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ORIGINAL ARTICLE

Reproductive biology and abundance of the freckled sandskate *Psammobatis lentiginosa* McEachran,1983 in the southwest Atlantic

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Abstract

The reproductive biology and abundance of the freckled sandskate *Psammobatis lentiginosa* in the southwest Atlantic was investigated. Specimens of *P. lentiginosa* were captured from 35°15′S to 45°19′S with a gap between 39°20′ and 44°22′S, from 49 to 164 m depth, which was consistent with most previous studies. Major concentrations of *P. lentiginosa* were detected between 35° and 37°S, and between 90 and 130 m depth. Females matured at larger sizes than males; L_{50} (estimated size at which 50% of individuals are sexually mature) was 313 mm TL (total length) and 333 mm TL for males and females, respectively. Oviposition in *P. lentiginosa* occurs in winter and spring in northern areas, and in summer in the southern area. Given their relatively small size, *Psammobatis* spp. may be less susceptible to population depletion than other skates. Nonetheless, factors such as increasing fisheries pressure and habitat disturbance due to trawling may be impacting on those species in the study area.

Key words: *Abundance, distribution,* Psammobatis*, reproduction, skate, southwest Atlantic.*

Introduction

Skates are a common component of the demersal fish community along the South American continental shelf and have become a concern in Argentina because of the considerable and increasing catches in recent decades due to international demand (from 761 tons in 1992 to 23,618 tons in 2006; Cousseau et al. 2007). The life history characteristics of skates, such as slow growth, low fecundity and late maturity which is typical of most rajid species, indicates that they are particularly vulnerable to fishing pressure and over-exploitation (Walker & Hislop 1998). In fact, there is historic evidence of a major decline in chondrichthyan populations from fisheries around the world (Stevens et al. 2000) and Argentina is no stranger to this situation. Indeed, a considerable decline in the biomass of several coastal and shelf skate species have been documented in Argentine waters (Massa et al. 2004).

The genus *Psammobatis* is endemic to South America and consists of eight species, distributed along the Atlantic and Pacific coasts: *Psammobatis lentiginosa* McEachran, 1983, *P. normani* McEachran, 1983, *P. rudis* Günther, 1870, *P. scobina* (Philippi, 1857), *P. extenta* (Garman, 1913), *P. rutrum* Jordan, 1890, *P. bergi* Marini, 1932 and *P. parvacauda* McEachran, 1983 (McEachran 1983; Menni & Stehmann 2000; Lamilla & Sáez 2003; Cousseau et al. 2007).

The freckled sandskate *P. lentiginosa* is a small skate occurring from southern Brazil (32°S) to northern Patagonia, Argentina (45°S) from 40 to 170 m depth (McEachran 1983; Cousseau et al. 2007). This species attains a maximum total length (TL) of 467 mm and first maturity was reported at 325 and 335 mm TL for males and females, respectively (Cousseau et al. 2007). Due to the lack of available information on this species, the IUCN red list status indicates 'Data Deficient' at

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this time, and a review of the assessment for this species is suggested in the short term (Kyne 2007).

Previous studies on the genus *Psammobatis* have focused on taxonomy and distribution (Cousseau et al. 2000 and references therein; Menni & Stehmann, 2000). More recently, several studies regarding reproductive biology (Braccini & Chiaramonte 2002; Mabragaña & Cousseau 2004; San Martín et al. 2005) and feeding ecology (Braccini & Perez 2005; Mabragaña & Giberto 2007; San Martin et al. 2007) have been published. These studies were undertaken on the following species: *P. extenta*, *P. bergi*, *P. normani* and *P. rudis*.

Given the paucity of published information on *P. lentiginosa*, the aim of this study was to describe their reproductive biology (size at maturity, sexual dimorphisms, egg-case), pattern of distribution, and estimate their abundance in the Argentine waters.

