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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Testing the relationship between otolith morphometric and growth patterns in the deep-sea fish *Chlorophthalmus agassizi* Bonaparte, 1840 (North Aegean Sea): A comparison of classical and ANN approaches

Derin deniz balığı *Chlorophthalmus agassizi* Bonaparte, 1840'da (Kuzey Ege Denizi) otolit morfometrik özellikleri ile büyüme örüntüleri arasındaki ilişkinin incelenmesi: Klasik ve ANN yaklaşımlarının karşılaştırılması

Mukadder Arslan İhsanoğlu[1]* • Ali İşmen[1] • Cahide Çiğdem Yiğin[1] • Melike İdil Öz[2]

[1]Faculty of Marine Science and Technology, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye
[2]Vocational School of Marine Technologies, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye

*Corresponding author: mukadderarslan@gmail.com

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Abstract: This study evaluates whether otolith morphometric descriptors can reliably reflect growth patterns in the deep-sea fish *Chlorophthalmus agassizi* (Bonaparte, 1840) and assesses the additional explanatory value of artificial neural network (ANN) models compared with classical approaches. A total of 95 specimens were collected monthly between September 2006 and September 2008 by trawling at depths of 100–500 m in Saros Bay (North Aegean Sea). Mean total length and weight were 11.43±0.22 cm (range:7.2–17.1 cm) and 11.07±0.66 g (range:1.88–33.42 g), respectively. Otolith weight ranged from 0.0016 to 0.0067 g, while otolith length varied between 2.73 and 4.37 mm. Relationships among total length (TL), total weight (TW), otolith length (OL), and otolith weight (OW) were examined using both classical regression analyses and ANN-based predictions. Strong relationships were observed for TL–TW (R^2=0.95), TL–OL (R^2=0.90), TL–OW (R^2=0.88), and OL–OW (R^2=0.86), whereas the TW–OW relationship showed lower explanatory power (R^2=0.65). These findings indicate that otolith morphometrics provide reliable proxies for growth patterns in *C. agassizi*, while ANN models offer complementary insights into potential nonlinear relationships.

Keywords: Shortnose greeneye, deep sea fishes, morphometric analysis, otolith structure, machine learning

Öz: Bu çalışma, otolit morfometrik tanımlayıcılarının derin deniz balığı *Chlorophthalmus agassizi* (Bonaparte, 1840)'da büyüme desenlerini güvenilir şekilde yansıtıp yansıtamayacağını ve yapay sinir ağı (ANN) modellerinin klasik yaklaşımlara kıyasla sağladığı ek açıklayıcı değeri değerlendirmektedir. Toplam 95 birey, Eylül 2006 ile Eylül 2008 tarihleri arasında Saros Körfezi'nde (Kuzey Ege Denizi) 100–500 m derinliklerde trol ile aylık olarak örneklenmiştir. Ortalama toplam boy ve ağırlık sırasıyla 11.43±0.22 cm (aralık:7.2–17.1 cm) ve 11.07±0.66 g (aralık:1.88–33.42 g) olarak belirlenmiştir. Otolit ağırlığı 0.0016–0.0067 g arasında değişirken, otolit uzunluğu 2.73–4.37 mm aralığında bulunmuştur. Toplam boy (TL), toplam ağırlık (TW), otolit uzunluğu (OL) ve otolit ağırlığı (OW) arasındaki ilişkiler hem klasik regresyon analizleri hem de ANN tabanlı tahminler kullanılarak incelenmiştir. TL–TW (R^2=0.95), TL–OL (R^2=0.90), TL–OW (R^2=0.88) ve OL–OW (R^2=0.86) ilişkileri güçlü bulunurken, TW–OW ilişkisi daha düşük açıklayıcılık göstermiştir (R^2=0.65). Bu bulgular, otolit morfometrisinin *C. agassizi*'de büyüme desenleri için güvenilir bir gösterge olduğunu ortaya koyarken, ANN modellerinin olası doğrusal olmayan ilişkiler hakkında tamamlayıcı bilgiler sunduğunu göstermektedir.

Anahtar kelimeler: Yeşilgöz balığı, derinsu balıkları, morfometrik analiz, otolit yapısı, makine öğrenmesi

INTRODUCTION

The deep sea is defined as the region below the epipelagic zone (deeper than 200 meters), where sunlight does not penetrate. The animal communities found here are quite different from those in other regions. Characteristics of deep-sea species include slow growth, long lifespans, late sexual maturity, low egg production, and extreme sensitivity to environmental variables. Therefore, the pelagic ecosystem is a fragile environment with a low likelihood of recovery once damaged. Deep-sea fish stocks are extremely vulnerable to fishing; due to their low reproductive rates, they collapse quickly and recover very slowly (Öz, 2023).

Evaluating the biodiversity of deep-sea ecosystems is crucial for understanding their stability and vulnerability to disturbances (Merrett and Haedrich, 1997). Therefore, the long-term sustainability of fisheries depends on enhanced management and effective utilization of marine resources (Merrett and Haedrich, 1997; Jacquet, 2011), which requires a thorough understanding of the impacts of trawling on marine ecosystems. Studying deep-sea ecosystems is important for assessing the ecological risks posed by fishing activities. Given the significant changes that fishing can cause, pre- and post-fishing assessments are vital to determine the extent of these impacts (Atkinson et al., 2011; Paramo et al., 2012).

