*Falkland Islands Fisheries Department*

# Age and growth of *Zygochlamys patagonica* populations from four scallop beds in Falkland Islands waters, 2005 fishing season

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## Introduction

The Patagonian scallop *Zygochlamys patagonica* (King and Broderip 1832) is a pectinid bivalve mollusc distributed around the southern tip of South America from 42°S in the Pacific to 35°S in the Atlantic (Lasta and Bremec 1998), the Burdwood Bank (Lasta and Zampatti, 1981) and the Falkland Islands shelf (Bizikov and Middleton, 2002). It is mainly found on sandy and muddy substrates in depth ranging from 40m to 200m (Ciocco *et al*, 1998), and although it is most abundant along the 100m isobath (Lasta and Bremec, 1998) it has been observed in Falkland Island waters inshore as shallow as 10m (personal observation).

In December 2001 an experimental fishery was established in the Falkland Islands, initially using the Uruguayan vessel, *Avel Mad* and then another Uruguayan trawler, *Holberg,* from December 2003 onwards. At present, this species is fished on 5 beds (Rachel, Fiona, Marina, Avel Mad and Holberg, which are located to the east and northeast of the Falkland Islands in approximately 130m depth (Figure 1).

Fundamental to understanding the population dynamics and life-history of any marine species is knowledge of its patterns of growth (Beamish and McFarlane 1983). Such knowledge can be used to estimate numerous other age-specific parameters such as longevity, hatching dates, age at maturity, age at migration to nursery grounds, age at recruitment to the fishery (King 1995; Quinn and Deriso 1999). Age composition data can also be used to construct catch curves from which mortality rates are calculated. Such data are imperative for the proper assessment and management of any fishery on that species. The considerable economic importance and fishing of sea scallop stocks underscore the need for accurate age and growth estimates for this species.

Techniques presently employed for age determination in scallops include acetate peels (Richardson *et al* 2002), stable isotope techniques (Krantz *et al* 1984), the interpretation of lines visible on the exterior of the shell (Stevenson and Dickie 1954), usage of X-ray photographs (Cattaneo-Vietti *et al* 1997) and reading bands on the hinge ligament (Merrill *et al* 1965).

Using mark and recovery studies it has been discovered that scallops deposit growth checks or growth bands in late winter and early spring (Paul, 1981). Scallops deposit calcium carbonate in the form of calcite to the shell margin in concentric increments. During the summer when growth rates are quicker the distance between these increments is larger (Taylor and Venn 1978). In the

winter months when growth slows the increments are closer together, forming what is classed as a concentric ring or check on the shell surface. (Figure 2, Materials and methods).

The interpretation of external lines is complicated by a series of shock or disturbance lines. Sea scallops are extremely sensitive to physical disturbances and sudden changes in environmental conditions. In response to this the scallops retract their mantle and stop calcification along the shell margin, leaving a noticeable line after calcification begins again. Distinguishing these disturbance lines from annual growth rings can be extremely difficult and also very subjunctive (Stevenson and Dickie 1954). Additional methods, like using X-ray photographs has been proved to be very effective. (Cattaneo-Vietti *et al* 1997). However these methods can be subjunctive and therefore not conclusive.

In view of these uncertainties additional methods for accurately interpreting these growth rings have been investigated. (Krantz *et al* 1984). The two valves of a bi-valve shell are joined together dorsally by a horny elastic ligament, made from conchiolin which secreted by the mantle. The ligament is rarely mineralised and its layers correspond with those of the shell. Initial experiments, by the Falkland Islands Fisheries Department, reading the ligament scar in *Zygochlamys patagonica* show distinct bands, which are not clearly visible on the shell of this species. The present study compares and assesses the accuracy of three traditional methods 1.) Counting bands on the shell surface 2.) X-ray photographs 3.) Counting bands on the shell ligament .

The technique of counting the growth rings on the shell ligament is used in this study to estimate the age structure of four scallop beds in the Falkland Islands Conservation Zone.

## Materials and Methods

Random samples of *Z. patagonica* were collected at 130-139m depth on the Uruguayan vessel *Holberg* from four scallop beds, Fiona (n=113), Rachel (n=115), Avel Mad (n=128) and Holberg (n=125) to the north and north-west of the Falkland Islands during commercial operations between January and February 2005 (See Figure 1).

