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RELATIONSHIPS OF OTOLITH DIMENSIONS AND WEIGHT WITH BODY LENGTH OF THREE LETHRINID SPECIES (ACTINOPTERYGII, LETHRINIDAE) FROM YEMEN

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Relationships of Otolith Dimensions and Weight with Body Length of Three Lethrinid Species (Actinopterygii, Lethrinidae) from Yemen. Jawad, L. A., Al-Shwafi, N. A. A. & Aguilar, G. — Relationships between fish length and otolith length, width, and weight were studied in three lethrinid species *Lethrinus borbonicus* Valenciennes 1830, *Lethrinus lentjan* (Lacepède 1802), and *Lethrinus mahsena* (Fabricius, 1775) collected from the south of the Red Sea at the costs of the Republic of Yemen. These relationships are important for future research into the biology of these species, including their diet, feeding habits, age, and growth. Linear regression models were used to investigate the relationships between otolith length and total fish length (TL), otolith weight and TL, and otolith width and TL. A non-linear regression model was used to investigate the relationship between otolith weight and TL. The morphometric relationships indicated that otolith length exhibited the highest correlation with total fish length among the other two otolith variables. This study is the first to examine the relationship between fish size and otolith size and weight in three lethrinid species obtained from the coast of the Red Sea in Yemen.

Key words: *Lethrinus borbonicus*, *Lethrinus lentjan*, *Lethrinus mahsena*, stomach contents, archaeology, sagitta.

Introduction

The Snubnose emperor *Lethrinus borbonicus* Valenciennes, 1830 is a marine species that lives in association with reefs at depths of up to 40 metres (Lieske and Myers, 1994). This species reaches a maximum total length of 400 mm, with a common total length of 250 mm (Carpenter & Allen, 1989). It is distributed throughout the Red Sea and the Gulf, extending south to Durban in South Africa and east to North Bay Reef in the Andaman and Nicobar Islands (Froese & Pauly, 2023). The Snubnose emperor inhabits sandy areas near reefs during the day, sometimes in small groups. They are solitary at night, ranging over reef flats and slopes where they primarily feed on echinoderms, molluscs and crustaceans (Carpenter & Allen, 1989).

The pink ear emperor *Lethrinus lentjan* (Lacepède 1802), a marine species, sometimes enters brackish water and lives in association with reefs at depths ranging from 10 to 90 metres (Kailola et al., 1993). This species reaches a maximum total length of 520 mm (Toor, 1964), with a common total length of 400 mm (Bouhlel, 1988). This species has a maximum lifespan of 19 years (Grandcourt, 2002). It is distributed throughout the Indo-West Pacific region, from the Red Sea and the Arabian Gulf to East Africa, the Ryukyu Islands, and Tonga (Froese & Pauly, 2023). The pink ear emperor resides on sandy bottoms in coastal areas, deep lagoons, and near coral reefs (Sommer et al., 1996). Juveniles and small adults are commonly found in loose groups over seagrass beds, mangrove swamps, and shallow sandy areas, whereas adults are usually solitary in deeper waters. This species feeds mainly on crustaceans and molluscs, but also eats substantial amounts of echinoderms, polychaetes and fish (Carpenter & Allen, 1989). *Lethrinus lentjan* is a protogynous hermaphrodite (Allsop & West, 2003).

The sky emperor *Lethrinus mahsena* (Fabricius, 1775) is a marine species that lives in association with reefs at depths ranging from 2 to 100 metres (Lieske & Myers, 1994). Sky emperors reach a maximum total length of 650 mm (Carpenter & Allen, 1989), with a common total length of 400 mm (Carpenter & Allen, 1989). The maximum reported age of this species is 27 years (Grandcourt, 2002). This species is distributed throughout the Indian Ocean. It is found from the Red Sea and East Africa to Sri Lanka (Froese & Pauly, 2023). It is found over reef areas and in adjacent sandy and seagrass areas (Sommer et al., 1996). Its diet consists mainly of echinoderms (most frequently sea urchins), crustaceans, and fish; molluscs, tunicates, sponges, polychaetes, and other worms are consumed in smaller quantities. It is a protogynous hermaphrodite (Allsop & West, 2003).

