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Length-Weight Relationship, Condition Factor and Otolith Shape Indices of Four Creek-Associated Fish of the Northeastern Arabian Sea

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Abstract: This study aimed to estimate the relationship between fish size and otolith size of four creek-associated fishes (*Anodontostoma chacunda*, *Epinephelus diacanthus*, *Johnius glaucus* and *Mugil cephalus*) collected from the north-eastern Arabian Sea from November 2021 to November 2022. The numerical relations were established using regression between fish size (Total length-TL and Body weight-BW) and otolith dimensions (Length-OL, Weight-Owt, Area-OA, Width-OW and Perimeter-OP). All regressions between the fish size and otolith morphometric measurements were highly correlated ($R^2 > 0.8$), which indicates the robustness of the model. Taxonomists can use findings from this study for species confirmation and reconstruction of past species assemblages. These findings might provide insight into predicting the prey size in food and feeding studies to explore the food web dynamics.

Key words: Otolith, condition factor, mean area, marine fish

Introduction

Fish body weight and length can be used to perform the length-weight relationship (LWR) calculation (Oliveira et al. 2020). It is considered one of the most significant factors influencing individuals, populations and assemblages of fish (le Cren 1951). The LWR helps to generate important information for fisheries management by predicting individuals' weight from their length, i.e. biomass and conservation of fish species (Sabbir et al. 2020, Azad et al. 2020). It also enables the estimation of growth patterns, general health of fish, habitat conditions, life history traits, as well as the morphological characteristics of the fish (Froese 2006). LWR is also important in stock assessment and intra/inter-specific morphological comparison of populations (Singh & Serajuddin 2017, Kashyap et al. 2015).

Teleost fishes have three pairs of otoliths, namely sagitta, lapillus and asteriscus (David et al. 1995). They have various biological functions, including hearing, balancing, swimming, acoustic communication and locomotion (Proper & Lu 2000, Chase et al. 2015). Sagittal otoliths are generally the largest and are often used for shape analysis studies. The 2D shapes of otoliths show intraspecies and interspecies variation (Popper et al. 2005, Bose et al. 2020). Generally, otoliths

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have been used to study the age, taxon, growth and size of fishes that are important for monitoring population structures, trophic interactions and stock assessment (Campana et al. 2000, Viva et al. 2015, Khan et al. 2018). Otolith shape studies have been used to delineate fish stocks from different geographic locations and ecological conditions that affect somatic growth and metabolism, resulting in variation in otolith morphology (Bose et al. 2020, Campana & Casselman 1993, Mahé 2019). Otolith size and its morphometry can be used as a taxonomic tool for species identification and delineation of fish stocks due to high levels of inter and intraspecific variations (Stransky & Maclellan 2005, Aneesh Kumar et al. 2017, Ferri et al. 2018, D'Iglio et al. 2021). Otolith dimensions such as length, weight, width, area and perimeter grow linearly with increasing fish size and age (Donkers 2004). The relationship between fish and otolith length can be developed by simple linear regression (Harvey et al. 2000). Back-calculation of the fish size and biomass is also possible from the fish size and otolith size relationship (Zan et al. 2015, Aneesh-Kumar et al. 2017). Otoliths are quite resistant to digestion and are an important tool for prey identification in several feeding biology studies (Pierce & Boyle 1991, Granadeiro & Silva 2000). Moreover, their particular calcareous structure (a concretion of calcium carbonate and other trace elements deposited in a protein matrix) prevents them from easy deterioration and makes it possible to utilize them in paleontological observations. It is reported that fossil otoliths are very helpful for studying ancient teleost fish fauna (Annabi et al. 2013). However, very few published reports are available on the relationship between fish size and the otolith size of the target fish.

The present study explored the relationship between length-weight and fish length-weight, otolith size and weight of four species of four different families.