Materials and methods

Study area

The Argentine Continental Shelf (ACS) comprises a part of the Southwest Atlantic (SWA) between 34 and 55°S. Water masses on this region consist of several water types: coastal, subantarctic, subtropical, and mixed waters (Bisbal 1995). In the north, the circulation is influenced by the warm, more saline, south-flowing Brazil Current, which runs along the continental margin of South America and moves offshore at about 36–38°S (Olson et al. 1988). In the south, a low-salinity current of subantarctic origin flows north along the Patagonian coast, from the Strait of Magellan (52° 30′S) to 40–42°S, where it veers offshore and flows northwards over the outer shelf and slope. These water masses are modified substantially by the inflow of glacial waters from the Magellan Strait at 52° 30′S and from freshwater inputs of the Negro and La Plata rivers (Guerrero & Piola 1997). These systems correspond to two biogeographic provinces: the Argentine Province in the north, extending up to Rio de Janeiro, Brazil and the Magellanic Province in the south, which also includes southern Chile (Menni et al. 2010). The study area was divided into two regions: northern (off Uruguay and north of Argentina, 34–41°S) and southern (north Patagonia, 41–48°S), according to the above-mentioned biogeographic provinces.

Sample collection

Data were collected from the SW Atlantic between 34 and 47°S, from the coast to the continental slope edge (Figure 1). They were obtained from research cruises carried out by the National Institute for Fisheries Research and Development (INIDEP), from 1998 to 2006 (Table I). These research cruises were designed for the assessment of demersal fish stocks, especially Argentine hake (*Merluccius hubbsi* Marini, 1933), following a random stratified (by depth and latitude) sampling design. The gear was a bottom trawl (200 mm mesh in the wings, and 120 mm in the cod end; vertical height 4 m, horizontal opening 15 m). The tow duration was 30 min.

General biological measurements and reproductive analysis

Specimens of *Psammobatis lentiginosa* were collected and frozen on board for subsequent examination in the laboratory. Each specimen was identified, sexed and weighed. Total length (TL) and disc width (DW) in mm were recorded for every specimen. The relationship between DW and TL, with TL as the dependent variable, was estimated separately for each sex in order to estimate for any skates with damaged tails. Total weight (W, in g) was recorded for each specimen. With these data, TL–W relationships were calculated separately for each sex; the data were ln-transformed and the null hypothesis of no difference between slopes was tested with Student's *t*-test (Zar 1984).

Maturity status of the reproductive organs was assessed visually following Mabragaña et al. (2002) and Ebert (2005). In males, clasper length (CL, measured from the tip of the pelvic fins to the tip of the claspers), the degree of calcification of the claspers, number of rows of thorns in the alar

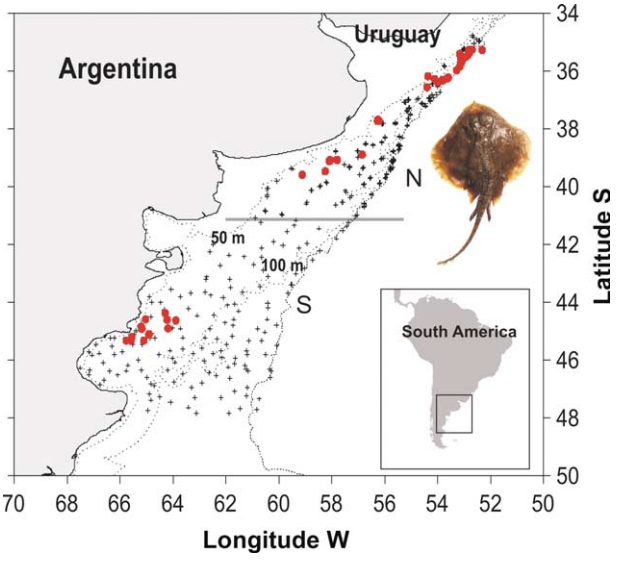

Figure 1. Study area showing positions of trawl stations. Red circles indicate positive trawls with *Psammobatis lentiginosa* and black crosses indicate negative trawls. N = northern region and S = southern region.

Table I. Surveys used for collection of distribution[D], abundance[A] and biological[B] data for *Psammobatis lentiginosa*. EH, R. V. *Dr. Eduardo L. Holmberg*; OB, R. V. *Capitán Oca Balda*. Positive depth indicates actual depth where the species was found. A few additional specimens collected between 1998 and 2000 in the area were also used for biological studies.