For years, it has been known that one of the objectives of taxonomic and biometric investigations of otoliths is to identify the species of fish eaten by piscivorous animals and to estimate their size and weight (Battaglia et al., 2015). To this end, species identification guides and otolith atlases have been produced (Campana, 2004; Tuset et al., 2008; Sadighzadeh et al., 2012), and relationships between otolith size and fish length have been established (Waessle et al., 2003; Longenecker, 2008; Battaglia et al., 2010; Škeljo & Ferri, 2012; Battaglia et al., 2015; Giménez et al., 2016). Similarly, it is possible to reconstruct paleoenvironments and paleofaunas using otoliths recovered from archaeological and palaeontological sites (Nolf, 1995; Schulz-Mirbach & Reichenbacher, 2006). Reconstructing the actual size and mass of otoliths from lethrinid fish specimens consumed by piscivorous animals could provide valuable insights into the feeding ecology of predators of the lethrinid species examined in the present study. However, information on the relationship between otolith size and fish length is unavailable for members of the Lethrinidae family from the Red Sea. The main aim of this study is therefore to establish relationships between otolith size and total length in three lethrinid species (*Lethrinus borbonicus*, *L. lentjan* and *L. mahsena)* living off the coast of Yemen in the Red Sea.

Material and Methods

Samples of the three lethrinid species were collected from the Salif (15° 19' 01.06" N, 42° 39'49.80" E), Hudydah (14° 32' 51.66" N, 42° 49' 20.19" E) and Kamaran (15° 17' 54.51" N, 42° 37' 39.20" E) (Fig. 1) for *L. borbonicus*, *L. lentjan* and *L. mahsena* respectively. Fish specimens from the three localities were collected in February 2014. The specimens were obtained from fishers operating in the areas using gill net to catch fishes. A total of 175 specimens of *L. borbonicus*

