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Relationship between fish size and otolith size of four deep-sea fishes from the Western Bay of Bengal, India

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The present study provides the otolith morphology and morphometric relationships with fish size of four deep-sea fishes (*Parascombrops pellucidus* Alcock, 1889, *Alepocephalus blanfordii* Alcock, 1892, *Lamprogrammus niger* Alcock, 1891, *Pterygotrigla hemisticta* (Temminck & Schlegel, 1843)) collected from western Bay of Bengal during March 2020. Among these, the equations were derived for the first time for three species (*P. pellucidus*, *A. blanfordii*, *L. niger*). Sampling was done as a part of deep-sea exploratory survey of FORV *Sagar Sampada* along the deeper shelf regions of the Bay of Bengal at a depth range of 200 – 1000 m using high-speed demersal trawl (HSDT-CV). The numerical relations established using regression between fish size (TL) and various otolith morphometric measurements (otolith length (OL), otolith height (OH), otolith weight (OWe), otolith area (OA) and otolith perimeter (OP)) can be used to predict the prey size in food and feeding studies for studying the food web dynamics of less-studied deep-sea fishes. LWR of the otolith of selected species showed a negative allometric growth (*t*-test, $p < 0.5$). The higher r^2 value (> 0.70) obtained for the relationship between fish size (TL) and various otolith morphometric measurements indicates the robustness of the model. The representative images of otoliths of these fishes will be helpful to the taxonomists for the species confirmation and reconstruction of past species assemblages in the palaeontological studies.

[**Keywords**: Deep-sea fishes, Indian water, Morphometry, Otolith, Western Bay of Bengal]

Introduction

Otolith morphology is gaining much importance in many ichthyological studies and otoliths of more than 3000 species are available in various otolith atlases and online databases[1-3]. Otoliths have many biological functions in fishes *viz*., locomotion, hearing and balancing[4,5], swimming and acoustic communication[6], etc. Otoliths have a broad spectrum of usage in fisheries and ichthyology research. They are used as the tools for predicting size of the fish in food web dynamics studies and their morphology has wide uses in palaeontology, phylogeny, evolutionary and interpretation of historical fisheries[7,8].

In fisheries, otolith morphology has a significant role in understanding taxonomical identification of species[9,10], stock discrimination and spatio-temporal variation in population structure[11,12] and in pray size and type in feeding studies[13]. Otolith morphological variability also helps in measuring biodiversity along with conventional biodiversity indices such as richness, evenness and dominance[14]. Fishes possess three pairs of otoliths *viz*., sagitta, asteriscus, lapillus, among these sagittal otoliths are preferred over the other two due to its large size and high intra-specific morphological variation[15].

Many past and recent studies on the Indian deep-sea fishes are restricted to taxonomy[16,17], basic life history characteristics such as length-weight relationships[18-19] and feeding and reproductive biology[20,21]. Studies on the morphology and morphometric relationships of the otoliths of deep-sea fishes of India are found to be limited[22-24]. Further, the equations are derived for very few fishes and found to be inadequate considering the rich deep-sea fish diversity of India[25,26]. Hence, it is highly imperative to derive similar equations for a maximum number of species for understanding the food and feeding pattern and to advance our knowledge on food web dynamics in deep-sea fishes of the Indian EEZ.

Many of the studies on the relationship between fish size and otolith morphometric measurements are found to be restricted to the Arabian Sea and

Andaman Sea[22-24,27] and similar studies are absent in Bay of Bengal waters. Hence, the numerical equations provided in the present study tries to fill this gap for reconstructing the fish size from various otolith morphometric measurements and understanding the spatial variations in these relationships.

Material and Methods

Samples were collected from western Bay of Bengal waters (Lat. 10°49.516′ – 16°57.040′ N; Long. 80°22.608′ – 82°59780′ E) as part of deep-sea exploratory surveys conducted onboard FORV *Sagar Sampada* (Cruise no. 398) of Centre for Marine Living Resources & Ecology (CMLRE), Ministry of Earth Sciences (MoES), Government of India, using a High-Speed Demersal Trawl (Crustacean version) during March 2020 at a depth range of 200 – 1000 m. Four deep-sea fishes were selected for the present study (*Parascombrops pellucidus* Alcock, 1889; *Alepocephalus blanfordii* Alcock, 1892; *Lamprogrammus niger* Alcock, 1891; and *Pterygotrigla hemisticta* (Temminck & Schlegel, 1843)) belonging to four families *viz*., Acropomatidae, Alepocephalidae, Ophidiidae and Triglidae, respectively.