Vessel/year	Area (°S)	Depth (m)	No. tows	Seasons	Positive depth (m)	No. positive tows
EH/1999[DB]	34–41	43–332	93	Spring	65–133	14
EH/2001[DB]	35–48	41–431	202	Winter–spring	63–114	31
OB/2004[DAB]	34–39	48–235	60	Spring	66–133	9
OB/2005[DAB]	34–39	49–251	60	Winter	49–122	8
OB/2005[DAB]	43–46	55–98	41	Summer	79–88	2
OB/2006[DAB]	34–41	44–250	86	Winter–spring	66–127	12

thorn patch (RT) and shape of the efferent duct were recorded. Males were assigned to one of three categories: immature (short, uncalcified claspers, alar thorn patch not yet developed, efferent ducts straight), maturing (longer semicalcified claspers, alar thorn patch developing, efferent ducts beginning to coil) and mature (long, fully calcified claspers, alar thorn patch fully developed, efferent ducts greatly coiled). In females, oviducal gland width (WOG), number and size (in mm) of ovarian follicles, were recorded. Females were categorized as: immature (undeveloped thread-like uteri, ovaries with non-distinguishable ovarian follicles, and undeveloped oviducal glands), maturing (ovaries with distinguishable white or opalescent ovarian follicles and developing oviducal glands) and mature (wide uteri, vitellogenic ovarian follicles in their ovaries, and widened oviducal glands). Measurements of egg-cases in uteri were recorded following standard methods (Hubbs & Ishiyama 1968; Ishiyama & Ishihara 1977; Ebert & Davis 2007; Mabragaña et al. 2009). Ten morphometric characteristics were recorded (Figure 2). All measurements were taken with Vernier calipers at 0.1 mm precision.

Overall sex ratio was determined and differences were evaluated using a Chi-squared test. Size at maturity was estimated for both sexes as follows: the proportion of mature individuals in 10 mm TL intervals was calculated, and a logistic ogive was fitted to the data using a maximum likelihood approach in order to estimate the size at which 50% (L_{50}) of individuals are sexually mature (Roa et al. 1999).

Spatial distribution and abundance

Detailed data of the surveys used to estimate abundance and infer the distribution of *Psammobatis lentiginosa* are recorded in Table I. The total biomass of *P. lentiginosa* caught in each trawl was recorded. The density was calculated as follows:

$$D_i = C_i/a_i$$

where D_i is the biomass density, C_i is catch in kg and a_i the swept area in nm^2 (distance of trawling $\times$ distance between the net wings) in fishing haul i.

To characterize the abundance of *P. lentiginosa*, mean densities were averaged over 1° latitude intervals using all hauls, irrespective of whether the species was caught or not. Frequency of occurrence by degree of latitude was calculated as the number of times *P. lentiginosa* was present in each haul, related to the total number of trawl stations, including trawls with no *P. lentiginosa* (García de la Rosa 1998). Average densities by depth ranges were estimated in the same way. Distribution and abundance maps were produced using Surfer 7.

