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Assessment of Population Growth and Fishing Vulnerability of *Helicolenus dactylopterus* along the Syrian Coast (Eastern Mediterranean Sea)

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Abstract

Between July 2023 and September 2024, 647 distinct Helicolenus dactylopterus specimens were captured in the coastal waters of Syria in the eastern Mediterranean Sea. Advanced analysis techniques, such as artificial neural networks and fuzzy logic, were applied to these samples. During the study, the largest captured individual was 35.35 cm long and was estimated to be 26 years. By applying the von Bertalanffy growth equation to the total length data, had derived the formula TL_t =45.806 (1-$e^{-0.05 (t + 4.144)}$)), which indicates negative allometric growth (b = 2.93). The growth performance index (Φ') was calculated as 2.01, providing a measure of growth efficiency. The study also estimated various mortality coefficients for *Helicolenus dactylopterus*. The coefficients were as follows: Z = 0.52 y^{-1} (total mortality rate), F = 0.31 y^{-1} (fishing mortality rate), M = 0.21 y^{-1} (natural mortality rate), and E = 0.60 y-1 (exploitation rate). The survival coefficient (S) was determined to be 0.59 y^{-1}. Analysis of the population growth (FP) of *Helicolenus dactylopterus* from the Syrian coast, a value of 58.2, indicated a large growth rate within the local marine environment. However, the study also found that fisheries were exploited at a fishing vulnerability of 51.5.

The population dynamics of *Helicolenus dactylopterus* in Syrian seawater can be gleaned from the findings of this study. The sustainable management of this species requires the implementation of conservation measures, according to them. In addition, the results enrich our knowledge of *Helicolenus dactylopterus*' growth, mortality, and vulnerability to fishing, creating the basis for future research and management strategies.

Keywords: Expert System; Growth; *Helicolenus dactylopterus*; Syrian Water; Vulnerability

Introduction

Helicolenus dactylopterus is a marine fish from the Sebastinae subfamily of the Scorpaenidae family, known for its cryptic coloration and sit-and-wait predation [1]. It is found throughout the Atlantic Ocean, from Nova Scotia to Venezuela and from Iceland and Norway to South Africa, including the Mediterranean Sea. Adults inhabit soft bottom areas on the continental shelf and upper slopes, while larvae and juveniles are pelagic, typically at depths of 150 to 600 meters (up to 1,100 meters) [1,2].

This species is the most commercially important scorpionfish in the Mediterranean and is listed as Least

Concern by The IUCN Red List as of 2013 [3,4].

Determining fish age through traditional methods is challenging and requires skilled analysis of annual growth rings. However, recent studies show that convolutional neural networks (CNNs) can accurately predict fish age by analyzing otolith images [5].

In the northwest Atlantic, high-resolution X-ray computed tomography has been used to examine vertebral centra for age estimation, alongside various growth models to analyze growth patterns [6].

The age and maturity of species such as Epinephelus aeneus, Thunnus thynnus, and others were effectively estimated using a Multilayer Perceptron neural network model [7-16]. Modern methodologies, including expert systems, have also been employed to assess fish vulnerability and conservation risks.

These include fuzzy logic expert systems for estimating intrinsic vulnerability to extinction, evaluating species risks from fishing, and assessing vulnerability to climate change [17-20]. Additionally, a model based on fuzzy logic has been proposed to estimate fishery population growth [21].

The biological characteristics of *Helicolenus dactylopterus* along the Syrian coast have not been thoroughly studied. This research aims to address this gap by examining the growth dynamics and susceptibility of this scorpionfish species to fishing practices.

To achieve this, the researchers utilized advanced methodologies, such as artificial neural networks and fuzzy logic, within an expert system framework. This study marks a significant effort to enhance our understanding of *Helicolenus dactylopterus* and its relationship with fishing activities.

Materials and Methods

Between July 2023 and September 2024, a thorough collection of 769 specimens of *Helicolenus dactylopterus*, known as the Blackbelly rosefish, was carried out along the Syrian coast. Various fishing techniques, including the use of trawl nets, were employed to gather these specimens (Figure 1).

A B

Figure 1: A. *Helicolenus dactylopterus*. B. Syrian coast (Eastern Mediterranean Sea).

