A proposed model to estimate the growth of the fishery populations by expert system

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Abstract:

When studying the growth of fishery populations (FP), the question of validation of growth parameter estimates often arises due to the lack of reliability of some of the methods used in obtaining such estimates. It has been suggested a model, which aims to find an advanced scientific model to estimate the growth of FP by artificial intelligence technologies such as fuzzy logic and thus determine the ability to make decisions regarding this growth. An expert system has been built that contains inference rules which consist of four input variables (Von-Bertalanffy Growth Function, VBGF parameter K; Age at Recruitment, T_r; Natural Mortality Rate, M; Exploitation Rate, E) For each population target or proposed of fisheries populations. The research has highlighted the important results:

- The proposed model depends on a strong inference system in which all cases studied for four input variables were discussed and It could be applied to all fishery populations, which helps to increase opportunities to improve fishing management and sustainability.
- A high degree of reliability of the model to estimate the growth of FP compared to the Musick`s criterion of the growth of the FP, which is based on the only value of VBGF parameter K in assessing the growth of FP.

Keywords: Fishery population, Fuzzy logic, Fuzzy inferencing unit.

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نموذج مقترح لتقييم نمو جماعات المصايد السمكية باستخدام النظام الخبير

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الملخص:

غالباً ما تثار عند دراسة نمو جماعات المصايد السمكية (FP) مسألة التحقق من صحة تقديرات معامل النمو بسبب عدم موثوقية بعض الطرق المستخدمة في الحصول على مثل هذه التقديرات. ولذلك تم اقتراح نموذج يهدف إلى إيجاد نموذج علمي متطور لتقدير نمو الـ FP من خلال تقنيات الذكاء الاصطناعي مثل المنطق الضبابي وبالتالي القدرة على اتخاذ القرارات بشأن ذلك النمو. لقد تم بناء نظام خبير يحتوي على قواعد استدلال تتكون من أربعة متغيرات مدخلة (معامل النمو لبيرتلانفي K؛ العمر عند الإمداد T_r؛ معامل النفوق الطبيعي M؛ معامل الاستغلال E) لكل جماعة مستهدفة أو مقترحة من جماعات المصايد السمكية.

سلط البحث الضوء على نتائج هامة:

– يعتمد النموذج المقترح على نظام استدلال قوي حيث تمت مناقشة جميع الحالات التي تمت دراستها لأربعة متغيرات مدخلة ويمكن تطبيقه على جميع جماعات المصايد السمكية، مما يساعد على زيادة فرص تحسين إدارة الصيد واستدامته.

– درجة عالية من الموثوقية في النموذج لتقدير نمو الـ FP مقارنة بمعيار Musick، والذي يعتمد فقط على قيمة معامل النمو لبيرتلانفي (K) في تقييم نمو جماعات المصايد السمكية.

الكلمات مفتاحية: جماعة المصايد السمكية، المنطق الضبابي، وحدة الاستدلال الضبابي.

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1. Introduction:

It is common practice in fisheries research to focus on three dynamic factors affecting its structure and current state: recruitment, growth rate and mortality (Zabel *et al.*, 2003). During the study of the fishery population, we take into account the calculation of these factors mainly, and thus gives a close estimate of the situation expressed through a descriptive formula that attempts to approximate between these influencing factors.

The fuzzy logic is a form of logic, used in some expert systems and applications of artificial intelligence. This logic was created in 1965 by the Azerbaijani scientist "Lotfi Zada". He noted that traditional approaches do not provide an appropriate model for approximate thinking patterns as being accurate. Most patterns of human thinking and all common sense logic fall into this category (Zadeh, 1996). Fuzzy logic in the broad sense is a logical system based on a generalization of the classical logic with two values [0, 1], to infer in unconfirmed circumstances. In the narrow sense, it is theories and techniques that use the fuzzy sets, which are unlimited groups. This logic represents an easy way to describe and represent human experience, as it provides practical solutions to real problems, which are cost effective and reasonable solutions, compared to other solutions that provide other technologies (Zadeh, 1997). In the classical set, an element can either belong to the set or never belong to it. While in the fuzzy set, an element can belong to a specific group boundary.

An example of studies that have used this type of modern methods (expert system) (Cheung *et al.*, 2005; Cheung *et al.*, 2007; Jones and Cheung, 2017; Hamwi and Ali-Basha, 2019).