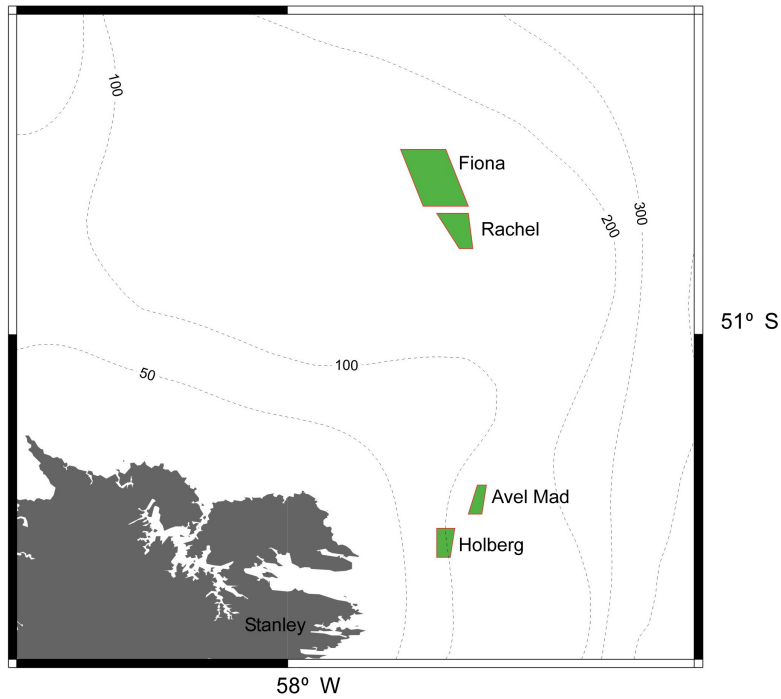



**Figure 1:** Map of scallop beds sampled in this study to the north and north west of the Falkland Islands.

Shell height (defined as the maximum distance between the dorsal hinge and ventral margin) to the nearest mm, total mass without epibionts, shell mass, abductor muscle mass, gonadal mass to the nearest 0.1g were measured.

In this study three traditional methods of ageing scallops were investigated; counting bands on the shell surface (Berkman 1990), X-ray photographs (Cattaneo-Vietti *et al* 1997) and counting the hinge ligament bands (Merrill *et al* 1965) to compare the growth periodicity between the ligament and shell and to determine the most accurate method. The same shells and ligaments were used for comparison of the accuracy of the individual methods.

### Counting bands on the shell surface

Upper (left) undamaged shell valves free of epibionts were used for growth analysis. Prior to reading the shells were cleaned of organic matter with warm 5% NaOCl (bleach) solution, washed in 96% ethanol, rinsed with water and dried at 60˚c for 12 h. External, macroscopically visible shell bands were counted following the methods of Merrill *et al* (1965). Counts were compared with the other methods (see Figure 2).

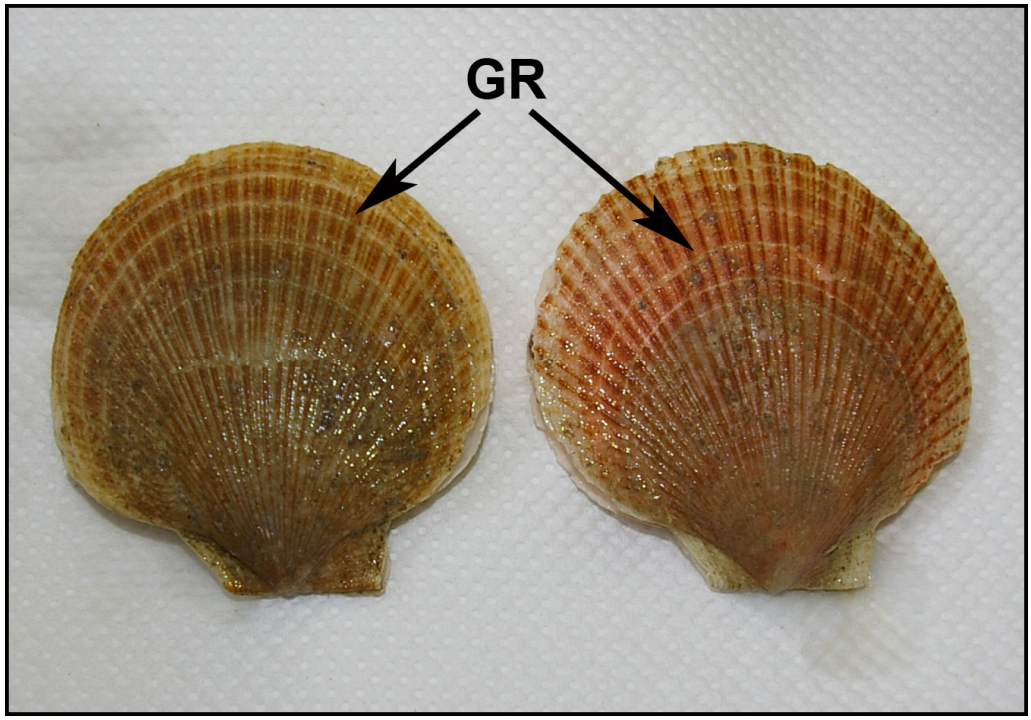



**Figure 2:** Photograph of *Z. patagonica* shell showing bands on the shell surface.

### X-ray photographs

Shells were prepared as the above method and taken to King Edward VI Memorial Hospital, Stanley, for X-ray analysis. The cleaned upper valve was placed on an X-ray plate with station and scallop number placed next to each shell. X-rays were taken on a GE Medical Systems Proteus XR/A machine, using digital cassette at 100cm with radiation settings of 50KV and exposure time of 3.2 seconds following the techniques of Heilmayer *et a*l (2003). These counts were also compared with the other two methods. Figure 3 shows the X-rayed shells and the visible growth rings.

