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Original article

Reproductive biology of the eyespot skate *Atlantoraja cyclophora* (Elasmobranchii: Arhynchobatidae) an endemic species of the Southwestern Atlantic Ocean (34ºS - 42ºS)

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Atlantoraja cyclophora is an endemic skate to the continental shelf of the Southwestern Atlantic Ocean (22ºS-47ºS) and a by-catch species in commercial bottom trawl fisheries. The morphometric relationships, the size at maturity and the reproductive cycle of this species were analyzed, with samples collected between 34ºS and 42ºS. The size range was 190 to 674 mm total length (TL) for males and 135 to 709 mm TL for females. Sexual dimorphism between the relationships TL - disc width and TL - total weight was found, with females wider and heavier than males. The mean size at maturity for males was estimated in 530 mm TL and for females in 570 mm TL. The gonadosomatic index (GSI) in mature females varied seasonally and showed the highest value in December. The maximum follicular diameter and oviductal gland width did not show any seasonal pattern. Females with eggs in the uterus were present most of the year. The reproductive activity in males would be continuous throughout the year, evidenced by the lack of variation in the GSI between seasons. The results obtained suggest that *A. cyclophora* might undergo an annual reproductive cycle, in coincidence to that reported for this species in Brazilian populations.

Keywords: Arhynchobatidae, Dimorphism, Elasmobranchs, Maturity, Reproduction.

Atlantoraja cyclophora es una raya endémica de las plataformas continentales del Océano Atlántico Sudoccidental (22ºS-47ºS) que se captura incidentalmente en las pesquerías comerciales de arrastre de fondo. Se estudiaron las relaciones morfométricas, el ciclo reproductivo y se estimó la longitud media de madurez sexual de esta especie con muestras colectadas entre 34ºS y 42ºS. El rango de tamaño fue 190 a 674 mm de longitud total (LT) en machos y 135 a 709 mm LT en hembras. Se observó dimorfismo sexual entre las relaciones LT - ancho de disco y LT - peso total, siendo las hembras más anchas y pesadas que los machos. La talla de madurez se estimó en 530 mm LT para machos y en 570 mm LT para hembras. El índice gonadosomático (IGS) en hembras maduras varió estacionalmente, con el valor más alto en Diciembre. No se registró variación estacional respecto al diámetro máximo folicular y al ancho de la glándula oviductal. Se observaron hembras con huevos en los úteros durante la mayor parte del año. La actividad reproductiva en los machos sería continua durante todo el año, dada la falta de variación del IGS entre estaciones. Se sugiere que *A. cyclophora* experimenta un ciclo reproductivo anual, similar a lo reportado para esta especie en aguas de Brasil.

Palabras Clave: Arhynchobatidae, Dimorfismo, Elasmobranquios, Madurez, Reproducción.

Introduction

The genus *Atlantoraja* (Menni, 1972) comprises three endemic species of the Southwestern Atlantic: *A. castelnaui*, (Ribeiro, 1907), *A. cyclophora* (Regan, 1903) and *A. platana* (Günther, 1880) (according to Ebert, Compagno, 2007). *Atlantoraja cyclophora* is distributed from Cabo Frio, Brazil (22ºS) to San Jorge Gulf in Argentina (47ºS) and inhabits from the coast out to maximum depths of 300 m in Brazil and up to the 130 m isobath in Argentina (Oddone, Vooren, 2004; Cousseau *et al*., 2007). This vulnerable species (Massa *et al*., 2006) is taken as by-catch along all its distribution area by commercial bottom trawl fisheries (Paesch, Domingo, 2003; Oddone, Vooren, 2005; Tamini *et al*., 2006; Góngora *et al*., 2009; Estalles *et al*., 2011; Massa, Hozbor, 2011; Orlando *et al*., 2011). The coastal

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ecosystem of the Southwest Atlantic Ocean, between 34ºS and 42ºS and <50 m deep, constitutes the region where the greatest landings of cartilaginous fish are recorded (Massa *et al*., 2004; Massa, Hozbor, 2011). The multi-fleet fishery that operates in the area comprises a total of 46 species, of which 19 are cartilaginous fish (Sánchez *et al*., 2011).

Knowledge of the reproductive biology of species is essential to understand its life history and for the development of responsible management strategies (Leonard *et al.,* 1999). Oddone, Vooren (2005) studied the reproductive biology of *A. cyclophora* in southern Brazil between 100 and 300 m depths, and later, Oddone *et al.* (2008) complemented the reproductive studies of this species in southeastern Brazil, up to 146 m depth. In Argentina, Estalles *et al.* (2011) reported estimates of size at maturity for males and females of *A. cyclophora* in the San Matías Gulf (41°S-42°S), but there is no information on reproductive variables in the area between 34°and 42° S. Also, like other elsamobranchs (Chiaramonte, Pettovello, 2000; Mabragaña, Cousseau, 2004; Colonello *et al*., 2007b), a latitudinal gradient in the maximum TL and size at maturity has been noted for *A. cyclophora* (Oddone, Vooren, 2005; Oddone *et al*., 2008; Estalles *et al*., 2011).

The aim of this work was to increase the knowledge of the life history features of *A. cyclophora* in a commercially important area, where reproductive variables about the species remain unknown. In this context, we analyzed the morphometric relationships, the reproductive cycle and size at maturity of *A. cyclophora* in the Southwestern Atlantic Ocean, between 34°and 42°S (excluding San Matías Gulf).

