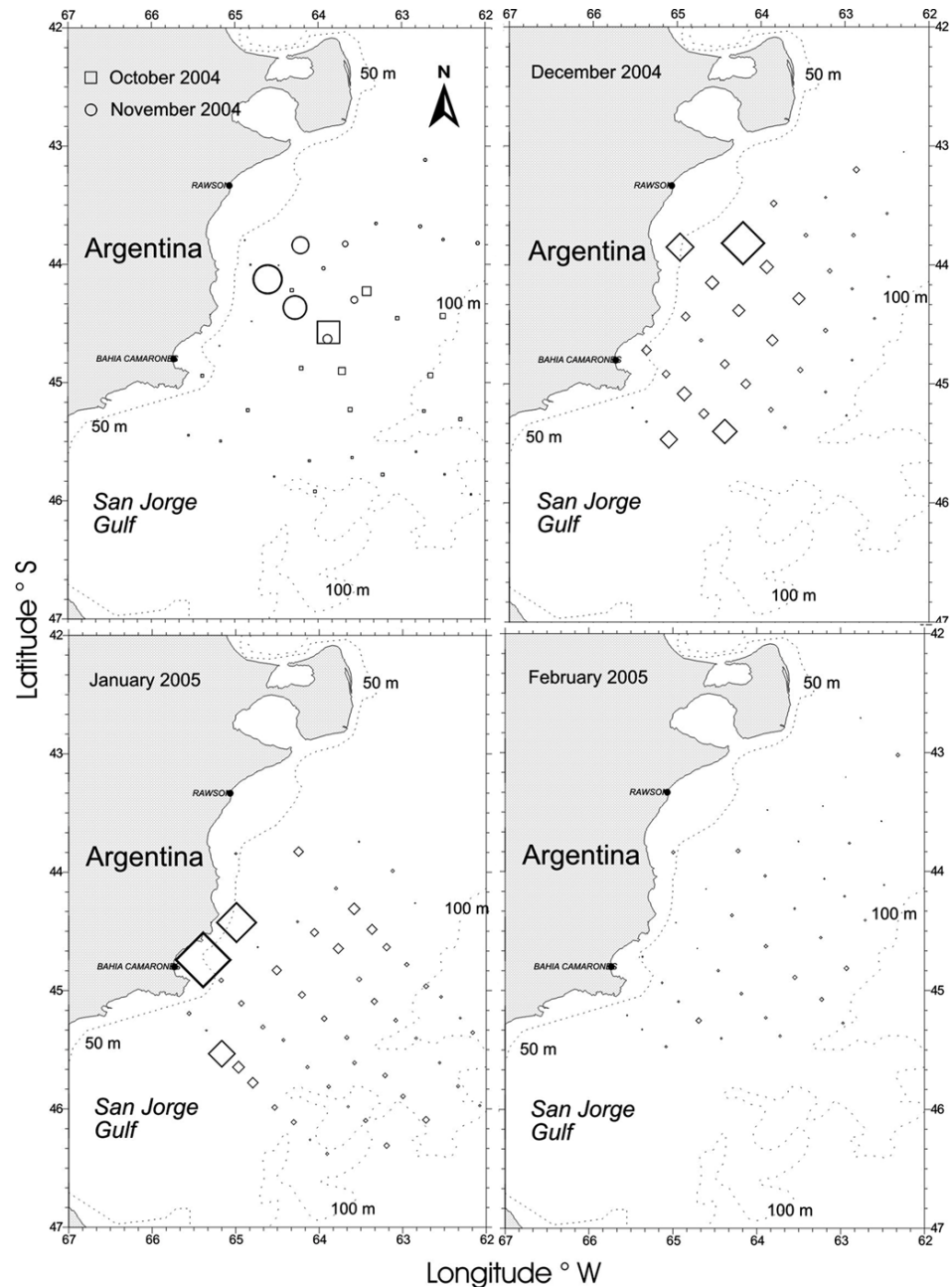
Número de ejemplares de merluza común (*Merluccius hubbsi*) muestreados durante campañas de investigación realizadas en el área nor-patagónica desde octubre de 2004 a febrero de 2005

Month	Number of trawls	Number of individuals sampled	Number of ovaries collected
October 2004	27	18,508	52
November 2004	12	5,443	429
December 2004	42	10,274	1034
January 2005	55	10,467	1283
February 2005	41	11,562	980

