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LIFE HISTORY PARAMETERS IN THE EDIBLE SNAIL
ADELOMELON ANCILLA FROM PATAGONIAN WATERS

Soledad Zabala^{1*}, Pablo E. Penchaszadeh², Héctor O. Panarello³,
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ABSTRACT

Life history parameters, including size-age, production, mortality and size at reproductive maturity, were studied on the edible snail *Adelomelon ancilla* to provide useful management data. Stable oxygen isotope ratios confirmed semiannual formation of internal growth marks. *Adelomelon ancilla* can reach up to 18 years at a size of 150 mm, fitting to a Gompertz growth model. Size at which 50% of the population matured was 73.5 mm in males (7 years) and 93.5 mm in females (9 years). The long lifespan of this species is comparable to other large gastropods, in particular volutids from southern Atlantic Ocean. Longevity, low somatic production, low population density, late reproductive maturity and direct development with few embryos, makes *A. ancilla* a vulnerable resource that will require a proper management approach incorporating estimates of these life history parameters.

Key words: age, growth, fisheries management, conservation, oxygen stable isotopes.

INTRODUCTION

The growth rate of an organism provides basic ecological data and is one of the prime parameters to describe population dynamics. Furthermore, fisheries managed with size limits require accurate estimates of age and growth to protect reproductive capacity of stocks and to estimate the sustainable stock yield (Prince & Shepherd, 1992; Jennings et al., 2001; Hilborn & Walters, 2004; King, 2007). In terms of tonnage and economic value, marine mollusks are among the most important invertebrate fishery resources in the world (FAO, 1998a, b). Marine gastropods represent about 2% of world mollusk catches (Leiva & Castilla, 2002). Fishing statistics show an increase in the number of countries in the gastropod world landing records, rising from 23 in 1979 to 47 in 2010 (FAO, 2010). Catches of mollusks have decreased significantly since 2002, and this may be due to their extreme vulnerability to habitat degradation, overexploitation, and predation by alien species (FAO, 2010). More than 50% of marine resources are overexploited, and food demands are increasing with the growing population (Lodeiros, 2011). Currently, a

scallop fishery is considered the only mollusk fishery of significance for the economy in northern Patagonia (Ciocco et al., 2006). However, gastropods of the family Volutidae have been identified as a potential resource for artisanal diving fisheries, although to date most catches are sporadic and small in the north Patagonic gulfs (Ciocco, 1995, 1999; Bigatti & Ciocco, 2008, Bigatti et al., 2008), but the interest in gastropod fisheries is increasing in the zone. In the case of volutid gastropods, large body size and somatic production, coupled with slow growth rate, late reproductive maturity and direct development make this group extremely vulnerable to overexploitation (Bigatti et al., 2007). For this reason, typical body sizes at specific ages, size/age at reproductive maturity and growth estimates are necessary for effective fisheries management of the species. The marine snail *Adelomelon ancilla* (Lightfoot, 1786) is a neogastropod belonging to the family Volutidae. This species is distributed along the southern tip of South America, from 30°S (Brazil) in the southwestern Atlantic to Ushuaia in the Beagle Channel and northward into the Pacific to Isla Chiloé at 25°S in central Chile (Castellanos & Landoni, 1992; Zabala,

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2013). *Adelomelon ancilla* is dioecious, with internal fertilization. Females attached the egg-capsules to hard substrata. Hatching occurs at crawling stage, after complete intracapsular development, feeding on the intracapsular fluid (Penchaszadeh et al., 1999, Penchaszadeh et al., 2009). This species is a top-predator of benthic communities, preying principally on other gastropods and on bivalves (Botto et al., 2006; Bigatti et al., 2009; Zabala et al., 2013).

Tag-recapture techniques, analyses of modal shift in sizes of cohorts, and studies of growth layers in the shell spire, statoliths or opercula are commonly used to estimate growth rates of gastropods (Tarr, 1992; Richardson et al., 2005; Henry & Jarne, 2007). However, the effects of tagging (McShane, 1988) and uncertainty in the rate of production of growth layers observed (Day & Fleming, 1992; McShane & Smith, 1992; Day et al., 1995) have meant that estimates of age and growth cannot be made with precision using these techniques. The use of oxygen stable isotopes (OSI) analysis is proposed as an alternative method for aging shells of gastropods and determining growth rates (Gurney et al., 2005). Epstein et al. (1951, 1953) established a relationship between seawater temperature and the relative abundance of oxygen stable isotopes in the calcium carbonate of the shells of mollusks and other marine invertebrates. Subsequently, many studies have used OSI to determine growth rates and age for various gastropods (e.g., Panarello, 1987; Geary et al., 1992; Cespuglio et al., 1999; Kennedy et al., 2001; Keller et al., 2002; Cledón et al., 2005a; Giménez et al., 2004; Bigatti et al., 2007; Arrighetti et al., 2011, 2012). The application of this technique is possible when the shell is laid down in isotopic equilibrium with the seawater, the salinity is known or constant, and seasonal fluctuation in seawater temperature is such that the magnitude of the corresponding seasonal oscillations in OSI values are discernible. In the study site, water temperature ranges between 9.7°C (late winter) to 18.3°C (late summer) and salinity is rather constant at 34‰ (Rivas & Beier, 1990), so these oscillations permit determine age and growth rate (Gurney et al., 2005) of *A. ancilla*.

The main goal of this work was to study life history parameters of *A. ancilla* in Golfo Nuevo, Patagonia, particularly examining its growth, age and size at reproductive maturity, mortality and production, which will generate data useful for future management of this valuable resource.

MATERIALS AND METHODS

Sampling and Morphometric Parameters

Specimens of *Adelomelon ancilla* were captured monthly during 3 years (2001–2004), in Golfo Nuevo, Patagonia (42°48'S, 64°54'W) by SCUBA diving between 5 to 15 m depth (according to the tide). In order to test the population density, sampling was performed using three random transects per month crossing 100 m in length and 2 m wide, parallel to the coast, at the same depth. Animals were taken to the laboratory, where soft parts were removed from the shell of live animals using a press. Shell length (SL) and male penis length (PL) were measured with a vernier caliper and spiral growth trajectory (SG) was also measured with a thread and caliper to the nearest millimeter (Fig. 2). Shell-free wet mass (SFWM) was determined to the nearest gram after removing marine water from the tissues using a paper towel. The relationships between these morphometric parameters were described by linear regression. Each individual was sexed by the presence or absence (female or male, respectively) of reproductive accessory glands (albumen and capsule gland) and vagina. The sex ratio was compared to parity (1:1) with the χ^2 test.

