Correlation of otolith morphometry with length and weight in barracuda *Sphyraena forsteri* (Cuvier, 1829) at the Coastal Fishing Port of Tasikagung Rembang, Central Java

Octavia C. Budiati, Djumanto, Suwarman Partosuwiryo, Namastra Probosunu

Laboratory of Aquatic Resources Management, Department of Fisheries, Faculty of Agriculture, Gadjah Mada University, Bulaksumur Yogyakarta, Indonesia. Corresponding Corresponding author: Djumanto, lely4192@yahoo.com

Abstract. Barracuda (*Sphyraena forsteri*) is often caught in the waters of the Java Sea using purse seine fishing gear. Therefore, this study aims to determine the relationship between fish length and weight and barracuda otolith morphometry. The samples used consisted of 155 barracuda, 103 males and 52 females, collected from fishermen who fished in the Java Sea and landed their catch at the Tasikagung Coastal Fishing Port in November 2023. Morphometric measurements of otoliths included length, weight, width, area, and perimeter. The shape index was calculated based on six descriptors, including Aspect Ratio (AR), Ellipticity (E), Circularity (C), Roundness (RO), Rectangularity (Rt), and Form Factor (FF). The results showed that the barracuda otoliths were elongated and had an irregular surface and a convex shape. There were significant differences in otolith morphology between the left and right sides in weight, width, area and perimeter. In contrast, there are substantial differences in weight and width between female and male otoliths. The growth in length and weight of barracuda has a positive relationship to otolith morphometry, and the strongest relationship was found in the relationship between the length and weight of the fish, and the length and weight of the otolith.
Key Words: bigeye barracuda, characteristics, morphological, otolith.

Introduction. The waters of the Java Sea are within the Fishery Management Area of the Republic of Indonesia (WPPNRI) 712. Fishing potential in this location includes both pelagic and demersal species. Furthermore, Tasikagung Coastal Fishery Port (CFP) is in Rembang Regency, Central Java Province, specifically on the northern coast of Java Island, which has excellent potential for fishery activities. Fishery Port Information Center stated that approximately 78678377 kg of fish was caught from January to December 2023, with a production value of 623.9 billion IDR (https://pipp.kkp.go.id/). From 2018 to 2023, the production volume was estimated at 113596140 kg with a value of 951.6 billion IDR (https://pipp.kkp.go.id/). Fishing gear used includes purse seine and mini purse seines, yielding catches such as *Priacanthus tayenus, Nemipterus nematophorus, Leiognathus equulus, Upeneus sulphureus, Sphyraena forsteri, Selaroides leptolepis, Decapterus* spp., *Euthynnus affinis*, rays, squids, and others.

Barracuda is a group of pelagic marine fish found in tropical waters with warm climates, congregating in small schools, particularly in shallow waters or along coral reefs. They are known by local names such as "alu-alu," "tunul," and "kacangan." The distribution in Indonesia includes the waters of West Sumatra, Java Sea, Ambon Sea, and South Sulawesi (Syahfutra et al 2023). Barracuda production in Tasikagung from January to December 2023 amounted to 348520 kg with a production value of 180129.4 USD (https://pipp.kkp.go.id/). These catches represent the yield captured by fishermen over 2023. Fishing gear often used is purse seine, with vessels ranging from over 30 GT to less than 30 GT. After landing, fish is unloaded at the auction site, marketed fresh, and shipped to several cities such as Semarang, Yogyakarta, Pekalongan, Jakarta, and other

areas. Processing can also be carried out into salted and smoked fish as preserved products (Sampels 2015).

The otolith is a calcareous structure in the inner ear of fish formed through biomineralization within the body. The three otolith types, namely sagitta, lapillus, and asteriscus, have distinct morphologies specific to different fish species (Lombarte & Castellón 1991; Bostanci et al 2016). The environment and genetic factors of fish with varying life histories influence otolith shape and morphology, leading to variations. This structure records a fish's life history, storing information about age, size, growth, and ontogeny. It continues to grow throughout life and is not absorbed during stress. The otoliths can also be used in recognizing fish development, age determination, and fishery resource management. Microstructure analysis is used to identify fish populations, predator-prey behavior in ecosystems, and migration patterns (Campana & Thorrold 2001; Rodriguez-Mendoza 2006; McFarlane et al 2010; Dehgani et al 2016). The size and shape of otoliths vary according to fish size and species. The relationship between fish length and otolith size is potentially helpful for estimating fish size and age. Otoliths grow in length and width proportionally with body size, while thickness and weight show linear growth with increasing age (Donkers 2004; Dehgani et al 2016). Investigations on fish otolith are rare in Indonesia. Hence, exploring morphometric relationships with length and weight can benefit various studies for age determination, growth, and population dynamics. This study aimed to examine the morphometric characteristics of otoliths of barracuda and their relationship with fish length and weight. These data are essential for determining policies for managing barracuda fish resources in Java Sea waters.

