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EYE LENS STRUCTURE OF THE OCTOPUS ENTEROCTOPUS MEGALOCYATHUS: EVIDENCE OF GROWTH

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ABSTRACT The need for age determination for the proper management of octopus fisheries has directed research attention to the few hard structures in the octopod’s soft body, beak, statoliths, and the vestigial shell. So far, none of these structures have proved reliable or practical for the purpose. Eye weight, pigment, and nitrogen content have been used successfully in age determination of vertebrates. Given the structural similarity of lenses between octopus and vertebrate, we explore the possibility of using octopus eye lens weight, diameter, and structural marks as age indicators. The lenses of 228 octopi were obtained from the commercial catch from Ancud and Queilen, in Chiloe, Chile. They were measured, weighed, and prepared for histological analysis of the concentric lines structure. The prehatching nucleus was identified, and the total number of lines counted. The lines start to form in the prehatching larvae. Lens diameter and weight showed a much smaller variation than body length or weight, with an apparent correspondence of size or weight classes of body measurements to a lens diameter or weight.

KEY WORDS: age, histology, octopod, eye, lens, octopus, Enteroctopus

INTRODUCTION

Age determination of soft-bodied organisms has always been a major problem for fishery biologists (Tesch 1971). Therefore, population size structure has been used as an alternative method (Gayalino et al. 1993), a technique that works for populations with a clearly defined recruitment and with a life span of several years (Allen 1966, Jones 1981). It has been used in cephalopods with reservation (Guerra 1979, Nepita & Defeo 2001), because they have short life spans of 1 or 2 y, and recruitment extends for several months, with a wide variation of sizes even from a single parent (Cortez et al. 1999, Boyle & Rodhouse 2005).

The lack of hard structures in the body of an octopus has prevented the determination of age. The beak, statoliths, and stylets have been proposed as structures where daily growth marks are registered (Raya et al. 1994, Raya & Hernández-Garcia 1998, Perles-Raya et al. 2010, Doubleday et al. 2006). Although the technique for preparing and reading stylets has improved, its application to Enteroctopus megalocyathus has not given satisfactory age readings during our investigations, with age underestimated. The aim of this contribution is to present a technique to visualize the eye lens structure and to evaluate its application as a tool for age determination in E. megalocyathus. We present the correlation of E. megalocyathus eye lens weight and diameter to its mantle length, total length, and weight. We also present a technique to observe the structure of octopus lenses under light microscopy, discussing its potential for age determination.

METHODOLOGY

Two hundred twenty-eight individuals of E. megalocyathus were subsampled from a monthly sample of the commercial catch of a fisheries population from the ports of Queilen and Ancud, Chiloe, Chile, carried out by the Instituto de Fomento Pesquero (IFOP). The organisms were measured and weighed fresh, and their eye lenses fixed. After fixation in neutral formalin (Luna 1969), the lenses were measured in diameter with vernier calipers and weighed with a digital plate scale with 0.01-g precision. For microscopic analysis, they were treated with decalcifying solution (Table 1) prior to dehydration and paraffin inclusion (Table 2). Sections were stained with Harry’s hematoxylin-eosin stain (Luna 1969).

Thin sections and microtome sections were observed in clear field and phase contrast microscopes. Digital images were taken with a Leica microscope (model DM 1000) with a camera (Leica Microsystems, Wetzlar, Germany). The program Leica Application Suite (v. 1.6.0) was used to capture and edit the images. ArcSoft Panorama Maker and PowerPoint were used to integrate the images. The concentric lines were counted manually. It is possible to count the number of concentric lines under 400× and 1,000×. In order not to duplicate the count of lines between consecutive images, it is important to identify marks that permit the continuity between images. Identifying marks are also necessary to stitch consecutive images into 1 single image (Fig. 1).

Lens diameter, and weight of left and right eyes were analyzed independently for their correlation to mantle and total length, and total fresh weight with Excel (Microsoft). Correlations...
between eye lens body parameters were evaluated with Pearson’s correlation index (Hampton & Havel 2006).

### RESULTS

#### Lens Structure

Preliminary analysis of the octopus lenses showed concentric layers (Fig. 2), which are evident as dark, clear concentric bands. Under phase contrast microscopy, secondary lines are made evident (Fig. 2B). A nucleus is identified with a diameter of 130 μm (Fig. 3), which corresponds to the diameter of the eye lens in prehatching larvae (Fig. 4), but not to the diameter of the larval eye lens nucleus, which in Figure 3 was identified with a diameter of 50 μm.