Materials and Methods

Study area and sampling. A total of 974 specimens of *A. cyclophora*, 488 males and 486 females, were collected in the Southwestern Atlantic Ocean between 34ºS and 42ºS, from bottom trawl surveys carried out by the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP) between 2002 and 2007 (Fig. 1). Samples were also obtained from commercial landings at Mar del Plata harbor. In the research surveys, the gear used was a standard Engel type bottom trawl of 120 mm mesh size, with a vertical height of 5 m and a horizontal opening of 20 m. The standard tow duration was 15 min at a speed for 4 knots (7.41 km h^{-1}) and up to 50 m at depth. For the commercial hauls, a bottom trawl gear of 120 mm mesh-size was used, with variable length depending on the boat. The total length (TL, mm) from the snout tip to the tail tip, disc width (DW, mm) between lateral tips of pectoral fins, total weight (TW, g), liver weight (LW, g) and sex were recorded for each individual. Additional reproductive variables were also registered: the inner claspers length (ICL, mm) measured from the apex of the cloaca to the clasper tip, alar thorns row number (ATR) and testes weight (TTW, g) expressed as gonadosomatic index GSI for males ($GSI = TTW/TW \cdot 100$); and oviductal gland width (OGW, mm), uterus width (UW, mm), ovarian weight (OW, g) expressed as gonadosomatic index ($GSI = OW/TW \cdot 100$) and the largest ovarian follicles diameter (LOFD, mm) and number for females. The maximum width and length (excluding the horns) of the egg capsules obtained from the left and right uteri were also recorded. Maturity status was assessed by a macroscopic analysis of the reproductive organs, following a histologically validated maturity scale proposed by Colonello (2009), with modifications. Males were classified into 3 reproductive stages and females into 4 reproductive stages (Tab.1).

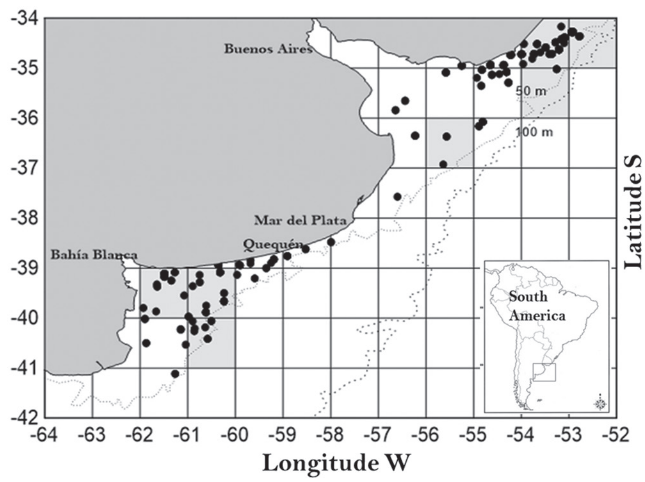

Fig. 1. Map of the study area showing trawl stations carried out in research cruises during 2002 and 2007 (dark dots) and the commercial capture (dark statistical rectangles of 1 degree by 1 degree) where *Atlantoraja cyclophora* were collected.

Tab. 1. Morphological criteria used to determine macroscopically the stage of sexual maturity of males and females *Atlantoraja cyclophora*. Criteria adapted from Colonello (2009).

Stage		Males	Females
		Macroscopic characteristics	
Juvenile	1	Testes undeveloped and abundant epigonal organ. Sperm ducts thin and non-contoured. Claspers without calcification, not exceeding the pelvic fins.	Ovaries without visible oocytes. Oviductal glands undifferentiated. Uterus thin and fully adhered to the dorsal wall of the abdominal cavity.
	2	Testes in maturation with developed spermatic vesicles, abundant epigonal organ between these. Sperm ducts little development. Claspers without calcification, exceeding the pelvic fins.	Ovaries with transparent and larger previtellogenic oocytes. Oviductal glands and uteri differentiated but not fully developed.
Adult	3	Testes with spermatic vesicles and little epigonal organ between these. Sperm ducts contoured with developed accessory glands. Claspers calcified, exceeding the pelvic fins.	Ovaries with yolked oocytes of different size, without distinguishing a litter. Oviductal glands fully formed. Uterus widened with thin walls.
	4		Ovaries with yolked oocytes of different sizes without distinguishing a larger litter. Oviductal glands large and irrigated. Uteri dilated with egg capsules inside.

Data analyses. Normality and homoscedasticity were tested for the whole sample by Shapiro-Wilk's and Levene's tests, respectively. When deviations from normality and homogeneity were detected or, there were not mean-variance relationship to apply a transformation, a nonparametric test was used (Zar, 1999). The length frequency distributions between sexes were compared by the Kolmogorov-Smirnov test, using the statistic: $KS=n(1)n(2)/d$, where $n(1)$ and $n(2)$ are the sample sizes and d is the greatest common divisor of $n(1)$ and $n(2)$ under the normal approach based on the asymptotic distribution of *KS* adequately standardized (Hollander, Wolfe, 1999). The relationships between TL-DW, TL-TW, and TL-LW were estimated for each sex. The x and y variables for the allometric equation $y=ax^b$ were log-transformed and the equation were expressed as the linear relationship between y and x: $\log(y)=\log(a)+ b\log(x)$ (Sokal, Rohlf, 1987). Parameters a and b were estimated by the least-square regression (Ordinary least square regression, Warton *et al*., 2006) and the null hypothesis of no differences between slopes was tested using ANCOVA (Zar, 1999). The null hypothesis of the isometric growth (H0: b=3) (Froese, 2006), was tested using the statistic: $ts=(b-3)/Sb$, where Sb is the standard error of the slope (Sokal, Rohlf, 1987). Changes in the reproductive organs as ICL, OGW, UW and GSI relative to TL, were used to further assess the onset of maturity. The symmetry and functional parity of the ovaries and the morphology of the egg capsules were tested by a paired t-test, in both cases (Zar, 1999). In order to estimate the size at 50% maturity ($TL_{50\%}$), a logistic ogive was fitted to the data using a maximum likelihood approach and the differences in $TL_{50\%}$ between the sexes were evaluated through a log-likelihood test (Aubone, Wöhler, 2000). Temporal changes of GSI, HSI (HSI = LW/TW·100), OGW, and LOFD of adult individuals were analyzed by ANOVA followed by post hoc comparisons with Tukey test (Zar, 1999). When it was not possible to assume the normality and homogeneity of variance, the no parametric Kruskal-Wallis H-test was used (Zar, 1999), followed by nonparametric multiple comparisons testing described in Conover (1999).

