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Assessing fish length-otolith relationships in Scorpaenidae species: Implications for sustainable fisheries management in Antalya Bay, Türkiye

by

Habil Uğur Koca[1,a], Seval Bahadir Koca[1,b], Mehmet Cilbiz[1,c], Laith A. Jawad[2,3,d]*

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[1]*Isparta University of Applied Sciences, Eğirdir Fisheries Faculty, Isparta-Republic of Türkiye*

[2]*School of Environmental and Animal Sciences, Unitec Institute of Technology, Auckland, New Zealand*

[3]*Marine and Aquatic Life Research Group, Scientific Research Centre, Al-Ayen Iraqi University, An Nasiriyah, Iraq*

[a] *(https://orcid.org/0000-0002-6674-696X)*
[b] *(https://orcid.org/0000-0002-7507-3816)*
[c] *(https://orcid.org/0000-0002-7686-7570)*
[d] *(https://orcid.org/0000-0002-8294-2944)*

* Corresponding author: *laith_jawad@hotmail.com*

Abstract

This study explores relationships between fish size (total length) and otolith dimensions (weight, length, width) in four scorpaenid species from Antalya Bay, Türkiye, supporting sustainable fisheries management. Key contributions include: (1) Stock assessment, strong fish length-otolith correlations (especially in *Scorpaena elongata*, *Scorpaena notata*, *Scorpaena scrofa*, and *Helicolenus dactylopterus*) improve age-based stock assessments, aiding catch limit setting and population monitoring. (2) Species-specific management, variable relationships (e.g., otolith weight vs length in *S. elongata/ notata*, otolith length/width in *S. scrofa/dactylopterus*) suggest tailored measures, like size-selective fishing to protect juveniles. (3) Ecosystem-based management, otolith-derived size estimates enhance food web modeling and biodiversity impact assessments. By refining otolith-to-size tools, this study aids policymaking and conservation, promoting Mediterranean fisheries' sustainability and socio-ecological balance.

Key words: Scorpaenidae, otolith morphology, fish length estimation, Mediterranean Sea

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1. Introduction

Effective marine resources management relies on accurate biological data to ensure the sustainable exploitation of fish stocks. A critical aspect of this understands fish age, growth, and population dynamics, which are essential for stock assessments and fisheries management policies (Başusta et al., 2020; Khan et al., 2018; Nazir & Khan, 2019; Viva et al., 2015; Yılmaz et al., 2019). Otoliths, calcified structures in the inner ears of fish (Campana, 2004; Popper & Lu, 2000), serve as invaluable tools in fisheries science due to their role in age estimation, growth back-calculation, and stock delineation as they play an important role in taxonomy, age estimation, growth analyses, and stock assessment (Campana et al., 2000). Additionally, otolith morphology varies significantly among species, making them useful for taxonomic identification and evolutionary studies, including analyses of ancient teleost fauna and their importance of otoliths has been emphasized by many researchers (Annabi et al., 2013; Nolf, 1995).

In fisheries management, otolith size and weight are often correlated with fish length and biomass, allowing researchers to reconstruct growth histories and assess population health (Aneesh-Kumar et al., 2017; Başusta et al., 2020; Nazir & Khan, 2019; Tarkan et al., 2007; Yılmaz et al., 2019). Such relationships are typically modeled using linear regression analyses (Battaglia et al., 2010, 2015), providing key inputs for growth models and yield assessments in both marine and freshwater ecosystems.

This study focuses on four commercially and ecologically important species in the Mediterranean: slender rockfish (*S. elongata*), found at depths of 75–800 m (Sanches, 1991), this species plays a role in deep-sea trophic webs, feeding on fish and benthic invertebrates (Maigret & Ly, 1986); small red scorpionfish (*S. notata*), a demersal species (10–700 m depth) with a maximum age of 8 years (Ordines et al., 2009), its population dynamics are relevant for small-scale fisheries management; red scorpionfish (*S. scrofa*), a slow-growing, long-lived species (up to 500 mm total length [TL]) that supports regional fisheries (Schneider, 1990); and blackbelly rosefish (*H. dactylopterus*), a deep-water species with a maximum recorded age of 43 years (Allain & Lorance, 2000), making it vulnerable to overfishing and requiring careful stock monitoring.

Despite their ecological and commercial importance, data on otolith-fish size relationships for these species are scarce, particularly along the Mediterranean coast of Türkiye. Given the increasing pressure on marine resources, such baseline studies are crucial for developing sustainable harvest strategies and implementing ecosystem-based fisheries management (EBFM). Therefore, this study examines the relationships between fish length, otolith size (length and width), and otolith weight (OWe) in *S. elongata*, *S. notata*, *S. scrofa*, and *H. dactylopterus* from Antalya Bay, Türkiye, contributing to improved fisheries assessment and conservation efforts in the region.