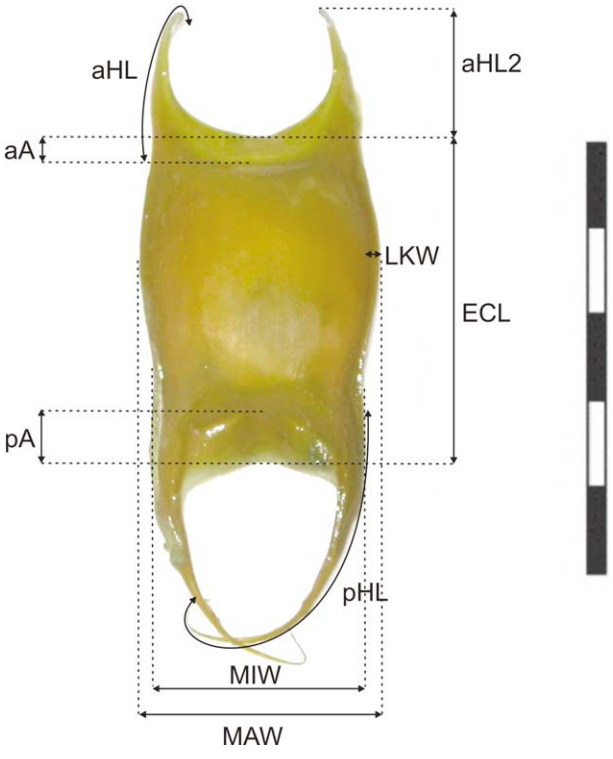

Figure 2. Dorsal view of the egg case of *Psammobatis lentiginosa* showing the morphometric characters utilized in the study. ECL, egg case length (without horns); MAW, egg case width (maximum); MIW, egg case width (minimum); aHL, anterior horn length; pHL, posterior horn length; LKW, lateral keel; aA, anterior apron; pA, posterior apron pA; aHL2, anterior horn length 2. Scale bar = 10 mm per unit.

Results

Reproduction

A total of 170 specimens of *Psammobatis lentiginosa* (98 females and 72 males) were collected off Buenos Aires province and northern Patagonian waters (Figure 1, Table II). The overall sex ratios (males : females) in both areas were 1.4 : 1 and 1.3 : 1, respectively, and were not significantly different from unity (χ^2; $p > 0.05$). Length–weight relationships of males and females ($W = 5E - {}^{06}TL^{2.9891}$) were not significantly different ($t = 0.342$; $df = 164$; $p > 0.05$).

Males ranged from 244 to 418 mm TL (Figure 3). The smallest mature male measured 296 mm TL, whereas the largest immature individual was 343 mm TL. Clasper length increased rapidly between 300 and 330 mm TL (Figure 4a). Specimens with CL up to 30 mm and more than 2 RT were all adults (Figure 4b). Maximum clasper length was 39 mm. Estimated size at 50% maturity (L_{50}) was 313 mm TL (Figure 5) and corresponded to 74.9% of maximum TL observed in this study.

Females ranged in size from 173 to 467 mm TL (Figure 3). The smallest mature female measured 329 mm TL while the largest immature was 343 mm TL. Females showed a rapid increase in oviducal gland width for individuals between 305 and 340 mm TL (Figure 6). Estimated L_{50} was 333 mm TL (Figure 5) and corresponded to 71.3% of maximum TL observed in this study. Females with egg cases (fully developed) were observed in the northern area in both seasons sampled, late winter and early spring and in the southern area in summer, at depth ranging from 63 to 116 m (Figure 7), although insufficient samples were available to identify peak oviposition times. Most females carried egg-cases in both uteri, and if only one egg case was present, it was in the left. Percentage of females carrying egg-cases in relation to total mature females were 16.1% in winter and 18.7% in spring (northern area) and 14.3% in southern area. Both ovaries were functional

Egg-cases of *P. lentiginosa* (Figure 2) are small (34.6–40.6 mm in length, horn excluded), and rectangular in shape, with maximum width (MAW) about 63–71% of ECL. The surface of the case is relatively smooth but finely striated under magnification; the dorsal surface is covered with a layer of fine and scattered longitudinal fibres, whereas the ventral surface is naked. Coloration inside the uteri is dark green. Both anterior and posterior apron edges are slightly concave. LKW is narrow (7–8% of MAW) and aHL2 is relatively short (< 40% of ECL). Posterior apron is wider (2–3.3 times) than anterior ones. Posterior horns are longer than anterior horns (1.9–2 times) and relatively short (0.9–1.18 times ECL). Egg cases measurements data are shown in Table 3.

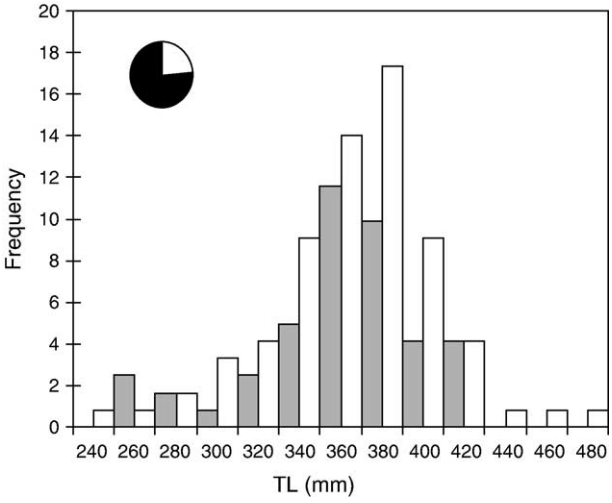

Figure 3. Length frequency distribution of *Psammobatis lentiginosa* ($n = 170$) examined in this study. Females are represented by white bars and males by grey bars. In the upper left corner the proportion of adults (black) and juveniles (white) is shown.