Research on the biology and population structure of deep-sea fish has increased in recent years. This may be due to the high sensitivity of deep-sea species to environmental change and anthropogenic pressures (Koslow et al., 2000; Merrett and Haedrich, 1997). Deep-sea species generally grow slowly, reach sexual maturity later, and have low reproductive capacity, making them highly vulnerable to hunting and habitat

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loss (Merrett and Haedrich, 1997). Therefore, it is important to investigate the ecology of deep-sea species and take measures to protect them (Clark et al., 2016). Ear stones (otoliths) have long been considered reliable tools for age determination and growth studies in teleost fishes (Campana, 2001). These structures provide valuable information not only for age estimation but also for otolith morphometry, which allows for stock identification, habitat use, and growth parameters among populations (Tuset et al., 2008). Morphometric traits such as otolith length, width, and weight often show significant relationships with size and age of the fish and can be used as indicators of differences among populations (Lombarte and Lleonart, 1993). However, studies on the otolith morphology and growth of *C. agassizi* are quite limited; only a few studies have been conducted in the Ionian Sea, the Aegean Sea, and the Eastern Mediterranean Sea (Anastasopoulou et al., 2006; Başusta et al., 2015).

The Northern Aegean Sea, particularly the Gulf of Saros, forms an ecologically unique region at the interface between the Black Sea and the Mediterranean water masses (Ünlüata et al., 1990). This dynamic hydrographic structure hosts a diverse fish community, including deep-sea taxa. However, there is virtually no information available on the biology and growth of *C. agassizi* in this region. Filling this knowledge gap is crucial not only for understanding the biological characteristics of this rare species but also for assessing the structure of deep-sea fish communities in the Northern Aegean Sea.

The Shortnose Greeneye, scientifically known as *C. agassizi* Bonaparte, 1840, a member of the family Chlorophthalmidae, is a demersal fish species typically found inhabiting benthic environments with muddy substrates. Its distribution spans bathymetric depths ranging from 50 to 1000 meters. It is relatively rare deep-sea benthopelagic species inhabiting the continental slopes of the Eastern Atlantic and the Mediterranean Sea (Whitehead et al., 1986). Although *C. agassizi* is not considered a commercially important species, its ecological role within deep-sea ecosystems is significant, as it contributes to energy transfer between benthic and pelagic compartments and serves as prey for larger predatory fishes (Macpherson, 1981).

In Turkish waters, *C. agassizi* lives in the Aegean and Mediterranean Seas (Mater et al., 2010). Studies carried out in Türkiye and around the world are mostly focused on length-weight relationships of the species (Edelist, 2014; Bilge et al., 2014; Basusta et al., 2015; Merella et al., 1997; Erdoğan et al., 2024; Chi-Espínola et al., 2023), morphometric measurements (Özaydın et al., 2007; Filiz and Bilge, 2004), distribution, population parameters (Dalyan et al., 2021; Bayhan et al., 2018; Ramírez et al., 2019; Dereli et al., 2021; Vega-Cendejas et al., 2023), and its feeding (Anastasopoulou and Kapiris, 2008; Sever et al., 2013; Viji et al., 2017), reproduction (Cabiddu et al., 2010) and otolith biometry (Coşkun, 2025).

Otolith morphometrics has been widely used as a valuable tool for investigating growth dynamics and life-history traits in fishes; however, its ability to reliably reflect growth patterns in deep-sea species remains insufficiently tested. Given the inherent limitations of deep-sea datasets, including slow growth rates and narrow size ranges, the present study explicitly addresses the following research question: can otolith morphometric descriptors serve as robust proxies for growth patterns in the deep-sea fish *C. agassizi*, and do artificial neural network (ANN) models provide additional explanatory power compared with classical morphometric approaches? By directly testing this relationship using systematically collected samples from the North Aegean Sea, this study moves beyond descriptive assessment and provides a hypothesis-driven evaluation of otolith–growth linkages.

The present study aims to provide length-weight relationship and morphometric information on the otolith structure and describe the growth patterns of *C. agassizi* in the Gulf of Saros. Specifically, otolith morphometric indices, age structure, and growth parameters were examined, thus contributing to the limited literature on this rare deep-sea fish. It also provides essential information for ecological and fisheries research in the region. In this context, this study explicitly tests whether otolith morphometric descriptors can reliably reflect growth patterns in *C. agassizi*, and evaluates whether ANN-based models provide additional explanatory power compared to classical morphometric approaches.

MATERIALS AND METHODS

A cumulative total of 95 specimens were documented on a monthly basis from September 2006 to September 2008 at depths that varied between 100 and 500 meters within Saros Bay, located in the Aegean Sea, utilizing a commercial bottom trawl net (Figure 1). The bottom trawl net with a mesh size of 44 mm was towed for 30 minutes at a speed of 2.5 knots per hour.

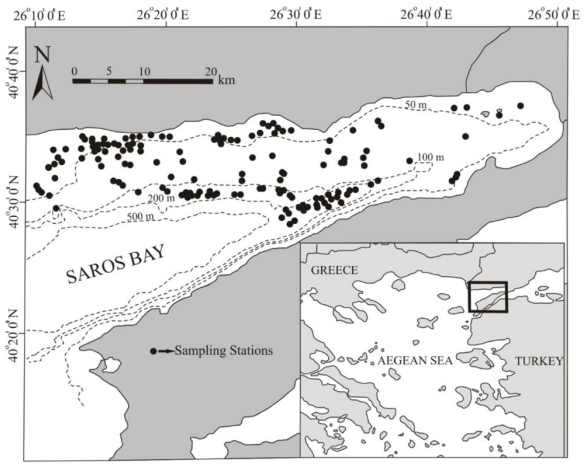

Figure 1. Trawl sampling locations within Saros Bay, situated in the North Aegean Sea

The total length (TL) of each specimen was assessed with precision to the nearest millimeter, and the mass was recorded with an accuracy of 0.01 grams. The lengths of otoliths were quantified with a precision of ±0.01mm derived from digital imagery, while the weights of the otoliths were meticulously documented to ±0.0001 grams utilizing a highly sensitive digital balance.

