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Temporal variation in size at maturity of the snail *Zidona dufresnei* from the southwestern Atlantic Ocean after ten years of fishery exploitation

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ABSTRACT: The snail *Zidona dufresnei* is a marine resource that has been continually exploited by trawling over the past 20 yr. Although research into this fishery started 10 yr ago, no regulations have been implemented to date. In the present study, the histologically estimated size at maturity of both sexes of *Z. dufresnei* was found to be 131 mm for females and 128 mm for males. These values are lower than those determined in 1999 for *Z. dufresnei* in the same fishing area. In females, significant differences in size at first maturity were found between 1999 and 2009 in the size classes 121 to 150 mm and 151 to 180 mm. In males, significant differences between years were found in the size class 121 to 150 mm. This is the first report of changes in the size at first maturity of marine snails subjected to fishery exploitation. Effects of *Z. dufresnei* reproductive cycle, growth rate, size at maturity and population management should be taken into account in *Z. dufresnei* fishery.

KEY WORDS: Size at maturity · Exploited population · Gastropod · Temporal variation · Size selection

INTRODUCTION

Fishing is a sorting process that selectively removes individuals and the genetic changes associated with fishing have become known as fisheries-induced evolution (Conover et al. 2005). The intense selection differentials imposed by many fisheries may drive the evolution of life history traits (Hutchings 2005, Brown et al. 2008). The decrease in size at maturity observed in several commercially exploited fish stocks may be due to fisheries-induced evolutionary changes (Ernande et al. 2004, Morita & Fukuwaca 2007, Sattar et al. 2008). For example, size at maturity of *Solea solea* decreased from 286 mm in 1960 to 246 mm in 2002 (Mollet et al. 2007), and in the Japanese chum *Oncorhynchus keta* size at maturity has decreased by about 50 mm since the 1960s (Eggers et al. 2003). This should favor small-maturing genotypes as their traits become more common in the population (Law 2000, Hutchings & Baum 2005). However, increased costs of reproduction associated with early maturation result in higher natural mortality (Landers et al. 2001, Conover et al. 2005, Hutchings 2005). High fishing mortality and size-selective fishing are the factors that drive most fisheries-induced evolution.

Over the last few decades, the volutid snail *Zidona dufresnei* (Donovan, 1823) has been subjected to unregulated commercial exploitation. Yields of adults are estimated to be 1300 t of flesh yr^{-1}, with most landings taking place at the harbors of Mar del Plata in Argentina and La Paloma in Uruguay (Ministerio de Agricultura, Ganaderia y Pesca. www.minagri.gob.ar/SAGPyA/pesca/index.php). This species inhabits the western coast of the southern Atlantic Ocean, at 35 to 60 m depth on sandy bottoms, from Río de Janeiro, Brazil (22° S) to San Matías Gulf, Argentina (42° S) (Kaiser 1977). *Z. dufresnei* is a temperate species, spawning in austral spring and summer (Giménez & Penchaszadeh 2002). The potential lifespan of *Z. dufresnei* in the Mar del Plata region is >17 yr, maturation

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starts at an age of ~8 to 9 yr and the growth rate is slow (Giménez et al. 2004). But the development of management strategies is hampered by the lack of information on the population dynamics of this resource.

On this basis, the Argentine and Uruguayan fisheries of *Zidona dufresnei* are likely to be seriously endangered by high levels of exploitation (Giménez et al. 2005). The objective of this study is to determine histologically the size at first maturity and the mature proportion of *Z. dufresnei* and to compare the obtained values with those reported by Giménez & Penchaszadeh (2003) for the same population at the same location 10 yr ago.

MATERIALS AND METHODS

Snail collection. Specimens of *Zidona dufresnei* were collected monthly during the reproductive period between October 2008 and March 2009. 265 specimens, including males and females, were caught by bottom trawling in the Mar del Plata area, Argentina (38° 20′ S 57° 37′ W) at depths of 40 to 60 m (Fig. 1). Each snail was measured with vernier calipers at a precision of 1 mm, and weighed (wet weight without shell) at a precision of 0.1 g.

