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Relationships between fish size and otolith size of four bathydemersal fish species from the south eastern Arabian Sea, India

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Summary

The objective of this study was to estimate a prey body size from the hard parts (e.g. otoliths) of a fish species frequently found in the guts of predators. Length–weight relationships between otolith size (length, height, weight and aspect ratio) and fish size (total length and weight) were determined for four fish species captured in the Arabian Sea by bottom trawl (2015 survey on-board FORV *Sagar Sampada*, 200–300 m depth), off the west coast of India: *Psenopsis cyanea*, *Pterygotrigla hemisticta*, *Bembrops caudimacula* and *Hoplostethus rubellopterus*. No significant differences were noted between the size of the left and right otoliths (*t* test) in any of the four species. The length–weight relationship of the otolith in all four species showed a negative allometric growth pattern (*t* test, $p < .05$). The data fitted well to the regression model for otolith length (OL), otolith height (OH) and otolith weight (OW) to total length (TL) and total weight (TW). Results showed that these relationships are a helpful tool in predicting fish size from the otoliths and in calculating the biomass of these less-studied fish species during feeding studies and palaentology.

1 | INTRODUCTION

Templemann and Squires (1956) and Echeveria (1987) reported the use of otolith in calculating the size of fishes. Otoliths, especially sagittae or sacular otoliths, are taxonomically distinct (Longenecker, 2008). By establishing a relationship between the fish length and otolith size, it is possible to back-calculate the fish size and biomass (Echeveria, 1987; Gamboa, 1991; Garcia et al., 1998; Granadeiro & Silva, 2000; Harvey, Loughlin, Perez, & Oxman, 2000; Martin-Smith, 1996; Tarkan, Gaygusuz, Gaygusuz, & Acipinar, 2007; Waessle, Lasta, & Bavero, 2003). For most species, the relationship between otolith length and fish length can be described by a simple linear regression (Battaglia, Malara, Ammendolia, Romeo, & Andaloro, 2015; Battaglia, Malara, Romeo, & Andaloro, 2010; Gamboa, 1991). High levels of interspecific variation in the otolith size and morphology are considered as useful taxonomic tools for species identification and discrimination of fish stocks (Campana, 2004; Campana & Casselman, 1993; Campana, Chouinard, Hanson, FreÂchet, & Brattey, 2000; Stransky & MacLellan, 2005; Tracey, Lyle, & Duhamel, 2006). Sagittal otoliths, however, are primarily used for age determinations (Boehlert & Yoklavich, 1984; Chilton & Beamish, 1982; Horn & Sullivan, 1996; Jenkins & Davis, 1990; Strelcheck, Fitzhugh, Coleman, & Koenig, 2003; Tracey & Horn, 1999; Vieira, Figueiredo, Figueiredo, & Menezes, 2013). They are also species-specific (Morrow, 1979). Sagittae morphology and morphometrics have been used in trophic studies (Campana et al., 2000; Sadighzadeh et al., 2014; Saetersdal, 1953; Templemann & Squires, 1956).

Four species belonging to four families (Centrolophidae, Percophidae, Trachichthyidae and Triglidae) were studied where no information was available on otolith and fish size relationships. These species are: *Psenopsis cyanea* (Alcock, 1890); *Bembrops caudimacula* Steindachner, 1876; *Pterygotrigla hemisticta* Temminck and Schlegel, 1893; and *Hoplostethus rubellopterus* Kotlyar 1980, being the dominant species caught during the bottom trawling operations beyond 200 m depths. Despite their dominance along the south eastern Arabian Sea, their ecology and stock structures had not yet been investigated. Considerable work has been carried out on the biology of fishes in continental shelf waters of the Arabian Sea (Sreedhar, Sudhakar, & Meenakumari, 2013; Venu & Kurup, 2002a,b, 2006). A majority of the work has been done regarding their distribution, abundance and length–weight relationships (Deepu, Haridas, & Kurup, 2007; Jayaprakash et al., 2006; Sreedhar et al., 2013; Thomas, Venu, & Kurup, 2003). The main objective of this study was to estimate the relationship between otolith size (length, height and aspect ratio) and fish size of these four species from Indian waters.