Results

Length distributions and morphometric relationships. Males ranged from 190 mm TL to 674 mm TL, whereas females ranged from 135 mm TL to 709 mm TL. There were significant differences between sexes in the size frequency distribution (KS=0.16, n=974, p=0.01). The higher frequencies observed were in the classes between 540 – 600 mm TL for males and 600-620 mm TL for females (Fig. 2). There were significant differences between sexes in the relationships TL-DW (ANCOVA: $F_{(1,\ 869)}$=12.74, p<0.0001) and TL-TW (ANCOVA: $F_{(1,\ 877)}$=9.42, p<0.0001) (Fig. 3a-b). Females were found to be wider and heavier than males. This dimorphism was found to start at 290 mm TL for both cases, but it was more evident in individuals >500 mm TL. For the relationship TL-LW, the female livers were significantly heavier than those of males (ANCOVA: $F_{(1,\ 721)}$=16, p<0.0001) (Fig. 3c).

According to the comparison of the angular coefficient "b" with the theoretical value of 3, males grew isometrically (b=3.03, d.f=444, t=1.41, p=0.15), while female growth was found to be positively allometric (b=3.16, d.f=433, t=8.26, p<0.0001) increasing their weight in greater proportion than their length (Fig. 3b).

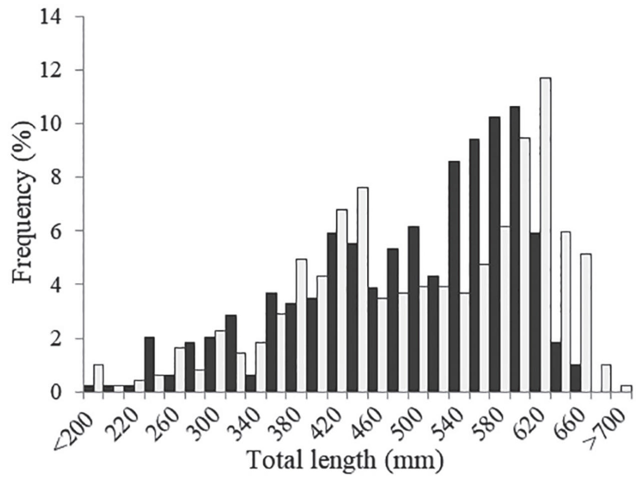

Fig. 2. Total length frequency distribution of males (dark bars, n= 488) and females (light bars, n = 486) of *Atlantoraja cyclophora*.

Reproductive organs development and size at maturity. In male individuals, a gradual increase in the clasper length to TL was evident between 500 and 550 mm TL (Fig. 4a) as well as the number of alar thorn rows (Fig. 4b). The GSI does not reflect a clear trend of testicular development as a function of TL (Fig. 4c). The size of the smallest adult male was 490 mm TL and the largest juvenile was 604 mm TL. All males > 604 mm TL were adults, with inner clasper length > 178 mm, alar thorn rows > 2 and testes weight > 14 g (Tab. 2). The males $TL_{50\%}$ was estimated in 537 mm TL (IC 95%, 425.6 ≤ TL_{50} ≤ 649.2), which corresponded to 79.7% of the maximum TL observed (Fig. 4d).

In females, both ovaries were functional and similar in mass (t=-0.81, d.f=172, p=0.42). Through the macroscopic analysis it was observed that the ovaries developed simultaneously. There were no differences in the number (t=-1.43, d.f=53, p=0.16) and diameter (t=- 0.06, d.f=41, p=0.95) of largest ovarian follicles between ovaries. The relationship between TL and oviductal gland and uterus width had a phased development, with an increase between 520 and 550 mm TL (Figs. 5a-b). The GSI reflects that development of the ovaries occurs abruptly and their weight increased from 550 mm TL (Fig. 5c). The smallest adult female size was 525 mm TL and the largest juvenile was 650 mm TL. All females > 650 mm TL were adults, with oviductal gland width > 27 mm, uterus width > 10 mm and ovary weight > 23 g (Tab. 2). Total length at 50% maturity was estimated at 570 mm TL (IC 95%, 436.9 ≤ TL50 ≤ 704.8) for females, which corresponded to 80.4% of the maximum TL observed (Fig. 5d). This value was significantly greater in females than in males (t=17.56, d.f=1, p<0.0001).

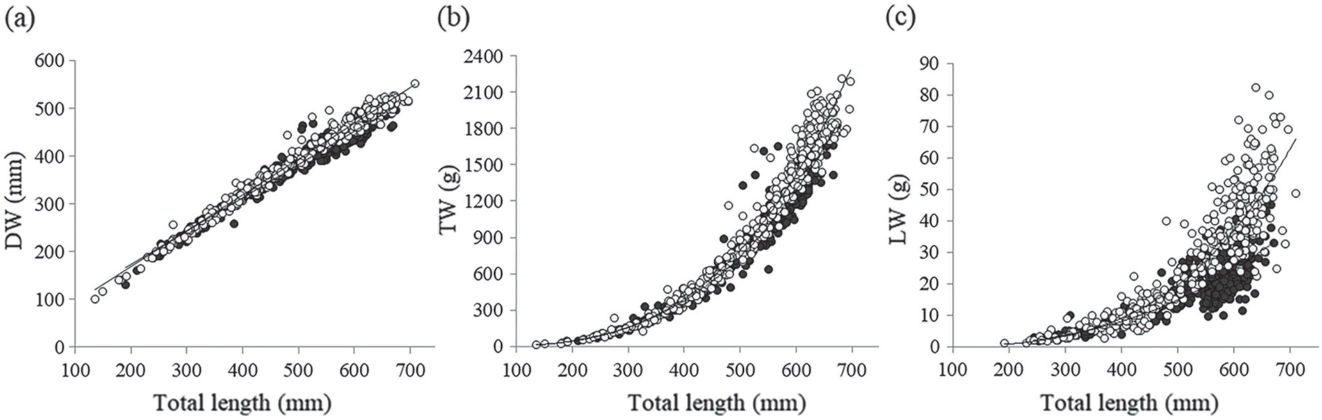

Fig. 3. Relationship between total length and **a.** disc width (DW); **b.** total weight (TW) and **c.** liver weight (LW) of males (dark dots) and females (light dots) *Atlantoraja cyclophora*. The curves were fitted by: **a.** males DW = 33.51 + 0.71TL(r=0.96, n=438), females DW = 18.70 + 0.71TL (r=0.98, n=435); **b.** males TW = $(5 \times 10^{-6})TL^{3.031}$ (r=0.98, n=446), females TW = $(2 \times 10^{-6})TL^{3.162}$ (r=0.98, n=435); **c.** males LW = $(5 \times 10^{-7})TL^{2.759}$ (r=0.83, n=365); females LW =$(9 \times 10^{-9})TL^{3.459}$ (r=0.90, n=360).