Table II. Number of specimens of *Psammobatis lentiginosa* used for biological studies per season and area. N, northern area (34–41° S); S, southern area (41–48° S).

Season	Area	Males	Females
Early spring	N	40	51
Late spring	N	8	12
Late winter	N	16	27
Summer	S	5	7
Winter	S	3	1
Total		72	98

Table III. Measurements (mm) of the egg-cases of the 17 skates analysed. Range, mean value and standard deviation (SD). ECL, egg-case length (without horns); MAW, egg case width (maximum); MIW, egg case width (minimum); aHL, anterior horn length; pHL, posterior horn length; LKW, lateral keel width; LKT, keel thickness; aA, anterior apron; pA, posterior apron; aHL2, and straight distance from anterior apron to apix of anterior horn.

	Range	Mean	SD
ECL	34.6–40.6	37.9	2.5
MAW	24–27.7	25.5	1.7
MIW	19.2–24.5	21.3	2.5
aHL	18–25	20.0	3.2
pHL	35–48	39.3	5.2
LKW	1.8–2	1.9	0.1
LKT	0.6–1	0.8	0.2
aA	2–3.8	2.9	0.7
pA	5.6–7.7	6.9	0.7
aHL2	1–15.6	13.9	1.9

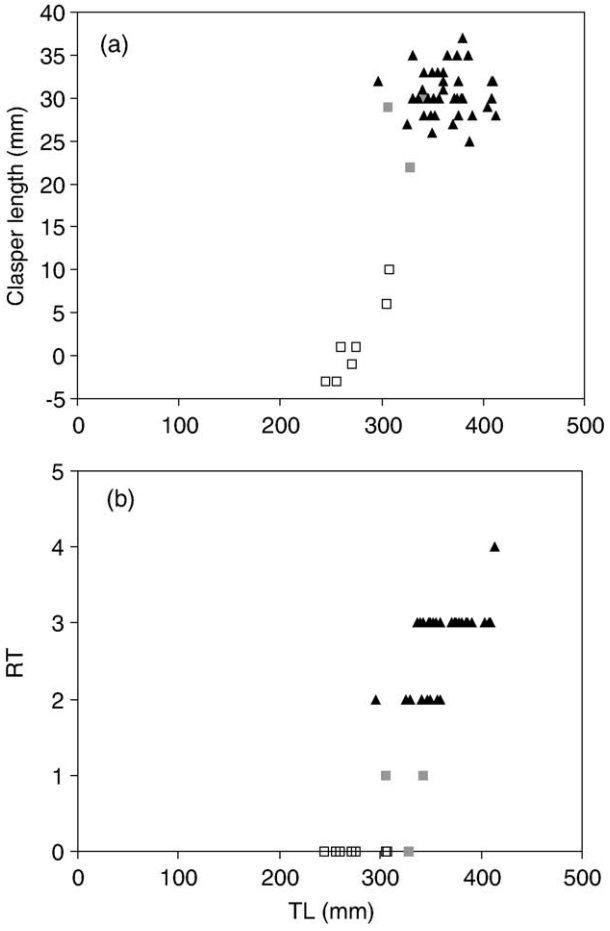

Figure 4. Relationship between (a) clasper length and (b) number of rows in the alar thorn patch (RT) and total length for male *Psammobatis lentiginosa*. Empty squares represent immature males, full squares maturing males and triangles mature males.

Distribution and abundance patterns

Psammobatis lentiginosa were found from 35°15′S to 39° 20′S in the northern area and from 44°22′S to 45° 19′S in the southern area, over a depth range of 49–149 m. They were absent between 40 and 44°S (Figure 1). Species occurrence and relative densities ranged from 13.3 to 15% and 10–190 kg/nm^2 in the northern area during 2004–2006. Major concentrations and occurrence of *P. lentiginosa* were found between 35° and 37°S (Figure 8a–c and Figure 9a).