Age and Growth

In order to confirm if external shell growth marks (Fig. 1) corresponded to internal growth band pattern, the shells of 11 individuals were cut along the whorls following the spiral growth trajectory from the apex to the posterior end of the aperture (Fig. 2). This set of specimens was collected at the same time. The cut surface was ground with sandpaper, using grits of P400, P1200, P2400 and P4000 grade and subsequently polished using a 1 μ m polycrystalline diamond suspension. The polished shell cuts were examined by stereomicroscope. Visible internal growth marks were identified (Fig. 4) on both sides of the shell, and the corresponding growth trajectory length SG_i from the apex to the mark *i* was measured. X-rays photographs of the shells (Fig. 3) were taken to confirm internal growth marks with an X (RX) LADEM/VETTER Rem-150 instrument and the follow parameters settings: 50 mA, 30 KV voltage and 0.06 s exposure time.

Periodicity of growth band formation was evaluated by means of oxygen stable isotope (OSI) analysis ($\delta^{18}\text{O}$, ratio of isotopes $^{18}\text{O}/^{16}\text{O}$). $\delta^{18}\text{O}$ in biogenic calcium carbonate structures

is negatively correlated with temperature during shell deposition. This relation is nearly linear between 5°C and 30°C, as demonstrated empirically by Epstein & Lowenstam (1953) and Epstein et al. (1953). Three representative specimens, two females of 130 mm (Fig. 8) and 150 mm (Fig. 6), and one male of 138 mm SL (Fig. 7) were used for OSI analysis. We extracted carbonate samples (approximately 10 mg each) from the shell prismatic layer along the SG by means of a dremel (bit size 0.5 mm) at a sample-to-sample distance of 1 to 3 mm, when possible (70 samples from individual in Fig. 6, 65 from individual in Fig. 7 and 45 samples from individual in Fig. 8). The first sample (SG ~ 0 mm) was taken near the apex; meanwhile the last samples were taken closer to the apertural lip. Oxygen isotope analyses were carried out in the INGEIS-UBA laboratories following the usual techniques (McCrea, 1950; Sharp, 2007). Samples were reacted with "100%" H_3PO_4 , cryogenically purified and measured in a Finnigan MAT Delta S, triple collector, double inlet system, mass spectrometer, again the working standard, "carrara marble". All data are reported in the conventional per mil deviation ($\delta^{18}O_{\text{‰}}$), defined as:

$$d^{18}O (\text{‰}) = \left[\frac{(^{18}O/^{16}O)_S - (^{18}O/^{16}O)_R}{(^{18}O/^{16}O)_R} \right] \times 1000$$

and referred to the V-PDB standard, through the NBS-19 (NIST) reference material (Gonfiantini, 1978, 1984). The analytical uncertainty is $\pm 0.1\text{‰}$ (2σ based on repeated analysis of a laboratory working standard over a 30-year period). $\delta^{18}O$ values were converted into water temperature by the paleotemperature equation of Epstein et al. (1953), as modified by Craig (1965) and Anderson & Arthur (1983):

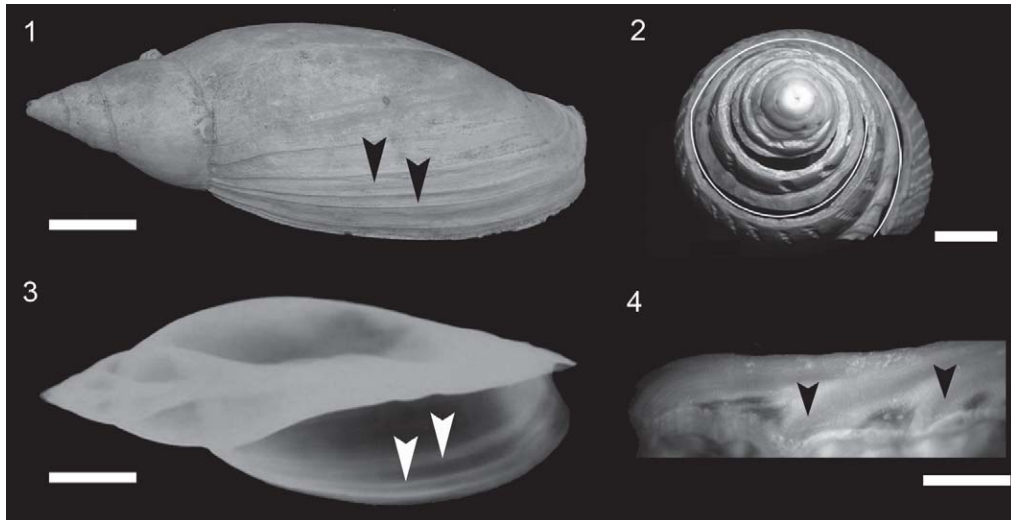
$$T(^{\circ}C) = 20.6 - 4.34 (\delta^{18}O_{\text{aragonite}} - \delta^{18}O_{\text{water}} + 0.27\text{‰})$$

Sea water $\delta^{18}O_{\text{water}}$ was estimated at -0.30‰ from the gridded data (version 1.1) of Le Grande & Schmidt (2006, see also the corresponding NASA website <http://data.giss.nasa.gov/o18data>).

Visual shell marks coinciding with $\delta^{18}O$ peaks were interpreted as late winter (maximum) or late summer (minimum) growth marks, and the distance between two subsequent late winter or late summer growth marks as the annual shell increment. Thus, we interpreted each growth mark, and its corresponding shell growth trajectory length SG_i , as a size-at-age data pair. SG_i was translated into shell length SL_i by means of the linear relationship between the two parameters. The iterative non-linear Newton algorithm was used to fit a growth model to the size-at-age data. The Gompertz growth model was found to fit these data best:

$$SL_t = SL_{\infty} * e^{-e[-K * (t - t_0)]}$$

where SL_{∞} is asymptotic shell length, K is the



FIGS. 1–4. *Adelomelon ancilla*. FIG. 1: External growth marks (arrows); FIG. 2: Spiral growth trajectory (SG), where the samples for oxygen isotopes were taken; FIG. 3: Internal growth marks (arrows) viewed by X-rays; FIG. 4: Detail of internal growth marks (arrows) under stereoscopic microscope. Scales bars: Figs. 1–3 = 2 cm; Fig. 4 = 2 mm.

body growth coefficient, t is age and t_0 is the theoretical age at which length equals zero (Brey, 2001).

Overall growth performance was estimated by the index:

$$P = \log (K * SL_{\infty}^3)$$

and displayed in the form of an auximetric grid of $\log(K)$ versus $\log (SL_{\infty}^3)$, as described by Moreau et al. (1986) and Pauly et al. (1996).

