# Can a change in the spawning pattern of Argentine hake (*Merluccius hubbsi*) affect its recruitment?*

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Argentine hake (*Merluccius hubbsi*) inhabit waters of the Southwest Atlantic Ocean between 22° and 55°S, at depths ranging from 50 to 500 m (Cousseau and Perrota, 1998). This species has historically been among the more abundant fish resources in the Argentine Sea, where its biomass has ranged between one and two million metric tons annually since 1986 (Aubone et al., 2000). In this area, there are two identified fishing stocks, limited by the 41°S parallel. The southern group (Patagonian stock) is the more important with an abundance of about 85% of the total biomass estimated for this species in 1999 (Aubone et al., 2000). During the late 1990s, the spawning biomass of both stocks and their recruitment indices declined drastically, both of which were attributed to an increase in exploitation (Aubone et al., 2000).

The Patagonian stock of Argentine hake spawns from November through March and peak spawning occurs in January (Macchi et al., 2004). This species is a batch spawner and has indeterminate annual fecundity, which is to say that unyolked oocytes continuously mature and are spawned throughout the reproductive season (Macchi and Pájaro, 2003). Thus, to estimate total fecundity, it is necessary to determinate the number of eggs released at one spawning (batch fecundity) and to estimate the number of batches spawned in a reproductive season (spawning frequency). Macchi et al. (2004) estimated these parameters for the southern stock of *M. hubbsi*. They analyzed total egg production during the reproductive season and determined that the size composition of the spawning fraction influences the reproductive potential of the stock.

Reproductive activity of the Patagonian hake historically has taken place mainly in coastal waters off the Chubut province at depths near 50 m, in the area known as Isla Escondida (43°30′–44°S) (Ciechomski et al., 1983). Since 1997–98, a movement of reproductive hake to deeper waters and a decrease in fish density have been observed (Ehrlich et al.[1]). These changes, mainly in the location of the spawning area, may have affected the reproductive potential of this species, reducing the survival of eggs and larvae. If so, we would expect a negative effect on the number of juveniles recruited after this period.

In this note, we hypothesize that a change in spawning site for Patagonian hake can affect species recruitment. We studied temporal changes in the location and density of spawning aggregations, egg production, and recruitment of this stock in different years between 1988 and 2001.

## Materials and methods

Samples of *M. hubbsi* were collected from the area where the Patagonian stock is known to reproduce during four acoustic surveys in December 1988, 1993, 1996, and 2000 and during six trawl cruises carried out in January between the years 1996 and 2001.

Acoustic surveys covered the Isla Escondida area between 43° and 45°S (Fig. 1). A SIMRAD EK400/QD echointegrator was used for the 1988 survey and a SIMRAD EK500 echosounder and BI500 postprocessing program were employed for subsequent surveys. To avoid possible biases due to the presence of fish in the near-bottom, acoustic transects were carried out at night when hake assume a more pelagic behavior. Trawl catches were carried out during the day, when fish are concentrated close to the bottom, and immediately after each acoustic transect. Because trawls were intentionally biased to those areas of higher fish density, their positions were different between 1988 and 2000. Nevertheless, the study area, transect design, and sampling effort were similar for all cruises covering the main spawning shoals.

In January, information was collected from trawl surveys to assess the Patagonian stock of juvenile hake between 1996 and 2001. These cruises covered a wide area between 43° and 47°S that included a section

* Contribution 1357 from the Instituto Nacional de Investigación y Desarrollo Pesquero, Mar del Plata, Argentina.

[1] Ehrlich, M. D., P. Martos, A. Madirolas, and R. P. Sánchez. 2000. Causes of spawning pattern variability of anchovy and hake on the Patagonian shelf. ICES CM 2000/N:06.

Manuscript submitted 2 July 2003 to the Scientific Editor's Office.

Manuscript approved for publication 20 December 2004 by the Scientific Editor.

Fish. Bull. 103:445–452 (2005).