Materials and Methods

Fieldwork sampling

The Arabian Sea is the north-western part of the Indian Ocean between India and the Arabian Peninsula. The study area is located in Mumbai City in the north-western part of the Arabian Sea between latitudes $18^{0}50'$-$19^{0}20'$N and longitudes $72^{0}56'$-$72^{0}81'$E (Fig. 1). Samples were collected from November 2021 to November 2022 and catches were a part of small-scale fisheries, including gill net and dol net. A total of 468 specimens (*Anodontostoma chacunda* Hamilton, 1822; *Epinephelus diacanthus* Valenciennes, 1828; *Johnius glaucus* Day, 1876 and *Mugil cephalus* Linnaeus, 1758) were taken for length-weight relationship studies.

Otolith shape analysis

Otoliths from four creek-associated fish species were collected from the roof of the mouth by exposing the ventral surface of the cranium (Schneidervin & Hubert 1986). Each right otolith (sagitta) photograph was taken using a stereo microscope (Olympus SZX16) (3.2X). Otolith dimensions, such as length (mm), width (mm), area (mm^2) and perimeter (mm), were quantified using the 'ShapeR' package in 'R 4.1.2' studio software (Libungan & Pálsson 2015).

Statistical analysis

Length measurements were recorded as total length (L) from the tip of the mouth to the end of the caudal fin measured to the nearest 0.1 cm. The total weight (W) was measured using a digital weighing balance with an accuracy of 0.01 g. Length-weight relationship of the selected species was determined using the cube law suggested by Le Cren (1951), $W = aL^b$, where W = body weight, L = total length, a = intercept and b = slope of the regression line. The coefficient of determination (R^2) was estimated to explore the degree of association between L and W. When applying the LWR formula on sampled fish, b may deviate from the "ideal value" of 3 that represents an isometric growth (Ricker and Carter 1958) because of certain environmental circumstances or the condition of the fish. When b is less than 3, fish become slimmer with increasing length, and growth will be negatively allometric. When b is greater than 3.0, fish become heavier, showing positive allometric growth and reflecting optimum conditions for growth. The condition factor is used for comparing the condition, fatness or well-being of fish based on the assumption that heavier fish of a given length are in better condition (Wootton 1998). Fulton's condition factor was calculated following the formula proposed by Fulton (1904) as Fulton's $K = 100 \times W / L^3$, where W = weight of the fish (g) and L = length of the fish (cm). A simple power regression model was fitted to determine the degree of association (R^2) between fish size (length-weight) and otolith dimensions (length, weight, width, area and perimeter). All the statistical analyses were done using MS-Excel and R programming language versions 4.1.2 & 4.2.1. For all statistical we used a significance level of 95% ($p < 0.05$).

