Investigation into the morphology and comparative assessment of otolith dimensions in *Mugil cephalus* collected from the Sosa coastline.

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Abstract

This research investigates the interrelationships among sagitta otolith metrics in *Mugil cephalus* (flathead mullet) sourced from the Sousse Sea in eastern Libya. A sample of 20 individuals was examined for various parameters, including sagitta weight, length, and height, alongside total weight and length. The findings reveal significant correlations between sagitta weight and total weight, sagitta length and height, as well as total length and sagitta weight. Regression equations were established to quantify these relationships, offering a mathematical basis for comprehending the interactions among the variables. The study emphasizes the role of sagitta weight and total length as reliable indicators of total weight, while sagitta height serves as a predictor for sagitta length. These results carry important implications for fisheries management, ecological studies, and conservation efforts, particularly in elucidating the growth patterns and ecological roles of *Mugil cephalus* populations.

Furthermore, the research highlights the necessity for sufficient sample sizes, thorough statistical evaluations, and the consideration of ecological variables in conducting effective otolith research on *Mugil cephalus*.

ملخص:

يبحث هذا البحث في العلاقات المتبادلة بين مقاييس حصوات الأذن في أسماك البوري المسطح الرأس التي تم الحصول عليها من بحر سوسة في شرق ليبيا. تم فحص عينة من 20 فردًا من أجل معايير مختلفة، بما في ذلك وزن السهم والطول والارتفاع، إلى جانب الوزن الإجمالي والطول. تكشف النتائج عن وجود ارتباطات مهمة بين وزن السهم والوزن الإجمالي، وطول السهم وارتفاعه، وكذلك الطول الإجمالي ووزن السهم. تم إنشاء معادلات الانحدار لقياس هذه العلاقات، مما يوفر أساسًا رياضيًا لفهم التفاعلات بين المتغيرات. تؤكد الدراسة على دور وزن السهم والطول الإجمالي كمؤشرات موثوقة للوزن الإجمالي، في حين يعمل ارتفاع السهم كمتنبئ لطول السهم. تحمل هذه النتائج آثارًا مهمة على إدارة مصايد الأسماك والدراسات البيئية وجهود الحفاظ، وخاصة في توضيح أنماط النمو والأدوار البيئية لمجموعات أسماك البوري المسطح الرأس. علاوة على ذلك، يسلط البحث الضوء على ضرورة وجود أحجام عينات كافية، وتقييمات إحصائية شاملة، والنظر في المتغيرات البيئية في إجراء أبحاث فعالة على حصوات الأذن على *Mugil cephalus*.

Introduction

Mugil cephalus, widely referred to as the flathead mullet, is a fish species that has garnered significant attention in research pertaining to its biological characteristics, ecological roles, and interactions with the environment. This species is distributed across coastal waters in tropical, subtropical, and temperate regions of the world's oceans. Adult flathead mullets typically inhabit these coastal areas (Eschmeyer et al., 1983). They exhibit primarily diurnal feeding behaviors, consuming a diet that consists of detritus, micro-algae, and various benthic organisms (Blaber, 1976).

Otoliths, often referred to as "earstones," are rigid structures composed of calcium carbonate that are situated just behind the brain in bony fish as *Mugil cephalus* (Campana & Neilson, 1985). There are

three distinct types of otoliths, each playing a crucial role in the fish's ability to maintain balance and perceive sound. The sagitta, the largest of the three pairs, is primarily responsible for sound detection and the conversion of sound waves into electrical signals. The asteriscus also contributes to sound detection and hearing processes. Lastly, the lapillus is involved in sensing gravitational forces as well as sound (Popper and Lu, 2000). The otolith of *Mugil cephalus* has been the subject of various studies to determine different aspects of the species. The study investigated the development and yearly recurrence of opaque bands in the sagittal otoliths of sea mullet from the southeastern region of Australia, confirming the annual periodicity and identifying the specific timing of the formation of both opaque and translucent zones in the otoliths of fish ranging from 0 to 11 years of age (Smith et al., 2003).

