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Relationship between liver weight, body size and reproductive activity in *Atlantoraja cyclophora* (Elasmobranchii: Rajidae: Arhynchobatinae) in oceanic waters off Rio Grande do Sul, Brazil

Relação entre peso do fígado, tamanho corporal e atividade reprodutiva em *Atlantoraja cyclophora* (Elasmobranchii: Rajidae: Arhynchobatinae) em águas oceânicas do Rio Grande do Sul, Brasil

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Abstract

Samples of *Atlantoraja cyclophora* were obtained by bottom-trawling surveys on the outer continental shelf and upper slope of the Rio Grande do Sul State, Brazil, at depths between 100 and 300 m. For a sample of 459 individuals, the total length, eviscerated weight and liver weight were recorded. Liver weight of the males varied between 2.4 and 36 g, and 2.4 and 65 for the females. Females had significantly heavier livers in all total length classes. For the males, the hepatosomatic index varied between 1.5 and 3.5 and for the females between 0.53 and 4.95. Mean hepatosomatic index was significantly higher in the females. Liver weight and total length according to the equations $LW=0.00065*TL^{2.648}$ for males and $LW=0.00309*TL^{2.171}$ for females.

Key words: egg capsules, sexual dimorphism, yolk, reproductive stages.

Resumo

Amostras de *Atlantoraja cyclophora* foram obtidas através de cruzeiros de pesquisa com arrasto de fundo na plataforma continental externa e talude superior do estado do Rio Grande do Sul, Brasil, em profundidades entre 100 e 300 m. Para 459 indivíduos foram registrados o comprimento total, o peso eviscerado e o peso do fígado. Este último variou nos machos de entre 2.4 a 36 g e nas fêmeas de entre 2.4 a 65 g. As fêmeas tiveram fígados significativamente mais pesados que o dos machos em todas as classes de comprimento total. Nos machos, o índice hepatossomático variou de entre 1.5 e 3.5 e nas fêmeas de entre 0.53 e 4.95. O peso do fígado aumentou com relação ao o peso total segundo a relação $LW=0.00065*T^{L2.648}$ nos machos e $LW=0.00309*TL^{2.171}$ nas fêmeas.

Palavras-chave: cápsulas ovígeras, dimorfismo sexual, vitelo, estágios reprodutivos.

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Introduction

Oviparity is a lecithotrophic mode of reproduction occurring in all species of Rajoidei, being the family Rajidae altogether with the Heterodontiformes a single-oviparous group (*i.e.*, producing eggs capsules with a single embryo inside) (Compagno, 2005; Musick and Ellis, 2005).

The skate genus *Atlantoraja* Menni, 1972 is endemic to the Western South Atlantic coast of South America, demersal on continental shelves, with three species: *A. castelnaui*, *A. platana*, and *A. cyclophora* (Compagno, 2005). The latter occurs along the Brazilian coast from Cabo Frio, Rio de Janeiro (22°S) to Golfo de San Jorge in Argentina (47°S), inhabiting from coastal waters to depths of up to 300 m (Oddone and Vooren, 2004).

Reproduction of *A. cyclophora* usually takes place throughout the year (Oddone, pers. obs.), with oviposition occurring at similar intensities during both summer and winter (Oddone and Vooren, 2005). Males attain sexual maturity at the mean total length of ~49 cm and females at 53 cm (Oddone and Vooren, 2005). Females deposit egg capsules with mean dimensions of 68x39 mm (Oddone *et al*., 2004) and the young hatch with 11.5 cm total length (Oddone, pers. obs.).

The elasmobranchs liver is a large organ filling a considerable portion of the body cavity, varying from 1% to 6% in bottom dwelling species like skates (Holmgren and Nilsson, 1999). It functions as a reservoir of blood (Tota, 1999).

The aim of this paper is to understand the variation in liver weight by sex and season, and to discuss its relationship with reproduction.

Material and Methods

A total number of 459 specimens of *Atlantoraja cyclophora* (245 females, 214 males) were collected during six bottom-trawling surveys on the outer continental shelf and upper slope off the Rio Grande do Sul State, Brazil. The study area is situated between Chuí and Cape Santa Marta Grande, between the latitudes 30°40'S and 34°30'S, at depths between 100 and 300 m (Figure 1). Cruises occurred in August-September of 2001 and March-April of 2002 at the R/V *Atlântico Sul*. Throughout the text, these surveys are referred to as "winter" and "summer" surveys, respectively.