2. Materials and methods

2.1. Study area and fish sampling

Specimens of four scorpaenid species were collected for this investigation, totalling 124 fish: 34 *S. elongata*, 28 *S. notata*, 35 *S. scrofa*, and 27 *H. dactylopterus* (Fig. 1). The collection took place in Antalya Bay on the 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 TL of *S. elongata*, *S. notata*, *S. scrofa*, and *H. dactylopterus* ranged from 144–332 mm, 139–311 mm, 109–328 mm, to 110–298 mm, respectively, with mean values and standard deviations (SDs) of 211.74 ± 4.170, 237.75 ± 4.545, 189.71 ± 5.611, and 208.37 ± 5.469, respectively. Fish were captured using a commercial bottom trawl net with a 44 mm mesh size (22 mm in the cod end). The fishing area had a water depth of 40–160 m. After collection, the fish were kept on ice until they arrived at the laboratory, where they were identified following Hureau and Litvinenko (1986). The TL (TL, from the snout to the end of the upper and lower caudal fin lobes [combined]) was measured to the nearest millimeter.

2.2. Otolith sampling

Sagittae were pulled out, cleaned, dried, and stored dry in numbered Eppendorf tubes for the following inspection. The otolith length (OL), defined as the longest horizontal dimension between the rostrum and posterior end of the otolith passing through the center of the otolith, and the otolith width (OW), defined as the longest vertical dimension between the dorsal and the ventral ends of the otolith, were measured under a Nikon SMZ 80 Stereo microscope (Fig. 3). The total OWe was measured using a standard analytical scale (Radwag model Was/X) to the nearest 0.0001 g. A paired *t*-test was used to evaluate differences between the right and left sagittae.

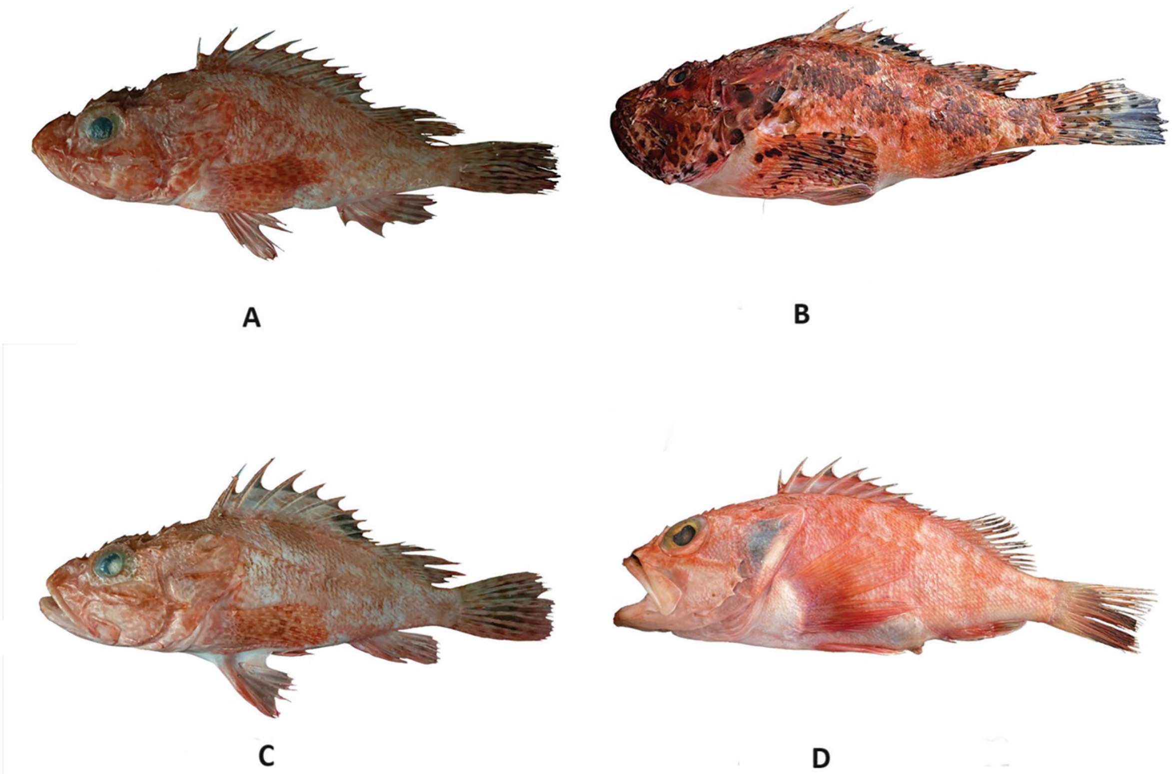

Figure 1

Images of the four scorpaenid species examined. **(A)** *S. elongata*, 239 mm TL, **(B)** *S. notata*, 305 mm TL, **(C)** *S. scrofa*, **(D)** *H. dactylopterus*, 229 mm TL. TL, total length.