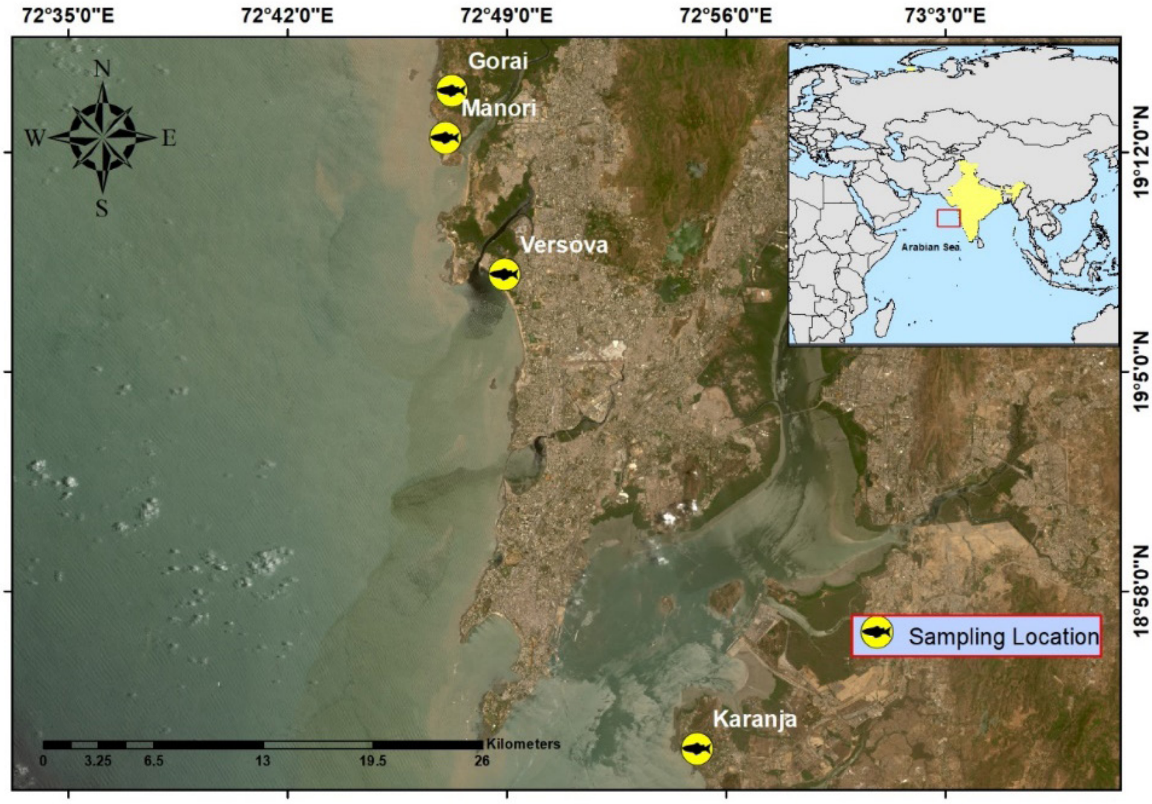

Fig. 1. Sampling sites of the study.

Results

The estimated parameters of the length-weight relationship are presented in Table 1, i.e., sample size (N), minimum and maximum total length (TL), minimum and maximum body weight (BW), mean of length and weight, standard error (SE), intercept (a), slope regression value (b), coefficient of determination (R^2) and Fulton's condition factor (k). Based on the calculated 'b value', *A. chacunda*, *E. diacanthus* and *J. glaucus* showed positive allometric growth (b>3); whereas *M. cephalus* showed negative allometric growth (b<3). The Fulton's condition factor (general well-being indicator) ranges from 0.97 (*M. cephalus*) to 1.45 (*E. diacanthus*). The calculated correlation coefficient between TL and BW for all four species is highly correlated (R^2> 0.8).

The estimated parameters of otolith dimensions are presented in Table 2. The shape and morphometric measurements of otoliths are presented in Figs 2 and 3, respectively. We found that, among the four selected species, *J. glaucus* possessed bigger otoliths (OL – 5.19±0.14mm; OWt – 0.22±0.0004gm) and *A. chacunda* had smaller otoliths (OL – 2.84±0.02; OWt – 0.0035±0.001). Relationships between fish size and different otolith dimensions (TLxOL; TLxOWt; TLxOA; TLxOW; TLxOP; BWxOL; BWxOWt; BWxOA; BWxOW; BWxOP) of selected species showed a good correlation (R^2>0.7). The correlation coefficient between the otolith dimensions (OLxOWt; OLxOA; OLxOW; OLxOP; OAxOWt; OWxOWt; OPxOWt) also indicated a significant relationship among themselves (R^2 > 0.7; Fig. 3).