Material and Method

Description of the study sites. Barracuda was obtained from the catches of fishermen operating in the National Fisheries Management Area of the Republic of Indonesia (WPPNRI-712) Java Sea. Fishermen caught the barracuda using a purse seine measuring 600 m long. The catch landed at the Tasikagung Rembang fishing port (Figure 1). Sampling was conducted in November 2023, and 200 samples were randomly selected. Subsequently, the samples were taken to the Laboratory of Fisheries Resource Management, Gadjah Mada University, for sex determination, fish length and weight assessments, and morphometric otolith measurement.

Fish and otolith data collection. The total length of barracuda samples was measured using a ruler with an accuracy of 0.1 cm, while weight was measured through a digital scale with an accuracy of 0.01 g. Fish were dissected to determine the sex, distinguished by the presence of ovaries or testes. Otoliths are located within the head cavity. The sagitta otolith was selected for observation. The "up through the gill" method was used to retrieve otoliths by dissecting the gills and opening the area until the bones in the neck area were visible. The bone was cut, the saccule sac was opened so the otoliths inside were exposed, then both the left and right otoliths were retrieved using tweezers. The retrieved otoliths were cleaned with water, dried, and stored in small plastic containers. Each container was labeled with a number showing whether it contained the left or right part to prevent mixing.

After dissection, otolith weight (OM) was measured using a microscale with an accuracy of 0.0001 g. Subsequently, the otolith was photographed using a photo box to ensure clear and contrasting images followed by framing with millimeter blocks to determine the scale for morphometric data collection. Morphometric analysis was conducted using ImageJ software, including measurements of otolith length (OL), width (OW), area (OA), and perimeter (OP) (Figure 2).

Data analysis. Some fish species have different morphometrics between the left and right otoliths and between males and females (Başusta & Dürrani 2021). Differences in mean morphometry of left and right otoliths and females and males were analyzed using Origin software. A paired t-test with a 95% confidence level was used to determine the differences in mean morphometry of left and right otoliths and between female and male fish. The null hypothesis (H0) is accepted if t-count < t-table shows no significant

difference in mean between left and right otoliths or between female and male fish. In contrast, the alternative hypothesis (H1) is accepted if t-count > t-table, which shows that there are significant differences between left and right otoliths or between females and males. The relationship between total length and individual weight with OL, OM, OW, OA, and OP is determined using linear correlation analysis described by the equation y = axe + b at 95%. The shape of the otolith is described using shape indices, namely Aspect Ratio (AR), Ellipticity (E), Circularity (C), Roundness (RO), Rectangularity (Rt), and From Factor (FF), which are calculated using Microsoft Excel. The shape index formula and explanation are presented in Table 1.