## Results

### Hake abundance

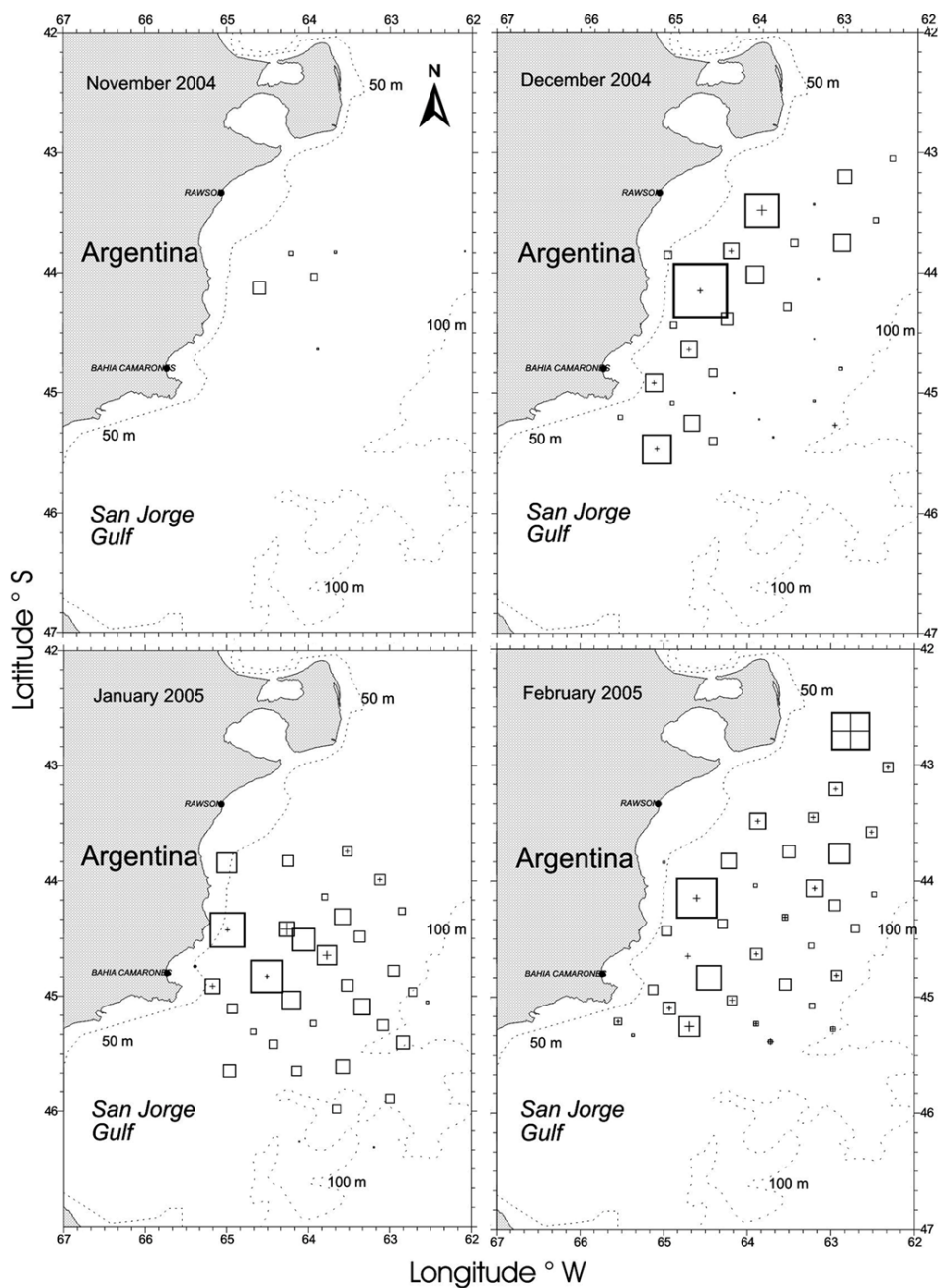
*M. hubbsi* abundance (t-nautical mile<sup>-2</sup>) estimated from different trawl stations performed between October 2004 and February 2005 showed spatial variations during the spawning season (Fig. 2). At the beginning of this period (October 2004) the highest densities (100-300 t-nautical mile<sup>-2</sup>) were observed at intermediate depth, between the 50 m and 100 m isobaths, from 44° to 45°S. One month later the most abundant shoals (200-400 t-nautical mile<sup>-2</sup>) were detected near the coast between 44° to 44°30'S (Fig. 2). During December, these fish schools (300-580 t-nautical mile<sup>-2</sup>) were sited at the same latitude as for November but inshore near the 50 m isobath. In January 2005 location of hake aggregations (500-750 t-nautical mile<sup>-2</sup>) remained in the coast at 50 m depth, but displaced to the southern area in front of Bahía Camarones (between 44°30' and 45°S). Later, in February, a decline in hake density was observed in all sampled area, with values lower than 50 t-nautical mile<sup>-2</sup> (Fig. 2).