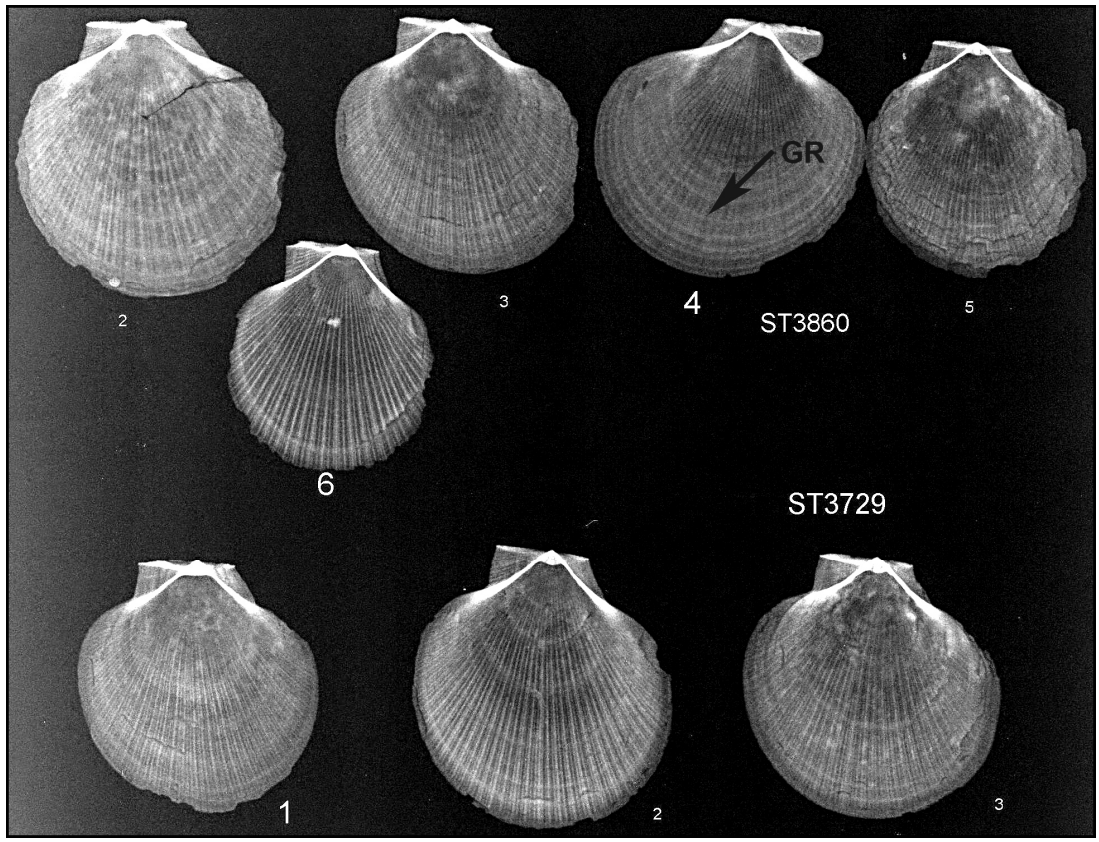



**Figure 3:** X-rayed shells of *Z. patagonica* with growth ring indicated. GR-growth ring.

### Counting growth bands on the hinge ligament

Shells were cleaned, processed as above (but both upper and lower valves were left held together by the ligament) and left to dry at room temperature for three days. The shells were then separated. The drying process is very important as it ensures that the ligament is attached to one of the valves in one piece. If the shell is dried too quickly the ligament will be brittle and break down the middle, and if it is still moist it will have a' rubberlike' consistency and tear in the middle. The shell was removed from around the ligament with a pair of cutting pliers, leaving approximately 2mm of shell around the ligament. The ligament was mounted sideways on a microscope slide in the thermo-plastic cement crystal bond (see Figure 4).


**Figure 4:** *Z. patagonica* ligament mounted in crystal bond on slide.

The mounted ligament was ground on a Metaserv 2000 grinder polisher using 600 grit paper until the shell was ground away and a longitudinal-section of the ligament was visible (Figure 4). It was finished with 800 grit paper. The growth bands were viewed under a Olympus SZX12 light microscope at 2x (Figure 5). NB. It is very important to place a drop of immersion oil on the ligament before viewing to refract the light so the bands can be seen more clearly. This method was compared to the other two methods. During the present study ligament preparations were used to age all the individuals

**Figure 5:** Photograph of the ligament being ground on the Metaserv 2000 grinder polisher.

Ageing precision was established by reading 479 individual ligaments blind. All ligaments were read twice by the first author ($R1_1$). The second author ($R2_1$) read a sub-sample of 100 ligament preparations and the readings were compared using IPAE (Beamish and Fournier, 1981).

$$IAPE = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{\left|Xij - Xj\right|}{Xj}\right]$$

Length at age data were fitted using a non-linear least squares regression to the von Bertalanffy growth model:

$$L_t = L_\infty(1 - \exp[-K(t - t_0)])$$

The data from the Fiona and Rachel beds was combined as there was not enough variation in the data from the individual beds, and also for stock assessment purposes the Fiona and Rachel beds are classed as one.