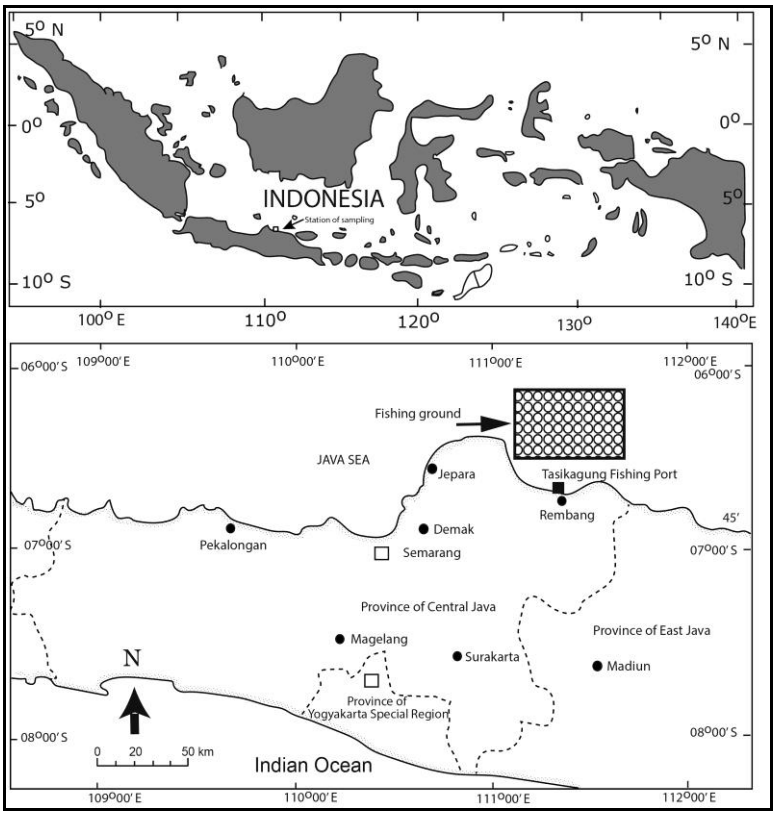

Figure 1. Map of barracuda (*Sphyraena forsteri*) fishing ground and sampling locations at the Tasikagung Fishing Port, Rembang, Central Java.

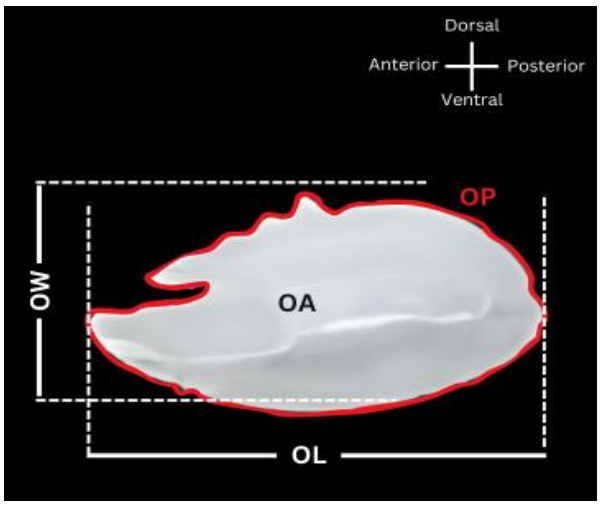

Figure 2. Procedure for measuring and recording morphometric data of barracuda (*Sphyraena forsteri*) otoliths.

Table 1

The indices used for the shape of barracuda (*Sphyraena forsteri*) otoliths

Shape index	*Formula*	*Description*
AR	$\frac{OL}{OW}$	AR>1 shows an elongated shape of otolith.
E	$\frac{OL - OW}{(OL+OW)}$	It signifies a proportional change in axes.
C	$\frac{OP^2}{OA}$	Comparison of otolith shape with that of a full circle.
RO	$\frac{4OA}{\pi OL^2}$	When comparing otolith with a perfect circle, RO=1 denotes a perfect circular shape.
Rt	$\frac{OA}{OL.OW}$	Describes the variation of otolith length and width concerning area; Rt=1 implies a perfect square-shaped otolith.
FF	$\frac{4\pi OA}{OP^2}$	FF=1 shows a regular surface like a circle; FF<1 shows an irregular otolith surface.

Results. 200 barracuda were used for otolith studies, comprising 134 males and 66 females. The number of successfully retrieved otoliths was 155, from 103 males and 52 females. Length ranged from 22.5 to 36.3 cm, with an average of 28.24±2.27 cm, while weight ranged from 58.5 to 228.8 g, with an average of 114.06±30.38 g. The length range of males was between 22.5 and 36.2 cm, with an average length of 27.5±1.714 cm. On the other hand, the total size of females ranged from 25.4 to 36.3 cm, with an average length of 29.6±2.538 cm. The weight of males was between 58.5 and 147.3 g, with an average of 103.6±19.038 g, while the weight of females ranged from 72.8 to 228.8 g, with an average of 134.7±37.288 g.

Otolith shape index. The six descriptors used to describe the shape of the otoliths, and the average value of the shape index are presented in Table 2. The sagitta otolith was elongated, with an irregular surface and a convex shape. The calculated AR was 2.053 (AR>1), showing that the otolith was elongated. The E was 0.346, suggesting proportional changes in the axis, while the RT value was 0.705 (Rt≠1), indicating the otolith was not perfectly square. The C was 20.169, and the RO (Roundness) was estimated at 0.437 (Ro≠1), showing that the otolith was not perfectly circular. Due to the irregular surface, the Form Factor index value was 0.627 (FF<1).