2 | MATERIALS AND METHODS

Sampling was carried out in the deep-sea fisheries expeditions onboard FORV *Sagar Sampada* (cruise no: 338) during 2015. A total of three sampling stations (9°01. 909′–12°14. 081′ Lat.; 74°19. 401′–75° 48. 029′ Long.) were covered at depth ranges from 200 to 300 m using a 38 m high speed demersal trawl II. Biometric characteristics of the fishes were measured on-board. Samples were identified at species level using standard identification keys (Alcock, 1898, 1899; FAO, 1984), preserved in 5% formaldehyde, and brought to the onshore laboratory for further analyses.

A total of 282 otoliths from four fish species were analysed for the study. After taking morphometric measurements the sagittal otoliths were removed by making a cut in the cranium. The collected otoliths were cleaned, dried and stored in glass vials. Length (OL) and post-rostrum height (OH) measurements of the otoliths were taken using a digital vernier calliper with a rated accuracy of 0.03 mm with the sulcus acusticus oriented towards the observer. The otolith length (OL) is the longest dimension between rostrum and post rostrum, and the height (OH) is the dimension from the dorsal to ventral edge taken at right angles to the length through the focus of the otolith (Smale, Watson, & Hecht, 1995). Individual otolith weight (OW; in milligrams) was determined using an electronic balance (Metler Toledo, ML 503) with an accuracy of 0.001 g. The aspect ratio (AR) is the ratio between otolith length (OL) and otolith height (OH) and estimated by dividing the otolith height by the otolith length. The relationship between the otolith size (length, height, weight, aspect ratio) and fish size (total length [TL], total weight [TW]) were determined using a power regression model between various measurements (Le Cren, 1951; Zar, 1984). The equations were first calculated with both the right and left otoliths. A *t* test was used to check the difference between the regressions (Fowler & Cohen, 1992). The regression coefficients were compared and when significant differences ($p < .05$) were not found, the *H*0 hypothesis (*b* right = *b* left) was accepted. Sexual dimorphism in the relationship between various measurements was analysed by ANCOVA.

3 | RESULTS

The highest number of specimens analysed was in *Psenopsis cyanea* (Alcock, 1890) followed by *Bembrops caudimacula* Steindachner, 1876, *Pterygotrigla hemisticta* Temminck and Schlegel, 1893, and

TABLE 1 Relationship between otolith length (OL), weight (OW) and for size ranges total length (TL) and total weight (TW) of four bathy-demersal fish species captured during a routine survey, south-eastern Arabian Sea in 2015, using a bottom trawl.

		Total length (cm)	Total weight (g)	Otolith length (mm)	Otolith weight (mg)	Otolith height (mm)	Relationship between	Regression parameters for Otolith length-weights		Standard Error (SE) of the regression parameteres		Correlation coefficient
	n	Min–Max	Min–Max	Min–Max	Min–Max	Min–Max		*a*	*b*	*SE (a)*	*SE (b)*	R^2
Psenopsis cyanea	205	9.9–20.4	5–65	5.26–11.33	0.008–0.045	2.97–5.78	OL × OW	0.00006	2.6855	0.0288	0.0324	.97
Bembrops caudimacula	27	15.3–21.1	28–64	4.17–5.50	0.009–0.022	2.3–3.42	OL × OW	0.0003	2.5836	0.234	0.33869	.708
Pterygotrigla hemisticta	21	13.5–18.5	24–68	3.94–5.71	0.009–0.03	2.69–4.32	OL × OW	0.0004	2.4588	0.2886	0.4214	.6541
Hoplostethus rubellopterus	25	8–11	5–15	2.23–3.17	0.002–0.006	1.94–2.65	OL × OW	0.000001	2.7994	0.2854	0.6758	.482

Min-Max, minimum and maximum values observed; *n*, sample size; '*a*' and '*b*', regression parameters; *SE*, standard error; R^2, Correlation coefficient.

