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# Age determination and growth rate of a *Callista chione* population from the southwestern coast of Portugal

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**ABSTRACT:** The age and growth of the smooth clam *Callista chione* from the southwestern coast of Portugal were estimated during a 1 yr study period by using both the surface growth rings and internal shell microgrowth lines (by acetate peel method). The von Bertalanffy growth curves obtained by these 2 methods were, respectively:  $L_t = 91.9[1 - e^{-0.18(t + 0.22)}]$  and  $L_t = 98.1[1 - e^{-0.15(t + 0.43)}]$ . Based on these, the counting of surface growth rings is appropriate for a quick age estimation of individuals up to 10 yr old (~75 mm shell length, SL). For older specimens, analysis of the growth lines in the cross section of shells is recommended, because close to the shell border it becomes difficult to distinguish growth rings on the shell surface. Rapid shell growth occurred in spring and summer, whereas slow growth occurred during autumn and winter, with the deposition of an annual growth ring. The overall growth performance and the phi-prime index were used to compare growth parameters with data from literature about venerid bivalves. These parameters indicated that *Callista* spp. have a higher growth performance than other venerid bivalves and this is correlated with geographical latitude. The smooth clam achieves sexual maturation at 4 yr of age and reaches the minimum landing size (60 mm SL) after 5 yr.

**KEY WORDS:** *Callista chione* · Smooth clam · Age · Growth rate · Growth performance · Surface rings · Acetate peel · Portugal

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## INTRODUCTION

Knowledge on growth parameters is essential for understanding the biology and productivity of bivalves. Studying vital rates (namely growth) is necessary for modelling population dynamics, which, in turn, is crucial to support exploitation and management (Laudien et al. 2003, Peharda et al. 2007) and to propose effective measures for the protection of the species (Katsanevakis 2007). Growth rates also indicate how much time is required to reach a certain marketable size (Urban 2000), and the relationship between size and age is essential to implement appropriate management strategies (Keller et al. 2002).

Several methods are used to estimate age and growth of bivalves, but there are practical problems with most of them. Size-frequency distribution analysis is a very subjective method, inappropriate for species

with a relatively long annual recruitment period and/or highly variable individual growth rates within age groups (Seed 1976, Cerrato 1980). Mark and recapture experiments demand a lot of time to gather data and should only be carried out in areas where fishing activities are prevented (Gaspar et al. 2004a). Analyses of oxygen and carbon isotopic composition are also used for determining the age of bivalves, although the determination of equilibrium or disequilibrium conditions between carbonate and seawater is often difficult, chiefly when large changes in both temperature and seawater isotopic composition take place throughout time (Keller et al. 2002).

The counting of growth rings on the shell surface represents the quickest and most economical method. Although used frequently, this method has several weaknesses (Pannella & MacClintock 1968, Richardson et al. 1990), e.g. the presence of false rings (Keller

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et al. 2002) and, in older specimens, an eroded umbonal region, or one in which the most recently formed rings are deposited too close together to allow distinction (Richardson 2001). These constraints can be overcome if the acetate peel technique is used to estimate age and growth (Richardson 2001); unfortunately this technique is quite time consuming.

Several studies on the growth rates of bivalves have employed counting the annual growth rings (1) visible on the shell surface or (2) in the microstructure of polished and etched shells. Richardson et al. (1990) studied the growth of *Mytilus edulis* from offshore production platforms (North and Irish Seas), concluding that only growth rings visible in acetate replicas are a reliable indicator of age. In a study on the growth of *Donax trunculus* from southern Portugal, Gaspar et al. (1999) observed that the results obtained from both methods provided different estimates of growth rates for the first 2 yr. These authors considered that the age can be more accurately determined from shell internal bands (shell cross sections and acetate peel replicas) than directly from external rings. In a study involving venerid species, Gaspar et al. (2004a) estimated age and growth of *Chamelea gallina* from southern Portugal, concluding that counting of external rings is appropriate for a quick estimate of age, but the use of internal shell growth rings is recommended for the estimation of von Bertalanffy growth parameters. Morosan & Orensanz (2004) estimated the age and growth of *Amiantis purpuratus* in Argentina, the shell sections of which showed almost exact correspondence between internal and external bands.

Knowledge on the age and growth of the smooth clam *Callista chione* (Linnaeus, 1758) is relatively sparse. The first published work on *C. chione* growth was carried out by Hall et al. (1974) using thin sections of shells, but no growth parameters were estimated. Forster (1981) used mark and recapture experiments to estimate growth parameters of a smooth clam population from Whitsand Bay (UK). Keller et al. (2002) obtained information on the growth rates and the settlement time of *C. chione* from Trieste Gulf (Italy) by analyzing the shell isotopic composition. The external and internal growth rings were used to estimate the growth rates of smooth clam populations from the Aegean and Thracian Seas (Greece) by Metaxatos (2004) and Leontarakis & Richardson (2005), respectively.

Bivalve fisheries play an important socio-economic role on the southwestern coast of Portugal. In this region, the smooth clam constitutes the target of a specific fishery carried out by the dredge fleet (Gaspar et al. 2001). The purpose of the present study was to estimate the age and growth of a *Callista chione* population off Arrábida (southwestern Portugal). Two age

determination techniques (counting of annual growth rings visible on shell surfaces and those on microstructure of polished and etched shells) were compared to ascertain which method is the most efficient in estimating the age of this species.