**Figure 2**

**Spatial distribution of *Merluccius hubbsi* density values ( $\text{t} \cdot \text{nautical mile}^{-2}$ ) estimated from trawl surveys carried out from October 2004 to February 2005 in the north-Patagonian area. The size of the symbols is proportional to the density values, which ranged between 0 and  $750 \text{ t} \cdot \text{nautical mile}^{-2}$**

Distribución espacial de los valores de densidad de *Merluccius hubbsi* ( $\text{t} \cdot \text{milla náutica}^{-2}$ ) estimados de cruceros de arrastre realizados desde octubre de 2004 a febrero de 2005 en el área nor-patagónica. El tamaño de los símbolos es proporcional a los valores de densidad, que varían entre 0 y  $750 \text{ t} \cdot \text{milla náutica}^{-2}$



**Figure 3**

Spatial distribution of gravid (square) and spawning females (plus) of *Merluccius hubbsi* in the north-Patagonian area, from November 2004 to February 2005. The size of the symbols is proportional to the percentage of each stage, which ranged between 0 and 25%

Distribución espacial de hembras grávidas (cuadrado) y en desove (cruz) de *Merluccius hubbsi* en el área nor-patagónica, desde noviembre de 2004 a febrero de 2005. El tamaño de los símbolos es proporcional al porcentaje de cada estadio, que varía entre 0 y 25%



### Spawning areas

To determine the main reproductive areas of Argentine hake in the Patagonian region during the period October 2004 - February 2005, we consider the proportion of gravid females (with hydrated oocytes) and spawning females (with day-0 POF) by trawl station. In general both criteria coincided, in areas with a high proportion of gravid females a high incidence of spawning individuals was observed (Fig. 3). Moreover, seasonal variation of spawning aggregations showed the same spatial pattern observed for the most abundant shoals of Argentine hake (Fig. 2).

During October 2004, no spawning individuals of *M. hubbsi* were detected in the Patagonian area. First evidence of oocyte hydration was observed in November, with low percentages of gravid females by trawl station (< 10%). These specimens were collected near the 44°S latitude, at 66–77 m depths (Fig. 3). During December 2004, reproductive activity of hake increased, with gravid and spawning females

distributed from 43° to 45°30'S, between 60 and 85 m depth, but the highest percentages of gravid individuals were located inshore mainly in the northern area (Fig. 3). In January 2005, an expansion of the hake spawning area was observed, with gravid females distributed from the coast to the 100 m isobath. However, reproductive activity was most important in the southern area near Bahía Camarones (Fig. 3). During February 2005, spatial distribution of reproductive hake females was wider than in January, showing spawning individuals (with day-0 POF) in all sampled area (Fig. 3).

Analyzing the spatial distribution of post-spawning females during the reproductive period, we detected an increase of this stage as the breeding season progressed (Fig. 4). Nevertheless, in contrast to that observed with the gravid or spawning condition, spent females mainly dominated the offshore area at depths near the 100 m isobath. During February 2005, the post-spawning sector increased in area including intermediate depth waters between 80 m and 100 m (Fig. 4).

