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Investigating otolith mass asymmetry in four fish species from Antalya Bay, Mediterranean coast of Türkiye

by

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Abstract

Otolith weight (OWe) asymmetry plays a crucial role in the vestibular function of the inner ear, potentially affecting its performance. Typically, OWe asymmetry values range from −0.2 to +0.2 (−0.2 < X < +0.2). In this study, we collected 136 fish specimens from the Gulf of Antalya, located along the Mediterranean coast of Turkey, which included the species *Nemipterus randalli*, *Boops boops*, *Scorpaena elongata*, and *Scorpaena notata*. Our findings revealed that the level of OWe asymmetry in these four teleost species increases with the total length (TL) of the fish. Evaluating OWe asymmetry is essential for understanding its potential impact on larval settlement in this significant fishing region. The results also showed that *N. randalli* and *B. boops* exhibited lower levels of OWe asymmetry compared with *S. elongata* and *S. notata*. Environmental factors, which indirectly influence somatic growth and otolith formation, may explain the significant differences observed, as the species inhabit distinct environments.

Key words: *Nemipterus randalli*, *Boops boops*, *Scorpaena elongata*, *Scorpaena notata*, ecological factors, Antalya Bay, Türkiye

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1. Introduction

Fish performance can vary significantly under different lighting conditions or when their otoliths exhibit uneven weight distribution (Bouriga et al., 2021; De Jong et al., 1996; Egorov & Samarin, 1970; Hilbig et al., 2002; Hoffman et al., 1977; Jawad et al., 2020; Lychakov & Rebane, 2004; Rahman & Anken, 2002; Takabayashi & Ohmura-Iwasaki, 2003; von Baumgarten et al., 1982). One of the key effects of otolith weight (OWe) asymmetry is the mismatch or abnormality between the right and left otoliths, which can significantly alter a fish's auditory properties (Jawad et al., 2021; Lychakov, 2006; Lychakov & Rebane, 2005). This asymmetry can also damage the vestibular and auditory systems. However, Lychakov et al. (2006) noted that the precise morphological and biological outcomes of otolith asymmetry remain uncertain.

In symmetrical fish species, OWe asymmetry typically falls within the range of $-0.2 < X < +0.2$ or <20% (Lychakov, 1992; Lychakov & Rebane, 2004, 2005; Lychakov et al., 1988; Takabayashi & Ohmura-Iwasaki, 2003). However, these studies did not establish a clear link between OWe irregularity and fish length or weight (Lychakov & Rebane, 2004, 2005). Moreover, when OWe asymmetry remains below critical thresholds, as seen in symmetrical fish species, no significant operational impairments are observed (Lychakov & Rebane, 2005; Lychakov et al., 2006). As anticipated by Egorov and Samarin (1970), Lychakov (1992), Samarin (1992), Lychakov (2002), and Scherer et al. (2003), the total weight unevenness of the otolith may influence the fish's sensory reception.

Among the prominent members of the Sparidae family in the Mediterranean Sea is the bogue, *Boops boops* (Bauchot & Hureau, 1984; Linnaeus, 1758). This species is both demersal and semi-pelagic and is found on various substrates such as sand, mud, rock, and seagrass beds. It is typically found at depths of up to 350 m, although it is more abundant within the upper 100 m and occasionally in coastal waters. The bogue forms schools that rise to the surface mainly at night (Bauchot, 1987) and is captured using methods such as bottom trawls, purse seines, beach seines, and trammel nets.

Despite the increasing body of research on OWe asymmetry, data on OWe irregularities in the four teleost species studied here remain scarce in the literature, particularly in the waters of Turkey's Mediterranean coast. This study aimed to measure the level of OWe asymmetry in two scorpaenid species, *Scorpaena elongata* and *S. notata*; the nemipterid species *Nemipterus randalli*; and the sparid species *B. boops*, all collected from Antalya Bay on Turkey's Mediterranean coast. Additionally, the asymmetry was analyzed across different fish lengths.

