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BIOLOGICAL ASPECTS OF THE SAILFIN DORY *Zenopsis conchifer* (LOWE, 1852) CAUGHT BY DEEP-SEA TRAWLING FISHERY OFF SOUTHERN BRAZIL

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ABSTRACT

Biological aspects of sailfin dory, *Zenopsis conchifer*, were studied from 839 individuals obtained from deep-sea commercial bottom trawling off southern Brazil at depths up to 526 m in 2002 and 2003. Samples included fish from 101 mm Lt and 15 g up to 640 mm Lt and 2.9 g. The sex-ratio was 50% at 150 mm Lt and between 300–350 mm Lt, with females outnumbering males in the remaining size classes. Reproductive activity seems to peak between July and August (austral winter). Size at attainment of 50% maturity (L_{50}) was 311 mm Lt in females. The mean length and maturity of the specimens increased with depth, suggesting that larger fish concentrate in deeper waters.

RESUMO

Aspectos biológicos do peixe-galo-de-profundidade, *Zenopsis conchifer*, foram estudados a partir de 839 peixes amostrados na pesca comercial de arrasto de profundidade (até 526 m) no sul do Brasil entre 2002 e 2003. As amostras incluíram peixes entre 101 mm TL e 15 g até 640 mm TL e 2.952 g. A proporção sexual foi próxima à paridade na classe de tamanho de 150 mm TL e entre 300–350 mm TL, sendo que as fêmeas predominaram nas demais classes. A atividade reprodutiva apresentou um pico durante o inverno. O tamanho de primeira maturação (TL_{50}) nas fêmeas foi de 311 mm TL. Os comprimentos corporais e a maturidade sexual aumentaram com a profundidade, sugerindo que os maiores exemplares se concentram águas profundas.

Descriptors: Zeidae, Size structure, Sex ratio, Maturity, Bathymetry, Southern Brazil.

Descritores: Zeidae, Estrutura de tamanhos, Proporção sexual, Maturidade, Batimetria, Sul do Brasil.

INTRODUCTION

The recent development of a multi-gear, deep-sea fishery has represented a major challenge for current knowledge of demersal and benthic fauna of the outer shelf and upper slope waters off southern Brazil. A chartered foreign fishing vessel program was launched in the early 2000s by the Brazilian Ministry of Agriculture. This program was designed not only to evaluate the fishery potential of deep-sea waters within the Brazilian exclusive economic zone, but also as an alternative to reduce the fishing effort in the heavily-exploited fishing grounds of the inner shelf. This resulted in the development of fisheries directed to deep-sea species of both finfish and shellfish previously unexploited or marginally exploited as incidental catch (PEREZ et al., 2003; PEREZ; PEZZUTO, 2006).

Among the fish species assemblage found by the deep-sea fishery, profitable concentrations of Sailfin dory (*Zenopsis conchifer* (Lowe, 1852)) were initially identified and then temporarily exploited by the deep-sea bottom trawling fleet (PEREZ et al., 2003). Although less valuable than other resources such as monkfish (*Lophius gastrophysus* Miranda Ribeiro, 1915), deep-sea crabs (*Chaceon* spp.) and deep-sea shrimps (family Aristeidae) (PEREZ et al., 2002; PEREZ; PEZZUTO, 2006; PEZZUTO et al., 2006a, 2006b), the species investigated (along with the Argentine short-finned squid *Illex argentinus* (Castellanos, 1960)) had already been considered a valuable by-catch for the deep-sea fishery off southern Brazil before the fishery development (PEREZ et al., 2003, 2009a).

