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SUMMARY: The regressions between otolith size (length and width), otolith weight and fish length of the benthopelagic species, *Beryx splendens* living in the Arabian Sea coasts of Oman were provided. No differences between right and left otolith sizes and weight were detected by t-test, so a single linear regression was plotted against standard length (SL) for otolith length (OL), otolith width (OW) and otolith weight (OWE). Data fitted well to the regression model for both OL and OWE to SL ($R^2$ 0.6-0.8). These relationships provide a reliable tool in feeding studies and also provide support to palaeontologists in their research on fish fossils.

Keywords: benthopelagic fish, otolith, otolith weight, fish-otolith sizes, *Beryx*, Arabian Sea, Sultanate of Oman.

RIASSUNTO: In questo lavoro viene studiata la regressione tra la forma (lunghezza e larghezza), il peso degli otoliti e la lunghezza della specie bentopelagica *Beryx splendens* che vive nell’ambiente costiero dell’Oman nel Mare Arabico. Tramite t-test non sono state evidenziate differenze tra la forma e il peso degli otoliti destro e sinistro, è stata registrata una regressione lineare tra la lunghezza standard (SL) e lunghezza (OL), larghezza (OW) e peso (OWE) degli otoliti. I dati coincidono con il modello di regressione sia per OL sia per OWE in rapporto a SL ($R^2$ 0.6-0.8). Questo rapporto fornisce un ottimo strumento di supporto per studi sull’alimentazione e per i paleontologi nelle loro ricerche sui pesci fossili.

Parole chiave: pesci bentopelagici, otoliti, peso degli otoliti, forma degli otoliti, *Beryx*, Mare Arabico, Sultanato dell’Oman.

**Introduction**

Benthopelagic fishes are species usually living near-bottom environment of the deep-sea (Mauchline, Gordon, 1991) and playing an important ecological role in the transfer of energy from the top surface layer of the sea to the deep environment. During their diel vertical migration, the benthopelagic fishes feed on micronekton and return back to the deeper water layer during the daytime to avoid predation (Merrett, 1986).

The high biomass of benthopelagic fish communities in all oceans, especially in subtropical and tropical seas is an important food resource in the marine trophic web (Mauchline, Gordon, 1991, Bailey *et al.*, 2006).

Studies on feeding behaviour have shown the benthopelagic species to be among the primary trophic source for commercially important benthic fishes (Martin, Christiansen, 1997; Bergstad, Wik, 2003; McIntyre *et al.*, 2006). Moreover, several other predators, such as marine mammals...
might rely on these food resources (Hassani et al., 1997; Pauly et al., 1998).

The identification and quantification of the benthopelagic fish preys are frequently difficult tasks in the feeding studies (Battaglia et al., 2010). In general, the prey specimens are already partially or totally digested and the hard remains in stomachs, intestines, faeces and scats are the only diagnostic features that can be considered. Among those hard remains, otoliths are quite resistant to the digestion and they are considered the important tool for prey classification in several dietary studies (Pierce, Boyle, 1991; Pierce et al., 1991; Granadeiro, Silva, 2000). The examination of sagittae from faeces of marine mammals and sea birds usually required to examine the regurgitated digestive pellets in order to identify the preys (Duffy, Laurenso, 1983; Johnstone et al., 1990; Pierce, Boyle, 1991).

For the above reasons and for their high interspecific variability, number of keys and identification guides on fish otolith morphology has been published (Smale et al., 1995; Campana, 2004; Lombarte et al., 2006; Tuset et al., 2008). The importance of estimation of the biomass of the otolith and their numerical abundance are fundamental to understand fish prey’s energy contribution to predator diet. The relationship between fish length and otolith size and weight is usually used in several fish species to build the body size and prey biomass. In such a practice, the otolith measurement has been used (Wyllie Echeverria, 1987; Gamboa, 1991; Granadeiro, Silva, 2000). The examination of sagittae from faeces of marine mammals and sea birds usually required to examine the regurgitated digestive pellets in order to identify the preys (Duffy, Laurenso, 1983; Johnstone et al., 1990; Pierce, Boyle, 1991).