Gonadal maturity. The gonad, which is peripheral to the digestive gland and occupies the upper part of the spire, was removed and fixed in Bouin's solution for 18 h. A medial portion of the preserved gonads was dehydrated in ethanol, embedded in paraffin wax, and sectioned at 6 µm. The sections were stained with hematoxylin and eosin (H&E). Criteria used for determining gonadal maturity were the existence of spermatozoa in the spermatic tubules for males and the presence of oocytes undergoing vitellogenesis for females, as suggested by Giménez & Penchaszadeh (2003). Photographs of histological sections were taken using a Zeiss Axiostar microscope with a digital camera. We determined the percentage of mature females and males in this population.

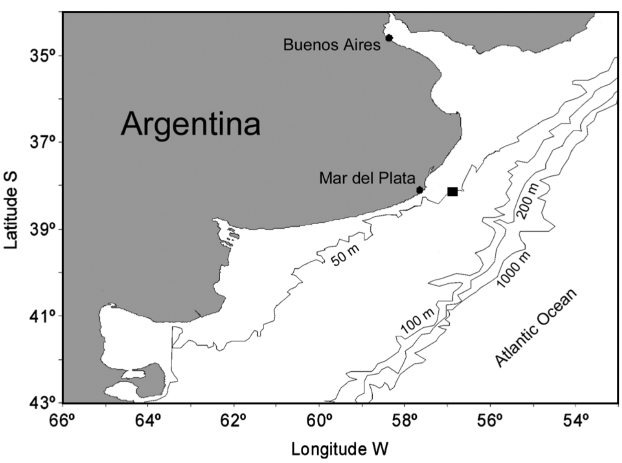

Fig. 1. Fishing location (■), Mar del Plata (38° 20′ S, 57° 37′ W), Argentina

Size at onset of maturity. The percentages of mature females and males in each 10 mm size class (snail shell length,) from the total individuals in each size class were plotted against shell length and then fitted, using a nonlinear modeling procedure, to the logistic equation.

$$P_m = a/1 + (SL/SL_0)^b \quad (1)$$

where P_m is the proportion of mature females or mature males, SL is snail shell length, and SL_0, *a* and *b* are constants. The shell length at which 50% of the gonads are mature is defined as the size at first marurity SL_{50}.

Data analysis. Chi-square analyses of heterogeneity were performed to compare the proportions of males and females that were mature and immature for size classes between 90 to 180 mm.

The proportions of mature and immature individuals in 240 specimens obtained by the authors in 1999 (including females and males in size classes between 90 and 210 mm) were compared to the proportions that were mature and immature in the 2009 population. Analyses of heterogeneity between years in each 30 mm (SL) size class were done for the size classes between 90 to 180 mm. All statistical analyses were performed using STATISTICA 6.0.

RESULTS

A total of 265 snails were sexed with sizes ranging from 97 to 210 mm SL. The histological examination showed immature and mature females. In immature females, the ovaries were undeveloped, lacking oocytes and oogenic stages (Fig. 2A). Mature females had developing ovaries, with growing oocytes and vitellogenic oocytes (Fig. 2B).

Gonadal maturity in males was determined by whether stages of spermatogenesis, including spermatozoa, could be identified within the spermatic tubules. Males lacking developing cells were considered immature (Fig. 2C). Testes of mature males exhibited all stages of spermatogenesis and the presence of mature spermatozoa (Fig. 2D). The size at maturity estimated graphically, was found to be 131 mm for females and 128 mm for males. The relationships between the percentages of females and males with mature gonads and SL are shown in Fig. 3; each size class included a total of 10 to 17 mature and immature individuals. The parameters of the fitted logistic equations to describe the onset of maturity are shown in Table 1.

