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Species biology of elasmobranch by-catch in bottom-trawl fishery on the northern Patagonian shelf, Argentina

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ABSTRACT: The present study analyzes the species composition of elasmobranch by-catch of bottom trawlers that targeted common hake *Merluccius hubbsi* on the northern and central Patagonian shelf during 2001, 2002 and 2003. Six surveys were conducted, and a total of 20 species of elasmobranchs were observed. *Zearaja chilensis* and *Squalus acanthias* were present in all surveys. The mean values of relative abundance ranged between 9.12 and 151 ind. km^{-2} for *Z. chilensis* and between 8.24 and 298 ind. km^{-2} for *S. acanthias*. *Bathyraja brachyurops*, *B. macloviana*, *B. magellanica*, *Discopyge* sp. and *Psammobatis lentiginosa* were registered only in 1 survey, and their relative abundance did not exceed 15 ind. km^{-2}. There were no patterns detected between the mean size of the individuals and the depth of capture for any of the captured species. Length-to-weight relationships were estimated for 14 species, and size-at-maturity was estimated for 8 species.

KEY WORDS: By-catch · Size-at-maturity · Elasmobranchs · Length-to-weight relationships

INTRODUCTION

Elasmobranchs are particularly vulnerable to overexploitation. Their K-selected life-history strategy results in low growth rates and low resilience to fishing mortality (Hoenig & Gruber 1990, Frisk et al. 2001). Thus, management of any fishery that captures sharks and skates, either directly (target species) or indirectly (by-catch), must consider the impact on their populations to avoid overfishing and population decline (Cortés 2000). A decrease in elasmobranch abundance may directly (i.e. reducing predation) or indirectly (i.e. reducing competition) affect other species of the marine community (Stevens et al. 2000, Shepherd & Myers 2005, Ruocco et al. 2012), since they are key species in most ecosystems (Stevens et al. 2000). Despite the key role that elasmobranchs play in ecosystems, the basic biological information needed for responsible management is lacking for many species, including minimum, maximum and average sizes, age-at-maturity estimations and length-to-weight relationships. These data are essential for understanding growth rate, age structure and other aspects of elasmobranch population dynamics. In Argentine waters, studies on elasmobrachs have been neglected, but in the last 10 yr this situation has changed (Lasta 2003). This new data led to the creation in 2007 of a national plan of action for elasmobranch conservation and management (Perez Comesaña et al. 2011). The first step in this plan was to carefully review the available information on several species and to identify knowledge gaps in order to determine key lines of research (Perez Comesaña et al. 2011). In this context, the amount of information available and the number of works published increased significantly (Lasta 2003, Colonello et al. 2011, Perez Comesaña et al. 2011) in an effort to increase baseline information on elasmobranchs. Several of these studies involved the analysis of reproductive and trophic characteristics (Lucifora et al. 1999, Koen Alonso et al. 2001, Crespi-Abril et al. 2003, Elías et al. 2005, Ruocco et al. 2006, Scenna 2011).

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Bottom-trawl fishery uses non-selective gear (Kelleher 2005) and captures several non-target species. In Argentina, bottom trawling is practiced over the Argentine shelf to capture the common hake *Merluccisus hubbsi* (Marini, 1933). This resource sustains one of the most important fisheries in Argentina in terms of both landings and fishing effort. Since the early 1980s the main fishing grounds of this fishery (where most of the fishing effort is located) are in the Patagonian region (south of 41° S) (Bezzi et al. 1994, Aubone et al. 2004). Elasmobranchs are a common but unspecified by-catch in this fishery as they are in many of bottom-trawl fisheries worldwide (Stevens et al. 2000, Kelleher 2005). Unfortunately, few species-specific data from elasmobranchs are available on the main fishing grounds of northern Patagonia, and less is known about the status of each stock affected. However, recently, large annual landings of elasmobranchs have been a cause of concern in Argentina. Only a few studies have focused on evaluating the fraction of the population that is affected by the fisheries in Argentina (Chiaramonte 1998, Perez Comesaña et al. 2011). Up to present, no studies have been conducted to determine the species of elasmobranchs affected by the common-hake bottom-trawl fishery. In order to address this situation, the objectives of this paper are to report elasmobranch species affected by the common-hake bottom-trawl fishery that operates in northern Patagonia and to provide baseline information on sex ratios, estimations of the species' size-at-maturity (whenever this was possible), and the proportion of mature individuals captured.

MATERIALS AND METHODS

Fishing methods and study area

Surveys were conducted on board 3 vessels of 42 m in length and 1200 HP in engine power equipped with bottom-trawl nets. The opening of each net was approximately 30 m wide and 3 m in height, and the mesh size was 120 mm. Vessels fit in Category IV of the bottom-trawl fleet that fishes common hake *Merluccius hubbsi* which represents >70% of the total fishing effort in the studied area (Sánchez et al. 2011). Surveys were conducted on the Argentine shelf between 41 and 47°S in a depth range of 60 to 120 m (Fig. 1), which is the major fishing ground for bottom trawlers. Also, this area comprises the most important reproductive ground for common hake (Pájaro et al. 2005); thus, a permanent closure is in place to protect juveniles (Fig. 1).