2. Materials and methods

2.1. Study area and fish sampling

Fish specimens of the four teleost species (*N. randalli*, *B. boops*, *S. elongata*, and *S. Notata*) taken for this investigation (Fig. 1) were collected from Antalya Bay, Mediterranean coast of Türkiye (36° 49′ 42″ N–36° 45′ 21″ N; 30° 50′ 22″ E–31° 20′ 05″ E) (Fig. 2) between October 2020 and September 2021. The biodata of the four fish species examined in this study is given in Table 1. The fish were caught using a commercial bottom trawl net with a mesh size of 44 mm (22 mm mesh size in the cod end). The fishing area's water depth ranged from 40 m to 160 m. Samples of the four teleost species assessed were kept on ice until they were brought to the laboratory and were identified according to the methods outlined by

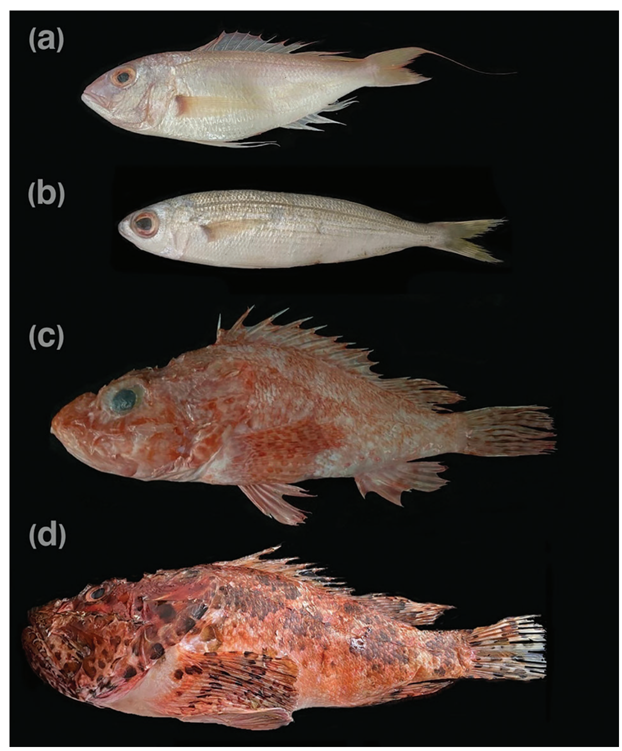

Figure 1

Specimens of fishes examined. (A) *N. randalli* (231 mm TL, male, TL range 126–240 mm); (B) *B. boops* (161 mm TL, male, TL range 138–225 mm); (C) *S. elongate* (239 mm TL, male, TL range 144–332 mm); (D) *S. notata* (305 mm TL, female, TL range 139–311 mm). TL, total length.

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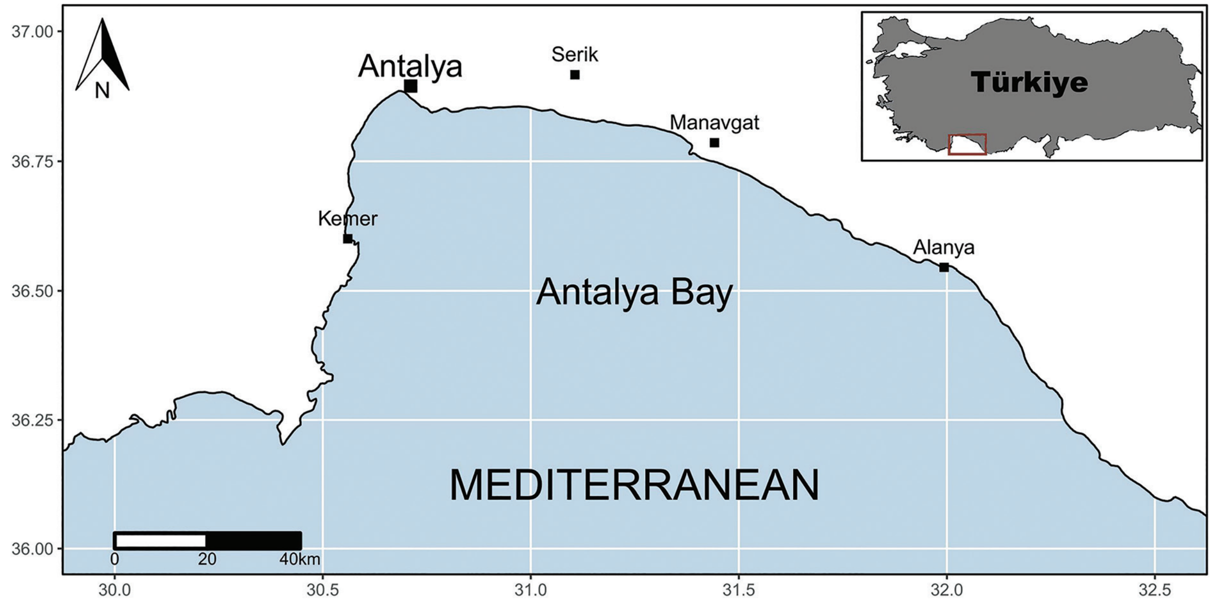

Figure 2

Map showing the location of fish samples collection from Antalya Bay, Mediterranean coast of Türkiye.