Linear regression analysis (y=a+bx) was used to evaluate the relationships between total length and otolith length (TL–OL), total length and otolith weight (TL–OW), and total weight and otolith weight (TW–OW). A power model ($y=ax^b$) was used to describe the relationship between otolith length and otolith weight (OL–OW). The coefficient of determination (R^2) was calculated for each relationship. OL denotes otolith length, OW signifies otolith weight, TL represents total fish length, TW indicates total fish weight, while a and b are associated parameters (Sparre and Venema, 1998). The length-weight relationship of the specimens was determined utilizing the equation $W=a\times L^b$. Here, W represents total weight (g), L denotes total length (cm), and a and b are regression coefficients (Ricker, 1975). The various growth forms of fish were identified through the implementation of Student's t-test as delineated by the equation proposed by Sokal and Rohlf (1981): ts=(b–3)/SE(b), where ts represents the t-test value, b denotes the slope, and se(b) signifies the standard error associated with the slope. The value of b serves as an indicator of the fish's growth type: a b value of 3 signifies isometric growth, whereas deviations from this value indicate allometric growth (specifically, negative allometry is characterized by b<3 and positive allometry is characterized by b>3). All statistical evaluations were performed at a significance level of 5%.

For the regression parameters the two model were tested, Classical Model and Artificial Neural Network (ANN) Model. The predictive accuracy of the model evaluated using: Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). The MAPE interpreted according to the scale of Lewis (1982), where values blow 10% indicate excellent prediction, values between 10-20% indicate good prediction, values between 20-50% indicate acceptable, and values over 50% indicate bad prediction. All analyses were performed in Phyton using the pandas, numphy, statsmodels, and scikit-learn libraries.

RESULTS

A total of 95 specimens were analyzed. The total length and weight of *C. agassizi* in Saros Bay, ranged from 7.2cm to 17.1cm with a mean of 11.43±0.22cm and from 1.88g to 33.42g with a mean of 11.07±0.66g. The dimensions of otolith length and weight exhibited a range from 2.73mm to 4.37mm (mean:3.21±0.11) and from 0.0016g to 0.0067g (mean: 0.0038±0.0003), respectively. The variances in morphometric parameters between the left and right otoliths of *C. agassizi* were determined to be statistically insignificant (t-test, P>0.05). Consequently, the right otolith was chosen for further morphometric examination (Figure 2).

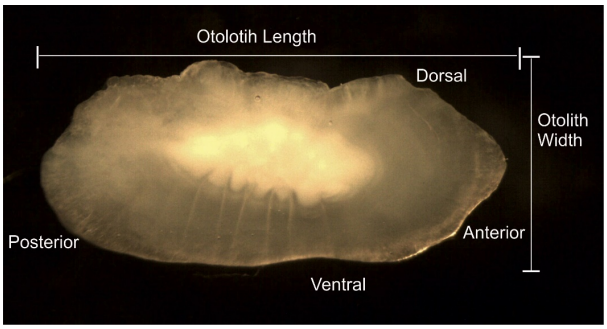

Figure 2. Image of right sagittae of *C. agassizi* (Otolith Length=3.7 mm)

The following relationships were calculated (Figure 3, 4, 5, 6, 7): Total length – total weight relationship $TW=0.004\times TL^{3.16}$ ($R^2=0.95$), (95% CI for b=3.01-3.30) The relationship between total length and otolith length is represented by the equation $OL=0.2129\times TL+0.731$ ($R^2=0.90$). The correlation between total length and otolith weight is expressed by the equation $OW=0.0007\times TL-0.0043$ ($R^2=0.88$). Furthermore, the relations hip between otolith length and otolith weight is articulated through the equation $OW=0.0002\times OL^{2.70}$ ($R^2=0.86$). Total weight – otolith weight relationship $OW=0.0002\times TW+0.0014$ ($R^2=0.65$).

The classical log–log regression model produced a highly significant relationship between total length and total weight ($p<0.001$). The estimated parameters were biologically consistent with growth patterns. The model's predictive errors were low: MAE=1.11g, RMSE=1.54g, MAPE=10.9%. According to the criteria of Lewis (1982), the MAPE value indicates good predictive performance. These results confirm that the power function provides an accurate representation of the length-weight relationship. In contrast, the ANN model yielded a MAPE value of 45.2% indicating only acceptable capability. The ANN approach did not outperform the traditional length-weight regression model.

