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Assessment of Dusky Spinefoot *Siganus luridus* Population Dynamics along the Syrian Coast (Eastern Mediterranean Sea) Utilizing Different Expert System Techniques

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Abstract

A total of 1115 random samples of *Siganus luridus* were collected over a one-year period (January 2023 - December 2023) from the Syrian coast in the eastern Mediterranean Sea. These samples were obtained through fishing activities carried out by local fishermen. Advanced techniques, including artificial neural networks and fuzzy logic, were used to analyze the collected samples. The age composition analysis revealed the presence of 5 distinct age groups, with the second age group being the most dominant, comprising 32.29% of the total individuals. The largest individual measured had a total length of 21.09 cm and was estimated to be 5 years old. The von Bertalanffy growth equation for total length was derived as TLt = 29.99 (1-e-0.21 (t+0.779)), indicating negative allometric growth (b = 3.23). The growth performance index (Φ') was calculated as 2.28. The estimated mortality coefficients were as follows: total mortality rate (Z) = 0.89 per year, fishing mortality rate (F) = 0.32 per year, natural mortality rate (M) = 0.57 per year, and exploitation rate (E) = 0.36 per year. The survival coefficient (S) was determined to be 0.41. The population growth of *S. luridus* from the Syrian coast (FP = 33) indicated a moderate growth pattern within the local marine environment. The fishing vulnerability was determined to be 50.1 FV. Consequently, these fish face a significant threat along the Syrian coast. This study provides valuable insights into the population dynamics of *S. luridus* along the Syrian coast and highlights the importance of conservation measures for sustainable management of this species. The results contribute to our understanding of the growth, mortality, and vulnerability to fishing of *S. luridus* and serve as a foundation for future research and management strategies.

Keywords: Expert System; Growth; Siganus *luridus*; Syrian Coast; Vulnerability

Abbreviations

IUCN: International Union for Conservation of Nature; LC: Least Concern; CNNs: Convolutional Neural Networks; MLP: Multilayer Perceptron; FP: Fishery Population; AIC: Akaike Information Criterion; TL: Total Length.

Introduction

The dusky spinefoot, scientifically known as *Siganus luridus*, is a captivating marine species that belongs to the rabbitfish family, Siganidae. It is primarily found in the western Indian Ocean but has made its way to the

Mediterranean Sea through the Suez Canal, a fascinating occurrence known as Lessepsian migration [1,2]. This species is typically found at depths ranging from 2 to 40 meters in areas with firm substrates, such as coral reefs and rocky formations. The larvae tend to remain near the water's surface, where they sustain themselves by consuming phytoplankton and zooplankton starting from just 3 days old. As adults, dusky spinefoot fish are herbivores and display diurnal activity patterns. In the Mediterranean, this species has gained significance in fisheries and is actively targeted for commercial purposes. However, in other regions like Kenya, it is often caught incidentally as bycatch. Due to its culinary appeal, the dusky spinefoot is highly regarded as a sought-after food fish [3].

The *S. luridus* was last evaluated for inclusion in The IUCN Red List of Threatened Species in 2017 and was classified as Least concern (LC) [1,2].

Traditional methods of determining the age of fish pose challenges and require skilled individuals to meticulously examine annual growth rings. However, recent research has demonstrated that convolutional neural networks (CNNs) can accurately predict fish age by analyzing images of otoliths [4].

In the northwest Atlantic Ocean, researchers have utilized high-resolution X-ray computed tomography to analyze vertebral centra and estimate fish age. Multiple growth models have also been employed to study patterns of growth [5].

The maturity and age of *Gymnura*. *Altavela*, *Thunnus thynnus* and Epinephelus aeneus were successfully predicted using a Multilayer Perceptron artificial neural network model with a configuration of (1, 10, 2) [6-9].