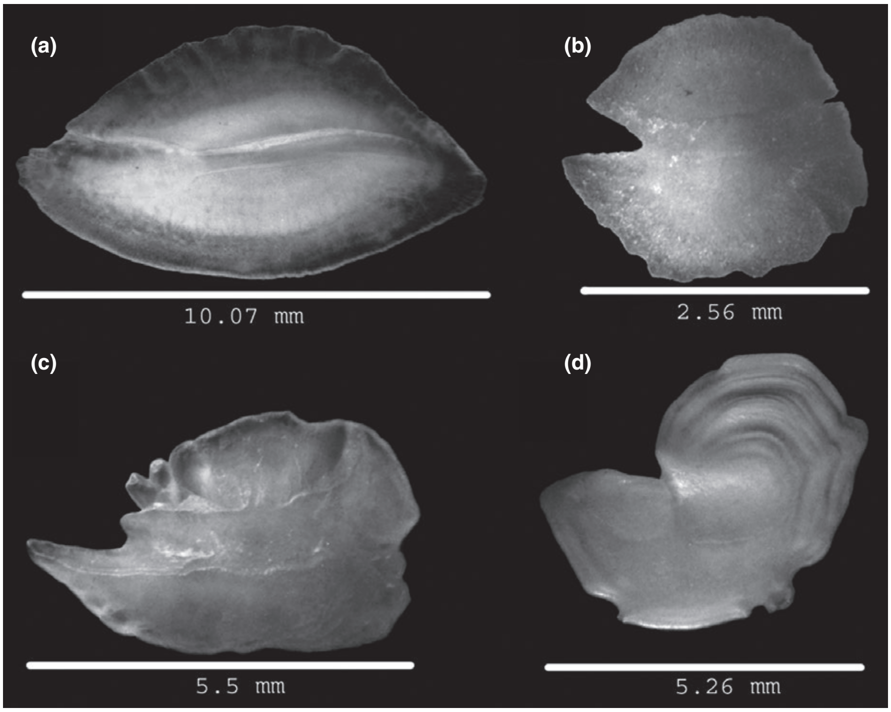

FIGURE 1 Otolith shapes of the four species studied: (a) *Psenopsis cyanea* (TL = 17.4 cm, *W* = 46.34 g), right otolith (OL = 9.82 mm, OW = 0.0282 g, OWi = 5.03 mm); (b) *Pterygotrigla hemisticta* (TL = 16.1 cm, *W* = 45 g), right otolith (OL = 2.68 mm, OW = 0.004 g, OWi = 2.39 mm); (c) *Bembrops caudimacula* (TL = 20.1 cm, W = 58 g), right otolith (OL = 5.52 mm, OW = 0.016 g, OWi = 3.32 mm); (d) *Hoplostethus rubellopterus* (TL = 9.4 cm, W = 14 g), right otolith (OL = 5.26 mm, OW = 0.022 g, OWi = 3.32 mm) (TL, total length; *W*, weight; OL, otolith length; OW, otolith weight; OH, otolith height)

Hoplostethus rubellopterus Kotlyar 1980. Previous misidentification of *H. mediteranneus* from Indian waters has been corrected to *H. rubellopterus* in the present study according to Vinu et al. (2016). Table 1 provides the overall basic statistics on the size and weight ranges covered, the otolith lengths, weights and heights for all four species as well as the regression parameters for their relationships.

3.1 | Otolith morphology

The representative otoliths of each species are shown in Figure 1. showing their characteristic morphology, which is fully in line with the descriptions and nomenclatures identified by Smale et al. (1995) and Tuset, Lombarte, and Assis (2008).

The ranges of morphometric measurements on fish length and weight as well as otolith dimensions of the four species are shown in Table 1. The *P. cyanea* otolith was the largest among the four species (length 7.78 ± 1.59 mm, weight 0.02 ± 0.01 mg, and height 4.16 ± 0.73 mm). The differences in morphometric measurements of both left and right otoliths in the four fish species are not statistically significant (*t* test, $p < .05$). Hence, the right otolith was selected for morphometric analysis. Sexual dimorphism in the relationship between fish size and otolith size was also not statistically significant (ANCOVA $p > .05$). The length–weight relationship of otoliths of all four species showed negative allometric value (*t* test, $p < .05$) (Table 1).

The relationship between fish size and otolith size is shown in Table 2. High values of the coefficient of correlation (R^2) were obtained for otolith length, and in the height of *P. cyanea* and *B. caudimacula*.

The otolith height was best correlated with the total length for *P. cyanea*, compared to the other three species ($R^2 = .92$). The otolith length showed the highest correlation for predicting total length

TABLE 2 Relationship of various morphometric measurements of fishes and their otoliths.