Biomass and Production

Individual somatic production was calculated by the mass-specific growth rate P_i (SFWM) method according to Brey (1999, 2001) from the size-frequency distribution, the size-body function and the growth model parameters:

$$P_i = M_i * G_i$$

where M_i represents mean individual body mass at size i and G_i the annual mass specific growth rate at size S_i given by:

$$G_i = b * K * \ln (SL_{\infty} / SL_i)$$

where b represents the slope of the regression growth function.

Smaller sizes classes are likely to be under-sampled due to small individuals are very cryptic, living buried in the substratum. In addition, gastropods collection was performed by SCUBA diving. Thus, population production (P) and production-to-biomass ratio (P/B) based on size distribution were not calculated.

Mortality

Mortality is one of the processes regulating size and structure of a population. There are different types of mortality; here we use mortality as “the monotonous decrease in number of an age class with time, a process caused by predation, parasitism and diseases” (Brey, 2001). We presumed that mortality in *A. ancilla* can be described by the single negative exponential mortality model based on a virtual handbook (Brey, 2001) and used the corresponding size-converted catch curve (Pauly, 1984a, b) to estimate total mortality rate Z (y^{-1}):

$$N_j / \Delta t_j = N_0 * e^{-Z * t_j}$$

where N_j is the number in the size class j , Δt_j is time required to grow through this size class j , and t_j is age at midsize of size class j . Size-frequency data (SFD) by themselves are not sufficient for an analysis of mortality. Because mortality is defined as decrease in numbers with time and SFD show changes in numbers with size, we have to “translate” size into time (= age). This can be achieved by a growth function. Hence, to derive information on mortality from SFD, we need both a size-frequency distribution and a growth function. This curve was based on the size-frequency distribution of the individuals sampled and the Gompertz growth function (Brey 1999; 2001).

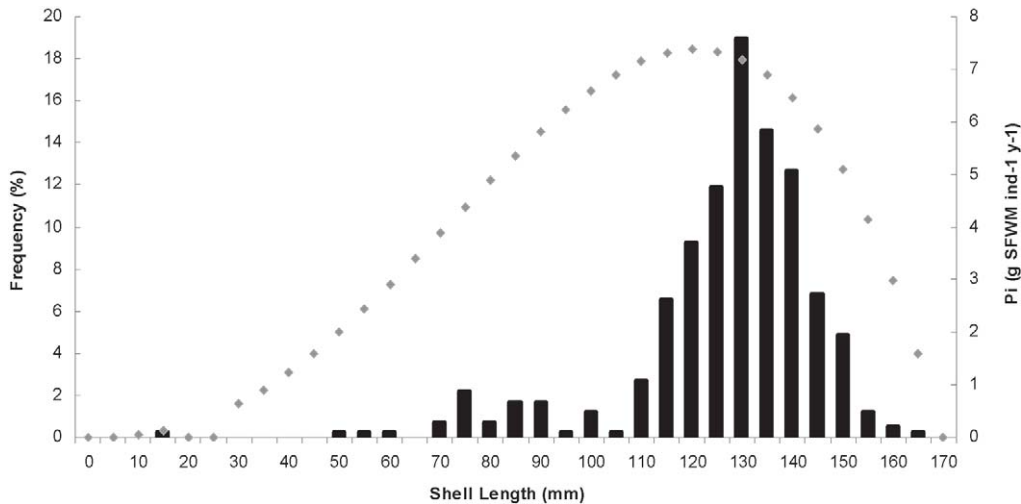
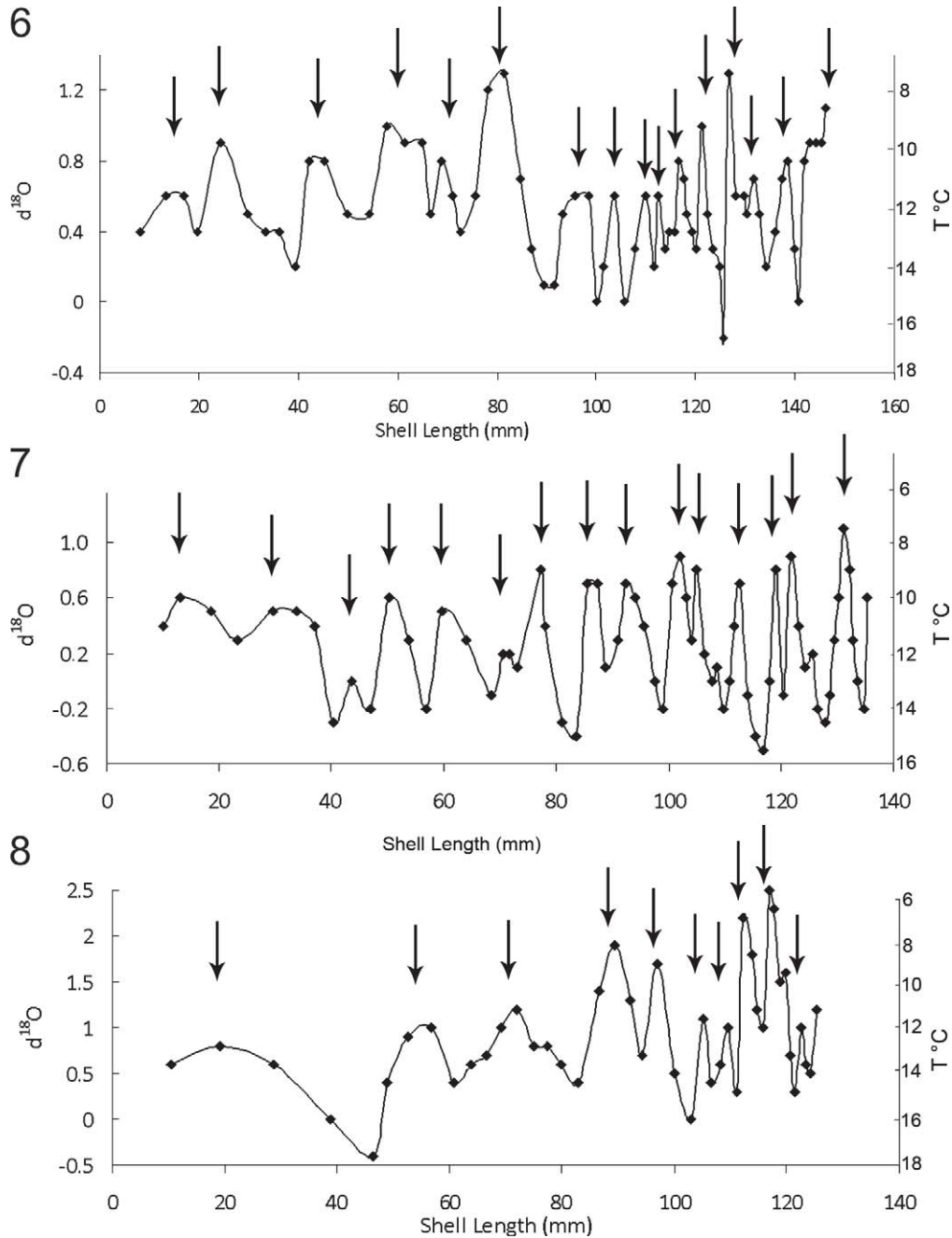


FIG. 5. Size-frequency distribution of *Adelomelon ancilla* (N = 234) from Golfo Nuevo area. Superimposed dotted line indicates individual somatic production P_i (g SFWM year⁻¹) per size class.