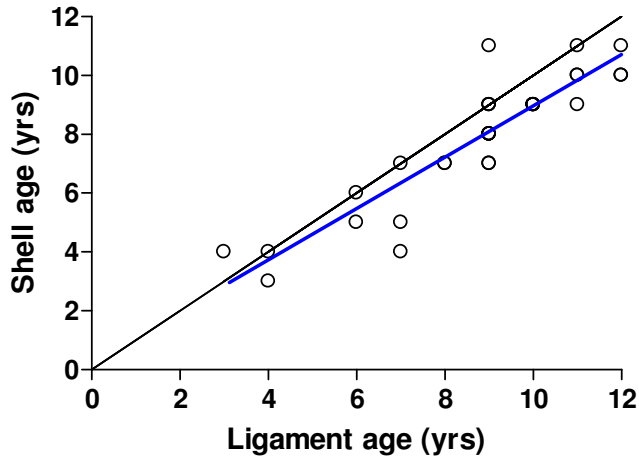
## Results

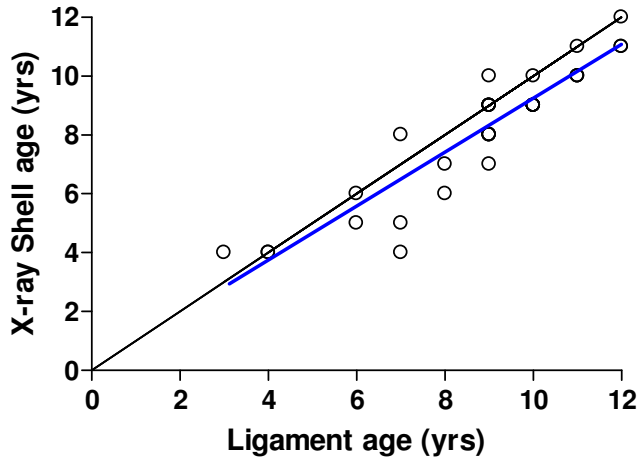
### Comparison of the different reading methods.

Ligament age, shell age and X-ray photographs were read separately and the relationship between ligament age vs shell age, ligament age vs X-ray age and shell age vs X-ray age were compared. (n=35). The reading comparisons between the shell age and X-ray were not significantly difference (ANCOVA $P>0.05$), but when comparing ligament age against shell and X-ray age there was a significant difference (ANCOVA $P<0.05$) . In all cases there was an underestimation of the age on the shell and X-ray counts compared to that of the ligament (Figure 6).

### Ligament reading and processing

The clarity of the banding in the ligament varied and of the initial preparations only 85% were readable (n=479). The remaining 15% were considered impossible to read due to the bands not being visible or stress marks making the bands illegible. Figure 7 shows a ligament that is impossible to read, a legible ligament with stress marks, a very clear preparation and a ligament that has not yet laid down the first band.



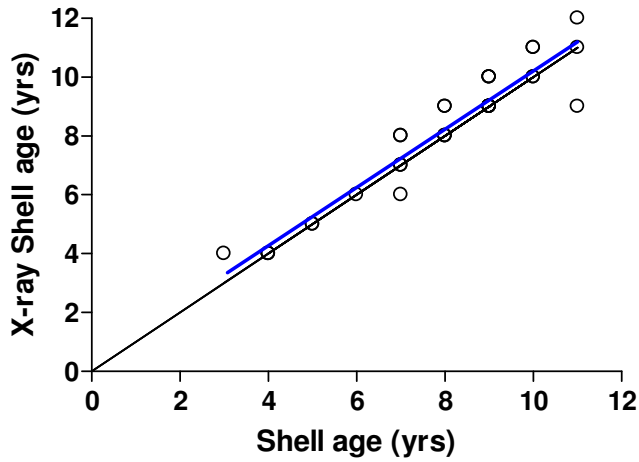




**Figure 6:** Relationships of ligament vs shell, ligament vs X-ray photographs and shell vs X-ray photographs for *Z. patagonica* in the Falkland Islands. Black line=line of equality, blue line=regression between the two readings