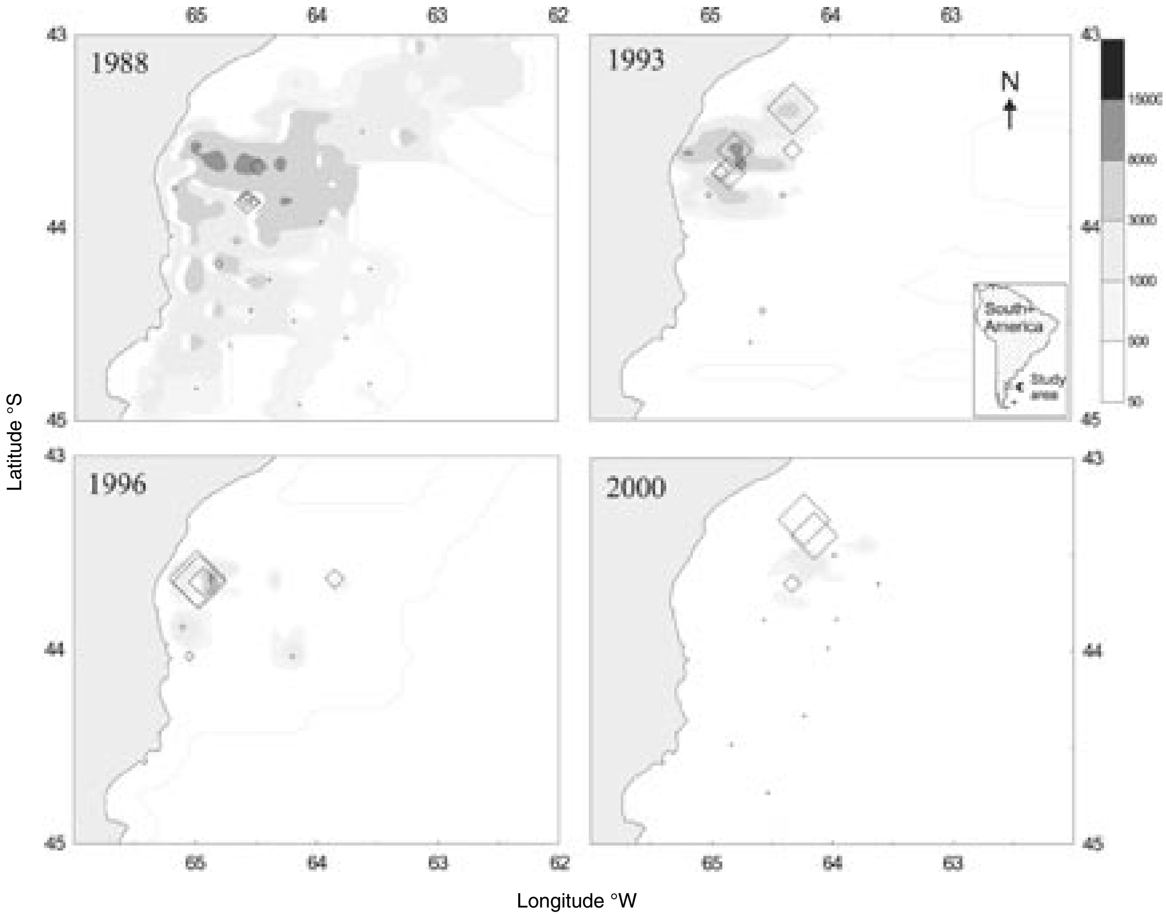


**Figure 1**

Distribution and density ($s_A$) of Argentine hake (*Merluccius hubbsi*) estimated from acoustic surveys carried out during December (1988, 1993, 1996, and 2000) in the Isla Escondida area. The size of the symbols is proportional to the percentage of spawning females (with hydrated oocytes). Vertical shaded scale represents scattering coefficient values (sA), where 7.14 $s_A$ units = 1 t/nautical mile$^2$.

of the main spawning ground of hake. Thus, to analyze spawning individuals we used only data from 33 fish stations located offshore within the spawning area between 43°30′ and 46°S (Fig. 2). Trawl station sites were the same during all cruises. In January of 1996 and 2001 additional information from catches obtained inshore near Isla Escondida was analyzed (Fig. 2).