Species	Relationship between	Length-weight regression		Parameters of relationships		
		a	*b*	*SE* (*a*)	*SE* (*b*)	R^2
P. cyanea	OL × TW	0.0478	2.9921	0.063048	0.071058	.895
	OH × TL	3.1015	1.0692	0.01257	0.02034	.9297
B. caudimacula	OL × TL	5.843	0.383	0.063551	0.091838	.736
	OL × TW	0.7554	2.5978	0.17288	10.52085	.8132
H. rubellopterus	OH × TL	4.3077	0.6453	0.03967	0.0782	.791
	OW × TW	242.38	0.7923	0.128652	0.1266	.762
P. hemisticta	OL × TW	1.7522	3.2893	0.15487	0.36662	.78
	OL × TL	7.4325	0.799	0.05081	0.1203	.658

R^2, Correlation Coefficient, 'a' and 'b', regression parameters; SE, standard error; OL, otolith length; OH, Otolith height; OW, otolith weight; TL, total length; TW, total weight.

TABLE 3 Exponential formula derived for estimating fish size from the otolith size.

Species	Exponential formula	R^2
P. cyanea	TL = 3.1015 $OH^{1.0692}$	.9297
	TW = 0.0478 $OL^{2.9921}$	.895
B. caudimacula	TL = 5.843 $OL^{0.383}$	.736
	TW = 0.7554 $OL^{2.5978}$	.8132
H. rubellopterus	TL = 4.3077 $OH^{0.6453}$	.791
	TW = 242.38 $OH^{0.7923}$	.762
P. hemisticta	TL = 7.4325 $OL^{0.799}$	.685
	TW = 1.7522 $OL^{3.2893}$	.78

TL, total length; TW, total weight; OL, otolith length; OW, otolith weight; OH, otolith height.

and weight for *B. caudimacula*, although this correlation was not very strong (R^2 > .736). The aspect ratio of the otoliths was not correlated with the fish size in any of the four species. Otolith weight and height gave the most accurate estimate for total length for *H. rubellopterus*. Otolith weight was significantly correlated with the total weight of the fish (R^2 = .76). Otolith length of *P. hemisticta* allowed good estimates for total weight of the fish (R^2 = .78) compared to total length (R^2 = .63). The R^2 value for estimates for fish size from the otolith for *P. hemisticta* were less satisfactory compared to the other three species. The power regression equation fit well compared to the linear regression for expressing the relationship between the morphometric measurements. The exponential formulae derived for the various size variables of otolith are given in Table 3.

4 | DISCUSSION

Little information is available on the otolith morphology of deep-sea fishes from Indian waters. The main reason behind the difficulty in obtaining data is the absence of a targeted fishery due to the limited commercial importance. The information is available only from scientific expeditions and as bycatch from deep-sea trawlers (Venu & Kurup, 2002a,b, 2006; Vipin et al., 2011, 2015). The prey species identified from partly digested material removed from the guts of predators are often classified as either unidentified or at the family or genus level (Akhilesh et al., 2013). An accurate identification of the prey species is essential for studies on the trophic structure and food web dynamics.

The results are in conformity with earlier studies that reported the relationship between otolith size and fish size (Jawad, Ambuali, Al-Mamry, & Al-Busaidi, 2011; Metin & Ilkyaz, 2008). The strong correlation between the otolith size and the somatic size suggests that somatic growth has a significant influence on the otolith accretion, as reported by Munk (2012). The aspect ratio was found to be unsuitable for extrapolating fish length and weight in the four fish species selected for the present study.

No significant difference was observed between the right and left otolith, which the literature expected (Harvey et al., 2000; Hunt, 1979; Waessle et al., 2003). The linear relationship between otolith length and fish length depends upon the growth stanza of the fish (Mugiya & Tanaka, 1992); these relationships become curvilinear in some larval or juvenile fishes (West & Larkin, 1987). A majority of previous studies focused on the relationships between fish size and otolith length (OL), weight (OW) or otolith height (OH) (Battaglia et al., 2010, 2015; Harvey et al., 2000; Waessle et al., 2003).

The relationship between otolith size and form may change at intervals relative to fish size (Frost & Lowry, 1981), different distributional areas, the stock and sexes (Campana & Casselman, 1993; Karakulak, Erk, & Bilgin, 2006; Reichenbacher, Kamrani, Esmaeili, & Teimori, 2009; Sparre, Ursin, & Venema, 1989) as well as ontogenetic changes in the life history (Hare & Cowen, 1995). Using otoliths sampled from predatory fish, it may well be that the size may change due to their exposure to chemical and mechanical abrasions in the digestive tract (Granadeiro & Silva, 2000), which might affect the prediction of the prey size, and there is a chance of errors in the extrapolation because of these interactions. The estimation of the specific equations provided in the present study can be useful for studies on food and feeding as well as for paleontological studies, population dynamics, and yield estimates.

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