The Chi-square analysis showed significant differences in the proportion of mature females in the

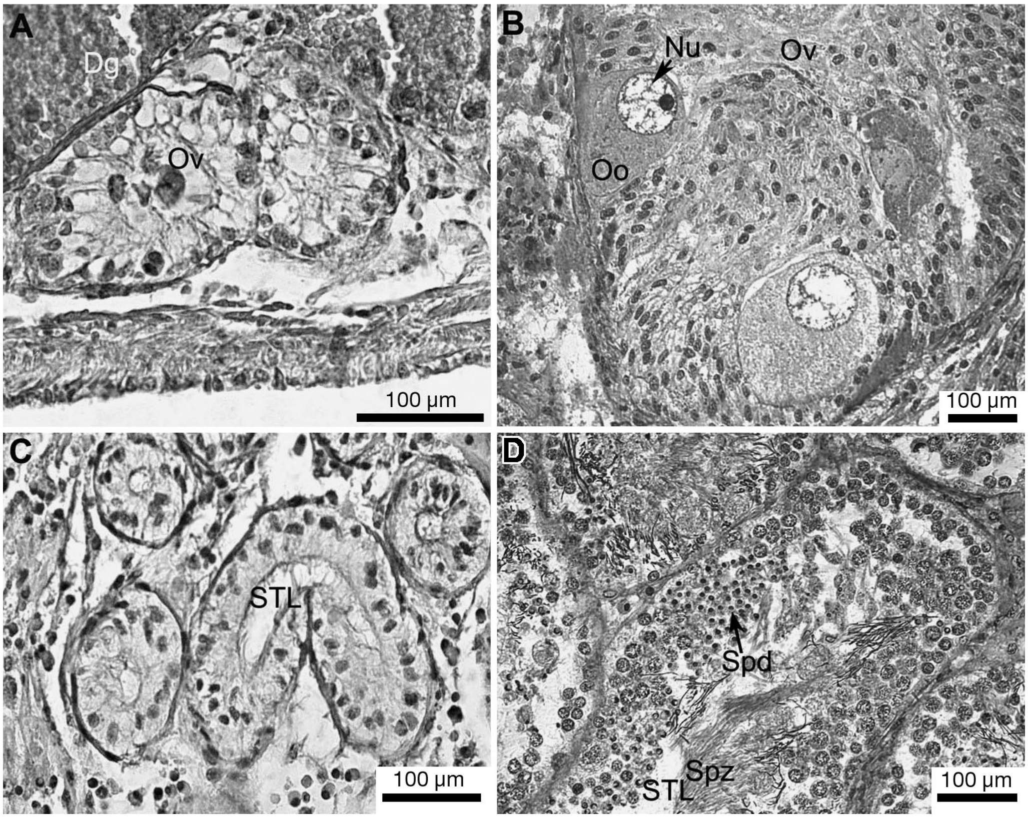

Fig. 2. *Zidona dufresnei*. (A) Immature ovary of a 13.8 cm shell length (SL) female; (B) mature ovary of a 16.8 cm SL female; (C) immature testis of a 12.1 cm SL male; (D) mature testis of a 18.3 cm SL male. Images show the digestive gland (Dg), growing oocytes (Oo), nucelus (Nu), ovary (Ov), spermatid (Spd), spermatozoa (Spz) and spermatogenic tubule lumen (STL)

population between 1999 and 2009 in the size classes 121 to 150 mm (30 females 1999; 38 females 2009; $p < 0.001$) and 151 to 180 mm (30 females 1999; 34 females 2009; $p < 0.001$). There was also a significant difference in the proportion of mature males in the population between years in the size class 121 to 150 mm (30 males 1999; 32 males 2009; $p < 0.001$). For sizes longer than 180 mm, all specimens were mature. In size classes between 121 and 180 mm in 2009, a non significant difference in the proportion of males and females was found (62 males 2009; 69 females 2009; $p > 0.01$).