Sailfin dory is a deep-sea (50–600 m) demersal species belonging to the family Zeidae

(NELSON, 2006). A typical inhabitant of upper-slope bottoms and seamounts (HAIMOVICI et al. 1994; ZIDOWITZ et al., 2002), the species is widespread, ranging from Indonesia to the western Atlantic and between latitudes 58°N–34.5°S (e.g. HEEMSTRA, 1980; GLOERFELT-TARP; KAILOLA, 1984; RAGONESE; GIUSTO, 2007). Sailfin dories have been observed in the field either as solitary individuals or small schools of up to six fish swimming slowly at a small distance from the bottom (PAKHORUKOV, 2008). The few data available on food and feeding suggest a stenophagous diet that appears to shift with growth, as recruits have been found to prey on zooplankton (MUTO et al., 2005) whereas juveniles and adults take small fish and squid (MACPHERSON, 1983; BOWMAN et al., 2000). The recurrent occurrence of the species off the European coast, particularly from the last two decades onward, suggests that global warming is playing a significant role in the distribution of *Z. conchifer* and other tropical deep-sea fishes, as they used to be very rare or absent north of 41°N before the 1950s (QUÉRO, 1998).

The existence of potentially fishable concentrations of *Z. conchifer* in some areas of its distribution range is well known (YESAKI et al., 1976; HAIMOVICI et al., 1994; PEREZ; PEZZUTO, 2006; RAGONESE; GIUSTO, 2007). Off southern Brazil, the species has often been part of the by-catch of the deep-sea gillnet fishery directed to monkfish and deep-sea bottom trawling directed to monkfish and Brazilian codling (*Urophycis mystacea* Miranda Ribeiro, 1903) (PEREZ; WAHRLICH, 2005; PEREZ et al., 2009b). Recent research surveys in the region show that the species concentrates between 200–400 m and in two latitudinal strata: 23–25°S and 29–30°S (HAIMOVICI et al., 2008). The Sailfin dory standing stock biomass in the region has been estimated at 38,876 t with a maximum sustained annual yield of 4,896 t (HAIMOVICI et al., 2008; PEREZ, 2006).

Among the members of the family Zeidae, specific in-depth biological studies have mostly been undertaken for the John Dory (*Zeus faber* Linnaeus, 1785), off Atlantic Europe and in the Mediterranean and Chinese waters (STERGIOU; FOURTOUNI, 1991; SILVA, 1992; AKYOL, 2001; DUNN, 2001; YONEDA et al., 2002, 2006). In contrast, apart from relatively abundant data on distribution and new occurrences, few biological reports have been published for species of the genus *Zenopsis* (e.g. *Z. nebulosus*, PARIN et al., 1988; SMITH; STEWART, 1994; *Z. oblonga*, PARIN, 1989; *Z. conchifer*, MACPHERSON, 1983; WEISS et al., 1987, HAIMOVICI et al., 1994; ZIDOWITZ et al., 2002; FOCK; ZIDOWITZ, 2004 and *Z. stabilispinosa*, NAKABO et al., 2006).

Considering the exposed above, the importance of the species within both Brazilian deep-sea fishery and shelf break/upper slope ecosystem contexts (HAIMOVICI et al., 1994, 2008; PEREZ et al., 2003; PEREZ; WAHRLICH, 2005; PEREZ; PEZZUTO, 2006), and the expected low resilience time and medium-to-high vulnerability of this and related species stocks (FROESE; PAULY, 2011), the aim of this paper was to furnish information on size composition, sex ratio, maturity and reproductive aspects of dories caught by the deep-sea trawling fishery, as a contribution to the currently poor knowledge on the biology of *Z. conchifer* off southern Brazil.

MATERIAL AND METHODS

Samples of *Z. conchifer* were obtained from commercial deep-sea trawling fishery throughout a sub-program of scientific fishery observers launched jointly with the Brazilian Ministry of Agriculture's deep-sea fishing program carried out off southern Brazil (23–34°S) (for details, see PEREZ et al., 2003). Samples were collected following fishing hauls, deep-frozen onboard and then delivered to the laboratory abroad. Each sample was discriminated by fishing vessel, fishing areas (including initial and final position and depths of each haul) and fishing date. Sampling took place in 2002 and 2003. A summary of samples collected for this work is presented in Table 1.