The fuzzy logic processing system is incorporated into the so-called FIU (Fuzzy Inferencing Unit). This unit includes three basic processing units: The first unit: includes the input and output system. The second unit: provision by users. And the third unit: it handles the given rule (The Math Works, 2021).

The phases of building the proposed fuzzy model (The Math Works, 2021):

1. Fuzzification phase: involves defining the membership functions of input variables to determine the degree of truth in each rule.
2. Inference phase: Includes determining the outcome of each rule alone, and its inputs are the outputs of the previous step, which are the value derived from the outputs of each rule from the application of inference rules.
3. Composition phase: means reaching to one result for all rules by combining results of sub-rules.
4. Defuzzification phase: involves converting the single fuzzy result of all rules reached in the previous step to defuzzified integer.

We try, through our proposed model, to extrapolate the growth of FP affected by the previous factors (recruitment, growth rate and mortality), but by giving a real specific value that expresses to a large extent the growth of this population away from the approximate conclusion or abstract description of the case.

When studying FP, the question of verifying estimates of growth parameters for these populations and their current state often arises due to the unreliability of some of the methods used to obtain these estimates. One possible approach is the comparative approach which has the added advantage of allowing in certain cases to be inferred on the growth of FP. Thus, the problem can be broken down into the following questions:

1. Is the current method of the expert system capable of giving a clear specific value to the growth of FP, or is it sufficient to describe them only? (e. g., whether in terms of dependence on the value of factor (b) derived from log10 linear regressions ($W = aL^b$) as the growth of a specific fish species or by comparing the VBGF parameter K or the growth performance index (Φ') of Pauly with those calculated coefficients for fish of the same species from different water regions).

2. Is there a high degree of reliability of the proposed model to estimate the growth of the FP?

This research presents an advanced scientific model to estimate a specific and clear value for the growth of FP by the techniques of artificial intelligence (expert system) and thus determining the ability to make decisions in order to their current state accurately. In addition to increasing opportunities to improve fishing management and sustainability.

2. Materials and Methods:

An expert system was used to study the growth of FP by means of a model consisting of four inputs and one output. Where the basic variables are described as follows: results of VBGF parameter K, M, T_r and E as inputs to the search model, because many researchers interested in this type of research depend only on describing the growth of fish through the Von-Bertalanffy coefficients (L_∞, K) and factor (b) of weight-length relationship, in addition to using Pauly Index (Φ') to make an approximate comparison between the studied species and the same species from different aquatic environments. The four inputs calculate from the mathematical equations as: The VBGF parameter K is of the Von-Bertalanffy growth model: $\mathbf{L_t = L_\infty / [\,1 + e^{-k\,(t-t0)}]}$ where: L_t is the length (cm) at time t (years), L_∞ is the asymptotic length (cm) and t_0 is the theoretical age at birth (Bertalanffy, 1938).

The corresponding age at recruitment (T_r) calculate as: $\mathbf{T_r = -(1/k)*\ln(1-L_r/L_\infty)+t_0}$ (Beverton and Holt 1957) where: length at recruitment (L_r) determine using equation: $L_r = L' - [K (L_\infty - L_0)/Z]$.

The Natural mortality rate (M) estimate from the equation of Pauly (1980) as: $\mathbf{\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T}$ where: L_∞ and K are the parameters of the Logistic growth model and T is the mean water temperature.

According to Cushing (1968), the Exploitation rate: $\mathbf{E = F*A / Z}$ where: F and Z are fishing and total mortality and (A) Annual mortality rate (A = 1 – S). Survival rate (S) estimate from the equation (Ricker, 1975): $S = e^{-z}$.

While output is the growth of FP, which is value of the interaction of the four inputs (K, T_r, M, E) among them during the lifespan of this population. And for the design of this fuzzy model, the MATLAB R2021a software was used as a software tool as it contains groups of special solutions within the Fuzzy Logic Toolbox (The Math Works, 2021) as well as using its library of fuzzy logic, and rely one type of fuzzy inference unit is the Mamdani model as it works mainly to give the linguistic value the most description of the process under consideration as well as the fact that the membership functions in the output are of variable type and not linear (Sivanandam *et al.*, 2007).