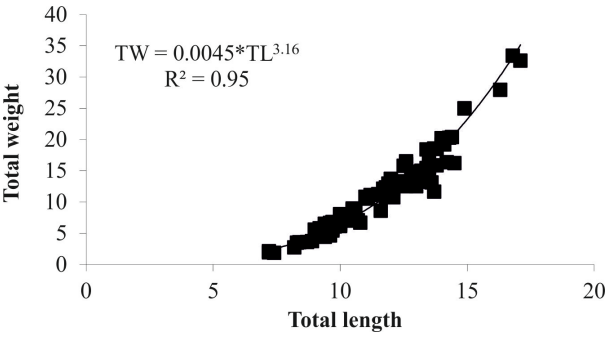

Figure 3. Length-weight relationship parameters of *C. agassizi*

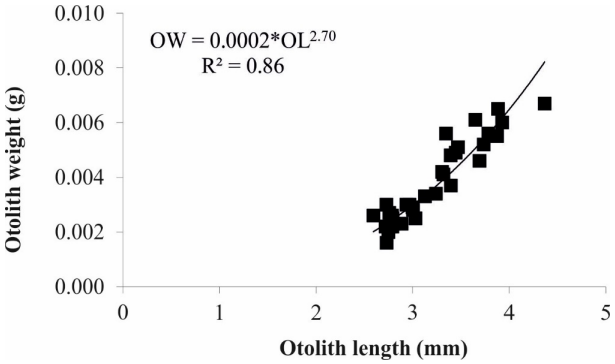

Figure 4. Otolith length-otolith weight relationship parameters of *C. agassizi*

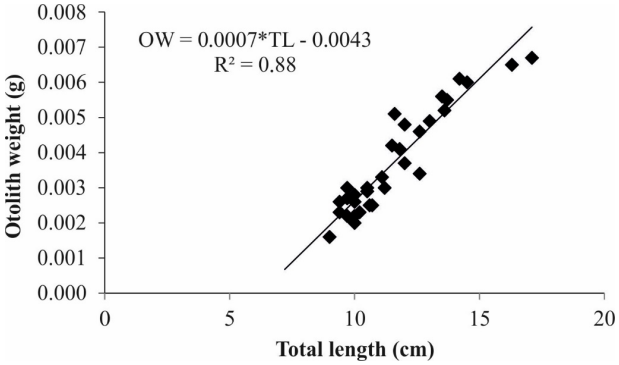

Figure 5. Total length-otolith weight relationship of *C. agassizi*

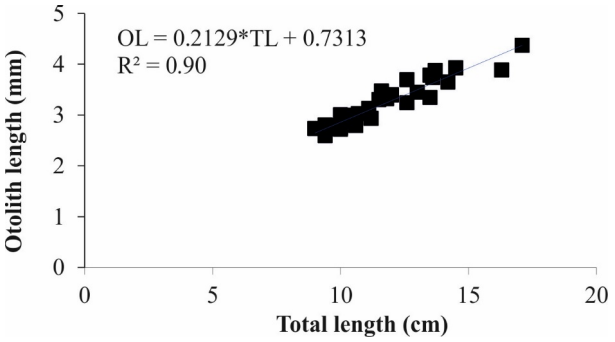

Figure 6. Total length-otolith length relationship parameters of *C. agassizi*

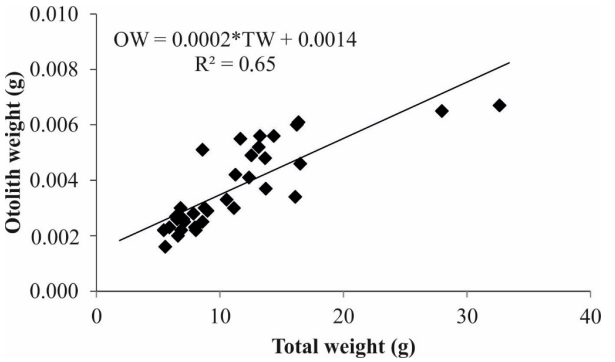

Figure 7. Total weight-otolith weight relationship parameters of *C. agassizi*

The analysis of the model performance metrics (MAE, RMSE, MAPE) are shown in Table 1, where classical regression models consistently outperform Atrificial Neural Network (ANN) models across all variable combinations.

Table 1. Performance metrics of classical regression and ANN models for morphometric predictions

Model	MAE	RMSE	MAPE
Classic (TL-TW)	1.1	1.5	10.92
ANN (TL-TW)	4.5	5.9	45.18
Classic (OL-TL)	0.5	0.6	4.19
ANN (OL-TL)	1.15	1.45	9.72
Classic (OL-OW)	0.0004	0.0005	11.87
ANN (OL-OW)	0.0009	0.0012	22.54
Classic (TL-OW)	0.0004	0.0005	12.11
ANN (TL-OW)	0.0009	0.0012	22.76

The TL-OL classical model yields the best overall performance with MAPE=4.19%, representing excellent forecast accuracy. In comparison, the ANN model for the same relationship shows a moderate increase in error (MAPE=9.72%), yet still falls the excellent accuracy threshold (<10%). This clearly supports the superiority of the classical approach for this transformation, while also showing that ANN can still perform well for relationship with strong linear components.

For the OW related models (OL-OW, TL-OW) error values remain low for both modelling techniques. Classical model produce MAPE values around 11-12%, corresponding to good forecast accuracy (10-20% range), whereas ANN models yield higher MAPE values (22-23%), which reflect moderate accuracy. Despite the overall low absolute errors in these models, the consistent pattern of higher MAPE in ANN reinforces the conclusion that classical regression provides more reliable predictions for these variable pairs.

DISCUSSION

This research offers significant understanding regarding the developmental patterns and otolith morphometric associations of *C. agassizi* in Saros Bay, located in the Northern Aegean Sea. The observed length-weight relationship suggests a positive allometric growth, indicating that larger individuals of *C. agassizi* gain weight at a faster rate than smaller individuals. This allometric growth pattern is consistent with findings from other deep-sea fish species, where adaptations to energy storage are critical for survival in the nutrient-limited and often harsh conditions of deep-sea environments (Edelist, 2014; Bilge et al., 2014). To this point, no other research has elucidated the otolith morphometry of *C. agassizi* within the marine environments of Turkey. A limited number of investigations have scrutinized the length-weight relationship of the species, the majority of which have indicated a positive allometric correlation. However, b value below 3 were calculated in studies by Diaz et al. (2000), Borges et al. (2003), Giacalone et al. (2010), and De La Hoz et al. (2016). Research carried out to this point concerning the length-weight relationship is presented in Table 2. The observed differences

between these studies can likely be attributed to variations in sample size and regional differences. The high r^2 values for length-weight and otolith morphometric relationships in our study, suggest that these parameters can reliably reflect the growth and physiological condition of *C. agassizi* and can serve as useful proxies for assessing fish size and health in future population studies. The notable correlations among total length, otolith length, and otolith weight suggest that otolith morphometrics may serve as a dependable approach for estimating ichthyological size and age.