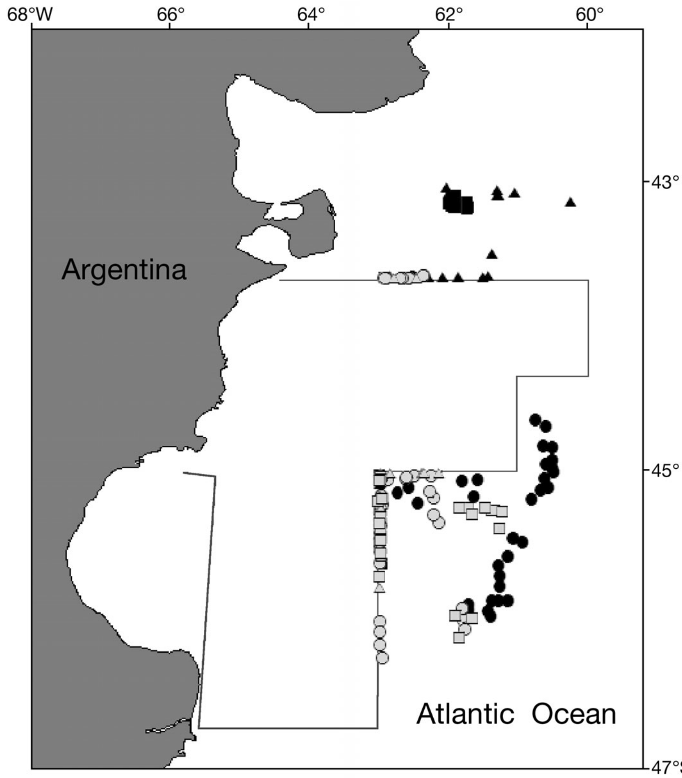

Fig. 1. Map of the study area and the different surveys. ●: September 2001; ▲: December 2001; ■: March 2002; ●: August 2002; ▲: January 2003; ■: July 2003. The area enclosed by the black line represents the permanent closure for the *Merluccius hubbsi* fishery

Data collection

Six surveys were carried out in September and December 2001, March and August 2002, and January and July 2003 (Fig. 1), and a total of 57 tows were analyzed (8 in September 2001, 6 in December 2001, 6 in March 2002, 14 in August 2002, 17 in January 2003, and 6 in July 2003). The duration of each tow was 4 h, and towing speed was approximately 4 knots (7.2 km h^{-1}). In each tow, elasmobranchs were identified using species keys (Menni et al. 1984, Cousseau et al. 2000). Specimens were sexed, and total length (TL, cm) was measured on board. In order to determine the proportion of mature animals captured, individual maturity was determined on board by direct observation of the macroscopic gonad status. Females were considered mature when the ovaries presented large and yellowish oocytes, oviducts were well developed and oviductal glands were large (>2 mm maximum width) and whitish (Colonello et al. 2011). In the case of males, the criteria for defining sexual maturity were wide and rose-colored testes, the presence of seminal fluid in the spermatic ampulla, the presence of a coiling epididymis and the claspers were longer than the tips of posterior pelvic fin-lobes, with the skeleton hardened and the axial cartilages hardened and pointed (Colonello et al. 2011).

Statistical analysis

The size-at-maturity of species was calculated as the proportion of mature males and females in 1 cm TL classes (TL50%). For both sexes, a logistic curve of maturity was fitted by regression to the proportion of mature individuals in the size classes using the least-square method and the relationship:

$$P_i = \frac{1}{1+e^{-(a+b \cdot TL_i)}} \quad (1)$$

where P_i and TL_i are, respectively, the proportion of mature individuals and the mantle length of size class '*i*', and *a* and *b* are constants. Size-at-maturity was calculated as TL50% = −*a*/*b*, and goodness-of-fit of the model was tested with a generalized linear model (GLM), assuming a binomial distribution of the data and using a logit link-function. Additionally, sex proportions during each survey were estimated and differences from a 1:1 ratio were analyzed using the binomial test. Data regarding tow duration and speed were recorded to estimate the relative abundance of each species, expressed as the number of individuals per km^2 swept area. The frequency of occurrence of each species was estimated as:

$$\%FO_i = \frac{T_j}{T} \times 100 \quad (2)$$

where $\%FO_j$ is the frequency of occurrence of species '*j*' expressed as percentage, T_i is the number of tows on which the species '*j*' was present and *T* is the number of tows analyzed. In order to analyze the mean size variation as a function of depth, the Friedman test for multiple dependent samples was performed for each species. For this test, the variable 'depth' was categorized in ranges of 10 m. For each species, the length–weight relationship was fitted by a linear regression using the least-square method on the natural logarithm of the variables. Model comparisons between sexes were made by analysis of covariance. Also, the hypothesis of isometric growth was tested using Student's *t*-test for slope comparisons.

RESULTS

Relative abundance

Twenty species of elasmobranchs were recorded (Table 1). The relative abundance and frequency of occurrence of species were variable (Tables 2 & 3). *Zearaja chilensis* and *Squalus acanthias* were the only species present in all surveys and were present in >90% of the tows analyzed, reaching values of relative abundance >140 ind. km^{-2} (Table 2). No spatial aggregation was observed for either species (Fig. 2). The major abundances of *Z. chilensis* were observed in autumn and winter, and the major abundances of *S. acanthias* were observed in winter and spring (Table 2). *Schroederichthys bivius*, *Psammobatis normani* and *Psammobatis rudis* were present in 5 out of 6 surveys, and their frequencies were lower (%FO between 60 and 80%; Table 3). Their relative abundances were <45 ind. km^{-2} (Table 2). The first 2 species presented a marked spatial aggregation and were more abundant in the southern region of the studied area (Fig. 2). The highest abundances were observed in winter and spring for both species (Table 2). Conversely, *P. rudis* was present in the northern and southern region of the studied area (Fig. 2), and the highest abundances were observed in autumn and winter (Table 2). The presence of *Bathyraja albomaculata*, *B. macloviana*, *B. scaphiops*, *Atlantoraja cyclophora*, *Myliobatis* sp., *Amblyraja doellojuradoi*, and *S. guggenheim* was sporadic throughout the samples. They were recorded in 1 of the 6 surveys with low values of%FO (<14%; Table 3), and the relative abundance was <45 ind. km^{-2} (Table 2).

Length-to-weight relationship

Length-to-weight relationship was estimated for 14 species (Table 4). The covariance analysis revealed no significant differences in the length-to-weight relationships between males and females for any of the species (Table 4); therefore, 1 equation was used for each species, and the parameters were calculated using both sexes combined (Table 4). Six species presented allometric growth type (Table 4).