Several studies have employed modern methodologies, such as expert systems, to assess various aspects of fish vulnerability and conservation risks. These include:

- The use of a fuzzy logic expert system to estimate the intrinsic vulnerability of marine fish to extinction caused by fishing [10].
- Utilizing an expert system to evaluate the vulnerability and conservation risks of marine species resulting from fishing activities [11].
- Applying fuzzy logic to determine the vulnerability of marine species to climate change [12].
- Estimating the vulnerability of specific Sparidae fish species in the eastern Mediterranean Sea (Syrian coast) using the fuzzy logic approach [13].

Additionally, a model has been proposed to estimate the growth of fishery populations using an expert system based on fuzzy logic [14].

Research on *S. luridus* along the Syrian coast is severely limited in the field of biology. This study represents a pioneering effort on the Syrian coast, investigating the growth and vulnerability of fishing activities on this particular species of Siganidae. Modern and advanced methodologies, such as artificial neural networks and fuzzy logic, are employed within the expert system framework to accomplish this research.

Materials and Methods

Throughout the year (January 2023 - December 2023), a comprehensive collection of 1115 *Siganus luridus* specimens, commonly known as the Dusky Spinefoot, was obtained using diverse fishing techniques such as set hand-lines, fish traps, gillnets, and Trammel nets along the Syrian coastline (Figure 1).

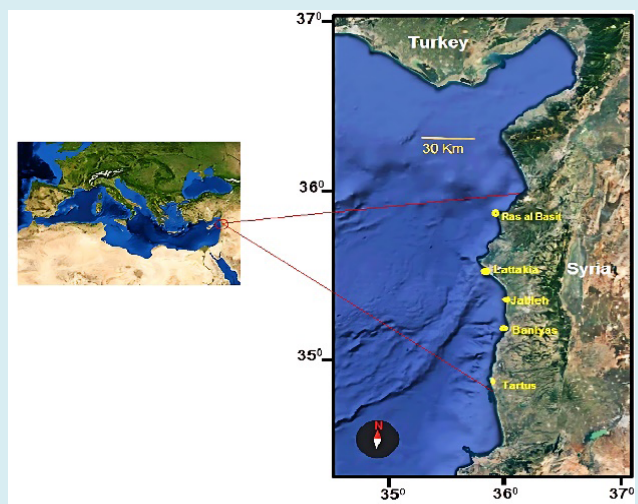

Figure 1: Syrian coast (Eastern Mediterranean Sea) (N: 36.6°; S: 35.5°; E: 35.7°; W: 35.6°).

Age and Maturity

In the study conducted by Hamwi [6-9], a Multilayer Perceptron artificial neural network model with a configuration of Obota C, et al. [1,2,10] was employed to estimate the maturity and age of *S. luridus*. The model utilized the total length of the fish as the input parameter into the updated network model (Figure 2).