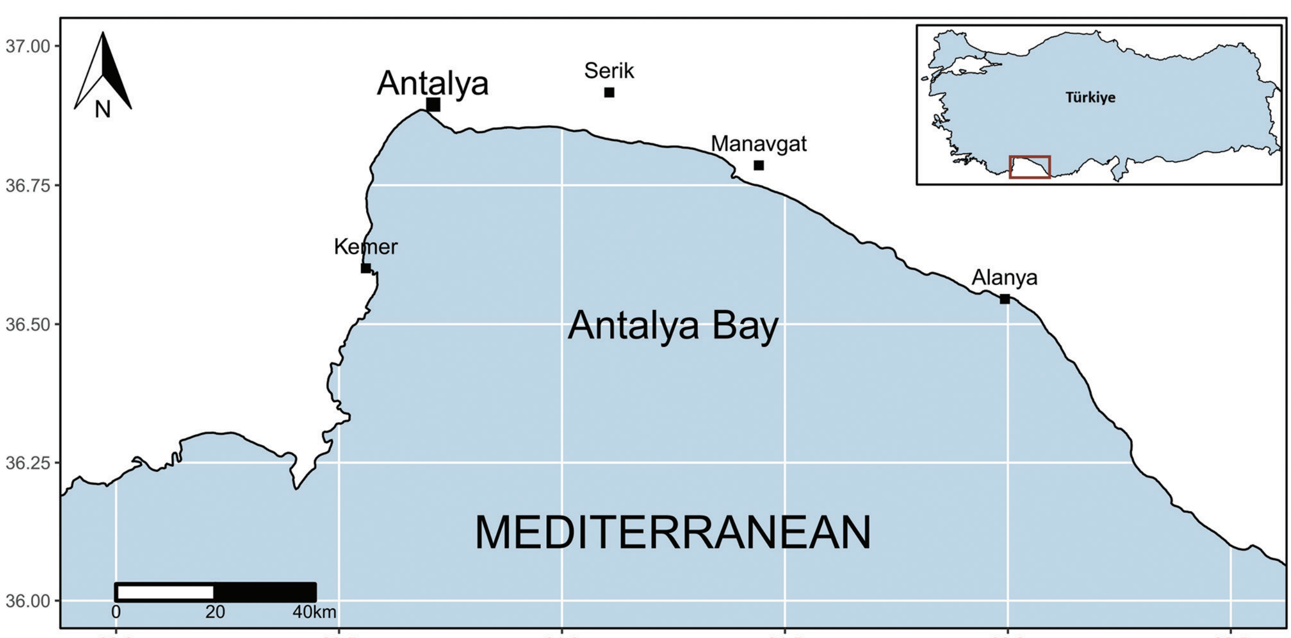

Figure 2

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

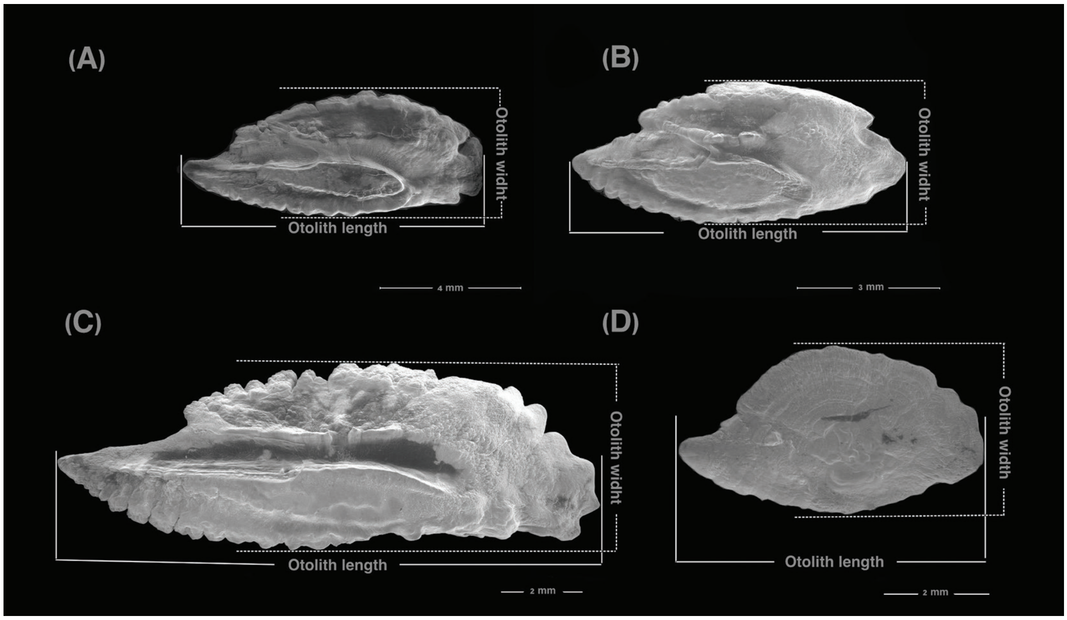

Figure 3

Representative otolith of the four scorpaenid species examined showing OL and OW. **(A)** A, *S. elongata*, 148 mm TL, **(B)** *S. notata*, 139 mm TL, **(C)** *S. scrofa*, 328 mm TL, **(D)** *H. dactylopterus*, 134 mm TL. OL, otolith length; OW, otolith width; TL, total length.

2.3. Statistical analyses

The Shapiro–Wilk test was used to determine the normality of the data distribution. For data that followed a normal distribution, one-to-one comparisons were made using the *t*-test, while non-normally distributed data were analyzed using the Wilcoxon test. Statistical analyses were conducted at a significance level of 0.05. To investigate the relationship between fish length and otolith parameters, a logarithmic transformation was applied to the data to convert non-linear relationships into linear form. Statistical analyses and graph plotting were performed using R packages: rstatix (v.0.7.2) (France), ggtrendline (v.1.0.3) (France), and ggplot2 (v.3.4.4) (China), (New Zealand), within RStudio (v. 2024.04.2) (Kassambara, 2023; Mei et al., 2022; Wickham, 2016). Errors in recording OL, width, and weight can obscure differences, making the results unreliable (Palmer, 1994). To avoid such errors in this study, measurements were taken by a single reader and repeated twice (Lee & Lysak, 1990). Average otolith measurements and weights were used for analysis. For *S. elongata* and *S. notata*, no significant differences in OL and width values ($p > 0.5$) were found between