RESEARCH ARTICLE

Age and growth in *Odontocymbiola magellanica* (Gastropoda: Volutidae) from Golfo Nuevo, Patagonia, Argentina

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Abstract Growth, age and somatic production of the benthic predator *Odontocymbiola magellanica* were studied in Golfo Nuevo (42°S 65°W), on the South American Atlantic shelf. Stable oxygen isotope ratios confirmed semiannual formation of internal and external shell growth marks. Mean shell length (SL) of females was 115 and 112 mm for males, while population modal shell-free wet mass (SFWM) was 62.8 g. A Gompertz growth function ($SL_\infty = 200$ mm, $K = 0.197$, $t_0 = 5.486$) fitted 113 pairs of size-at-age data (12 shells) best. *O. magellanica* is a long-lived species, reaching up to 20 years of age. The maximum individual somatic production of 29.3 g SFWM per year is attained at 145 mm SL, which corresponds to about 12 years of age. The life span of this volutid seems to be twice compared with other large gastropods. *O. magellanica* is a valuable and exploitable resource regarding its large size and somatic production, but on the other

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hand, its slow growth, late maturity and direct development makes it extremely vulnerable to overexploitation.

Introduction

The Neogastropod *Odontocymbiola magellanica* (Volutidae: Odontocymbiolinae) occurs along the South Atlantic coast from 35°S, until the Magallanes Strait reaching the Chiloé Island in the Pacific coast of Chile (42°S); it also occurs in the Malvinas (Falklands) Islands (Weaver and Dupont 1970; Castellanos 1970; Castellanos and Landoni 1992; Gallardo and Penchaszadeh 2001). Recent studies on South Western Atlantic volutids were published by Giménez and Penchaszadeh (2002, 2003), Giménez et al. (2004, 2005) and Cledón et al. (2005a, b, 2006), who studied the growth and age of *Zidona dufresnei* and *Adelomelon brasiliana* (both subfamily Zidonidae) in Mar del Plata. Penchaszadeh and De Mahieu (1976) and Penchaszadeh et al. (1999) studied basic aspects of the egg capsules of *O. magellanica* and more recently Bigatti and Penchaszadeh (2005) reported the existence of the phenomenon of imposex near patagonic harbors. Lasta et al. (2000) mention the species as a potential fishery resource of the artisanal fleet of the Patagonian coasts. Argentinean snails are exported as fresh meal or canned products to different markets, mainly to Asian countries, with only a small proportion being used locally. Only the large muscular foot, representing 60% of the whole body mass without shell, is used for consumption (Giménez et al. 2005). The high-scale exploitation of the snail *O. magellanica* is a

matter of time, since many fishery resources not previously exploited are being incorporated to the international market, in particular mollusks.

The aim of this study is to analyze individual growth, age and somatic production in *O. magellanica* in order to provide basic parameters of population dynamics, which will be useful for evaluation and future management of this valuable resource in the artisanal fisheries of the patagonic Argentinean waters.

Materials and methods

Sampling

Samples were taken in Golfo Nuevo Patagonia (42° 43′S 65° 01′W). About ten individuals of *O. magellanica* were captured monthly between September 2000 and September 2005 by scuba diving in depths from 5 to 20 m during low tides, 1,000 m off the coast. Soft parts were weighed (shell-free wet mass, SFWM) to the nearest 1 g and shell length (SL) was measured with a vernier caliper to the nearest 1 mm. Spiral growth (SG) trajectory was measured with a thread to the nearest 1 mm (Fig. 1).