Depth distribution of the freckled sand skate showed variation over the three years analysed. In 2004, the major concentrations were recorded between 50 and 70 m, whereas in the following years, *P. lentiginosa* occurred in deeper water (91–110 and 111–130 m depth, respectively) (Figure 9b). In the southern area, *P. lentiginosa* was recorded in only 2 of the 41 tows performed (4.17%) with densities between 2.8 and 22 kg/nm^2.

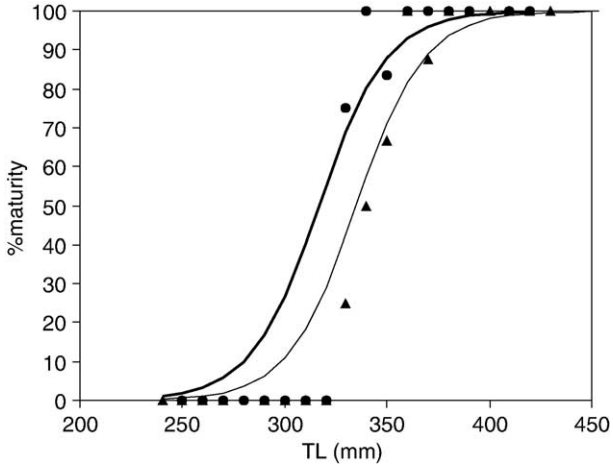

Figure 5. Maturity of *Psammobatis lentiginosa* at total length (mm). The solid line indicates a logistical ogive fitted by maximum-likelihood techniques. Black dots, males and black triangles, females.

Discussion

The freckled sandskate was captured from 35°15′S to 45°19′S with a gap (no recorded specimens) between 39°20′S and 44°22′S, from 49 to 164 m depth. This is in accordance with reports by McEachran (1983) and Cousseau et al. (2007). However, Perier et al. (2006) noted that *Psammobatis lentiginosa* is a common component of the bycatch in the San Matías gulf fishery, Argentina (41–42°S, 64–65°W), an area not covered by the research cruises used in this study. Even though this species is spread along the Argentine province and the northern part of the Magellanic province, it showed more affinity to the warmer temperatures of the Argentine province, as reflected in its major concentration which was detected between 35 and

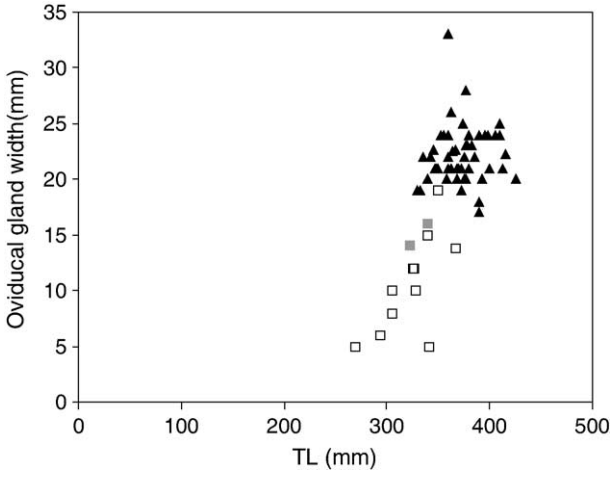

Figure 6. Relationship between the width of the oviducal gland and total length of *Psammobatis lentiginosa*. Empty squares represent immature females, full squares maturing females and triangles mature females.

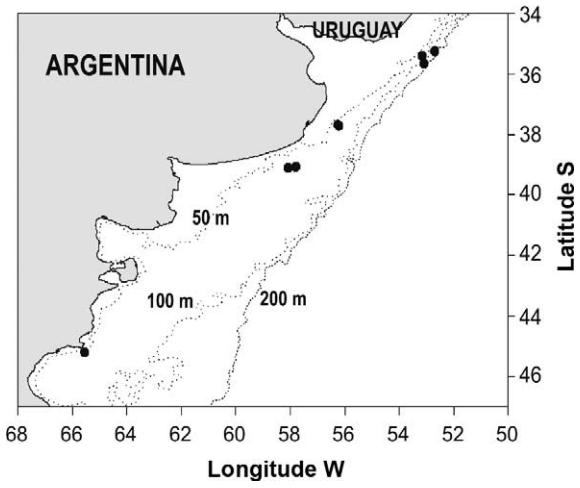

Figure 7. Study area showing the sites where females of *Psammobatis lentiginosa* bearing egg-cases were found.