sexes, so these values were combined when calculating the relationship between fish TL and otolith dimensions. However, OWe was significantly different between sexes in these species ($p < 0.5$), so OWe was analyzed separately by sex in relation to fish TL. In *S. scrofa* and *H. dactylopterus*, no significant differences ($p > 0.5$) in OL, width, and weight were found between sexes, so data for these variables were combined when analyzing their relationship with fish TL. Differences between the right and left sagittae were assessed using a paired *t*-test. The relationship between otolith measurements (length, width, weight) and fish size (TL) was determined using linear and non-linear regressions.

3. Results

Ranges and means (±SD) of OL, width, and weight are shown in Table 1. The various correlations between fish length and OL, width, and weight are presented in Table 2. The relationships between fish length and otolith dimensions for the four scorpaenid fish species are illustrated in Figs 4–7. OWe exhibited the highest correlation for predicting total fish length in male *S. elongata* ($r^2 = 0.95$) and *S. notata* ($r^2 = 0.93$), as well as in combined sexes of *H. dactyleptorus* ($r^2 = 0.98$). The strongest correlation for predicting total fish length in *S. scrofa* was observed with OL ($r^2 = 0.92$). These findings provide the first correlations between otolith characteristics and total fish length for the four scorpaenid species studied from Antalya Bay.

Table 1

Minimum and maximum OL (µm), OW (µm), OW (g) and SDs of four scorpaenid fish species collected from Antalya Bay, Mediterranean Sea coast of Türkiye