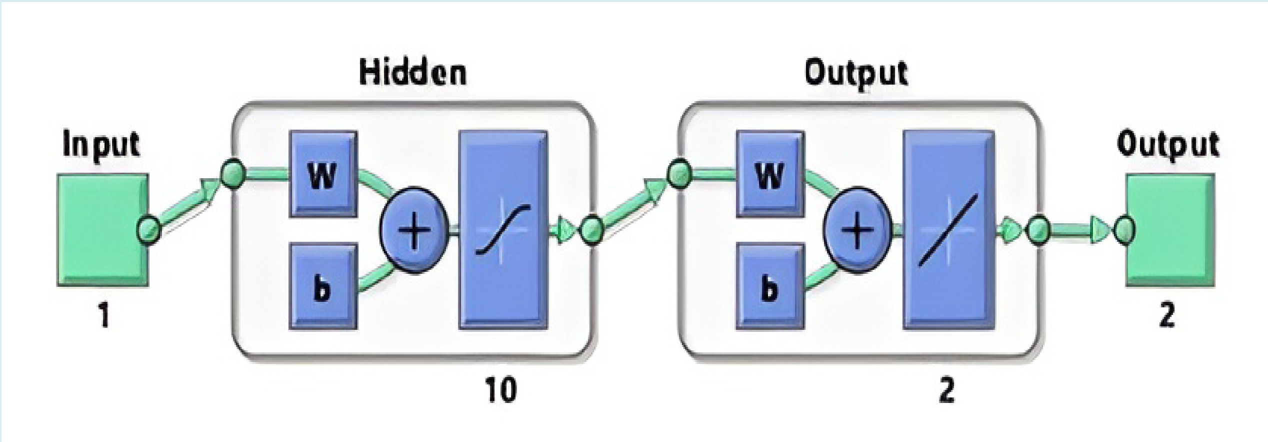

Figure 2: Artificial neural network, multilayer perceptron (MLP).

Growth Of Fishery Population (FP)

To estimate the growth of the S. luridus population along the Syrian coast, Hamwi, et al. [14]. developed an expert system model based on fuzzy logic. The model utilized specific parameters (K, Tr, M, E) as inputs to the system, employing fuzzy logic techniques to analyze and interpret the data (Figure 3). The von Bertalanffy equation was employed to determine the parameters (K, TL_∞), with the selection of the appropriate growth model guided by the Akaike Information Criterion (AIC) [AIC = N ln (WSS) + 2M]. In this equation, N represents the number of data points, WSS is the weighted sum of squares of residuals, and M denotes the number of model parameters. The aim was to compare available models that describe the growth characteristics of the fish species [15]:

$$TL_t = TL_\infty / [1 + e^{-K(t-t_0)}]$$

TL_t represents the total length of the fish at a given age (t), while TL_∞ denotes the hypothetical asymptotic total length (cm) that the fish can potentially achieve. The growth coefficient is represented by K, and t_0 signifies the theoretical age at which the length of the fish is assumed to be zero.

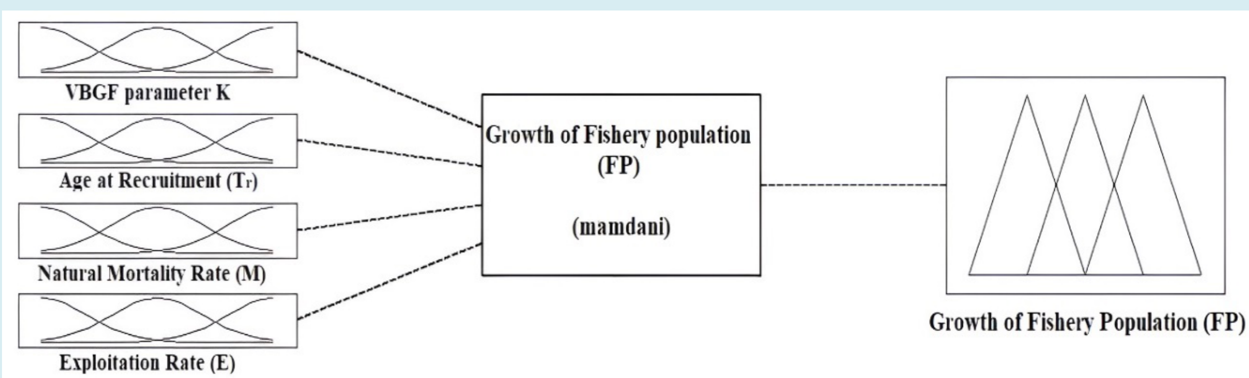

Figure 3: Fuzzy inference system variables (Inputs: K, Tr, M, E; Output: FP).

To estimate the total mortality rate (Z), the Ricker method Ricker WE, et al. [16] was employed. This involved calculating the regression equation for the catch curve ($\ln N_t = a - Zt$) across the entire population.

The natural mortality rate (M) was determined through the use of a specific relationship:

$$\log M = -0.0066 - 0.279 \log TL_\infty + 0.6543 \log K + 0.4634 \log T$$ [17].