FIGS. 6–8. $\delta^{18}\text{O}$ profile corresponding to the shell length of three individuals of *Adelomelon ancilla*. FIG. 6: 150 mm SL; FIG. 7: 138 mm SL; FIG. 8: 130 mm SL. Arrows indicate position of annual internal growth marks (maximum) formed at low water temperatures (late winter). Water temperature (right hand scale) computed from carbonate $\delta^{18}\text{O}$ by the paleotemperature equation of Epstein et al. (1953), see text for details.

Size, Weight and Age at Reproductive Maturity

Samples of gonad of both sexes were processed by standard histology procedures in order to determinate the maturation stage. The detailed methods, gonad general structure and gametogenic cycle are described in Penchaszadeh et al. (2009). The individual size range used was 46 mm to 168 mm in shell length (SL). Individuals without gonad were assigned to the immature condition. The SL at gonadic maturation was determined as the minimum SL at which gonads were developed, for both sexes. Females and males were considered mature whenever their gonads presented vitellogenic oocytes or spermatozoa in the lumen of the tubules, respectively. Immature (stage = 0) females were characterized by the presence of undeveloped ovaries, lacking oocytes and oogenic stages or with early oocytes in pre-vitellogenesis process. Mature (stage = 1) females had developing ovaries, with growing and vitellogenic oocytes. Immature males were characterized by the absence of

developing or mature spermatozoa. Gonadic maturity was determined by whether stages of spermatogenesis, including the presence of mature spermatozoa into spermatogenic tubules. The mature-immature data set was plotted against SL to allow extrapolation of the minimum SL at maturation, and the SL at which 50% and 100% of the population was mature. To estimate size at which 50% of the population is sexually mature (SL_{50}), we calculated the SL at which half of the individuals sampled exhibited mature gonads (Gendron, 1992; Bigatti et al., 2008; Averbuj et al., 2010). To do so, logistic regressions of SL–gonadic maturity were applied to fit mature-immature data on an SL axis (mature = 0; immature = 1). The functions calculated were:

$$Y = 1/(1+e^{-(a+b \cdot X)}) \text{ and } SL_{50} = -a/b$$

where Y represents gonadic maturation, X the shell length in mm (SL) and a, b were constants.

In addition, shell-free wet body mass (SFWM) vs. shell length (SL) of both sexes and male penis length (PL) vs. SL were calculated as additional maturation index (Gendron, 1992).

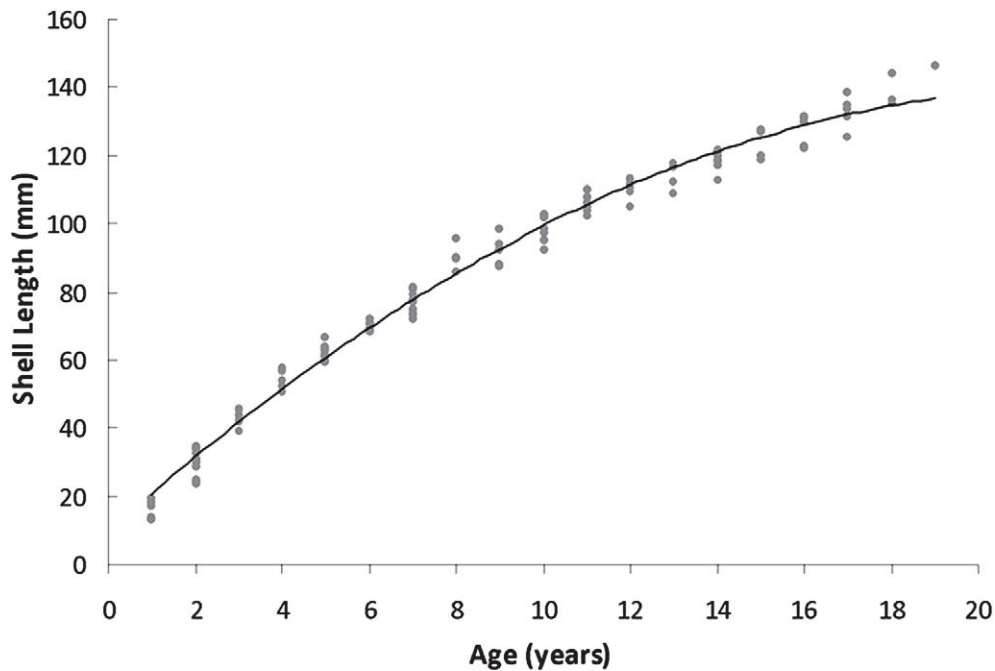


FIG. 9. Gompertz growth model for *A. ancilla*. $SL_t = 170 e^{-e^{-(0.140 \cdot (t - 5.500))}}$; $r^2 = 0.974$; $N = 142$ size-at-age data pairs obtained from the 11 specimens.

RESULTS

A total of 234 individuals of *Adelomelon ancilla* were captured, ranging from 15 to 168 mm in total shell length (SL) (Fig. 5). Juveniles lesser than 15 mm were not registered, because they are very cryptic. Males showed an average of 128.0 ± 18.1 mm SL, while females showed an average of 130.3 ± 16.4 mm SL. The sex ratio of this population of *A. ancilla* (57% females and 43% males) was not statistically different from parity ($\chi^2 = 0.0196$, $df = 1$, $p = 0.888$) throughout the sampled period. Shell-free wet body mass ranged from 3 g to 139 g. Males showed an average of 70.4 ± 27.2 g of SFWM, while females showed an average of 67.4 ± 20.4 g of SFWM. SFWM was related to SL by:

$$\text{Log (SFWM)} = -4.3325 + 2.9082 \cdot \log \text{SL}; \quad (r^2 = 0.75; N = 234)$$

Growth trajectory length SG, that is, the distance from apex to measurement points along the growth spiral (Fig. 2) was linearly related to SL:

$$\text{SG} = 0.985 \text{SL} + 52.600; \quad (r^2 = 0.78; N = 175)$$

The density of *A. ancilla* from Golfo Nuevo, northern Patagonia, population ranged from 0.007 to 0.037 individual/m² (mean = 0.022 ± 0.021 individual/m²). The distribution of this population was observed in small groups within the transects.