## MATERIALS AND METHODS

Samples of *Callista chione* were collected by commercial dredgers from a site off Arrábida (SW coast of Portugal; 15 to 20 m depth; Fig. 1) at approximately monthly intervals between January and December 2004. The shell length (SL, maximum distance along the anterior–posterior axis) of a total of 120 individuals (ranging between 22.76 and 92.56 mm SL) was measured to the nearest 0.01 mm using a digital caliper.

The valves were examined for the presence of surface annual rings, and the anterior–posterior length of each ring was measured with a digital caliper (Fig. 2A,B). The internal structure of each shell was observed by examining acetate peel replicas of polished and etched radial sections of resin-embedded valves (a detailed description of the method can be found in Lutz [1976] and Richardson [1989]). The depo-

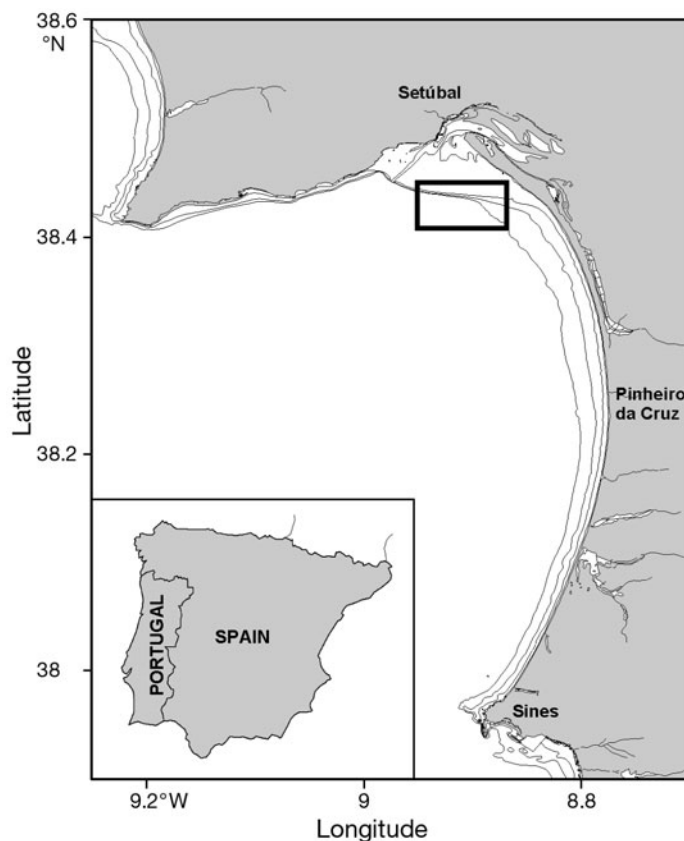


Fig. 1. Map showing the location of the *Callista chione* bed studied. Latitude and longitude scales are represented in centesimal degrees

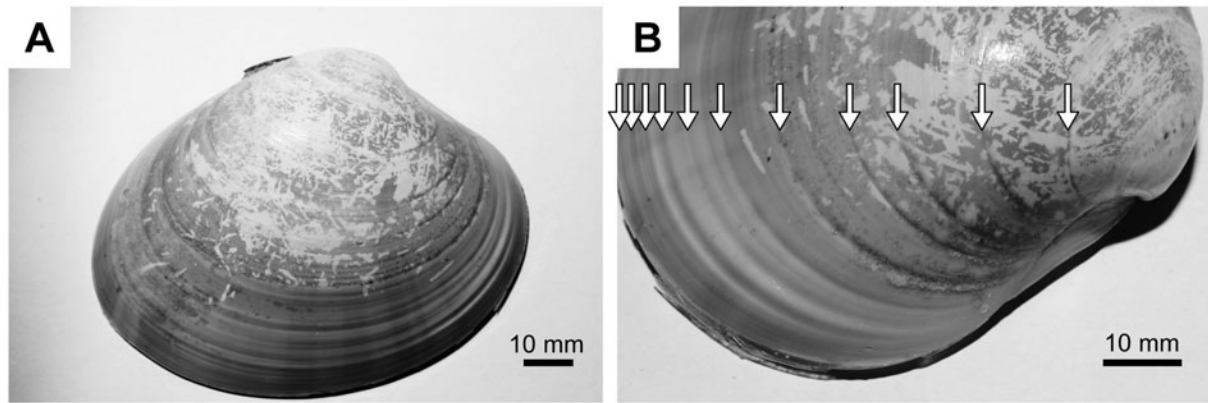


Fig. 2. *Callista chione*. (A) Shell and (B) surface growth rings (arrows) visible on the shell

sition pattern of growth lines was used to identify the position of each growth ring. For each growth ring, the distance between the umbo and the ring was marked and measured (to the nearest 0.01 mm). Since these measurements are relative to shell height, data were converted into shell length using the following allometric relationships ( $n = 174$  and  $r = 0.992$ , where  $H$  is shell height and  $L$  is shell length; Gaspar et al. 2002):

$$\text{Log}H = -0.163 + 1.043\text{log}L \quad (1)$$

Von Bertalanffy growth (VBG) functions were fitted separately to the age–length data obtained for the 2 methods described above (surface shell rings and internal growth patterns) using the NLIN procedure of Statistica Software (Release 5.1). This interactive curve-fitting procedure employs a non-linear, least-squares regression (quasi-Newton method) and estimates the von Bertalanffy growth constant ( $K$ ), the asymptotic maximum length ( $L_\infty$ ) and the theoretical age at length zero ( $t_0$ ; von Bertalanffy 1938):