Argentine hake were collected with a bottom net with a mouth width of about 20 m, a height of about 4 m, and with 20-mm mesh at the inner cover of the codend. Total length (TL) in cm, total weight (TW) in g, and sex were recorded for each fish sampled; for females a subsample was randomly selected from different trawl stations (Table 1) and the maturity stage was determined for each individual. 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 and Pájaro, 2003). This scale was validated by the histological analysis of ovaries collected during December 2000 and January 2001 (Macchi et al., 2004). Females were classified as reproductively active or inactive, according to the presence of yolked oocytes and atresia stages following the criteria of Hunter et al. (1992). When we consider the codes used in the visual assessment of maturity, stages 2 and 3 corresponded to active females, which were capable of spawning at the time of capture or in the near future (Hunter et al., 1992).

Abundance of active females was estimated from data collected during each survey. Information obtained from sampling the trawl catch was expanded to obtain estimates of the number of individuals per length class, following the method described by Macchi et al. (2004).

During December, information from acoustic surveys was used to assign a different weight to each trawl station, based on the relative density and size of the school targeted by the trawl. The transect segment that contained a given trawl was determined and the average value of the water column scattering coefficient

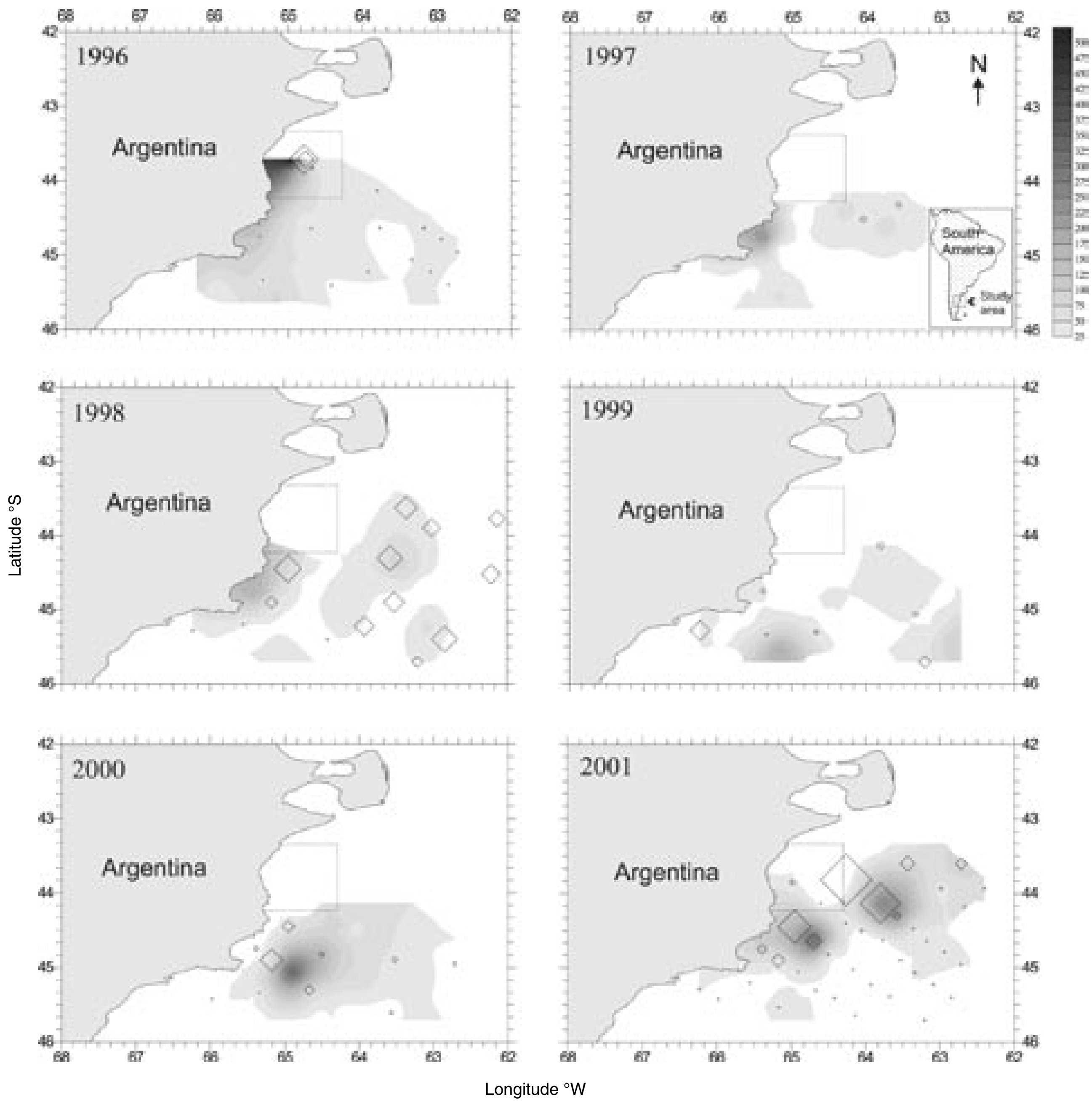


**Figure 2**

Distribution and density of Argentine hake (*Merluccius hubbsi*) estimated from trawl surveys carried out during January (1996–2001) in the offshore area. The size of the symbols is proportional to the percentage of spawning females (with hydrated oocytes). The square shows the Isla Escondida area. Vertical shaded scale represent biomass in t/nautical mile$^2$.

(sA) was calculated and weighed by the corresponding number of acoustic observations.