Age and Growth

The $\delta^{18}\text{O}$ profiles showed a distinct oscillating pattern in the analyzed shells (Figs. 6–8). The average range of -0.42‰ to $+1.63\text{‰}$ $\delta^{18}\text{O}$ corresponds to a temperature range of about 10.2°C to 17.5°C . The distinct grey colored shell growth marks visible in the shell cuts (Fig. 4) were situated close to the maximum and minimum $\delta^{18}\text{O}$ values (Figs. 6–8). Thus, one mark was formed at the end of the summer (minimum peak), and another at the end of the following winter (maximum peak). The internal marks were confirmed by X-rays (Fig. 3). The largest animal studied (Fig. 6), which measured 150 mm SL, revealed peaks corresponding to an age of 18 years.

The 142 size-at-age data pairs obtained from the 11 analyzed specimens best fitted to the Gompertz growth model (Fig. 9):

$$\text{SL}_t = 170 e^{-e^{-(0.140 \cdot (t - 5.500))}}; \quad (r^2 = 0.974; N = 142)$$

Overall growth performance of *A. ancilla* was $P = 5.84$ (Fig. 10). The observed relationship between length and calculated SFWM of *A. ancilla* ($\text{Log (SFWM)} = -a + b \cdot \log \text{SL}$) was used for production estimates. Individual somatic production (P_i) increased steadily with size to a maximum of $7.38 \text{ g SFWM year}^{-1}$ at 120 mm SL and decreased again thereafter. The distribution of total annual production P

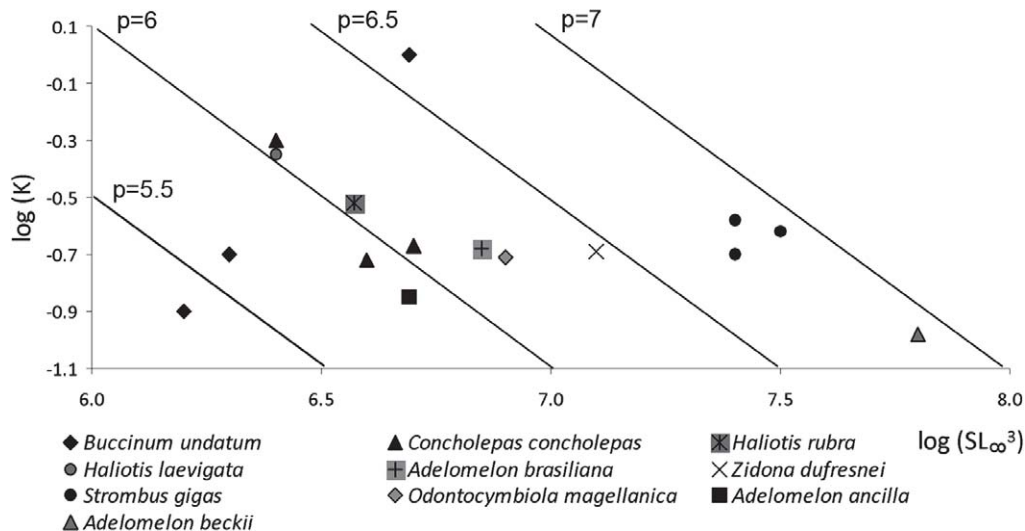


FIG. 10. Auximetric grid comparing growth performance in actual or potential marine gastropod resources. Growth performance index $P = \log (K \cdot \text{SL}_\infty^3)$.

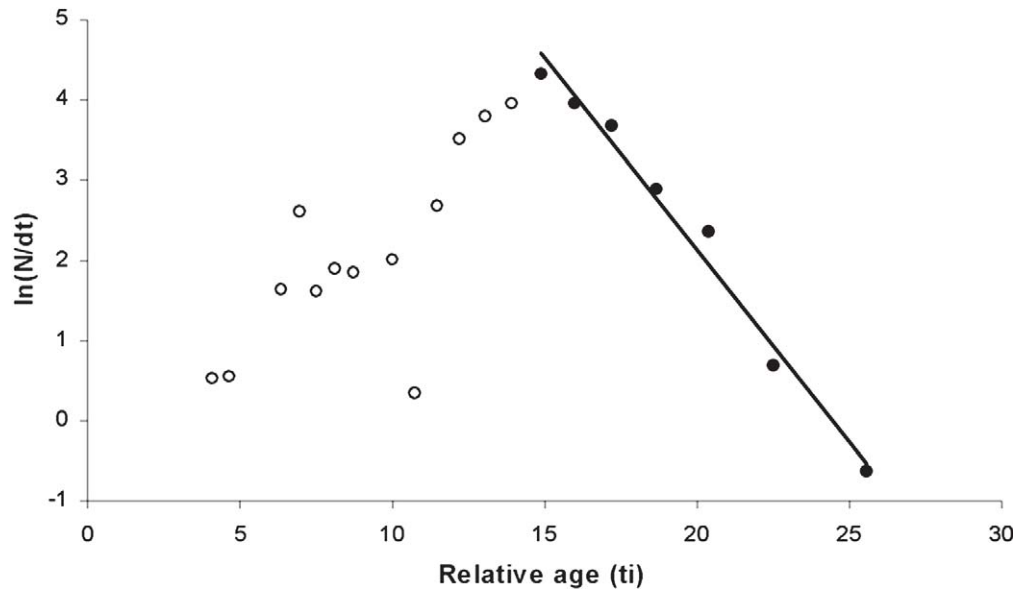


FIG. 11. Size-converted catch curve based on the size–frequency distribution (Fig. 5) and the growth function (Fig. 9) of *A. ancilla*. Dots: data included in regression; circles: data excluded from regression. $\ln(N/dt) = -0.436 ti + 10.941$; $r^2 = 0.98$; 95% confidence range of slope = ± 0.110 .

and the abundance among the size class are illustrated in Figure 5.

The size converted catch curve (Fig. 11) indicates that animals younger than 12 years are strongly under-represented in our sample. Total mortality rate Z of *A. ancilla* amounted to 0.063 y^{-1} (95% confidence range ± 0.110 , Fig. 11). Size-converted catch curve (Fig. 11) does not show the typical pattern of populations exploited by fisheries.

