RESEARCH ARTICLE

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Individual growth and somatic production in *Adelomelon brasiliana* (Gastropoda; Volutidae) off Argentina

Abstract Growth, age and somatic production of the benthic predator *Adelomelon brasiliana* were studied at the southern limit of its distribution on the South American Atlantic shelf. Stable oxygen isotope ratios confirmed annual formation of internal shell growth marks. Modal shell length of the population was 140 mm, while modal shell-free wet mass was 255 g. A logistics growth function ($SL_\infty = 186.28$ mm, $K = 0.185$, $t_0 = 4.601$) fitted 131 pairs of size-at-age data (25 shells) best. *A. brasiliana* is a very long-lived species, reaching up to 20 years of age. The maximum individual somatic production of 46 g shell-free wet mass $year^{-1}$ is attained at 145 mm shell length, which corresponds to about 12 years of age.

Introduction

The neogastropod *Adelomelon brasiliana* (Volutidae) occurs along the South American Atlantic coast between 23°S and 41°S. High Asian demand for gastropod meat induced the commercial exploitation of this species in the early 1990s in Uruguay, mainly as a response to the depletion of the "loco" (*Concholepas concholepas*) stock in Chile (Equipo EcoPlata Eds 1996; Rabí and Maraví 1997). The Argentinean stock is not commercially exploited, but

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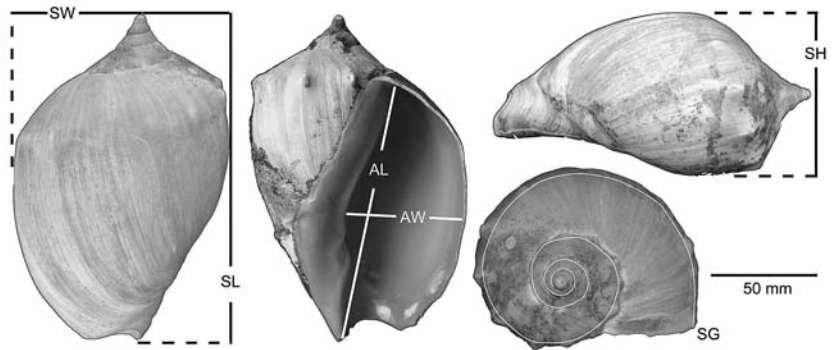E-mail: mcledon@bg.fcen.uba.ar

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A. brasiliana is captured in high numbers as bycatch of the shallow-water shrimp fishery along the coast of the Buenos Aires province. As in most Argentinean Volutidae, biological and ecological information on *A. brasiliana* is scarce (Lasta et al. 1998). There have been some studies on its egg capsules (Penchaszadeh and De Mahieu. 1976; Penchaszadeh et al. 2000a, 2000b) and a recent description of its reproductive cycle (Cledón et al. 2005).

The aim of the present study is to analyse individual growth, age and somatic production in order to provide some basic parameters of population dynamics, which will be required for evaluation and future successful management of this potentially valuable resource in Argentinean waters.

Materials and methods

The study was carried out along the coast of the Buenos Aires province, Argentina, off Mar del Plata (38°20′S; 57°37′W). About 20 individuals of *Adelomelon brasiliana* were captured monthly between November 2000 and December 2002 by one 30-min haul with a bottom trawl (15-m mouth opening, 40-mm mesh size in the cod end) towed by a 12-m fishing boat at approximately 15 m depth, 1000 m off the coast. Soft parts were weighed (shell-free wet mass, SFWM) to the nearest 1 g and shell length (SL), width (SW) and height (SH), aperture length (AL) and width (AW) and spiral growth trajectory (SG) (Fig. 1) were measured with a vernier calliper to the nearest 1 mm. The relationships between these morphometric parameters were described by linear regression.

