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Two distinct hyperostosis shapes in ribbonfish, *Trichiurus lepturus* Linnaeus 1758.

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This study provides a morphological description of bone enlargement (hyperostosis) in ribbonfish *Trichiurus lepturus*. Of 146 fish examined, 52.7% showed hyperostosis in the neural and hemal spines. Morphometric shape analysis revealed two distinct hyperostosis shapes, likely reflecting different ontogeny and/or environmental conditions, which could serve as a population marker.

Keywords: morphology; ossification; bony tissue; shape analysis

Bone abnormalities are common in many natural fish populations, but the underlying reasons are unclear. A common bone abnormality is the thickening of the periosteal ossification, which results in protuberances and enlargements of specific bones referred to as 'hyperostosis' (Murty, 1967; Gauldie and Czochanska, 1990; Schlüter et al., 1992; Smith-Vaniz and Carpenter, 2007). Hyperostosis gives affected bones a distinctive 'swollen' shape (Meunier et al., 2010; Giarratana et al., 2012) and has been described in the pterygiophores, skulls, claviculae, and interhaemal and interneural spines of approximately 92 fish species belonging to 22 families (Murty, 1967; Tiffany et al., 1980; Gauldie and Czochanska, 1990; Schlüter et al., 1992; Smith-Vaniz and Carpenter, 2007) in fish species worldwide. However, with the exception of Jawad (2013) no previous study has investigated the type and frequency of hyperostosis in any fish regionally.

This study provides the first morphological description of hyperostosis in ribbonfish *Trichiurus lepturus* (Linnaeus, 1758) from the Arabian Sea, off Oman. *T. lepturus* is the most dominant species of the six *Trichiurus* species within Omani fisheries and has an average weight of approximately 1.5 kg and a characteristic long body shape with total length of 50-100 cm (Abdussamad et al., 2006). It has a very broad geographical distribution compared to other *Trichiurus* species, and is found throughout tropical and temperate waters, between 45° S and 60° N (Cheng et al., 2001). *T. lepturus* moves in dense shoals, and feeds on several species of small fishes, squids and crustaceans (Randall, 1995). Hyperostosis has previously been reported in the interhaemal and interneural spines of *T. lepturus* off the coast of India (James, 1960; Lima et al., 2002), and the Gulf of Mexico (Olsen, 1971). Fossil records also indicate the presence of hyperostosis (Meunier et al., 2010).

As part of a larger study on ribbonfish biology and fisheries in Oman, *T*, *lepturus* were collected during 2014-2015 (mean total length, cm±S.D. = 98.3±6.7) from three landing sites at Masirah Island, Duqm and Al-Shuwaymiya in Oman, located between 17°90'N and 20°70'N and between 56°90'E and 56°55'E. A random sample of 146 fish was examined for hyperostosis by boiling them in water, removing their flesh, and checking for skeletal deformities. Of the fish examined, 77 (52.7%) had deformities on the haemal and neural spines (Fig. 1); these were measured (height, width and bone weight), photographed, and analysed for morphological shape variation.

Swollen bones ranged in height from 0.97 to 2.56 cm and in width from 0.35 to 1.39 cm, which are comparable to those found in other *T. lepturus* populations (James, 1960; Lima et al., 2002). To further investigate morphological variation in hyperostosis variation in the size and shape of 77 enlarged bones was explored via landmark-based morphometric shape analysis (Adams and Otárola- Castillo, 2013; Klingenberg, 2013). Digital images were used to mark the position of 9 landmarks and MORPHOJ (Klingenberg, 2011) was then used to statistically assess variation along the first two principal components (factors), explaining 53% of variability in bone shape. Two distinct bone shapes were found, an ‘irregular-round shape’ (n = 55; 71.4%) and a ‘oblong-shape’ (n = 22; 28.6%), confirmed by generalized Procrustes analysis (Rohlf and Slice, 1990) and by discrimination analysis (Mitteroecker and Bookstein, 2011) (Fig. 2; $T^2 = 261.98$, $P <$

0.001). Such variation in hyperostosis shapes may be the result of body size differences, but mean fish total body lengths were not significantly different among sample collection months (Analysis of Variance, ANOVA: d.f. = 144, P = 0.525).

Hyperostosis is common in marine teleost (Smith-Vaniz et al., 1995; Nelson, 2006), but its causes and consequences remain unclear (Meunier et al., 2010). Hyperostosis has been considered to be the result of bone disease, fungal infection, metabolic abnormality, and/or genetic factors (Grabda, 1982; Smith-Vaniz and Carpenter, 2007). A response to environmental factors, including water pollution and increasing temperatures, has also been cited as a potential cause for hyperostosis (Grabda, 1982; Schlüter and Kohring, 2002). Others have suggested the hyperostosis may have an adaptive kinematic role, perhaps associated with fin formation, buoyancy and equilibrium (Meunier and Huysseune, 1991).

Among Trichiuridae, the presence of hyperostosis in *T.lepturus* has been reported at a variety of different locations throughout its range (Table 1), and was considered to be indicative of the homogeneity of the species of *T.lepturus*, both in the Atlantic and Indo-Pacific waters (James, 1960). However, based on this study on the nature and distribution of hyperostosis among fish specimens, there appears to be substantial inter-population differences. For example, in the Arabian Sea the incidence of hyperostosis in *T.lepturus* was 52.7%, much higher than the 10% reported for Indian waters (James, 1960), but substantially lower than 94.5% reported for Brazil (Lima et al., 2002) or the 80% reported for *Lepidopus caudatus* (Giarratana et al., 2012) (Table 1).