The linguistic values representing the levels of the membership functions are divided into four of the Fuzzy Inference System (FIS) variables (inputs: K, T_r, M, E) and the output variable represented by estimating the growth of FP (Figure 1).

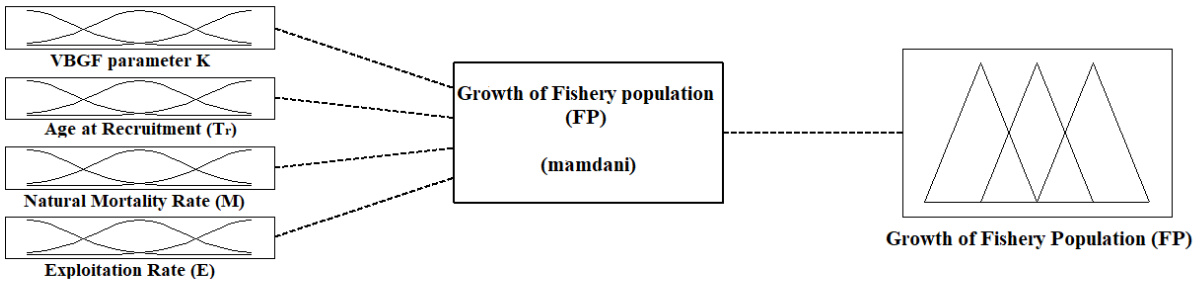
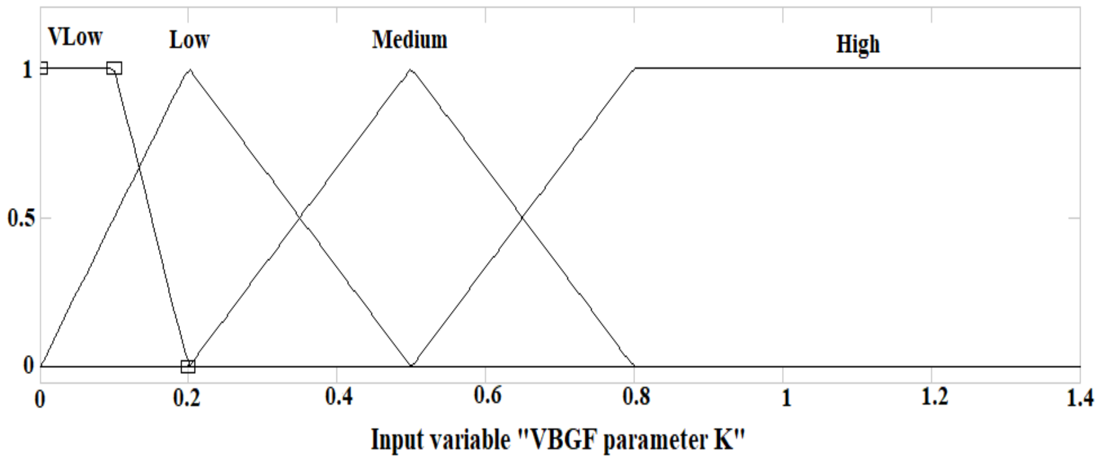


Figure 1. Fuzzy inference system variables (Inputs: K, T_r, M, E; Output: FP).

The first level describes the range of linguistic values represented by (Very Low), the second level is the range of low linguistic values (Low), the third level is the range of medium linguistic values (Medium), the fourth level is the range of high linguistic values (High) and the fifth level is the range of very high linguistic values (Very High), and in the same manner, the rest of the variables are described. In the fuzzification phase of inputs, the conversion of numerical inputs into linguistic variables is resorted to by verbal expressions with identification of the numerical range for each expression independently (On based easily obtainable life history and ecological characteristics of fish species available through FISHBASE (Froese and Pauly, 2022), as well as to a guide to fisheries stock assessment (Cooper, 2006). As if we say that the natural mortality rate (M) is high if the degree ranged between [0.35 – 0.80] (as shows a membership function of the test). The VBGF parameter (K), T_r, M, E have been fuzzed within the range [0 – 1.4] (Figure 2, A), [0.2 - 4] (Figure 2, B), [0 – 0.8] (Figure 2, C), and [0-100] (Figure 2, D), respectively.