Growth and age

Individual growth and age were inferred from internal shell growth marks in 25 shells covering the whole SL range by: (1) growth mark identification, (2) validation of annual growth mark formation and (3) quantitative size-at-age determination. To check for internal growth

Fig. 1 *Adelomelon brasiliana.*. Measurements of shells: shell length (*SL*), shell width (*SW*), aperture length (*AL*), aperture width (*AW*), shell height (*SH*), spiral growth length (*SG*)

marks, X-ray photographs of shells were taken with a Hewlett Packard Faxitron 43855 mammograph with a fixed anode, using AGFA-Strukturix D4 FW film and the parameter settings: focal film distance 45 cm, voltage 40 kV and 120- to 240-s exposure time. They revealed macroscopically visible bands perpendicular to the shell growth trajectory. Shell cuts were prepared to count and measure these marks. Cuts were performed along the whorls following the spiral growth trajectory from the apex to the posterior end of the aperture (Fig. 1). The cut surface was polished with fine-grained sandpaper and checked for growth marks in the three-layered shell by means of a stereomicroscope. Growth marks were numbered subsequently, and the distance from the shell apex to each mark, i.e. the growth trajectory length SG, was measured. Mark number and corresponding SG were interpreted as size-at-age data.

Stable oxygen isotope ratios ($\delta^{18}O$) were used to analyse whether these marks were formed annually, as described recently by Giménez et al. (2004) and others. The ratio of the stable oxygen isotopes ^{16}O and ^{18}O in biogenic $CaCO_3$ is inversely proportional to temperature during shell deposition. This relation is nearly linear between 5°C and 30°C (Epstein et al. 1951; Epstein and Lowenstam 1953). Therefore, a mollusc shell from an environment with rather constant salinity and a distinct annual temperature cycle will show an oscillating pattern of $\delta^{18}O$ along the major growth axis (see examples in Santarelli and Gros 1985; Richardson 2001; Giménez et al. 2004). Five representative specimens (three males of 137, 139 and 148 mm SL and two females of 136 and 147 mm SL) of *A. brasiliana* were selected for isotope analysis. From each shell, about 120 samples (approximately 125 µg each) were drilled from the central shell layer, at 1–4 mm from each other, along the SG. Shell areas damaged by drilling polychaetes were not sampled.

Stable oxygen isotope composition was determined in the Stable Isotope Laboratory of the Alfred Wegener Institute with a Finnigan MAT251 mass spectrometer coupled to an automatic carbonate preparation device. Results were reported in δ-notation versus the PDB (Vienna Pee Dee Belemnite) standard calibrated via NIST 19 (National Institute of Standards and Technology isotopic reference material 19). The precision of measurements was better than $\pm 0.08‰$ for $\delta^{18}O$, based on repeated analysis of a laboratory working standard over a 1-year period. Spatial coincidence of subsequent $\delta^{18}O$ peaks and subsequent shell growth marks would indicate that one mark is formed each winter.

The iterative non-linear Newton algorithm was used to fit growth models to the resulting set of size-at-age data pairs. The following logistic growth model: $SL_t = SL_\infty/(1 + e^{-k(t-t0)})$ was found to fit these data best.

Individual production

Individual annual somatic production P_i (SFWM) of *A. brasiliana* was calculated by the mass-specific growth rate method (see Brey 2001) using the size–growth function and the size–body mass relation such that: $P_i = M_i \times G_i$, where M_i represents mean individual body mass at size i and G_i is the annual mass-specific growth rate at size S_i given by: $G_i = b \times K \times \ln(SL_\infty/SL_i)$.

As samples were collected with a commercial bottom trawl with a mesh size of 70 mm, smaller size classes are likely to have been severely undersampled. Thus we refrained from computing population production (*P*) and production to biomass ratio (*P/B*) based on the sample size distribution, as these estimates would strongly underestimate true values.

Mortality

Total mortality rate Z according to the single negative mortality model $N_t = N_0 \times e^{-Z \times t}$ was estimated by a size-converted catch curve (Pauly 1984a, 1984b) such that: $\ln(N_i/\Delta t) = a + b \times t_i$, where N_i is number in size class i, Δt is the time required to grow through this size class, t_i is age at midsize of size class i, and $Z = -b$. This curve was based on the size-frequency distribution of the individuals sampled and the logistic growth function.

Results

Morphometrics

The 500 animals collected ranged from 34 to 174 mm SL; modal length was about 140 mm SL (Fig. 2).

SH, SW, AW and AL were linearly related to SL such that: $SW = 0.664 \times SL - 3.618$ ($r^2 = 0.979$; $N = 500$), $SH = 0.503 \times SL - 1.304$ ($r^2 = 0.979$; $N = 500$), $AW = 0.4081 \times SL - 7.2874$ ($r^2 = 0.972$; $N = 500$) and $AL = 0.8468 \times SL - 5.1959$ ($r^2 = 0.976$; $N = 500$).