Species	Sex	*N*	Variables	Left		Right		*p*
				Min–Max	Mean ± SD	Min–Max	Mean ± SD	
S. elongata	Male	14	OWe (g)	0.012–0.088	0.054 ± 0.021	0.012–0.088	0.053 ± 0.020	0.03
	Female	20	OWe (g)	0.029–0.150	0.072 ± 0.026	0.029–0.146	0.072 ± 0.025	0.48
	Combined sexes	34	OL (µm)	0.006–0.014	0.010 ± 0.002	0.006–0.014	0.010 ± 0.002	0.53
			OW (µm)	0.003–0.006	0.004 ± 0.001	0.003–0.006	0.004 ± 0.001	0.04
			OWe (g)	0.012–0.150	0.064 ± 0.026	0.012–0.146	0.064 ± 0.025	0.91
S. notata	Males	15	OWe (g)	0.012–0.066	0.048 ± 0.019	0.013–0.067	0.048 ± 0.019	0.81
	Females	13	OWe (g)	0.013–0.067	0.049 ± 0.021	0.012–0.069	0.049 ± 0.022	0.92
	Combined	28	OL (µm)	0.006–0.012	0.010 ± 0.001	0.006–0.012	0.010 ± 0.002	0.95
			OW (µm)	0.003–0.005	0.004 ± 0.001	0.002–0.005	0.004 ± 0.001	0.97
			OWe (g)	0.012–0.067	0.048 ± 0.02	0.012–0.069	0.048 ± 0.02	0.84
S. scrofa	Combined sexes	35	OL (µm)	0.004–0.002	0.009 ± 0.002	0.004–0.012	0.009 ± 0.002	0.92
			OW (µm)	0.002–0.006	0.004 ± 0.001	0.002–0.006	0.004 ± 0.001	0.98
			OWe (g)	0.011–0.114	0.049 ± 0.026	0.010–0.106	0.049 ± 0.026	0.96
H. dactylopterus	Combined sexes	27	OL (µm)	0.005–0.012	0.009 ± 0.002	0.005–0.012	0.009 ± 0.002	0.17
			OW (µm)	0.003–0.006	0.005 ± 0.001	0.003–0.006	0.005 ± 0.001	0.62
			OWe (g)	0.015–0.122	0.059 ± 0.029	0.015–0.125	0.058 ± 0.030	0.89

OW, otolith width; OWe, otolith weight; SD, standard deviation.

Table 2

Regression relationship parameters and descriptive coefficients between fish length and otolith parameters

Species	Sex	*N*	Measurements	Parameters of the relationship		
				Equation	r^2	*p*
S. elongata	Combined	68	OL (µm)	log(TL) = 0.752 × log(OL)—0.026	0.82	<0.001
			OW (µm)	log(TL) = 0.741 × log(OW)—0.815	0.85	<0.001
	Male	28	OWe (g)	log(TL) = 2.271 × log(OWe)—9.741	0.73	<0.001
	Female	40	OWe (g)	log(TL) = 1.686 × log(OWe)—7.895	0.75	<0.001
S. notata	Combined	56	OL (µm)	log(TL) = 1.022 × log(OL)—0.970	0.93	<0.001
			OW (µm)	log(TL) = 0.921 × log(OW)—1.577	0.77	<0.001
	Male	30	OWe (g)	log(TL) = 2.741 × log(OWe)—11.643	0.88	<0.001
	Female	26	OWe (g)	log(TL) = 2.596 × log(OWe)—11.492	0.88	<0.001
S. scrofa	Combined	70	OL (µm)	log(TL) = 0.867 × log(OL)—0.404	0.90	<0.001
			OW (µm)	log(TL) = 0.724 × log(OW)—0.801	0.86	<0.001
			OWe (g)	log(TL) = 2.050 × log(OWe)—9.134	0.88	<0.001
H. dactylopterus	Combined	54	OL (µm)	log(TL) = 0.711 × log(OL)—0.001	0.77	<0.001
			OW (µm)	log(TL) = 0.644 × log(OW)—0.411	0.95	<0.001
			OWe (g)	log(TL) = 1.968 × log(OWe)—8.874	0.98	<0.001

a, intercept; b, slope; N, number of otoliths; OL, otolith length, OW, otolith width; OWe, otolith weight; r^2, coefficient of determination of four scorpaenid fish species; TL, total length.