Discussion

Length-weight relationship

The b value of LWR of four marine species was close to the recommended range (2.5-3.5) suggested by Froese (2006): for *A. chacunda* it was calculated as 3.07. Our resulta are almost similar to the results found from Bangladesh (b=3.02) (Siddik et al. 2016); Malaysia (b=3.089) (Arshad et al. 2008) and Pakistan (b=2.9) (Hussain et al. 2010). Previously recorded b values of *E. diacanthus* from Indian waters (b= 2.5 - 3.2) (Ranjeet et al. 2015, Sivakami et al. 2006) were equal or higher than our results (b= 2.5). Estimated b value (3.2) for *J. glaucus* was higher than previous findings (b=3.02 - 3.05) from the Indian coast (Raje 2000, Samanta et al. 2020). The calculated b value of *M. cpehalus* (b=2.4) was slightly lower than the previous studies conducted in SE Iberian Peninsula (b= 2.9) and western Medi-

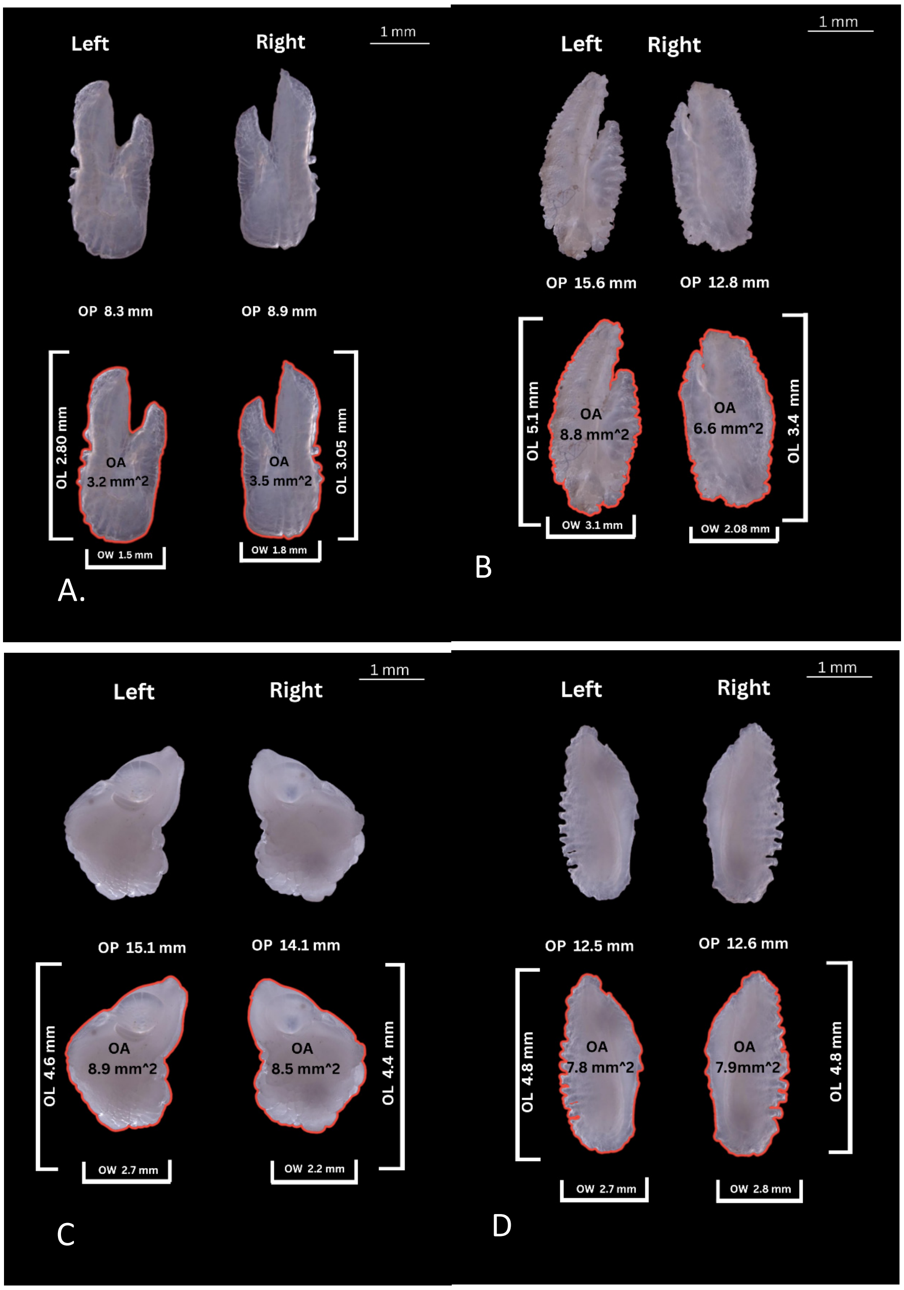

Fig. 2. Different morphometric measurements of otolith of the four species. *A. A. chacunda; B. E. diacanthus; C. J. glaucus. D. M. cephalus.*

terranean Sea (b= 3.3) (Andreu Soler et al. 2006, Verdiell Cubedo et al. 2006). There are several factors responsible for the variation of 'b value', including lack of standardised sampling procedures, especially fishing gear selection, as well as the preservation process, habitat, diet, gender, health condition, seasonal effects, etc. (Hasan et al. 2020, Hossain et al. 2016). These factors may act individually or in combination with others (Islam et al. 2020).

Fish size X Otolith size

Otoliths are considered one of the most powerful taxonomic features for fish species identification due to their significant inter-specific variability in shape. Otolith size and shape of tropical fish may directly reflect the body condition of individuals, regardless of fish size and age (Gagliano & McCormick 2004). However, only a few studies have focused on the classification of fish prey in certain geographical areas (Smale et al. 1995, Campana 2004, Lombarte et al. 2006, Tuset et al. 2008). Therefore, the main aim of the current study was to explore the marine predator's feeding habits and to provide information on the otolith morphology and their relationship equation with fish size. Our results could be useful in calculating the size and mass of preyand provide