Samples were examined and identified up to the species level with the help of standard identification keys and published papers[28-30]. Morphometric measurements of the fishes were collected onboard, and samples were transported to the CMLRE laboratory for future analysis. A total of 127 otoliths from four deep-sea fish species were collected from the roof of the mouth by exposing the ventral surface of the cranium[31]. Number of samples for each species ranged from 21 to 39 (21, 32, 35 and 39 for *A. blanfordii*, *P. hemisticta*, *P. pellucidus*, and *L. niger*, respectively). Otoliths were dried and stored in plastic vials for further morphometric analysis. In the present study, right otoliths were selected for the subsequent analysis since both right and left otoliths are considered mirror images of each other[22,23,30]. Otolith photographs were captured with the help of a stereo zoom trinocular microscope (Leica model No. S8APO Camera, Leica DFP-425) and weighed using digital weight balance (Metler Toledo, ML 503, accuracy 0.0001 g) in milligrams. All the otolith morphometric measurements *viz*., otolith length (OL), otolith height (OH), otolith area (OA) and otolith perimeter (OP) were taken in millimetres using the image analysing software “ImageJ”.

Fish size and fish otolith morphometric measurements were converted into logarithmic values (Log10) for excluding the possible outliers in the data[33]. A simple linear regression model according to Le Cren[32] was fitted to the data to understand the relationship between the otolith length and otolith weight, and otolith morphometric measurements and fish size (total length, TL). Least square method was followed to estimate regression parameters *a* and *b*[32-34], where *a* is the intercept of the regression curves and *b* is the slope[35].

Results

Table 1 furnishes the information regarding the sample size, minimum and maximum values of fish length, fish otolith length and weight for four species along with their regression parameters explaining the otolith growth pattern. The representative images of the otoliths of four species are given in Figure 1.

The study indicated that, among the four species selected, *L. niger* possesses bigger otoliths (otolith length, 25.29±3.12 mm; otolith weight, 374.8±77.33 mg) and *P. hemisticta* have smaller otoliths (otolith length,

Table 1 — Relationship between otolith length and otolith weight and for the size ranges (total length TL) of four deep-sea species captured in Bay of Bengal waters during 2020 using high speed demersal trawl. *n* = sample size; TL = total length; Min-Max = minimum and maximum values observed; “*a*” and “*b*” = regression parameters; *SE* = standard error; r^2 = correlation coefficient; CL = confidence limits

Species	*n*	TL (cm) Min-Max	OL (mm) Min-Max	OWe (mg) Min-Max	Regression parameters for otolith length and otolith weights					95 % CL	
					a	*b*	SE *a*	SE *b*	r^2	*a*	*b*
Parascombrops pellucidus Alcock, 1889	35	2.016-8.258	3.423-4.953	3.1-8.6	0.1338	2.559	0.107	0.18	0.86	0.0808-0.2214	2.191-2.926
Alepocephalus blanfordii Alcock, 1892	21	30.5-47.8	5.727-8.28	15.7-37.6	0.4705	2.079	0.242	0.29	0.73	0.1459-1.5176	1.479-2.679
Pterygotrigla hemisticta (Temminck & Schlegel, 1843)	32	13-21.1	2.256-3.48	2.1-6.5	0.2221	2.759	0.105	0.24	0.81	0.1352-0.3650	2.273-3.245
Lamprogrammus niger Alcock, 1891	39	32.8-66.7	9.66-25.29	37.8-374.8	0.1556	2.421	0.182	0.14	0.88	0.0663-0.3651	2.130-2.712

3.48±0.302 mm; otolith weight, 6.5±1.25 mg). Relationship between OL×OWe of four species showed negative allometric relation (*b* value range from 2.079 – 2.759) (*t*-test $P < 0.05$). The r^2 values for these relations were higher than 0.8 for three species and *A. blanfordii* showed lowest r^2 values (0.73).

