EISSN 2602-473X

AQUATIC SCIENCES AND ENGINEERING

Aquat Sci Eng 2025; 40(1): 22-29 • DOI: https://doi.org/10.26650/ASE20241570813

Research Article

Mathematical Modelling of the Population of *Potamon potamios* Olivier 1804 in Terms of Climatic Factors

Tuğrul Öntürk[1]

Cite this article as: Ontürk, T. (2025). Mathematical modelling of the population of *Potamon potamios* olivier 1804 in terms of climatic factors. *Aquatic Sciences and Engineering, 40(1)*, 22-29. DOI: https://doi.org/10.26650/ASE20241570813

ABSTRACT

The amount of the *Potamon potamios* Olivier 1804 population has many positive/negative effects on other aquatic life and is essential for aquatic biodiversity. It is therefore important to determine the population of *Potamon potamios* Olivier 1804. The population density of *Potamon potamios* Olivier 1804 is affected by temperature, precipitation, amount of water, and many other climatic factors. In this sense, mathematical model based on a fuzzy inference system was made to determine the population dynamics of this creature considering the climatic data in this study. In addition, correlation analysis has shown that this model can predict the population of this creature with 91% accuracy in untested climatic conditions.

Keywords: Population Variations, Fuzzy Logic Modelling, Fuzzy Inference System, Freshwater crabs, *Potamon potamios*

INTRODUCTION

Crabs are found in oceans all over the world, as well as in many freshwater and terrestrial species. There are species with a leg length of several metres (*Maja kaempferi* Temminck, 1836) with known lengths of less than a few (*Pinnotheres pisum* (Linnaeus, 1767)) (Brandis, 2001). Freshwater crabs live in many habitats, from the cold waters at the top of the Andes to rivers and lakes in the tropics, swamps and rainforest floors, and even arid areas. Some freshwater crab species are fully aquatic, while others are semi-terrestrial. A few species have adapted to living in trees and breathing air (Sternberg et al, 1999). Since they have legs, they are in the Brachyura infrateam of the Decapoda (Ten-legged) team. Although they have legs , the first pair of legs close to the head is used for hunting and catching. They do not have walking functions. The remaining pairs of legs perform the walking work (Brandis et al, 2000). Crabs are both a high-protein food source and play a role in the nutrition of some living organisms (Buck et al, 2003). However, their superior hunting and olfactory abilities, negatively dominate the fast-reproducing protozoa, plankton and fish populations (Giller and Malmqvist 2000). Temperature is one of the most important factors in the distribution of freshwater crabs. It has been reported that there are species of Potamon in the Middle East and species in Europe (Brandis et al, 2000; Brandis, 2001; Giller and Malmqvist, 2000. Regarding population density, the *Potamon potamios* Olivier species is mainly found in the Greek islands and the island of Cyprus to the southern coasts of Turkey. It shows less population density in the parts of the countries up to northeast Egypt close to the Mediterranean (Brandis et al. 2000). The regions where the species is most widely distributed in Turkey are the coastal and interior parts of the Mediterranean (Brandis et al, 2000; Özbek and Ustaoglu, 2005; Özbek and Ustaoglu, 2006; Öntürk, 2018).

The amount of *the P. potamios* population has many positive/negative effects on other aquat-

ORCID IDs of the author:
T.Ö. 0000-0002-6358-6112

[1]Deparment of Biology, Science Faculty, Eskişehir Osmangazi University, Eskişehir, Türkiye

Submitted:
20.10.2024

Revision Requested:
14.01.2025

Last Revision Received:
21.01.2025

Accepted:
21.01.2025

Online Published:
28.01.2025

Correspondence:
Tuğrul Öntürk
E-mail: tonturk@ogu.edu.tr

ic creatures and is essential for aquatic biodiversity. Therefore, it is essential to determine the population of *P. potamios*. The population density of *P. potamios* is affected by temperature, precipitation, amount of water, and many other climatic factors (Kennish, 1996). The main motivation of this study is to determine how the population dynamics of this creature are affected by climatic data. In this sense, the climate data were measured monthly for years between and the number of individuals identified in this period was recorded. In this study, considering data obtained from field studies, mathematical model based on the fuzzy inference system was constructed to determine the population change. Moreover, it has been shown in the correlation analysis that the untested data can be estimated with accuracy thanks to this mathematical model.

Materials and Methods

Data collection

The inputs in this study are the real data obtained from the 11 years of work conducted by Phd. Tuğrul Öntürk between and in Gökçekaya Dam Lake (Figure 1). In this study, *P. potamios* individuals were collected monthly, and the total number of individuals was determined. The samples collected during this process were marked with a water-resistant pen to prevent recounting and released back into the living spaces.