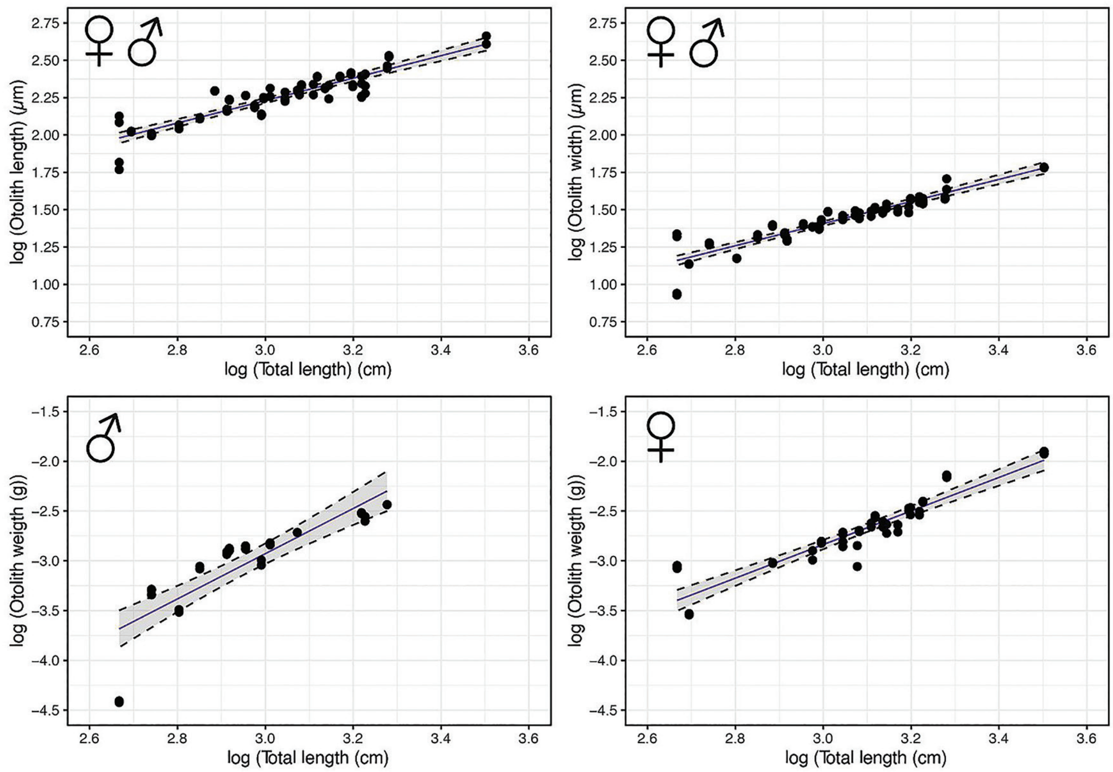

Figure 4

Relationship of TL with otolith variables for *S. elongata*. TL, total length.

4. Discussion

The relationship between fish size and otolith dimensions is a critical tool in fisheries science, supporting sustainable fisheries management by improving species identification, stock assessment, and understanding of population dynamics (Battaglia et al., 2015; Harvey et al., 2000; Mat Piah et al., 2017). While simple linear models have been traditionally used, they often fail to capture shape-related variations, leading to the adoption of more accurate allometric power functions (Gimenez et al., 2016; Lleonart et al., 2000; Lombarte & Lleonart, 1993; Souza et al., 2019; Valinassab et al., 2012). These models are essential for reconstructing fish size from otoliths, which is crucial for assessing growth rates, age structure, and biomass—key components of stock assessments and EBFM.

4.1. Otolith morphometrics for species and stock identification

Otolith shape and measurements are widely used in fisheries management to differentiate species and stocks (Bani et al., 2013; Dinh et al., 2015; Megalofonou, 2006). In this study, the lack of significant differences in otolith variables (length, width, weight) between left and right sides in *H. dactylopterus* and *S. scrofa* suggests that otoliths can be reliably used to distinguish these species from other scorpaenids in Antalya Bay. Similar findings have been reported in other regions, such as *Parapocryptes serperaster* in the Mekong Delta (Dinh et al., 2015) and *Thunnus thynnus* in the Mediterranean (Megalofonou, 2006), reinforcing the importance of otoliths in fisheries monitoring programs.

4.2. Implications for growth and stock assessment

The strong correlation between fish size and otolith traits ($r^2 > 0.93$ for most species) indicates that otolith growth closely follows somatic growth, a key consideration in age and growth studies (Nguyen & Dinh, 2020; Souza et al., 2019). However, variations in otolith size among the four scorpaenid species may reflect differing habitat conditions and food availability (Adandédjan et al., 2011, 2012; Mommsen, 1998), highlighting the need for localized studies to account for environmental influences on growth. Given that, Antalya Bay is a heavily polluted and high-traffic commercial zone, understanding these