Growth and age

In order to assess if external marks in the shell corresponded to periodical growth marks, morphological properties of these bands were studied in 12 individuals covering the whole SL range. To confirm if external marks (Fig. 2) corresponded to internal growth marks, X-ray photographs of shells were taken with a LADEM/VETTER Rem 150, using AGFA-Strukturix D4 FW film and the parameter settings: voltage 36–55 kV, 100 mA, 0.05 s exposure time.
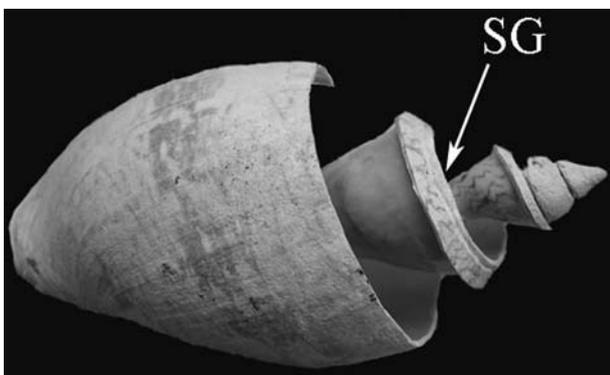
Fig. 1 Picture showing the spiral growth trajectory (SG), where the samples for oxygen isotopes were taken

Sectioned shells were prepared to count and measure these marks. Cuts were performed along the whorls following the SG 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. growth trajectory length SG was measured. SG and the corresponding confirmed growth mark number were interpreted as size-at-age data. Samples of five shells containing marks were metalized with gold–palladium and photographed under a Phillips XL 50 scanning electron microscope in order to look for differential deposition of calcium carbonate in the bands (Fig. 2).

Stable oxygen isotope ratios ($\delta^{18}O$) were used to analyze if these marks were formed at regular intervals, as described recently by Cledón et al. (2005a). The ratio of the stable oxygen isotopes ^{16}O and ^{18}O in biogenic $CaCO_3$ is inversely proportional to temperature during shell deposition (Epstein et al. 1951). This relation is nearly linear between 5° and 30°C (Epstein et al. 1951; Epstein and Lowenstam 1953). Therefore, a mollusk 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 Richardson 2001; Cledón et al. 2005a). Three representative specimens of *O. magellanica*, 108, 120 and 153 mm SL were selected for isotope analysis. From each shell, about 80 samples (approx. 10 mg each) were drilled from the central shell layer at 1–4 mm intervals along the cut from apex to shell aperture.

Oxygen isotope ratios ($\delta^{18}O$) were carried out by usual techniques (Epstein et al. 1951; Cledón et al. 2005a). Isotopic ratios were determined in a Delta S Finnigan Mat triple collector mass spectrometer, at Instituto de Geología Isotópica (INGEIS, Universidad de Buenos Aires). The isotopic composition is reported as deviation per mil ($\delta‰$) relative to the V-PDB standard. The analytical error is 0.1‰ for both $\delta^{13}C$ and $\delta^{18}O$.

Spatial coincidence of subsequent $\delta^{18}O$ maximum and minimum and shell growth marks would indicate that one mark is formed in winter and the next one in summer. As growth marks were found to be formed at regular intervals, data pairs of growth trajectory length SG and corresponding mark number were treated as size-at-age data and the iterative nonlinear Newton algorithm was used to fit growth models to these data. The Gompertz growth model $S_t = S_{oo} \times e^{-e[t-t*]}$ was found to fit these data best.