Table 1

Biological data of the four fish species from Antalya Bay, Mediterranean coast of Türkiye

Species	Number of specimens	Fish TL range (average) (mm)	±SD
Nemipterus randalli	33	126–240 (181.45)	5.469
Boops boops	41	138–225 (182.32)	2.449
Scorpaena elongata	34	144–332 (237.65)	4.170
Scorpaena notata	28	139–311 (221.53)	4.545

SD, standard deviation; TL, total length.

Hureau and Litvinenko (1986). The fish's total length [TL, from the snout to the end of the upper and lower lobes (combined) of the caudal fin] was measured to the nearest millimeter. Sagittae were separated, cleaned, dried, and stored dry in numbered small plastic tubes for subsequent analysis. Total OWe was measured using a standard analytical scale (Radwag model Was/X) to the nearest 0.0001 g. Differences between the right and left sagittae were evaluated using a paired *t*-test.

2.2. Statistical analysis

The OWe asymmetry (X) was computed using the following formula:

$$X = (MR–ML)\ MM^{-1}$$

where MR and ML are the OWe of the right and left paired otoliths, respectively, and MM is the mean weight of the right and left paired otoliths.

In theory, X values range from −2 to +2. These limit levels designate maximal asymmetry, while the '0' value denotes the absence of asymmetry between the right and left otoliths of the same fish. A negative value of X means that the left otolith is heavier than the right (ML > MR), whereas a positive value of X means the opposite. Individual errors in measuring sizes and OWe can mask the results of variation calculations that make them useless (Palmer, 1994). Accordingly, to avoid any unwanted error in this study, the otolith mass was attained by one individual who performed all readings twice (Lee & Lysak, 1990). The mean value of the OWe was used in this examination. The asymmetry coefficients for the different fish length groups in the four teleost species were found to be statistically insignificant ($p > 0.5$) using the ANOVA test. The results of the differences between the right and left sagittae using a paired *t*-test showed a significant difference in the features of the left and right otoliths ($p < 0.5$). All statistical analyses were performed using R packages: rstatix (v.0.7.2), ggtrendline (v.1.0.3), and ggplot2 (v.3.4.4) within RStudio (v. 2024.04.2) (California, USA) (Kassambara, 2023; Mei et al., 2022; Wickham, 2016). In this study, sexes were separated due to a significant difference observed in the OWe value between the left and right sides of the fish head of these specimens.

3. Results

The asymmetry values of the otolith weight of *N. randalli*, *B. boops*, *S. elongata*, and *S. notata* collected from Antalya Bay, Mediterranean coast of Türkiye, are presented in Table 2. The OWe asymmetry value obtained for the female individuals of *S. notata* (0.0397 ± 0.0645) was higher than those of the other three species investigated (Table 3).

The results of the current investigation revealed an increase in the level of OWe asymmetry in the four teleost species examined with an increase in the size of the fish (Table 2).

The highest percentage of specimens displaying OWe asymmetry was found in all female and male specimens of the species investigated, with the exception of a small size group of females of *B. boops* (41.7%) and small size individuals of males of *S. elongata* (12.5%). The asymmetry coefficients for the different fish length groups in the four teleost species were found to be statistically insignificant ($p > 0.5$). The otolith mass asymmetry was within the range of $-0.0249 \leq X \leq 0.3373$ for all the examined species (Table 2). The results of the differences between the right and left sagittae using a paired *t*-test showed a significant difference in the features of the left and right otoliths ($p < 0.5$).

4. Discussion

This study aimed to explore the bilateral OWe asymmetry among four teleost fish species collected from Antalya Bay, Mediterranean coast of Turkey. The observed OWe asymmetry of these species could potentially reduce the ability of juvenile fish to remain in or inhabit their appropriate habitats (Gagliano et al., 2008).