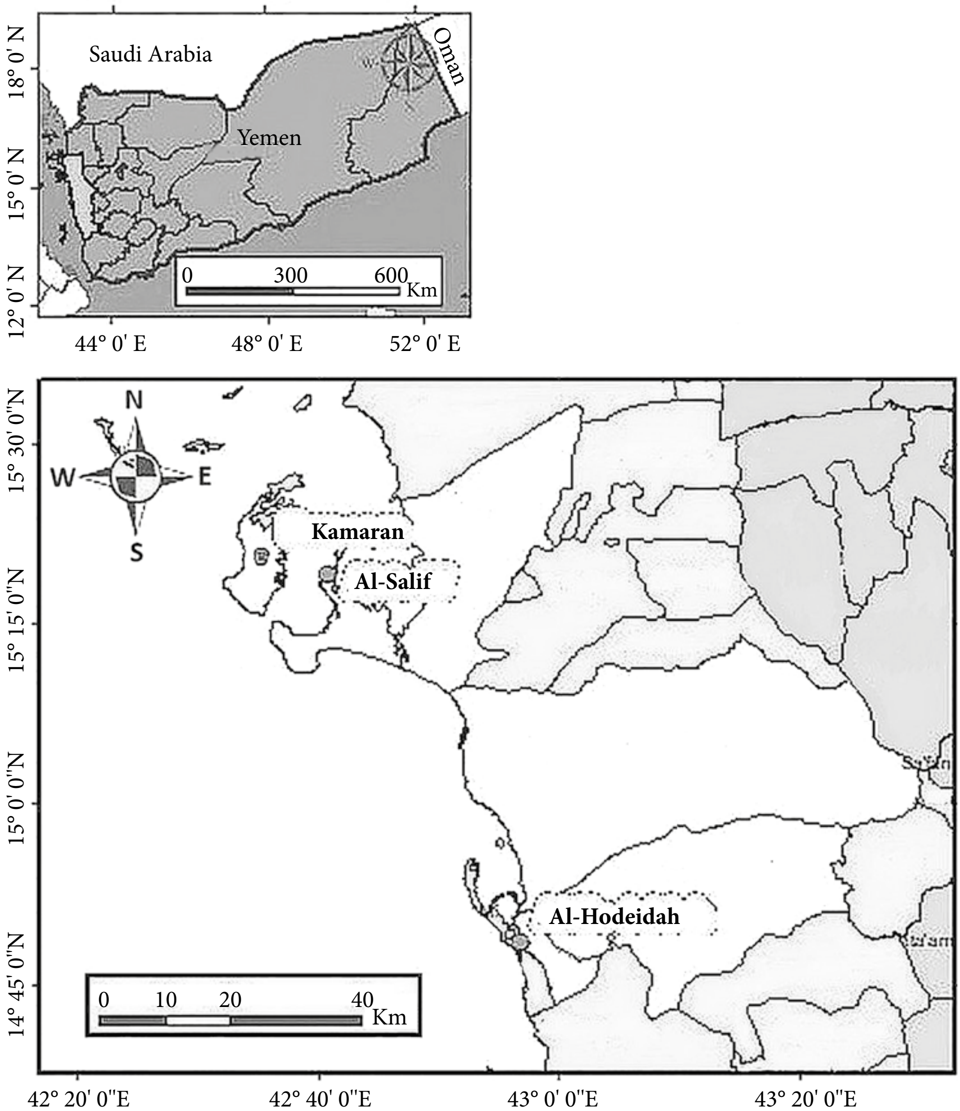

Fig. 1. Map showing the sampling locations

(n = 49), *L. lentjan* (n = 72), and *L. mahsena* (n = 54) were obtained captured during the sampling period. Fish specimens from the three localities were collected in February 2014. Total length (TL) of each fish was recorded to the nearest 1 mm and 0.01 g, respectively using measuring board. Sex was not determined. The sagittal otolith was extracted from both sides of the fish head by making an opening on the top of the cranium. The otic capsules were separate, and the otoliths were removed using a pair of fine forceps. They were washed with 70% ethanol and stored in a dry condition. All otoliths were photographed using Leica DF295 digital camera. The otolith length (OL), otolith width (OW) was measured to the nearest 0.001 mm using Leica Application Suit ver. 3.8 Imaging Software (Fig. 2). Otolith weight (OWe) was measured using a standard analytical scale (HR-250AZ, A&D Company Ltd) to the nearest 0.0001 g.

The relationships between otolith dimensions and fish length were established using non-linear (y = axb) regression model for the following parameters: TL–AL, TL–AH, TL–LL and TL–LW.

The relationships between otolith dimensions and fish length were established using linear (y = ax + b) and exponential ($y = ax^b$) regression model for the following parame-

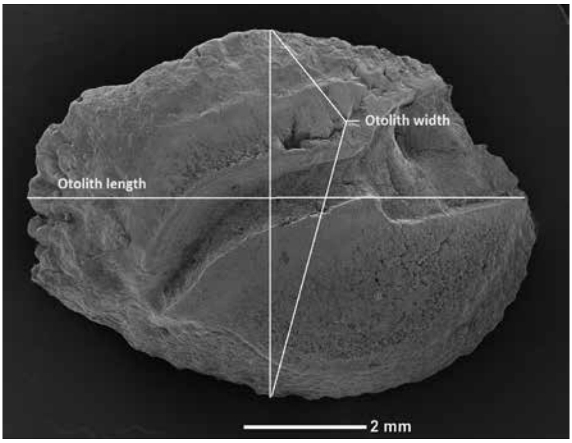

Fig. 2. Otolith of *Lethrinus borbonicus*, 232 mm showing otolith length and otolith width

ters: TL–OL, TL–OW and TL–OWe (Fig. 2). When significant differences ($P < 0.05$) were not found, the H0 hypotheses (*b*left = *b*right and *b*female = *b*male) were accepted. Where regression coefficients did not differ statistically, a single regression was reported for each variable by choosing the right otolith measurements and by pooling the data of both sexes. The t-test was used to compare the slopes with a value corresponding to isometry (b = 3) (Zar, 1999).