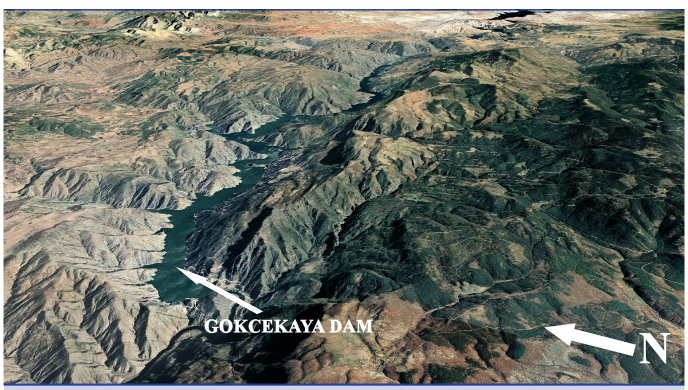

Figure 1. General view of the Gökçekaya Dam and its surroundings.

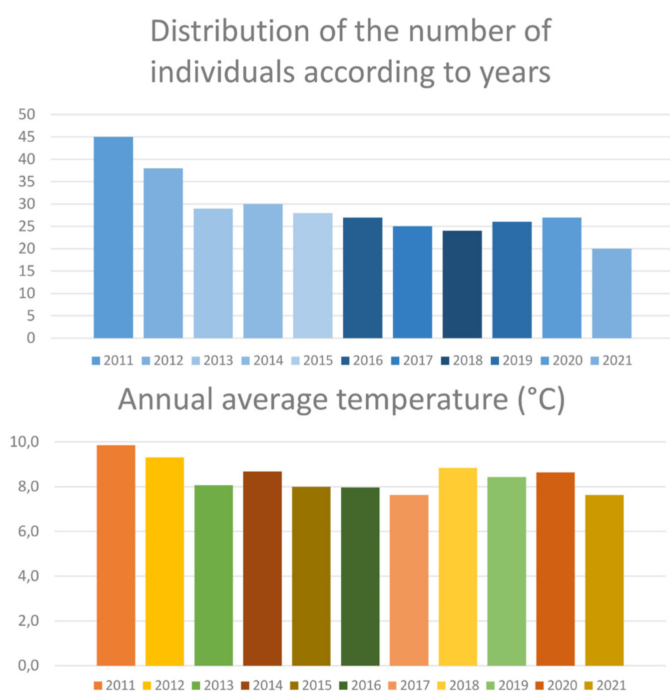

Figure 2. Number of individuals and temperature averages by years.

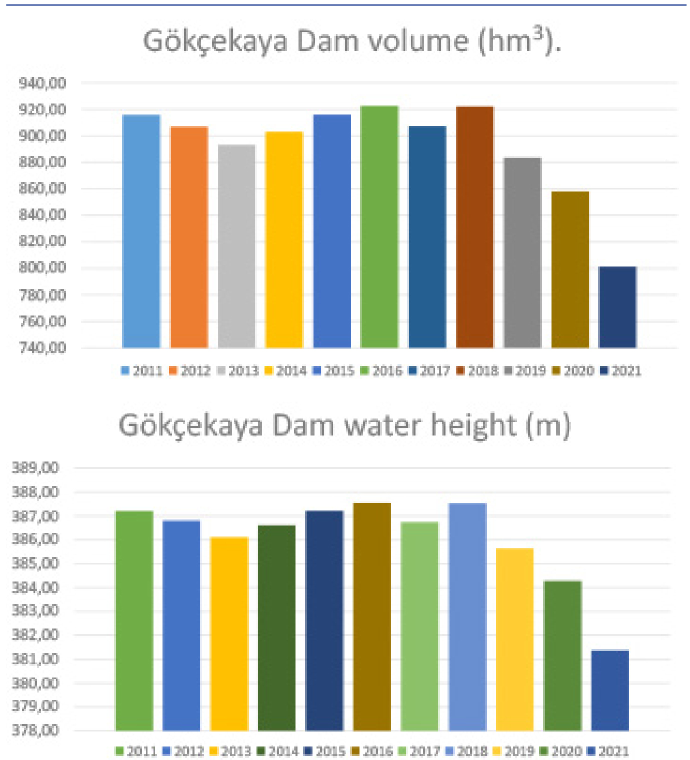

Figure 3. The volume of water collected in the dam and the height of the water by years.

In addition to the total number of individuals, the annual average temperature (Figure 2), dam volume , dam water height (Figure 3), annual average wind speed , annual average rainfall (Figure 4) were measured regularly.