There is clearly much variation in the frequency of hyperostosis within and among *T.lepturus* populations, and the present study highlights a further, perhaps interesting, within-population difference revealing two distinct hyperostosis shapes. It is possible that hyperostosis may be adaptive, providing some fine adjustment of the dorsal fins, as *T.lepturus* moves up and down the water column to forage. However, the average weight of these bone enlargements is very small (oblong shape = 0.585 g; rounded shape = 0.375 g), and given that the size-shape relationships are similar for both shape types, it is unlikely that these have any large effect on an individual's centre of mass or buoyancy. More probably, hyperostosis represents a pathology in this species, and the two shapes reflect changes in the resorption and thickening of the bone as a consequence of differences in ontogeny and/or environmental conditions (Capasso, 2005).

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Table 1. Occurrence of hyperostosis in neural and haemal spines for Trichiuridae family including two species in

Species	Number of Individuals examined	Number of exhibiting hyperostosis (%)	Location	Refer
Trichiurus lepturus	534	56 (10.5%)	Andaman Sea, Indian waters	(Jam
Trichiurus lepturus	52	49 (94.5%)	Brazilian coast	(Lim
Lepidopus caudatus	50	40 (80%)	Coast of Messina, Italy	(Gia
Trichiurus lepturus	146	77 (52.7%)	Arabian Sea	This

Figures

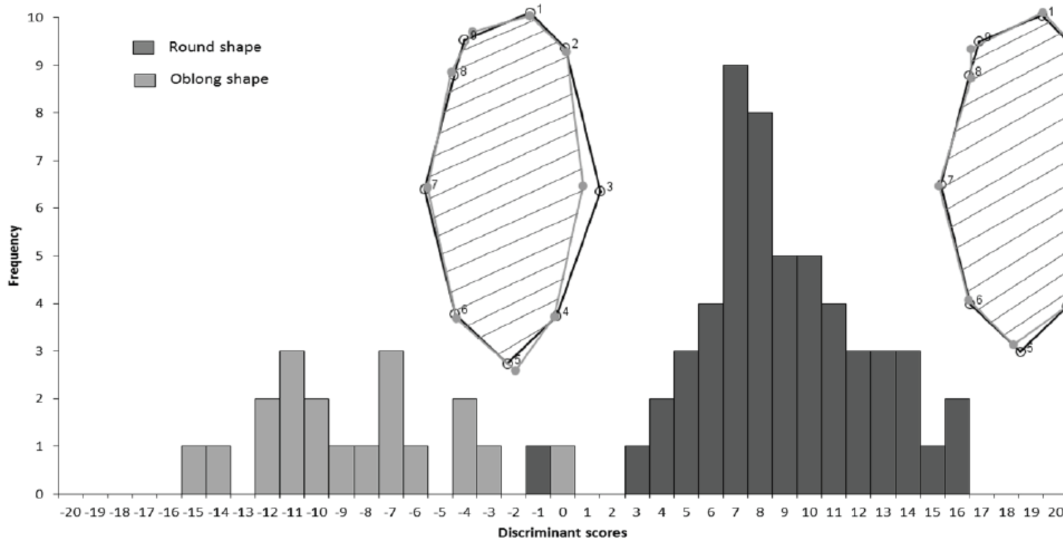

Figure 1. (a) Two shapes of hyperostosis found in *T. lepturus*, with scale ruler in cm. (b) and (c) show Radiographs of *T. lepturus* exhibiting hyperostosis.

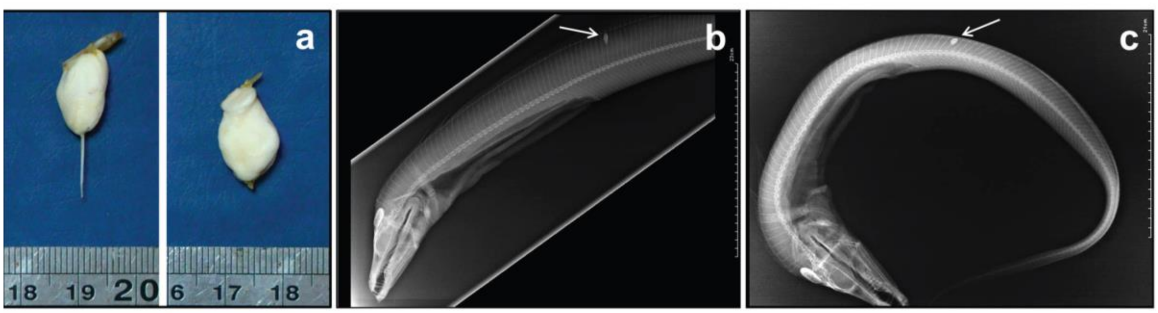

Figure 2. Discriminant scores for hyperostosis shapes for n=77 fish. Bars are coloured according to their shape classification: oblong (gray) and round (black) as determined by discrimination analysis. Insets are two examples of the different hyperostosis shapes (n=9 reference points). The black outline represents the mean shape across our entire sample, whilst the grey shaded area represents values of the hyperostosis for oblong shapes (left) and round shapes (right).