The number of active females for each survey was estimated by multiplying the number of hake within each length class by the proportion of females and the proportion of active females for that length class obtained for that survey (Marshall et al., 1998). The sum of values estimated across the size range was an index of the number of reproductive females in the sampled area during that survey.

Egg production of the Patagonian hake in December during the period 1988–2000 and in January from 1996 to 2001 was based on estimates of three variables: the abundance of active females per length class, the

**Table 1**
Number of Argentine hake (*Merluccius hubbsi*) sampled during research surveys carried out in the north Patagonian area in December and January, between 1988 and 2001.

| Period | Number of trawls | Number of individuals sampled | Number of females subsampled |
|---|---|---|---|
| December | | | |
| 1988 | 18 | 9527 | 2054 |
| 1993 | 6 | 2156 | 1060 |
| 1996 | 9 | 1563 | 690 |
| 2000 | 12 | 4390 | 708 |
| January | | | |
| 1996 | 38 | 17,715 | 1509 |
| 1997 | 33 | 12,687 | 842 |
| 1998 | 33 | 15,804 | 1092 |
| 1999 | 33 | 14,987 | 817 |
| 2000 | 33 | 14,389 | 958 |
| 2001 | 37 | 17,944 | 856 |

batch-fecundity–size relationship, and spawning frequency. The batch fecundity–total-length relationship and the spawning frequency values used for December (1988–2000) and for January (1996–2001) were those estimated in December 2000 and January 2001, respectively (Macchi et al., 2004). We assumed that these values were applicable to all previous years, because in general, annual differences of these variables were not significant for hake females of the same length range (Macchi et al., 2004).

Egg production by length for each month was estimated by multiplying the number of active females in each length class by the batch fecundity corresponding to that length class and by the number of spawnings estimated for each month. The sum of the egg production values estimated across the size range was the total number of eggs produced in the sampled area during each month (December or January) in different years.