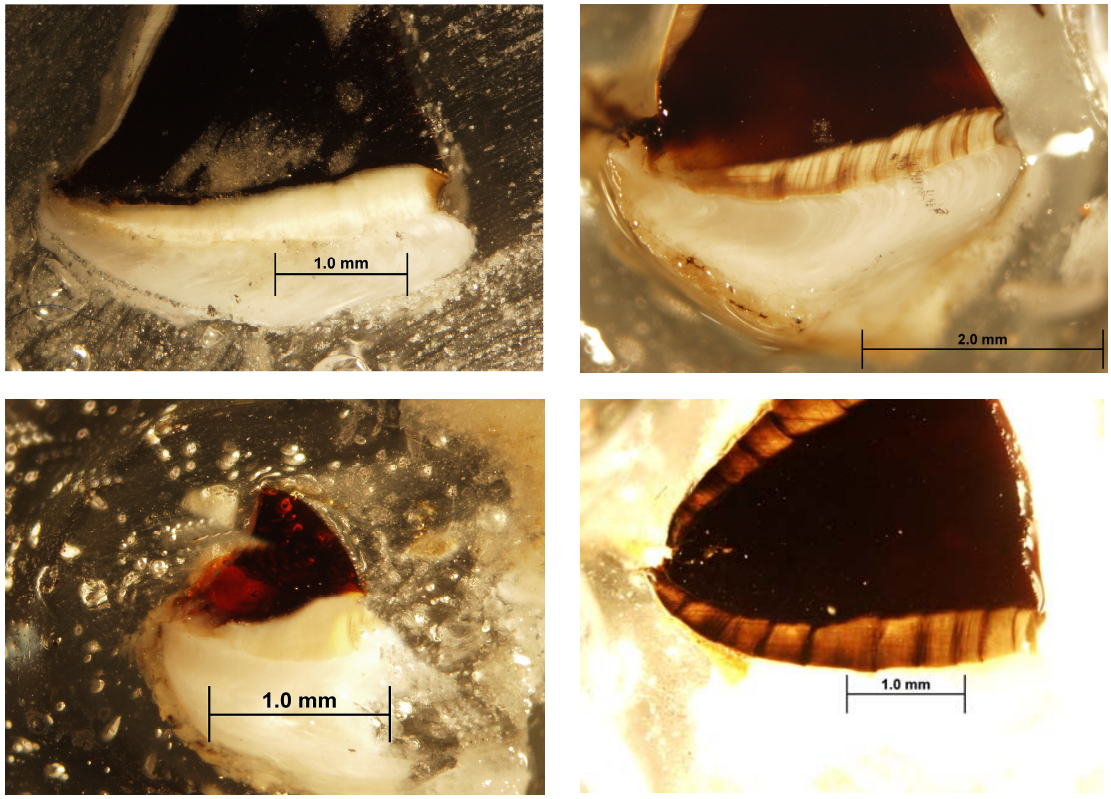
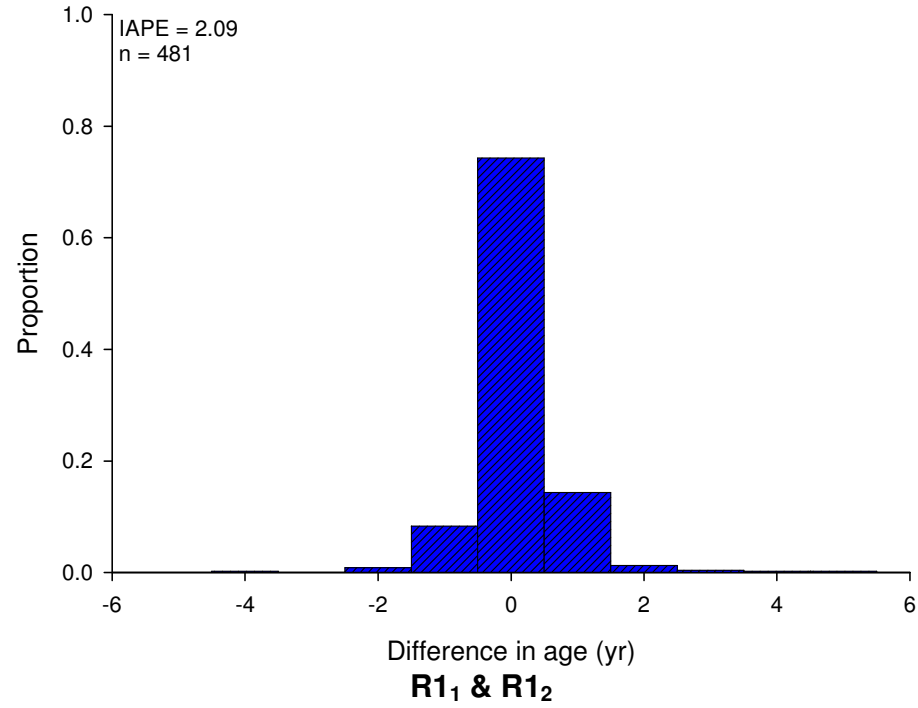



**Figure 7:** Ligament scar preparations of *Z.patagonica*.A.) Clockwise from top left. Unreadable ligament B.) Ligament scar with stress marks. (9+). C.) Clear preparation, no stress marks and clearly defined lines. (9+). D.) Ligament pre-banding. (0+).

### Ageing precision

The readings between $R1_1$ and $R1_2$ showed a very close agreement, with 74% of the readings being the same and 14% only showing a one year difference. (IAPE=2.09). After a short period of training $R2_1$ readings were 69% the same as $R1_2$. (IAPE=1.97) 16% of the reading were one year older than $R1_2$ and a majority of the ages that differed between the two readings were read as older individuals. (Figure 8).