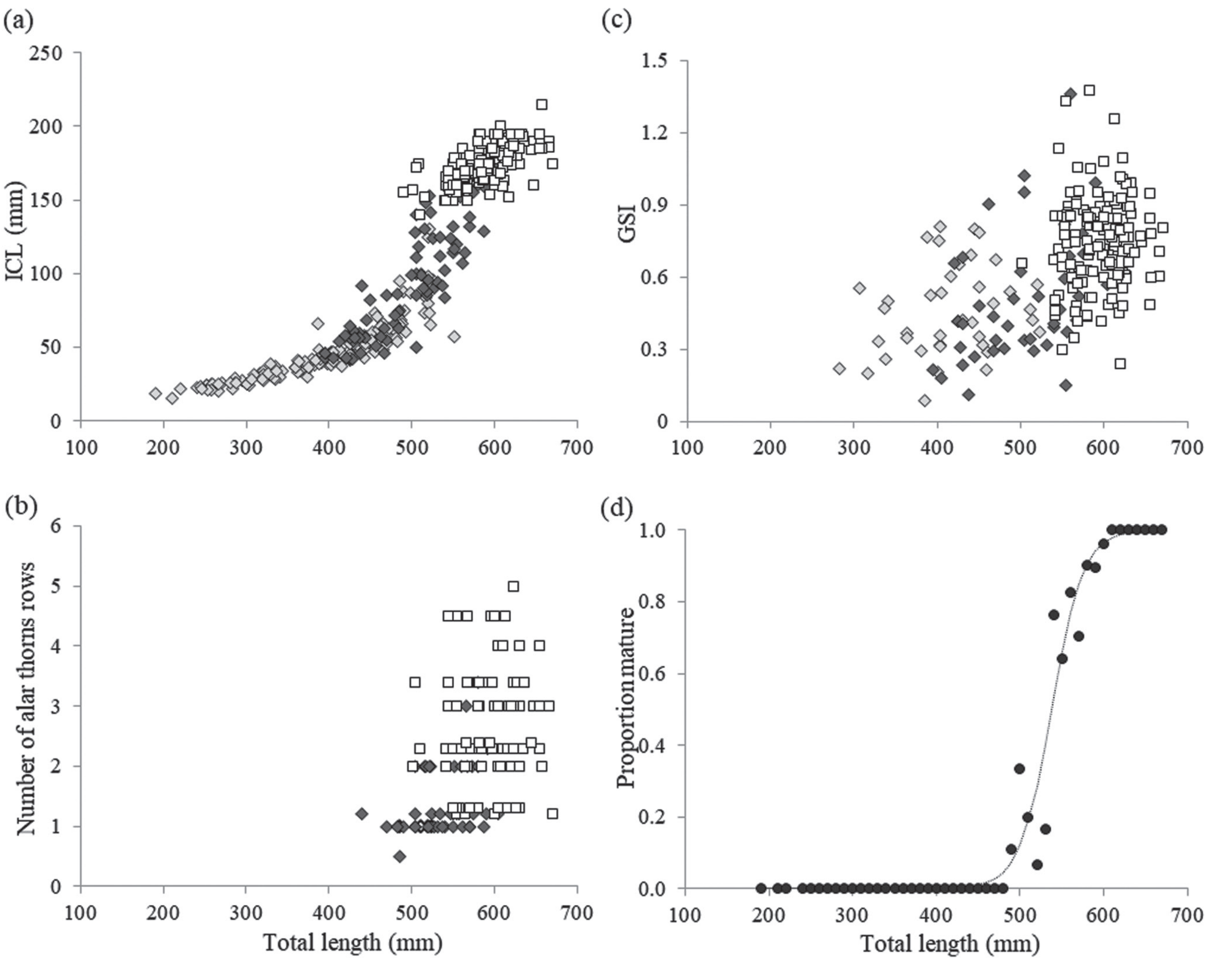

Fig. 4. Relationship between total length and **a.** inner claspers length (ICL); **b**. number of alar thorns rows; **c.** GSI; and **d.** proportion by mature individuals of *Atlantoraja cyclophora* males according to maturity stage (stage 1, light rhombus; stage 2, dark rhombus; stage 3, light square).