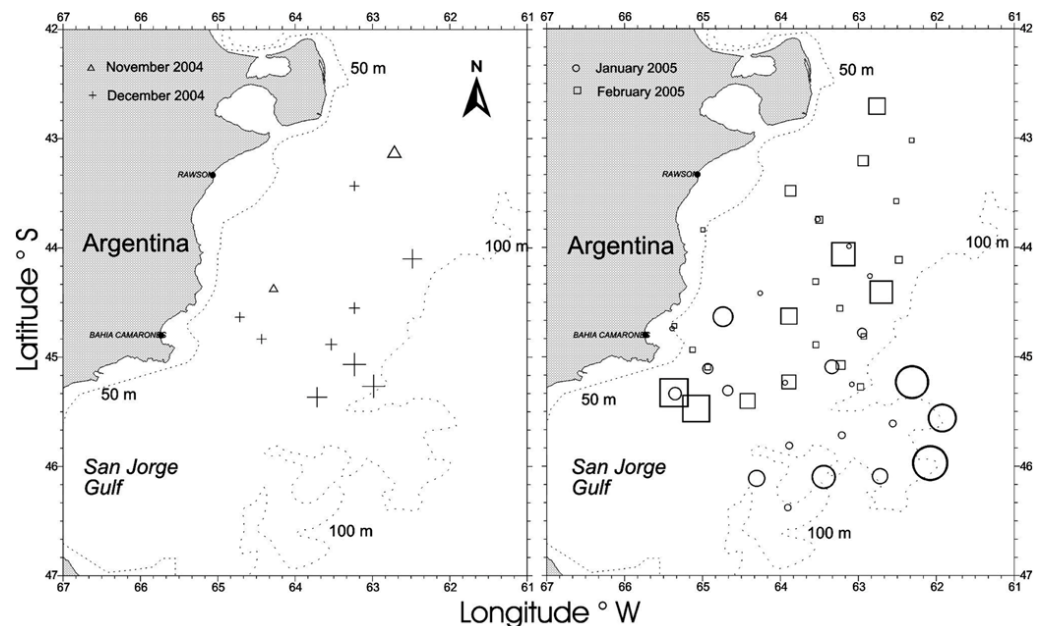


Figure 4

Spatial distribution of post-spawning females of *Merluccius hubbsi* in the north-Patagonian area, from November 2004 to February 2005. The size of the symbols is proportional to the percentage of this stage, which ranged between 0 and 20%

Distribución espacial de hembras en postdesove de *Merluccius hubbsi* en el área nor-patagónica, desde noviembre de 2004 a febrero de 2005. El tamaño de los símbolos es proporcional al porcentaje de este estadio, que varía entre 0 y 20%

**Table 2**

**Coefficients of the logistic functions ( $L_{50\%}$  and slope  $b$ ) obtained to estimate length at maturity (cm) in *Merluccius hubbsi* of the Patagonian stock during the reproductive period October 2004 - February 2005**

Coefficientes de las funciones logísticas ( $L_{50\%}$  y pendiente  $b$ ) obtenidas para estimar la longitud de primera madurez (cm) de *Merluccius hubbsi* del efectivo patagónico durante el período reproductivo octubre 2004 - febrero 2005

Month	Males			Females		
	$L_{50\%}$	$b$	$n$	$L_{50\%}$	$b$	$n$
October 2004	29.28	0.4931	1212	31.71	0.4166	944
November 2004	29.77	0.5086	3354	35.01	0.5285	2082
December 2004	27.04	0.5841	5472	34.82	0.6287	4782
January 2005	27.29	0.7256	6674	32.95	0.8546	3772
February 2005	26.98	0.7470	8324	32.34	0.7866	3213

### Size at maturity

Length at first maturity ( $L_{50\%}$ ) estimated for males of Argentine hake in different months of the period October 2004 – February 2005 ranged between 27.0 cm TL and 29.8 cm TL (Table 2). In the case of females  $L_{50\%}$  values were significantly higher ( $P < 0.01$ ) than those obtained for males of the same month and ranged between 31.7 cm and 35.0 cm TL (Table 2). Comparison of this variable for individuals of the same sex, but sampled in different months of the reproductive season, also showed significant differences ( $P < 0.01$ ). The  $L_{50\%}$  value estimated for all sampled period (October 2004 - February 2005) was 27.7 cm TL for males and 33.8 cm TL for females.