Table 2

Results of otolith shape index calculations

Shape index	*Male*		*Female*		*Min*	*Max*	*Average±SD*
	Left	*Right*	*Left*	*Right*			
AR	2.010	2.036	2.071	2.096	1.844	2.600	2.053±0.033
E	0.335	0.346	0.348	0.353	0.296	0.440	0.346±0.007
Rt	0.704	0.710	0.700	0.706	0.668	0.838	0.705±0.004
C	19.767	19.829	20.890	20.189	17.872	28.581	20.169±0.446
RO	0.448	0.439	0.431	0.430	0.370	0.496	0.437±0.007
FF	0.638	0.636	0.608	0.625	0.444	0.702	0.627±0.012

Comparison between left and right otolith morphometrics and between females and males is presented in Table 3. Based on a statistical analysis of otolith morphometry between left and right, the calculated t-value < t table for otolith length, while the t count > t table for otolith weight, width, area, and edges. The initial hypothesis (H0) was accepted, which means that the lengths of otoliths between left and right have no significant differences, while otolith weight, width, area and perimeter between left and right have substantial differences.

Table 3

Otolith morphometric t test results between the left and right sides and between male and female barracuda (*Sphyraena forsteri*)

Parameter	*Testing*	*Mean*		*SD*		*t-stat*	*Prob>t*	*Note*
		L	*R*	*L*	*R*			
Otolith length (cm)	L vs R	0.7390	0.7405	0.0615	0.0612	0.9777	0.3290	Not sig.
Otolith weight (g)	L vs R	0.0314	0.0316	0.0074	0.0075	3.620	0.0004	Sig.
Otolith width (cm)	L vs R	0.3637	0.3579	0.0258	0.0286	5.0575	0.0000	Sig.
Otolith area (cm2)	L vs R	0.1896	0.1884	0.0269	0.0269	2.2521	0.0255	Sig.
Otolith perimeter (cm)	L vs R	1.9514	1.9327	0.1667	0.1496	2.9882	0.0031	Sig.
		F	M	F	M			
Otolith length (cm)	F vs M	0.7625	0.7322	0.0714	0.0557	3.8988	0.0001	Sig.
Otolith weight (g)	F vs M	0.0329	0.0318	0.0085	0.0073	1.1841	0.2390	Not sig.
Otolith width (cm)	F vs M	0.3662	0.3646	0.0309	0.0223	0.4507	0.6531	Not sig.
Otolith area (cm2)	F vs M	0.1973	0.1886	0.0318	0.0237	2.6381	0.0096	Sig.
Otolith perimeter (cm)	F vs M	2.0047	1.9248	0.1984	0.1276	3.7269	0.0003	Sig.

Note: L - left; R - right; F - female; M - male.

Statistical analysis of the morphometry of female and male otoliths showed t values < t table for otolith weight and width. T count > t table was obtained for otolith length, area, and edge between females and males. The initial hypothesis (H0) was accepted, meaning there is no significant difference in otolith weight and width between females and males. The alternative hypothesis (H1) is accepted for otolith length, area, and perimeter, so that between females and males, there are significant differences.

Differences in the shape of left and right otoliths, and between females and males. The morphometry of barracuda otoliths on the left and right sides, as well as between females and males landed at Coastal Fishing Port (CFP) Tasikagung Rembang is presented in Figure 3. The left otolith has a mean OM of 0.0322±0.0077 g, OL of 0.74±0.06 cm, OW of 0.03±0.02 cm, OA of 0.19±0.02 cm², and OP is 1.95±0.16 cm. Meanwhile, the right otolith had a mean OM of 0.0324±0.0077 g, OL of 0.74±0.06 cm, OW of 0.35±0.02 cm, OA of 0.19±0.02 cm², and OP was 1.94±0.14 cm. Significant differences existed between the left and right otoliths regarding otolith weight, width, area, and circumference (t-count > t-table).

The results of otolith morphometry measurements show that female barracudas have an OL of 0.76±0.07 cm, OM of 0.033±0.0085 g, OW of 0.36±0.03 cm, OA of 0.19±0.03 cm², and OP was 1.98±0.18 cm. Male otoliths have an OL of 0.73±0.05 cm, OM of 0.0320±0.0072 g, OW of 0.35±0.02 cm, OA of 0.18±0.02 cm², and OP of 1.91±0.12 cm. Between male and female otoliths there were significant differences in length, area and circumference, with the calculated t value (t count) being greater than the critical t value (t table).