Materials and Methods

Fish specimens were collected during the period 2007-2008 throughout the southern coasts of Oman using bottom trawls. The specimens were identified following Randall (1995). In most cases the caudal fin was damaged, so standard length (SL; most anterior point to the base of hypural plate at caudal flexion) in place of total length was considered and measured to the nearest millimetre. Sagittae were (total of 132 individuals, i.e., 264 otoliths) removed through a cut in the cranium to expose them then cleaned and stored dry in glass vials and the left and right otolith were considered separately. Specimens with obvious evidence of calcite crystallization (Strong et al., 1986) or other aberrant formations were rejected. Each sagittae, systematically placed with the sulcus acusticus oriented through the observer and its length was determined using hand-held vernier callipers and defined as the longest dimension between the rostrum and postrostrum axis (nomenclature of Smale et al., 1995) and width as the dimensions from the dorsal to ventral edge taken at right angles to the length through the focus of the otolith. Individual otolith weight (in milligram) was determined using an electronic balance. The relationship between otolith size (length, width) and weight and fish size (SL) were determined using least squares linear regression for the following parameters: otolith length (OL)-fish length (SL), otolith width (OW)-fish length (SL), and otolith weight (OWE)-fish length (SL). These equations were first calculated for both left and right otoliths and the t-test was used to check any differences between regressions. The regression coefficients were compared and when significant differences (P<0.05) were found, the \( H_0 \) hypothesis (b\(_{\text{right}}\) = b\(_{\text{left}}\)) was accepted. When the equations did not differ statistically, a single linear regression was reported for each parameter (OL; OW; OWE). The significance of the linear regressions was verified using the F-test.

Results

The range of the standard length of the specimens used in this study is 130-240 mm with a mean of 204.1 mm. The fish lengths available for the species in question were those observed in
commercial fisheries and research surveys but the extremes of length ranges were under sampled. Regression of the difference between left and right otolith on fish length indicated slopes not significantly different from zero with 0.0048, 0.0129, 0.0805 correlation for otolith length, width and weight respectively. Results of regression analysis are given in Table 1.

The range in observed values for otolith length, width, and weight of the species in question are 9-16, 7-11, and 0.07-0.22 respectively. A linear regression model was used to determine the relationship between the fish length and otolith size and weight. Results of regression analyses are given in Table 2. In otolith weight and length the regression model appeared to adequately describe the relationship with fish length with both high correlation (0.7998 and 0.5901 respectively) and significant estimates for slopes and intercepts. No observations at lengths less than 130 mm were not may be not be appropriate.

### Tab. 1 - Results of regression analysis of the difference between left and right otolith dimension on fish length.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Intercept</th>
<th>Slope</th>
<th>Correlation</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>204.27</td>
<td>1.681</td>
<td>0.0048</td>
<td>Not significant</td>
</tr>
<tr>
<td>Width</td>
<td>204.71</td>
<td>4.117</td>
<td>0.0129</td>
<td>Not significant</td>
</tr>
<tr>
<td>Weight</td>
<td>202.70</td>
<td>1651.30</td>
<td>0.0805</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

### Tab. 2 - Results of regression analysis of fish length on otolith dimension. SD = standard deviation of the estimated fish length.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Intercept</th>
<th>Slope</th>
<th>Correlation</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>1.5943</td>
<td>16.238</td>
<td>0.5901</td>
<td>17.4909</td>
</tr>
<tr>
<td>Weight</td>
<td>91.1660</td>
<td>696.7009</td>
<td>0.7998</td>
<td>20.3630</td>
</tr>
<tr>
<td>Width</td>
<td>241.3500</td>
<td>-3.8678</td>
<td>0.0224</td>
<td>3.4115</td>
</tr>
</tbody>
</table>

**Discussion**

Due to their high inter-specific variability in shape, otoliths are considered as a profound taxonomic tool in fish species identification (Battaglia et al., 2010). Therefore the identification of fish preys is supported by some reference works (Smale et al., 1995; Campana, 2004; Lombarte et al., 2006; Tuset et al., 2008), however, only certain geographical areas are covered and the access to reference material remains requisite (Santos et al., 2001). Thus, an essential objective of researchers studying the marine predators’ feeding habits is to add more information to what is already available of the fish otolith morphology and on the estimation of specific equations, which is useful to calculate the size and mass of preys.

The results of the present paper address to this need, providing SL-OL, SL-OW and SL-OWE relationships for the benthopelagic fish species, *Beryx splendens*. Despite the importance role of this species in top predators’ diet, its biology and ecology had not been well investigated until today in Oman at least.