In the laboratory, samples were thawed at ambient temperature. Dories were weighed to the nearest 0.1 g or 10 g (depending on the individual weight of each specimen) and had their total length measured to the nearest millimetre. Following the weighing/measurements, each fish was dissected, sexed and had the gonads removed and weighed to the nearest 0.1 g. Maturity was assigned by the macroscopic examination of the gonads and, because of the current absence of specific references, were scored according to Vazzoler's (1996) general five-point scale: (I) immature, (II) in maturation, (III) mature, (IV) spent and (V) recovering.

Because the length data of neither sex fitted the conditions of normality and homoscedacity, a two-sample Kolmogorov-Smirnov test was employed to test differences in size structure between sexes, whereas a Wilcoxon signed-rank test was used to assess whether there were size differences between the two fishing areas. Length–body weight relationships were estimated for males and females. The standard potential function $BW = aL^b$ provided the best fit for length–body weight relationships, where L is the total length (mm), BW is the body weight (grams), a (=y-intercept) and b (slope) are regression constants, the latter being the allometry coefficient. Possible departures from isometric growth (i.e. $b = 3$) were

tested with Student's *t* test. Differences between sexes were tested with ANCOVA (test of homogeneity of slopes) using \log_{10} -transformed data. The proportions of males and females per month, depth, fishing area and size class were calculated, and the hypothesis regarding an equal sex ratio (i.e. 1 female: 1 male) were tested using the χ^2 test. All statistical tests were considered at a 0.05 significance level.

Size-at-maturity (L_{50}) was defined as the size at which 50% of females and males become mature (VAZZOLER, 1996) and was estimated using the frequency of mature specimens (in pooled 10 mm intervals) sampled. The percentage mature by length class and sex were fitted to a logistic curve with the formula $P_i = 1/1 + e^{-(a + bL_i)}$, where P_i represents the relative frequencies of mature individuals (i.e. ovaries at stages III and IV) at each *i*th L_t class, *a* and *b* are regression constants, and $L_{50} = -a/b$ (KING, 1995).

The gonadal development was assessed only for females. Because the maturing process in young fish may introduce considerable noise in the investigation of reproductive patterns (WOOTTON, 1999), only females with sizes larger or equal to the L_{50} were included in the analysis. Gonado-somatic relation indexes, which represent the proportion of gonadal tissue in relation to body mass, were calculated according to Vazzoler (1996) using the following formulas: $GSI_1 = OW/BW \times 100$ and $GSI_2 = OW/SW \times 100$, where *OW* is the ovarian weight and *SW* is the somatic weight (i.e. $SW = BW - OW$).

Since the development of the ovary influences the total weight of the fish during the

reproductive cycle, the differences between GSI_2 and GSI_1 (ΔGSI) will tend to be highest just prior to spawning, indicating the timing of reproductive activity (WOOTTON, 1999). Therefore, the average ΔGSI was analysed in relation to time (months of the year) and bathymetry in order to identify the seasonality and depths of reproductive activity.

RESULTS

The size range of females and males of *Z. conchifer* were 105–640 mm L_t and 101–560 mm L_t respectively (Table 1). Both sexes had two main components in their size frequencies, with modes at 200 and 400 mm L_t for females and 250 and 350 mm L_t for males (Fig. 1). Length frequency structure differed significantly between sexes (Kolmogorov-Smirnov test, $D = 0.384$, $P < 0.00001$). A total of 627 females and 175 males were sampled (Tables 1 and 2), corresponding to an overall ratio of 3.6 females to each male. Females also outnumbered males in most size classes, although parity of sexes was found at 150 mm L_t and between 300–350 mm L_t ($\chi^2 = 0-0.31$, $P > 0.05$). Dories larger than 600 mm L_t were exclusively female. Body sizes differed significantly between fishing areas, being larger in the northern sector (23.6–24.8°S) (Wilcoxon's $V = 5397.5$, $P < 0.00001$). However, no difference in the established sex ratio (i.e. predominance of females) between the two sampled fishing areas (Table 1) was found ($\chi^2 = 12.55-127.94$, $P > 0.05$).