The von Bertalanffy parameters TL_∞ and K were utilized, along with the average surface water temperature (T) in the fishing area. During the study period, the average surface water temperature was recorded as 21.7 °C.

The fishing mortality rate (F) was calculated as F = Z - M [16].

The exploitation rate (E) was calculated as E = F / Z [18], where F is the fishing mortality rate, Z is the total mortality rate.

The survival rate (S) was given by the equation S = e-Z [16].

The determination of the total length (TLc) and age (Tc) at first capture involved the utilization of equations proposed by Beverton, et al. [19]:

$$TLc = TL' - [K (TL\infty - TL') / Z]$$
$$Tc = - (1/K) * \ln (1 - TLc / TL\infty) + t0$$

TL' represents the average total length of the captured fish, while K, TL∞, and t0 are the von Bertalanffy parameters. Additionally, the total mortality rate (Z).

The equations proposed by Beverton, et al. [19] were used to determine the total length (TLr) and age (Tr) at recruitment:

$$TLr = TL' - [K (TL\infty - TL0) / Z]$$
$$Tr = - (1/K) * \ln (1- TLr / TL\infty) + t0$$

TL0: total length when the fish is at the hatching moment or age zero.

The growth performance index (ΦTL`) can be determined using the equation proposed by Pauly, et al. [20]: ΦTL` = logK + 2logTL∞

The relative yield-per-recruit (Y'/R) model presented in the following is based on the Beverton, et al. model [21]:

$$Y'/R = [E * U(M/K)] * [1 – (3U / (1 + m) + (3U2 / (1 + 2m) – (U3 / (1 + 3m)]$$

Where: U = 1-(Lc/L∞); m = (1-E) / (M/K) = (K/Z); E = F/Z.

Relative biomass-per-recruit (B'/R) is estimated from the relationship [16]: B'/R = (Y'/R) / F.

Fishing Vulnerability (FV)

In order to assess the vulnerability of S. luridus to fishing, the model developed by Hamwi, et al. [13] was employed. The expert system utilized the parameters (TLmax, K, Tmax, M, S) as inputs, employing fuzzy logic techniques to analyze and evaluate the fishing vulnerability of the species (Figure 4).

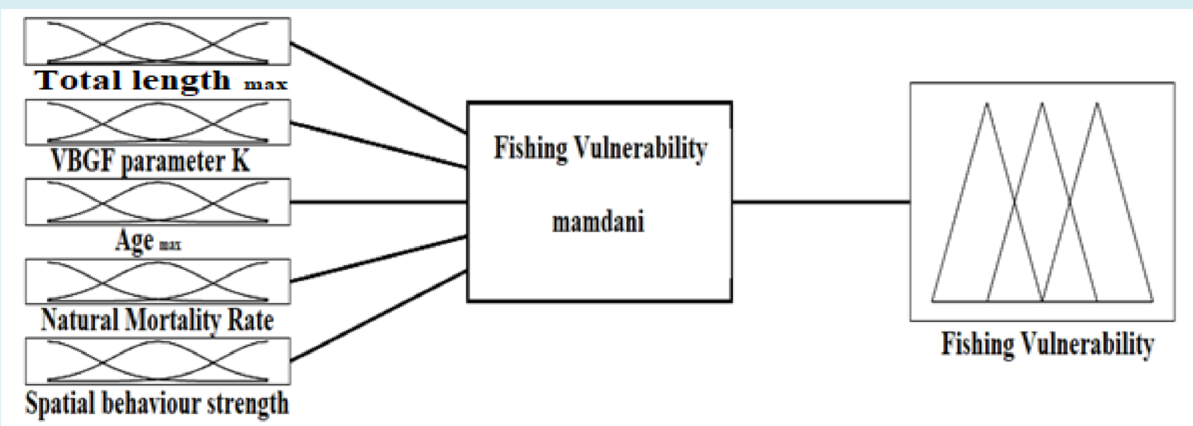

Figure 4: Fuzzy inference system variables (Inputs: TLmax, K, Tmax, M, S; Output: FV).