$$L_t = L_\infty(1 - e^{-K(t-t_0)}) \quad (2)$$

Since individual growth is a non-linear process, the comparison of growth among different organisms or taxa is very difficult due to the problem of correlation between  $K$  and  $L_\infty$ . To overcome this problem, several growth performance indexes have been used, namely, the overall growth performance (OGP,  $P$ ) and the phi-prime index ( $\phi'$ , growth performance index) (Pauly 1979, Munro & Pauly 1983). In the present study, the OGP was used to compare the growth parameters obtained in our work with those from literature on venerid bivalves, whereas  $\phi'$  was calculated and compared with values from the literature on *Callista* spp., using the following expressions:

$$P = \log(K \times L_\infty^3) \quad (3)$$

$$\phi' = \log K + 2\log L_\infty \quad (4)$$

## RESULTS

Acetate peel replicas of *Callista chione* shell sections are shown in Fig. 3. It was possible to identify 3 layers (described by Taylor et al. 1973): an outer composite prismatic layer, a middle crossed lamellar layer, and an inner homogeneous/complex crossed layer (Fig. 3A). Observation of the prismatic layer revealed distinct growth patterns deposited parallel to the ventral edge of the shell (Fig. 3C). Although poorly defined, these growth lines were also visible in the inner layer (Fig. 3A) and in the hinge plate region (Fig. 3B). The growth bands appeared as narrow dark lines (slow shell growth) separated by wider transparent regions (rapid shell growth; Fig. 3D). In older individuals, at the ventral shell margin these growth bands are often associated with depressions in the shell (Fig. 3E). The gradual decrease in the growth increment zone was the key to distinguishing annual rings from false rings (caused by stress or shell damage). The former were characterized by the progressive narrowing of growth bands, whereas stress rings were characterized by a sudden disruption of the natural growth pattern. Both types of rings were usually associated with a cleft in the shell surface. Examples of clefts in the shell surface are also shown in Fig. 3; these correspond to shell deformations caused by sand inclusion (Fig. 3F to 3H) and shell damage (Fig. 3I to 3K).

Examination of the acetate peels of shell sections revealed seasonal variation in the percentage of individuals with a growth ring at the ventral margin of their shells. Fig. 4 shows the monthly percentage of individuals with a growth ring at the shell margin and the seasonal variation in seawater temperature. This *Callista chione* population began depositing narrow growth increments at the beginning of autumn, coincident with decreasing seawater temperatures. In September and October, 71% of the shells examined showed a growth mark at or close to the shell margin,