Fig. 2 **a** External growth marks (*arrow*). **b** Internal growth marks under stereoscopic microscope; *scale bar* 50 μm. **c** Internal growth marks viewed by X-rays; *scale bar* 2 cm. **d** Internal growth marks viewed by SEM; *scale bar* 200 μm
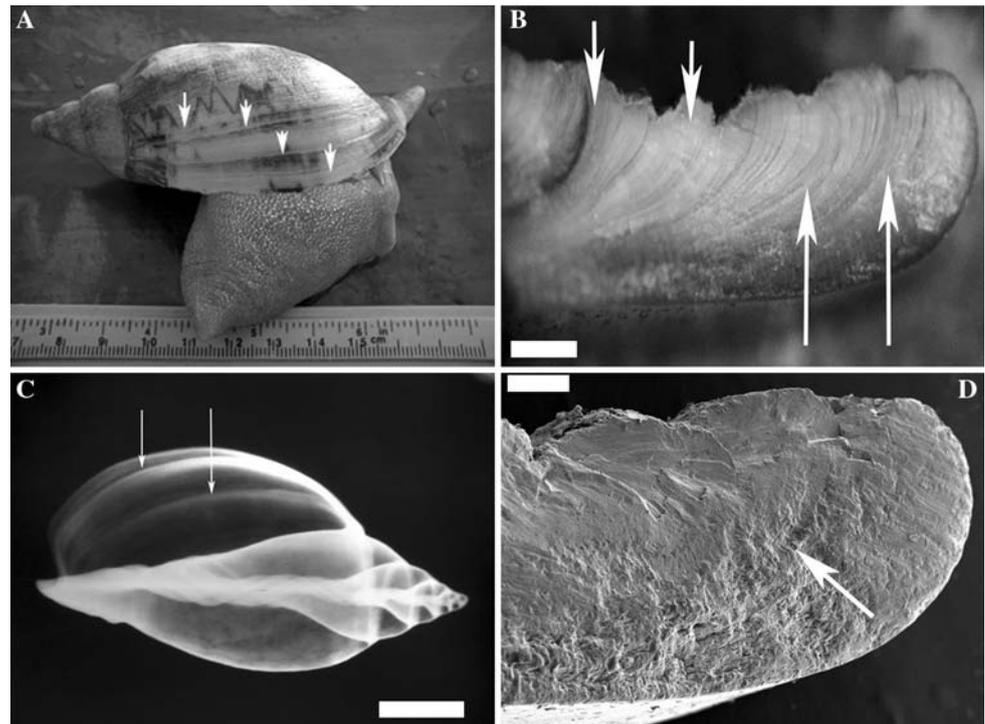
Individual production

Individual annual somatic production P_i (SFWM) of *O. magellanica* was calculated by the mass-specific growth rate method (see Brey 2001) using the size–growth function and the size–body mass relation: $P_i = M_i \times G_i$ 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: $G_i = b \times K \times \text{In}(\text{Sl}_\infty/\text{Sl}_i)$ where b represents the slope of the regression growth function, K is the growth constant, Sl_∞ is shell length at infinite age and Sl_i is the shell length at the time i.

As samples were collected by scuba diving and small individuals are very cryptic, living buried in the substrate (Bigatti 2005), smaller size classes are likely to be severely under sampled. Thus we restrained 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.

We used the index of overall growth performance (OGP) $P = \log(K \times L_\infty^3)$ (e.g. Moreau et al. 1986; Munro and Pauly 1983; Pauly 1979) to compare growth between various large gastropod species.

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, b)

$\ln(N_i/\Delta t) = a + b \times t_i$ 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 Gompertz growth function.

Results

Morphometrics

The 355 animals collected ranged from 29 to 198 mm SL with the mode at about 110 mm (Fig. 3).

Shell-free wet mass ranged from 0.6 to 321.4 g while modal SFWM was 62.8 g (SD = 37.4). SFWM was related to SL by

$$\log(\text{SFWM}) = -4.7960 + 3.2201 \times \log \text{SL}; r^2$$
$$= 0.861; N = 355.$$

Growth trajectory length SG, that is, the distance from apex to measurement point along the growth spiral (Fig. 1) was linearly related to SL by