### Length distributions and sex ratio

Figure 5 shows the length-frequency distributions obtained for males and females during different months of the reproductive period analyzed. Juveniles of both sexes dominated in October 2004 with a main mode at 26 cm TL, but in the case of males a second mode of adult fish at 38 cm TL was observed. In November, this last group became principal for males; for females juveniles continued dominating in the samples, but another group corresponding to adult individuals with a mode at 44 cm was observed (Fig. 5). During December, size-frequency distribution for males basically did not change, but females showed and increase in adult proportion respect to November, with a main mode in 40 cm TL and two secondary modes in 26 cm TL and 18 cm TL (Fig. 5). During January and February 2005, length distributions for males and females were basically composed by adult specimens,

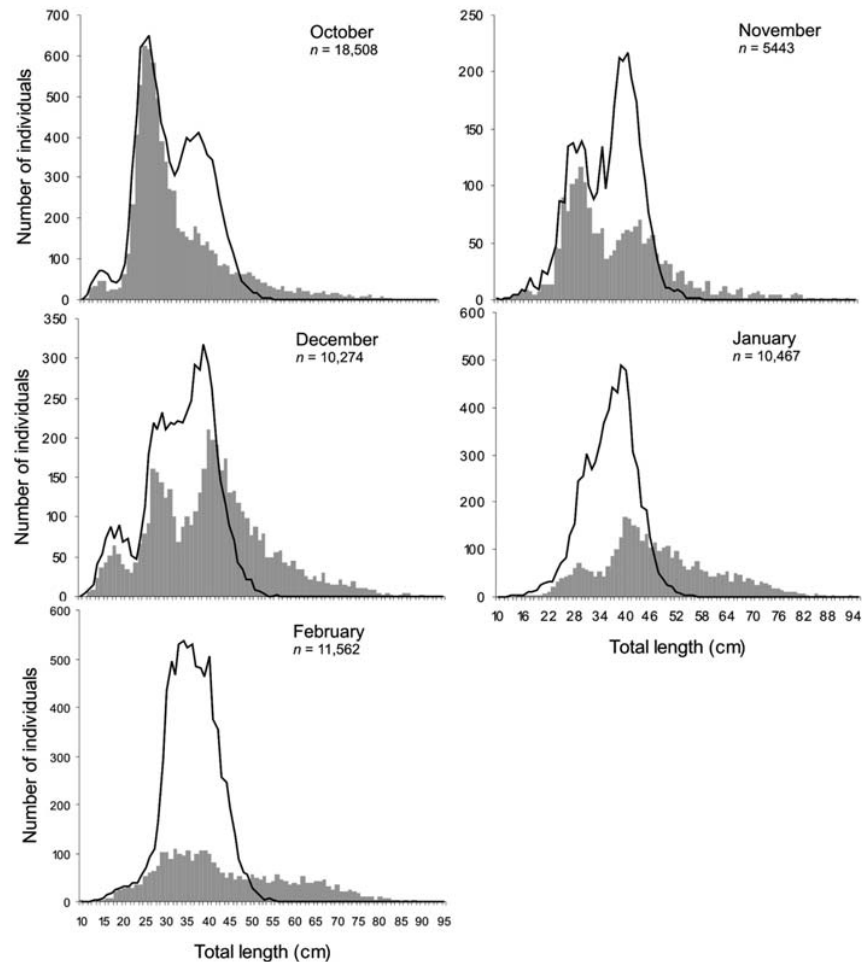
with modes between 36 and 40 cm TL (Fig. 5). In general, a decline in female proportion was observed for both months in comparison with December 2004. During February, this decrease was more important than in January, mainly in young females between 35 cm and 45 cm TL (Fig. 5).

Spatial distribution of the sex ratio (M:F) showed considerable variation during the spawning season (Fig. 6). In October 2004, sex ratio was about one for all sampled area showing similar proportions of males and females, except in those stations with high hake densities, where males dominated the samplings sites (M:F = 2-3). During November, male proportion increased mainly in the coastal area between 44° and 44°30'S, in coincidence with the location of gravid females (Fig. 6). The same pattern was observed in December and January, with high proportions of males mainly in those sites where females were gravid or in spawning stage (M:F = 5-6). During February, males dominated all the area from 42°30'S to 46°S, but the highest M:F values (10-13) were observed inshore, mainly south of the 44°S latitude in front of Bahía Camarones (Fig. 6).