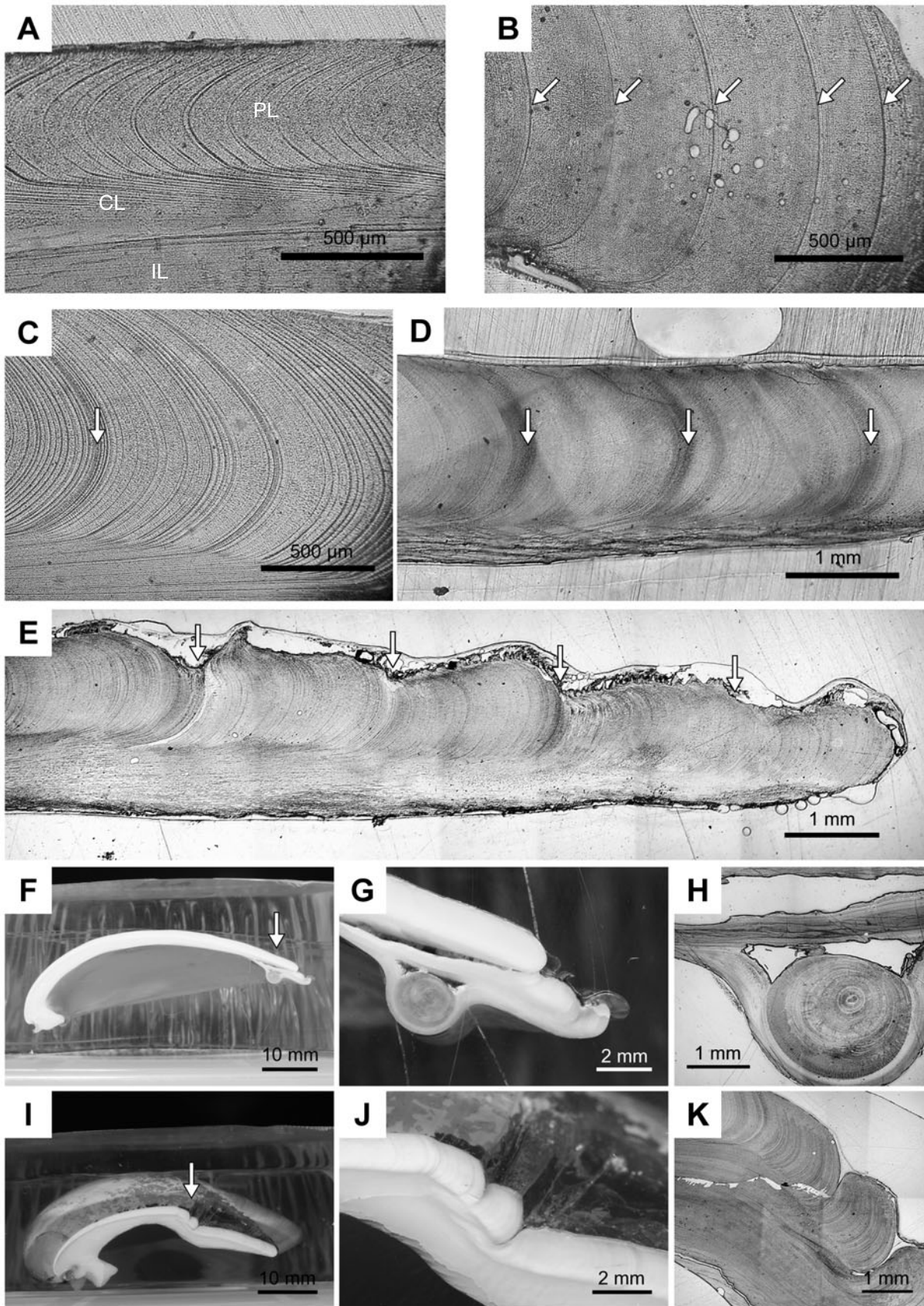


Fig. 3. *Callista chione*. Photomicrographs of acetate peel replicas of shell sections and blocks of resin-embedded shell: (A) micro-growth bands and shell layers (PL: outer prismatic layer, CL: middle crossed lamellar layer, IL: inner homogenous/complex crossed layer), (B) growth lines (arrows) in the hinge plate region, (C) growth patterns deposited forming an annual growth ring (arrow), (D) narrow dark lines (arrows) correspond to slow shell growth (internal growth rings), while the wider transparent regions represent rapid shell growth, (E) several growth rings with formation of distinct clefts in shell surface (arrows), (F) resin-embedded shell with a sand grain enclosed (arrow), (G) detail of sand grain enclosed in shell, (H) acetate peel replica showing the microstructure of the sand grain enclosed in the shell, (I) resin-embedded shell with 2 evident clefts resulting from shell breakage (arrow), (J) detail of clefts in the shell and (K) acetate peel replica showing the breakage effect in shell microgrowth

reaching 86% of the shells in November, indicating that rapid shell growth took place in spring and summer, while the period of slow shell growth occurred during autumn and winter. This result also indicates that these growth rings are deposited once a year and therefore can be considered annual.

The mean length-at-age estimated using both the surface growth rings and internal shell growth patterns are presented in Table 1. The maximum age determined using internal growth lines in shell sections was greater than that obtained through the surface growth rings (17 and 14 yr, respectively). Using the internal band method, the length  $\pm$  SD estimated for the first year was  $18.09 \pm 1.9$  mm SL. For 17 yr olds, only 1 individual was sampled, with a size of 92.56 mm SL. The shell length estimated for the first year using the surface rings was  $19.31 \pm 2.9$  mm SL and for 14 yr olds  $84.06 \pm 9.2$  mm SL. The variability in the estimation of mean length-at-age (represented by the respective standard deviations) was lower from growth lines in the cross-section than from external rings (Table 1).

Based on the age-length keys obtained by each method, the VBG equations that describe the growth of *Callista chione* were estimated as:

Surface rings:  

$$L_t = 91.9(1 - e^{-0.18(t+0.22)}) \quad (5)$$

Internal bands:  

$$L_t = 98.1(1 - e^{-0.15(t+0.43)}) \quad (6)$$

The VBG growth equation obtained using data from surface rings displayed a lower asymptotic size ( $L_\infty = 91.9$  mm SL) and a higher growth rate ( $K = 0.18 \text{ yr}^{-1}$ ) than those obtained from internal growth bands ( $L_\infty = 98.1$  mm SL;  $K = 0.15 \text{ yr}^{-1}$ ). The graphical representation of these equations shows that the growth curves estimated by both methods provided coincident growth rates until clams were 10 yr of age (Fig. 5).

Using these VBG equations and the size at first maturation previously estimated for this *Callista chione* population (50.81 mm SL; Moura et al. 2008), we estimated the respective age at first matu-

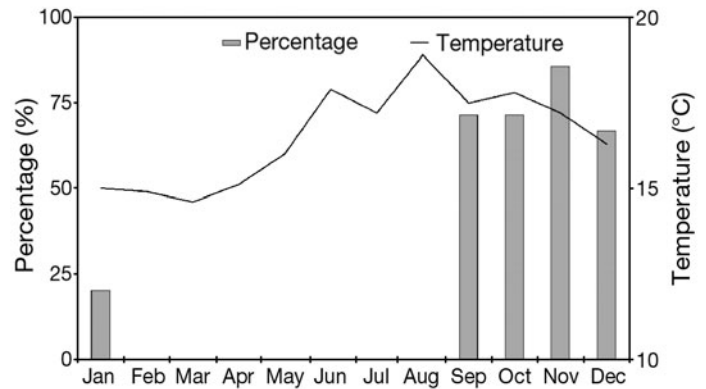


Fig. 4. *Callista chione*. Monthly frequency of individual clams with a growth ring at the shell margin and the variation in seawater temperature during the study period

riety. According to these calculations, the smooth clam off Arrábida reaches sexual maturation at between 4.25 (surface growth rings) and 4.44 yr of age (internal growth bands). Concomitantly, *C. chione* attains minimum landing size (MLS = 60 mm SL) when they are between 5.69 and 5.88 yr old, according to external rings and microgrowth bands, respectively.