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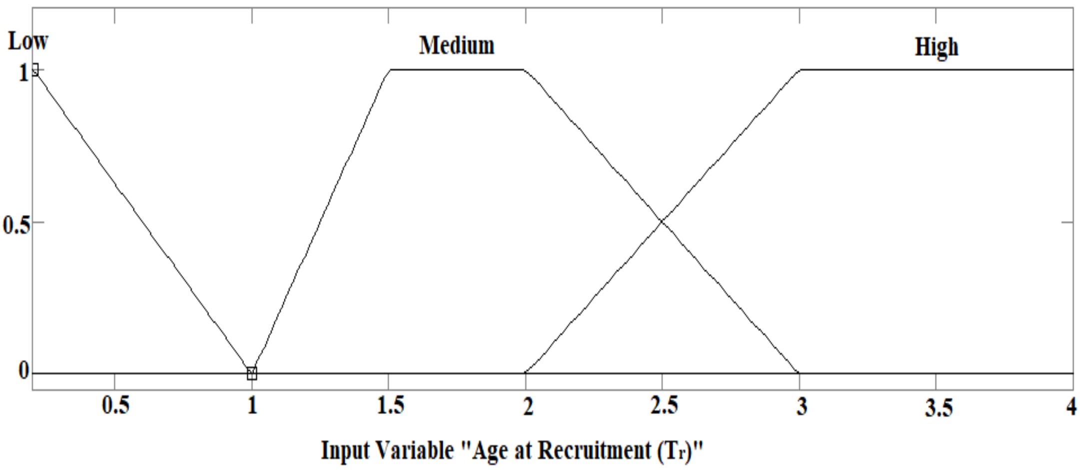

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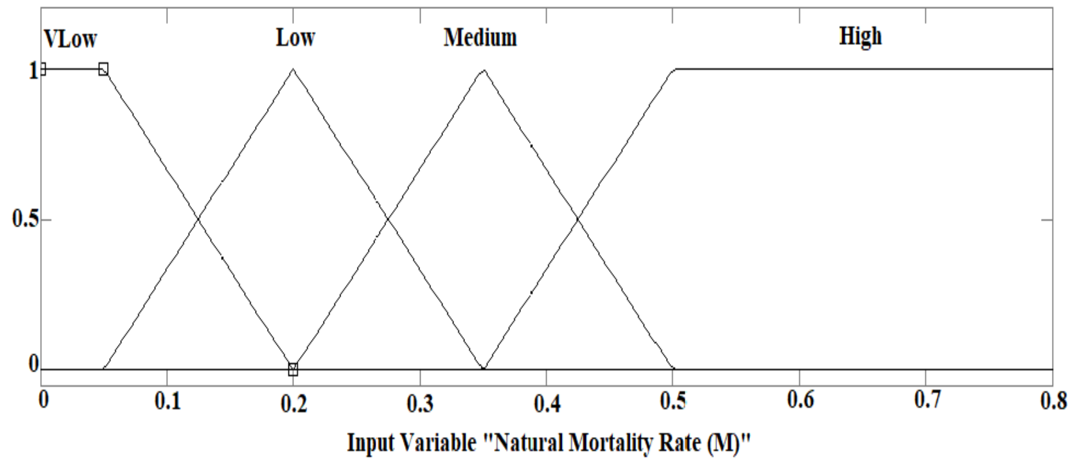

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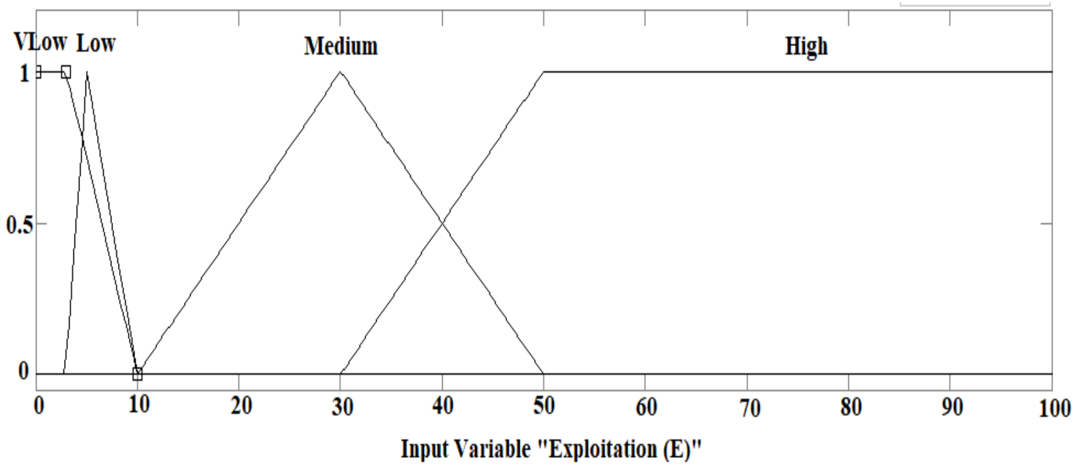