Age and Maturity

The study conducted by Hamwi [7,8] employed a Multilayer Perceptron artificial neural network model configured as (1, 10, 2) to estimate the maturity and age of the *Helicolenus dactylopterus* species. This revised network model used the fish's total length as the input parameter (Figure 2).

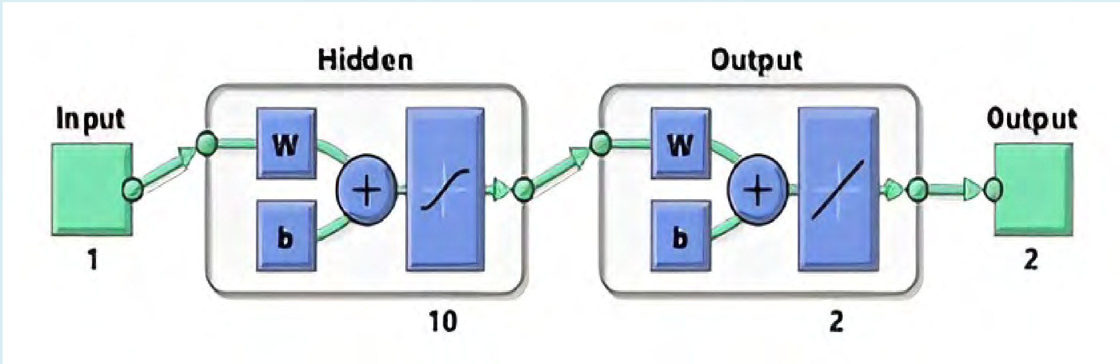

Figure 2: Artificial neural network, multilayer perceptron (MLP).

Fishing Population Growth (FP)

Hamwi, et al. [21] created an expert system model utilizing fuzzy logic to estimate the growth of the *Helicolenus dactylopterus* population along the Syrian coast. This model incorporated specific parameters (K, Tr, M, E) as inputs and employed fuzzy logic techniques for data analysis and interpretation (Figure 3).

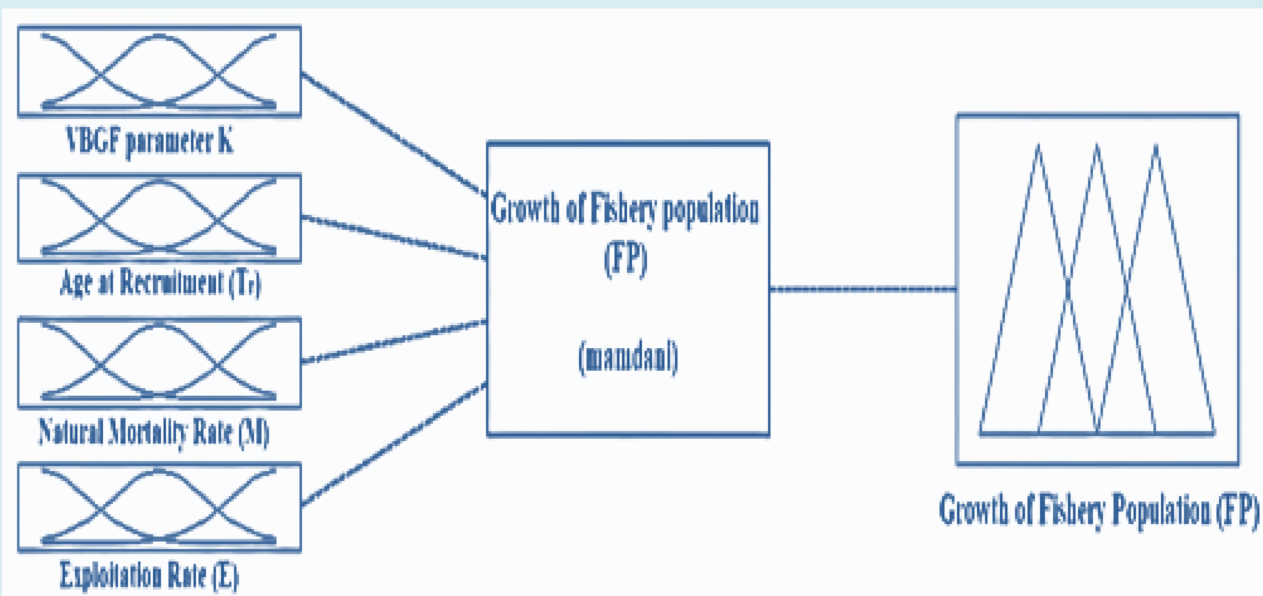

Figure 3: Fuzzy inference system variables (Inputs: K, T_r, M, E; Output: FP).