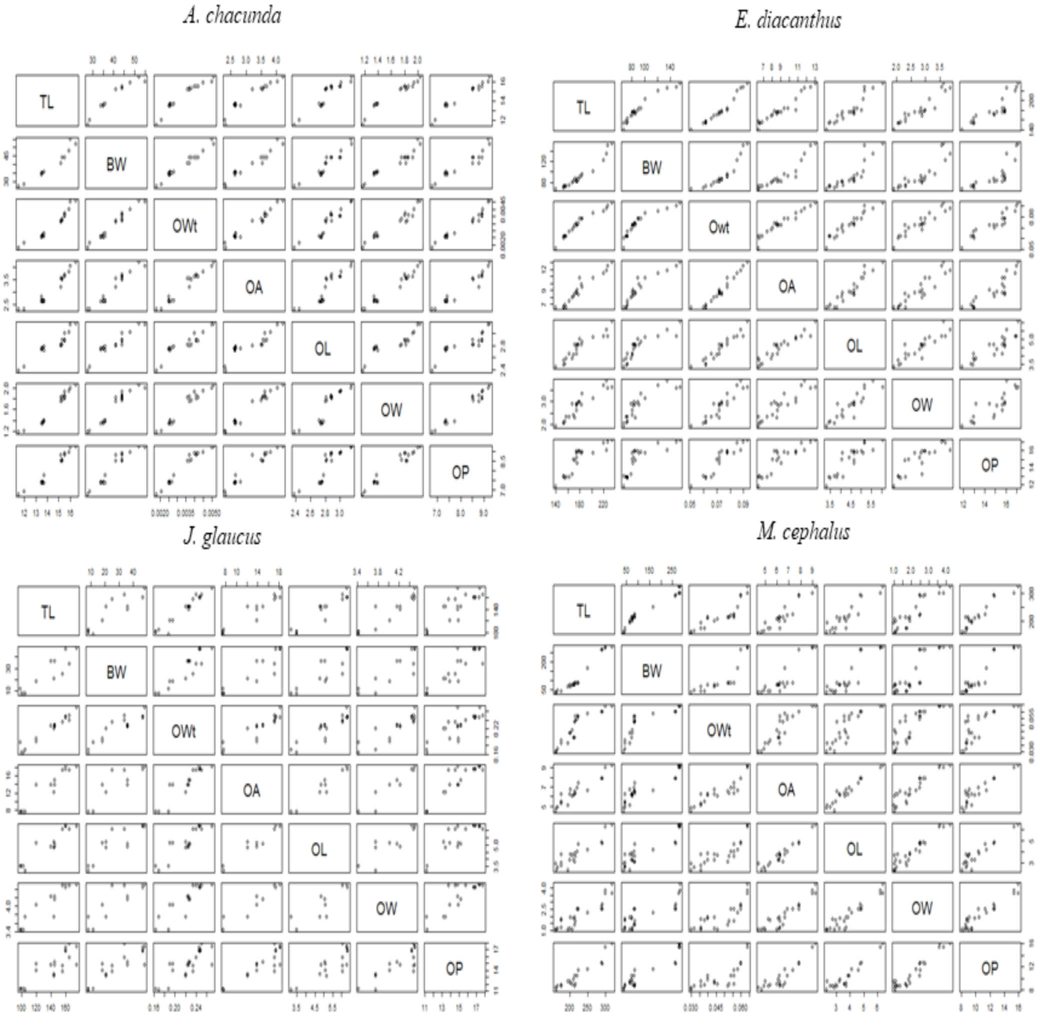

Fig. 3. Correlation between fish length (TL), fish weight (BW) and otolith indices. Owt=otolith weight(gm); OA=otolith area (mm^2); OL=otolith length (mm); OW=otolith width (mm); OP=otolith perimeter (mm).

a baseline reference for trophic studies on the Arabian Sea for identifying and classifying prey and estimating its biomass and size. Based on the morphology of otoliths, we found that demersal fishes (*E. diacanthus* and *J. glaucus*) had bigger otoliths than pelagic or epipelagic fishes (*A. chacunda* and *M. cephalus*). Several authors used simple linear functions to describe fish size and otolith size relationships for many fishes (Battaglia et al. 2015, Mat Piah et al. 2017). Lombarte & Cruz (2007) established a relationship between otolith size, habitat and depth of water. They found that small and very small otoliths characterised epipelagic fishes, whereas demersal fishes had larger otoliths and that otolith size increased with increasing depth until 750 m. In the abyssal community (1000 to 2000 m depth), fishes were characterised by a decrease in the otolith size and an increase in the proportion of species with very small otoliths (Lombarte & Cruz 2007). Epipelagic fishes have smaller otoliths due to background noise and excessive movement of heavy otoliths in rough seas (Paxton 2000). On the other hand, it was also reported that species belonging to sound-producing groups (e.g., sciaenids) had larger otoliths (Cruz & Lombarte 2004). In our study, the high coefficients of determination (R^2>0.7) between otolith size and fish size of the selected fish species showed that fish size might be reliably estimated using the otolith dimensions. Several studies have reported that the relationship between fish length and otolith dimensions can be used to back-calculate fish length from otoliths (Harvey et al. 2000, Zan et al. 2015, Aneesh Kumar et al. 2017, Yilmaz et al. 2019). Fish length is positively correlated with otolith length, weight, otolith area, otolith width and otolith perimeter, which is supported by other studies (e.g. Ankita & Khan 2022). A significant relation between fish length and otolith size indicated that the somatic growth of fish had a major impact on otolith growth (Munk 2012). The correlation be-

Table 1. Length-weight relationship of the selected fish species (TL = Total length, TW = Total weight, N = sample size, Max = maximum, Min, minimum, a and b = constant parameters in equation $W = aTL^b$, CI = confidence interval, R^2 = coefficient of determination, I=Isometric growth, A^+ = Positive allometric, A^- = Negative allometric, K= Fulton's condition factor, SD = standard deviation)