The mean OWe asymmetry for all four species ranged from −0.2 to 0.2, consistent with findings from previous studies (Bouriga et al., 2021; Jawad, 2013; Jawad & Sadighzadeh, 2013; Lychakov et al., 2008). The asymmetry values of *S. elongata* and *S. notata* exceeded critical thresholds (Table 1). Bouriga et al. (2021) suggested that high OWe may be linked to a fish's physiological state, habitat, and environmental factors (both abiotic and biotic), as previously noted by Grønkjaer (2016) and Izzo et al. (2018), who studied fish from various latitudes and longitudes. While abiotic factors may contribute to elevated asymmetry levels, the varying latitudes and longitudes may not be as relevant in the case of *S. elongata* and *S. notata*. *S. elongata* is a sedentary species found in rocky habitats (Eschmeyer & Dempster, 1990), while *S. notata* is typically found in rocky littoral zones (Hureau & Litvinenko, 1986). Additionally, variations in environmental and anthropogenic factors can significantly impact otolith development (Munday et al., 2011). For example, Ben Lamine et al. (2011) highlighted the pollution issues facing the Gulf of Tunis, including metal contamination and urban waste discharge. Other studies have indicated that pollution can affect otolith growth (Elsdon & Gillanders, 2002; Munday et al., 2011; Perry et al., 2015). Metals accumulate in fish from polluted areas and are transferred through the food chain, influencing

Table 2

Squared coefficient of asymmetry (CV^2_a) value and mean OWe of four teleost fish species collected from Antalya Bay, Mediterranean coast of Türkiye

Character	CV^2_a mean + SD	CV^2_a minimum	CV^2_a maximum	*N*	OWe mean (g) + SD	% of individuals with asymmetry
Nemipterus randalli						
Females	0.0183 ± 0.0148	−0.0253	0.3373	13	0.036 ± 0.009	7.7
Males	0.0181 ± 0.0146	−0.0249	0.3371	20	0.045 ± 0.016	14.3
Boops boops						
Females	0.0181 ± 0.0145	−0.0344	0.3370	18	0.025 ± 0.007	27.8
Males	0.0180 ± 0.0143	−0.0510	0.3368	23	0.021 ± 0.005	33.3
Scorpaena elongata						
Females	0.0301 ± 0.0417	−0.3662	0.3665	20	0.072 ± 0.026	100
Males	0.0303 ± 0.0420	−0.3660	0.3667	14	0.054 ± 0.021	7.1
Scorpaena notata						
Females	0.0397 ± 0.0645	−0.3660	0.3663	13	0.049 ± 0.021	100
Males	0.0362 ± 0.0260	−0.3658	0.3660	15	0.048 ± 0.019	100

OWe, otolith weight; SD, standard deviation.

Table 3

Squared coefficient of asymmetry (CV^2_a) and mean OWe by the size of four teleost species collected from Antalya Bay, Mediterranean coast of Türkiye

Character	CV^2_a mean + SD	CV^2_a minimum	CV^2_a maximum	*N*	OWe mean (g) + SD	% of individuals with asymmetry
Nemipterus randalli						
Females						
140–160	0.0181 ± 0.0134	−0.3661	0.3374	3	0.0294	100
161–180	0.0185 ± 0.0139	−0.3662	0.3376	4	0.0349	100
181–200	0.0187 ± 0.0142	−0.3663	0.3378	6	0.0400	100
Males						
140–200	0.0178 ± 0.0147	−0.3661	0.3372	13	0.0361	100
201–260	0.0181 ± 0.0156	−0.3663	0.3374	7	0.0550	100
Boops boops						
Females						
140–200	0.0183 ± 0.0140	−0.3662	0.3367	12	0.0209	100
201–260	0.0185 ± 0.0143	−0.3664	0.3368	6	0.0260	100
Males						
140–200	0.0178 ± 0.0141	−0.3655	0.3364	19	0.0201	100
201–260	0.0180 ± 0.0142	−0.3656	0.3365	4	0.0246	100
Scorpaena elongata						
Females						
140–250	0.0303 ± 0.0456	−0.0255	0.09496	12	0.0570	100
251–400	0.0307 ± 0.0458	−0.0257	0.09498	8	0.0707	100
Males						
140–210	0.0307 ± 0.0423	−0.0253	0.0959	11	0.0361	100
211–270	0.0310 ± 0.0431	−0.0256	0.0957	3	0.0767	100
Scorpaena notata						
Females						
140–250	0.0396 ± 0.0642	−0.0346	0.0768	2	0.0210	100
251–400	0.0398 ± 0.0638	−0.0348	0.0769	11	0.0632	100
Males						
140–250	0.0263 ± 0.0257	−0.0512	0.1527	13	0.0341	100
251–400	0.0265 ± 0.0255	−0.0515	0.1534	2	0.0641	100