Size structure, sex proportion and size-at-maturity

The smallest individual captured was 21 cm TL (*Zearaja chilensis*; Fig. 3) and the largest was 120 cm

Table 1. List of elasmobranchs captured by bottom-trawl fishery and number of individuals (M: males; F: females) captured in each survey. *Surveys where the proportion of sexes was significantly different from 1:1

	Survey (no. of tows)					
	Sep 2001 (8)	Dec 2001 (6)	Mar 2002 (6)	Aug 2002 (14)	Jan 2003 (17)	Jul 2003 (6)
Batoidea						
Myliobatiformes						
Myliobatis sp.			M: 0 F: 1			
Rajiformes						
Amblyraja doellojuradoi (Pozzi, 1935)	M: 1 F: 2					M: 1 F: 0
Atlantoraja cyclophora (Regan, 1903)			M: 1 F: 4			
Bathyraja albomaculata (Norman, 1937)	M: 9 F: 10					M: 0 F: 1
Bathyraja brachyurops (Flower, 1910)	M: 11 F: 17	M: 0 F: 2		M: 6 F: 8	M: 23 F: 13	
Bathyraja macloviana (Norman, 1937)	M: 14 F: 18					M: 0 F: 1
Bathyraja magellanica (Steindachner, 1903)			M: 4* F: 12	M: 0 F: 1	M: 0 F: 6	M: 4 F: 3
Bathyraja multispinis (Norman, 1937)	M: 3 F: 8					M: 0 F: 4
Bathyraja scaphiops (Norman, 1937)		M: 0 F: 4				M: 0 F: 1
Psammobatis lentiginosa (McEachran, 1983)	M: 18 F: 16	M: 0 F: 12			M: 5 F: 4	
Psammobatis normani (McEachran, 1983)	M: 43 F: 50	M: 0 F: 4		M: 132* F: 109	M: 68* F: 105	M: 67 F: 77
Psammobatis rudis (Günther, 1870)	M: 4 F: 3	M: 8 F: 7	M: 3 F: 5		M: 43* F: 139	M: 84 F: 78
Zearaja chilensis (Guichenot, 1848)	M: 140* F: 180	M: 69* F: 29	M: 107* F: 29	M: 87* F: 60	M: 158* F: 117	M: 268* F: 189
Torpediniformes						
Discopyge sp.			M: 16* F: 29		M: 0 F: 4	
Galeomorphii						
Carcharhiniformes						
	F: 17	F: 9		F: 12	F: 15	F: 39
Galeorhinus galeus (Linnaeus, 1758)	M: 1* F: 10	M: 1 F: 0	M: 10 F: 5			
Mustelus schmitti (Springer, 1939)	M: 14 F: 10	M: 0 F: 1	M: 1 F: 0			M: 4 F: 0
Schroederichthys bivius (Müller & Henle, 1841)	M: 26*	M: 0		M: 19	M: 15	M: 129*
Squalimorphi						
Squaliformes						
Squalus acanthias (Linnaeus, 1758)	M: 17* F: 61	M: 2 F: 6	M: 2 F: 6	M: 116* F: 74	M: 101* F: 223	M: 1053* F: 117
Squalus cf. *mitsukurii* (Jordan & Snyder, 1903)					M: 6 F: 3	M: 3 F: 0
Squatinomorphii						
Squatiniformes						
Squatina guggenheim (Marini, 1936)					M: 1 F: 4	

Table 2. Mean relative abundance (ind. km^{-2}) of elasmobranch species and mean relative abundance (kg km^{-2}) of *Merluccius hubbsi* captured in the surveys conducted on the Patagonian shelf. Standard error is shown in parentheses

Species	Sep 2001	Dec 2001	Mar 2002	Aug 2002	Jan 2003	Jul 2003
Elasmobranch by-catch						
Amblyraja doellojuradoi	4.39 (1.39)					1.53 (0.21)
Atlantoraja cyclophora			4.21 (2.32)			
Bathyraja albomaculata	5.00 (0.62)					1.34 (0.20)
Bathyraja brachyurops	8.29 (2.65)	1.90 (0.30)		11.20 (9.49)	8.98 (7.94)	
Bathyraja macloviana	10.28 (7.49)					1.57 (0.21)
Bathyraja magellanica			2.77 (0.63)	1.43 (0.23)	1.25 (0.08)	5.37 (0.21)
Bathyraja multispinnis	4.81 (0.35)					2.04 (0.16)
Bathyraja scaphiops		5.61 (0.61)				1.48 (0.14)
Discopyge sp.			4.62 (3.33)		1.58 (0.01)	
Galeorhinus galeus	1.89 (0.23)	0.97 (0.09)	27.22 (10.08)			
Mustelus schmitti	47.87 (27.05)	1.38 (0.4)	1.81 (0.51)			8.24 (5.60)
Myliobatis sp.			1.81 (0.15)			
Psammobatis lentiginosa	11.06 (1.32)	4.16 (1.32)			6.20 (2.64)	
Psammobatis normani	24.26 (8.57)	3.84 (0.48)		18.05 (4.87)	7.31 (1.91)	35.60 (13.70)
Psammobatis rudis	3.05 (1.63)	8.15 (7.32)	16.34 (9.01)		3.33 (0.49)	40.65 (13.58)
Schroederichthys bivius	14.81 (6.98)	3.43 (0.56)		23.79 (12.18)	2.55 (0.42)	42.77 (56.71)
Squalus acanthias	20.23 (13.34)	3.66 (10.35)	8.24 (10.60)	145.6 (10.84)	9.72 (2.05)	298.6 (81.34)
Squalus cf. *mitsukurii*					1.38 (0.12)	1.57 (1.01)
Squatina guggenheim					1.38 (1.21)	
Zearaja chilensis	64.44 (38.27)	34.68 (10.14)	141.1 (73.81)	113.2 (52.17)	9.12 (1.52)	113.6 (11.43)
Target fish						
Merluccius hubbsi	6563.24 (709.31)	4580.69 (596.66)	13421.06 (138.52)	9446.29 (1300.87)	5004.86 (672.85)	6175.18 (481.52)