The work at hand presents a preliminary useful tool for better understanding the trophic relationships in the Arabian Sea coasts of Oman food web. The rebuilding of prey biomass from otolith size and weight may of benefit to the benthopelagic fishes of the Arabian Sea Coasts of Oman as to show their role in the bottom of the sea trophic structure, as pointed out by number of feeding studies in several fish groups (Castr iota et al., 2007; Falautano et al., 2007; Consoli et al., 2008; Karakulak et al., 2009). However, up to this day, there is a severe lack of data in the Arabian Sea coasts of Oman which hindered an appropriate quantification of their prey biomass and classification to species level in the diet of Arabic Sea coasts of Oman benthic predators. Nothing on record about stomach content of benthic and benthopelagic fishes of the studied area.

On contrary of the previous studies on the relationship between fish and sagitta sizes and weight (Wyllie Echeverria, 1987; Gamboa; 1991; Granadeiro, Silva, 2000; Harvey et al., 2000; Wessle et al., 2003; Battaglia et al., 2010), this paper supplies additional information by considering both the otolith length (OL), otolith width (OW) and otolith weight (OWE). It is more suitable to calculate more than two equations (SL-OL, SL-OW and SL-OWE) since the tip of the otolith rostrum or the dorsal or ventral edges of the otolith may be damaged, making it impossible to measure the OL or OW. Moreover, the coefficient of determination of the SL-OL and SL-OWE linear regression attained a higher value than in the SL-OW (Table 2).
In contrast with the findings of Waessle et al. (2003); Harvey et al. (2000), the otolith of the species in question did not show significant differences in size between left and right sagittae. This finding is in agreement with the results of Battaglia et al. (2010).

In spite of all data fitted well with the linear regressions (SL-OL and SL-OWE), it is advisable to use these equations within the fish size range limit reported for this species in the results section. Authors who studied wide range of fish length and include larvae in their sample, have supplied two different SL-OL regressions, one for the small sized fish and another for the adult specimens (Nishimura, Yamanda, 1988; Linkowski, 1991). Since the individuals of B. splendens collected in the present paper belong to the 130-240 mm SL range, the regressions SL-OL and SL-OWE calculated here in can be accepted.

It is important at this stage to draw the attention to some limitations to the use of biomass reconstruction from otolith size and weight. The growth of individuals belonging to the same species may show some variations for different areas and stock (Campana, Casselman, 1993; Reichenbacher et al., 2009) or between sexes (Wyllie Echeverria, 1987). Furthermore, otolith size might become underestimation due to the exposure of the otoliths to chemical and mechanical abrasion in the digestive track of predators (Jobling, Breiby, 1986; Granadeiro, Silva, 2000).

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References

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Relationship between fish size and otolith in *Beryx splendens*


Riassunto Lungo

Nel tentativo di comprendere meglio le catene trofiche che consentono il sostentamento di pesci commercialmente importanti, l’analisi dei contenuti stomacali risulta particolarmente importante. Attraverso questo tipo di studi, infatti, è possibile individuare le specie predate e conoscere le condizioni ecologiche ottimali per il supporto di grandi banchi di pesce pescabile. Sfortunatamente, nella maggior parte dei casi, il contenuto stomacale risulta parzialmente digerito e solo poche parti anatomiche possono ancora essere studiate per ottenere le informazioni cercate. Tra queste, gli otoliti sono particolarmente importanti perché sono in buona parte resistenti alla digestione e hanno morfologie specie-specifiche. Lo studio degli otoliti può dunque fornire informazioni importanti nella ricostruzione delle catene trofiche marine.

In questo lavoro viene studiata la regressione tra la forma (lunghezza e larghezza), il peso degli otoliti e la lunghezza della specie bentopelagica Beryx splendens che vive nell’ambiente costiero dell’Oman nel Mare Arabico. Tramite t-test non sono state evidenziate differenze tra la forma e il peso degli otoliti destro e sinistro, è stata registrata una regressione lineare tra la lunghezza standard (SL) e lunghezza (OL), larghezza (OW) e peso (OWE) degli otoliti. I dati coincidono con il modello di regressione sia per OL sia per OWE in rapporto a SL (R² 0.6-0.8). Questo rapporto fornisce un ottimo strumento di supporto per studi sull’alimentazione e per i paleontologi nelle loro ricerche sui pesci fossili.