Table 1. Summary of Sailfin dory (*Zenopsis conchifer*) samples used in this study. Geographical areas are latitudinal divisions used for statistical purposes (PEREZ; PEZZUTO, 2006). Latitude is decimal transformed. - : no data. * average between the beginning and ending depths of each haul.

Geographical area	Latitude interval(°S)	Depth range*(m)	Females		Males		Undetermined	
			Size		Size		Size	
			<i>n</i>	range (mm)	<i>n</i>	range (mm)	<i>n</i>	range (mm)
North	23.667–24.825	284–506	449	140–630	120	140–560	27	140–379
Central	25.033–27.400	262–355	99	105–640	41	101–530	2	158–163
Not specified	-	-	79	200–573	14	170–439	8	150–260
Total	23.667–27.400	262–506	627	105–640	175	101–560	37	140–379

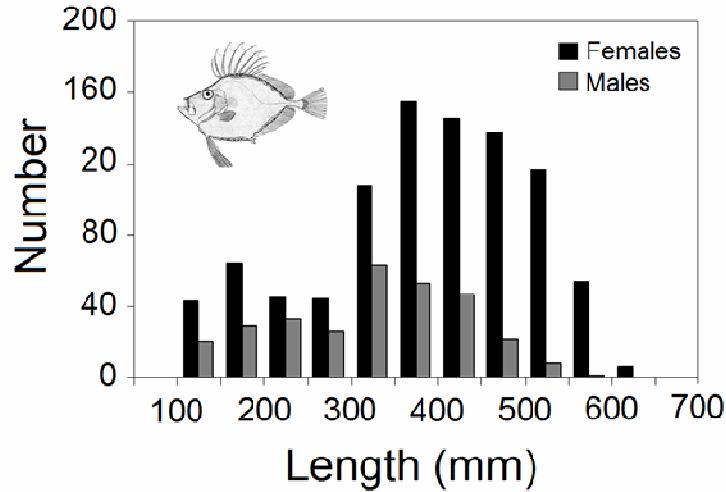


Fig. 1. *Zenopsis conchifer*. Length–frequency composition for females and males caught by deep water trawling fishery off southern Brazil.

Regarding the bathymetric distribution, there were 1.7–7.9 females to each male between 300–450 m depth, and 1:1 sex ratio ($\chi^2 = 0.48$, $P > 0.05$) was found at 550 m. There was a tendency to an increase in body size with depth for both females and males (Fig. 2). Females were present from January to

September and males from January to August. Females outnumbered males in all months. In September, just one female was sampled and there were no samples of either sex between October and December.

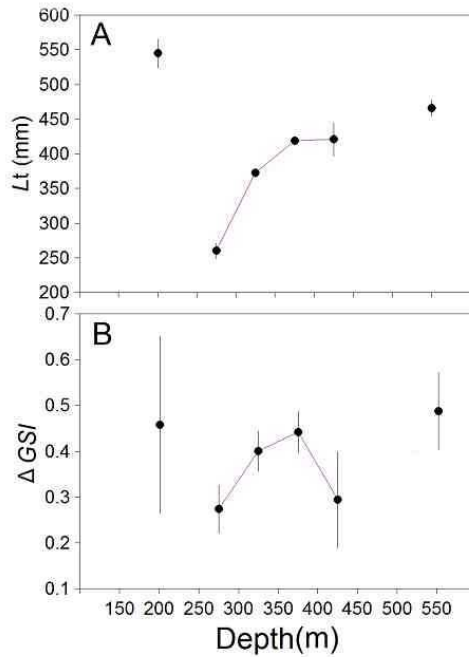


Fig. 2. *Zenopsis conchifer*. Effect of bathymetry on (A) size (both sexes pooled) and (B) ΔGSI for female dories caught by deep water trawling fishery off southern Brazil. Values are means \pm S.E.