The von Bertalanffy equation was used to identify the parameters (K, TL_∞), while the Akaike Information Criterion (AIC) [AIC = N ln (WSS) + 2M] facilitated the selection of the most suitable growth model. In this context, N refers to the number of data points, WSS indicates the weighted sum of squares of residuals, and M represents the number of parameters in the model. The research aimed to compare various growth models that characterize the fish species [22]: $TL_t = TL_\infty / [1 + e^{-K(t-t0)}]$.

TL_t refers to the total length of the fish at a given age (t), while TL_∞ indicates the theoretical maximum total length (in cm) that the fish could attain. The growth coefficient is represented by K, and t0 is the theoretical age at which the fish's length is assumed to be zero.

To estimate the total mortality rate (Z), the Ricker method [23] was applied, which involved calculating the regression equation for the catch curve (ln Nt = a - Zt) across the entire population.

The natural mortality rate (M) was calculated using a specific formula:
Log M = -0.0066 - 0.279 log TL_∞ + 0.6543 log K + 0.4634 log

T [24].
The von Bertalanffy parameters TL_∞ and K were utilized, along with the average surface water temperature (T) of 25.11 °C in the fishing area.

The fishing mortality rate (F) was calculated by finding the difference between the total mortality rate (Z) and the natural mortality rate (M) [25]: F = Z - M. The exploitation rate (E) was then determined using the formula E = F / Z [26]. The survival rate (S) was derived from the equation $S = e^{-Z}$ [23].

To calculate the total length (TL_c) and age (T_c) at first capture, equations proposed by Beverton and Holt were utilized [27]: $TL_c = TL' - [K (TL_\infty - TL') / Z]$; $T_c = -(1/K) * \ln(1 - TL_c / TL_\infty) + t_0$.

In these equations, TL' represents the average total length of the captured fish.

The total length (TL_r) and age (T_r) at recruitment were calculated using the equations formulated by Beverton and Holt [27]: $TL_r = TL' - [K (TL_\infty - TL_0) / Z]$; $T_r = -(1/K) * \ln(1 - TL_r / TL_\infty) + t_0$.

Here, TL_0 denotes the total length of the fish at the time of hatching or at age zero.

The growth performance index ($\Phi_{TL}`$) was computed using the equation proposed by Pauly and Munro [28]: $\Phi_{TL}` = \log K + 2\log TL_\infty$.

The relative yield-per-recruit (Y'/R) model, based on the Beverton and Holt framework [28], is expressed as: $Y'/R = [E * U^{(M/K)}] * [1 - (3U / (1 + m) + (3U^2 / (1 + 2m) - (U^3 / (1 + 3m)]$. In this equation, $U = 1 - (L_c/L_\infty)$, m = (1-E) / (M/K) = (K/Z), and E = F/Z.

The estimation of relative biomass-per-recruit (B'/R) is derived from the following relationship [25]: B'/R = (Y'/R)/F.

Fishing Vulnerability (FV)

To assess the vulnerability of *Helicolenus dactylopterus* to fishing, the model created by Hamwi, et al. [20] was applied. This expert system incorporated specific parameters (TL_{max}, K, T_{max}, M, S) as inputs and utilized fuzzy logic techniques to analyze and evaluate the species' fishing vulnerability (Figure 4).