$$\text{SG} = -2.4409 + 0.3517 \times \text{SL}; r^2 = 0.962; N = 355.$$

Age and growth

The δ^{18}O profiles showed a distinct oscillating pattern in the analyzed shells (Fig. 4). According to the
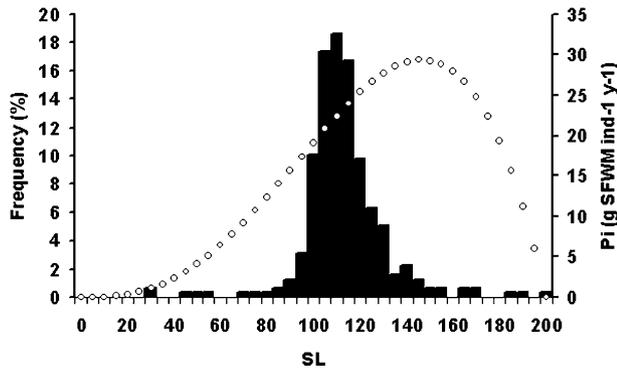
Fig. 3 *O. magellanica* size–frequency distribution of 355 animals from Golfo Nuevo, Patagonia during 2000–2005. *Dots superimposed curve* of individual production P_i (shell-free wet mass per year in grams) versus size (standard length in millimeters)

paleotemperature equation of Epstein and Lowenstam (1953), the amplitude of about 1 ‰ corresponds to a temperature range of $> = 4°C$. Distinct dark orange colored shell growth marks visible in the shell cuts
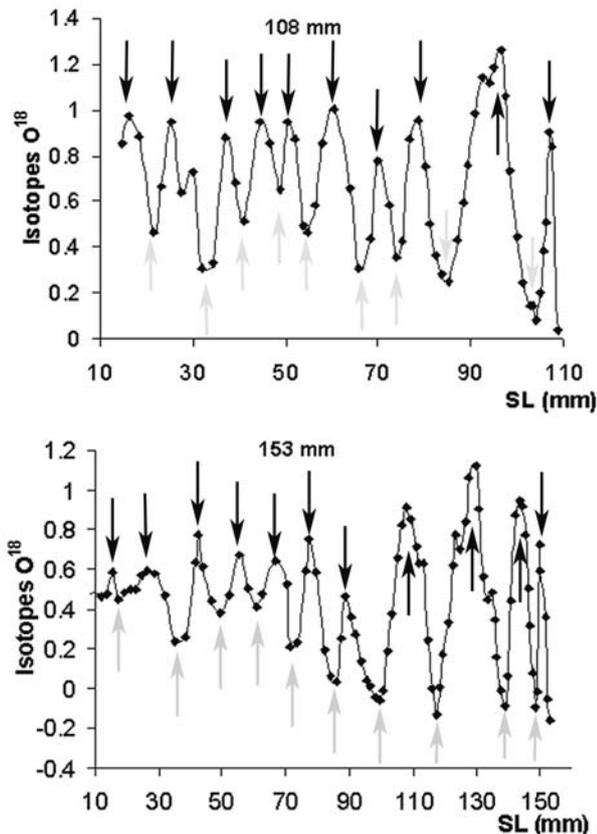
Fig. 4 $\delta^{18}O$ profile plotted against corresponding shell lengths of *O. magellanica* of 108 and 153 mm, respectively. *Black arrows* correspond to winter marks; *gray arrows* correspond to summer marks
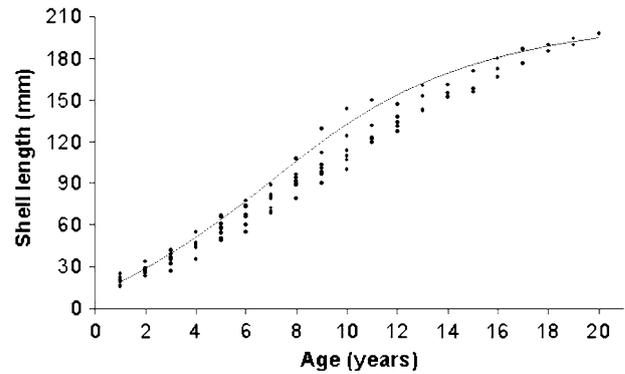
Fig. 5 Gompertz growth model fitted to 113 size-at-age data pairs obtained from the 12 specimens of *O. magellanica* from Golfo Nuevo. $SL_t = 200\ e^{-e(-0.197 \times (t-5.486))}$; $r^2 = 0.916$; $N = 113$

were situated closely to the maximum and minimum $\delta^{18}O$ values (Fig. 4), that is, there are two marks formed each year. One mark is formed during each temperature minimum period in spring and other is formed during each maximum on the following autumn. The oldest studied animal was 198 mm SL corresponding to 20 years of age.