Size, Weight and Age at Reproductive Maturity

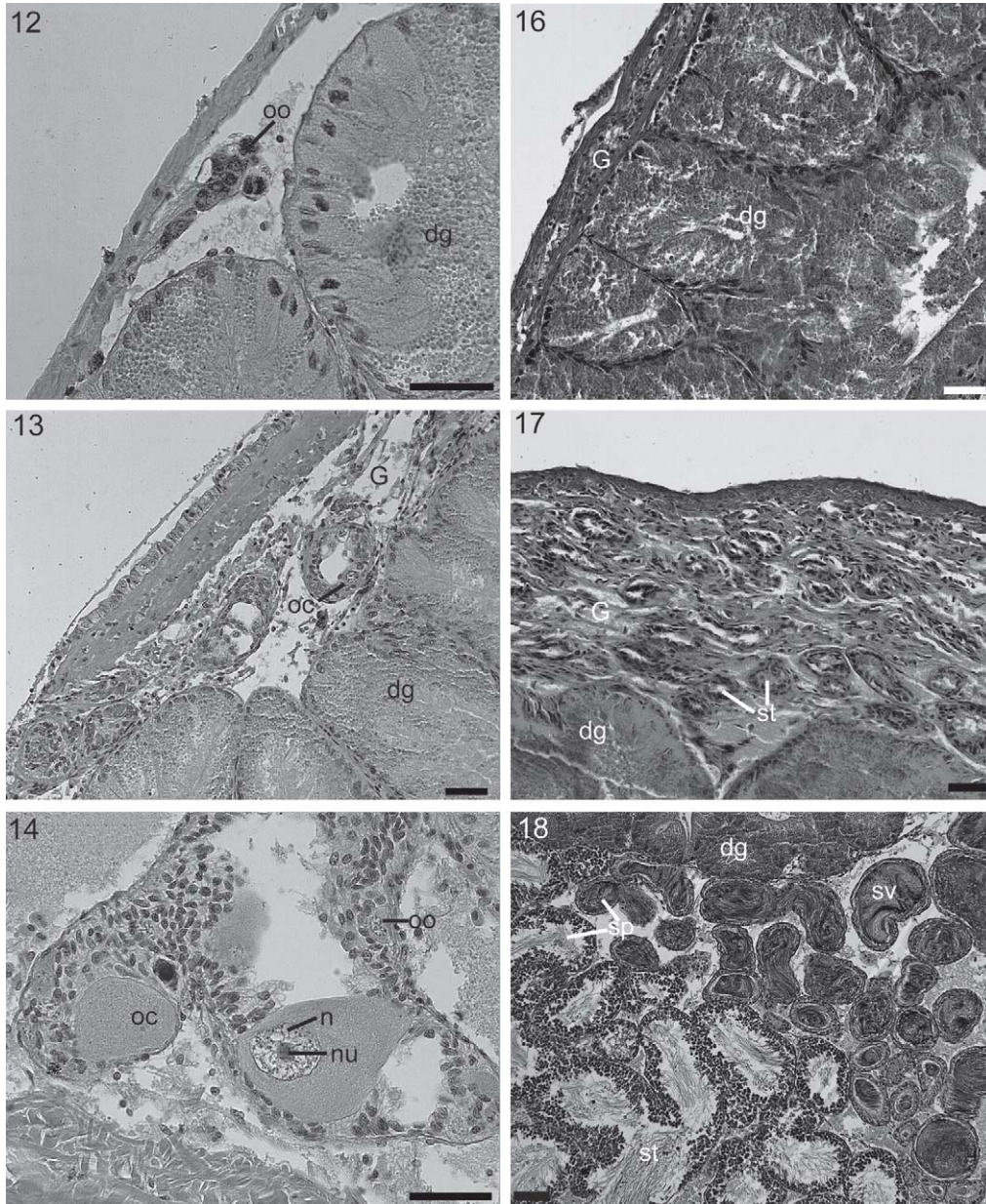
The histological examination showed immature and mature stages in both sexes, which were characterized in Figures 12–17. Females have vitellogenic oocytes at a minimum size of 93 mm in SL. The size at which all the females were mature was 97 mm (Fig. 20). Thus, the SL at which 50% of the female population was considered to be mature (SL_{50}) was 93.5 mm (Fig. 18). Males with mature spermatozoa (ready for evacuation) in the lumen of their tubules occurred at a minimum size of 67.5 mm in SL. At 88 mm in SL, all the males were mature (Fig. 21). The size at which 50% of the male population was considered to be mature (SL_{50}) was 73.5 mm (Fig. 19).

The SFWM inflexion point was similar in both sexes, 85 mm for females ($r^2 = 0.9033$; $N = 122$) (Fig. 22) and 86 mm for males ($r^2 = 0.9176$; $N = 112$) (Fig. 23). In both cases, the SFWM inflexion point in shell length was not coincident with the gonadic maturation size. On the other hand, a positive correlation between shell length and penis length in males was observed ($r^2 = 0.6514$; $N = 89$; $p < 0.05$). The penis structure in *A. ancilla* males developed prior to gonad maturation. Moreover, all males over 60 mm in SL had a conspicuous penis.