Specimens were measured immediately after the capture. Total length (*TL*) was recorded to the nearest mm with an ichthyometer, eviscerated weight (*EW*) and liver weight (*LW*) were recorded to the nearest g with a roman scale. Hepatosomatic index (*HSI*) for each specimen was calculated as: $HSI=(LW/EW)*100$. The eviscerated weight was used because it is a more adequate body mass indicator than total weigh, as it is not affected by individual variation in the mass of the digestive tract, liver and reproductive organs (Perez and Vooren, 1991).

The significance test used was the Student *t*-test (Sokal and Rohlf, 1987). Results were expressed presenting the *t* value and the degrees of freedom (*df*). In all cases *p* express the probability and *n* the sample size. Significance level used in the tests was 0.05. Mean values were expressed altogether with the standard deviation as: *m±sd*. The potential relationship between *LW* and *TL* were estimated directly through non-linear regression using the quasi-Newton algorithm to minimise the sum of squares of the prediction errors.

Results

In adult males there was a seasonal difference in the *LW*, being the mean *LW* in winter significantly higher than the mean *LW* in summer ($t=-2.64$; $p<0.05$; $df=164$). In adult females, no significant seasonal difference in *LW* was detected. Females had significantly heavier livers than

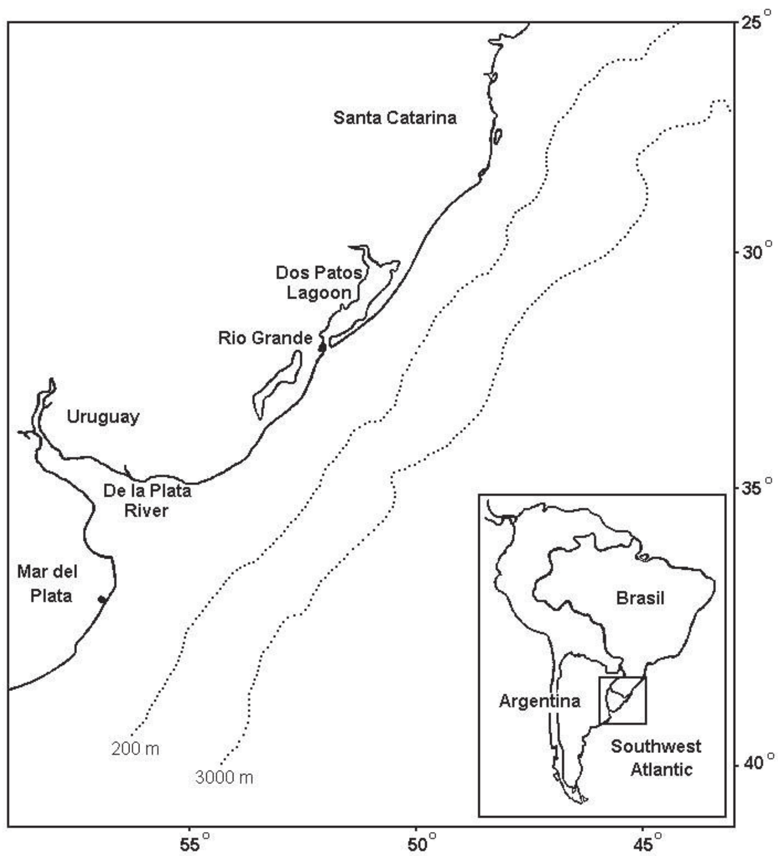

Figure 1. Study area: Rio Grande do Sul state's continental shelf and slope.

the males in all classes of 1 cm *TL* (t=10.67; p<0.05; df=448, Figure 2).

The mean *HSI* was significantly higher in the females (t=-10.1; p<0.05; df=423). As expected according to the *LW-TL* relationship, the *HSI* for the males was found to vary seasonally, with significantly higher values in winter (t=3.1; p<0.05; df=186) for skates between 40.0 and 60.0 cm *TL*. For the females, no significant seasonal difference in the *HSI* was observed (t=-1.81; p>0.05; df=223).