Results and Discussion

The analysis of the age composition of *Siganus luridus* revealed the presence of five distinct age groups. Among these, the second age group was the most dominant, accounting for 32.29% of the total population. In contrast, the fifth age group represented only 2.15% of the overall catch, indicating a relatively short lifespan for this species along the Syrian coast (Figure 5).

Examining the relative frequency of individuals in different total length (TL) categories, it was observed that individuals with total lengths ranging from 12.5-13.5 cm and 13.6-16.5 cm were the most prevalent, accounting for 30.76% and 25.11% respectively. On the other hand, individuals with total lengths of 19.6-21.9 cm were the least represented, comprising only 3.23% of the population.

Within the scope of this study, *S. luridus* individuals from the Syrian coast exhibited a maximum total length of 21.9 cm at the age of 5+. Conversely, the smallest recorded total length for an individual was 4.6 cm at the age of 0+. In the Sirt Gulf and western part of the Libyan coast, the recorded total lengths ranged from 10.2 cm to 25.5 cm, with the most frequent length being 15 cm, and at the age of 7, the maximum recorded total length reached 25.5 cm [22]. In the eastern Mediterranean Sea (Lebanon), the maximum observed total length was 24.5 cm at the age of 6 [23]. In Alexandria, Egypt, the observed total length ranged from 3.8 cm to 17 cm [24] (Table 1).

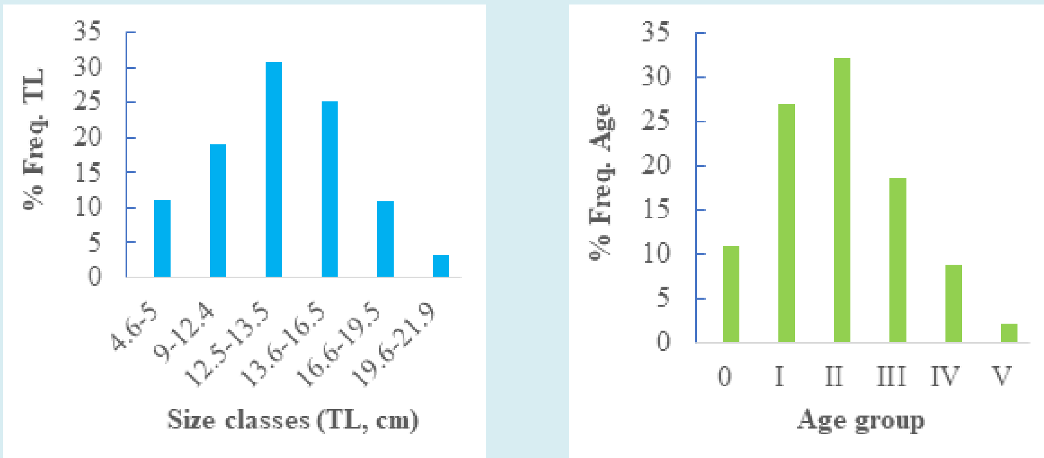

Figure 5: A. Total length frequency distribution (TL); B. Age composition for Siganus luridus in Syrian waters.

Location and author	Age	Total length (TL, cm) min	
Lebanon, eastern Mediterranean Sea [23]	6	8.1	25
Syrian coast	5	4.6	22
Libyan coast [22]	7	10	26
Egypt, Alexandria [24]		3.8	17

Table 1: Maximum-minimum total length and age of *Siganus luridus* from different water bodies.