37°S. Within the genus *Psammobatis*, three other species are associated with warmer waters, *P. bergi*, *P. extenta* and *P. rutrum*, whereas the remaining species show an affinity to the colder waters of the Magellanic Province (McEachran 1983; Cousseau et al. 2007). The gap in the distribution of *P. lentiginosa* between 39 and 45°S in the shelf seems not to be a problem in sampling design, because the area was almost completely sampled during research cruises. Some questions arise from this anomaly: are these two isolated populations? Is there any kind of connection between them? Morphometric and especially molecular studies will help to clarify this hypothesis.

Within the Chondrichthyes, viviparous species generally have annual, biennial or triennial reproductive cycles, while the general trend in oviparous species is egg production throughout the year with seasonal peaks, in which there is a greater proportion of females carrying egg-cases (Hamlett 2005; Ebert et al. 2006). Due to the lack of monthly information and because not all seasons were equally sampled in each region, the full extent and peak of the egg-laying season for *P. lentiginosa* could not be determined. In the northern area, samplings were carried out in late winter and spring, and females carrying egg-cases were found in both seasons. In the southern area the sampled seasons (winter and summer) were equally scarce to make a statement. According to Mabragaña & Cousseau (2004), oviposition in *P. normani* occurs in winter and spring off Buenos Aires province and in late summer in south Patagonian waters, whereas late summer oviposition takes place in *P. rudis*. In the coastal *Psammobatis* species, *P. extenta* and *P. bergi*, females carrying egg-cases were found throughout the year (Braccini & Chiaramonte 2002; San Martín et al. 2005), with a maximum during the summer.

Sexual dimorphism in length–weight relationships (LW), size at maturity and maximum size is quite variable among skate species (Marçal 2003; Ebert 2005; Oddone & Vooren 2005; Oddone et al. 2005; Colonello et al. 2007; Cousseau et al. 2007; Arkhipkin et al. 2008; Estalles et al. 2009; Paesch & Oddone 2009; YIgIn & Ismen 2009). In *P. lentiginosa* maximum size and size at maturity were greater in females than males, whereas no intersexual difference in LW relationship were found. This pattern is not shared by all *Psammobatis* species (Braccini &