D

Figure 2. Fuzzification process of input variables: A. VBGF parameter K (year^{-1}), B. Age at Recruitment (T_r, year), C. Natural Mortality Rate (M, year^{-1}), D. Exploitation Rate (E, year^{-1})

In the defuzzification phase of the outputs, it is used to convert the linguistic outputs extracted from the rules into numerical values by giving verbal expressions to them with the identification of the numerical range for each expression independently, such as saying that status of the FP is moderate if its Membership Function (MF) from 20 to 60 (100 being the most status of FP), while it is large if the MF ranges from 40 to 80 as shown in Figure (3).

Several models have been developed that differ from each other by representing data in different fuzzy sets, and thus in the creation of multiple fuzzy rules, and we chose this model that gave the closest expected result to the values of real data to the growth of the fishery populations.

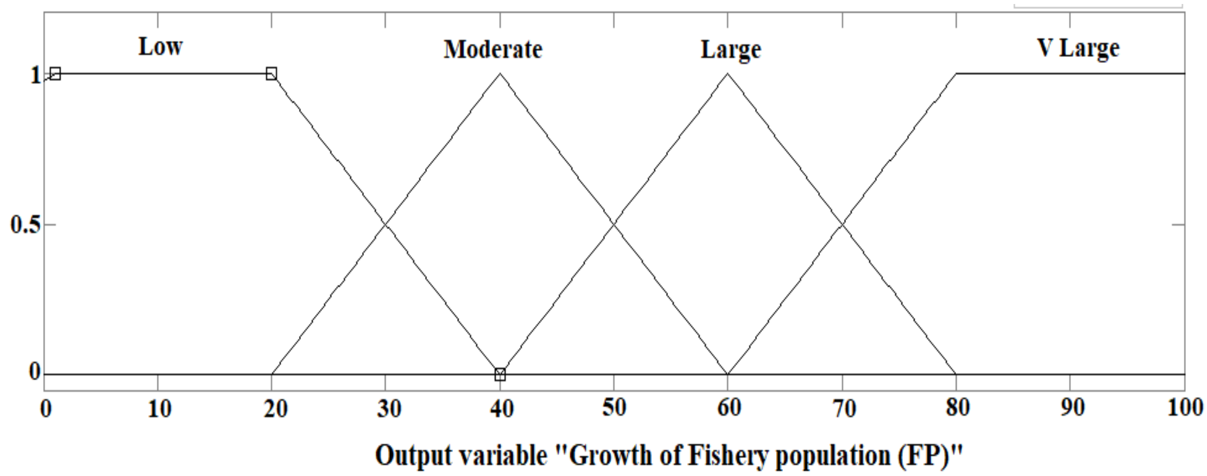

Figure 3. Defuzzification process of output variable "Fishery population (FP)".

We have entered 4 input variables for each of them a number of fuzzy sets, where the rules are formed by combining the different data according to their fuzzy sets and linking them with a logical relationship between input variables and output variable, and the appropriate rules were set and the contradictory rules were removed until we reached 8 fuzzy rules, and the summation method is used to aggregation the rules and the Centroid method to defuzzification of the model, Which it depends on finding the equilibrium point by calculating the weighted mean of the fuzzy output area, i.e. each fuzzy set is converted to a single clear value through the fuzzy rules, and obtaining fixed values, and at each input value of input variables produce output value of the fishery population. The following table (1) explains the inference rules that are used in the proposed fuzzy model, which are formulated as a set of rules IF – THEN by using the MATLAB R2021a software (The Math Works, 2021).