To analyze the relationship between egg production and recruitment, estimates of the relative abundance at age 1 (number of individuals per trawl hour) of Argentine hake were used as a recruitment index. These data were obtained from samples to assess hake juveniles collected from the whole area covered during the cruises carried out in January 1997–2001. In 2002, this index was estimated with samples collected in the same area, but in a different month (March) (GEM, unpubl. data[2]). The number of age-1 individuals in year $t$+1 was the recruitment index corresponding to the year $t$.

## Results

### Abundance of hake and location of spawning females

Figure 1 shows the acoustic densities estimated for Argentine hake and the distribution of spawning females (with hydrated oocytes) in the Isla Escondida area during December 1988, 1993, 1996, and 2000. A decline in hake abundance from 1988 to 2000 was observed—in particular, a drastic decrease in 2000, when the mean density value (14.6 t/nautical mile$^2$) was thirty times less than that estimated in 1988 (469.2 t/nautical mile$^2$). During December 1988–96, spawning females were mainly located in the northern area (between 43° and 44°S) inshore at depths lower than 50 m. In 2000 reproductive activity was concentrated at the same latitude as in previous years, but offshore (Fig. 1).

In January 1996 the highest densities of *M. hubbsi* and the spawning females of this species were located in the Isla Escondida area (Fig. 2). Between 1997 and 2000 we did not obtain data from this zone, but the increase in the proportion of spawning hake in deep waters observed since 1998 indicates a spatial change in the reproductive area. During January 2000 and 2001, in addition to the increase of reproductive females offshore, the abundance of hake was higher than that estimated previously for the same area (Fig. 2). In January 2001, trawl stations located near Isla Escondida showed very low values of hake density, in contrast to that observed offshore. This contrast could be attributed to the movement of individuals from the traditional spawning area near the coast to deeper water.

### Egg production

Egg production estimated for December in the Isla Escondida area showed a considerable decrease from 1988 to 2000 (Fig. 3). The number of eggs produced

[2] GEM (Grupo de Evaluación Merluza). 2002. Evaluación del estado del recurso merluza (*Merluccius hubbsi*) al sur de 41° S, año 2002. Unpubl report. INIDEP, CC. 175, Mar del Plata (7600), Argentina.

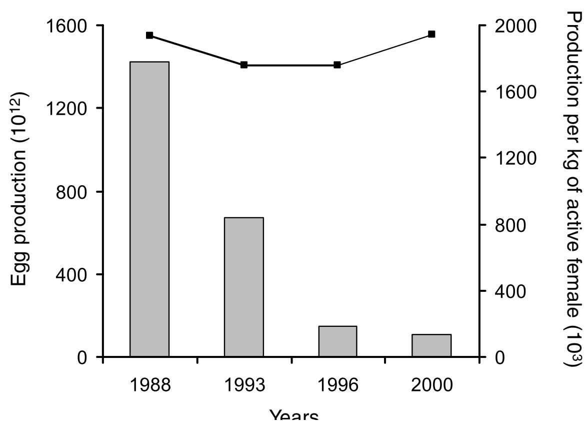


**Figure 3**

Egg production of Argentine hake (*Merluccius. hubbsi*) estimated for December (1988, 1993, 1996, and 2000) in the Isla Escondida area (bars), and production by unit-weight of reproductively active female (line) for the same month.

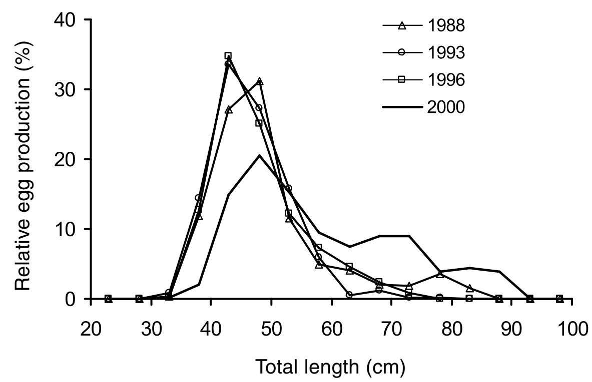


**Figure 4**

Relative egg production (%) by length class estimated for Argentine hake (*Merluccius hubbsi*) from December 1988, 1993, 1996, and 2000.