Table 1. *Callista chione*. Mean length-at-age of individuals from Arrábida (southwestern Portugal), estimated from external growth rings and from growth bands in acetate peel replicas of shell sections. SL: shell length

| Age (yr) | Surface rings         |                         | Internal bands        |                         |
|----------|-----------------------|-------------------------|-----------------------|-------------------------|
|          | Mean SL (mm) $\pm$ SD | SL range (mm) (min-max) | Mean SL (mm) $\pm$ SD | SL range (mm) (min-max) |
| 1        | 19.31 $\pm$ 2.9       | 16.17–24.43             | 18.09 $\pm$ 1.9       | 15.46–20.94             |
| 2        | 29.95 $\pm$ 5.3       | 22.76–36.82             | 29.75 $\pm$ 2.5       | 26.15–33.30             |
| 3        | 40.17 $\pm$ 5.7       | 31.77–48.09             | 41.36 $\pm$ 3.8       | 35.74–45.67             |
| 4        | 49.32 $\pm$ 4.6       | 41.71–54.88             | 49.02 $\pm$ 3.3       | 43.85–52.51             |
| 5        | 56.72 $\pm$ 6.0       | 49.10–63.82             | 56.00 $\pm$ 3.2       | 51.06–60.58             |
| 6        | 62.86 $\pm$ 6.2       | 52.73–70.20             | 62.23 $\pm$ 4.4       | 55.10–68.79             |
| 7        | 67.62 $\pm$ 5.8       | 58.95–74.53             | 66.52 $\pm$ 4.7       | 60.18–74.18             |
| 8        | 72.26 $\pm$ 6.0       | 64.38–79.28             | 70.86 $\pm$ 4.3       | 66.88–77.48             |
| 9        | 75.25 $\pm$ 6.5       | 65.72–82.28             | 74.77 $\pm$ 4.3       | 70.50–81.80             |
| 10       | 77.36 $\pm$ 6.8       | 68.21–84.44             | 76.96 $\pm$ 4.3       | 72.56–83.63             |
| 11       | 79.73 $\pm$ 7.6       | 69.75–88.00             | 78.84 $\pm$ 4.6       | 73.30–84.73             |
| 12       | 81.50 $\pm$ 8.1       | 72.56–89.27             | 82.61 $\pm$ 3.6       | 76.65–85.75             |
| 13       | 85.31 $\pm$ 8.5       | 75.46–90.54             | 84.00 $\pm$ 3.6       | 77.88–86.53             |
| 14       | 84.06 $\pm$ 9.2       | 77.55–90.56             | 85.90 $\pm$ 3.7       | 79.67–88.56             |
| 15       | –                     | –                       | 90.47 $\pm$ 0.6       | 90.05–90.89             |
| 16       | –                     | –                       | 91.52                 | –                       |
| 17       | –                     | –                       | 92.56                 | –                       |



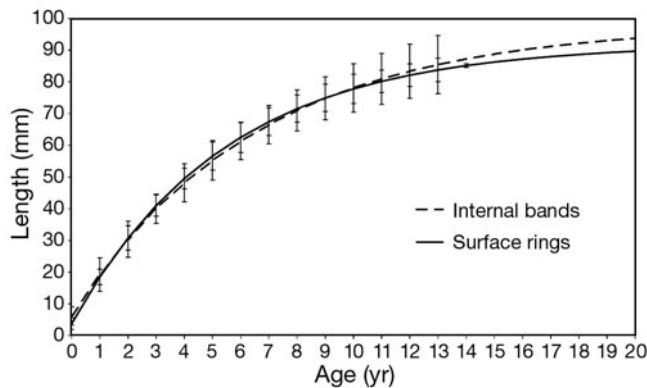


Fig. 5. *Callista chione*. von Bertalanffy growth curves determined from surface rings and from internal bands in acetate peel replicas of shell sections (error bars represent standard deviation of mean shell length)

OGP and  $\phi'$  values obtained in the present study using surface shell rings were  $P = 5.13$  and  $\phi' = 3.17$ , respectively, whilst when age was estimated using the microgrowth patterns in shell sections OGP was 5.15 and  $\phi'$  was 3.16.

## DISCUSSION

In the present study it was possible to identify distinct growth patterns on the prismatic layer of the shells. The annual growth rings, corresponding to slow shell growth, appeared as narrow dark lines separated by wider transparent regions (rapid shell growth) and, in older individuals, recently deposited growth rings were often associated with a depression which corresponded to a cleft in the outer shell layer. Several shell deformations were also observed in the clams; most of them were probably caused by dredging (e.g. Robinson & Richardson 1998, Ramsay et al. 2000, Gaspar et al. 2004b). However, factors other than fishing may also cause the formation of shell scars, namely predation (Richardson et al. 1980, Hughes & Seed 1981), storms and other abnormal environmental conditions (Richardson et al. 1980, Checa 1993, Henderson & Richardson 1994). The majority of shell deformations comprised the inclusion of sand grains or the formation of deep clefts. The diversity of shell deformations observed suggests that *Callista chione* has a high capacity for shell repair.