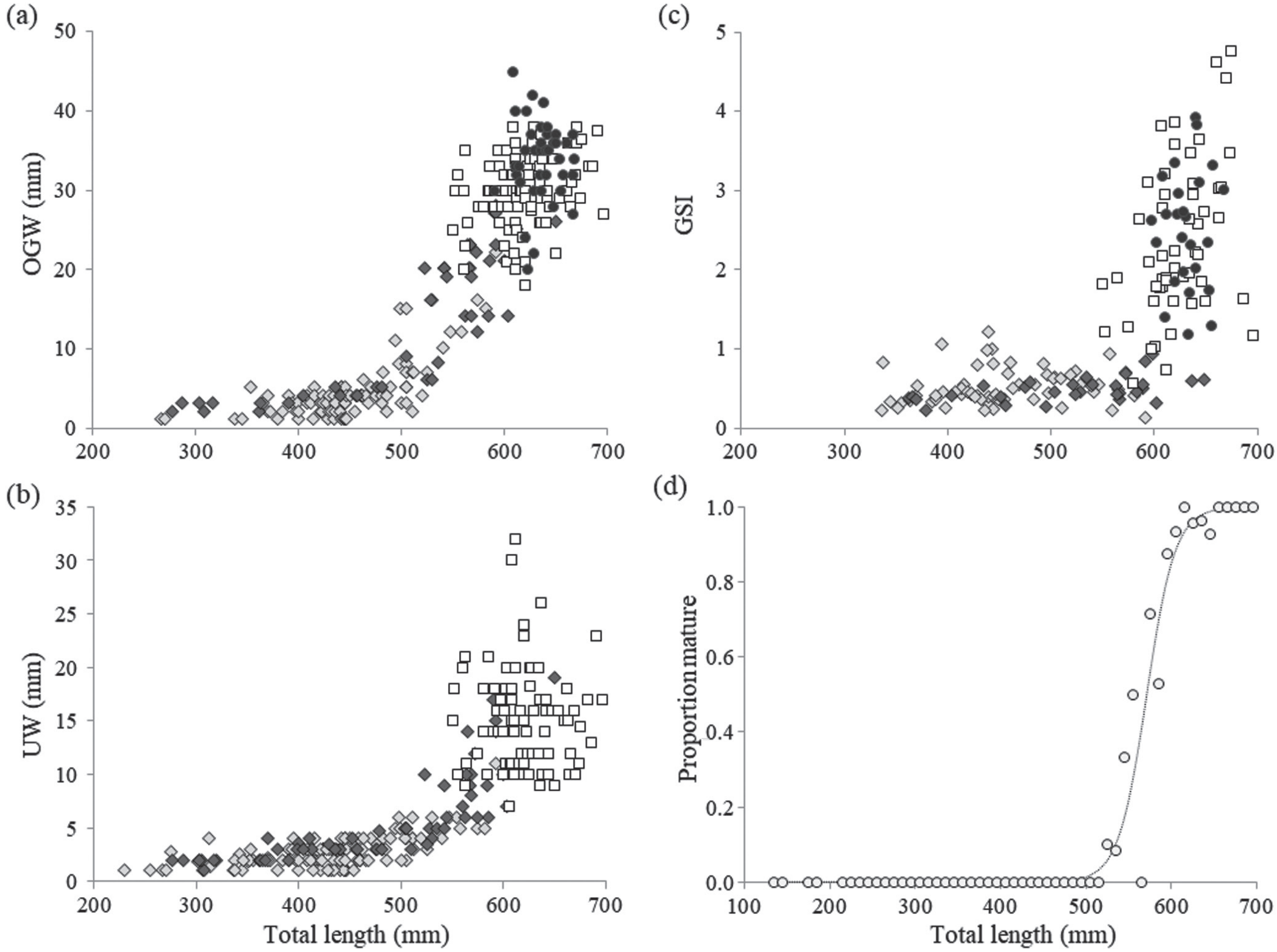

Fig. 5. Relationship between total length and **a.** oviductal gland width (OGW); **b.** uterus width (UW); **c.** GSI; and **d.** proportion by mature individuals of *Atlantoraja cyclophora* females according to maturity stage (stage 1, light rhombus; stage 2, dark rhombus; stage 3, light square; stage 4, dark dots).

Tab. 2. Range (mean ± s.d) of the total length (TL, mm) and the reproductive variables recorded for juvenile and adults of *Atlantoraja cyclophora*. ICL, inner clasper length (mm); ATR, alar thorn rows (nº); TTW, testis weight (g); OGW, oviductal gland width (mm); UW, uterus width (mm); OW, ovary weight (g) and n, sample size.

		Males							
		TL	n	ICL	n	ATR	n	TTW	n
Juvenile	1	190 – 551 (390.2 ± 79.1)	163	15 – 130 (46.3 ± 20.7)	143	0 - 1 (0.6 ± 0.5)	6	0.2 – 5 (2.1 ± 1.2)	42
	2	285 – 604 (495. ± 6 58.7)	110	42 – 178 (98.3 ± 41.1)	78	0.5 – 3.4 (1.4 ± 0.6)	41	0.6 – 14 (4.7 ± 3.3)	43
Adult	3	490 – 674 (589.7 ± 35.2)	215	140 – 215 (174.6 ± 12.6)	167	1.2 – 5 (2.5 ± 0.7)	140	3 – 17 (9.3 ± 2.7)	144
		Females							
		TL	n	OGW	n	UW	n	OW	n
Juvenile	1	135 – 592 (417.5 ± 83.5)	210	1 – 23 (5.0 ± 4.7)	91	1 – 11 (2.8 ± 1.6)	125	0.4 – 10 (3.2 ± 2.1)	62
	2	267 – 650 (497.8 ± 97.5)	81	2 – 28 (13.3 ± 8.8)	41	1 – 9 (5.7 ± 4.2)	53	0.6 – 13 (5.1 ± 3.4)	30
Adult	3	480 – 709 (619.6 ± 38.4)	127	18 – 39 (30.3 ± 4.6)	98	7 – 32 (15.2 ± 4.8)	84	0.6 – 13 (5.1 ± 3.4)	53
	4	525 – 675 (631.4 ± 24.4)	61	20 – 45 (33.2 – 5.1)	47	-	-	18.2 – 76 (42.2 ± 15.1)	26

Reproductive cycle. Males showed a significant difference in the GSI mean values between November and December (ANOVA: $F_{(9,\ 129)}$=2.39, p=0.01) (Fig. 6a). Despite this difference, the GSI it seems to be stable throughout the year. Also, significant differences were found in male HSI (H=46.76, d.f=9, p<0.0001), which decreased in autumn and increased in spring and summer (Fig. 6b). Seasonal variations were detected in the GSI (ANOVA: $F_{(8,\ 66)}$=2.85, p=0.008) and HSI (H=38.47, d.f=8, p<0.0001) for females (Figs. 6c-d). The highest GSI value recorded in December was significantly different from all months except November and July. The HSI was similar to male pattern with a decrease in autumn an increase in spring. The largest ovarian follicles diameter (LOFD) ranged between 13 and 40 mm and the modal value was 26 mm, for both egg-carrying and no egg-carrying females. It was possible to identify macroscopically 3 different size groups of LOFD: one between 13-25 mm, the most frequent between 26 - 33 mm, and a less frequent between 34 - 40 mm (Fig. 7a). Probably, the latter group represents the pre-ovulatory follicles. Although it was not possible to record the follicular size of all the adult females sampled, it was observed that females with follicles > 34 mm were present in March and from July to December. Females with eggs in the uterus were observed during all the sampled months excepting January, February and June (Fig. 7b). No significant differences were detected in the OGW (ANOVA: $F_{(9,134)}$=1.23, p=0.28) and LOFD (ANOVA: $F_{(7,\ 36)}$=1.24, p=0.30) throughout the year (Fig. 8a-b). However, the lowest values of the LOFD were observed in April (Fig. 8b).