per unit of weight (kg of active females) declined from 1988 to 1996, and to a value of around 1700 eggs/kg in the last year (Fig. 3). During December 2000, however, relative egg production increased to 2000 eggs/kg, which can be attributed to the effect of a higher proportion of larger females in reproductive activity. In fact, when the percentage of eggs produced by length class was analyzed, the distribution obtained for December 2000 was different from that for 1988, 1993, and 1996 (Fig. 4). During the earlier years, production mainly depended on young females (<50 cm TL), whereas in December 2000 most of the eggs produced (about 70%) where spawned by females larger than 50 cm TL.

Egg production estimated for the offshore area in January increased from 1996 to 2001 (Fig. 5), in contrast to that observed during December in shallow water near Isla Escondida. The number of eggs produced per unit of weight of active females was similar in 1996 and 1997 (about 1600 eggs/kg), but increased in 1998–2001 to about 1800 eggs/kg. This increase was similar to that observed for December 2000, which was attributed to the higher proportion of larger females within the spawning fraction of hake. In fact, percentage-distribution of eggs produced by length class showed a change beginning in 1998 (Fig. 6). In 1996 and 1997, 70% of the eggs were produced by young females (<50 cm TL), but subsequent production of old females increased to 60% in 1998–99 and to 70% in 2000–01.

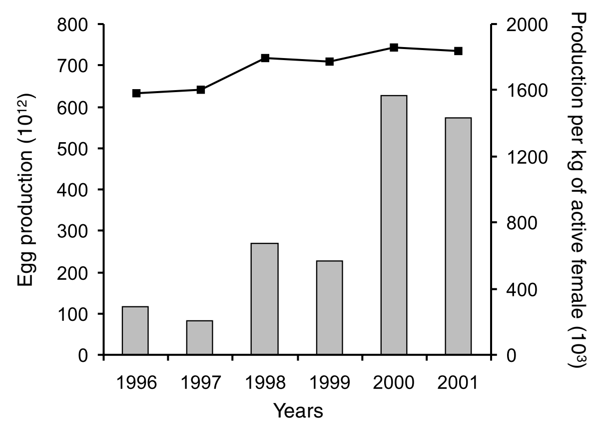


**Figure 5**

Egg production of Argentine hake (*Merluccius hubbsi*) estimated for January (1996–2001) in the offshore area (bars), and production by unit-weight of reproductively active female (line) for the same month.

### Recruitment

Relative abundance data for hake at age 1 (year $t$+1) in the north Patagonian area were contrasted with the egg production obtained in January from the previous year (t). To estimate egg production, only information from the offshore area was used; thus, the number of eggs estimated was a fraction of that produced by all spawning females in January. However, the increase in egg production observed offshore for the parental stock in 2000 and 2001 was coincident with higher values of age-1 recruitment estimated one year later during 2001 and 2002, respectively (Table 2).

## Discussion

The spatial pattern of *M. hubbsi* spawning aggregations inshore and offshore of the north Patagonian area between 1988 and 2001 has changed since 1998. This

**Table 2**

Egg production estimates for Argentine hake (*Merluccius hubbsi*) for January cruises (1996–2001) taken offshore of the north Patagonian area, and indices of abundance at age 1 corresponding to these annual classes.

| Year | Egg production ($10^{12}$) | Index of age-1 hakes (individuals per trawl hour) |
|---|---|---|
| 1996 | 116.625 | |
| 1997 | 81.774 | 347 |
| 1998 | 270. 512 | 438 |
| 1999 | 228.020 | 133 |
| 2000 | 627.484 | 250 |
| 2001 | 572.485 | 1367 |
| 2002 | | 2444 |