TL (*Galeorhinus galeus and Myliobatis* sp.). The mean size of all species was >35 cm. Mature individuals represented >50% of the total captured for all species except in *Bathyraja brachyurops*, *G. galeus*, *Atlantoraja cyclophora* and *Z. chilensis* and in females of *Schroederichthys bivius* (Table 3). Particularly, *B. scaphiops*, *Discopyge* sp., *Mustelus schimitti* and *Squatina guggenheim* presented the highest percentage (>80%) of mature individuals. Size-at-maturity was estimated for *B. brachyurops*, *B. macloviana*, *Psammobatis lentiginosa*, *P. normani*, *P. rudis*, *Z. chilensis*, *S. bivius* and *Squalus acanthias* (Table 3). For *B. brachyurops* and *P. lentiginosa* size-at-maturity was only estimated for males. Deviations from the 1:1 sex ratio were observed for *B. magellanica*, *Z. chilensis*, *P. normani*, *P. rudis*, *Discopyge* sp., *S. acanthias*, *S. bivius* and *G. galeus* (Table 1). *Z. chilensis* and *S. acanthias* presented a marked sexual segregation, with males more frequent in the surveys (Table 1). Regarding size variations with depth, the only species that presented significant differences were *B. magellanica* and *Z. chilensis* (Table 5). The largest individuals of *B. magellanica* were observed in the depth range of 100–109 m, and the largest individuals of *Z. chilensis* were observed in the depth ranges of 60–69 and 70–79 m (Table 5).

DISCUSSION

Elasmobranchs currently represent one of the most threatened groups of all marine species due to the increasing fishing effort and, consequently, the overfishing of their populations (Stevens et al. 2000). Concern about the current status of elasmobranch populations has increased among researchers, and several studies have been conducted to address this topic (IUCN 2003). In Argentina, studies on elasmobranchs have been neglected in the past, and most research efforts have been directed to assess bony-fishes due to their economic importance. At present, this situation is changing with the creation of a national plan of action for conservation and management of elasmobranchs (Wöhler et al. 2011). Studies have been conducted on several elasmobranch species to rectify the lack of basic biological knowledge (Ruocco et al. 2006, Perez Comesaña et al. 2011, Scenna 2011). However, the information available so far is not sufficient to develop adequate management actions. A major problem in Argentina's fisheries is the scarce information available regarding both species biology and the specific composition of the elasmobranchs affected. Several species of elasmobranchs are discarded at sea; thus, they are not recorded in fishing

Table 3. Biological information for elasmobranchs captured on the Argentine shelf, showing size-at-maturity (TL50 %), smallest mature (SM) and largest immature (LI) individual males (M) and females (F), total length (TL) and size range in parentheses. Letters '*a*' and '*b*' are the parameters of the logit function used to estimate TL50 %. FO: frequency of occurence. Dash: no data

Species	TL50 % (cm)	SM–LI	*a*/*b*	TL (cm)	% Mature individuals	FO (%)
Amblyraja doellojuradoi	F: – M: –	F: – M: –	F: – M: –	46.5 (42–51)	F: 50 M: 0	3
Atlantoraja cyclophora	F: – M: –	F: – M: –	F: – M: –	51.5 (42–61)	F: 20 M: 0	3
Bathyraja albomaculata	F: – M: –	F: – M: –	F: – M: –	69.5 (51–88)	F: 66 M: 85	14
Bathyraja brachyurops	F: – M: 71.3	F: 69–71.3 M: 63.5–71.4	F: – M: –290.25/4.07	68 (36–83)	F: 40 M: 49	30
Bathyraja macloviana	F: 57.8 M: 54.3	F: 33.5–57 M: 57–58	F: –310.07/5.36 M: –302.06/5.56	48.5 (32–65)	F: 50 M: 64	10
Bathyraja magellanica	F: – M: –	F: – M: –	F: – M: –	54 (38–70)	F: 70 M: 75	17
Bathyraja multispinnis	F: – M: –	F: – M: –	F: – M: –	86.5 (54–119)	F: 75 M: 66	10
Bathyraja scaphiops	F: – M: –	F: – M: –	F: – M: –	46.5 (41–73)	F: 80 M: –	3
Discopyge sp.	F: – M: –	F: – M: –	F: – M: –	36 (25–47)	F: 82 M: 89	7
Galeorhinus galeus	F: – M: –	F: – M: –	F: – M: –	104 (70–120)	F: 20 M: 16	5
Mustelus schmitti	F: – M: –	F: – M: –	F: – M: –	74 (59–89)	F: 100 M: 93	9
Myliobatis sp.	F: – M: –	F: – M: –	F: – M: –	120	F: 100 M: –	2
Psammobatis lentiginosa	F: – M: 41.1	F: – M: 42–42	F: – M: –200.25/4.87	37 (26–48)	F: 62 M: 86	16
Psammobatis normani	F: 42.9 M: 48.3	F: 41.4–55 M: 42.1–52.8	F: –200.36/4.67 M: –210.3/4.35	41 (25–57)	F: 70 M: 55	80
Psammobatis rudis	F: 41 M: 41.46	F: – M: –	F: –212.25/5.17 M: –210.24/5.07	37 (23–51)	F: 42 M: 54	70
Schroederichthys bivius	F: 55 M: 64.9	F: 65.8–71 M: 66–66	F: –300.06/5.45 M: –300.07/4.62	61.5 (40–83)	F: 0.05 M: 94	66
Squalus acanthias	F: 72.85 M: 66.1	F: 58–67 M: 53–65	F: –289.24/3.97 M: –269.24/4.07	65 (35–95)	F: 45 M: 70	90
Squalus cf. *mitsukurii*	F: – M: –	F: – M: –	F: – M: –	64 (52–76)	F: 68 M: 84	15
Squatina guggenheim	F: – M: –	F: – M: –	F: – M: –	35 (28–40)	F: 100 M: 100	2
Zearaja chilensis	F: 92.5 M: 74.4	F: 83–85 M: 72–79	F: –330.26/3.57 M: –310.25/4.17	64.5 (21–108)	F: 12 M: 29	100