SFWM ranged from 1.4 to 400.2 g; modal mass was about 255 g. SL and SFWM were exponentially related such that: $\log(SFWM) = 3.5622 \times \log(SL) - 5.2008$ ($r^2 = 0.971$; $N = 500$).

SG, that is, the distance from apex to measurement point along the growth spiral (Fig. 1), was linearly related to SL such that: $SG = 2.827 \times SL + 2.728$ ($r^2 = 0.924$; $N = 131$).

Age and growth

The $\delta^{18}O$ profiles showed a distinct oscillating pattern in all five shells analysed (Fig. 3). According to the paleotemperature equation of Epstein and Lowenstam (1953), an amplitude of about 1‰ corresponds to a temperature range of $\geq 4°C$, which is in the range of the annual cycle observed in the investigation area (Guerrero and Piola 1997; Cledón et al. 2005). The distinct dark-orange-coloured shell growth marks visible in the shell cuts were situated closely behind the maximum $\delta^{18}O$ values (Fig. 3), that is, one mark is formed during each temperature minimum period in winter. Apparently no growth band is formed during the first winter, which is, however, clearly indicated by the first $\delta^{18}O$ peak (Fig. 3). The oldest animal found was 20 years of age, since it formed 19 growth marks.

The 131 size-at-age data pairs obtained from the 25 specimens analysed were fitted best by the logistic growth model (Fig. 4) such that: $S_t = 186.28/(1 + e^{-0.185(t - 4.601)})$ ($r^2 = 0.924$; $N = 131$).

Individual production

Individual somatic production (P_i) increased steadily with size to a maximum of 46.1 g SFWM year^{-1} at 145 mm SL and decreased again thereafter (Fig. 2).

The size-converted catch curve (Fig. 5) does not show a straight descending right arm, i.e. the single negative mortality model does not fit the data and hence a mortality rate Z cannot be calculated.

Discussion

Validity of ageing approach

Traditional methods of ageing molluscs such as counting growth marks on/in the shells are not reliable by themselves, as they lack a validation of the time intervals at which those marks are formed. In environments with an annual temperature amplitude of several degrees Celsius, stable oxygen isotope analysis can provide such validation, because $\delta^{18}O$ of carbonate shell deposits vary with temperature (Richardson 2001). Changes in salinity can affect $\delta^{18}O$ too (Epstein and Lowenstam 1953), but such changes are negligible in the investigation area (constantly around 33.8 PSU, Guerrero and Piola 1997). Therefore, the $\delta^{18}O$ profile in the shell of *Adelomelon brasiliana* reflects the water temperature cycle, i.e. each $\delta^{18}O$ peak corresponds to one winter water temperature minimum, thus providing a valid shell age scale.

A. brasiliana from the Mar del Plata area (maximum age = 20 years) appears to be rather long lived compared to other large gastropods such as *Buccinum undatum* (12 years, Gendron 1992), *Concholepas concholepas*