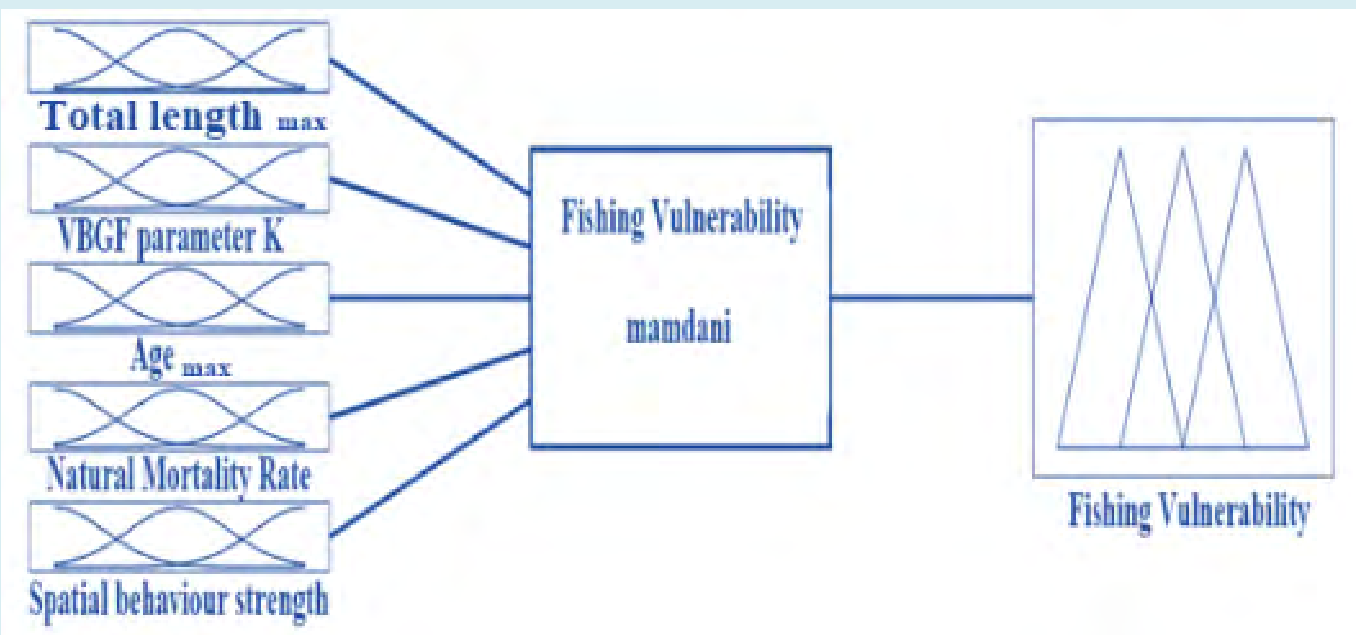

Figure 4: Fuzzy inference system variables (Inputs: TLmax, K, Tmax, M, S; Output: FV).

Results

The analysis of the age structure of the *Helicolenus dactylopterus* population identified 26 distinct age groups. The eight-year age group was the most prevalent, comprising 13.26% of the total population. In contrast, the age groups of twenty-one, twenty-two, twenty-three, twenty-four, twenty-five, and twenty-six accounted for just 0.13% each of the overall catch, suggesting that this species has a long lifespan along the Syrian coast (Figure 5).

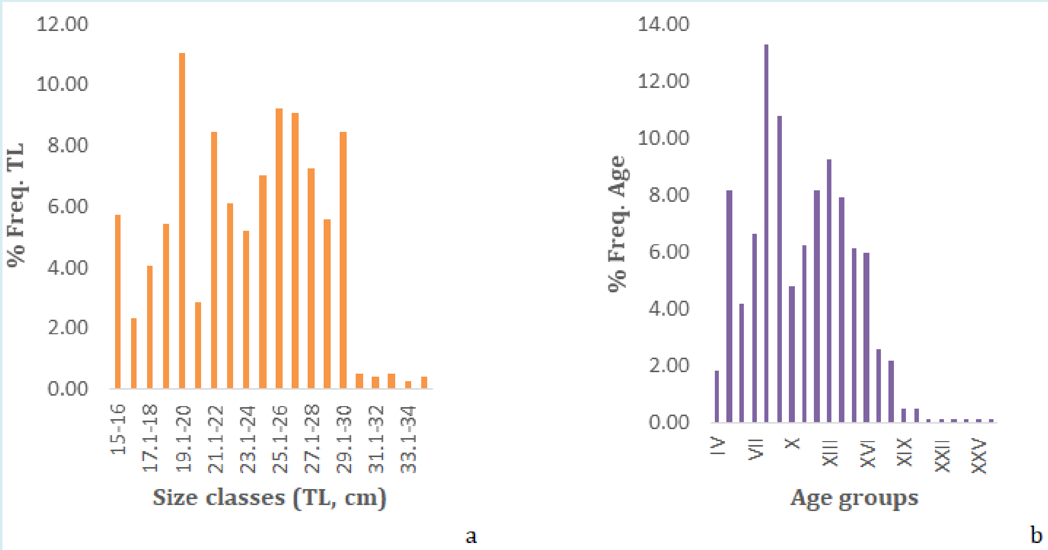

Figure 5: a. Total length frequency distribution (TL); b. Age composition for *Helicolenus dactylopterus* in Syrian waters.