In order to use the fuzzy inference system to easily predict, an Graphical User Interface (GUI) was created to obtain the final result represented by the input membership functions of the 8 rules studied from the inference rules (the first four columns represent from left to right and respectively represent K, T_r, M and E and the final result of the fuzzy expert system (the fifth column represents the growth of FP, e. g., Input variables (0.15; 1.83; 0.436; 0.52) to *Boops boops*) (Figure 4).

Within the proposed model, the input values (K, Tr, M, E) of fish species (6 species) were randomly selected from the published scientific references to obtain the results of their growth (Table 2).

Table 1: Inference rules (IF – THEN) defined in the fuzzy expert system to assessment the growth of the fishery population.

Rule	Condition	Consequence
1	IF VBGF K is High OR M is VLow THEN	Growth of FP is VLarge
2	IF VBGF K is High OR M is Low THEN	Growth of FP is Large
3	IF VBGF K is Medium OR M is Medium THEN	Growth of FP is Moderate
4	IF VBGF K is Low OR M is High THEN	Growth of FP is Low
5	IF T_r is Low OR E is High THEN	Growth of FP is Low
6	IF T_r is Medium OR E is High THEN	Growth of FP is Moderate
7	IF T_r is High OR E is Low THEN	Growth of FP is Large
8	IF T_r is High OR E is VLow THEN	Growth of FP is VLarge

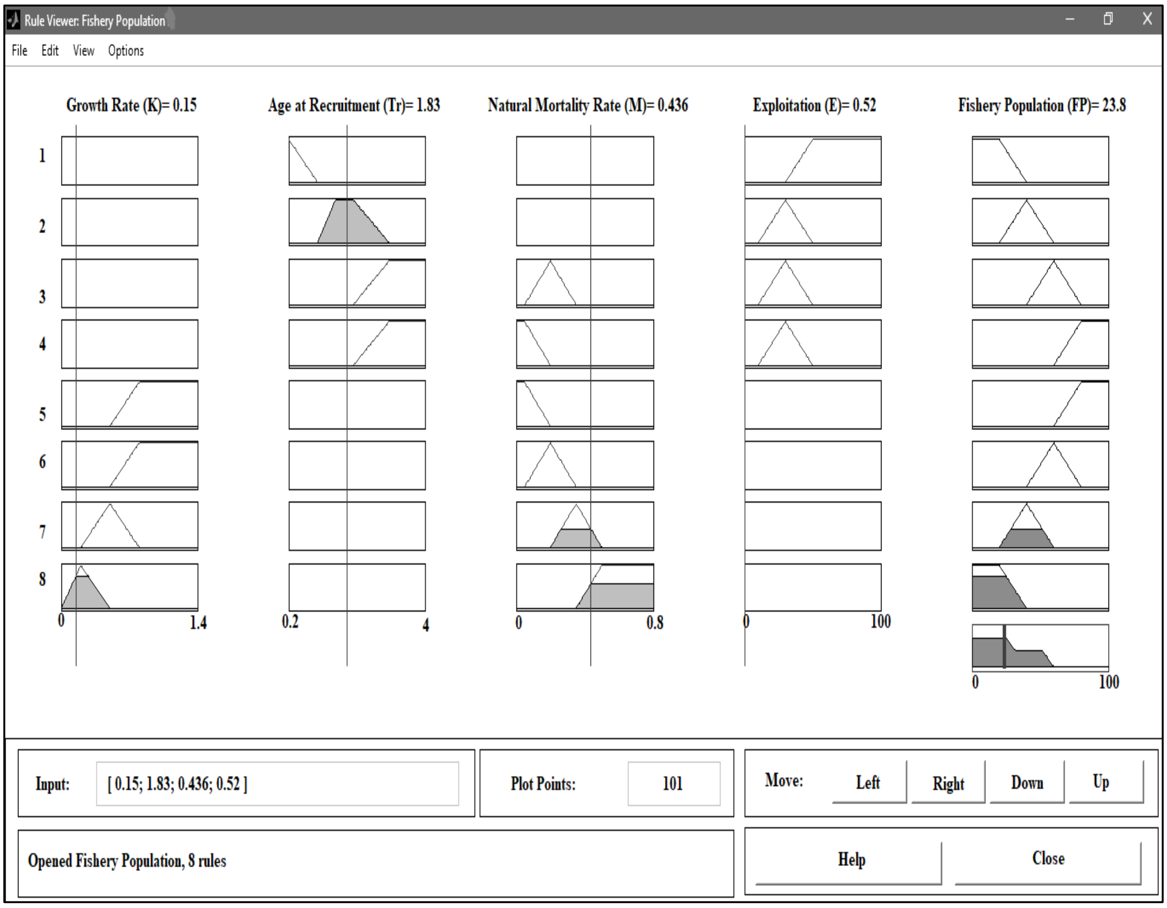

Figure 4. Graphical User Interface (GUI) to estimate the growth of the fishery population (e. g., Input variables to *Boops boops*).