Rapid shell growth occurred in spring and summer, when wide microgrowth increments were deposited, whilst slow growth occurred during autumn and winter, with the deposition of narrow growth increments and the formation of an annual growth ring. The timing of growth in *Callista chione* appears to be influenced by factors related to seawater temperature. Some researchers suggest that growth increments in bivalves are directly or indirectly related to tem-

perature (Gaspar et al. 2004a), while others indicate alternative physical and biological factors that also influence shell deposition (Rhoads & Pannella 1970, Leontarakis & Richardson 2005). In a recent study on the reproductive cycle of the smooth clam from the southwestern Portuguese coast (Moura et al. 2008), it was determined that this population has no resting period and that a new gametogenic cycle began in early November, immediately after several spawning episodes. During this period, the energetic reserves are probably directed towards the recovery of gonads, inducing a phase of slow growth in *C. chione*. A similar growth pattern was observed in a population of smooth clams from Greece (Thracian Sea; Leontarakis & Richardson 2005). Other bivalve species from the Algarve coast (southern Portugal), namely *Donax trunculus* and *Chamelea gallina*, also showed the same seasonal growth pattern (Gaspar et al. 1999, 2004a).

The estimated growth curves obtained from surface growth rings and internal microgrowth patterns revealed that both methods provided similar estimates of growth rates until 10 yr of age ( $\approx 75$  mm SL). Afterwards, the age of smooth clams was more accurately determined based on the internal growth bands in shell sections than directly from surface growth rings. This had already been expected, because the growth rate is slower in older specimens and, consequently, it becomes more difficult to distinguish and measure surface rings close to the edge of the shell. For this reason, the examination of surface rings (more rapid and economic) might be appropriate for estimating the growth rates on *Callista chione* specimens up to 75 mm SL or 10 yr old, whereas the analysis of shell microstructure is highly recommended for estimating the growth rates of individuals  $>75$  mm SL. Similarly, Leontarakis & Richardson (2005) reported that growth rings on smooth clams from Greece (Thracian Sea) were clearly visible on the shell surface and in acetate peel treatment of shell cross sections, although, in individuals  $>10$  yr old, rings became relatively narrow and more closely spaced. In general, these results contradict the conclusions of another study carried out in Greece (Aegean Sea) by Metaxatos (2004), where the number of internal growth rings closely matched the number of external rings, therefore suggesting that surface annual growth rings could be used as an accurate age marker.

The growth curves estimated according to the 2 methods employed in the present study indicate that *Callista chione* grow relatively quickly during the first 5 yr of life and then growth gradually slows. The minimum landing size stipulated for the smooth clam (60 mm SL) is reached when it is around 5.5 yr old. The present results are in agreement with other studies on the age and growth of *C. chione* (Forster 1981, Keller et al. 2002, Metaxatos 2004, Leontarakis & Richardson

Table 2. *Callista chione*. Growth parameters for *C. chione* from distinct geographical areas, estimated using different age determination techniques.  $L_{\infty}$ : asymptotic maximum length, SL: shell length,  $K$ : von Bertalanffy growth constant. Methods were SR: surface rings, AP: acetate peels, MR: mark and recapture, IC: isotopic composition

| Study area                            | Method | $L_{\infty}$<br>(mm SL) | $K$  | Maximum age<br>(yr)          | Source               |
|---------------------------------------|--------|-------------------------|------|------------------------------|----------------------|
| <b>Northeastern Atlantic</b>          |        |                         |      |                              |                      |
| Arrábida, Portugal                    | SR     | 91.9                    | 0.18 | 14                           | Present study        |
|                                       | AP     | 98.1                    | 0.15 | 17                           | Present study        |
| Whitsand Bay, UK                      | MR     | 105.8                   | 0.02 | >40 (predicted for 90 mm SL) | Forster (1981)       |
| <b>Mediterranean Sea</b>              |        |                         |      |                              |                      |
| Gulf of Trieste, Italy (Adriatic Sea) | IC     |                         |      | 12                           | Keller et al. (2002) |
| Gulf of Euboikos, Greece (Aegean Sea) | SR, AP | 93                      | 0.24 | 17                           | Metaxatos (2004)     |
| Thassos Island, Greece (Thracian Sea) | SR, AP | 62.7                    | 0.24 | 12                           | Leontarakis &        |
|                                       | SR, AP | 57.8                    | 0.26 | 16                           | Richardson (2005)    |

2005; Table 2). Despite not having estimated growth parameters, Keller et al. (2002), like the other researchers, described *C. chione* as a species with rapid growth during the first years and with quite slow growth in the latter years of life.

The asymptotic sizes ( $L_{\infty} = 91.9$  and  $98.1$  mm SL, for surface rings and internal growth lines, respectively) estimated in the present study are similar to the results obtained for the population from the Aegean Sea (Metaxatos 2004). In our study, *Callista chione* displayed slower growth rates ( $K = 0.18$  and  $0.15$ , external rings and internal growth lines, respectively) than did the populations studied in Greece, with  $K = 0.24$  in the Aegean Sea (Metaxatos 2004) and  $K = 0.24$  or  $0.26$  in the Thracian Sea (Leontarakis & Richardson 2005). The slower growth rate in the present study had been expected, because these smooth clams were collected in Atlantic waters, whereas the others were sampled in warmer Mediterranean waters. The lifespans estimated in the present work were 14 and 17 yr (for sur-

face rings and internal growth lines, respectively), which were relatively similar to the maximum ages obtained by Keller et al. (2002), Metaxatos (2004) and Leontarakis & Richardson (2005). In contrast, the Atlantic population of *C. chione* studied in the UK by Forster (1981) showed very dissimilar results, with a larger asymptotic size, a much slower growth rate and a much higher predicted maximum age. These discrepancies could possibly be a consequence of the mark-and-recapture method used by Forster (1981) and its inherent practical problems. Besides, this author only used individuals with a SL > 73 mm to estimate growth rates. Therefore, his results are probably age-biased since *C. chione* grows faster in the first years of its life.