The highest value of the *HSI* of the males in winter was significantly lower than the *HSI* of the females in both seasons (t=6.20; p<0.05; df=321), confirming the difference between sexes regarding the hepatic condition (Figure 3).

The relationship between *LW* and *TL* is described by the equations $LW=0.00065*TL^{2.648}$ (R^2=0.76) for males and $LW=0.00309*TL^{2.171}$ (R^2= 0.64) for females.

Discussion

In sharks sexual dimorphism of the liver is common (Silva and Lessa, 1991), the females having heavier livers than the males. This also seems to be common in skates (Rajidae), as it has been observed in *Sympterygia bonapartii*, *Atlantoraja cyclophora* and *A. platana* (Mabragaña *et al.*, 2002; Oddone, 2003; Marçal, 2003).

In the present study, the *LW* of *A. cyclophora* increased equally in both sexes up to a certain *TL,* from where females began to show higher values. This dimorphism is probably related to the energetic expense of females during the vitellogenesis, oocyte maturation and gestation. Females store great quantities of lipids in the liver during the pre-vitellogenic phase of the reproductive cycle (Lucifora *et al.*, 2002) and the production of vitellogenin (the precursor to egg yolk proteins) takes place in the liver (Gelsleichter, 2004).

In elasmobranchs, the variation in the *LW* is strongly correlated with the reproduction. In the viviparous species the liver weight diminishes with the gestation proportionally to the amount of organic substances provided to the embryos by the mother (Ranzi, 1933). According to Lucifora *et al.* (2002) variations in the *LW* throughout the life span in viviparous elasmobranchs are due to an increase of the energetic expenses that females face during their reproductive cycle.

Such accompaniment of the reproductive cycle by the *LW* occurs in *A. cyclophora* even with regard to liver coloration throughout the life span and reproductive stages, varying in *A. cyclophora* from light beige to black. This was also observed for *A. platana*, *A. castelnaui* and *Rioraja agassizi* (Oddone, pers. obs.). However, such coloration may not have a simple direct relationship with different life stages of the skates. At least for *A. cyclophora,* it is not a simple process of darkening of the liver with the ageing of the skates, because we observed all liver colours in all size (age) classes as well as in

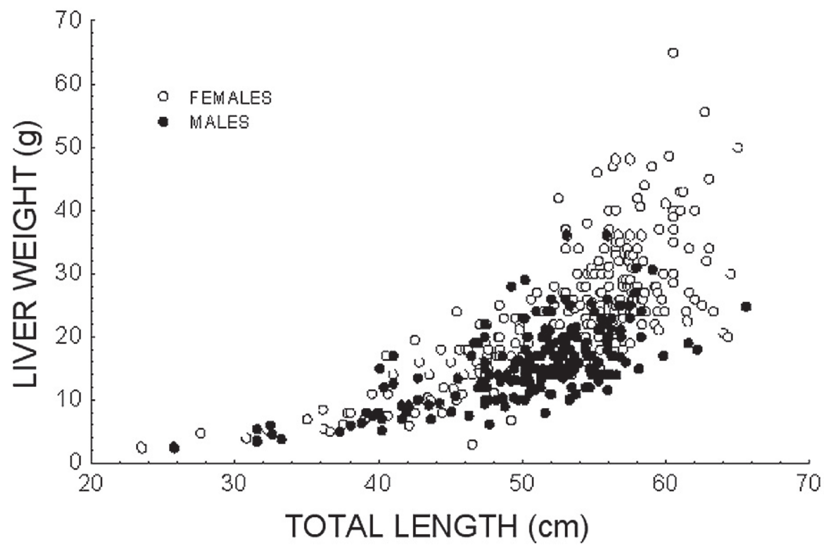

Figure 2. Relationship between liver weight (g) and total length (cm) for males (full circles) and females (empty circles) of Atlantoraja cyclophora.