Most females (61.6%) were in an advanced maturation stage (Table 2). In contrast, only 30.3% of the males sampled were sexually mature. Spent males were the least frequently encountered (Table 2). The mean size of fully mature females was 442 mm *Lt*. Maturing and mature males were 328 and 394 mm *Lt*, respectively (Table 2). Female size-at-maturity (L_{t50}) occurred at 311 mm *Lt*. It was not possible to estimate the L_{t50} for males with the present data. The allometry coefficients of length–body weight relationships were $2.75 (\pm 0.055 \text{ S.E.})$ for females and $2.69 (\pm 0.053 \text{ S.E.})$ for males (Fig. 3). A *t*-test showed that the allometry coefficients of both sexes differed significantly from the isometry ($b = 3$) ($P < 0.00001$), indicating a

negative allometric growth. Females were in better condition than males, and the constants of the length–body weight relationships differed significantly between sexes (ANCOVA, $P < 0.001$).

The monthly variation of ΔGSI is depicted in Figure 4. Because of the lack of samples from September to December, only data from January to August were available. Dorries seem to begin their reproductive activity in May, peaking in the austral winter (June–August). As regards the bathymetry, the ΔGSI appears to increase with depth, although the high value at 200 m and low value observed between 400 and 450 m were most likely caused by large roaming individuals (Fig. 2).

Table 2. Number of females and males of Sailfin dory (*Zenopsis conchifer*) of each maturity stage with corresponding mean total length (*Lt*), mean body weight (BW), standard deviation (S.D.), and range.

Maturity stages	<i>n</i>	%	<i>Lt</i> (mm)		BW (g)	
			Mean \pm S.D.	Range	Mean \pm S.D.	Range
Females						
Immature	102	16.3	207 \pm 68	105–470	148.4 \pm 191.6	20–1,300
Maturing	139	22.2	427 \pm 83	208–596	915.4 \pm 421.8	108.8–1,920
Mature	307	49.0	442 \pm 70	210–610	1,071.8 \pm 409.9	116–2,770
Spent	79	12.6	440 \pm 87	271–640	1,025.7 \pm 481.9	201.3–2,925
Total	627	100.0	399 \pm 114	105–640	876.9 \pm 515.3	20–2,925
Males						
Immature	58	33.1	221 \pm 103	101–530	201.7 \pm 233.3	15–1,010
Maturing	64	36.6	328 \pm 67	200–480	468.9 \pm 284.8	94.9–1,330
Mature	49	28.0	394 \pm 54	304–560	754.1 \pm 329.4	325–1,875
Spent	4	2.3	386 \pm 31	345–418	640.0 \pm 165.9	485–870
Total	175	100.0	313 \pm 104	101–560	464.1 \pm 353.5	15–1,875

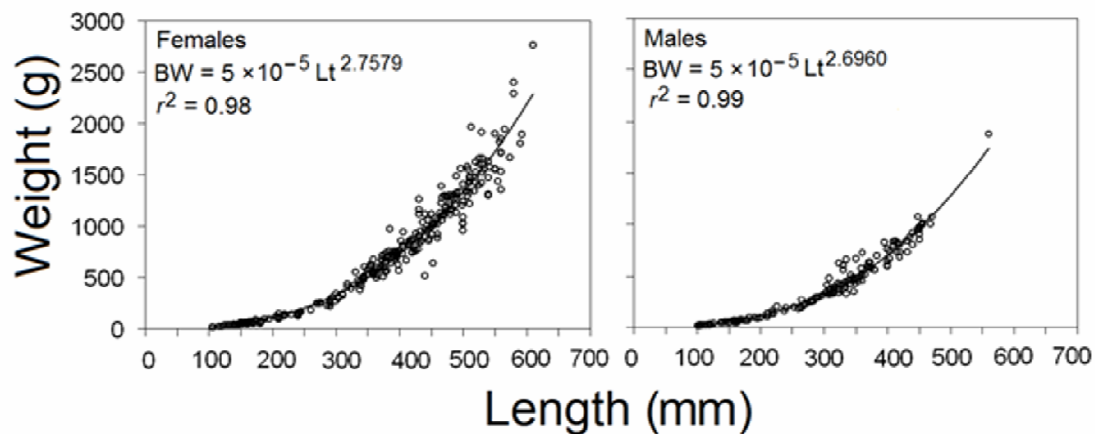


Fig. 3. *Zenopsis conchifer*. Length–weight relationships of females and males caught by deep water trawling fishery off southern Brazil.