Relationship between otolith and length or weight. The relationship between total length and weight to otolith size is presented in Figure 4. The growth of barracuda, specifically in total length, was proportional to an increase in otolith size. The relationship between these parameters was explained using linear regression equations. The analysis showed a linear and positive relationship between the length and weight of fish to OL, OM, OW, OA, and OP. The growth in total length of fish with length and weight of otolith can be represented by the equations OL = 0.0193 TL + 0.1984 and OM = 0.0024 TL – 0.0363, with 0.51 coefficient of determination each, showing a relatively strong relationship. Based on the results, every 1 cm of growth in the length of barracuda corresponded to a 0.0193 cm rise in otolith length and a 0.0024 g increase in otolith weight.

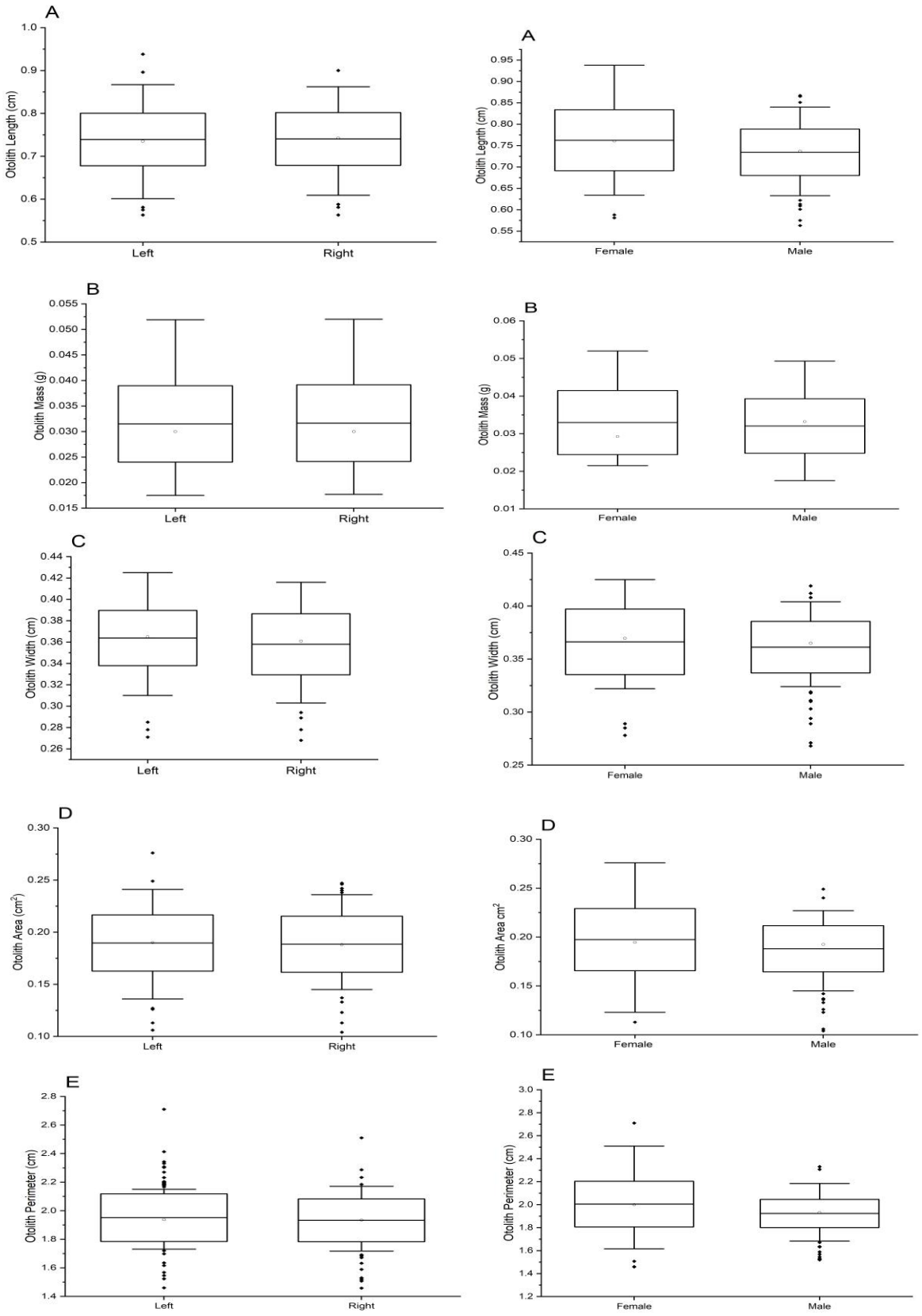

Figure 3. Distribution of barracuda otolith morphometric parameters between the left and right sides (left panel), as well as between females and males (right panel) from top to bottom, namely otolith weight (panels A, A), otolith length (panels B, B), otolith width (panels C, C), otolith area (Panels D, D) and otolith perimeter (panels E, E), respectively.