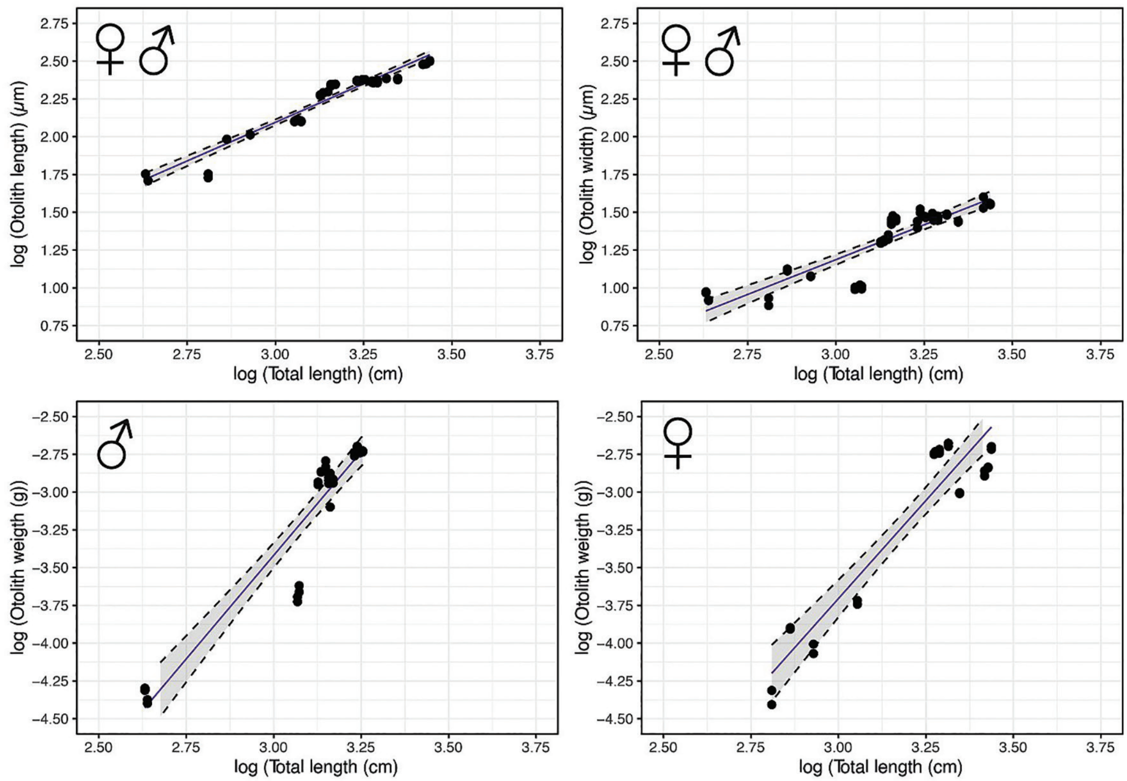

Figure 5

Relationship of TL with otolith variables for *S. notata*. TL, total length.

relationships is vital for assessing fish health and resilience to anthropogenic stressors.

4.3. Geographical and environmental influences on otolith-fish relationships

Differences in otolith-fish size relationships across locations suggest that environmental factors (e.g., salinity, pollution, temperature) significantly impact fish growth (Aydin et al., 2004). Seasonal growth variations (Bolognini et al., 2013; Richter et al., 2000; Safran, 1992) further emphasize the need for year-round sampling to improve stock assessment models. Such data are critical for adaptive fisheries management, particularly in regions like the northeastern Mediterranean, where overfishing and habitat degradation threaten marine biodiversity.

4.4. Applications in fisheries management and conservation

The strong otolith-fish size correlations observed in this study support their use in reconstructing fish size distributions from otoliths in catch data, aiding in the estimation of population structure and mortality rates (Jawad et al., 2011; Park et al., 2018). Additionally, since otoliths are often preserved in fisheries surveys even when fish are damaged, multiple regression models (e.g., OL–TL, OW–TL) enhance data reliability (Takasuka et al., 2008).

4.5. Future research needs for sustainable fisheries

While this study provides foundational data for scorpaenid species in Antalya Bay, expanded research is needed to: (1) assess population structure across different seasons to account for growth variability; (2) link otolith dynamics to environmental stressors (e.g., pollution, climate change) to predict fishery responses; and (3) develop regional otolith-fish size models for more species, improving stock assessments in the Mediterranean.

In conclusion, Otolith-fish size relationships are a powerful tool for sustainable fisheries management, offering insights into growth, stock structure, and ecosystem health. Given the ecological and economic importance of scorpaenid species in the Mediterranean, integrating otolith-based analyses into fisheries monitoring programs will enhance management strategies, ensuring long-term resource sustainability in Antalya Bay and beyond.