statistics, while landed species are often recorded under main items such as 'sharks' and 'skates' (Perez Comesaña et al. 2011, Sánchez et al. 2011). The bottom-trawl fishery that targets *Merluccisus hubbsi* on the Argentine shelf is not an exception, and the low reliability of the landing statistics of elasmobranchs is a major problem. The present study provides important information about the elasmobranch species affected by this fishery. During the studied period, 20 species of elasmobranchs were registered. Out of the 40 species of sharks described on the Argentine shelf (Menni & Lucifora 2007), only 6 were captured. Regarding the order Rajiformes, 12 species were captured of the 24 described (Menni & Lucifora 2007). Also, 1 species of the order Myliobatiformes and 1 of the order Torpediniformes were identified in catches.

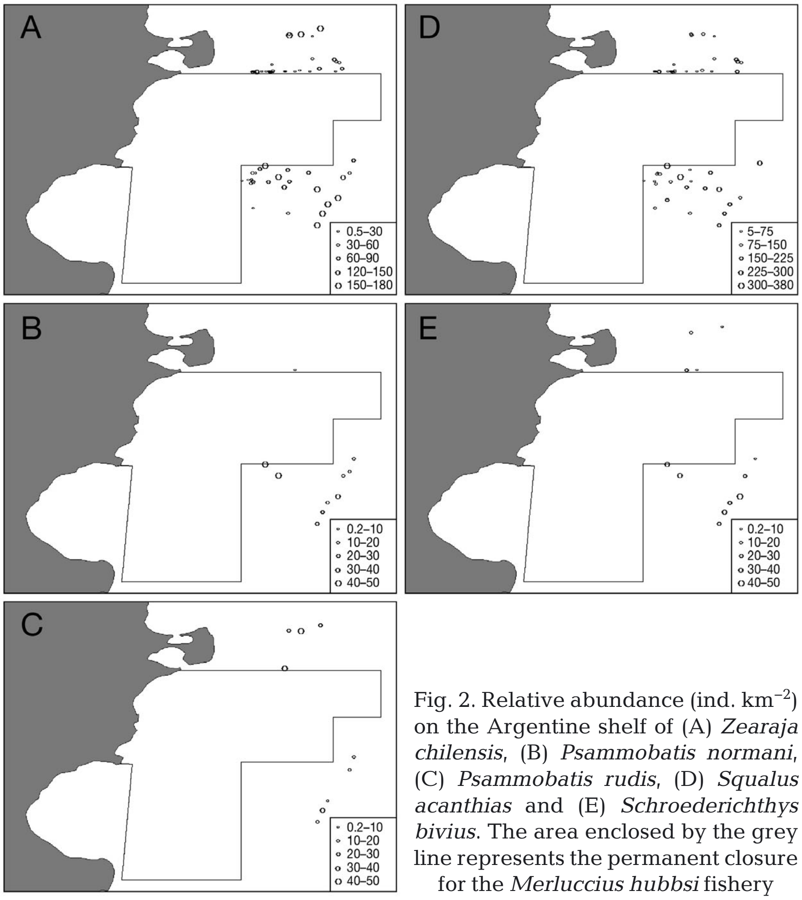

Fig. 2. Relative abundance (ind. km^{-2}) on the Argentine shelf of (A) *Zearaja chilensis*, (B) *Psammobatis normani*, (C) *Psammobatis rudis*, (D) *Squalus acanthias* and (E) *Schroederichthys bivius*. The area enclosed by the grey line represents the permanent closure for the *Merluccius hubbsi* fishery

Zearaja chilensis and *Squalus acanthias* presented the highest values of relative abundance and were present in all surveys. It is well known that both species are the most abundant elasmobranchs in Argentine waters (Cousseau et al. 2000). Despite this, biological information on them is still scarce (Perez Comesaña et al. 2011). For *Z. chilensis*, the size range observed was similar to that reported by García de la Rosa (1998) for the same region. Estimations of the size-at-maturity (92 cm for females and 76 cm for males) are similar to previous estimations (91 cm for females and 77 cm for males) (Perez Comesaña et al. 2011). Recently, the existence of a new species, *Dipturus argentinensis*, similar to *Z. chilensis* has been proposed using morphological and molecular evidence (Diaz de Astarloa et al. 2008). Considering this, it is possible that some individual *D. argentinensis* were present in our samples; thus, although estimations given in the present study are reliable, they should be verified. For *S. acanthias*, the size range observed was also similar to that reported previously (Menni et al. 1981, García de la Rosa 1998, Gosztonyi & Kuba 1998, Di Giácomo et al. 2009), but the size-at-maturity was not estimated. Our estimations are a novel contribution to the knowledge of the species on the Argentine shelf. However, this parameter has been estimated in other regions of the world, and the results show that the size-at-maturity of *S. acanthias* is highly variable depending on the region considered. Estimations vary from 70 cm (North Sea; Sosinski 1978) to 109 cm (NE

Table 4. Length-to-weight relationship parameters for some elasmobranch species (ANCOVA, $p > 0.05$, df = 2). The 95 % confidence intervals of the slope and intercept of the regression are shown in parentheses. The hypothesis of isometric growth was tested using a Student's *t*-test