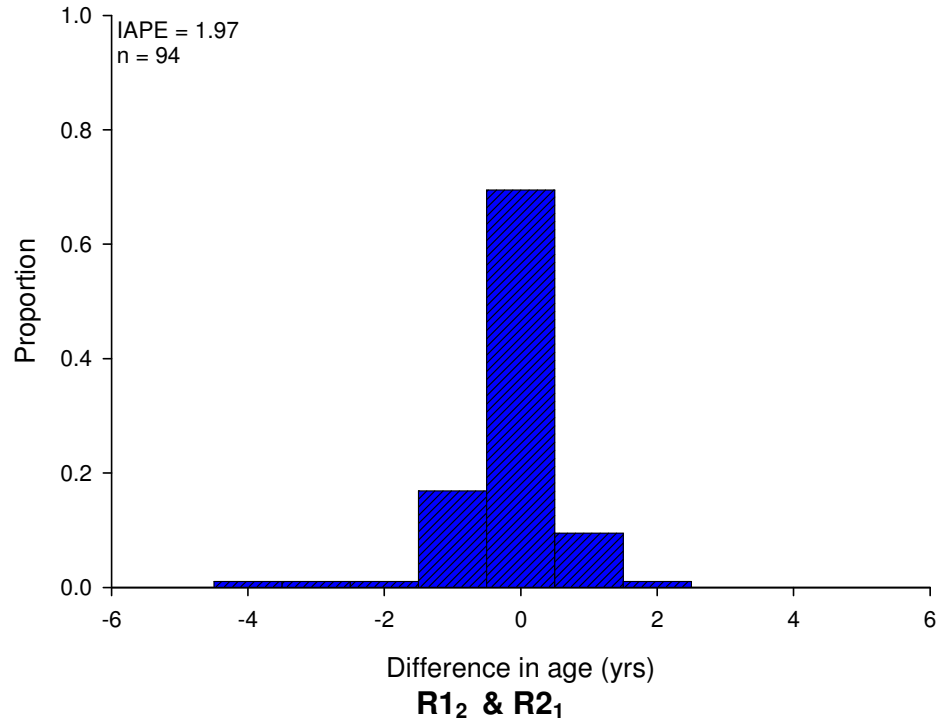




**Figure 8:** Histogram illustrating the difference in ligament reading from $R1_1$ & $R1_2$ and $R1_2$ & $R2_1$ from ligaments of *Z. patagonica*.

## Growth

Calculated von Bertalanffy growth parameters are presented in Table 1. This illustrates that *Z. patagonica* is a relatively slow growing species with faster growth during its early years ($t_0$=*-0.61).* Scallops on the Holberg bed attain a greater theoretical maximum size ($L_\infty$65.65), but the Avel Mad bed displays the fastest growth rate ($K$=0.620).

In all beds sampled the average size for year 1 individual is 24.3mm. Between 1 & 2 size increases by 7.64mm. In the 3rd year growth increases quickly by 15.1mm, but decreases in the fourth year to 7.36mm. After this growth rates decline.

Table 2 presents an observed age length key for the combined sample examined during this study.

**Table 1:** Parameter estimates for non-linear least squares fits of the von Bertalanffy growth curve to the individual height at age.

| | $K$ | $L_\infty$ | $t_0$ | $N$ |
|---|---|---|---|---|
| **Fiona / Rachel** | 0.351 | 63.66 | -0.716 | 228 |
| **Avel Mad** | 0.620 | 57.59 | -0.685 | 130 |
| **Holberg** | 0.186 | 65.35 | -0.319 | 125 |
| **All beds** | 0.399 | 60.60 | -0.610 | 483 |