<table>
<thead>
<tr>
<th>Regent</th>
<th>Time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% Chloroform, 50% *</td>
<td>4</td>
</tr>
<tr>
<td>Solvent</td>
<td>4</td>
</tr>
<tr>
<td>50% solvent, 50% resin</td>
<td>8</td>
</tr>
<tr>
<td>Resin without catalyst</td>
<td>8</td>
</tr>
<tr>
<td>Resin with catalyst</td>
<td>72, at ambient temperature (&lt;20°C), or 8 h in the stove at 40–60°C</td>
</tr>
</tbody>
</table>

Note: Proceed with these baths after following the dehydration process described in Table 2 up to the second bath of chloroform. * Solvent for synthetic resin.
Preliminary analysis of line count of 3 organisms (Table 6) showed 67 lines for prehatching larvae of unknown age. So far, line count has varied between 542 and 571, which, if interpreted as day growth marks, would be equivalent to 13.9–14.6 mo (Fig. 5), and to 2.2 mo for the prehatching larvae (Fig. 4).

**Biometry**

Fresh weight of the organisms varied between 498 g and 5,750 g, with a total length between 46 cm and 127 cm, and a mantle length between 84 mm and 213 mm. The eye lens diameters varied between 2.32 mm and 9.82 mm, with a weight varying between 0.09 g and 0.56 g.

Variations between left and right lenses were observed during sample preparation (Table 4). These differences induced us to process each eye lens separately. These differences are not evident graphically (Fig. 6) or statistically (Table 4). However, an interesting association of variables shows up when the eye lens measurements are placed as the independent variable, and the organism lengths and weight are used as the dependent variables (Fig. 6). A range of mantle lengths or total lengths are scattered around every value of eye lens diameter or weight. The lens diameter–weight correlation was high ($R = 0.86$), with wider fluctuations for diameter than for weight (Table 4). A Pearson correlation analysis (Hampton & Havel 2006) showed higher correlation of female eye lens measurements to total length (Table 5).

**DISCUSSION**

Eye weight, pigments, and nitrogen contents have been used to determine age in rabbit (Wheeler & King 1980), kangaroo (Poole et al. 1982, Augusteyn et al. 2003, McLeod et al. 2006), cattle (Raines et al. 2008), and euphausiid crustaceans (Harvey et al. 2010). These are characteristics that keep constant, independent of diet and environmental variables. We have found a very low correlation of eye lens measurements with the organism weight and length. Even though eye measurements have a very low variability, the wide dispersion on body measurements could be the source of the lack of correlation, somehow observed graphically (Fig. 6), in which a range of weights or mantle length correspond to a value of eye measurement.

The numbers of lines counted on the preliminary samples of this study suggested a corresponding number of lines to days of age, and to eye weight and diameter, but this will have to be ascertained with a significant sample size. Wentworth and Muntz (1992) report that lens formation starts on embryonic

<table>
<thead>
<tr>
<th>Table 4. Measurements of sampled octopi and their eye lenses.</th>
</tr>
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<tbody>
<tr>
<td>Diameter (mm)</td>
</tr>
<tr>
<td>Right lens ($n = 228$)</td>
</tr>
<tr>
<td>Maximum</td>
</tr>
<tr>
<td>Minimum</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>SD</td>
</tr>
<tr>
<td>Diameter Cor. C.</td>
</tr>
<tr>
<td>Weight Cor. C.</td>
</tr>
<tr>
<td>Left lens ($n = 205$)</td>
</tr>
<tr>
<td>Maximum</td>
</tr>
<tr>
<td>Minimum</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>SD</td>
</tr>
<tr>
<td>Diameter Cor. C.</td>
</tr>
<tr>
<td>Weight Cor. C.</td>
</tr>
</tbody>
</table>

Cor. C., correlation coefficient for lenses vs body measurements.
stage IX, with the formation of a nucleus and overlying layers formed from processes of the lentigenic cells. The nucleus size observed in adult octopi does not correspond to the nucleus of prehatching larvae. Therefore, the nuclei so far observed may be an artifact of the level at which the slide was made. Figures 4 (for prehatching larvae), 5, and 6 for adult octopi show that the widths of the concentric lines are homogeneous, independent of the age of the organisms. Giuditta and Prozzo (1974) report an increase in nuclear number relative to increase in body weight, with nuclear density steadily increasing in *Octopus vulgaris* reared in tanks, but with differences between organisms reared in dark and light. These authors proved that the rates of increment in number of nuclei and tissue weight became higher than normal in octopi reared in transparent boxes.

Given the small variability and ease of measurement of eye lens weight and diameter, we propose the use of this parameter as a tool to evaluate population structure through size frequency analysis, using a correlation factor with body size and weight estimated for every different population. These measurements could later be used for age estimation if the line number in the internal structure of the eye lenses is correlated to age, weight, and diameter.
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