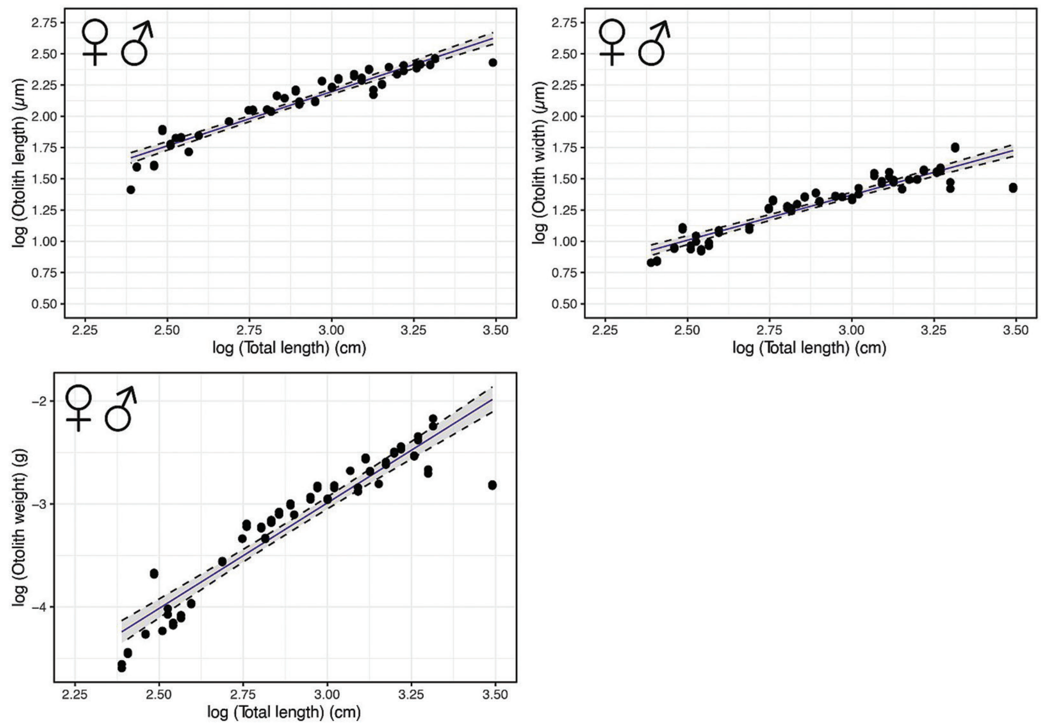

Figure 6

Relationship of TL with otolith variables for *S. scrofa*. TL, total length.

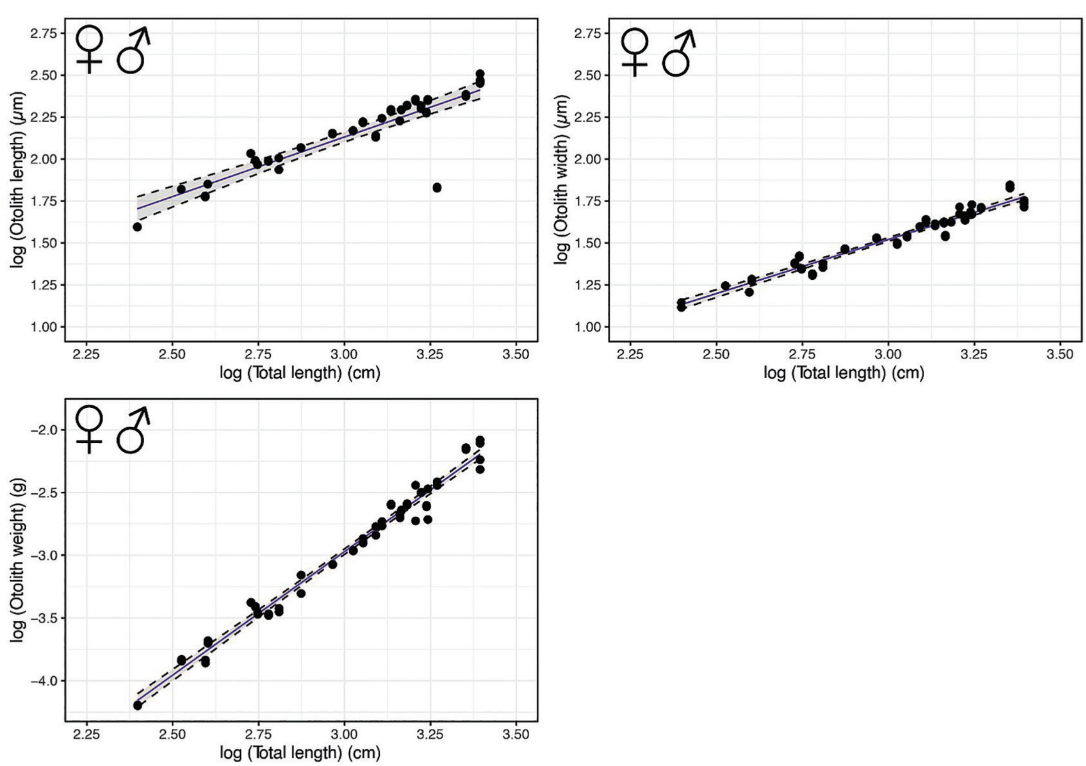

Figure 7

Relationship of TL with otolith variables for *H. dactylopterus*. TL, total length.

Conflict of interest

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

Data availability statement

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

Ethics statement

This work 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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