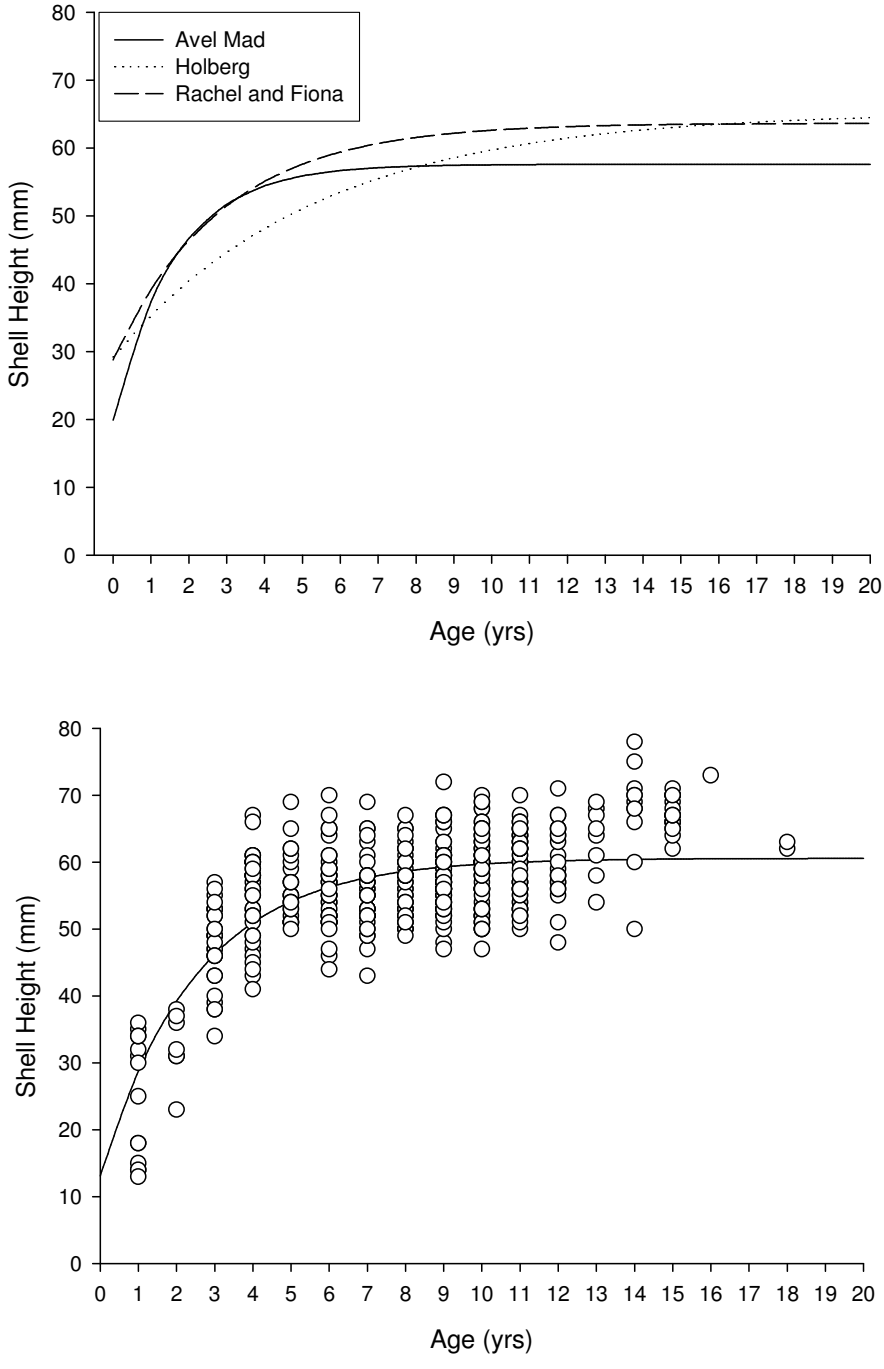



**Figure 9:** von Bertalanffy derived growth curves for *Z. patagonica* from Rachel/ Fiona, Avel Mad and Holberg beds, and for all the beds combine

**Avel Mad**

| | Age (years) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Length (mm)** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **Total** | **% Freq** |
| **30** | | | 1 | | | | | | | | | | | | | | | | | 1 | 0.8 |
| **35** | | | | | | | | | | | | | | | | | | | | 0 | 0.0 |
| **40** | | | | | 1 | | | | | | | | | | | | | | | 1 | 0.8 |
| **45** | | | | 1 | | | | 1 | | 1 | | | 1 | | | | | | | 4 | 3.1 |
| **50** | | | | | 1 | | 1 | 3 | 7 | 10 | 8 | 10 | 1 | 1 | | | | | | 42 | 32.3 |
| **55** | | | | | | | 1 | 3 | 3 | 13 | 6 | 7 | 4 | | | | | | | 37 | 28.5 |
| **60** | | | | | | | 1 | | 3 | 7 | 8 | 10 | 1 | 1 | | | | | | 31 | 23.8 |
| **65** | | | | | | 1 | | 1 | | 2 | 4 | 2 | 1 | | | 1 | | | | 12 | 9.2 |
| **70** | | | | | | | | | | 1 | 1 | | | | | | | | | 2 | 1.5 |
| **Total** | 0 | 0 | 1 | 1 | 2 | 1 | 3 | 8 | 0 | 0 | 0 | 0 | 8 | 2 | 0 | 1 | 0 | 0 | 0 | **130** | 100 |
| **Mean** | 0.0 | 0.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 4.3 | 5.7 | 5.4 | 7.3 | 1.6 | 1.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | | |
| **SD** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 2.3 | 5.1 | 3.0 | 3.8 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | |

**Holberg**

| | Age (years) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Length (mm)** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12 | 14 | 15 | 16 | 17 | 18 | **Total** | **% Freq** |
| **30** | | | | 1 | | | | | | | | | | | | | | | | 1 | 0.81 |
| **35** | | | | 1 | | | | | | | | | | | | | | | | 1 | 0.81 |
| **40** | | | | | | | | | | | | | | | | | | | | 0 | 0.00 |
| **45** | | | | | 2 | | | | | | | | | | | | | | | 2 | 1.63 |
| **50** | 1 | | | 2 | | 1 | 1 | 1 | 5 | 3 | 5 | 2 | | | | | | | | 21 | 17.07 |
| **55** | | | | | | 1 | 2 | 3 | 10 | 16 | 7 | 5 | 4 | | | | | | | 48 | 39.02 |
| **60** | | | | | | | | | 2 | 6 | 15 | 9 | 2 | | | 1 | | | | 35 | 28.46 |
| **65** | | | | | | | | | | 2 | 4 | 6 | 2 | | | | | | | 14 | 11.38 |
| **70** | | | | | | | | | | | | | 1 | | | | | | | 1 | 0.81 |
| **Total** | 1 | 0 | 0 | 4 | 2 | 2 | 3 | 4 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 1 | 0 | 0 | 0 | **123** | 100 |
| **Mean** | 1.0 | 0.0 | 0.0 | 1.3 | 2.0 | 1.0 | 1.5 | 2.0 | 5.7 | 6.8 | 7.8 | 5.5 | 2.3 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | | |
| **SD** | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.7 | 1.4 | 4.0 | 6.4 | 5.0 | 2.9 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | |

**Fiona and Rachel combined**

| | Age (years) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Length (mm)** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | **Total** | **% Freq** |
| **10** | | 3 | | | | | | | | | | | | | | | | | | 3 | 1.32 |
| **15** | | 3 | | | | | | | | | | | | | | | | | | 3 | 1.32 |
| **20** | 1 | | 1 | | | | | | | | | | | | | | | | | 2 | 0.88 |
| **25** | | 1 | | | | | | | | | | | | | | | | | | 1 | 0.44 |
| **30** | 1 | 5 | 2 | | | | | | | | | | | | | | | | | 8 | 3.52 |
| **35** | | 2 | 3 | 2 | | | | | | | | | | | | | | | | 7 | 3.08 |
| **40** | | | | 3 | 2 | | 1 | 1 | | | | | | | 1 | | | | | 8 | 3.52 |
| **45** | | | | 8 | 4 | | 2 | 2 | 1 | 1 | | | | | | | | | | 18 | 7.93 |
| **50** | | | | 6 | 4 | 11 | 11 | 9 | 3 | 1 | 3 | | | | 1 | | | | | 49 | 21.59 |
| **55** | | | | 3 | 12 | 6 | 10 | 7 | 1 | | 2 | 1 | 1 | 1 | | | | | | 44 | 19.38 |
| **60** | | | | | 9 | 4 | 3 | 4 | 5 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | | | 2 | 36 | 15.86 |
| **65** | | | | | 2 | 1 | 3 | 2 | 3 | 2 | 1 | 1 | 2 | 4 | 4 | 10 | | | | 35 | 15.42 |
| **70** | | | | | | | 1 | | | | | 1 | | | 3 | 5 | 1 | | | 11 | 4.85 |
| **75** | | | | | | | | | | | | | | | 2 | | | | | 2 | 0.88 |
| **Total** | 2 | 14 | 6 | 22 | 33 | 22 | 31 | 25 | 13 | 5 | 7 | 5 | 5 | 6 | 12 | 16 | 1 | 0 | 2 | **227** | 100 |
| **Mean** | 1.0 | 2.8 | 2.0 | 4.4 | 5.5 | 5.5 | 4.4 | 4.2 | 2.6 | 1.3 | 1.8 | 1.3 | 1.7 | 2.0 | 2.0 | 5.3 | 1.0 | 0.0 | 2.0 | | |
| **SD** | 0.0 | 1.5 | 1.0 | 2.5 | 4.1 | 4.2 | 4.2 | 3.2 | 1.7 | 0.5 | 1.0 | 0.5 | 0.6 | 1.7 | 1.3 | 4.5 | 0.0 | 0.0 | 0.0 | | |

**Table 2:** Composite age length-key for the analysed scallop beds of *Zygochlamys patagonica* for all beds sampled in January & February 2005.

## Discussion

Although not validated in *Z. patagonica* it is likely that one mark is laid down annually on both the shell and ligament hinge as in other species (Merrill, 1965; Cattaneo-Vietti et al., 1997). As in many marine scallop species during the summer when growth rates are faster the distance between the increments is large. In winter when their growth rates are reduced the increments are closer together and form what is known as a concentric ring or check on the shell surface and bands on the ligament hinge.

Although the preferred method for age determination in this study was counting the bands on the ligament hinge we also compared readings taken from shells and from X-ray photographs of the shells. We concluded that both the shell and X-ray determined ages were underestimated compared to those taken from the ligament hinge because the initial rings on the shell surface are very difficult to distinguish and the rings adjacent to the shell margin become compressed and difficult to discern. This was also noted by Bizikov and Middleton (2002). The banding on the ligament hinges were found to be reasonably simple to read, however, 15% of the original preparations were unreadable because they showed no signs of banding or the banding was obscured by numerous stress marks.

All of the ligaments were read twice by the first author and then a sub-sample of 94 were read by the 2$^{nd}$ author. Overall both inter and intra-reader comparisons showed good agreement with IAPE values of less than 3% which suggests a good precision.

*Zygochlamys patagonica* is a relatively slow growing scallop and attains a maximum observed age of 18 years. It grows to an average shell height of 24.3 mm in its first year. Between 1 and 2 years the average growth is 7.64mm per year, but the scallop achieves maximum growth during the third year with an average 15.1mm per year. After reaching 5 years growth rates were seen to slow considerably. Growth rates on individual scallop beds varied slightly with the highest on the Avel Mad bed followed by Fiona/Rachel and Holberg beds respectively. A comparison with the von Bertalanffy parameters in Bizikov and Middleton's (2002) study illustrated that growth rates on the Avel Mad bed were slightly lower. Differences in the parameters between the two studies may be attributed to

the different methods used in age determination. The present study examined a longitudinal section through the hinge and ligament that was ground and polished resulting in a clearer preparation that was easier to read as it highlighted the presence of the earlier bands. The former study examined ligaments that were split in half and mounted on blue tac, which made it very difficult to discern the first few growth bands.

Bizikov and Middleton (2002) validated the 1st annual band on both ligaments and the shells from 19 young scallops that were sampled from mussel rafts at Goose Green. The rafts were exposed to the sea from the 20th February 2001 to the 20th March 2002 so the maximum ages of the scallops could be no more that 13 months. The scallops ranged in size from 21 to 31 mm and a closer examination revealed that two of them had no winter bands on the shell or the ligament, while the remained had one clear band. They found that the length to the 1st band was between 0.55 mm to 0.90 mm. We measured the distance to the 1st band on the ligaments of 345 scallops from different beds and found that they had a large variation from 0.1 to 0.95 mm (mean = 0.39 mm SD ± 0.17). This would suggest that settlement and thus spawning occur throughout early spring to late autumn. Those that settled in early spring would have a relatively larger distance to the first band compared with those that had settled in late autumn. As the frequency distribution of the distances to the 1st band contained a wide single mode our conclusions were that there was not an obvious peak of spawning. Campodonico *et al* (2001) suggest that spawning continued throughout spring to late autumn with the possibility of two peaks in early spring and late autumn respectively.

The annual band formation on the ligament hinge of *Z. patagonica* was not validated in this study and therefore must be a priority in any further study on this species. Small sample sizes were used from each bed and future studies should look to increasing the numbers aged per bed to achieve accurate age length keys. Other methods of age determination such as acetate peels (Peharda *et al*., 2002) and stable isotope analysis (Krantz *et al*., 1984) should also be investigated.

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