Table 2. LWR parameters ascertained by various researchers for *C. agassizii*

Author	Area	n	Sex	TL_{min} (cm)	TL_{max} (cm)	a	b	r^2	SE_b	G
Wilk et al. (1978)	New York Bight	134				0.00312	3.38			
Merella et al. (1997)	Balaeric Island	39		9.1	17.7	0.003	3.28	0.98		
Diaz et al. (2000)	Caribbean Sea	108		5.0	17.0	1.21 E-05	2.82	-	-	
Borges et al. (2003)	Algarvae	6		8.5	15.5	0.00786	2.90	0.92		
Filiz and Bilge (2004)	Sıgacık, North Aegean Sea	378		7.7	17.5	0.00270	3.37	0.98		
Anastasopoulou et al. (2006)	Ionian Sea	4200	F+M	4.5	20.1	0.0000026	3.17	0.98	-	-
Giacalone et al. (2010)	Gulf of Castellammare	34				0.0090	2.94	0.92		
Innal et al. (2012)	Gulf of Antalya	319	F+M	7.5	18.2	0.0066	3.03	0.936		
Bilge et al. (2014)	Atlanto-Mediterranean	889	F+M	5.0	18.7	0.0033	3.28	0.960	0.022	A+
Edelist (2014)	Southeastern Mediterranean	78	F+M	4.0	12.5	0.0065	3.05	0.909	0.016	
		454	F+M	7.0	18.6	0.0038	3.24	0.969	0.089	A+
Başusta et al. (2015)	Northeast Mediterranean	165	F	7.0	18.6	0.0035	3.28	0.982	0.071	A+
		289	M	7.0	17.5	0.0049	3.13	0.944	0.098	A+
De La Hoz et al. (2016)	Caribbean Sea	220				0.00720	2.90	0.945		
Chi-Espinola et al. (2023)	Gulf of Mexico	74	F+M	11.4*	19.5*	0.0038	3.40	0.952	-	A+
		209	F+M	8.4	17.2	0.0017	3.55	0.942	0.061	A+
Erdoğan et al. (2024)	İskenderun Bay	124	F	8.4	17.2	0.0025	3.42	0.944	0.075	A+
		85	M	9.6	17.0	0.0013	3.65	0.941	0.101	A+
This study	Saros Bay, North Aegean Sea	95	F+M	7.2	17.1	0.0045	3.16	0.95	0.073	A+

n: number of specimens, F: Female, M: Male, *: Standart Length, $TL_{min.}$: Minimum Total Length, $TL_{max.}$: Maximum Total Length, a and b: equation parameters, r^2: correlation factor, SE_b: standard error b, G: growth type, A+: positive allometry

In particular, the correlation between total length and otolith weight (r^2=0.88) emerges as a valuable instrument for stock assessments, given that otolith weight can be determined with minimal processing and may function as an expedient indicator of fish size. This finding aligns with previous research on deep-sea species, where otoliths have been utilized as a key method for aging and estimating fish growth in environments where direct observations of fish populations are difficult (Anastasopoulou and Papakonstantinou, 2007; Paramo et al., 2012). Coşkun (2025)'s findings from the Northeastern Mediterranean showed that otolith dimensions in *C. agassizi* increased with fish length and weight. Our data from Saros Bay also support this general trend; however, the differences in otolith measurements indicate that region-specific otolith–body relationships should be calculated for this species.

Although the shortnose greeneye is recognized as a significant component of the Mediterranean deep-sea fish assemblages (D'Onghia et al., 2006), there exists a paucity of information regarding the size composition, depth distribution, growth patterns, reproductive behaviors, or mortality rates of this species within the confines of Saros Bay, situated in the Northern Aegean Sea. The otolith measurement data derived from this investigation will enhance local resource management practices and act as a reference point for evaluating the impacts of fishing on this previously unexploited population. In subsequent research endeavors, extending the duration of sampling and analyzing the effects of environmental variables could yield a more nuanced comprehension of the population dynamics associated with this species.

The present study compared the predictive performance of classical regression models and Artificial Neural Networks (ANN) for estimating relationships TL-TW, OL-TL, OL-OW, and TL-OL variables. The results consistently demonstrated that classical regression models outperform ANN models in terms of prediction accuracy across all variable combinations. In particular, the classical OL-TL model exhibited the highest performance, with a MAPE value below 5%, which is classified as excellent accuracy according to widely excepted error interpretation threshold (Lewis, 1982; Hyndman and Koehler, 2006). This suggest that the OL-TL relationship follows a linear structure that can be efficiently captured by a simple paramedic model, minimizing estimation errors.

In contrast, ANN models yielded higher error rates, most notably in the TL-TW relationship where the ANN produced a MAPE of 45%, corresponding to reasonable to poor accuracy levels. High ANN error values may be attributed to several well-documented factors. First, ANNs typically require larger data sets and carefully tuned hyper parameters to avoid over fitting or underfitting (Bishop, 1995; Zhang et al., 1998). Given the moderate size and linear nature of the dataset, the ANN may not have been able to effectively learn the underlying functional relationship. Additionally, classical models often outperform ANNs when the true relationship is predominantly linear, as simpler models introduce less variance and exhibit greater generalizability (Shmueli, 2010).

For the OW related models, both techniques produced low absolute errors; however, classical regression continued to outperform ANN, with MAPE values in the good accuracy

range (10-20%), compared to the ANN model's moderate accuracy (20-50%). This consistent pattern reinforces the conclusion that ANNs offered no practical advantage for the transformations examined in this study. Similar findings have been reported in ecological modelling and fisheries biology, where ANN performance is highly dependent on data volume, noise and nonlinear complexity (Lek and Guégan, 1999; Olden et al., 2004). When these conditions are not met, traditional statistical methods often remain more reliable.