Results

The total length of the three lethrinid species ranging from 154–385, 160–492, and 165–504 mm for *L. borbonicus*, *L. lentjan*, and *L. mahsena* respectively. The minimum, maximum and the mean total length of fishes and otoliths characteristics are shown in Table 1. No significant differences (***t***-test for paired comparisons, $P > 0.30$) were noted between left and right otolith length and weight; therefore, the right otoliths were chosen for following analysis.

The results showed that the otolith of *L. lentjan* is the largest followed by that of *L. borbonicus* and *L. mahsena* from the perspective of the otolith length, width, and weight (Table 1). All regressions were highly significant ($P < 0.001$). The relationship between fish total length and otolith weight was exponential for the three lethrinid species examined, while it is linear for the relationship of the fish total length with the otolith length and width. The coefficient of determination (R^2) ranged from 0.9274 to 0.9937, where the minimum and the maximum R^2 values were observed in the relationship TL–OWe of *L. borbonicus* and the highest vales in the relationship TL–OL of *L. borbonicus*. The relationships between fish length and otolith length, width, and weight are shown in Table 1 and Figure 3.

Table 1. **Descriptive statistics for total length (TL), mm; otolith length (OL), mm; otolith width (OW), mm; and otolith weight (OWe), gm of the three lethrinid species collected from the Red Sea coasts of Yemen**

Characters	Lethrinus borbonicus n = 49	Lethrinus lentjan n = 72	Lethrinus mahsena n = 54
Fish total length (Mean)	154–385 (267.9)	160–492 (323)	165–504 (332.8)
Otolith length (OL)	63.5–104.9	65.6–156.9	64.1–92.3
Otolith width (OW)	45.8–74.8	46.0–98.7	49.1–82.1
Otolith weight (OWe)	0.187–0.365	0.19–0.574	0.172–0.268
TL–OL	Y = 0.0183x + 3.413, R^2 = 0.994	Y = 0.28x + 1.975, R2 = 0.993	Y = 0.0082x + 5.003, R^2 = 0.991
TL–OW	Y = 0.0199x + 2.945, R^2 = 0.972	Y = 0.0147x + 2.681, R^2 = 0.987	Y= 0.0096x + 3.528, R2 = 0.981
TL–OWe	$Y = 0.0074x^{0.656}$, R^2 = 0.927	$Y = 0.0016x^{0.9508}$, R^2 = 0.990	$Y = 0.0251x^{0.377}$, R^2 = 0.992