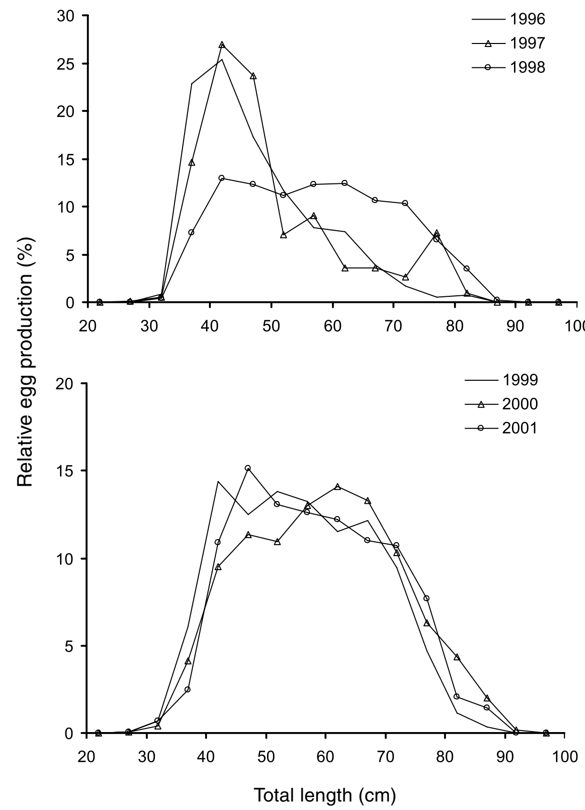


**Figure 6**

Relative egg production (%) by length class estimated for Argentine hake (*Merluccius hubbsi*) in January from 1996 to 2001.

change was characterized by a decrease in density on shoals and a movement of spawning females to deeper water, withand a more scattered distribution than in the early 1990s. Our results confirm previous observations reported by Ehrlich et al.[1], who analyzed ichtyoplankton samples collected from 1973 to 1999, in the traditional spawning area of Isla Escondida. These authors did not observe significant environmental anomalies that might have affected the spawning of hake and associated the change with the high levels in fishing exploitation in the 1990s. These shifts in the pattern of reproduction led to the following question: "How does the movement of the center of spawning affect the recruitment of Patagonian hake?"—given that different environmental conditions could be present in the new spawning area.

Our analyses show that the abundance of active females offshore of the north Patagonian area increased from 1998 to 2001, coinciding with a significant decrease in hake biomass in the shallow waters of Isla Escondida. During these years, demographic changes in the offshore area were characterized by an increase of larger females (>50 cm TL) compared to previous years. The increase in proportion of older individuals in spawning condition may result in a greater contribution to egg production because of the higher fecundity produced by larger females (Mairteinsdottir and Thorarinsson, 1998). In fact, egg production estimated for the offshore Patagonian hake during January showed an increase since 1998, with the highest values in 2000 and 2001 (400% more than those estimated in 1996–97). A high proportion (70%) of these eggs were spawned by females larger than 50 cm TL (≥5-year old, Otero et al., 1986), whereas in January 1996 and 1997 eggs were mainly produced by young females.

Because of the displacement of active females to deep water, the offshore north Patagonian area from 43°30′ to 45°S and between 50 m and 100 m depths was considered an important section of the spawning ground for Patagonian hake after 1998. The comparison between the January 1996 and 2001 surveys, in which inshore and offshore samples of the north Patagonian area were collected, demonstrated this change. In January 1996, spawning of Patagonian hake was concentrated inshore (Isla Escondida), whereas in January 2001 reproduction of this stock took place mainly offshore (Fig. 2). For this reason, the offshore egg production value obtained after 1998 was considered a representative index of the spawning area.