The superior performance of classical models in the present analysis suggest that the variable relationship examined here exhibit strong linear tendencies, making them well suited to parametric approaches. While ANNs are powerful tools for capturing complex and nonlinear interactions, their advantages typically emerge only under high- dimensional of high nonlinear data structures-conditions not evident in this study. These findings are consistent with previous comparative modelling research in marine biology, morphometric prediction, and ecological forecasting (Guisan and Zimmermann, 2000; Özesmi and Özesmi, 1999) which also concluded that model choice should be driven by the underlying data characteristics rather than algorithmic complexity.

Overall, integration of both the performance metrics and standard MAPE interpretation threshold reveals a consistent trend: Classical regression models outperform ANN model in accuracy, stability, and predictive reliable across all tested relationship. These results connectively suggest that the underlying data structure is predominantly linear, and that ANN models-requiring larger sample sizes and more complex parameter optimization-do not offer an advantage for the examination transformations.

In summary, the current findings highlight the importance of selecting modelling approaches that align with both the structure of the dataset and the complexity of the biological relationships being examined. Classical regression models demonstrated superior productive ability, stability, and interpretability, making them more suitable for the transformations considered in this study. Future research may explore hybrid modelling approaches, cross-validation with expanded datasets, or ANN architectures optimized for small-sample ecological data to further evaluate the generalizability of these conclusions. Furthermore, historical biological datasets provide valuable baselines for assessing long-term ecological changes and avoiding the shifting baseline syndrome (Pauly, 1995; Mc Clenachan et al., 2012). Given the limited information on the otolith biometry of *C. agassizi* in the northern Aegean Sea, the present study offers a historical reference for future temporal and regional comparisons.

CONCLUSION

This study presents the first comprehensive analysis of otolith morphometrics and growth patterns of *C. agassizi* from Saros Bay, North Aegean Sea. The results revealed a positive allometric growth pattern and strong correlations between otolith morphometric indices and body size parameters. The absence of significant differences between left and right otoliths further supports the reliability of otolith-based analyses for this species. Strong correlations between fish total length, otolith length, and otolith weight highlight the potential of otolith morphometrics as reliable indicators for estimating fish size and age in deep-sea populations. These findings offer valuable baseline data that can support future ecological and fisheries management efforts, particularly given the current lack of information on this species in the region. Moreover, the data provide a critical reference for assessing potential impacts of emerging fishing activities on this previously unexploited deep-sea population. Expanding the temporal scope of sampling and incorporating environmental variables in future studies will further enhance understanding of *C. agassizi*'s population dynamics and contribute to the conservation of deep-sea biodiversity in the Northern Aegean Sea. For our data, classical regression models generally provided more accurate and stable predictions of morphometric relationships than artificial network. Although ANN models showed acceptable performance in some variable combinations, their accuracy remained highly dependent on data structure and sample size. Classical regression, by contrast, yielded consistently lower MAE, RMSE, and MAPE values, particularly for the OL-TL relationship. Overall, the results highlight the importance of selecting modelling techniques according to data characteristics rather than methodological complexity.

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AUTHORSHIP CONTRIBUTIONS

Mukadder Arslan İhsanoğlu: Conceptualization, Data curation, Formal analysis, Writing–original draft. Ali İşmen: Project administration, Supervision, Validation. Cahide Çiğdem Yiğin: Writing–review and editing, Data curation, İdil Öz: Writing–review and editing, Data curation.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest or competing interests.

ETHICAL APPROVAL

The study was conducted between 2006-2008. The Journal has been requesting ethical documentation for studies conducted since 2020.

DECLARATION OF AI USE

English translation and editing assistance was partially supported by artificial intelligence-based tools (ChatGPT, OpenAI, 2026).

DATA AVAILABILITY

The data generated and analyzed during the current study are available from the corresponding author on reasonable request.

REFERENCES

Anastasopoulou, A., & Kapiris, K. (2008). Feeding ecology of the shortnose greeneye *Chlorophthalmus agassizi* Bonaparte, 1840 in the eastern Ionian Sea (eastern Mediterranean). *Journal of Applied Ichthyology, 24*, 170–179. https://doi.org/10.1111/j.1439-0426.2007.01028.x

Anastasopoulou, A., & Papaconstantinou, C. (2007). Morphometric analysis of the deep fish *Chlorophthalmus agassizi* in the Ionian Sea (Greece). *Rapport Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée*, 38.

Anastasopoulou, A., Yiannopoulos, C., Megalofonou, P., & Papaconstantinou, C. (2006). Distribution and population structure of *Chlorophthalmus agassizi* on an unexploited fishing ground in the Greek Ionian Sea. *Journal of Applied Ichthyology, 22*, 521-529. https://doi.org/10.1111/j.1439-0426.2006.00782.x

Atkinson, L.J., Field, J.G., & Hutchings, L. (2011). Effects of demersal trawling along the west coast of southern Africa: Multivariate analysis of benthic assemblages. *Marine Ecology Progress Series, 430*, 241–255. https://doi.org/10.3354/meps08956

Başusta, A., Çalta, M., Ateşşahin, T., & Özel, F.V. (2015). Length–weight relationship of greeneye fish (*Chlorophthalmus agassizi*). *Ege Journal of Fisheries and Aquatic Sciences*, 32, 209-211. https://doi.org/10.12714/egejfas.2015.32.4.06

Bayhan, Y.K., Ergüden, D., & Cartes, J.E. (2018). Deep-sea fisheries in Mersin Bay. *Acta Zoologica Bulgarica, 70*, 259–268.

Bilge, G., Yapıcı, S., Filiz, H., & Cerim, H. (2014) Weight–length relations for 103 fish species from Turkish seas. *Acta Ichthyologica et Piscatoria, 44*, 263–269.

Bishop, C.M. (1995). *Neural networks for pattern recognition*. Oxford University Press.