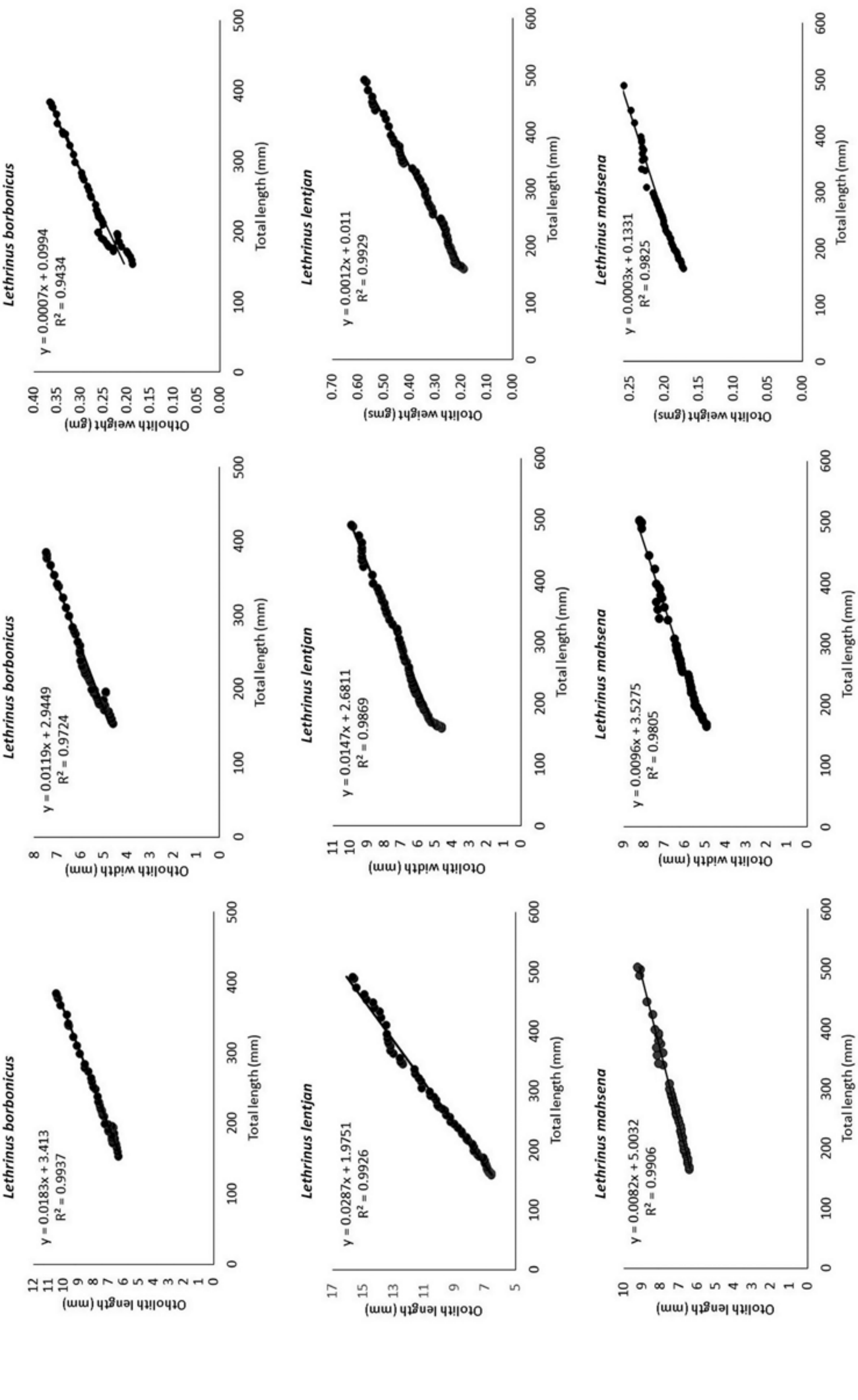

Fig. 3. Relationships of total length (TL) — otolith length (OL), total length (TL) — otolith width (OW), and total length (TL) — otolith weight (OWe) and of *Lethrinus borbonicus*, *Lethrinus lentjan*, and *Lethrinus mahsena* collected from the Red Sea cost of republic of Yemen

Discussion

Pérez Comesaña et al. (2014) and Riestra et al. (2020) have proposed that the concurrent presence of several bone elements in predator faeces particularly increases the likelihood of prey identification. This is true whether the focus is on the presence/absence or minimum number of individuals. However, using several hard elements can lead to overestimation of the number of individuals in a predator's stomach (Hájková et al., 2003). In the present study, otoliths are currently recognized as one of the most useful tools to reconstruct initial size of prey fish in food samples of predators. However, otoliths are subjected to an inconstant level of chemical and mechanical abrasion in the digestive system of predators. Henceforth, small otoliths are likely to be totally disappeared and thus some species may fail to be noticed (Echeverria 1987, Pierce & Boyle, 1991, Pierce et al., 1993). In addition to acid digestion, otoliths may sustain physical damage during predator ingestion or sample collection and handling. In such cases, it may be impossible to rebuild fish size or identify the prey. This may be true for cyprinids, which have relatively small otoliths (Tarkan et al., 2007).