### Discussion

Previous studies based on abundance of Argentine hake, eggs in plankton samples showed that reproductive activity of the Patagonian stock begins between November and December (Ehrlich & Ciechomski 1994). Other authors analyzing the egg production during one breeding season (December 2000 - March 2001) suggested the beginning of





**Figure 5**

**Length frequency distributions obtained for males (line) and females (gray bars) of *Merluccius hubbsi* in the north-Patagonian area from October 2004 to February 2005**

Distribuciones de frecuencia de talla obtenidas para machos (línea) y hembras (barras grises) de *Merluccius hubbsi* en el área nor-patagónica desde octubre de 2004 a febrero de 2005

spawning in November for this stock, but no samples were obtained in that month (Macchi *et al.* 2004). During the reproductive period 2004-2005, it was possible to collect samples of *M. hubbsi* in October and November, and to determine that the first gravid females start to appear during November but in low proportions.

Spatial distribution of hake aggregations in the north-Patagonian area (43°- 46° S) showed a movement of this species previous to the onset of spawning (October) from deeper waters (more than 100 m depth) toward the coast (near the 50 m isobath), where reproduction takes place. During 2004 this process began in November-December in the northern area (44°S), and one month later the most abundant shoals moved to the south (44°30' - 45°S) following the 50 m