The parameters in the von Bertalanffy growth equation for total length were determined through the following calculations: TLt = 29.99 (1-e-0.21(t + 0.779)) (AIC= 1441.75; WSS= 0.0024; 95% confidence= 1.31). According to Bariche [23], the hypothetical asymptotic total length growth of *S. luridus* in the eastern Mediterranean Sea (Lebanon) was reported to be 27.49 cm. Shakman, et al. [22] found that in the Sirt Gulf and western part of the Libyan coast, the hypothetical asymptotic total length growth of *S. luridus* was 30 cm. In the present study, the hypothetical asymptotic total length growth of *S. luridus* was determined to be 29.99 cm.

The growth rate of total length in *S. luridus* was assessed by examining the growth coefficient (k) derived from the von Bertalanffy equation. The calculated value for total length growth was determined to be 0.21. It is worth noting that this value is relatively lower compared to the corresponding values observed in the eastern Mediterranean Sea (Lebanon) (0.33), but equal to the values observed along the Libyan coast (0.21). The findings of this study revealed a positive allometric growth pattern (b = 3.23) for total length, indicating a more rapid increase in total length relative to other dimensions. Notably, this positive allometric growth pattern (3.20) was specifically observed in the coastal region of Lebanon.

Based on the findings of this study, the average age and total length of *S. luridus* individuals at first capture were determined to be 1.45 years and 11.20 cm, respectively. Similarly, the average age and total length of individuals at recruitment were found to be 0.87 years and 8.78 cm, respectively. The ratio of the length at first capture to the asymptotic length (L_c/L_∞) serves as an indicator of whether the harvested fish are predominantly juveniles or mature individuals. If the (L_c/L_∞) ratio is less than 0.5, it suggests that the majority of the catch consists of juvenile fish species [25]. In this study, the estimated (L_c/L_∞) ratio was 0.37, which is less than 0.5. This indicates that the majority of the catch in the *S. luridus* fishery mainly comprises juvenile fish.

Furthermore, the growth performance index (Φ') for total length growth was calculated and recorded as 2.28. However, in the specific context of the Lebanon coast, the growth performance index was slightly higher at 2.40.

Within the scope of this study, the total mortality coefficient (Z) of *S. luridus* was estimated to be 0.89 per year. The fishing mortality coefficient (F) and natural mortality (M) were calculated as 0.32 per year and 0.57 per year, respectively, while the survival rate (S) was determined to be 0.41 per year. Additionally, the exploitation mortality coefficient (E) was found to be 0.36 per year.

Figure 6 displays the relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) for a range of exploitation rates (E) ranging from 0.05 to 1.00 as a variable input parameter. Based on the first derivative of the yield function with respect to the exploitation rate, the values of Emax (exploitation rate which produces maximum yield), E0.1 (exploitation rate at which the marginal increase of relative yield-per-recruit is 1/10th of its value at E = 0), and E0.5 (value of E under which the stock has been reduced to 50% of its unexploited biomass) were estimated using the current value of the exploitation rate, as illustrated in Figure 6. The maximum value of (Y'/R) was achieved at Emax= 0.668 y-1. The value of E0.1 for S. luridus was calculated as 0.557 y-1, while E0.5 was estimated to be 0.328 y-1 [24,25].