Egg capsule. The length and width of the 36 egg capsules in uteri ranged between 63 – 77 mm (71.4 ± 3.15) and 40 – 48 mm (43.9 ± 2.12) respectively. No differences were found in the mean values of the maximum length (t=-1.01, d.f=15, p=0.326) and width (t=-0.39, d.f=15, p=0.696) between the left and right egg capsules.

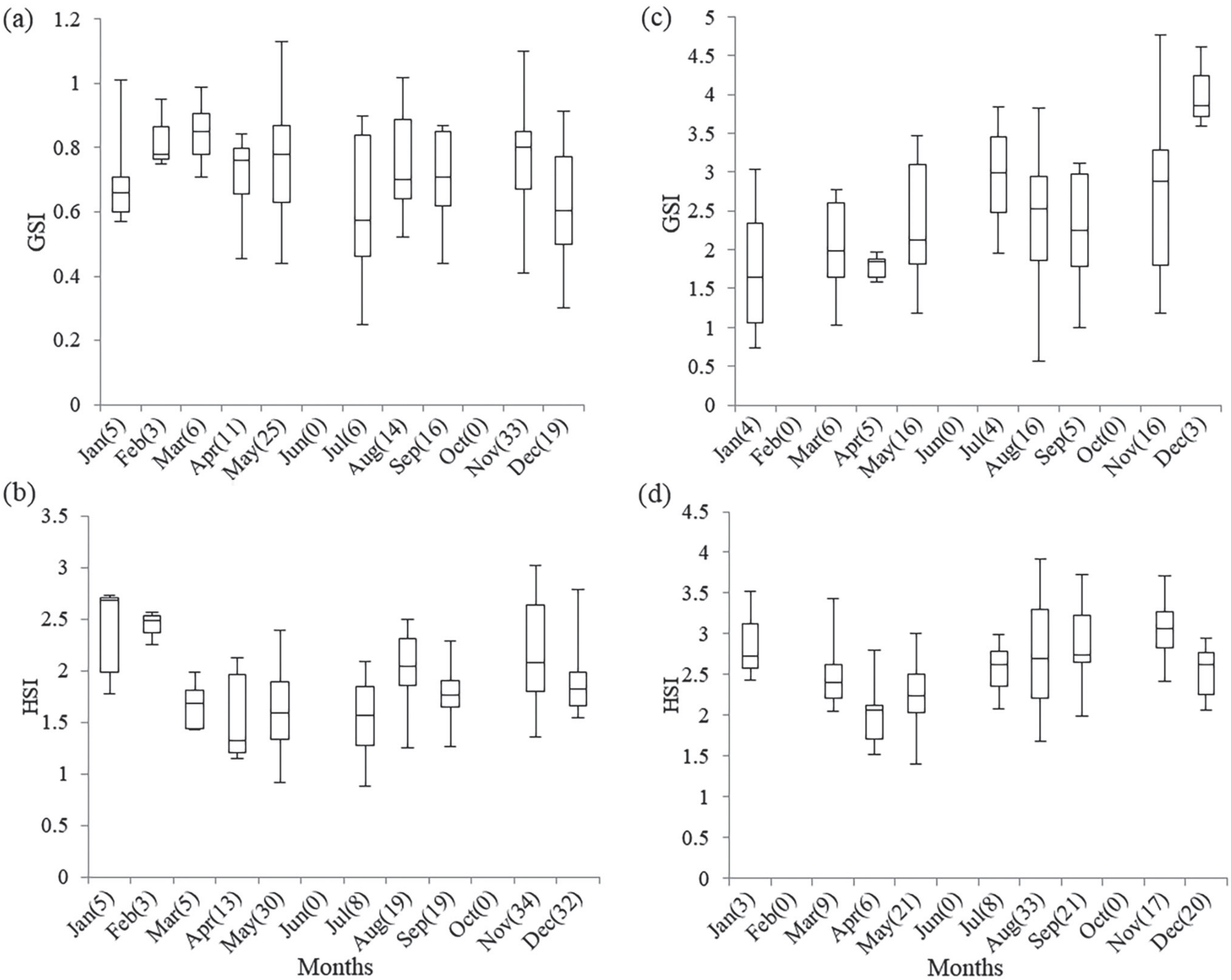

Fig. 6. Seasonal variation in gonadosomatic (GSI) and hepatosomatic (HSI) indexes for **a.-b.** males and **c.-d.** females of *Atlantoraja cyclophora.* The number of samples analyzed is between parentheses. The boxes represent the interquartile range between Q1 and Q3 with the 50% of data, the central line represents the median value and whiskers extend to the maximum and minimum values.