Species	N	TL (cm)	TW (gm)	a	95% CI of a	b	95% CI of b	R^2	P-value	Type of Growth	K (Mean ± SD)
A. chacunda	265	8.2-18.0	6.0-80.0	0.01	0.008-0.014	3.07	2.98-3.17	0.94	0.00012	I	1.32±0.12
E. diacanthus	205	14.0-22.0	41.0-155.0	0.011	0.006-0.009	3.09	2.91-3.27	0.91	0.00021	I	1.45±0.14
J. glaucus	215	10.2-28	8.0-257.0	0.005	0.003-0.007	3.27	3.13-3.40	0.95	0.00031	A^+	1.08±0.16
M. cephalus	281	10.0-30.0	9.0-283.0	0.023	0.016-0.032	2.70	2.59-2.81	0.90	0.00011	A^-	0.94±0.18

Table 2. Descriptive statistics of otolith dimensions (OL = otolith length, OWt = otolith weight, OA = otolith area, OW = otolith width, OP = otolith perimeter).

Species	Otolith dimensions									
	OL (mm)		OWt (gm)		OA (mm²)		OW (mm)		OP (mm)	
	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE
A. chacunda	2.38-3.16	2.84±0.02	0.0018-0.0051	0.0035±0.001	2.32-4.21	3.21±0.08	1.18-2.04	1.63±0.039	6.78-9.24	8.23±-0.112
E. diacanthus	3.32-6.06	4.42±0.09	0.051-0.093	0.07±0.001	6.46-13.06	8.80±0.29	1.92-3.86	2.73±0.08	11.85-17.17	14.79±0.22
J. glaucus	3.17-6.32	5.19±0.14	0.164-0.27	0.22±0.004	7.54-18.19	14.19±0.51	3.42-4.51	4.14±0.051	11.19-17.76	14.69±0.29
M. cephalus	2.27-6.41	3.89±0.16	0.03-0.064	0.05±0.002	4.46-9.24	6.58±0.18	1.01-4.26	1.99±0.12	8.05-15.97	10.57±0.33

Table 3. Equations derived for estimating fish size from otolith size (TL = total length, OL = otolith length, OWt = otolith weight, OA = otolith area, OW = otolith width, OP = otolith perimeter, R^2 = coefficient of determination)

Species	Equation	R^2
A. chacunda	$TL = 3.7179OL^{1.3094}$	0.82
	$TL = 86.177OWt^{0.312}$	0.96
	$TL = 8.5728OA^{0.4603}$	0.94
	$TL = 8.5728OW^{0.4603}$	0.96
	$TL = 2.3763OP^{0.8624}$	0.95
E. diacanthus	$TL = 5.5143OL^{0.7883}$	0.84
	$TL = 208.98OWt^{0.9381}$	0.95
	$TL = 5.0692OA^{0.58}$	0.92
	$TL = 9.3054OW^{0.6491}$	0.86
	$TL = 0.9832OP^{1.0741}$	0.74
J. glaucus	$TL = 4.0803OL^{0.7547}$	0.83
	$TL = 88.555OWt^{1.2214}$	0.95
	$TL = 3.2999OA^{0.5495}$	0.86
	$TL = 1.0656OW^{1.812}$	0.84
	$TL = 0.8034OP^{1.0637}$	0.70
M. cephalus	$TL = 9.131OL^{0.6625}$	0.83
	$TL = 245.84OWt^{0.7864}$	0.84
	$TL = 3.3842OA^{1.0001}$	0.88
	$TL = 16.847OW^{0.4316}$	0.78
	$TL = 2.1909OP^{0.9843}$	0.89

tween fish and otolith size can be affected by various factors, including species of fish, food availability, habitat condition and environmental factors (Aydin et al. 2004). Therefore, further studies are needed to understand the impact of these factors.

Conclusions

The relationships between fish size and otolith size in the current study can be used to predict the prey size in food and feeding biology. The representative images of otoliths provided can be used as a diagnostic character in taxonomic and palaeontological studies. Hence, further studies on otolith morphology, morphometric relationships and shape indices are inevitable to address these aspects more convincingly.

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