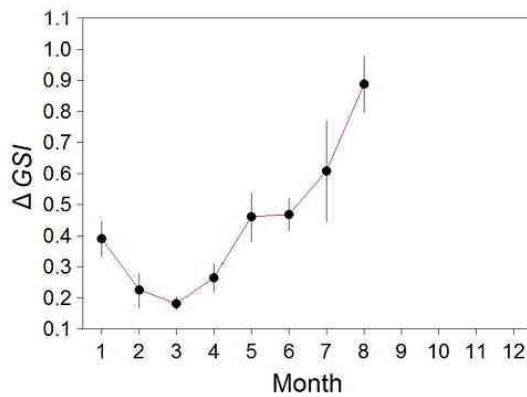


Fig. 4. *Zenopsis conchifer*. Monthly variation of ΔGSI of female dories caught by deep water trawling fishery off southern Brazil. Values are means \pm S.E.

DISCUSSION

The recent advance of industrial trawling fishery into deep waters has brought with it a shift in the commercial bony fish species retained in the catches. The myriad of sciaenid species and a few of the Paralichthyidae fish and searobins (Triglidae) traditionally exploited on the inner shelf (HAIMOVICI et al., 1997; PEREZ et al., 2001) have been replaced by distinctive deep-sea fish families such as, for instance, Lophiidae, Zeidae, Merlucciidae and Phycidae, among others (HAIMOVICI et al., 1994; PEREZ et al., 2003; PEREZ; PEZZUTO, 2006). This depth-related shift in exploited fish assemblages has also been found at higher latitudes and reflects the contrasting environmental conditions between shallow- and deep-sea habitats (KOSLOW et al., 2000). Unsurprisingly, *Zenopsis conchifer* figures among the catches of the deep-sea trawling fishing, as it has long been recognized as a typical component of the deep-sea demersal bony fish assemblage off southern Brazil (HAIMOVICI et al., 1994).

Sailfin dory have been found to occur exclusively in waters ≥ 200 m off southern Brazil and no occurrence in shallower waters has thus far been observed, as reported by other authors elsewhere (e.g. QUÉRO et al., 1990). This is in agreement with the results of research surveys carried out to the south of the study area (HAIMOVICI et al., 1994). Except for the bias found at 200 m, there has been a clear tendency to an increase in body size with depth between 250–550 m. The ΔGSI also followed the same trend. This, along with the 1:1 sex ratio found at 550 m deep, suggests that reproductive activity occurs in deep waters. This may reflect an ontogenetic movement to deeper waters, where dories may benefit from (1) bathymetric differences in prey availability,

(2) avoidance of inter- and intra-specific competition and predation and (3) extended longevity resulting from lowered metabolism induced by colder water. In addition, reproductive output would also be optimized because larger, older females inhabiting deeper waters would tend to produce more (and higher quality) progeny (GREEN, 2008). On the other hand, smaller, immature dories occurring at shallower bottoms are exposed to warmer temperatures, which accelerates metabolism resulting in faster growth rates. This is known as the “bigger-deeper paradigm” (MACPHERSON; DUARTE, 1991).