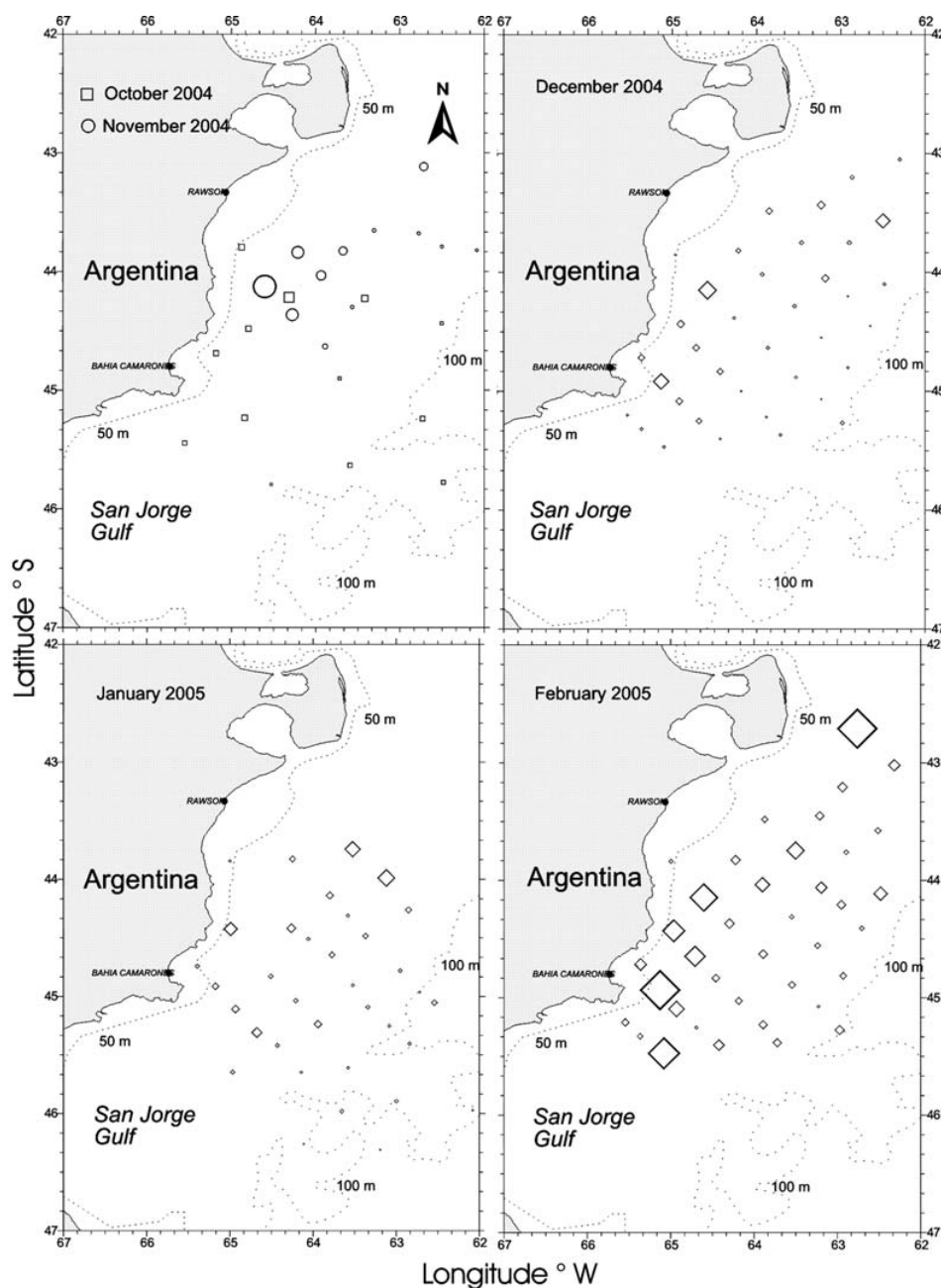


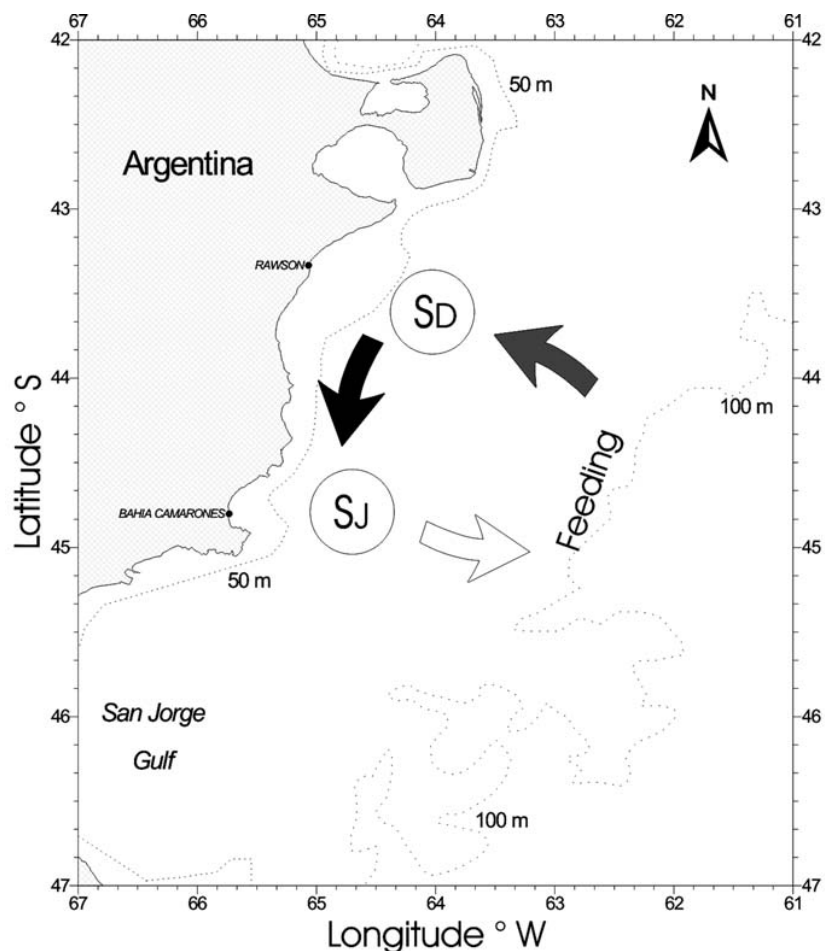
Figure 6

Spatial distribution of the sex ratio (M:F) obtained for *Merluccius hubbsi* in the north-Patagonian area from October 2004 to February 2005. The size of the symbols is proportional to the M:F values, which ranged between 0.40 and 13

Distribución espacial de la relación de sexos (M:F) obtenida para *Merluccius hubbsi* en el área nor-patagónica desde octubre de 2004 a febrero de 2005. El tamaño de los símbolos es proporcional a los valores de M:F, que varían entre 0.40 y 13

isobath. During February 2005, density of hake decreased in the area as a consequence of displacements of this species offshore after spawning (Fig. 7). The movement from deeper waters to the coast observed in pre-spawning females is coincident with the hypothesis of a local stock of hake sited between 43° and 48°S, which stay in external platform waters during winter and later migrates for spawning (Perez Comas 1990). On the other hand, latitudinal

displacement of spawning aggregations observed from December to January may be associated with the increases in water temperature during summer (Pájaro *et al.* 2005). The movement of fish toward deeper waters observed since February would be related to feeding, taking into account previous reports that mention full stomachs in post-spawning females collected offshore (Angelescu & Prenski 1987).