The study conducted by Reis et al. (2023) examined the asymmetry in the sagitta of Mugil cephalus specimens collected from the Köyceğiz Lagoon System in the Aegean Sea. A total of 656 fish were analyzed for otolith characteristics, including size and weight, with the objective of determining the asymmetry values for otolith length (OL), otolith width (OW), and otolith weight (OWe). The findings revealed that the asymmetry value for OL surpassed that of both OW and OWe, and it was observed that these asymmetry values increased in correlation with the fish's length. The study identified ecological factors such as water temperature, salinity, depth, and contaminants in the Köyceğiz Lagoon System as potential contributors to the observed asymmetry. Furthermore, a subsequent investigation (2024) highlighted concerns regarding small sample sizes and inadequate statistical methods in the chemical analysis of adult New Zealand mullet Mugil cephalus through otolith examination, underscoring the necessity for appropriate sample sizes and robust statistical approaches in otolith research. Additionally, research on the

growth of the Green Jack Caranx caballus Günther indicated a relationship between sagitta length and fish length in Mugil cephalus within the Mexican Central Pacific (2019), suggesting that sagitta length is a significant factor in understanding the growth dynamics of Mugil cephalus populations. Collectively, these studies underscore the critical importance of analyzing otolith characteristics such as size and weight to gain insights into the growth patterns and asymmetry of Mugil cephalus populations, while emphasizing the need for rigorous methodologies that account for sample size, statistical analysis, and ecological influences.In this paper, the relationship among sagitta measurements would be studied in M. *cephalus* collected from Susa city in eastern area in Libya. furthermore, the regression equations for these measurements would be formed using R software assisting detect normality of these measurements in the area and initiation the local records to help comparing them with measurements in other area in the world in the future.

Material and Methods

A total of 20 *Mugil cephalus* specimens were randomly gathered from artisanal fishing activities in the Sousse Sea, located in eastern Libya, between April and May 2024. These specimens were promptly transported to the marine laboratory at Omar Al-Mukhtar University, where the morphological characteristics of their sagitta were analyzed.

Following the completion of morphometric assessments as total length (TL) and total weight (TW), the heads of the *Mugil cephalus* specimens were identified and excised, allowing for the extraction of the sagitta from their capsules. These were subsequently cleaned of any external debris, dried, and preserved for future analysis.

The weight (SW), length (SL), and height (SH) of each individual fish's sagitta were measured with precision, utilizing a sensitive balance for weight to the nearest 0.0001 g, and a Vernier caliper along

with Digimizer for length and height to the nearest 0.1 mm. The study adopted a description of the general morphology of the sagitta, following the criteria established by Tuset et al.

The data collected throughout the research was meticulously input into the R file for statistical analysis. Subsequently, the correlation coefficients for the different variables were computed, and regression equations were formulated for those variables that demonstrated significant relationships.

Results

The descriptive analysis of the data was illustrated in Table (1) indicates that the total weight of the fish varied significantly, with the minimum recorded weight being 232.6 grams, an average weight of 402.4 grams, and a maximum weight reaching 920 grams. In contrast, the Sagitta weight exhibited a minimum weight of 396 grams, an average weight of 508.9 grams, and a maximum weight of 632 grams. This disparity highlights the differences in weight distribution between the total fish weight and the fish Sagitta weight.

Table (1). Descriptive statistics of measurements; Total Weight (TW), Sagitta Weight (SW), Total Length (TL), Sagitta Length (SL), Sagitta High (SH)

	Minimum	Mean ($\bar{X}$)	Maximum
Total Weight	232.6	402.4 ±209.8	920.7
Sagitta Weight	396	508.9 ±64.4	632
Total Length	12	13.65 ±1.2	17
Sagitta Length	3.02	5.77 ±2.29	12.37
Sagitta High	1.74	2.99 ±1.17	5.59

A comparative examination of the longitudinal measurements reveals that the total length of the fish ranged from a minimum of 12 cm to an average of 13.65 cm, with a maximum length of 17 cm. For the Sagitta, the lengths were notably smaller, with a minimum of 3.02 cm, an average of 5.77 cm, and a maximum of 12.37 cm.

Additionally, the height measurements for the sagitta showed a minimum of 1.74 cm, an average of 2.99 cm, and a maximum height of 5.59 cm.

Correlation matrix

An examination of the correlation matrix among various variables revealed a robust positive correlation between the length and height of the Sagitta (p-value=6.8×10^{-9}, r=0.92) and both the total weight and the weight of the Sagitta (p-value=1.9×10^{-4}, r=0.74). Additionally, a positive correlation was observed between the total length and the Sagitta weight (p-value=0.092, r=0.39), as well as between the total weight and the total length (p-value=0.018, r=0.52).