Borges, T.C., Olim, S., & Erzini, K. (2003). Weight–length relationships for fish discarded in the Algarve (southern Portugal). *Journal of Applied Ichthyology, 19*, 394-396. https://doi.org/10.1111/j.1439-0426.2003.00480.x

Cabiddu, S., Follesa, M.C., Porcu, C., & Cau, A. (2010). Gonad development of *Chlorophthalmus agassizi*. *Acta Ichthyologica et Piscatoria*, *40*, 167–177. https://doi.org/10.3750/AIP2010.40.2.10

Campana, S.E. (2001). Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology, 59*(2), 197-242. https://doi.org/10.1006/jfbi.2001.1668

Chi-Espínola, A.A., Vega-Cendejas, M.E., & Hernández de Santillana, J.M. (2023). Length–weight relations of 39 continental-shelf and deep-water fishes from the Gulf of Mexico. *Acta Ichthyologica et Piscatoria, 53*, 59–64. https://doi.org/10.3897/aiep.53.101788

Clark, M.R., Althaus, F., Schlacher, T.A., Williams, A., Bowden, D.A., & Rowden, A.A. (2016). The impacts of deep-sea fisheries on benthic communities: A review. *ICES Journal of Marine Science, 73*(1), 51–69. https://doi.org/10.1093/icesjms/fsv123

Coşkun, Y. (2025). *Otolith Biometry of Shortnose Greeneye (Chlorophthalmus agassizi) Inhabiting Northeastern Mediterranean*. Master dissertation, Fırat University, Türkiye.

Dalyan, C., Gönülal, O., Kesici, N.B., Eryılmaz, L., Tunçer, S., & Öztekin, A. (2021). New and confirmed records and rare occurrences of some deep sea fishes in the Turkish waters of the northern Aegean Sea (Mediterranean Sea). *FishTaxa, 21*, 1–18.

De La Hoz-M, J., Motta, J., & Paramo, J. (2016). Length–weight relationships for 36 deep-sea fish in the Colombian Caribbean Sea. *Journal of Applied Ichthyology, 32*, 1356–1359. https://doi.org/10.1111/jai.13217

Dereli, H., Salman, M.A., Özaydın, O., & Tosunoğlu, Z. (2021). Spatial and temporal characteristics of demersal assemblages in Sığacık Bay, Central Aegean Sea, Turkey. *Çanakkale Onsekiz Mart University Journal of Marine Sciences and Fisheries, 4*, 116-129. https://doi.org/10.46384/jmsf.977558

Diaz, L.S., Roa, A., Garcia, C.B., Acero, A., & Navas, G. (2000). Length-weight relationships of demersal fishes from the upper continental slope of Colombia. Naga, ICLARM Quarterly *23*, 23–25.

D'Onghia, G., Sion, L., Maiorano, P., Mytilineou, C., Dalessandro, S., Carlucci, R., & Desantis, S. (2006). Population biology and life strategies of *Chlorophthalmus agassizii* in the Mediterranean Sea. *Marine Biology, 149*, 435–446. https://doi.org/10.1007/s00227-005-0231-y

Edelist, D. (2014). New length–weight relationships and Lmax values for fishes from the Southeastern Mediterranean Sea. *Journal of Applied Ichthyology*, *30*, 521-526. https://doi.org/10.1111/j.1439-0426.2012.02060.x

Erdoğan, Z., Koç, H.T., & Deniz, M. (2024). Length-weight and length-length relationships of *Chlorophthalmus agassizi* in İskenderun Bay, Türkiye. *Acta Biologica Turcica, 37*, 1–7.

Filiz, H., & Bilge, G. (2004). Length–weight relationships of 24 fish species from the North Aegean Sea, Turkey. *Journal of Applied Ichthyology, 20*, 431–432. https://doi.org/10.1111/j.1439-0426.2004.00582.x

Giacalone, V.M., D'Anna, G., Badalamenti, F., & Pipitone, C. (2010). Weight-length relationships and condition factor trends for thirty-eight fish species in trawled and untrawled areas off the coast of northern Sicily (central Mediterranean Sea). *Journal of Applied Ichthyology, 26*, 954–957.

Guisan, A., & Zimmermann, N.E. (2000). Predictive habitat distribution models in ecology. *Ecological Modelling,* 135, 147-186. https://doi.org/10.1016/S0304-3800(00)00354-9

Hyndman, R.J., & Koehler, A.B. (2006). Another look at measures of forecast accuracy. *International Journal of Forecasting*, *22*, 679–688. https://doi.org/10.1016/j.ijforecast.2006.03.001

Innal, D., Moutopoulos, D.K., Demir, I., & Dağ, L. (2012). Morphometric characters and length-weight relationship for *Chlorophthalmus agassizi* Bonaparte 1840 from Antalya Gulf (Mediterranean-Turkey). *Review of Hydrobiology*, *5*, 111–119.

Jacquet, J. (2011). Beyond food: Fish in the twenty-first century. In V. Christensen & J. Maclean (Eds.), *Ecosystem approaches to fisheries: A global perspective* (pp. 120–127). Cambridge University Press.

Koslow, J.A., Boehlert, G.W., Gordon, J.D.M., Haedrich, R.L., Lorance, P., & Parin, N. (2000). Continental slope and deep-sea fisheries: Implications for a fragile ecosystem. *ICES Journal of Marine Science, 57*(3), 548–557. https://doi.org/10.1006/jmsc.2000.0722

Lombarte, A., & Lleonart, J. (1993). Otolith size changes related with body growth, habitat depth and temperature. *Environmental Biology of Fishes, 37*, 297–306. https://doi.org/10.1007/BF00004637

Lek, S., & Guégan, J.F. (1999). Artificial neural networks as a tool in ecological modelling, an introduction. *Ecological Modelling, 120*, 65–73.

