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Comparative study of spawning pattern and reproductive potential of the Northern and Southern stocks of Argentine hake (*Merluccius hubbsi*)

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ABSTRACT

The reproductive biology of the Northern (Bonaerense) and Southern (Patagonian) stocks of *Merluccius hubbsi* in the Argentinean Sea is analyzed, including information on spawning areas, estimates of abundance and size composition of spawning females, fecundity, spawning frequency and egg quality. Samples of Argentine hake were obtained during the period of peak reproductive activity; May and January for the Northern and Southern stocks, respectively.

The size of the reproductive area for the Northern stock (35–38°S) was clearly smaller than the one estimated for the Southern population (43°30′–46°S), being 23,770 km^2 and 52,460 km^2 respectively. Spawning females from the Northern reproductive area were smaller (modal values between 35 and 40 cm TL) than those from the Southern stock (modal values between 38 and 50 cm TL), and they were also less abundant in number and had a lower spawning frequency (8–13 days and 5–7 days between partial spawning for the Northern and Southern stocks respectively). No differences in batch and relative fecundity between stocks were recorded (mean values of 526 and 530 hydrated oocytes g^{-1}), but the dry weights of hydrated oocytes from females of the Northern group were higher (3.08 mg for 100 hydrated oocytes) than those of the Patagonian stock (2.84 mg) for the same total length range. The egg production during the month of peak spawning of the Northern group depended mostly on the smaller females (<50 cm TL) and was in average 1 to 2 orders of magnitude lower than that estimated for the Southern stock (9×10^{12}–22×10^{12} eggs and 692×10^{12}–1295×10^{12} eggs for the Northern and Southern stocks respectively). Those differences in egg production and the high productivity and retentive characteristics described for the spawning area and nursery ground in Patagonian waters would justify the greater abundance and resilience of the Southern stock of Argentine hake. The low abundance of females in spawning capable stage observed during the reproductive season of the Northern group (autumn–winter), led us to postulate that currently it does not exist a pronounced reproductive peak in this stock similar to the one observed for the Southern hake group during the summer.

1. Introduction

Argentine hake (*Merluccius hubbsi*) is a demersal species distributed from 22°S to 55°S at depths mainly between 50 and 500 m (Cousseau and Perrotta, 1998). This is the main fishery resource for the Argentine and Uruguayan bottom trawler fleet (FAO, 2003), with an abundance of around one million tons, as estimated in 2012 (Irusta and D´Atri, 2013; Santos and Villarino, 2013). In Argentina, two main hake stocks were identified: the Northern or Bonaerense group (between 34°S and 41°S), which is shared with Uruguay into the Argentine–Uruguayan Common Fishing Zone, and the Southern or Patagonian group ranging between 41°S and 55°S. Studies of ichtyoplankton distribution (Ehrlich, 2000; Ehrlich and Ciechomski, 1994; Gonçalves Torres-Pereira, 1983) and gonadal maturity of Argentine hake individuals (Louge, 1996; Rodrigues and Macchi, 2010) showed that the reproductive activity of the Northern stock takes place mainly during autumn and winter, with a main peak in May, mostly at north of 38°30′S. As the reproductive period progresses spawning females move toward the northern area (Ehrlich, 2000; Rodrigues and Macchi, 2010), reaching Brazilian waters (32–34°S), where hake eggs have been observed during late winter (Gonçalves Torres-Pereira, 1983). Martos et al. (2005) define this region as a mixed water area, with a strong influence of the Rio de la Plata discharge (which conform a permanent saline front of large-scale) and characterized by a high primary productivity, driven mainly by the nutrient input from river discharges and by the high vertical stability of the water column (Acha et al., 2004; Viñas et al., 2002).

From an economic point of view the Southern group of *M. hubbsi* is the most important one, with an abundance of about 80% of the total biomass estimated for this resource in Argentina (Santos and Villarino,

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2013). Its reproductive activity takes place mainly in waters off the Chubut province, between 43° and 45°30′S at depths from 50 to 100 m. However, unlike the Northern stock, spawning occurs during spring and summer with a main peak in January (Macchi et al., 2004; Pájaro et al., 2005). The hydrography of the north Patagonian shelf is characterized by a frontal system produced as a result of the dynamics of tides. This tidal front separates homogeneous coastal waters from the stratified ones (Glorioso, 1987), and it is characterized by a high biological productivity caused by phyto-plankton blooms and large aggregations of copepods (Ramírez et al., 1990). In the Patagonian region the formation of this oceanographic structure occurs in spring and summer, during the spawning of the Southern hake stock. Therefore, this scenario clearly creates a suitable habitat for spawning and survival of the early life stages of this species (Sánchez and Ciechomski, 1995).

Since the 1990s both stocks of *M. hubbsi* have been exposed to high levels of exploitation and their biomass has decreased drastically, in particular the Northern group (Aubone et al., 2000; Irusta and D´Atri, 2013; Pérez, 2000; Santos and Villarino, 2013). Additionally, changes have been recorded on the length and age structure of both stocks (Irusta and D´Atri, 2013; Santos and Villarino, 2013) and in the location of spawning shoals for the Southern group (Macchi et al., 2005).