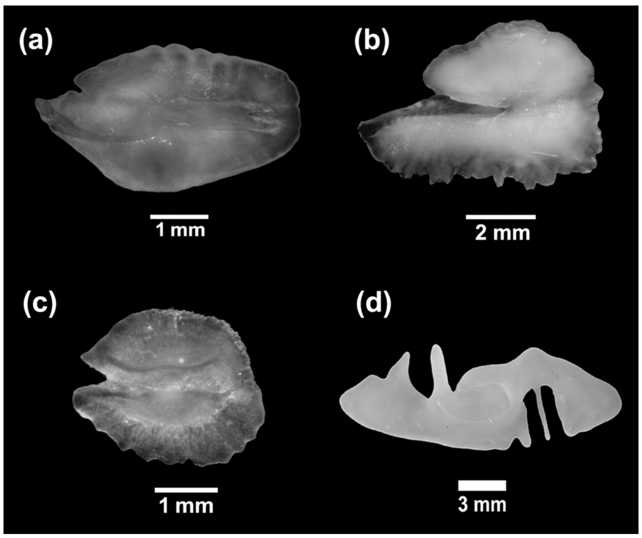

Fig. 1 — Otolith shapes of four species studied: (a) *Parascrombrops pellucidus* (TL = 9.52 cm), otolith (OL = 4.81 mm, OWe = 7.1 mg); (b) *Alepocephalus blanfordii* (TL = 42.5 cm), otolith (OL = 7.07 mm, OWe = 27.5 mg); (c) *Pterygotrigla hemisticta* (TL = 20.8 cm), otolith (OL = 3.06 mm, OWe = 4.8 mg); (d) *Lamprogrammus niger* (TL = 56.0 cm), otolith (OL = 21.97 mm, OWe = 250.6 mg). TL = total length; OL = otolith weight; OWe = otolith weight

The results of regression analysis for the association between fish size (TL) and otolith size measurement are given in Table 2. *P. pellucidus* showed a high coefficient of determination ($r^2 > 0.9$) for the relation between fish size and otoliths (r^2 is 0.93 for OA×TL and 0.91 for OL×TL and OP×TL) compared to other three species. However, *L. niger* showed very low r^2 values with all the variables (r^2 is 0.46 to 0.59). The r^2 values obtained for other two species ranged from 0.69 to 0.86 for these relations. Highest r^2 value of 0.93 was reported for the relationship between OA and TL (*P. pellucidus*) and lowest r^2 value of 0.46 was obtained for the relationship between OP and TL (*L. niger*). The study indicated that the equations derived using all otolith morphometric variables and otolith weight can give accurate estimations for reconstructing the prey size (r^2 ranges from 0.93 to 0.73) except for *L. niger* (r^2 ranges from 0.58 – 0.59) (Table 3). Otolith area and otolith length give better estimations for *P. pellucidus*, *P. hemisticta* and *L. niger*, and otolith weight was found to be most suited for predicting the size of *A. blanfordii*.

Discussion

The present study provides regression equations for predicting the fish size of four deep-sea fishes using various otolith morphometric measurements[30,36]. The

Table 2 — Relationship of various morphometric measurements of otolith of fishes collected from Bay of Bengal during 2020. Coefficient of determination (r^2), slope and intercept values (*a* and *b*), 95 % confidence limits and parameters of relationships (SE [*a*] and SE [*b*] are given. OW = otolith width; OWe = otolith weight; OA = otolith area; OP = otolith perimeter; TL = total length of the fish

Species	Relationship between	Parameters of relationships					95 % CL	
		a	*b*	SE (*a*)	SE (*b*)	r^2	*a*	*b*
Parascrombrops pellucidus Alcock, 1889	OL×TL	1.6953	1.0940	0.033	0.056	0.91	1.4484-1.9844	0.979-1.209
	OH×TL	3.4681	0.9629	0.0205	0.058	0.89	3.1505-3.8178	0.844-1.080
	OWe×TL	4.3409	0.3730	0.0208	0.0317	0.81	3.9363-4.7872	0.309-0.438
	OA×TL	2.7812	0.5440	0.019	0.024	0.93	2.5408-3.0443	0.495-0.593
	OP×TL	0.6312	1.0760	0.0576	0.057	0.91	0.4819-0.8268	0.959-1.193
Alepocephalus blanfordii Alcock, 1892	OL×TL	6.0446	0.9820	0.115	0.136	0.73	3.4634-10.5498	0.696-1.267
	OH×TL	9.7072	0.8960	0.089	0.127	0.73	6.3105-14.9322	0.627-1.165
	OWe×TL	9.7147	0.4360	0.0602	0.041	0.85	7.2649-12.9906	0.348-0.524
	OA×TL	6.6141	0.5840	0.105	0.077	0.74	3.9749-11.0056	0.421-0.747
	OP×TL	5.2109	0.6560	0.136	0.099	0.69	2.7016-10.0510	0.447-0.865
Pterygotrigla hemisticta (Temminck & Schlegel, 1843)	OL×TL	6.3610	1.0090	0.055	0.124	0.68	4.9042-8.2505	0.755-1.263
	OH×TL	6.0684	1.2320	0.033	0.087	0.86	5.1931-7.0912	1.055-1.410
	OWe×TL	11.1800	0.3550	0.019	0.033	0.79	10.2085-12.2441	0.287-0.423
	OA×TL	6.6262	0.6290	0.031	0.045	0.86	5.7173-7.6796	0.536-0.723
	OP×TL	2.6761	0.8480	0.078	0.08	0.78	1.8505-3.8700	0.683-1.013
Lamprogrammus niger Alcock, 1891	OL×TL	12.6207	0.5060	0.088	0.069	0.59	8.3699-19.0304	0.366-0.646
	OH×TL	19.9275	0.5590	0.066	0.082	0.55	14.6452-27.1149	0.391-0.726
	OWe×TL	19.9339	0.1960	0.061	0.026	0.58	14.9634-26.5553	0.141-0.250
	OA×TL	30.5545	0.2950	0.036	0.041	0.58	25.7889-36.2006	0.212-0.378
	OP×TL	11.9326	0.3880	0.118	0.068	0.46	6.8649-20.7416	0.249-0.528