Table 2. Input variables of fishes in the proposed model.

Scientific name	Input variables				Location	References
	K	T_r	M	E		
Boops boops	0.15	1.83	0.436	0.52	Syria	(Hamwi, 2012; 2011)
Oblada melanura	0.31	0.77	0.73	0.1	Syria	(Hamwi, 2017)
Boops boops	0.1531	1.23	0.458	0.464	Egypt	(Allam, 2003)
Oblada melanura	0.242	1.53	0.563	0.412	Egypt	(Mahmoud, 2010)
Parupeneus forsskali	0.27	0.25	0.69	0	Syria	(Hamwi and Ali-Basha, 2021, in print)
Sparus aurata	0.37	0.11	0.394	0.637	Egypt	(Al-Zahaby *et al.*, 2018)

For observing the accuracy and ability for the model to determining the growth of the selected fishery populations, we made a simple comparison process and with a certain approach between the results of the model to determine the growth of FP and the Musick`s criterion of VBGF parameter K (Table 3) for previously proposed populations.

Table 3: The Musick`s criterion

Parameter	High	Medium	Low	Very low
VBGF K ($year^{-1}$)	> 0.3	0.16 – 0.30	0.05 – 0.15	< 0.05

3. Results and discussion:

For instance, the fuzzy expert system gave a value (23.8) for the growth of FP of the Bogue (*Boops boops*) (100 being the most status of the growth of FP), which represents 0.8 low and 0.2 moderate (Figure 5) with a clear tendency to decrease and low growth to species in its fishing environment. And what supports this result and its conclusion is compatibility with what was obtained by Hamwi and Ali-Basha (2019) when estimation of the vulnerability of some Sparidae species to fishing by fuzzy logic method (e.g., The vulnerability of *Boops boops* was 53, ranging between 65% medium to 35% high), which indicates exposure of this species to poaching and limiting its attainable growth.

When monitoring the model accuracy and its ability to determine the growth of FP selected. We found that the model results for determining the growth of FP are much better and more specific than Musick's criterion for the VBGF parameter K for these species recorded from the fishing outcome during their study (Table 4). For example, the proposed model based on the four inputs was able to give a clear value (23.8) for the growth of *Boops boops*, which fully expresses the extent of the interactive effect of these transactions on the structure and state of the current *Boops boops* (the growth of *Boops boops*).