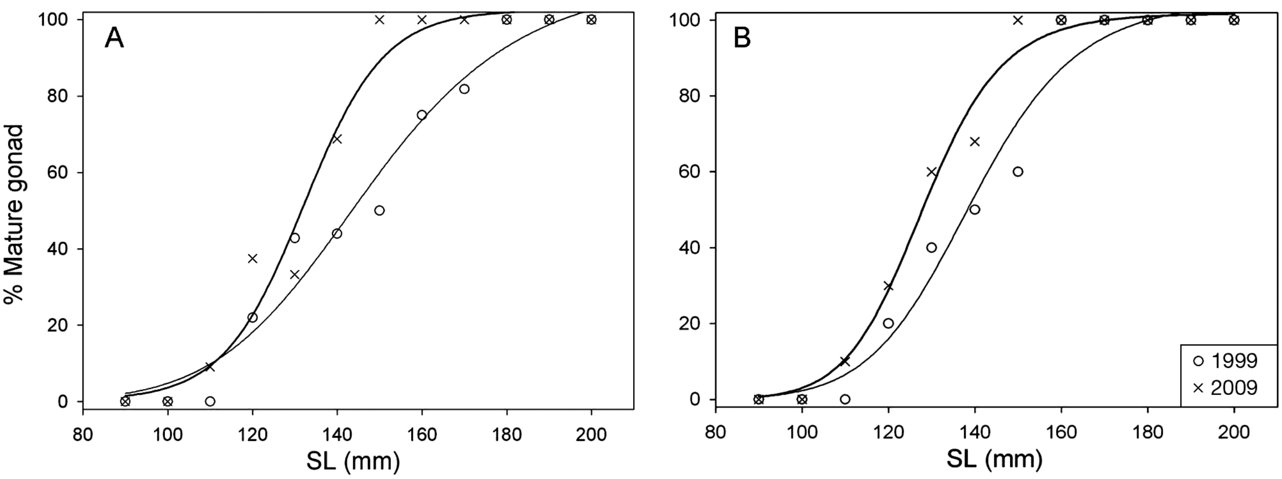

Fig. 3. *Zidona dufresnei.* SL_{50} logistic curves for the proportion of mature gonads, determined by histological criteria, as a function of shell length: (A) mature females (n = 84); (B) mature males (n = 90)

Table 1. *Zidona dufresnei.* Parameters and coefficient of determination (R^2) for logistic function $P_m = a/1 + (SL/SL_0)^b$ fitted data for each sex and both years

Year	Sex	n	*a*	*b*	SL_0	R^2
2009	Females	133	103.68	–13.53	131	0.99
	Males	132	101.81	–14.02	128	0.99
1999	Females	120	111.41	–8.02	147	0.99
	Males	120	105.43	–11.41	139	0.98

DISCUSSION

The size at first maturity of *Zidona dufresnei* has decreased compared with the values reported 10 yr ago. Giménez & Penchaszadeh (2003) recorded a first maturity size of 157 mm SL for females and 150 mm SL for males in catches from the year 1999 in the Mar del Plata area. In the present study, performed after 10 yr of fishery exploitation, maturity was reached at lower size for females and males.

This phenomenon has been described for many fish species subjected to commercial exploitation (Ishida et al. 1993, Helle & Hoffman 1995, Kaev 1999). However, there is little information on fisheries-induced evolution for invertebrates. Ignorance of life history traits and a lack of time series data contributes to the lack of management of some invertebrate fisheries (Linnane et al. 2009). Melville-Smith & de Lestang (2006) reported that females of the western rock lobster *Panulirus cygnus* have been undergoing variation in size at maturity over the last 30 yr. Landers et al. (2001) found that size at sexual maturity of female lobsters (*Homarus americanus*) had recently decreased, but it is unclear whether the change was caused by density dependent factors, environmental factors, or a combination of both. In the Tanner crab *Chionoecetes bairdi*, Zheng (2008) found a decrease in the size of females at first maturity, but causes for temporal changes are not completely understood. There is no available information about similar traits, such as fecundity and size at first maturity, and their change over time for mollusk or gastropod fisheries.