In Figure 4, on the right panel, fish weight and otolith morphometrics show a positive linear regression relationship. A relatively strong relationship exists between body weight and otolith length, mass, and area. The relationship between body weight and otolith weight is shown by the equations OL = 0.0015 W + 0.568, OM = 0.0002 W + 0.01, OW = 0.0005 W + 0.297, OA = 0.0007 W + 0.115, and OP = 0.0034 W + 1.549, with a coefficient of determination value respectively of 0.58, 0.59, 0.34, 0.54, and 0.50. Based on the results obtained, every increase of 1 g in fish weight will cause growth in otolith length, weight, width, area and circumference, respectively, by 0.0002 cm, 0.0015 g, 0.0002 cm, 0. 0005, 0.0007 cm^2, and 0.0034 cm.

The linear regression equation for the length of fish against otolith width was OW = 0.0065 TL + 0.1761, with a 0.27 coefficient of determination, showing that for every 1 cm growth in fish length, there was a 0.006 cm increase in otolith width. Furthermore, the area of otolith with equation OA = 0.0081 TL – 0.0390 and a 0.47 coefficient of determination showed that for every 1 cm growth in fish length, there was a 0.008 cm^2 increase in otolith area. The linear regression equation for otolith perimeter was OP = 0.0428 TL + 0.7329, with a 0.43 coefficient of determination, suggesting that for every 1 cm growth in fish length, there was a 0.04 cm increase in otolith perimeter.

Discussion. Otolith shape indices of barracuda different species showed similar results and resemblance. In the species *Sphyraena sphyraena* located in the Mediterranean Sea, the average results were as follows: Ar=3.0179, C=25.1100, E=0.5018, Ff=0.5019, Rt=0.7258, Ro=0.3068, showing elongated otolith that was neither square nor circular (Yedier 2021). *Sphyraena viridensis* in the coastal waters of Algeria has otolith shape indices with average values of Ff=0.338, Ro=0.342, C=37.281, Rt=0.722, E=0.457, while *S. sphyraena* had average otolith shape indices of Ff=0.372, Ro=0.333, C=34.010, Rt=0.727, E=0.47. Otolith shapes of both species show similarity, but *S. viridensis* has a more convex shape than *S. sphyraena* on the dorsal side. Moreover, the meeting point between the posterior and dorsal sides is perpendicular in *S. sphyraena* compared to *S. viridensis*. The ventral side of *S. sphyraena* is more convex than that of *S. viridensis*. The differences in otolith shape index values can be attributed to environmental factors such as temperature, and fish growth rates (Bourehail et al 2015).

Significant differences were found between the right and left otoliths for OM, OW, OA, and OP in *S. forsteri* landed at the Coastal Fishing Port of Tasikagung Rembang. The t-test was used to analyze OM, OW, OA, and OP. The left otolith had higher values than the right, but no significant difference was observed in OL. Similarly, in a study on *S. sphyraena*, significant differences were found in morphometric measurements of the right and left otolith, particularly in OW and OA (Yedier 2021). Significant differences between the right and left otolith were observed in *Carangoides coeruleopinnatus* in the Persian Gulf, specifically in OM and OA. The right otolith was heavier, while the left was more prominent in the area (Fashandi et al 2017). Similar significant differences between the right and left otolith were found in *Pagellus acarne* in the waters of Marmara Sea, Turkey, particularly in the OA, OP, OL, and OW (Yedier et al 2023).