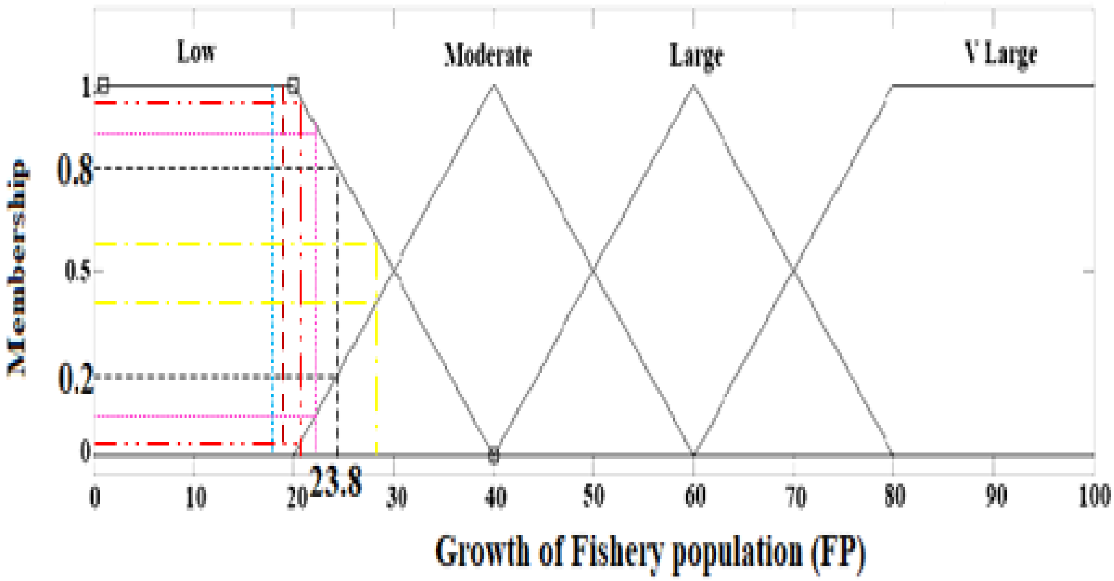

Figure 5. The growth of FP of *Boops boops* (Black; Pink), *Oblada melanura* (Light blue; Red), *Parupeneus forsskali* (Dark red) and *Sparus aurata* (Yellow) by the proposed model.

While, we find that Mulsick relied only on the VBGF parameter K, which describes only the state of individuals (expressing the rate (year^{-1}) at which the asymptotic length is approached) and not on the structure and state of the current *Boops boops*. We note his description of the growth of *Boops boops* as low according to the value of VBGF parameter k (0.15), which belongs according to his criteria to range (0.05 – 0.15) and this is insufficient and inaccurate to estimate the growth of *Boops boops* (Table 4).

It has been shown to us, according to the result of the proposed model of FP and its representation ratios for the growth of the target fishery populations, that it is more accurate and clearer than the Musick`s criterion, which is based only on the VBGF parameter K in evaluating the growth of the fishery population, in comparison with four important and basic inputs and linked them together in the proposed model.

Table 4. Output variable (growth of FP) by the proposed model and the Musick`s criterion of VBGF parameter K.

Scientific name		Growth of FP	Degree of membership and linguistic category
Boops boops	Present Model	23.8	(0.2) Medium : Low (0.8)
Boops boops		22	(0.1) Medium : Low (0.9)
Oblada melanura		21.3	(0.03) Medium : Low (0.97)
Oblada melanura		18.1	(1) Low
Parupeneus forsskali		19.6	(1) Low
Sparus aurata		29.6	(0.45) Medium : Low (0.55)
		VBGF parameter K (year^{-1})	
Boops boops	Musick's Criterion	0.15	(0.05 – 0.15) : Low
Boops boops		0.1531	(0.05 – 0.15) : Low
Oblada melanura		0.31	(0.16 – 0.30) : Medium
Oblada melanura		0.242	(0.16 – 0.30) : Medium
Parupeneus forsskali		0.27	(0.16 – 0.30) : Medium
Sparus aurata		0.37	> 0.30 : High

From the above, we can say that the expert system applied in this study to determine the growth of FP enabled us to answer the previously mentioned questions:

- First; Yes, the present method of the expert system is able to give clear specific value for the growth of FP. While the Von-Bertalanffy coefficients are only sufficient to describe the growth in general or imprecise comparison of growth factors without specifying or giving a value for this growth. More than its reliance on other transactions such as deaths, for example, as a coherent unit to provide an accurate and clear decision.

- Second, Yes, there is a high degree of reliability in the proposed model to estimate the growth of the FP. The output value explicit and specific to the growth of FP is based on four important interrelated inputs which are represented by specific ratios to describe the growth of FP compared to Musick`s criterion, which is based on the value of VBGF parameter K for assessing the growth of FP.

4. Conclusion:

The methods currently applied to determine the growth of FP is not sufficient to give a true and obvious value to them. Therefore, the proposed model is a new method that helps in determining the growth of FP very accurately. It is a strong inferential system in which all studied cases are discussed for the four tests. It can be applied to all fish species, which helps in the optimal management of their catch. The model was designed using Matlab software and a fuzzy logic library. It is easy to use by all academic and research institutions. We find it necessary to modify the methods of determining the growth of FP in order to better manage their fishing in an optimal manner and their sustainability. As future work, it is possible to rely on new models based on hybrid methods between artificial neural networks and fuzzy logic such as the adaptive fuzzy neural inference system (ANFIS). Traditional mathematical methods cannot solve many problems and therefore relying on more effective methods (artificial intelligence techniques) gives reliable results for the research.

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