Relative abundance of hake at age 1 (number of individuals/hour) in the north-Patagonian area, showed a decline from 1996 to 2000 and an increase in 2001 and 2002, reaching the highest values of the study period. The recruitment index obtained for 2002 (2444 individuals/h) was about twice that estimated for 2001 (1367 individuals/h). According to Santos et al.,[3] it is possible that this value has been overestimated, because it was determined

[3] Santos, B. A., E. B. Louge, and R. Castrucci. 2003. Estudio de las variaciones conjuntas de la temperatura y de la salinidad del área de cría de la merluza con los índices de abundancia de los grupos de edad 0, 1 y 2. (enero 1995–enero 2002). Tech. Rep. 10/03, 6 p. INIDEP, CC. 175, Mar del Plata (7600), Argentina.

from samples collected two months later (March) than those during 1996–2001. These authors suggested that the spatial distribution or catchability of juvenile hake could have changed from January to March, resulting in a greater abundance index during 2002.

The higher recruitment levels observed for Patagonian hake during 2001 and 2002 were coincident with higher indices of egg production estimated offshore in January during the two previous years (2000 and 2001). Therefore, in principle we concluded that the change in spatial location of spawners in the Patagonian stock did not appear to negatively affect the recruitment of this species. The next question to be answered is: "Why were recruitment indices in the early 2000s higher than in previous years?"

Several authors have analyzed the spawner-recruit relationship in different species and have concluded that recruitment is often positively correlated with spawner biomass estimated from virtual population analysis (VPA) (Myers and Barrowman, 1996). In the case of Patagonian hake, the increase in abundance at age 1 observed in 2001 and 2002 was not associated with higher values of the VPA-based spawner biomass in previous years (GEM, unpubl. data[2]). Thus, environmental and ecological factors affecting prerecruit mortality should be considered, mainly in association with a no-fishing area implemented in 1997. Moreover, the demographic composition and the nutritional state of spawning females (maternal effect) are other factors that have been related to recruitment levels (Trippel et al., 1997; Kjesbu et al., 1998; Cardinale and Arrhenius, 2000).

Analysis of hydrographic characteristics from the north-Patagonian waters in the 1980s and 1990s indicated that the Patagonian shelf, including the Isla Escondida area, is a relatively stable environment (Erhlich et al.[2]). On the other hand, analysis of temperature and salinity data collected from 1995 to 2002 in the nursery area of the Patagonian stock (San Jorge Gulf), showed that higher values of salinity and temperature during the time of hatching were associated with higher indices of abundance at age 1, one year later (Santos et al.[3]).

The high proportion of larger females in the offshore area mainly in 2000 and 2001 may have affected the quality as well as the quantity of hake progeny. In general, older females produce larger eggs and larger larvae with higher rates of survival, in combination with more egg batches over a longer spawning season (Kjesbu et al., 1996; Trippel, 1998). Previous reports showed that *M. hubbsi* older than 5-years have a longer spawning season (Macchi et al., 2004) and produce heavier eggs than young females do (Pájaro et al.[4]). Thus, an increase in the proportion of older spawning females in the stock may result in improved recruitment, as has been reported for other species (Mairteinsdottir and Thorarinsson, 1998).

The fishing regulation for Patagonian hake implemented in the late 1990s mainly affected bottom trawlers and the factory freezer fleet, which applied greater fishing effort in the north Patagonian area during the 1990s. It is possible that this decline in harvesting pressure by trawlers on Patagonian hake after 1997 influenced the reproductive success of this species. Stress can have a negative impact on fish reproduction (Campbell et al, 1994; Clearwater and Pankhurst, 1997). The potential effects of trawl avoidance can affect the reproductive physiology and behavior during spawning, which could lead to the production of fewer viable juveniles (Morgan et al., 1999).

Finally, other factors, such as predation and feeding conditions within the new spawning ground of Patagonian hake, can affect survival of the early life stages. In addition, future studies should include a comparison between the inshore and offshore waters of the north-Patagonian area with respect to the abundance of jellyfish (i.e., Medusae and Ctenophora), which are known to be major predators of fish eggs and larvae (Bailey, 1984; Fancett, 1988).

## Acknowledgments

We thank Jorge Hansen for assistance with the method used to estimate fish abundance. We would also like to thank Hector Cordo for reading and making suggestions to improve the manuscript.

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