OWe, otolith weight; SD, standard deviation.

otolith growth (Wang, 2002). This incorporation of metals into the otolith's crystal matrix, due to their metabolic inertness, supports earlier findings on the impact of metal accumulation on otolith growth (Vrdoljak et al., 2020). Kılıç et al. (2021) and Yalçın et al. (2023) reported that the Antalya coast in the eastern Mediterranean Sea is heavily polluted with heavy metals. Leventeli et al. (2019) found that the highest concentrations of heavy metals in the Duden Stream were Sr > Fe > Al > Mn > As > Ni > Cu > Pb > Cr > Se, while the Gulf of Antalya exhibited the sequence Sr > Fe > Al > Ni > As > Cu > Mn > Pb > Cr > Se. Both the Sr and Al concentrations exceeded permissible standards in these streams, which were higher than those found in the Eastern Antalya region (Yalçin, 2020).

Sagittal otolith morphology is influenced by both genetic and environmental factors (Annabi et al., 2013; L'Abée-Lund, 1988; Lombarte et al., 2010; Vignon & Morat, 2010). Changes in otolith mass asymmetry can adversely affect essential functions such as hearing and balance in fish. As a result, otolith asymmetry has been used as a bioindicator to assess the quality of aquatic habitats (Grønkjaer, 2016) and to evaluate the environmental impacts on fish populations. Our findings suggest that the sagittal OWe is greater in *S. elongata* and *S. notata* compared with *N. randalli* and

B. boops, which may be linked to the distinct ecological niches of these species (Lombarte & Cruz, 2007).

Consistent with previous studies (Al-Mamry et al., 2011a, 2011b; Jawad & Adams, 2021; Jawad et al., 2012; Mabrouk et al., 2014), our research shows that larger specimens of the four species exhibit greater asymmetry than younger individuals. The degree of fluctuating asymmetry in OWe increased with fish size (Table 2). Valentine et al. (1973) observed similar findings for fish species from CA, USA and proposed two explanations: ontogenetic differences that result in increased asymmetry with age and historical factors that contribute to this asymmetry. Thiam (2004) also suggested that the increase in asymmetry with fish size could be due to the prolonged exposure of older fish to adverse environmental conditions.

To assess the variation in mean OWe asymmetry among the four teleost species studied, we compared our results with known values from other species around the world. The lowest mean otolith mass asymmetry recorded was 0.0003 for *Lutjanus bengalensis* from the Sea of Oman (Jawad et al., 2012), while the highest was 0.2222 for *Rhynchorhamphus georgi* from the same region (Jawad et al., 2011). The wide range of mean otolith mass asymmetry values across species and regions may reflect the varying environmental exposures experienced by each species (Fey & Hare, 2008). The mean OWe asymmetry observed in the four teleost species in this study is near the upper end of the global range. For example, the OWe asymmetry of *B. boops* in this study is lower than that reported for the western Mediterranean Sea off the Tunisian coast by Ben Labidi et al. (2020).

Further research is needed to explore the influence of environmental factors on otolith mass asymmetry and fish behavior. It is important to include a wide range of specimens and body sizes to gain a comprehensive understanding of the relationship between otolith mass asymmetry and fish length.

Author contributions

Laith Jawad: Conceptualization; formal analysis; investigation; methodology; project administration; supervision; validation; visualization; writing original draft; writing review and editing.

Habil Uğur Koca: Conceptualization; data curation; investigation; methodology; project administration; resources.

Seval Bahadir Koca: Data curation; investigation; methodology; resources; validation; writing review and editing.

Mehmet Cilbiz: formal analysis; investigation; methodology; supervision; validation; visualization; review and editing.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data availability statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics statement

This study is based on commercial fish species, and the specimens were collected from a commercial catch. Therefore, ethical aspects are not applicable.

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