When examining the distribution of individuals within various total length (TL) categories, it was found that the most common size classes were those measuring between 19.1 and 20 cm, which constituted 11.05% of the population. In contrast, individuals in the 33.1 to 34 cm range were the least represented, accounting for only 0.26% of the total.

The data gathered in this study indicated that the maximum total length achieved by *Helicolenus dactylopterus* along the Syrian coast was 35.35 cm, observed in individuals aged 26 years. Conversely, the smallest recorded total length was 15 cm, corresponding to an age of 4 years.

The parameters for the von Bertalanffy growth equation for total length were calculated as follows: $TL_t = 45.806\ (1 - e^{-0.05\ (t + 4.144)})$.

The statistical analysis of this growth model produced the following results: AIC = -83.6341; WSS = 0.0203; and a 95% Confidence Interval of 4.55 for L∞ and 0.012 for K. The growth coefficient (k) obtained from the von Bertalanffy equation for *Helicolenus dactylopterus* was determined to be 0.05.

Additionally, the length-weight relationship demonstrated a negative allometric growth pattern, with a value of b = 2.93 for *Helicolenus dactylopterus*. The average age and total length of individuals at first capture were 12.11 years and 25.15 cm, respectively. For recruitment, the average age and total length were 10.46 years and 23.41 cm, respectively. Finally, the growth performance index (Φ') for the total length growth of *Helicolenus dactylopterus* was calculated to be 2.01.

The total mortality coefficient (Z) for *Helicolenus dactylopterus* was estimated at 0.52 per year. The fishing mortality coefficient (F) and natural mortality (M) were calculated to be 0.31 per year and 0.21 per year, respectively, leading to a survival rate (S) of 0.59 per year. The exploitation mortality coefficient (E) was determined to be 0.60 per year.

Figure 6 illustrates the relationship between exploitation rates (E), relative yield per recruit (Y'/R), and relative biomass per recruit (B'/R). The exploitation rates analyzed ranged from 0.05 to 1.00.

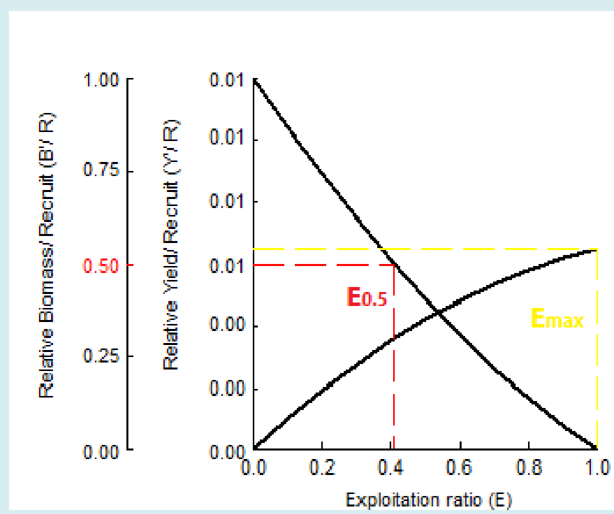

Figure 6: Relative yield per recruit (Y`/R) and biomass per recruit (B`/R) (Knife-edge selection) of *Helicolenus dactylopterus* collected from Syrian coast.

The analysis revealed several important values:

E_{max}, the exploitation rate that maximizes yield per recruit, was determined to be 1 y^{-1}.

The exploitation rate $E_{0.1}$, where the marginal increase in relative yield-per-recruit equals one-tenth of its value at E = 0, was also calculated as 1 y^{-1}.

$E_{0.5}$, the exploitation rate at which the stock's biomass is reduced to 50% of its unexploited level, was found to be 0.41 y^{-1}.