Species	Size range (cm) (min–max)	Slope	Intercept	R^2	Growth Type	Growth p-value	df
Bathyraja albomaculata	51–88	3.05 (2.98; 3.10)	–4.99 (–5.29; –4.68)	0.948	Isometric	>0.05	18
Bathyraja brachyurops	36–85	3.25 (3.18; 3.31)	–5.91 (–6.23; –5.58)	0.968	Isometric	>0.05	78
Bathyraja macloviana	32–65	3.05 (2.90; 3.18)	–5.05 (–5.70; –4.29)	0.987	Isometric	>0.05	31
Bathyraja maguellanica	38–65	3.04 (2.89; 3.17)	–5.15 (–5.58; –4.71)	0.991	Isometric	>0.05	29
Bathyraja multispinnis	54–119	3.08 (2.50; 3.66)	–5.38 (–5.69; –5.07)	0.973	Isometric	>0.05	13
Discopyge sp.	25–47	3.21 (3.14; 3.27)	–5.13 (–5.45; –4.81)	0.930	Allometric	<0.05	47
Galeorhinus galeus	68–146	3.22 (2.70; 3.74)	–6.57 (–6.89; –6.24)	0.990	Allometric	<0.05	19
Mustelus schmitti	59–88	2.61 (2.56; 2.66)	–3.98 (–5.24; –2.72)	0.897	Allometric	<0.05	29
Psammobatis lentiginosa	26–48	2.988 (2.92; 3.04)	–4.46 (–4.75; –4.15)	0.937	Isometric	>0.05	43
Psammobatis normani	23–56	2.79 (2.60; 2.97)	–4.09 (–5.36; –2.80)	0.860	Allometric	<0.05	653
Psammobatis rudis	22–52	3.03 (2.60; 3.34)	–5.04 (–5.33; –4.73)	0.929	Isometric	>0.05	272
Schroederichthys bivius	45–79	2.68 (2.63; 2.73)	–4.61 (–3.66; –5.56)	0.924	Allometric	<0.05	280
Squalus acanthias	34–97	3.16 (3.09; 3.22)	–6.21 (–6.53; –5.89)	0.959	Allometric	<0.05	1791
Zearaja chilensis	15–114	3.06 (2.99; 3.12)	–6.12 (–7.01; –5.42)	0.977	Isometric	>0.05	1447

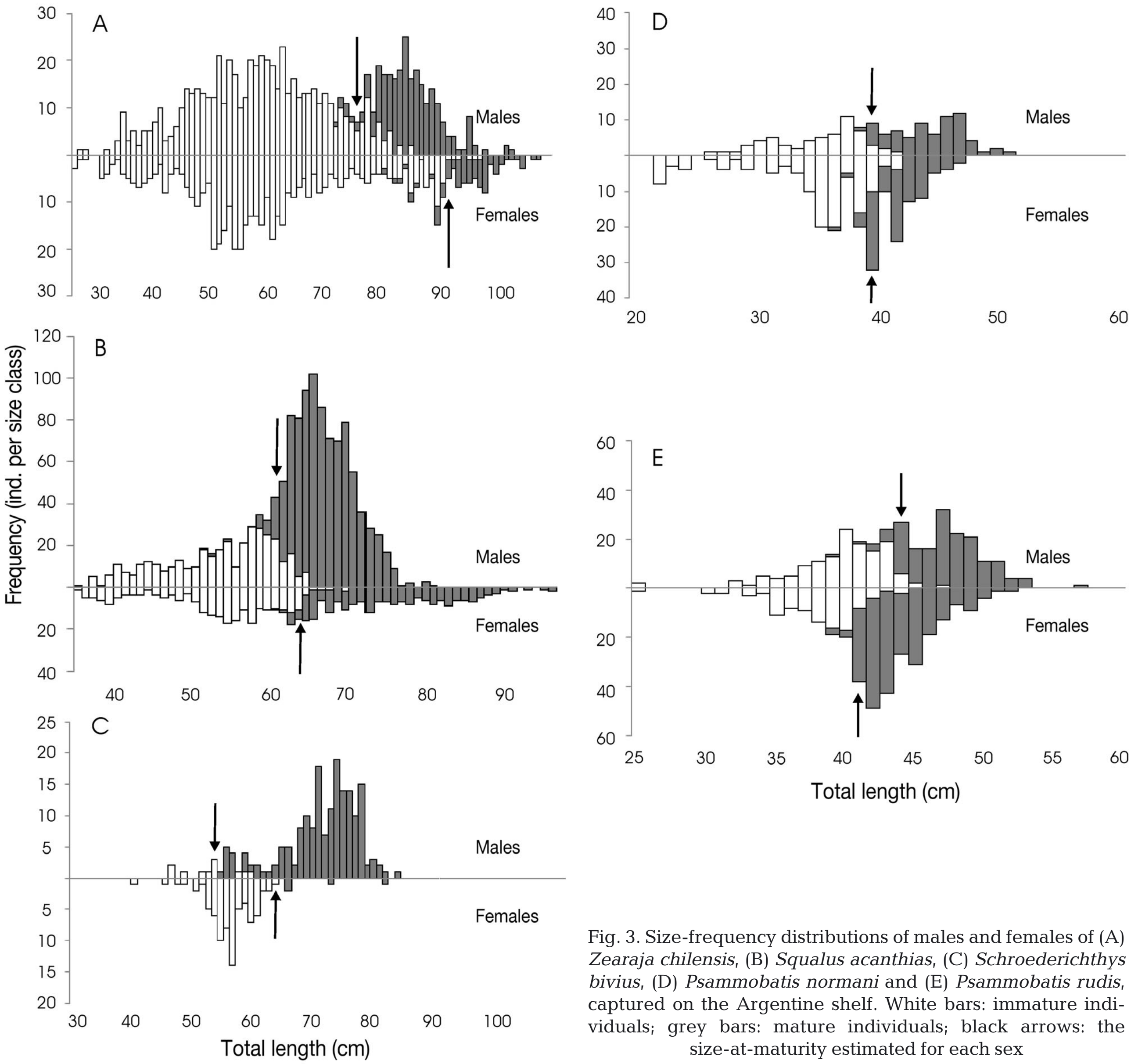

Fig. 3. Size-frequency distributions of males and females of (A) *Zearaja chilensis*, (B) *Squalus acanthias*, (C) *Schroederichthys bivius*, (D) *Psammobatis normani* and (E) *Psammobatis rudis*, captured on the Argentine shelf. White bars: immature individuals; grey bars: mature individuals; black arrows: the size-at-maturity estimated for each sex

Pacific; Ketchen 1972) in females and from 59 cm (NE Atlantic; Hickling 1930) to 82 cm (SE Black Sea; Avsar 2001) in males. Our estimations are within the range of values published for the species.