For many benthic invertebrate fisheries, a series of measures have been established to achieve sustainability objectives. For example, minimum legal size is a widely accepted management tool in fisheries. Giménez & Penchaszadeh (2003) suggested a minimum capture size of 160 mm SL for *Zidona dufresnei* as a management tool. However, the minimum legal size is below the size at first maturity for many species, such as *Panulirus cygnus* (Melville-Smith & de Lestang 2006) and the rock lobster *Jasus edwarsii* (Linnane et al. 2009). In Chile, the main gastropod fishery is the muricid *Concholepas concholepas*. It is a very important economic resource for the artisanal fishery. During recent decades various management strategies (including closure of the fishery) have been implemented in response to changes in catches of *C. concholepas* to achieve sustainable levels of exploitation (Leiva & Castilla 2002). In Chile, the most important management and conservation tools include the regulation of extraction and processing of benthic resources, the demarcation of areas for exploitation, and designation of marine protected areas.

The total annual weight of *Zidona dufresnei* landed has decreased by 90% (Ministerio de Agricultura, Ganaderia y Pesca. www.minagri.gob.ar/SAGPyA/pesca/index.php), from 1300 t in 1997 to 100 t in 2009 (Fig. 4). *Z. dufresnei* is captured all year round, even during the reproductive season from September to December (Giménez & Penchaszadeh 2002). In the same period, our results indicate the median size at which males and females in the population become mature has declined, and the proportion of mature individuals has increased

These changes may be a response to resource depletion, caused by permanent fishing of a resource with a slow growth rate (it may take as long as 10 yr to reach maturity) (Giménez et al. 2004). Environmental conditions for *Zidona dufresnei* remained much the same between 1999 and 2009. The temperature at 50 m depth was constant, and no pollutants were registered. No hydrographical change was found, other than damage due to the bottom trawling. However, changes due to bottom trawling could decrease food availability. Owing to its predatory lifestyle and large size, *Z. dufresnei* is likely to be affected.

According to Conover et al. (2009), evolutionary responses to the long-term exploitation of individuals from a population may include reduction in body size, age at maturation, and productivity. The *Zidona dufresnei* population from Mar del Plata may be

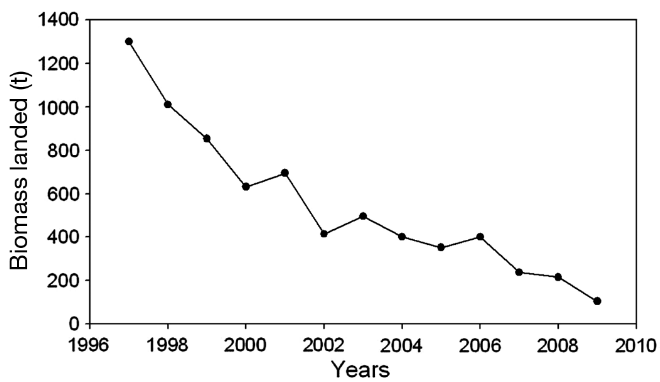

Fig. 4. *Zidona dufresnei.* Historical records of mean annual catch biomass (t), Mar del Plata. Ministerio de Agricultura, Ganaderia y Pesca. www.minagri.gob.ar/SAGPyA/pesca/index.php

undergoing this process according to present results. However, evolutionary changes were reversible for populations of the silverside fish *Menidia menidia*, which showed an increased growth rate after the implementation of protective measures (Conover et al. 2009). Based on our follow-up study results, we suggest that *Z. dufresnei* fisheries should be regulated with a minimum catch size of 180 mm SL for females and males. This way, only mature specimens will be caught. We also recommend a closed fishery season for *Z. dufresnei* during the reproductive season from September to January. *Z. dufresnei* is a vulnerable economic resource at risk of suffering over-exploitation. After 10 yr of continuous fisheries of *Z. dufresnei,* there is enough evidence to warrant implementing these recommendations.

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