Lewis, C.D. (1982). *Industrial and business forecasting methods*. Butterworths.

Macpherson, E. (1981). Resource partitioning in a Mediterranean demersal fish community. *Fish Biology and Ecology Studies, 4*, 183–193. https://doi.org/10.3354/meps004183

Mater, S., Kaya, M., & Bilecenoğlu, M. (2010). *Türkiye deniz balıkları*. Ege Üniversitesi Yayınları.

Mc Clenachan, L., Ferretti, F., & Baum, J.K. (2012). From archives to conservation: Why historical data are needed to set baselines for marine animals and ecosystems. *Conservation Letters*, *5*(5), 349–359. https://doi.org/10.1111/j.1755-263X.2012.00253.x

Merella, P., Quetglas, A., Alemany, F., & Carbonell, A. (1997). Length–weight relationships of fishes and cephalopods from the Balearic Islands (Western Mediterranean). *Naga, the ICLARM Quarterly, 20*(3–4), 66–68.

Merrett, N.R., & Haedrich, R.L. (1997). *Deep-sea demersal fish and fisheries*. Chapman and Hall.

Olden, J.D., Joy, M.K., & Death, R.G. (2004). An accurate comparison of methods for quantifying variable importance in artificial neural networks using simulated data. *Ecological Modelling, 178*, 389–397. https://doi.org/10.1016/j.ecolmodel.2004.03.013

Öz, M.İ. (2023). *The biological characteristics of three deep sea fishes from Saros Bay (North Aegean Sea)*. Doctoral dissertation, Çanakkale Onsekiz Mart University, Türkiye.

Özaydın, O., Uçkun, D., Akalın, S., Leblebici, S., & Tosunoğlu, Z. (2007). Length-weight relationships of fishes captured from İzmir Bay, Central Aegean Sea. *Journal of Applied Ichthyology, 23*(6), 695-696. https://doi.org/10.1111/j.1439-0426.2007.00853.x

Özesmi, S.L., & Özesmi, U. (1999). An artificial neural network approach to spatial habitat modelling. *Ecological Modelling, 116*, 15–31. https://doi.org/10.1016/S0304-3800(98)00149-5

Pauly, D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology & Evolution*, *10*(10), 430. https://doi.org/10.1016/S0169-5347(00)89171-5

Paramo, J., Wolff, M., & Saint-Paul, U. (2012). Deep-sea fish assemblages of the Colombian Caribbean Sea. *Fisheries Research*, *125*, 87–98. https://doi.org/10.1016/j.fishres.2012.02.011

Ramírez, J.M., Vázquez-Bader, A.R., & Gracia, A. (2019). Ichthyofaunal list of the continental slope of the southern Gulf of Mexico. *ZooKeys, 846*, 117–132. https://doi.org/10.3897/zookeys.846.31944

Ricker, W. E. (1975). *Computation and interpretation of biological statistics of fish populations* (Bulletin of the Fisheries Research Board of Canada No. 191). Fisheries Research Board of Canada.

Sever, T.M., Bayhan, B., Filiz, H., Taşkavak, E., & Bilge, G. (2013). Diet composition of five deep-sea fishes from the Aegean Sea. *Ege Journal of Fisheries and Aquatic Sciences, 30*, 61-67. https://doi.org/10.12714/egejfas.2013.30.2.03

Shmueli, G. (2010). To explain or to predict? *Statistical Science, 25*, 289–310.

Sokal, R.R., & Rohlf, F.J. (1981). *Biometry: The principles and practice of statistics in biological research*. Freeman.

Sparre, P., & Venema, S.C. (1998). *Introduction to tropical fish stock assessment: Part 1. Manual* (FAO Fisheries Technical Paper No. 306/1, Rev. 2). Food and Agriculture Organization of the United Nations.

Tuset, V.M., Lombarte, A., & Assis, C.A. (2008). Otolith atlas for the western Mediterranean, north and central eastern Atlantic. *Scientia Marina*, *72* (S1), 7–198. https://doi.org/10.3989/scimar.2008.72s17

Ünlüata, Ü., Oğuz, T., Latif, M.A., & Özsoy, E. (1990). *On the physical oceanography of the Turkish Straits*. In L. J. Pratt (Ed.), *The physical oceanography of sea straits* (NATO ASI Series, Series C: Mathematical and Physical Sciences, Vol. 318, pp. 25–60). Springer. https://doi.org/10.1007/978-94-009-0677-8_2

Vega-Cendejas, M.E., Chi-Espínola, A., & Aguilar-Medrano, R. (2023). Fish community structure along a depth gradient at the Western Gulf of Mexico. *Regional Studies in Marine Science*, *68*, 103237. https://doi.org/10.1016/j.rsma.2023.103237

Viji, V., Harish, K.C., Korath, A., & Sileesh, M.S. (2017). A critical analysis of diet in seventeen deep sea fishes along the South-eastern Arabian Sea. *Indian Journal of Fisheries, 64*, 17-21. https://doi.org/10.21077/ijf.2017.64.2.67233-03

Whitehead, P.J.P., Bauchot, M.L., Hureau, J.C., Nielsen, J., & Tortonese, E. (1986). *Fishes of the north-eastern Atlantic and the Mediterranean*. UNESCO.

Wilk, S.J., Morse, W.W., & Ralph, D.E. (1978). Length–weight relationships of fishes from the New York Bight. *Bulletin of the New Jersey Academy of Science*, *23*, 58–64.

Zhang, G., Patuwo, B.E., & Hu, M.Y. (1998). Forecasting with artificial neural networks: the state of the art. *International Journal of Forecasting, 14*, 35–62. https://doi.org/10.1016/S0169-2070(97)00044-7