Additionally, the fuzzy logic-based expert system developed by Hamwi, et al. [21] produced a growth value of 58.2 for the *Helicolenus dactylopterus* population along the Syrian coast. This value indicates a moderate growth of 0.10 and a large growth of 0.90, based on a maximum fishery population growth (FP) value of 100 (Figure 7).

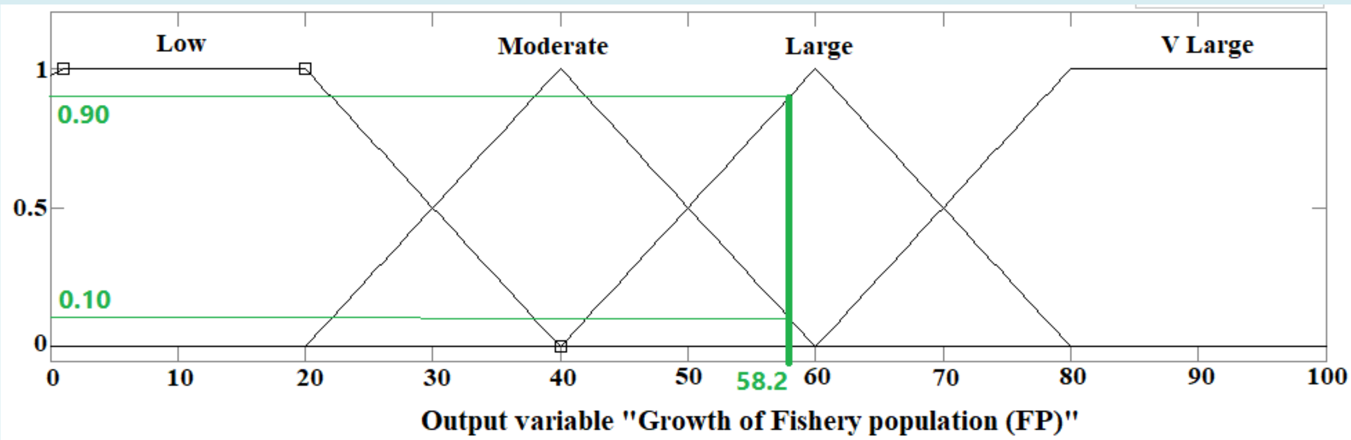

Figure 7: The growth of Helicolenus dactylopterus population off the Syrian coast.

Based on the fuzzy logic expert system created by Hamwi, et al. [20], *Helicolenus dactylopterus* exhibited a fishing vulnerability of 51.5 FV, where the maximum vulnerability value (FV) is 100. This indicates a high vulnerability level of 0.55 and a moderate vulnerability level of 0.45 (Figure 8).

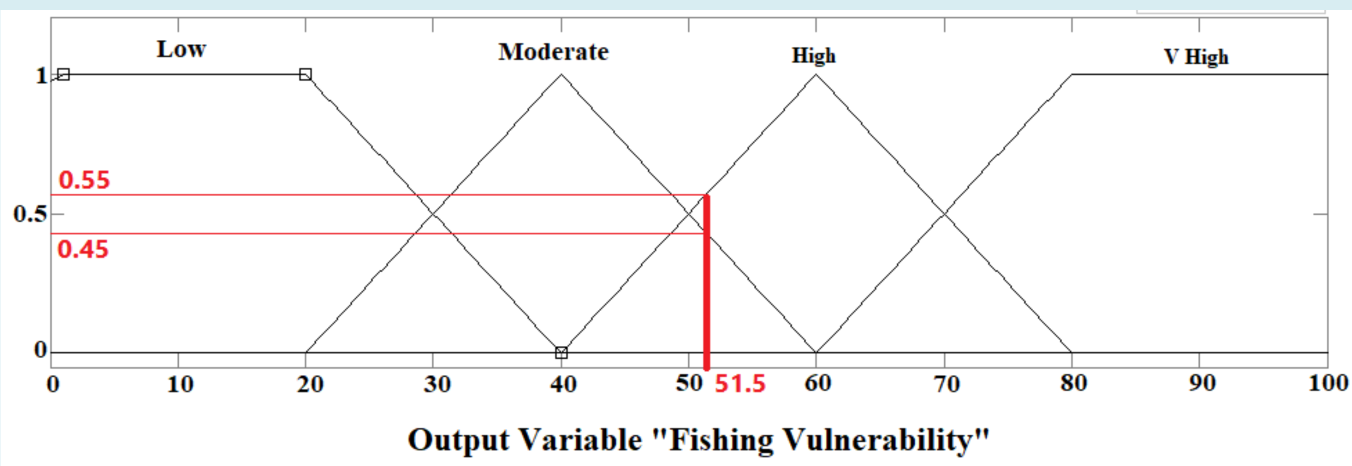

Figure 8: The vulnerability of Helicolenus dactylopterus to fishing off the Syrian coast.