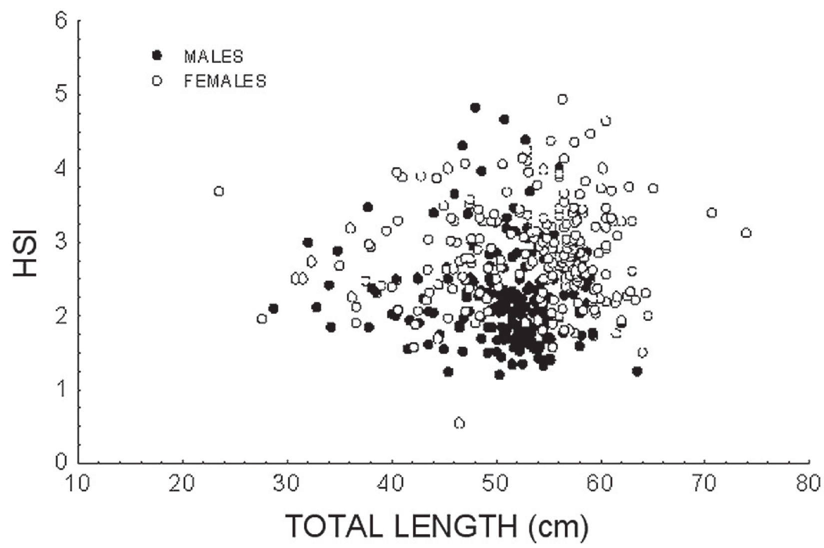

Figure 3. Relationship between hepatosomatic index (HSI) and total length (cm) for males (full circles) and females (empty circles) of Atlantoraja cyclophora.

different maturation stages with no clear relationship. So this is yet to be carefully analysed.

In males of *A. cyclophora*, the *HSI* was higher in winter. In *Psammobatis extenta* this fact was observed in both sexes (Braccini and Chiaramonte, 2002). However, the higher value of *HSI* in winter is more likely to be related with the higher proportion of adults in that sample, compared to the summer sample, that presented immature individuals in greater number. Besides, such difference (*HSI* winter=2.4; *HSI* summer=2.1), though statistically significant, could not have major biological significance.

In oviparous species the production of the egg capsule and its content may imply an enormous effort by the females. In *Scyliorhinus canicula* the secretion of the egg capsule proteins represent the greatest part of the reproductive effort (Mellinger and Wrisez, 1989) and this may be the case for the rajids also, specially considering the short interval between the formation of one pair of egg capsules and the following ones, which vary between 1 and 13 days in *Raja eglanteria*, for instance (Luer and Gilbert, 1985).

In *A. cyclophora* the maximum gonadosomatic index for males was accompanied by the maximum *HSI* value (Oddone, 2003), which was observed also for *Raja asterias* (Capapé, 1980) and could be indicating that an increase in the gonads weight is accompanied (or preceded) by the storage of substances in the liver. In the males of this species, two well defined annual peaks in the gonadosomatic index exist, while in the females such peaks are not that evident, as in *A. cyclophora*, confirming the absence of seasonality in the reproductive variables, like gonad weight, egg-lying frequency throughout the year, etc. (Oddone and Vooren, 2005). Annual cycles without activity peaks have been recorded for several rajid species, e.g. *Raja clavata*, *Dipturus chilensis*, *Atlantoraja platana*, *A. castelnaui and A. cyclophora* (Holden, 1975; Fuentealba and Leible, 1990; Oddone, 2003; Oddone and Vooren, 2005; Oddone, pers. obs.).

The large variation in the *HSI* range of the females as well as the presence of adult females with low values of *HSI* simply reflects the presence of sexual resting females with ovaries that are no longer (or temporarily not) producing vitellogenic follicles (Oddone and Vooren, 2005).

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Table 1. Summary statistics for *Atlantoraja cyclophora*'s males and females analysed in summer and winter; number of individuals (n), total length (TL), hepatosomatic index (HSI), liver weight (LW), standard deviation (s.d.) and mean values (m).

	WINTER		SUMMER	
	MALES	**FEMALES**	**MALES**	**FEMALES**
n	103	115	111	130
TL range	32.3-73.9	30.8-65.0	28.7-61	23.5-64.5
TL m	52.5	52.9	50.1	53.0
TL s.d.	5.7	7.6	6.4	7.2
LW range	2.4-48.0	3.4-65.0	2.4-36.0	2.4-107.0
LW m	21.8	24.1	14.5	14.4
LW s.d.	8.3	11.7	6.4	6.3
HSI range	1.2-4.8	1.5-4.9	1.2-4.4	0.53-4.47
HSI m	2.4	2.8	2.1	2.9
HSI s.d.	0.7	0.6	0.6	0.7

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