**Figure 7**

**Spawning cycle of *Merluccius hubbsi* in the north-Patagonian area. The arrows represent different periods: October-November (gray), December-January (black) and February-March (white). The circles show the main spawning sites in December (SD) and January (SJ)**

Ciclo de desove de *Merluccius hubbsi* en el área nor-patagónica. Las flechas representan diferentes períodos: octubre-noviembre (gris), diciembre-enero (negro) y febrero-marzo (blanco). Los círculos muestran las principales áreas de desove en diciembre (SD) y enero (SJ)

In general, during the reproductive season 2004-2005 spawning aggregations of Argentine hake in Patagonian waters were spatially coincident with those described for this stock in previous years (Macchi *et al.* 2004, Pájaro *et al.* 2005), but during January and February 2005, a great dispersion of gravid females was observed. This new pattern showed an expansion of the hake spawning area toward deeper waters in comparison to that reported for January 2001 and 2004 (Macchi & Pájaro 2005). This observation was corroborated during January 2006 (Dato 2006), and suggests that reproduction of the Patagonian hake stock could occur at temperatures lower than those previously reported for this species (Pájaro *et al.* 2005).

Length at maturity values for males during the reproductive period 2004-2005 were similar to those obtained in 2000-2001, but for females  $L_{50\%}$  was between 1 and 2 cm higher than that estimated for Argentine hake four years ago (Pájaro *et al.* 2005). Although the values obtained during 2004-2005 were much lower than those reported for this species in the 1980s (Simonazzi & Otero 1986, Ruiz & Fondacaro 1997), no decreasing in length at maturity for *M. hubbsi* was observed since the 2000s.

In October 2004, previous to the onset of spawning, hake aggregations showed a high proportion of juveniles in the north-Patagonian area, but between November 2004 and January 2005 these shoals consisted mainly of adult fish. In February, hake schools with high density values were not observed. Length distributions and sex ratio show variations during this reproductive period. During October, in addition with higher percentages of juveniles, sex ratio for adult hakes indicated similar proportion of males and females in most of the sampling sites. In November, at the beginning of spawning, the increase in male proportion suggests the arrival of this sex prior to females, as was previously mentioned for Argentine hake (Pájaro *et al.* 2005) and other species (Green *et al.* 1966, Eckman 1991, Morgan & Trippel 1996). During December, female proportion in the north-Patagonian area was higher than in November, but male-biased sex ratio dominated in those sites with high percentages of spawning females. A similar pattern was observed in January, but one month later male-biased samplings covered all the area, mainly inshore with M:F values higher than 10. This male concentration observed near the coast during February was consequence of the movement of females to deeper waters after spawning. Analysis of length distributions showed that decreasing

in adult female proportion after reproductive peak occurred mainly in young specimens (between 35 cm and 45 cm TL), which in general have a spawning period shorter than old females (Macchi *et al.* 2004). The displacement of post-spawning females to the offshore area was evident by the increases of spent individuals in deeper waters near the end of the reproductive season. This behavior indicates that males remain in the spawning area for a longer period than females as reported Pájaro *et al.* (2005) for the same species.

Therefore, the skewed sex ratio observed in the spawning area of *M. hubbsi* may be attributable to two sources: 1) local segregation produced by some reproductive behavior as courtship, in which males form groups with a single female, as was suggested for other species (Hunter & Goldberg 1980), 2) migration of post-spawning females to deeper waters, which causes male-biased samplings mainly in coastal areas.

We previously mentioned the expansion of the Argentine hake spawning to the offshore zone in Patagonia during January-February 2005 and January 2006. In contrast to that observed near the coast, reproductive activity in this external area in general was characterized by female-biased samplings. This observation could be explained in part by the second point mentioned above: the movement of spent females to deeper water, which may mask the possible local segregation caused by courtship.

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