In the present work, the OGP determined from both the microgrowth patterns in shell sections and the surface rings lie within the range of values determined by other authors for *Callista* spp. Indeed, the OGP for most *Callista* spp. has been found to fall within the

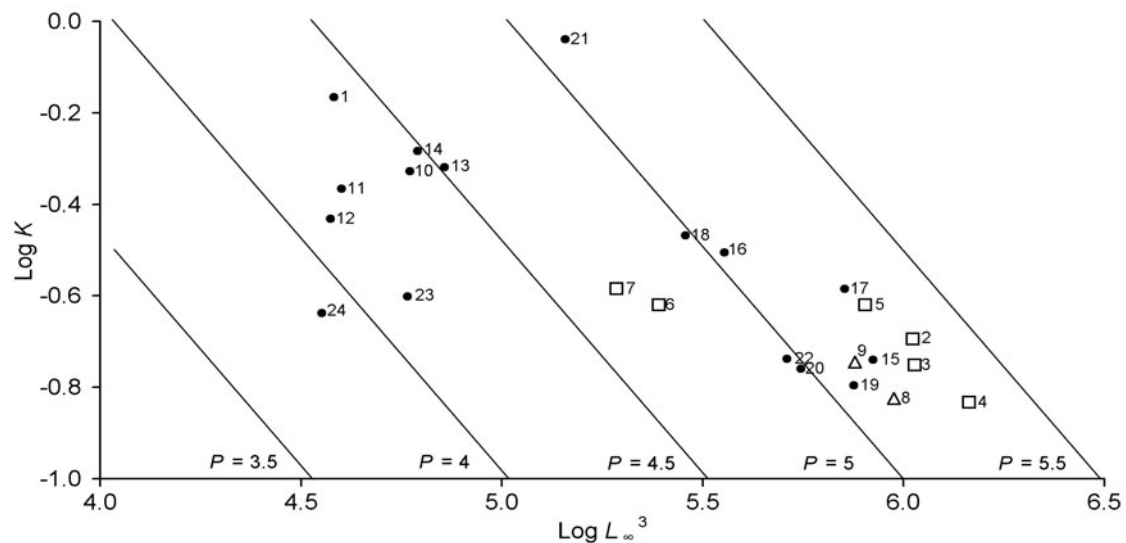


Fig. 6. Auximetric grid comparing overall growth performance (OGP,  $P$ ) in venerid bivalves. Diagonal lines indicate equal values of OGP. Numbers refer to the reference numbers in Table 3 ( $\Delta$ : present study;  $\square$ : *Callista* spp.;  $\bullet$ : other Veneridae)



Table 3. Values of von Bertalanffy growth constant ( $K$ ) and growth performance indices ( $P$ ,  $\phi'$ ) for various venerid bivalve species. Age determination method: LF: length-frequency, SR: surface rings, CS: cross sections, TS: thin sections, AP: acetate peels, MR: mark and recapture