The 113 size-at-age data pairs obtained from the 12 specimen analyzed were fitted best by the Gompertz growth model (Fig. 5):

$$SL_t = 200e^{-e(-0.197 \times (t - 5.486))}; r^2 = 0.916; N = 113$$

Individual production

Individual somatic production (P_i) increased steadily with size to a maximum of 29.36 g SFWM per year at 145 mm SL and decreased again thereafter (Fig. 3). OGP was 6.197.

Mortality

Mortality (Z) was –0.12. The value of $r^2 = 0.1$ indicates that the single negative exponential model does not fit the data. The size-converted catch curve (SCCC) cannot provide a reliable estimate of population mortality, (Fig. 6), since it does not show the typical pattern of populations exploited by fisheries.

Discussion

Traditional methods of ageing mollusks 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
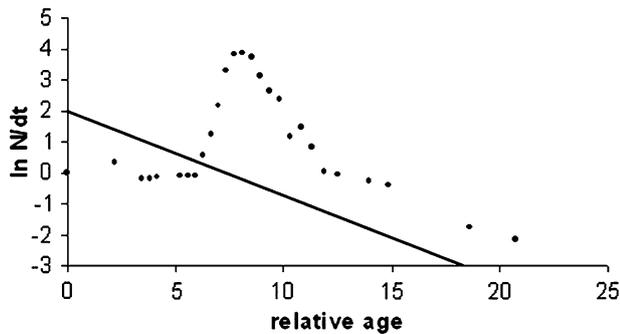
Fig. 6 Plot of ln(N/dt) versus relative age as required for a size-converted catch curve. The multi-mode pattern indicates that the single negative exponential mortality model does not fit the data in the population studied. N_i number in size class i; dt time required to grow through this size class

environments with an annual temperature amplitude of several °C, stable oxygen isotope analysis can provide such validation because δ^{18}O of carbonate shell deposits vary with temperature (Richardson 2001). Changes in salinity can affect δ^{18}O too (Epstein and Lowenstam 1953), but are negligible in the investigation area, constantly around 33.7 UPS (Esteves and De Vido 1980). The range of the annual temperature cycle in the studied area is between 8 and 17°C (Esteves and De Vido 1980), and the δ^{18}O profile in the shell of *O. magellanica* reflects the water temperature cycle, i.e. each δ^{18}O peak corresponds to minimum and maximum water temperature (spring and autumn), thus providing a valid shell age scale. In the volutids *Z. dufresnei* and *A. brasiliana* from northern Argentinean coastal waters, the shell marks are deposited annually (Giménez et al. 2004; Cledón et al. 2005a) differing with *O. magellanica* that deposits shell marks semiannually. These differences could be due to latitudinal position or to variations between the Odontocymbiolinae and Zidoninae subfamilies.

O. magellanica from Golfo Nuevo reaches a maximum age of 20 years, corresponding to individuals of 198 mm SL. *A. brasiliana* and *Z. dufresnei* from northern Argentina, reach similar maximum ages of 20 and 17 years, respectively (Cledón et al. 2005a; Gimenez et al. 2004). These species appear to be rather long lived compared with other large gastropods such as *Buccinum undatum* (12 years, Gendron 1992), *Concholepas concholepas* (10 years, Stotz 2000), *Gazameda gunii* (7 years, Carrick 1980), *Strombus costatus* and *S. gigas* (5 and 7 years, respectively, Wefer and Killingley 1980). The life span of several South Western Atlantic voluts seems to be twice compared with other large gastropods, probably reflecting a phylogenetic difference between families.