In this context, we hypothesize that changes in the parental stock structure may have consequences on the reproductive potential of hake, considering the relationship between the size of spawners and the quantity and quality of produced eggs (Trippel, 1998; Marshall et al., 1998). These changes should have been more significant in the Northern group, taking into account that the fishing activity on this stock has been much more intense during the last years and began earlier than in the Patagonian region. Therefore, the main goal of this paper was to compare the spawning pattern and reproductive potential of the Northern and Southern hake stocks, by estimating the egg production and oocyte quality. These variables were analyzed in relation to the size structure of spawners during the main reproductive peak of each stock, between 2009 and 2012.

2. Materials and methods

2.1. Spawning area, abundance and length distributions of active females

Samples of *M. hubbsi* were obtained from bottom trawls during 7 research surveys conducted by the National Institute for Fisheries Research and Development (INIDEP) during the reproductive peak of both Argentine hake stocks; three of them were carried out in the area of Buenos Aires Province (Northern or Bonaerense stock) in May 2009, 2011 and 2012, and the other four in the Patagonian area (Southern or Patagonian stock) in January 2009, 2010, 2011 and 2012 (Table 1; Fig. 1).

The fishing trawls were distributed in transects perpendicular to the bathymetry, covering the main reproductive areas of both stocks. Argentine hake specimens were captured at depths between 50 and 300 m using a bottom trawl with a mouth width of about 20 m, a height of about 4 m, and with a 20-mm mesh size at the inner lining of the codend.

Table 1
Number of Argentine hake (*Merluccius hubbsi*) specimens sampled during the research surveys carried out in autumn (Northern stock) and summer (Southern stock) between 2009 and 2012.

Stock	Year	Trawls	Research surveys date	*N* individuals sampled
Northern	2009	66	May 15–Jun 2	5287
	2011	77	May 17–Jun 7	7542
	2012	75	May 15–Jun 4	5980
Southern	2009	86	January 15–January 29	15813
	2010	83	January 22–February 2	19683
	2011	72	January 24–February 9	13487
	2012	89	January 11–January 22	19362

From each specimen it was recorded: total length (TL) in centimeters, total weight (TW), gutted weight (GW), and liver weight (LW) in grams, sex and macroscopic gonad maturity stage. For this, a visual maturity key of five stages was used: (1) immature, (2) developing, (3) spawning capable, (4) regressing and (5) regenerating (Macchi and Pájaro, 2003; Brown-Peterson et al., 2011). This scale was validated for females by histological analysis of 6425 ovaries (1922 from the Northern stock and 4503 from the Southern stock). The ovaries collected were preserved in 10% formalin during the cruise, and later they were weighed (GW) and a portion of tissue was removed from the center of each gonad, dehydrated in methanol, cleared in xilol and embedded in paraffin. Sections were cut at approximately 5 μm thick and stained with Harris' hematoxylin followed by eosin counterstain. Histological staging of ovaries was based on the stage of oocyte development, the occurrence of postovulatory follicles (POF) and atresia, following the classification described for the Southern stock of Argentine hake (Macchi et al., 2004).

Indices of abundance of active females per length class were estimated by stock and year of the period analyzed, during the main spawning peak of each hake population (May and January for the Northern and Southern stock respectively). The information obtained from sampling of the trawl catch was weighted in order to obtain estimates of abundance (number of individuals per length class) in the spawning area as detailed by Macchi et al. (2004). It was calculated by multiplying the number of hake within each length class by the proportion of active females for that length class (Marshall et al., 1998). The sum of values estimated across the size range was an index of the total number of active females for each year during the reproductive peak of each hake stock.

Length distributions of active females or spawning capable (Brown-Peterson et al., 2011) were analyzed, considering in these stages only those individuals capable of spawning at the time of capture or within this spawning season (Hunter et al., 1992).

2.2. Spawning frequency

The spawning frequency (number of days between partial spawnings) was estimated from the daily proportion of spawning females sampled for each year during the reproductive peak of each stock. This variable was determined by the incidence of females with day 1 POF (between 24 and 48 h from spawning), owing to that 48 h after spawning postovulatory follicles could not be consistently identified because of their rapid degeneration. On the other hand, the occurrence of postovulatory follicles less than 24 h old is affected by hour of sampling and sexual composition of the school (Hunter and Goldberg, 1980). Mean and variance were calculated according to the equations developed by Picquelle and Stauffer (1985).

2.3. Fecundity

Batch fecundity (BF: number of hydrated oocytes released per spawning) and relative fecundity (RF: number of hydrated oocytes per gram of body weight) were estimated gravimetrically with the hydrated oocyte method on fixed ovarian samples (Hunter et al., 1985), using only ovaries that showed no evidence of recent spawning (i.e., no POF). For these determinations were selected 141 ovaries of females from the Northern stock and 371 ovaries from the Southern stock. Three pieces of ovary, approximately 0.1–0.2 g each, were removed from the anterior, middle, and posterior parts of one gonad and weighed to the nearest 0.1 mg, and hydrated oocytes were counted. Batch fecundity for each female was the product of the mean number of hydrated oocytes per unit of weight and the total weight of the ovaries. Relative fecundity was determined as the batch fecundity divided by female weight (without ovary).

The relationships of BF to TL obtained first among years and later between stocks were compared on the basis of overlapping length ranges