Morphometrics of otolith for males and females showed significant differences in OL, OA, and OP, while OM and OW had no significant differences. In a previous study (Yedier et al 2023), significant differences were found between male and female *Carangoides malabaricus* in the Persian Gulf waters regarding OW and OA. Sagitta otolith of *Perca fluviatilis* showed significant differences between males and females in OL and OW, with males having more considerable length and width compared to females (Yilmaz et al 2014). Similar results were also found in several fish species, such as *Mullus surmuletus, Uranoscopus scabe,* and *Synaptura lusitanica* in the coastal waters of Valencia, Spain, with differences observed in the OL and OW (Jaramillo et al 2014). Gender differences in male and female fish, along with the size of the body and the sagittal otolith, are related to somatic growth (Bostanci et al 2012; Yilmaz et al 2014).

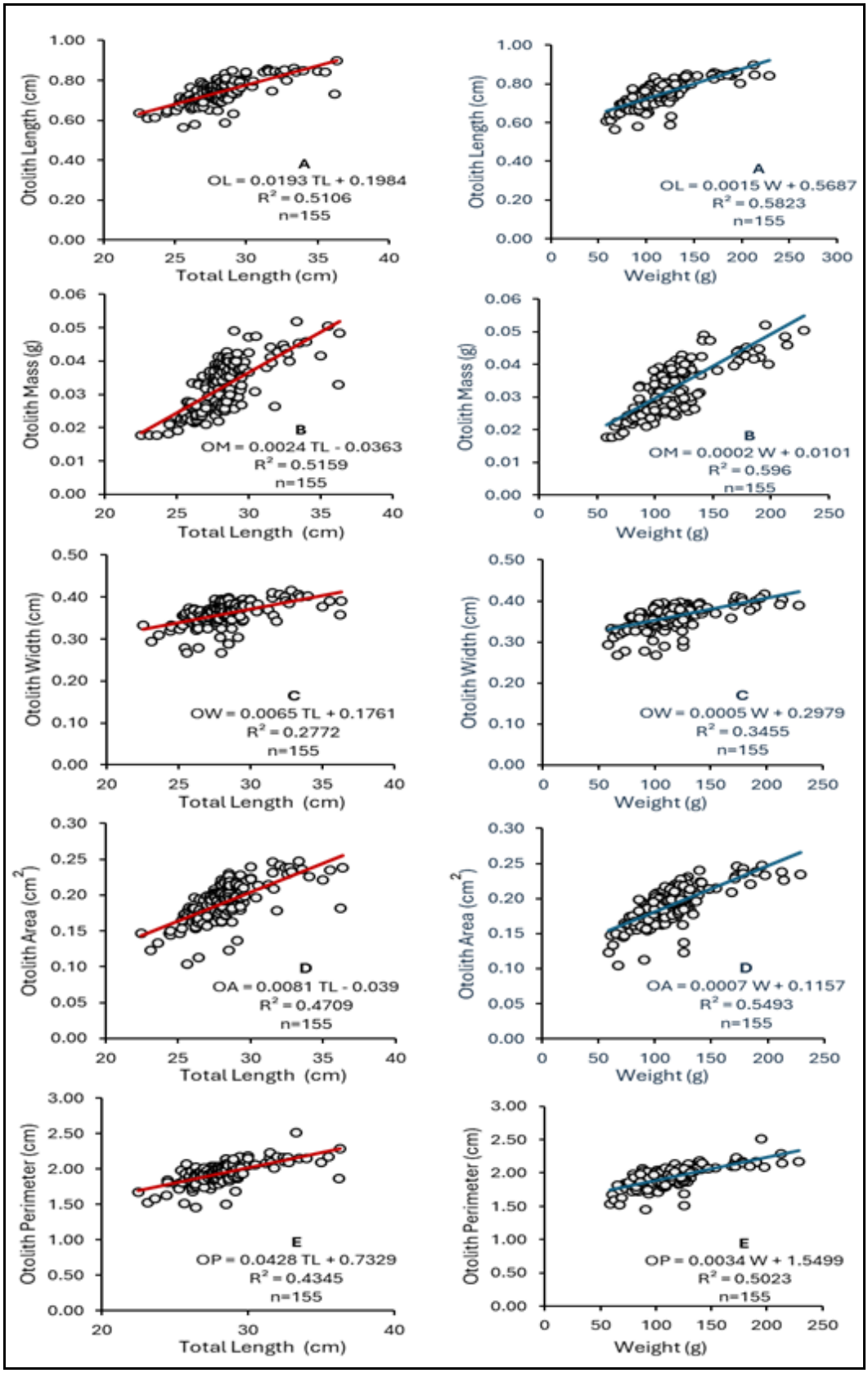

Figure 4. Linear regression relationship between total length (TL) and otolith morphometry, and weight and barracuda (*Sphyraena forsteri*) otolith morphometry. In order from top to bottom, namely Total Length (left panel) and weight (right panel) with length otoliths (A, A), otoliths mass (B, B), otolith width (C, C), otoliths area (D, D) and Peripheral otoliths (E, E).