Overall growth performance of *O. magellanica* (P = 6.197) is within the range of values referring to other large gastropod species from temperate regions (see Cledón et al. 2005a for more details). Its large size and somatic production makes *O. magellanica* a valuable and exploitable resource, but on the other hand, its slow growth, late maturity and direct development of the embryos inside attached egg capsules (Bigatti 2005) make it extremely vulnerable to overexploitation. This already happened with other commercial gastropods as *Haliotis rubra* and *H. laevigata* (Rogers-Bennett et al. 2002; Shepherd and Hearn 1983), *S. gigas* (Stoner and Ray-Culp 2000; de Jesús-Navarrete 2001), *C. concholepas* (Rabí and Maraví 1997) and in the Argentinean *Z. dufresnei* fishery (Giménez et al. 2004, 2005). Mortality results in *O. magellanica* could not be calculated, probably because the species is not under commercial exploitation, being consumed only locally. The results of this work should be taken into account when implementing policies for this resource of the Patagonian shelf.

References

Bigatti G (2005) Anatomía, ecología y reproducción del caracol rojo *Odontocymbiola magellanica* (Gastropoda: Volutidae) en golfos norpatagónicos. PhD Thesis, Universidad de Buenos Aires p 178

Bigatti G, Penchaszadeh PE (2005) Imposex in *Odontocymbiola magellanica* (Gmelin, 1791) (Mollusca: Gastropoda) in Patagonia. Comunicaciones de la Sociedad Malacológica del Uruguay 9(88):377–379

Brey T (2001) Population dynamics in benthic invertebrates. A virtual handbook. http://www.awi-bremerhaven.de/Benthic/Ecosystem/FoodWeb/Hanbook/main.html

Carrick N (1980) Aspects of the biology of molluscs on the continental shelf off Sydney, NSW with particular reference of the population biology of *Gazameda gunni* (Reeve, 1849). Masters Thesis, University of Sydney

Castellanos ZJA de (1970) Reubicación de algunas especies de Volutidae del Mar Argentino. Neotropica 16:1–4

Castellanos ZJA de, Landoni N (1992) Catálogo descriptivo de la malacofauna marina magallánica. Neogastropoda,

Volutidae, Volutomitridae, Cancellariidae, Olividae & Marginellidae. Comisión de Investigaciones Científicas, La Plata 10:43

Cledón M, Brey T, Penchaszadeh PE, Arntz W (2005a) Individual growth and somatic production in *Adelomelon brasiliana* (Gastropoda; Volutidae) off Argentina. Mar Biol 147:447–452

Cledón M, Penchaszadeh PE, Arntz W (2005b) Gonadal cycle in an *Adelomelon brasiliana* (Neogastropoda: Volutidae) population off Buenos Aires province, Argentina. Mar Biol 147:439–445

Cledón M, Theobald N, Gerwinski W, Penchaszadeh P (2006) Imposex and organotin compounds in marine gastropods and sediments from the Mar del Plata coasts, Argentina. J Mar Biol Assoc UK 86:751–755

Epstein S, Lowenstam HA (1953) Temperature shell-growth relation of recent and interglacial Pleistocene shoal-water biota from Bermuda. J Geol 61:424–438

Epstein S, Buchsbaum R, Lowenstam HA (1951) Carbonate water istopic temperature scale. Bull Geol Soc Am 62:417–426

Esteves JL, De Vido N (1980) Influencia de Puerto Madryn en Bahía Nueva mediante salinidad & temperatura. Evidencia de fenómenos de surgencia. Centro Nacional Patagónico, CONICET Contribución 26:1–40

Gallardo CS, Penchaszadeh PE (2001) Hatching mode and latitude in marine gastropods, revisiting Thorson's paradigm in the southern hemisphere. Mar Biol 138:547–552

Gendron L (1992) Determination of the size at sexual maturity of the waved whelk *Buccinum undatum* Linnaeus, 1758, in the Gulf of St. Lawrence, as a basis for the establishment of a minimum catchable size. J Shellfish Res 11:1–7

Giménez J, Penchaszadeh PE (2002) Reproductive cycle of *Zidona dufresnei*. Mar Biol 140:755–761