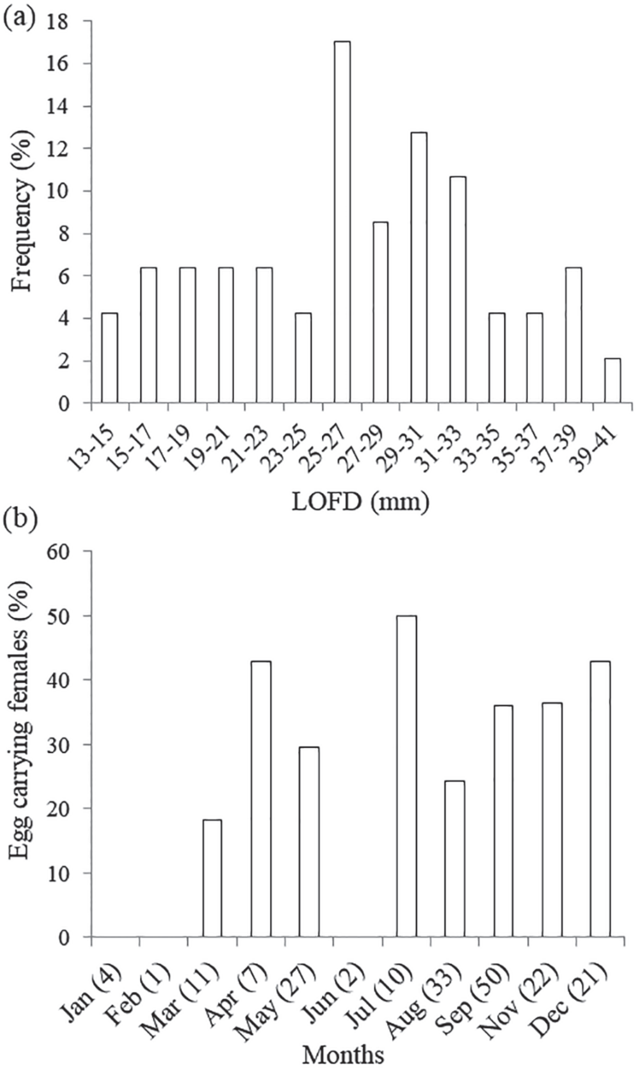

Fig. 7. a. Frequency distribution of the largest ovarian follicles diameter (LOFD) in mature females of *Atlantoraja cyclophora*. **b.** Seasonal variation in the proportion of egg-carrying females of *A. cyclophora*. The number of samples analyzed is between parentheses.

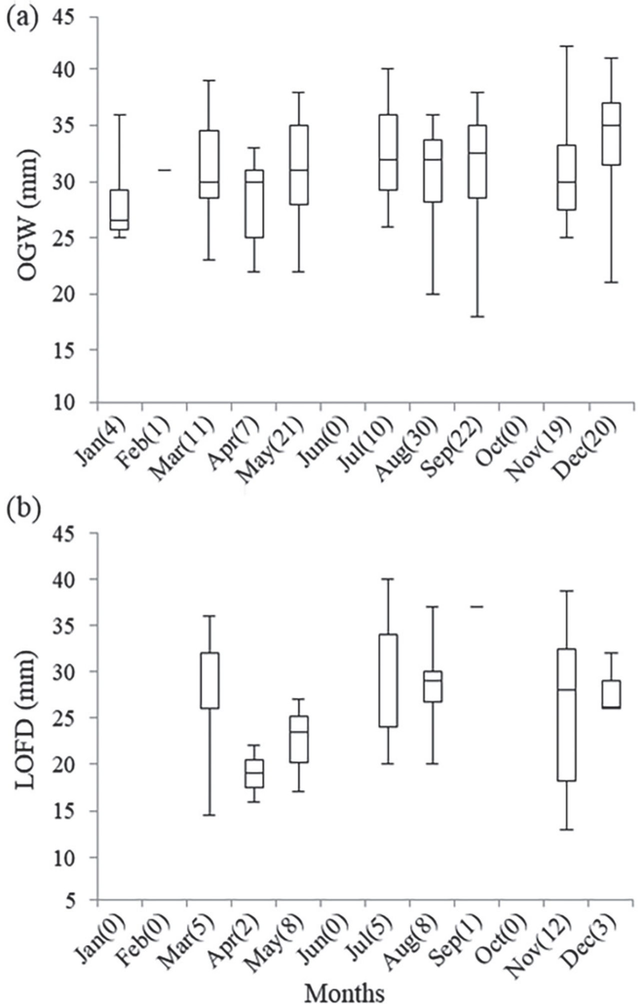

Fig. 8. Seasonal variation in **a.** oviductal gland width (OGW) and **b.** diameter of the largest ovarian follicle (LOFD) in *Atlantoraja cyclophora* females. The number of samples analyzed is between parentheses. The boxes represent the interquartile range between Q1 and Q3 with the 50% of data, the central line represents the median value and whiskers extend to the maximum and minimum values.

Discussion

The length frequency distribution significantly differed between sexes and it was more evident between adult individuals. The higher frequencies in both sexes were observed in individuals with sizes that exceeded the $TL_{50\%}$. However, these results are presented informatively, since part of the specimens come from commercial landings and the sample may be skewed due to the selective retention of larger specimens (Matta, Gunderson, 2007). It has been observed that all species of the genus *Atlantoraja* are sexually dimorphic in TL-DW and TL-TW ratio, with females heavier and wider than males (Oddone, Vooren, 2004; Oddone, Amorim, 2007; Coller *et al*., 2011; Colonello *et al*., 2012). Also, it is common in this genus that such dimorphism begins in immature individuals (Oddone, Amorim, 2007; Coller *et al*., 2011). In this work, a change in the morphology of *A. cyclophora* individuals was detected around 290 mm TL. This agrees with the positive allometric growth observed in this work for females, and by Oddone, Amorim (2007) in southeastern Brazil. However, the increment in weight of females was considerable from 500 mm TL and it was consistent with the maturity. The dimorphism in TL-LW ratio could be related to the higher reproductive energy requirements of females (Colonello *et al*., 2012). The increase of liver weight observed in larger females (>500 mm TL), suggests higher energy storage in females during maturation, in comparison to adult males. This is consistent with the fact that the liver actively participates in the synthesis of yolk precursors (Koob, Callard, 1999; Prisco *et al*., 2002; Díaz-Andrade *et al*., 2009).

Sexual dimorphism in maximum length and size at maturity has been observed in many chondrichthyans (Mabragaña *et al*., 2002; Ungaro, 2004; McFarlane, King, 2006; Oddone *et al*., 2007; Ebert *et al*., 2008; Colonello *et al*., 2016; Chierichetti *et al*., 2017). Viviparous elasmobranchs females usually mature and grow to large size than male, showing a positive correlation between litter and size (Colonello *et al*., 2011). However, this dimorphism is quite variable among skates. In *Psammobatis* Günther, 1870 and *Bathyraja* Ishiyama, 1958, males may exceed or equal the female's sizes and they can also reach sexual maturity at larger TL (Braccini, Chiaramonte, 2002; Mabragaña, Cousseau, 2004; Ebert, 2005; San Martín *et al*., 2005; Perier *et al*., 2010). Nonetheless, *A. cyclophora* females attain larger maximum size and size at maturity than males. Whatever the case, it does not seem to be a clear biological explanation for this.