Fig. 2 *Adelomelon brasiliana*. Size-frequency distribution of *A. brasiliana* ($N = 500$) from Mar del Plata in the years 2000–2002 [*dots* superimposed curve of individual production P_i (g shell-free wet mass year^{-1}) versus size (standard length, mm) in *A. brasiliana*]
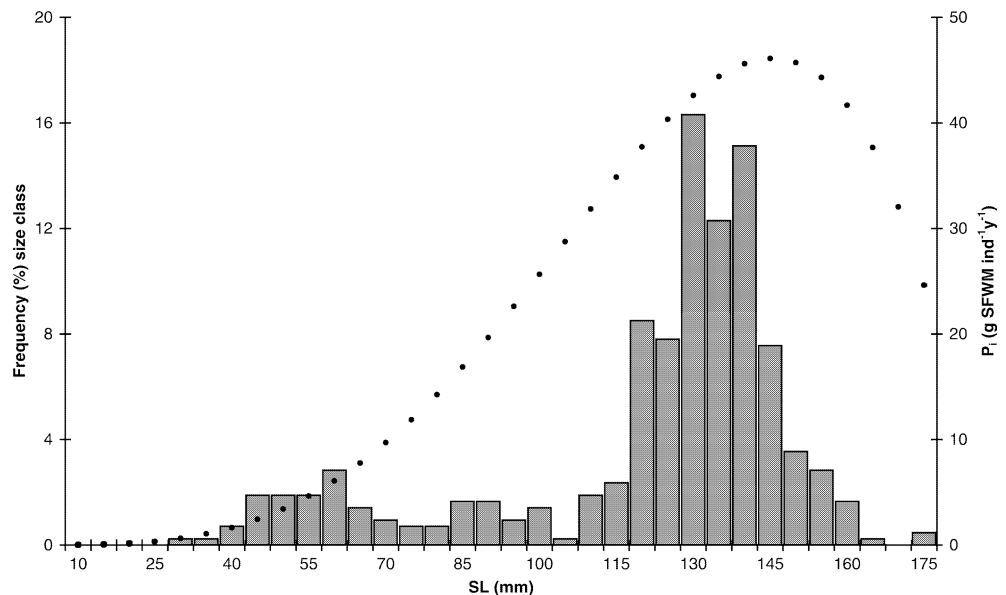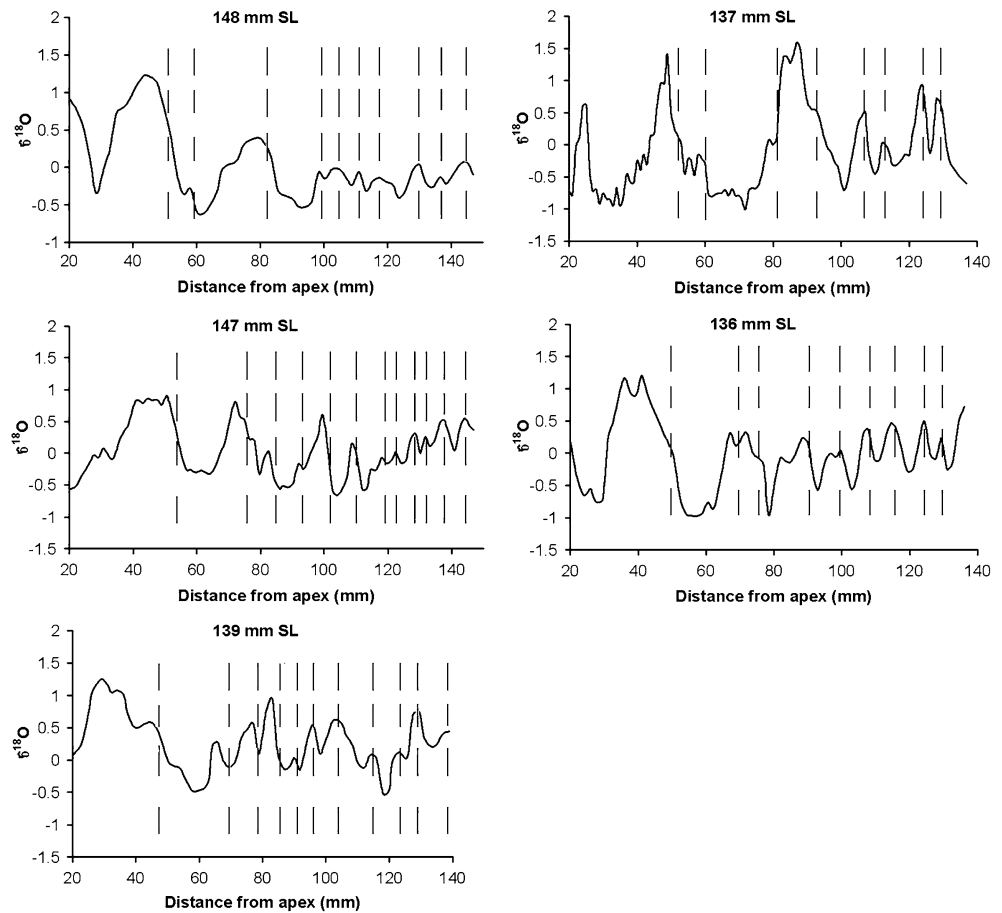
Fig. 3 *Adelomelon brasiliana.* $\delta^{18}O$ profile plotted against corresponding shell lengths of five *A. brasiliana* of 148, 147, 139, 137 and 136 mm, respectively. *Lines* indicate the position of the shell growth marks

(10 years, Stotz 2000), *Gazameda gunii* (7 years, Carrick 1980), *Strombus costatus* and *S. gigas* (5 and 7 years, respectively, Wefer and Killingley 1980) and *Zidona dufresnei* (17 years, Giménez et al. 2004).