The genus *Bathyraja* is represented by 11 species in the SW Atlantic, 8 of them are endemic to the Argentine continental shelf (Menni & Stehmann 2000, Díaz de Astarloa & Mabragaña 2004), and, in this study, 6 species were registered. *Bathyraja albomaculata*, *B. magellanica*, *B. scaphiops* and *B. multispinis* showed low values of relative abundance (<5 ind. km^{-2}) and a low frequency of occurrence (<20%). The low relative abundance and frequency in the studied area could be attributed to the fact that these species are more abundant south of 45° (Menni & Stehmann 2000, Scenna 2011). *Bathyraja macloviana* and *B. brachyurops* were more abundant and frequent in the studied area, which is consistent with previous observations for the region (Scenna 2011). For *B. brachyurops*, the size-at-maturity estimated for males (67.86 cm) was similar to sizes previously reported (66.4 cm) (Perez Comesaña et al. 2011, Scenna 2011). In the case of the female, the size-at-maturity was not estimated due to the restricted sample size composition. However, based on the sizes of the smallest mature and the largest immature individuals observed, it is likely that the size-at-maturity is close to the previous estimation of 73.4 cm (Perez

Table 5. Mean size (cm) of individuals in each depth range. Mean sizes that differed significantly on each depth range are marked with asterisk

Species	Depth (m)						
	60–69	70–79	80–89	90–99	100–109	110–119	120–129
Bathyraja albomaculata		65			67.2	69.7	
Bathyraja brachyurops			67.5	71.4	62.5	61.5	72.2
Bathyraja macloviana					47.2	52.4	
Bathyraja magellanica	57.6	52.5			72.7*	57.6	52.5
Bathyraja multispinnis					69.5	71.5	
Discopyge sp.	36.6	39.7					
Galeorhinus galeus		135.2	134.5	120		134	
Mustelus schmitti		75.3	72.7				
Psammobatis lentiginosa	35.2				31.9	38.7	40.3
Psammobatis normani		41	51.2	42.3	41.4	45.1	41
Psammobatis rudis	32.5	32.2			44.1	32.5	32.2
Schroederichthys bivius	73.5	70.1	74.1	70.8	73.1	68.2	
Squalus acanthias	74.2	65.7	60.3	64.2	61.1	59.2	66.5
Squalus cf. *mitsukurii*		63.2	58.4	68.9	67.3	63.2	58.4
Zearaja chilensis	80*	83.45*	59.9	58.3	58.7	56.5	55.8

Comesaña et al. 2011, Scenna 2011). These results should be considered with caution since there is a possibility that some of the individuals may have belonged to *B. cousseauae*. This species has recently been described by Díaz de Astarloa & Mabragaña (2004) and was not present in the species keys used. For *B. macloviana*, the estimated size-at-maturity for males in this study (36.5 cm) was significantly smaller than that reported in previous studies (53 cm) (Perez Comesaña et al. 2011, Scenna 2011). Due to the small number of males analyzed, this estimation should be carefully considered. In the case of females, estimations obtained in the present study (57.4 cm) were similar to those in previous studies (54 cm) (Perez Comesaña et al. 2011, Scenna 2011).

Skates belonging to the genus *Psammobatis* are small-sized individuals endemic to the southwestern Atlantic Ocean (Cousseau et al. 2000, Mabragaña 2007, Mabragaña & Giberto 2007). In the present study, 3 species were captured of the 7 described for the Argentine shelf (Menni & Stehmann 2000). *Psammobatis normani* and *P. rudis* were the most abundant and frequent species in the surveys. It is known that both species are the most common species of this genus on the Argentine shelf (Mabragaña 2007). For *P. normani*, the size range observed (25 to 57 cm) was similar to that reported by Mabragaña & Cousseau (2004) (24 to 58 cm). The size-at-maturity estimated for males in this study (44 cm) was similar to the size reported by Mabragaña & Cousseau (2004) (44.3 cm). In contrast, the size-at-maturity estimated for females (41.5 cm) was greater than that reported by Mabragaña & Cousseau (2004) (40.3 cm). For *P. rudis*, smaller individuals (23 cm) were recorded in the area than those reported by Mabragaña & Cousseau (2004) (26 cm). The maturity size estimated for both sexes (40 cm) was smaller than previous estimations (42.8 cm for females and 41.4 cm for males) (Mabragaña & Cousseau, 2004). *P. lentiginosa* was the least frequent species of the genus in our samplings with a %FO of 16%. A similar value of occurrence was reported by Mabragaña (2007) in the area. The size-at-maturity estimated for males (41.6 cm) was notably higher than that estimated by Mabragaña (2007) (31.3 cm). For females, the low sample size did not allow an estimation of the size-at-maturity, but it would be expected to find a similar difference compared to Mabragaña's (2007) estimation.

Schroederichthys bivius is commonly found along the continental shelf off Argentina, but few studies on this species have been conducted (Menni et al. 1979, Sánchez et al. 2009). Perez Comesaña et al. (2011) pointed out the lack of basic biological information about this species. In this sense, our results complement the existing information by proving the first estimations of the maturity size, sex proportions, size-frequency distribution and proportion of mature individuals for the species on the continental shelf. This species was frequently captured in our study (>60% of the tows analyzed), and the abundance was highly variable, with the lowest values in austral summer. Sánchez et al. (2009) found lower values of %FO for *S. bivius* (43.7% north of 45°S and 56% south of 46°S) on the Argentine shelf. Regarding the size of individuals, males reached greater values than females. This marked dimorphism in the maximum size is common in sharks belonging to Scyliorhinidae (Flammang et al. 2008).