The “bigger-deeper paradigm”, however, has been questioned and may not represent the only explanation for the larger body sizes of fish found in deep waters (RAGONESE; REALE, 1995). Large bodied individuals of eurybathic fish, although able to live at the upper bathymetric limit of their distribution and move freely along their species-specific depth range, may either concentrate (periodically or regularly) at preferential depths. This may be either caused by depth-related biotic and abiotic factors suitable for successful spawning or the exclusion from the shallower strata of their depth horizon by fishing activities (RAGONESE; REALE, 1995). In the present case, it may be possible that such roaming large individuals had caused the bias toward a large average body size and ΔGSI we found at the 200 m depth stratum. This may also explain the differences in body sizes between fishing areas, with smaller dories being caught in the shallower central area and their larger counterparts concentrating in the deeper northern area. This evidence is even more compelling if one considers that our samples came from an almost pristine stock that had never been commercially exploited before the 2000s (PEREZ et al., 2003, 2009a). Data from Sailfin dory distribution studies conducted elsewhere also suggest this possibility (e.g. QUIGLEY; FLANNERY, 1995; SWABY; POTTS, 1999; RAGONESE; GUIUSTO, 2007).

Size composition was bimodal for both males and females. Haimovici et al. (1994), on the other hand, found three distinctive modes skewed to the left, with a large mode around 180 mm L_t during winter, whereas in summer the authors found just one mode. Differences between their study and our data may be explained by the lower selectivity of the type of research fishing gear employed in relation to the commercial trawling nets, and the fact that they pooled females and males in their size frequency graphs. Most (80.5%) of the females sampled in the present study were above the L_{50} , implying that, theoretically, intense trawling fishing effort would lead to recruitment overfishing. Thus this should be taken into account in future management plans if the trawling fleet redirects its efforts towards the species.

Temporal analysis of ΔGSI suggested that the spawning season extends from May to August, peaking in the austral winter (June–August), in agreement with the pattern found to the south of the study area (HAIMOVICI et al., 1994). In addition, the simultaneous occurrence of mature and spent females during the spawning period suggests that *Z. conchifer* is a partial spawner. The apparent absence of recovery gonads in both sexes may be explained by the visual similarity of gonads in this condition to maturing (i.e. stage II) gonads (VAZZOLER, 1996), which could have led to misidentification.

The smallest individuals sampled in the present study were ~ 100 mm *Lt* and comprised fully metamorphosed fish. The absence of zaid fingerlings (post-larvae) in our samples suggests that the recruitment (settlement) areas are outside the study area. In fact, larvae of *Z. conchifer*, whereas seldom sampled in routine plankton surveys, have been found to occur mostly to the south of the study area (WEISS et al., 1987). This absence, however, could also be explained by the selectivity of the fishing gear, as Haimovici et al. (1994) employing low selective research fishing gears sampled dories as small as 50 mm *Lt*. Alternatively, our sampling efforts may have simply failed to coincide with pulses of settling fingerlings, as recruitment is thought to be episodic in deep-sea habitats (KOSLOW et al., 2000; FOCK; ZIDOWITZ, 2004). This latter possibility deserves a higher degree of consideration, as the apparent long longevity and slow growth rates of zaid fish (and other deep-sea demersal fish families) (SMITH; STEWART, 1994; RAGONESE, 2004) may have evolved as a buffer against possible recruitment failures (LEAMAN; BEAMISH, 1984).

Although not currently targeted on a commercial scale, the species forms part of the by-catch of an ongoing deep-sea trawling fishery directed to monkfish and Brazilian codling (PEREZ; PEZZUTO, 2006; PEREZ et al., 2009b). Bearing in mind that the southern Brazilian stock of Sailfin dories may present early-, middle- and late-maturing genotypes as do other long-living fish, the fishery will tend to remove the latter genotype that is expected to be present mostly in older, larger fish (RAGONESE, 2004). This is of concern because this slow moving fish would be highly vulnerable to fishing, particularly trawling. In the long run this would certainly compromise the stability of the stock. A sound management strategy in this case may perhaps be to concentrate the fishing effort on the intermediate size class, protecting juveniles by mesh regulations and the large adults by establishing refugia (CADDY; SEIJO, 2002). However, considering that trawling is a multi-species fishery activity particularly harmful to the exceptionally fragile deep-sea ecosystem (e.g. GIANNI, 2004), an integrated management plan

including also other vulnerable fish and shellfish species should be considered (KOSLOW et al., 2000; BAKER et al., 2009).

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