In elasmobranchs with wide geographic distribution, the same species can display an increment in life history patterns with increase in latitude (Templeman, 1987; Chiaramonte, Pettovello, 2000; Yamaguchi *et al*., 2000; Frisk, Miller, 2006; Colonello *et al*., 2007b). There are many hypotheses to explain this fact, these variations could be a consequence of oceanographic conditions, the effect of fishing pressure (Mabragaña, Cousseau, 2004), or the result of phenotypic plasticity (Licandeo, Cerna, 2007). The maximum TL and size at maturity recorded here were similar to that previously reported in northern Patagonian waters (Estalles *et al*., 2011) and greater than the registered for individuals from southern and southeastern Brazil (Oddone, Vooren, 2005; Oddone *et al*., 2008). In relation to these parameters, it is clear that *A. cyclophora* is a species of late maturity. Individuals analyzed in this study, mature when they reach 79.7% and 80.4% of their total growth (males and females respectively), in agreement with Brazilian populations (Tab. 3). However, the individuals of the San Matías Gulf have a later maturity despite being at the same latitude as the individuals analyzed in this work (between 41º- 42ºS and 34º- 42ºS, respectively) (Tab. 3). This could be due to the fact that these individuals are in a more protected marine environment with hydro-geographic characteristics that favor the spawning and reproduction of several species (Di Giacomo *et al*., 2005; Perier *et al*., 2011). On the other hand, although the bottom trawl fishery is developed in both regions, the fishing activity in the area between 34º- 42ºS is greater (Massa *et al*., 2004, Sánchez *et al.,* 2011).

In this work the TL–ICL relationship, together with the increase in the number of alar thorns were the best macroscopic parameters that represented the onset of sexual maturity in males, which ranged between 500 and 550 mm TL. On the other hand, size at maturity in female was established between 520 and 550 mm TL, based on a change in the OGW and in the uterus width (UW). The frequency distribution of LFOD recorded here showed that follicles with sizes bigger than 34 mm of diameter could be considered as pre-ovulatory. For this species this size had been previously estimated at 26 mm (Oddone, Vooren, 2005) and 30 mm (Oddone *et al*., 2008). However, the size of the egg cases of *A. cyclophora* examined in this work were similar those recorded by Oddone *et al.* (2004) from southern Brazil. According to Licandeo, Cerna (2007), the females of *Zearaja chilensis* (Guichenot, 1848) of the southernmost distribution from southern Chile would invest more energy in the production of larger egg cases instead of more quantity of eggs, than females of the northern region. More complementary studies of the ovarian fecundity of *A. cyclophora* are necessary to better understand their reproductive traits.

Tab. 3. Size range (mm) and size at fifty percent of maturity ($TL_{50\%,}$ mm) of *Atlantoraja cyclophora*, registered for different areas within its distribution range. F, females; M, males; N, number of individuals sampled; TL, total length. Other data references: (a) Oddone *et al.* (2008), (b) Oddone, Vooren (2004) (2005), (c) Estalles *et al.* (2011).

Study area		Size range	TL_{50}	TL_{50} / TL (%)	N
23º37'S-27º40'S[(a)] *Southeastern Brazil*	M	133 - 585	463	79.1	396
	F	115 - 680	532	78.2	401
30º40'S-34º30'S[(b)] *Southern Brazil*	M	287 - 635	485	76.4	214
	F	235 - 645	528	82.5	245
34º - 42ºS *Southwestern Atlantic Ocean*	M	190 - 674	537	79.7	488
	F	135 - 709	570	80.4	486
41-42ºS – 64-65ºW[(c)] *San Matías Gulf*	M	360 - 620	530	85.5	183
	F	340 - 690	590	85.5	299

According to the results registered here, the lack of seasonal variation of LFOD and OGW and the occurrence of females with eggs in the uterus throughout the year, *A. cyclophora* might undergo an annual reproductive cycle. In addition, the higher values in the female GSI observed in December, might be explained by a peak of reproductive activity in spring season, as was proposed by Oddone *et al.* (2008) in coastal waters off southeastern Brazil. Seasonal peaks of the reproductive activity are consistent with other skates that inhabit coastal (<50 m deep) and warmer waters of Southwestern Atlantic Ocean [*Sympterygia bonapartii* Müller & Henle, 1841 (according to Mabragaña *et al*., 2002); *A. castelnaui* (according to Collonelo *et al*., 2012); *Rioraja agassizi* (Müller & Henle, 1841) (according to Colonello *et al*., 2007a; Oddone *et al*., 2007)], where temperatures and photoperiod may affect egg laying rate (Colonello, 2009). The lack of reproductive seasonality is common in deeper waters with less environmental variability, as was observed in *B. albomaculata* (Norman, 1937) (according to Ruocco *et al*., 2006), therefore, due to the predominant geographical location of *A. cyclophora* within the study area (outer coastal shelf, 28.9 - 49.6 m bottom depth, 10.6 - 14.9ºC mean bottom temperature, Jaureguizar *et al*., 2006), a mixed coastal-deep reproductive pattern might be possible. On the other hand, the reproductive activity in *A. cyclophora* males analyzed in this work was continuous through the year, evidenced by the lack of variation in the GSI between seasons. This agrees with results reported for southern Brazil specimens (Oddone *et al*., 2008) and sets the possibility that males have the ability to produce sperm throughout the year. In summary, the results obtained in this work were consistent with those reported for this species in Brazilian populations (Oddone, Vooren, 2005; Oddone, Amorim, 2007; Oddone *et al*., 2008) and suggest that the pattern of sexual and morphometric development of *A. cyclophora* would be similar between regions. Especially, if it is taken into account that this species maintains its feeding habits along its distribution range, using similar food resources and possibly having the same trophic role (Barbini, Lucifora, 2016). Ebert *et al.* (2008) and Frisk, Miller (2009) exposed that for species with a large geographic range, the differences in size at maturity and other vital rates may have profound implications in the way that the species should be managed. In Argentina, *A. cyclophora* is one of the 5 principal species of skates landed (Massa *et al*., 2004; Tamini *et al*., 2006; Perez Comesaña *et al*., 2011) and presents latitudinal variations in maximum TL and size at maturity. This suggests the need to increase the biological studies tending to the conservation and proper management of the species.

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