The sharks *Squalus mitsukurii*, *Galeorhinus galeus* and *Mustelus schmitti* were less frequent in the samplings (<15% of the tows analyzed). However, *G. galeus* and *M. schmitti* presented a marked pattern of seasonal aggregation, reaching values >27 ind. km^{-2} in March 2002 and September 2001, respectively. This aggregation pattern is commonly found in several shark species (Jacoby et al. 2012), but no records for *G. galeus* and *M. schmitti* aggregations on the continental shelf have been published before.

The species *Atlantoraja cyclophora*, *A. doellojuradoi*, *Discopyge* sp., *Myliobatis* sp. and *Squatina guggenheim* were captured occasionally with low relative abundance (<5 ind. km^{-2}), indicating that their presence on the northern Patagonian shelf is not frequent. The first 2 species are more abundant in waters north of 41° S, while the low presence of the last 3 species may be a consequence of their coastal distribution (Vooren & Da Silva 1991, Cervigón et al. 1992, Cousseau et al. 2000, Menni et al. 2010).

The relationship between body length and weight is of great importance in fishery biology (Gulland 1983, Sparre 1991). Biomass estimates obtained from widely used analytical models, such as virtual population analysis, require the mean weight calculation of individuals per age or length class through the length-to-weight relationship. Therefore, obtaining accurate parameter estimations of the length-to-weight relationship is an important factor in the assessment of fish stocks. In this paper, estimations were reported for 14 different species of elasmobranchs that inhabit the Argentine shelf. There were no significant differences found in the length-to-weight relationships between both sexes for any of the species studied. This is a common pattern in several elasmobranch species (Kohler et al. 1996, Lucifora et al. 1999, Ruocco et al. 2006, Mabragaña 2007, Scenna 2011). Allometric growth type was observed in the length-to-weight relationships of 6 species. The variation between the estimated allometric coefficient and the theoretical value (3 in the case of a linear–volume relationship) means that individuals' gain/loss in average weight occurred at a different rate than expected. This value can be affected by several factors, including the amount of stomach contents, the stage of maturity, the liver weight and the general condition of the individuals (Frota et al. 2004). Thus, these variables should be considered in further estimations of length-to-weight relationships.

Several cases of size segregation in elasmobranchs have been reported in Argentine waters, mainly in coastal regions (Di Giácomo et al. 2009, Perier et al. 2011). It is known that shallow waters are used by several species of elasmobranchs as reproductive and nursery grounds, because these areas provide shelter and food availability for offspring (Heupel et al. 2007). Therefore, it is expected to find a heavy concentration of large individuals (adults) during reproductive periods and heavy concentration of small individuals (offspring) during breeding periods. In this study, the only species that presented significant differences in size in the different depth strata were *Bathyraja magellanica* and *Zearaja chilensis*. Both species presented the same pattern of larger sizes in shallower waters. The rest of the species presented no significant differences in the mean size of individuals in the different depth strata, probably due to the limited depth range considered.

A common ecological trait of many elasmobranch species is their tendency to concentrate in groups of many individuals in particular spatio-temporal patterns (Jacoby et al. 2012). This increases their susceptibility to being overexploited by fisheries that operate in those locations. On the Argentine shelf, few species presented a marked aggregation of individuals. The sharks *Galeorhinus galeus*, *Mustelus schmitti* and *Squalus acanthias* presented the highest abundances in summer, in spring and in winter, respectively. *Zearaja chilensis* presented the highest values of abundance in autumn and winter. The lack of knowledge concerning the population abundance of those species limits the analysis of the impact caused by fishing.

Our results have shown that most of the individuals affected by the bottom-trawl fishery were mature. This means that intense fishing pressure may lead to a reduction in recruitment having a negative effect on the population, since elasmobranchs are characterized by a direct relationship between recruitment and stock size (Holden 1977). However, for *Schroederichthys bivius* and *Zearaja chilensis*, most individuals captured (>70%) were immature. This situation is alarming since fishing mortality affects individuals that never spawned, and this will have a negative impact on both species (particularly in *Z. chilenses*, due to its high frequency and abundance). As precautionary measure, it will be necessary to alter the current fishery situation by reducing the fishery-associated mortality of elasmobranchs (i.e. temporal or spatial closures, use of specific repellent devices) in order to minimize the negative impacts on populations. Recently, Chiaramonte et al. (2011) showed that several elasmobranch species present high survival rates (>75%) after being released back into sea. Therefore, this practice would represent a simple way of reducing elasmobranch mortality and could be implemented in fishing activities.

Fishery management is evolving towards a more holistic approach (i.e. ecosystem-based management) to ensure the sustainability of resources (Zhou et al. 2010). This insight requires basic biological information of the species affected by the fishery (i.e. elasmobranchs). In Argentina, management of the common hake *Merluccisus hubbsi* bottom-trawl fishery has been conducted on a monospecific basis, due to the lack of biological knowledge regarding by-catch (Bezzi et al. 1994). The paucity of information on the population status of elasmobranchs (i.e. population sizes, fishing mortality) has been a major obstruction to comparisons with our results in an effort to determine the effect of the fishery over time. However, the data generated in the present study can be used as a basis for comparing the current species composition situation and the relative abundance of elasmobranch by-catch in the bottom-trawl fishery of northern Patagonia. Considering that fishing effort has not been reduced since 2003 and that a reduction is unlikely to be achieved in the near future in this fishery, continuous monitoring is necessary to obtain more information on the long-term temporal trends on elasmobranch populations. It is worth mentioning that, despite the call for continuous monitoring, no studies have been conducted since 2003 on the effects of this fishery on elasmobranch species composition.

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