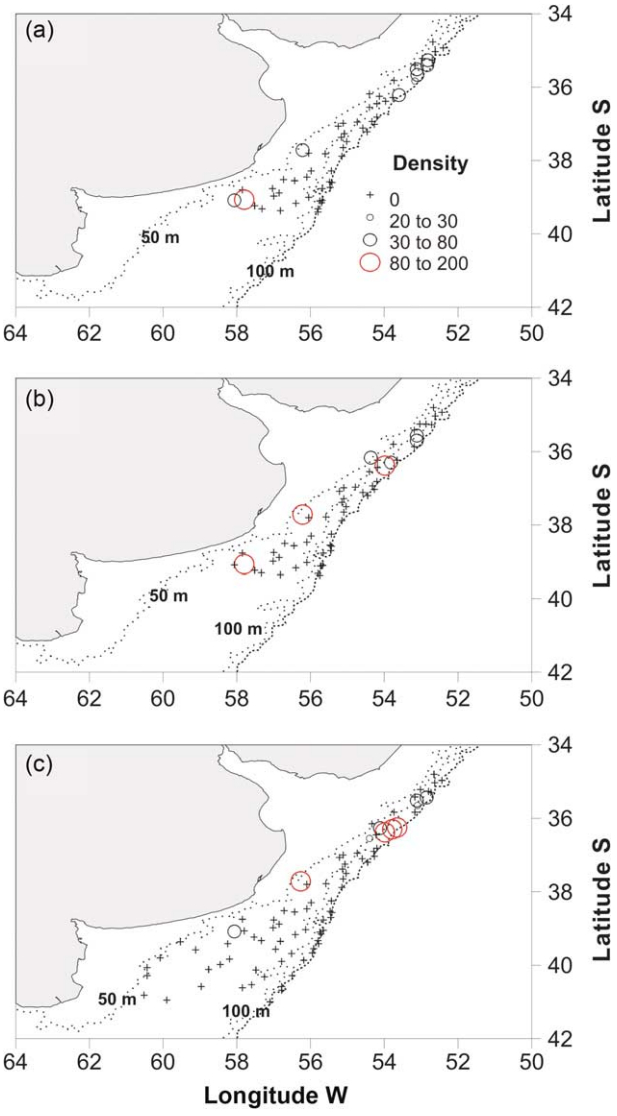

Figure 8. Study area showing estimated densities (t/nautical mile^2) of *Psammobatis lentiginosa* from four research cruises conducted in (a) 2004, (b) 2005 and (c) 2006 in the ZCPAU and south Buenos Aires province. Plus signs represent trawls with no catch.

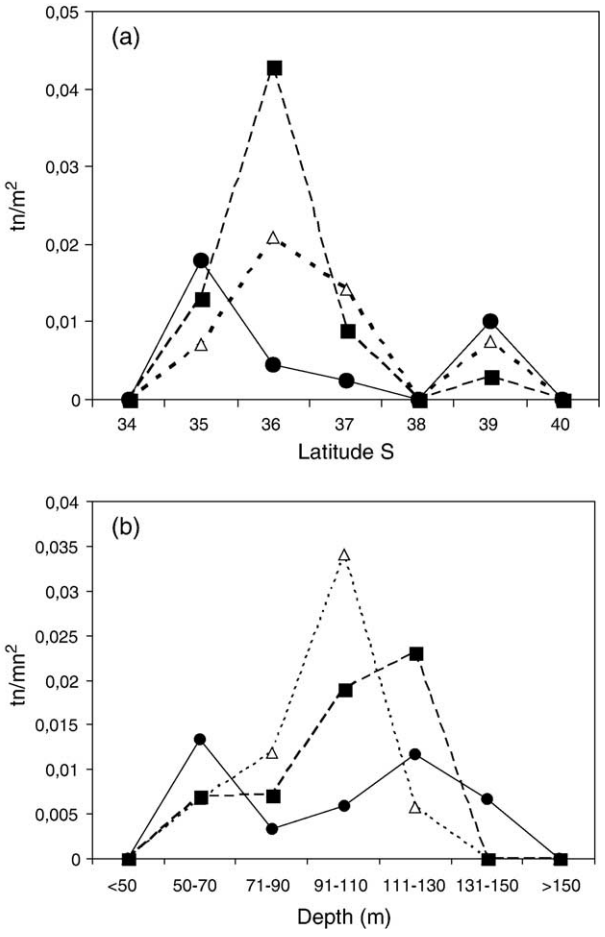

Figure 9. Estimated mean density (trawled number nautical mile^2) of *Psammobatis lentiginosa* (a) along latitude and (b) in relation to depth during (circles) 2004, (triangles) 2005, and (squares) 2006.

Chiaramonte 2002; Mabragaña & Cousseau 2004; San Martín et al. 2005). Therefore, there seems to be no fixed rule regarding sexual dimorphism.

It is a common belief that in an over-exploitation scenario, smaller species with earlier sexual maturity replace the largest with delayed sexual maturity (Agnew et al. 1999; Stevens et al. 2000; Braccini & Chiaramonte; 2002; San Martin et al. 2005). Decreasing biomass in southwest Atlantic skates was seen for several species (Massa et al. 2004), mainly due to fishing pressure. Even though *Psammobatis* spp. have traditionally been discarded at sea due to their small size, larger individuals are now being retained (Kyne 2007), but still there is no report on *P. lentiginosa* catches. Although *Psammobatis* spp. could be less susceptible to population depletion than other skates, given their small size, the increase in fishing pressure and habitat disturbance due to trawling activities could seriously impact on this species.

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