Giménez J, Penchaszadeh PE (2003) Size and sexual maturity in *Zidona dufresnei* (Caenogastropoda: Volutidae) of the south-western Atlantic Ocean (Mar del Plata, Argentina). J Mar Biol Assoc UK 83:293–296

Giménez J, Brey T, Mackensen A, Penchaszadeh PE (2004) Age, growth and mortality of the prosobranch *Zidona dufresnei* (Donovan, 1823) in the Mar del Plata area, South-Western Atlantic Ocean. Mar Biol 145:707–712

Giménez J, Lasta M, Bigatti G, Penchaszadeh PE (2005) The volute snail *Zidona dufresnei* (Donovan, 1823), an overexploited resource in the SW Atlantic Ocean. J Shellfish Res 24(4):1135–1140

de Jesús-Navarrete A (2001) Growth of the queen conch *Strombus gigas* (Gastropoda: Strombidae) cultured in four environments of Quintana Roo, Mexico. Rev Biol Trop 49(1):85–91

Lasta ML, Roux A, Bremec C (2000) Caracoles marinos de interés pesquero. Moluscos gasterópodos volutidos. INIDEP Mar del Plata. Informe técnico 31:1–13

Moreau J, Bambino C, Pauly D (1986) A comparison of four indices of overall fish growth performance, based on 100 tilapia populations (Fam. Cichlidae). In: Maclean JL, Dizon LB, Hosillos LV (eds) The first Asian fisheries forum. Asian Fisheries Soc, Manila, pp 201–206

Munro JL, Pauly D (1983) A simple method for comparing the growth of fishes and invertebrates. Fishbyte 1(1):5–6

Pauly D (1979) Gill size and temperature as governing factors in fish growth: a generalization of von Bertalanffy's growth formula. Ber Inst Meereskd Christian-Albrechts Univ Kiel 63:156

Pauly D (1984a) Length-converted catch curves: a powerful tool for fisheries in the tropics (part II). Fishbyte 2:17–19

Pauly D (1984b) Length-converted catch curves: a powerful tool for fisheries in the tropics (part III). Fishbyte 2:8–10

Penchaszadeh PE, De Mahieu GC (1976) Reproducción de gasterópodos prosobranquios del Atlántico Suroccidental Volutidae. Physis A 35(91):145–153

Penchaszadeh PE, Miloslavich P, Lasta M, Costa PMS (1999) Egg capsules in the genus *Adelomelon* (Caenogastropoda: Volutidae) from the Atlantic coast of South America. Nautilus 113:56–63

Rabí M, Maraví C (1997) Growth curves and specific growth rate of *Concholepas concholepas* (Bruguiere, 1789) (Gastropoda: Muricidae) in culture experiments. Sci Mar 61:49–53

Richardson CA (2001) Mollusks as archives of environmental changes. Oceanogr. Mar Biol Ann Rev 39:103–164

Rogers-Bennett L, Haaker PL, Huff TO, Dayton PK (2002) Estimating baseline abundances of abalone in California for restoration. Calif Coop Ocean Fish Invest Rep 43:97–111

Shepherd SA, Hearn WS (1983) Studies on Southern Australian abalone (genus *Haliotis*), IV Growth of *H, laevigata* and *H, rubra*. Aust J Mar Freshw Res 34:461–475

Stoner AW, Ray-Culp M (2000) Evidence for Allee effects in an over-harvested marine gastropod:density-dependent mating and egg production. Mar Ecol Prog Ser 202:297–302

Stotz W (2000) Informe Final Proyecto 97–36. Formulación de una metodología para el estudio de edad y crecimiento en el recurso loco. Universidad Católica del Norte Facultad de Ciencias del Mar. Dpto. de Biología Marina 1–152

Weaver CS, Dupont JE (1970) Living volutes, A monograph of the recent volutidae of the world. Delaware Mus Nat Hist Ser 1: I-XV: 1–375, pl. 1–79

Wefer G, Killingley JS (1980) Growth histories of strombid snails from Bermuda recorded in their O–18 and C-13 profiles. Mar Biol 60:129–135