We used the index of overall growth performance [OGP: $P = \log(K \times L_\infty^3)$] (e.g. Pauly 1979; Munro and Pauly 1983; Moreau et al. 1986) to compare growth between various large gastropod species. OGP of *A. brasiliana* ($P = 6.077$) is well within the range of values found in other large commercial gastropod species from temperate regions (Fig. 6). In this sense *A. brasiliana* would not be more susceptible to overfishing than *C. concholepas* or *Haliotis* sp. But *A. brasiliana* has a

different reproductive mode than these groups, which possibly causes a lower number of hatchlings per female than species with larval development such as *C. concholepas* and *Haliotis*.

Owing to its large size and frequent occurrence, *A. brasiliana* may be viewed as a valuable resource. On the other hand, its slow growth and late maturity (Cledón et al., submitted) will make it extremely vulnerable to overexploitation, a fate encountered by many gastropod populations, e.g. many abalone species in Australia and southern Asia (Rogers-Bennett et al. 2002), the queen conch *S. gigas* in the Caribbean Sea (Stoner and Ray-Culp 2000), *Concholepas concolepas*
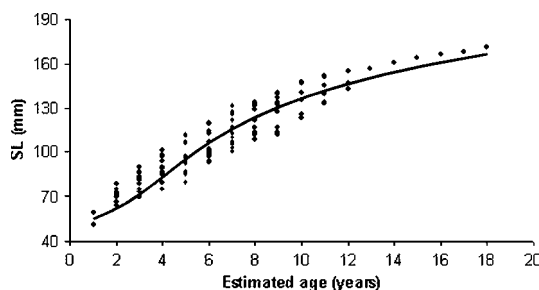

Fig. 4 *Adelomelon brasiliana.* Logistic growth curve fitted to 131 size-at-age data pairs obtained from 25 shells of SL = 186.26 mm/$(1 + e^{-0.185(t-4.601)})$; $r^2 = 0.92$; $N = 131$
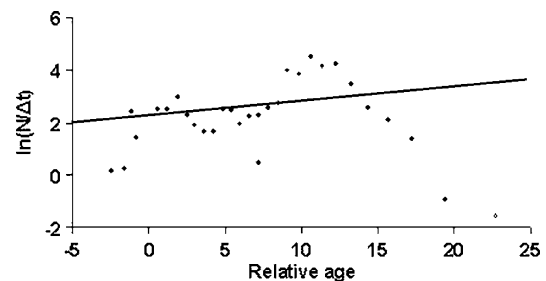

Fig. 5 *Adelomelon brasiliana.* Plot of $\ln(N/\Delta t)$ versus relative age as required for a size-converted catch curve. The multi-mode pattern indicates that the single negative exponential mortality model does not fit the data
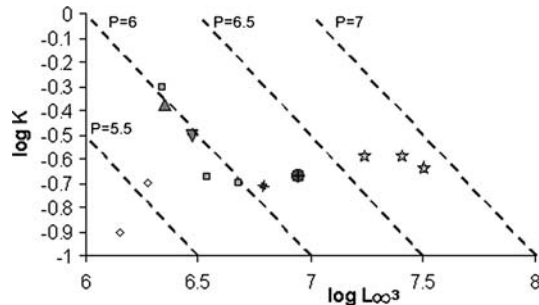
Fig. 6 Auximetric grid comparing growth performance in commercially exploited marine gastropod species [star: *Strombus gigas* (de Jesús-Navarrete 2001); circle: *Zidona dufresnei* (Giménez et al. 2004); cross: *Adelomelon brasiliana* (present study); square: *Concholepas concholepas* (Geaghan and Castilla 1987; Rabí and Maraví 1997; Rodriguez et al. 2001); triangle: *Haliotis laevigata* (Shepherd and Hearn 1983); inverted triangle: *Haliotis rubra* (Shepherd and Hearn 1983); rhombus: *Buccinum undatum* (Santarelli and Gros 1985; Kideys 1996)]. *Stipled lines* indicate lines of equal growth performance

(the Chilean "loco", Rabí and Maraví 1997) and currently Argentinean *Zidona dufresnei* (Giménez et al. 2004).

Therefore, regulations already proposed for the management of *A. brasiliana* in Uruguay (e.g. prohibition of the incorporation of more boats to the existing fishery, area limitation, fishery licensing, minimum mesh size of 120 mm, see Riestra and Fabiano 2000) should be implemented as soon as possible.

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