Discussion

This research indicated that *Helicolenus dactylopterus* specimens collected from the Syrian coast were larger than those found in the north-eastern and western Mediterranean Seas (Alborean Sea). The total lengths varied from 9.3 cm to 21.9 cm for individuals aged eight years [29], and from 2 cm to 30 cm for those aged twenty-four years [30]. In comparison, *Helicolenus dactylopterus* from the Portuguese continental slope exhibited even greater lengths, with a maximum total length of 37 cm recorded in a 27-year-old specimen [31] (Table 1).

Location and author	Age	Total length (TL, cm)	
		min	max
north-eastern Mediterranean Sea [29]	8	9.3	21.9
Syrian coast [(present study]	26	15	35.35
western Mediterranean Sea (Alborean Sea) [30]	30	3	36
Portuguese continental slope [31]	27	5	37

Table 1: Maximum-minimum total length and age of Helicolenus dactylopterus from different water bodies.

The estimated hypothetical maximum or asymptotic total length for this species appears to differ across geographical locations. According to Abecasis, et al. [32], the estimate in the Azores is 59.06 cm, whereas Demirhan, et al. [29] reported a lower estimate of 35.419 cm for the north-eastern Mediterranean Sea. In this study, the determined asymptotic total length for the species was found to be 45.806 cm.

These variations in the estimated asymptotic total length could be influenced by several factors, including environmental conditions, habitat traits, fishing pressures, and genetic variations among local populations. The growth rate of total length in *Helicolenus dactylopterus* was evaluated using the growth coefficient (k) derived from the von Bertalanffy equation, which was calculated to be 0.05. This value is notably lower than the 0.07 reported for the Azores [32]. Interestingly, the growth coefficient of 0.05 is consistent with the k value of 0.064 recorded in the north-eastern Mediterranean Sea [29].

The lower growth coefficient of 0.05 found in this study indicates a slower rate of total length growth for *Helicolenus dactylopterus* compared to the faster growth rate suggested by the higher coefficient of 0.07 from the Azores. This highlights possible regional variations in the growth patterns of this species.

This study offers valuable insights into the growth characteristics of the *Helicolenus dactylopterus* species, particularly regarding its total length. The data analysis indicated a negative allometric growth pattern, reflected by a growth coefficient (b) of 2.93. This finding implies that the fish's total length increases at a slower rate compared to other morphological dimensions.

Notably, similar negative allometric growth patterns have been observed in other regions. Specifically, growth coefficient (b) values of 2.71 and 2.92 have been recorded for *Helicolenus dactylopterus* populations in the north-eastern Mediterranean Sea and along the Portuguese continental slope, respectively [29,31].

The ratio of the length at first capture to the asymptotic length (L_c/L_∞) acts as a measure to determine whether the harvested fish are mainly juveniles or adults. A ratio exceeding 0.5 indicates that most of the catch consists of mature individuals [33]. In this study, the estimated (L_c/L_∞) ratio was found to be 0.55, suggesting that the catch in the *Helicolenus dactylopterus* fishery is primarily composed of mature fish.

Conclusions

This study provides valuable insights into the population dynamics of *Helicolenus dactylopterus* along the Syrian coast, highlighting the importance of conservation efforts for the sustainable management of this species. The results enhance our understanding of the growth patterns, mortality rates, and fishing vulnerability of *Helicolenus dactylopterus*, laying the groundwork for future research and management initiatives.

The findings have significant implications for managing the *Helicolenus dactylopterus* fishery in the region. Overfishing can severely impact the population's ability to maintain its numbers, leading to reduced abundance. Therefore, it is crucial to implement management strategies that limit the catch of *Helicolenus dactylopterus* to ensure the long-term sustainability of the fishery.

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