However, these latter correlations were of a lesser magnitude compared to the former. Other relationships identified in the analysis were weak and deemed insignificant, leading to their exclusion from

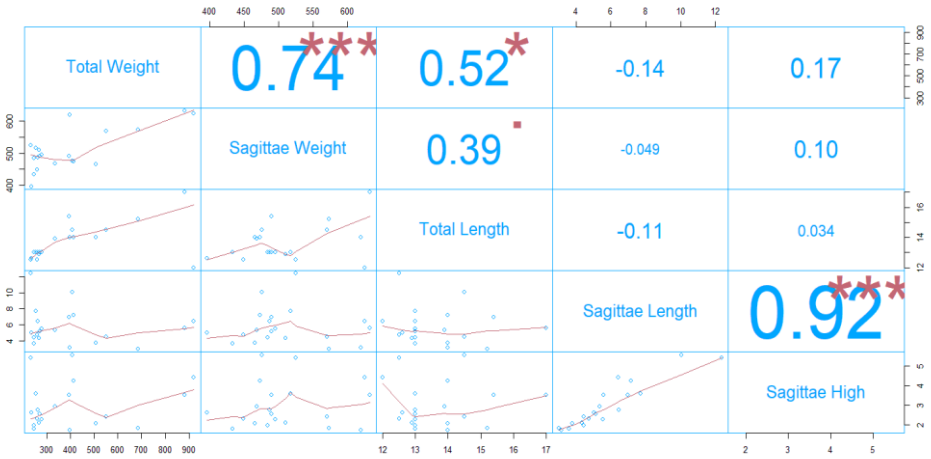

Fig. (1) The diagonal of the correlation matrix illustrates variables` names. Below this diagonal, one can observe the bivariate scatter plots accompanied by a fitted regression line. Conversely, above the diagonal, the correlation coefficients are presented alongside their corresponding significance levels, represented by asterisks. Each significance level is denoted by a specific symbol, where p-values of 0, 0.001, 0.01, 0.05, 0.1, and 1 are associated with the symbols "***", "**", "*", ".", " ", respectively.

further consideration.

Based on the findings, regression equations were derived to quantify the significant correlations identified in the analysis. These equations provide a mathematical framework for understanding the relationships between the variables of interest. These equations are presented in Table (2), which serves as a reference for the strength and nature of the correlations observed.

Table (2). Presents the regression equations, the F-statistic associated with the regression analysis and the significance levels across various variables.

	Regression Equation	F-statistic	p-value
Sagitta length & Sagitta height	**Sagitta length= 0.34 + 1.8 Sagitta height**	**103.7**	**6.8×10^{-9}**
Total weight & Sagitta weight	**Total Weight= -820 + 2.4 Sagitta Weight**	**21.8**	**1.8×10^{-4}**
Total length & Sagitta weight	**Total Length= 9.9 + 0.007 Sagitta Weight**	**3.15**	**0.092**
Total weight & total length	**Total Weight= -820 + 90 Total Length**	**6.7**	**0.018**

Regression equations serve as a valuable tool for estimating dependent variables, denoted as (y), through the use of independent variables, referred to as (x). In the present investigation, these equations were utilized to ascertain the dependent variables, namely Sagitta length, Total Weight, Total Length, and Total Weight, in relation to the independent variables, which include Sagitta height, Sagitta Weight, Sagitta Weight, and Total Length, respectively.

The analysis of the data presented in Figure 2 illustrates the correlation coefficients and regression equations among the variables under consideration. Additionally, it includes scatter plots that feature