Based on the results, the sagitta otolith of *S. forsteri* showed a morphometric correlation with the total length and weight. Morphometric correlation values of otolith with the total length of fish, in descending order, are as follows: OM, OL, OA, OP, and OW. Similarly, for the weight of fish, the correlation values, in descending order, are OM, OL, OA, OP, and OW. The relationship between fish length and OM and OL had a similar growth value of 51%. Fish weight was related to OM and OL, yielding a growth value of 59% and 58%, respectively. The length and weight of the otolith showed a positive relationship with the length and weight of the fish body, which formed a linear regression equation. These results indicate that the weight and length of the otolith can be used to estimate the length and weight of the fish body, and vice versa; the length and weight of the fish body can be used to estimate the length and weight of the otolith. The weight of the otolith is influenced by the somatic growth and the age of the fish, so a faster somatic growth and an older fish will have larger and heavier otoliths (Hanson & Stafford 2017).

Fish otolith forms due to calcium carbonate in the inner ear and is crucial in maintaining body balance and hearing. The morphometrics of each otolith varies due to genetic, environmental, and age factors (Cardinale et al 2004; Vignon & Morat 2010). Ecological factors, abundant food supply, and optimal growth conditions, contribute to increased otolith (Mamangkey 2002). This increase is associated with metabolic processes, which lead to calcium carbonate deposition, contributing to the relationship between fish length and otolith dimensions (Campana et al 1978; Mamangkey 2002). One environmental factor that can hinder otolith growth is the relatively low water temperature (Onay & Ceylan 2022).

The increase in otolith size is influenced by somatic body growth in fish. Slow growth can lead to heavier and denser otolith because calcium carbonate deposition continues throughout the fish's life, causing inhibition of growth rates. Conversely, when the fish environment is supportive, the growth rate becomes faster, and the formed otolith will be thin and light (Chahyadi & Windarti 2015). Differences in the shape and size of otolith between male and female fish are due to hormone levels, inhibited growth rates, and distinct habitats (Onay & Ceylan 2022). Pelagic and demersal fish can be distinguished by the otolith shape, with pelagic fish having high swimming activity aided by thin otoliths, while demersal fish have thicker otoliths (Wujdi et al 2016). Factors influencing the dimensions of barracuda otolith at CFP Tasikagung include, habitat, body metabolism, and somatic growth.

Conclusions. The sagitta barracuda otolith had an elongated shape with an irregular surface and a convex shape. The anterior part was elongated and pointed, while the posterior was oval and blunt. The morphometry of the otoliths between right and left sides shows significant differences in weight, width, area and perimeter. There is no significant difference in the morphometric shape of the otoliths between females and males regarding length, weight, and width. However, in the morphometric measurements of barracuda otoliths, there are significant differences in area and perimeter. The size and weight growth in male and female barracuda concerning otolith morphometry shows a positive linear relationship. Otolith length and otolith weight have the highest coefficient of determination.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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Authors:
Octavia Cahyaningrum Budiati, Laboratory of Aquatic Resources Management, Department of Fisheries, Faculty of Agriculture, Gadjah Mada University, Flora Street, Building A4, 55281 Bulaksumur Yogyakarta, Indonesia, e-mail: octavia01@mail.ugm.ac.id
Djumanto, Laboratory of Aquatic Resources Management, Department of Fisheries, Faculty of Agriculture, Gadjah Mada University, Flora Street, Building A4, 55281 Bulaksumur Yogyakarta, Indonesia, e-mail: lely4192@yahoo.com
Suwarman Partosuwiryo, Laboratory of Aquatic Resources Management, Department of Fisheries, Faculty of Agriculture, Gadjah Mada University, Flora Street, Building A4, 55281 Bulaksumur Yogyakarta, Indonesia, e-mail: suwarman.p@ugm.ac.id
Namastra Probosunu, Laboratory of Aquatic Resources Management, Department of Fisheries, Faculty of Agriculture, Gadjah Mada University, Flora Street, Building A4, 55281 Bulaksumur Yogyakarta, Indonesia, e-mail: probosunu@ugm.ac.id

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