| Taxon and Ref. no.               | $K$   | $L_{\infty}$ (mm SL) | $P$  | $\phi'$ | Latitude (°N) | Method | Study area                                             | Source                          |
|----------------------------------|-------|----------------------|------|---------|---------------|--------|--------------------------------------------------------|---------------------------------|
| <i>Anomalocardia brasiliiana</i> |       |                      |      |         |               |        |                                                        |                                 |
| 1                                | 0.682 | 33.67                | 4.42 |         |               | LF     | Guadeloupe, Carribean Sea                              | Monti et al. (1991)             |
| <i>Callista brevisiphonata</i>   |       |                      |      |         |               |        |                                                        |                                 |
| 2                                | 0.202 | 101.80               | 5.33 | 3.32    | 42.51         | SR, CS | Unkovskii Island, Peter the Great Bay, Sea of Japan    | Selin & Selina (1988)           |
| 3                                | 0.177 | 102.20               | 5.28 | 3.27    | 42.48         | SR, CS | Putyatín Island, Peter the Great Bay, Sea of Japan     | Selin & Selina (1988)           |
| 4                                | 0.147 | 113.40               | 5.33 | 3.28    | 42.53         | SR, CS | Tikhaya zavod inlet, Peter the Great Bay, Sea of Japan | Selin & Selina (1988)           |
| <i>Callista chione</i>           |       |                      |      |         |               |        |                                                        |                                 |
| 5                                | 0.240 | 93.00                | 5.29 | 3.32    | 38.50         | SR, TS | Gulf of Euboikos, Aegean Sea, Mediterranean            | Metaxatos (2004)                |
| 6                                | 0.240 | 62.70                | 4.77 | 2.97    | 40.40         | SR, AP | Thracian Sea, Mediterranean                            | Leontarakis & Richardson (2005) |
| 7                                | 0.260 | 57.80                | 4.70 | 2.94    | 40.40         | SR, AP | Thracian Sea, Mediterranean                            | Leontarakis & Richardson (2005) |
| 8                                | 0.150 | 98.10                | 5.15 | 3.16    | 38.20         | AP     | Arrábida, NE Atlantic, Portugal                        | Present study                   |
| 9                                | 0.180 | 91.10                | 5.13 | 3.17    | 38.20         | SR     | Arrábida, NE Atlantic, Portugal                        | Present study                   |
| <i>Chamelea gallina</i>          |       |                      |      |         |               |        |                                                        |                                 |
| 10                               | 0.470 | 38.95                | 4.44 |         |               | AP     | Algarve, S Portugal                                    | Gaspar et al. (2004a)           |
| 11                               | 0.430 | 34.17                | 4.23 |         |               | SR     | N Marmara Sea, Turkey                                  | Deval & Oray (1998)             |
| 12                               | 0.370 | 33.46                | 4.14 |         |               | AP     | N Marmara Sea, Turkey                                  | Deval (2001)                    |
| 13                               | 0.480 | 41.60                | 4.54 |         |               | TS     | W Adriatic, Ancona, Italy                              | Arneri et al. (1995)            |
| 14                               | 0.520 | 39.50                | 4.51 |         |               | TS     | W Adriatic, Neretva Estuary, Croatia                   | Arneri et al. (1997)            |
| <i>Mercenaria mercenaria</i>     |       |                      |      |         |               |        |                                                        |                                 |
| 15                               | 0.182 | 94.31                | 5.18 |         |               | SR     | English Channel, Southampton, UK                       | Hibbert (1977)                  |
| 16                               | 0.312 | 71.04                | 5.05 |         |               | AP     | Atlantic, Georgia, USA                                 | Walker & Tenore (1984)          |
| 17                               | 0.260 | 89.40                | 5.27 |         |               | AP     | Atlantic, Georgia, USA                                 | Walker & Tenore (1984)          |
| 18                               | 0.340 | 65.90                | 4.99 |         |               | AP     | Atlantic, Georgia, USA                                 | Walker & Tenore (1984)          |
| 19                               | 0.160 | 90.90                | 5.08 |         |               | AP, CS | Narragansett Bay, Rhode Island, USA                    | Jones et al. (1989)             |
| <i>Protothaca thaca</i>          |       |                      |      |         |               |        |                                                        |                                 |
| 20                               | 0.174 | 82.20                | 4.99 |         |               | SR, MR | Bay of Dichato, Chile                                  | Urban & Campos (1994)           |
| <i>Tapes philippinarum</i>       |       |                      |      |         |               |        |                                                        |                                 |
| 21                               | 0.913 | 52.40                | 5.12 |         |               | LF     | Kaneohe Bay, Pacific, Hawaii                           | Yap (1977)                      |
| <i>Venus antiqua</i>             |       |                      |      |         |               |        |                                                        |                                 |
| 22                               | 0.183 | 80.00                | 4.97 |         |               | MR     | Chiloé, Pacific, Chile                                 | Clasing et al. (1994)           |
| <i>Venus striatula</i>           |       |                      |      |         |               |        |                                                        |                                 |
| 23                               | 0.250 | 38.75                | 4.16 |         |               | SR     | Bristol Channel, UK                                    | Warwick et al. (1978)           |
| 24                               | 0.230 | 32.90                | 3.91 |         |               | SR     | Millport, Scotland                                     | Ursin (1963)                    |

range of 5 to 5.5 (Fig. 6, Table 3). Moreover, the OGP values indicate that species of the genus *Callista* have a higher growth performance (average OGP:  $P = 5.12$ ) than other venerid bivalves (average OGP:  $P = 4.79$ ; Fig. 6, Table 3). The  $\phi'$  values obtained in the present study according to both age determination methods are consistent with those previously calculated for other *Callista* spp. populations (Fig. 7, Table 3). This result indicates that the growth parameters  $K$  and  $L_{\infty}$  estimated in the present work are

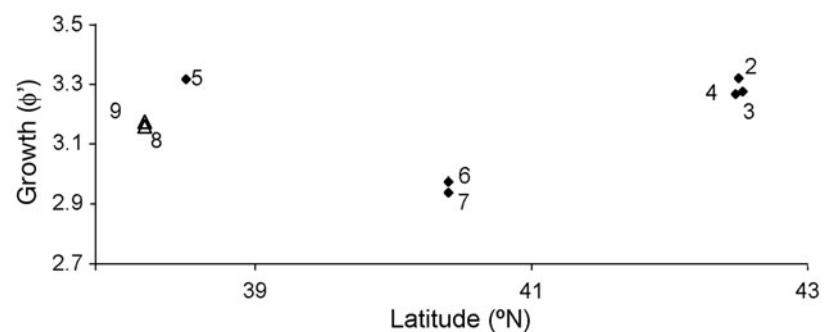


Fig. 7. *Callista* spp. Growth performance index values ( $\phi'$ ) along a latitudinal gradient. Numbers refer to the reference numbers in Table 3 (Δ: present study)

an accurate representation of the considered population, since it has been suggested that  $\phi'$  values are similar for the same species and genera (Munro & Pauly 1983, Brey 1999, Bellido et al. 2000). Yet, growth performance seems to present a positive correlation with latitude for the *Callista* spp. populations shown in Fig. 7. This may be related to differences in seawater temperature and food supply.

Knowledge on the age and growth of bivalve species is a fundamental requirement for studies of population dynamics and, consequently, for the successful management of a fishery. Taking into consideration the size at first maturity (50.81 mm SL) previously estimated by Moura et al. (2008), *Callista chione* needs >4 yr to reach sexual maturation. Unfortunately, comparisons with other smooth clam populations were impossible, since no further information is available on this subject.

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