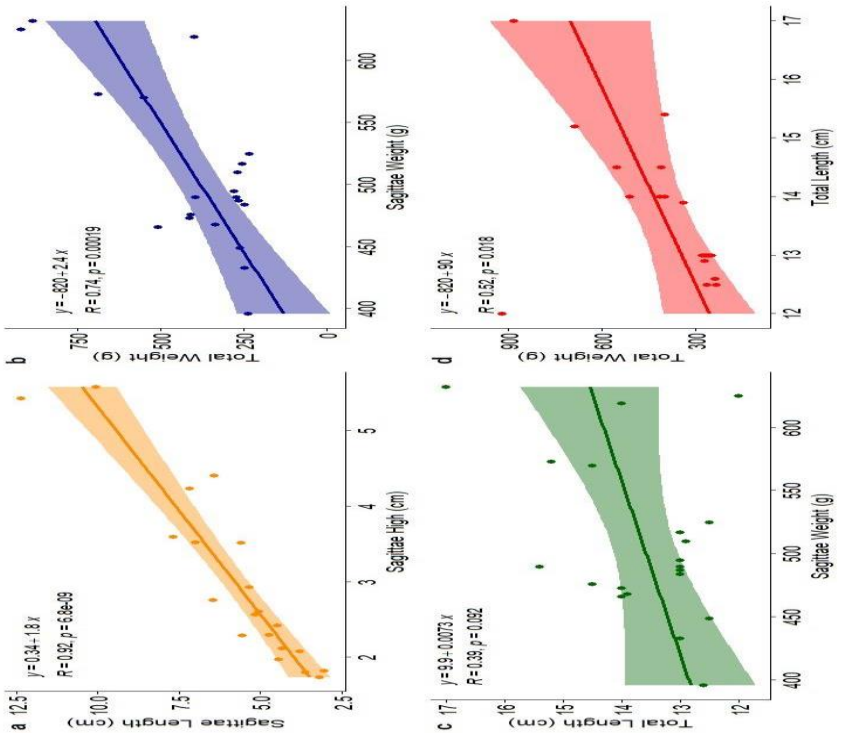

Fig. (2). presents graphical representations of the interrelationships among various variables. It displays scatter plots accompanied by a regression line, as well as the corresponding regression equations, correlation coefficients, and significance levels. Plot (a) illustrates the relationship between height and sagitta length. Plot (b) depicts the correlation between sagitta weight and total weight. Plot (c) examines the relationship between sagitta weight and total length. Finally, panel (d) explores the connection between total length and total weight.

the fitted regression line along with a 95% confidence interval as shaded areas arounf regression lines.

The results distinctly indicate positive correlations among all measured variables. Both sagitta weight and total length serve as effective predictors for determining total weight (F= 21.8, p-value= 1.8×10^{-4} ; F= 6.7, p-value= 0.018). Furthermore, sagitta weight can also be utilized to estimate total length (F= 3.15, p-value= 0.092), while sagitta height can be employed to estimate its length (F= 103.7, p-value= 6.8×10^{-9}).

This approach enhances the comprehension of various morphometric characteristics associated with sagitta measurements in fish, thereby elucidating their ecological functions and behaviors. Furthermore, it aids in the identification and diagnosis of atypical patterns in phenotypic measurements, as well as in recognizing biological abnormalities and their underlying causes.

Discussion

This study presented a descriptive analysis of fish morphometric characteristics, focusing on the relationships between sagitta weight, length, and height, as well as total fish weight and length. The results show significant variations in weight distribution between total fish weight and sagitta weight, with notable differences in length and height measurements. A correlation matrix revealed robust positive correlations between sagitta length and height, as well as between sagitta weight and total weight and length. Regression equations were derived to quantify these correlations, providing a mathematical framework for understanding the relationships between variables. The analysis demonstrates that sagitta weight and total length are effective predictors of total weight, while sagitta weight can estimate total length, and sagitta height can predict sagitta length. This study enhances our comprehension of sagitta measurements in fish, elucidating their ecological functions and behaviors, and facilitating

the identification of atypical patterns and biological abnormalities. The findings have significant implications for fisheries management, ecology, and conservation.

The examination of otolith characteristics, including size and weight, has demonstrated asymmetrical patterns in the sagitta of *Mugil cephalus*, which are affected by ecological factors such as water temperature, salinity, depth, and the presence of contaminants. Additionally, Reis et al. identified a correlation between sagitta length and fish length, indicating that sagitta length is a crucial element in understanding the growth dynamics of *Mugil cephalus* populations, despite this study reporting an insignificant relationship between the two variables. Moreover, Espino-Barr et al. established a connection between sagitta length and total length in *Mugil cephalus* within the Mexican Central Pacific (2019), while the current study also notes an insignificant relationship between these measurements. Conversely, the most significant relationships identified were between sagitta height and sagitta length, total weight and sagitta weight, total weight and total length, as well as between sagitta weight and total length. This review underscores the necessity of adequate sample sizes, rigorous statistical analysis, and the consideration of variables such as fish length and ecological influences in conducting precise and meaningful otolith studies in *Mugil cephalus*.

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