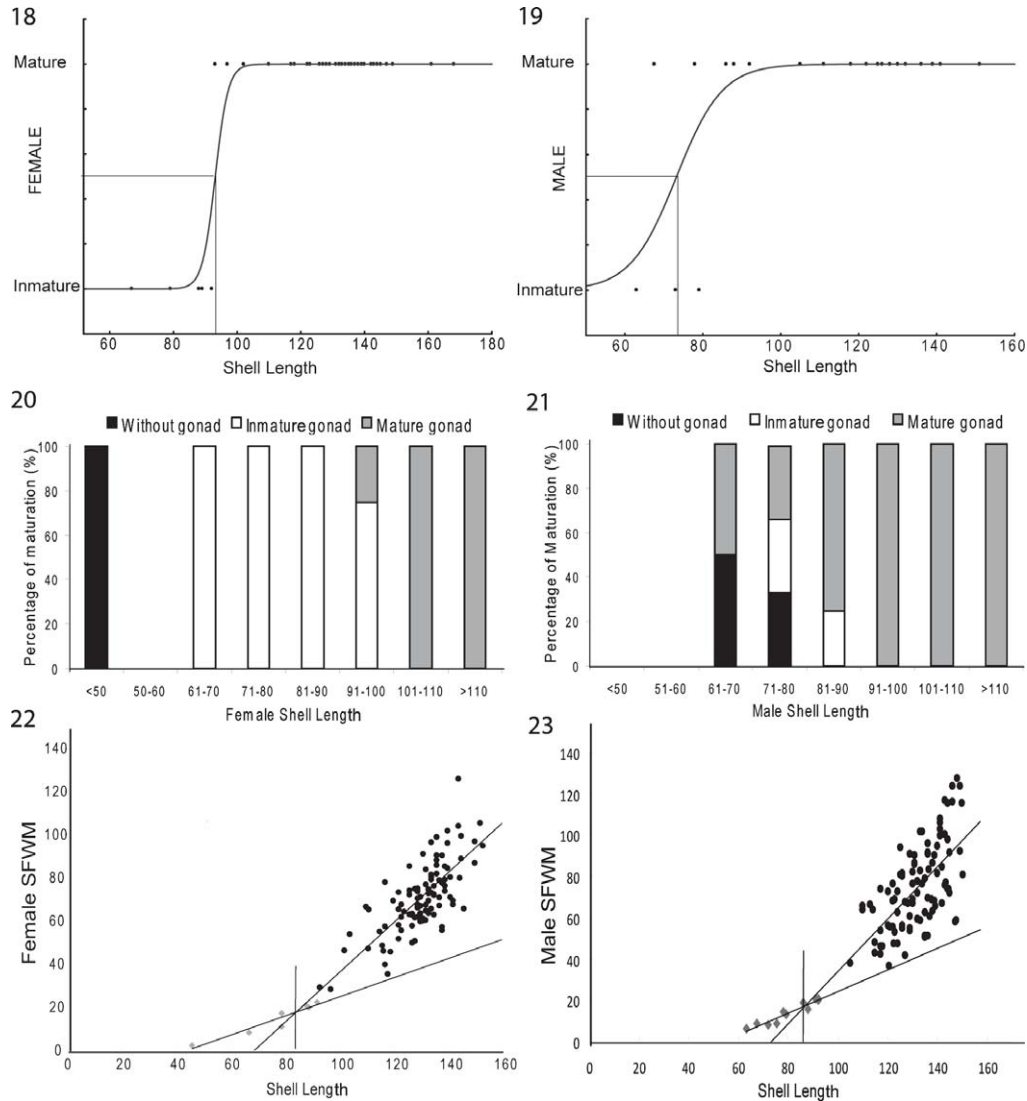
DISCUSSION

Stable Oxygen Ratios

The oxygen stable isotope (OSI) technique has the advantage of assessing age and growth related to the shell length in gastropods. OSI ratios may also be a useful tool to validate the frequency at which shell growth rings/layers are produced (Gurney et al., 2005). All shells used in this study showed clear oscillations in OSI ratio, which reflected the seasonal temperature cycle of shallow Patagonian waters. The average temperature inferred from the $\delta^{18}\text{O}$ profile



FIGS. 12–17. Histological sections showing gonadic stages of maturation of *Adelomelon ancilla*. FIGS. 12–14: Females. FIG. 12: Immature gonad with early oogonia (oo); FIG. 13: Developing gonad, with early oocytes (oc) in pre-vitellogenesis process; FIG. 14: Mature gonad, with vitellogenic oocytes. Note the extended cytoplasm with their nucleus (n) and nucleolus (nu); FIGS. 15–17: Males. FIG. 15: Immature gonad; FIG. 16: Developing gonad. Note the spermatogenic tubules (st) developed besides the digestive gland (dg); FIG. 17: Mature gonad. Note the mature sperm into the lumen of spermatogenic tubules and seminal vesicle (sv) evacuating spermatozoa (sp). Scales bars Figs. 12–16 = 50 μ m; Fig. 17 = 100 μ m.



FIGS. 18–23. Size (SL) at which half of the female (FIG. 18) and male (FIG. 19) individuals exhibit matures gonads (SL_{50}). Percentage of gonad maturation vs. shell length in females (FIG. 20) and males (FIG. 21). Relation between shell length (SL) and shell free wet body mass (SFWM) and size at first gonadic maturation of females (FIG. 22) 85 mm (perpendicular bar) and males (FIG. 23) 86 mm (perpendicular bar) of *A. ancilla*.

in *A. ancilla* shells, 10.2°–17.5°C, coincided with historic annual temperature range reported in the zone (9.7°–18.3°C) (Rivas & Beier, 1990). Furthermore, all the shells studied showed two growth marks per year; the first mark was produced in late winter coinciding with the $\delta^{18}O$ maximum, and the second mark was formed in

late summer in concordance with the $\delta^{18}O$ minimum. This semiannual pattern of shell marks was also observed in the volutid *Odontocymbiola magellanica* (Gmelin, 1791) (Bigatti et al., 2007), a sympatric species of *A. ancilla* in Golfo Nuevo. However, in other studied volutids, as *Zidona dufresnei* (Donovan, 1823) (Giménez

et al., 2004), *Adelomelon brasiliiana* (Dillwyn, 1817) (Cledón et al., 2005a), as well as in the olivid *Olivancillaria deshayesiana* (Ducros de Saint Germain, 1857) (Arrighetti et al., 2012), all from northern Argentinean coastal waters (temperature ranges from 22°C in late summer to 11°C in late winter), marks are deposited annually. These differences in patterns in shell mark deposition evidenced by Patagonian and species from northern waters in Argentina, might be related to inhabiting different biogeography regions (Argentinean and Magallanic provinces) (Bigatti et al., 2007).

Age, Growth, Production, Mortality and Reproductive Maturity

According to isotopic data and the internal growth marks observed in *A. ancilla* we determined that this species fits to a Gompertz growth model, reaching up to 18 years at 150 mm SL in the Golfo Nuevo region. The long lifespan of *A. ancilla* is comparable to other large gastropods, in particular other Argentine volutid species, for example, 20 years in a 198 mm SL *O. magellanica* individual (Bigatti et al., 2007), 17 years in a 198 mm SL *Z. dufresnei* individual (Giménez et al., 2004), 20 years in a 170 mm SL *A. brasiliiana* individual (Cledón et al., 2005a) and 29 years in a 380 mm SL *A. beckii* (Broderip, 1836) individual (Arrighetti et al., 2011).

The Gompertz growth function proposed for *A. ancilla* also fits to *Z. dufresnei* and *O. magellanica*, whereas for *A. beckii* and *A. brasiliiana* the function that best fitted the size-age data pair was the Von Bertalanffy and the Logistic, respectively (Giménez et al., 2004; Cledón et al., 2005a; Bigatti et al., 2007; Arrighetti et al., 2011). The differences between these functions could be inherent to the particular growth pattern and shell morphology that each species exhibits (Cledón et al., 2005a; Arrighetti et al., 2011), and could be reflecting different growing patterns. The species that grow and mature faster could be more suitable to commercial exploitation. Moreover, the overall growth performance of *A. ancilla* ($P = 5.84$) (Fig. 5) was minor than the values referring to other volutids and large gastropods species that are fishery resources in temperate regions along the world as shown in the auximetric grid (Fig. 10) (De Jesús-Navarrete, 2001; Giménez et al., 2004; Cledón et al., 2005a; Bigatti et al., 2007; Arrighetti et al., 2011). Individual somatic production (weight increment per year) of *A. ancilla*

was very low (maximum of 7.4 g SFWM at 120 SL) compared with the other studied volutids (Giménez et al., 2004; Cledón et al., 2005a; Bigatti et al., 2007; Arrighetti et al., 2011). This fact agrees, and it could be associated with the low (40%) foot output (% of foot weight consumable from total SFWM) recorded by Bigatti & Ciocco (2008). Moreover, the relationship between shell weight and SFWM in *A. ancilla* was higher (the shell is thick and heavy) than in the remaining volutids (shells are thinner and slight) (Zabala, 2013). The size-frequency distribution reported here is based on data collected from SCUBA diving by us (SZ and GB). Smaller individuals were not registered due to the cryptic condition of juveniles, which live buried in the soft substratum and feed on carrion (Zabala, 2013). The cryptic condition of juveniles could protect them from predators; however, predation was not reported in *A. ancilla* for juveniles nor egg capsules, as it was in other volutids from northern Patagonia (Bigatti et al., 2007; Roche et al., 2013). The lack of juveniles in the sampling is clearly indicated by the size-converted catch curve, where individuals smaller than 12 years of age are under-represented. Therefore, estimates of production and productivity based on this distribution would underestimate true population values, but represents the mature population under study.