Table 3 — Equations derived for estimating fish size from otolith size (TL = total length; OL = otolith length; OWe = otolith weight; OH = otolith height; OA = otolith area; OP = otolith perimeter; r^2 = coefficient of determination)

Species	Exponential formula	r^2
Parascombrops pellucidus Alcock, 1889	TL = 2.781 OA0.54	0.93
	TL = 0.631 OL1.09	0.91
	TL = 1.695 OP1.07	0.91
Alepocephalus blanfordii Alcock, 1892	TL = 9.714 OWe0.43	0.85
	TL = 6.614 OA0.58	0.74
	TL = 6.044 OL0.98	0.73
Pterygotrigla hemisticta (Temminck & Schlegel, 1843)	TL = 6.068 OH1.23	0.86
	TL = 6.626 OA0.62	0.86
	TL = 11.180 OWe0.35	0.79
Lamprogrammus niger Alcock, 1891	TL = 12.621 OL0.51	0.59
	TL = 19.933 Owe0.19	0.58
	TL = 30.554 OA0.29	0.58

association between otolith length and otolith weight is found to be negatively allometric[22,23]. There are no previous estimates are available for the comparisons except for *P. hemisticta*[22].

The *b* value obtained (b = 2.75, r^2 = 0.81) for the relationship between otolith length and otolith weight for *P. hemisticta* in the present study agrees with the previous estimation of Kumar *et al.*[22] (b = 2.46, r^2 = 0.65) when fishes were collected from the Arabian Sea. However, there is a spatial variation in the *b* values (b = 1.01) was noted with the previous estimation (b = 0.80) for the relationship between OL×TL[ref. 22]. Our studies indicated that *P. hemisticta* collected from two different oceanographic conditions (Arabian Sea and Bay of Bengal) showed a differential otoliths growth pattern. Both these waters are highly diverse in their physical, chemical and biological characteristics[37]. Otolith accretion rate is reported to be influenced by the prevailing oceanographic conditions[38]. The variations in the otolith growth rate (*b*) are possibly due to differences in the environmental conditions, food availability, competition among the species, which significantly influences the growth rate of the fish and also the mineral accretion in the otoliths[27,39].

It is worthy to note that otolith dimensions may underestimate the pray size as the thickness of otolith also changes along with the somatic growth instead of longitudinal growth after maturity due to mineral deposition[40,41]. In this condition, otolith weight can be more appropriate to reconstruct the prey size[36]. Also, underestimation of pray size can occur in the same species due to change in a geographical area, stock, sexes and oncogenic changes[42] and chemical damage in digestive track[43]. However, a better coefficient of relationships obtained in the present study indicates that these equations can give an accurate estimation of fish size.

Conclusion

The equations derived in the present study can be successfully used to predict the pray size in food and feeding analysis and the representative images of species provided can be used as a complementary diagnostic character in taxonomic as well as paleontological studies[22,23,44]. Indian waters are quite renowned for their high deep-sea fish diversity and similar studies from these waters are inadequate to understand the biology, life history, sensory constraints and stock/population structure. Hence, further studies on otolith morphology, morphometric relationships and shape are highly inevitable to address these aspects more convincingly.

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Conflict of Interest

The authors of this paper declare no competing or conflicts of interest.

Author Contributions

KB, AKV: Sample collection, taxonomic identification, methodology, data analysis, writing-original draft, writing- review and editing, visualization. HM: Sample collection, taxonomic, identification, writing- review and editing. PJ, SDK, PD: writing- review and editing.

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