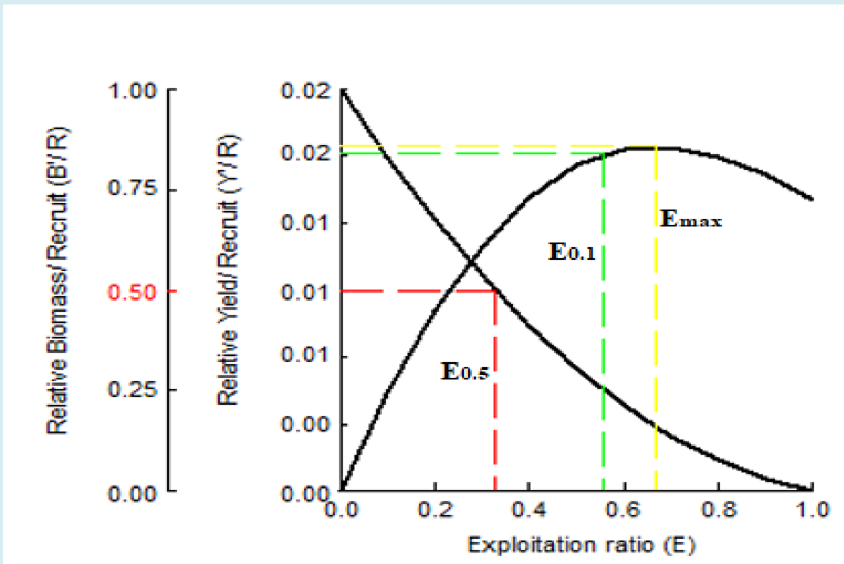

Figure 6: Relative yield per recruit (Y`/R) and biomass per recruit (B`/R) (Knife-edge selection) of *Siganus luridus* collected from Syrian coast.

Dusky Spinefoot, in general, are subjected to various environmental pressures (biotic and abiotic) on one hand, and pressures resulting from fishing and depletion of their populations on the other hand. As a result, two distinct stages are observed in the life of these fish: the unexploited phase (from hatching to the age at first capture, tc) and the exploited phase (from tc onwards) [26].

The relatively high natural mortality rate observed in the per-exploitation stage of *S. luridus* from the Syrian coast is attributed to significant stress caused by food scarcity and prevailing food relationships, such as predation by other species in the same area. Additionally, the occurrence of diseases affecting individuals can be attributed to pathogenic agents or pollution. In the current study, it was found that the exploitation of *S. luridus* resulted in a relatively high mortality rate, exceeding the allowable limit or the optimal exploitation rate (E0.5 = 0.328) [27]. The cause of this elevated mortality rate was linked to the pressure exerted by fishing operations. An exploitation rate exceeding 0.5 signifies an unsustainable fish stock, indicating overfishing and a reduction in the stock's biomass [28].

The fuzzy logic-based expert system, proposed by Hamwi, et al. [14] yielded a growth value of 33 for the *S. luridus* population along the Syrian coast. This value corresponds to a moderate growth of 0.70 and a low growth of 0.30, based on a maximum fishery population growth (FP) value of 100 (Figure 7). Additionally, the productivity of *S. luridus* was assessed using Musick's criterion for the growth coefficient (k), which ranged from moderate (0.16-0.30) [29]. The results indicated a clear preference for moderate growth within the Syrian coastal environment.

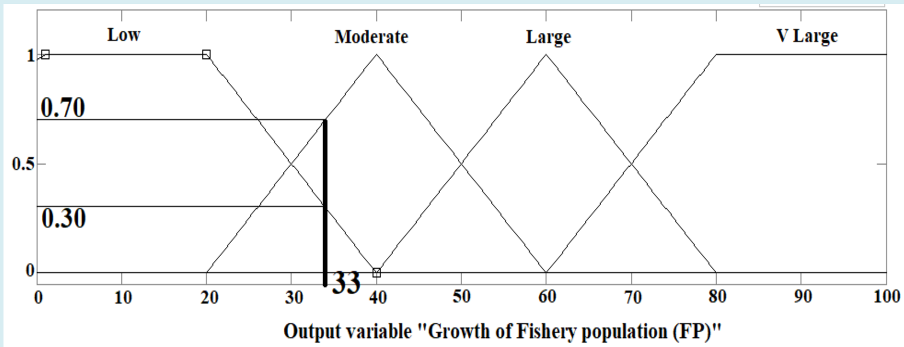

Figure 7: The growth of *Siganus luridus* population off the Syrian coast.

Based on the expert system (fuzzy logic) developed by Hamwi, et al. [13] *S. luridus* exhibited a fishing vulnerability of 50.1 FV (where the maximum value for fishing vulnerability, FV, is 100). This value indicates a high vulnerability of 0.50 and a moderate vulnerability of 0.50 (Figure 8), suggesting a strong predisposition towards being highly vulnerable to fishing activities. Consequently, these fish face a significant threat on the Syrian coast. Additionally, the intrinsic vulnerability assessment conducted by Fishbase classifies S. luridus as having a moderate vulnerability, with a rating of 39 out of 100.