In respect to the first reproductive maturity size of *A. ancilla* obtained by gonad histological section, males reached maturity at a smaller size (beginning at 68 mm, with $SL_{50} = 73.5$ mm) than females (beginning at 93 mm, with $SL_{50} = 93.5$ mm). The early male maturation also occurs in other volutids, such as *Z. dufresnei*, *O. magellanica* and *A. brasiliiana* (Giménez & Penchaszadeh, 2003; Cledón et al., 2005b; Bigatti et al., 2008). This difference in size at maturation might indicate that females need more time to be capable of reproduction (Cledón et al., 2005b). Other gastropods also show differences between sexes, for example, *Buccinum cyaneum* Bruguière, 1792 (Miloslavich & Dufresne, 1994) and in some buccinids from Japanese waters, in which males mature at a smaller SL than the females, indicating a more gradual process of maturation (Ilano et al., 2003) associated with a greater reproductive investment in females (Averbuj et al., 2010). Furthermore, the early maturation in males would allow matings between mature females, providing reproductive success of the population. In this sense, if the species is exploited females sizes captured must be bigger than the

SL₅₀, permitting some reproductive seasons that add individuals to the population.

The age at which 50% of *A. ancilla* individuals present gonadic maturation corresponded to 7 and 9 years, for males and females respectively. The late gonadic maturation in comparison with other caenogastropods from other latitudes (Carrick, 1980; Peralta, 2012) occurs also in other volutids and at similar sizes (e.g., *O. magellanica*: 90 mm SL at 8 years and 80 mm SL at 7 years; *Z. dufresnei*: 157 SL and 150 SL at 8 to 9 years both, for females and males respectively). The gonadic maturation of South Atlantic volutids seems to be rather late compared with other large gastropods from northern regions (temperate and tropical species), such as *Gazameda gunni* (Reeve, 1849) (2.5–3 years; Carrick, 1980), but similar to others like *Buccinum undatum* Linnaeus, 1758 (6 years; Gendron, 1992), *Strombus costatus* Gmelin, 1791, and *S. gigas* Linnaeus, 1758 (5 and 7 years, respectively; Wefer & Killingley, 1980).

The relationship between SFWM and SL is not a useful parameter of maturity in *A. ancilla*. In females, the rate change in the increased weight (break point) with respect to shell length was recorded at 84 mm. This increment in body mass is registered before gonadic maturity (93.5 mm) and could be attributable to an early investment in somatic growth, required for a subsequent reproductive investment (Averbuj et al., 2010) or is related to mass increase due to the development of the reproductive accessory glands (Cledón et al., 2005a). Penis length does not appear to be a good indicator of maturity, despite showing a significant positive correlation with size. The penis structure in *A. ancilla* males developed prior to gonad maturation, because all males over 60 mm in SL had a conspicuous penis.

Ecological Importance and Fisheries Suggestions

Small-scale fisheries, and particularly benthic invertebrate fisheries, have played an important role in the development of new fishery management principles and tools (Leiva & Castilla, 2002). Large marine gastropod landings of 1,000 tons/year were recorded in Argentina (Ministerio de Agricultura, Ganadería y Pesca, 2012). Nevertheless, there are few studies that detail the exploitation practices and fishery management. For some marine gastropods (e.g., *Concholepas concholepas* (Bruguère, 1789) in Chile and the abalone *Haliotis spp.* in

Baja California; Leiva & Castilla, 2002), due to their high economic value and excessive capture, the populations have shown serious problems of overexploitation (Tegner, 1989; Castilla, 1996; Ponce-Díaz et al., 1998; Hobday et al., 2001). Recently, Torroglosa & Giménez (2010) stated that *Z. dufresnei* presented a smaller size at reproduction maturation (131 mm and 128 mm for females and males respectively) on the same gastropod population ten years after exploitation. These authors mention that the decrease in the size at first maturity might be a response to resource depletion, caused by overfishing of the slow growing gastropods that occurs in the fishing zone, north of where our study was performed.

The ecological significance of *A. ancilla* in Patagonian shallow waters community is defined by its trophic position among the top benthic predators in the food web it inhabits (Zabala et al., 2013). Studies of *A. ancilla* populations showed extremely low densities at different sites, 0.007 and 0.037 ind/m² in the studied area and 0.007 ind/m² in offshore southern Atlantic Ocean (Zabala, 2013). All features of the population dynamics of *A. ancilla*, such as its longevity, low somatic production, low density, high trophic position and late reproductive maturity including direct development with few embryos inside the egg capsules (Zabala, 2013), place this species as a not recommendable resource for commercial exploitation in Golfo Nuevo populations. Nevertheless, *Adelomelon ancilla* is usually confounded with the sympatric *Odontocymbiola magellanica* due to their external shell similarity, as occurs in the Chilean marine gastropod artisanal fisheries (Osorio, 2002), and could be fished as by catch or target species in open ocean waters if commercial volutid fisheries proliferate. For this reason, and due to *A. ancilla* presents lower populations than *O. magellanica* in shallow waters of Golfo Nuevo (Zabala, 2013), we do not recommend its exploitation in the studied zone. However, in case that this species is exploited commercially in other places, we suggest a minimum size of 100 mm SL for both sexes. Thus, it would ensure that females (LT₅₀: 93.5 mm) can reproduce at least two seasons before harvest ensuring the reproductive success of the species.

Our results should be considered when developing an appropriate management of the resource, in concordance with the reproductive (Penchaszadeh et al., 2009) and ecological parameters (Zabala et al., 2013) of this vulner-

able species. The growth model proposed here should also be useful to integrate management and conservation policies (Leiva & Castilla, 2002).

In conclusion, the volutid *Adelomelon ancilla* appears to be more fragile and susceptible to overexploitation than other studied volutids. For this reason, conservation management policies should be defined carefully.

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