The left and right otoliths cannot have identical characteristics for rebuilding the length of prey fish. Using paired bones increases the likelihood of evaluating the smallest number of a species. However, the left and right sides of otoliths can only be paired if they are the same size and shape. The results of the present study showed that there were no significant differences between the left and right otoliths of a pair. Therefore, when calculating length from otolith size, it is not necessary to specify which side of the fish was used.

Linear functions have generally been considered satisfactory for describing the relationship between the size of fish and that of hard structures (Mann & Beaumont, 1980; Fickling & Lee, 1981; Hansel et al., 1988; Prenda & Granado-Lorencio, 1992). However, curvilinear relationships can also provide a better fit for certain species of fish (Radke et al., 2000; Acıpınar et al., 2004), as demonstrated in the present study. Kumar et al. (2015) found that otolith length, width and mass were good biomarkers of total length and weight in twelve species of sciaenids in the waters off Mumbai, India. Aguilar-Perera and Quijano-Puerto (2016) found high correlations between fish length and otolith length in the lionfish *Pterois volitans*, and concluded that otolith length and weight could be used to estimate lionfish length. The length and width of the otolith were considered an appropriate means of determining the length of blackspot snapper *Lutjanus ehrenbergii* in the Sea of Oman, off the coast of Muscat (Al-Busaidi et al., 2017).

The study investigated the associations between otolith length, width and weight, and total fish length. The results showed that otolith variables increase as fish grow in length, indicating that otolith growth is linked to fish growth. Otoliths develop through the deposition of incremental layers on their surface (Morales-Nin, 2000). However, otolith length was shown to be more closely connected to total length growth than otolith weight, which was found to have a slightly weaker link to total length than either length or width. Campana (2004) stated that the size and shape of otoliths frequently alter with fish growth. Holmgren and Wickström (2012) found positive correlations between otolith and somatic growth in cultured elvers at 20 °C (r = 0.900) and 26 °C (r = 0.817).

Except the work of Osman et al. (2021) and as far as we know, there are no published information on the relationships between otolith size and fish size of the members of the three lethrinid species collected from the Red Sea coast of Yemen. Osman et al. (2021) studied two lethrinid species *L. lentjan* and *L. microdon* from the northern part of the Red Sea at the Egyptian waters. They used several otolith morphological features to distinguish between the two lethrinid species. Their results on the relationship between the otolith dimensions and fish size of *L. lentjan* are comparable to those of the present study, with a slight variation. Such variation may be owing to disparity in environmental variables and habitat, as well as water temperature and dissolved oxygen effect on fish growth (Campana & Casselman, 1993; Cardinale et al., 2004; Zischke et al., 2016). Interspecific variations in otolith size could reflect the vertical distributions of species; for example, fishes that live at large depth have generally large otoliths (Tuset et al., 2003; Zischke et al., 2016).

Characteristically, otolith length exhibits a linear relationship to fish length until the fish reaches its maximum size and then; the otolith upsurges only in thickness (Blacker, 1974). Gauldie (1988) stated that the strong relationship between the fish length and otolith length is since both follow the same metabolic processes. Casselman (1990) stated that the comparative size of calcified structures is a sensitive indicator of growth. Studying the morphometric relationships, we resolved that otolith length is a good marker of fish total length in the three lethrinid species.

In conclusion, the relationships between the length, width and weight of otoliths and fish length were studied in three lethrinid species (*Lethrinus borbonicus* Valenciennes, 1830; *Lethrinus lentjan* Lacepede, 1802; and *Lethrinus mahsena* Fabricius, 1775) collected from southern Red Sea coasts in the Republic of Yemen. Linear and non-linear regression models were used to calculate these relationships. The morphometric analysis revealed that otolith length exhibited the strongest correlation with total fish length compared to the other two otolith variables. This study is the first to examine the relationship between fish size and otolith size and weight in the three lethrinid species found along the Red Sea coast of the Republic of Yemen.

Conflicts of interest. The authors declare that there is no conflict of interest.

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Data availability statement. There is no supporting data to make available.

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