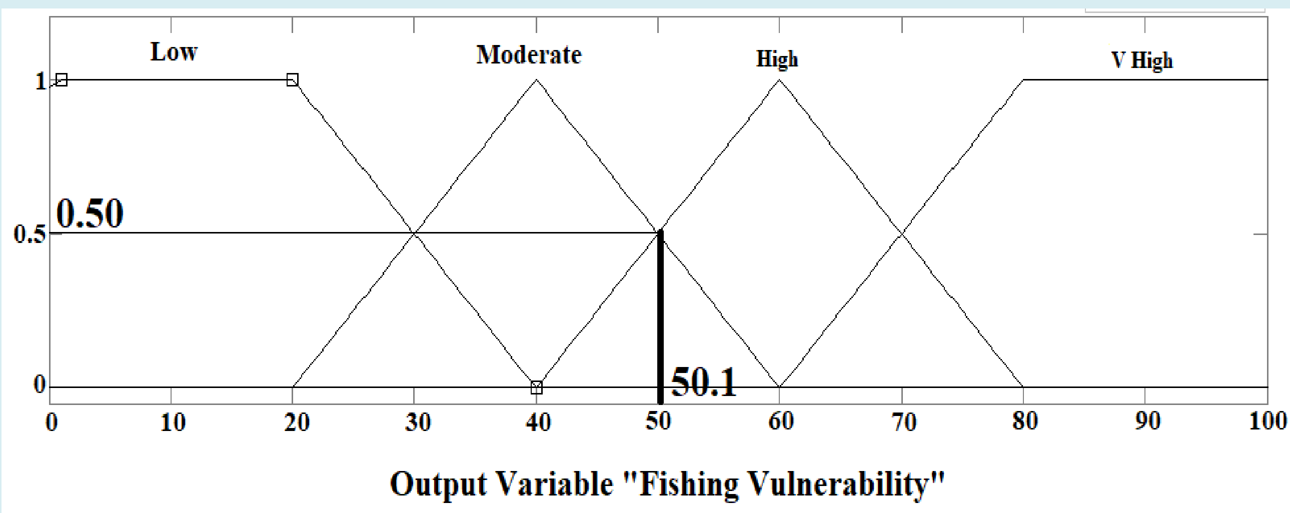

Figure 8: The vulnerability of *Siganus luridus* to fishing off the Syrian coast.

Conclusion

This study provides valuable insights into the population dynamics of *Siganus luridus* along the Syrian coast, highlighting the importance of conservation measures for the sustainable management of this species. The findings enhance our understanding of *Siganus luridus* growth, mortality, and susceptibility to fishing, laying the groundwork for future research and management strategies. These findings have significant implications for the management of the *Siganus luridus* fishery in the Syrian coastal region.

Overfishing can have a profound impact on the population's carrying capacity, leading to declines in abundance. Therefore, it is crucial to implement management strategies that minimize the catch of *Siganus luridus* and ensure the long-term sustainability of the fishery. These strategies may include promoting the use of modern and advanced tools, such as artificial neural networks and fuzzy logic, as efficient and time-saving tools; conducting regular stock assessments to monitor the population status of *Siganus luridus* and adjusting management measures accordingly;

strictly enforcing fishing bans during specific periods of the year by the General Authority for Fishery Resources and Aquatic Organisms, as well as adhering to appropriate fishing mesh sizes within the coastal environment of Syria. By implementing these measures, it becomes possible to mitigate the impact of harvesting individuals of *Siganus luridus*, ensuring the conservation of their lives, continued existence, reproduction, and expansion of their distribution range.

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Conflicts of Interest

The authors declare no conflict of interest.

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