Fuzzy logic approach

It is impossible to precisely define many problems, situations or events encountered due to the uncertainties they encompass. Because real life has an extremely complex and chaotic structure. It is very difficult to define everything we experience in our daily life with " 0 " and "1", to classify them only between two extremes like black and white, and to examine them under mathematical precision. Because there are also uncertainties in our lives that do not have sharp boundaries. Therefore, the necessity of having exact values about a phenomenon in mathematics has caused difficulties in practice, and for centuries, scientists have developed methods to find a solution. Mathematical precision was not enough despite the limitlessness and complexity of the universe. Although it is possible to explain concepts such as

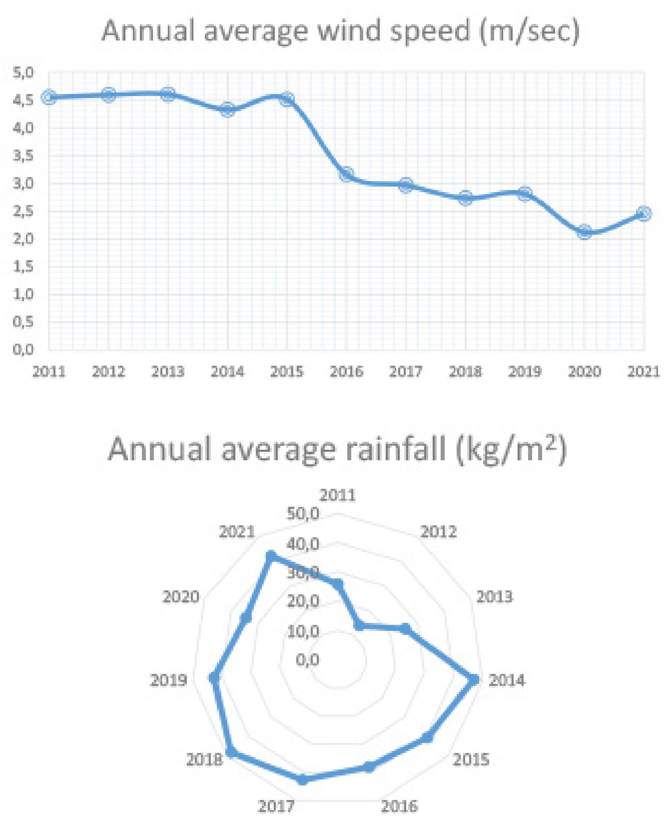

Figure 4. Average wind speeds and precipitation per square metre in kilogrammes in the study area by the year.

black-white, right-wrong, and good-bad with mathematical thinking, it is not possible to represent the entire universe with this binary logic alone. Based on this, the fuzzy set theory was introduced to the literature by Azeri origin Lütfi Aliasker Zade in 1965 with the study "L.A. Zadeh, Fuzzy sets. Information and Control 8(3):338–353." With this study, a new perspective was given to classical logic, which came from Aristotle, and machines learned the sentences produced by humans. Thus, the two-valued Aristotelian logic consisting of " 0 " and " 1 " has been generalised by evolving into a technology-supported logic. The fuzzy set generalises the two-choice membership status of "yes-no" to the concept of partial membership. In this case, the value of " 1 " indicates full membership to the set, the value of " 0 " indicates not being a member of the set, while values between " 0 " and " 1 " represent the concept of relative (partial) membership. Accordingly, an arbitrary element in a fuzzy set may belong to different fuzzy sets according to its degree of membership. The traditional set approach uses characteristic functions while expressing the sets. A traditional set with the help of characteristic functions is defined by

$$\chi_A \; : \; U \; \rightarrow \; \{0,1\}$$

$$x \; \mapsto \; \begin{cases} 1 & , \; x \in A \\ 0 & , \; x \notin A \end{cases},$$

where U is the universal set and $A \subseteq U$. In the fuzzy set approach, membership transitions of the elements in a universal set, fuzzy sets, occur gradually. If an element is included in any cluster, the element belonging to that cluster is graded. With this rating, an ambiguous situation occurs at the fuzzy set boundaries. For this reason, a function to measure the uncertainty in the case of an element belonging to a set is defined. Such functions are called "Membership Function", and the set formed by this function is called "Fuzzy Set". A fuzzy set A can be mathematically expressed as

Let U be a universal set. The fuzzy set A in U is characterised by its membership function $\mu_A\!: U$ and is defined as a set of ordered pairs;

$$A = \{(x, \mu_A(x)) : x \in U\}.$$

As the membership function, μ_A maps each element of U to a membership grade between and , the value of $\mu_A(x)$ is interpreted as the degree to which a point $x \in U$ belongs to the fuzzy set A.

In fuzzy sets, an element of a set that "somewhat belongs or does not belong to a set" is expressed as. As with traditional sets, the all-or-nothing logic is not true for sets. In the fuzzy system, the data to be used as input should be fuzzified, that is, these data should be converted to values between. The goal of this process is to express the data in question with verbal expressions. In the fuzzification process, the fixed logic calculations are determined first. Then, each point in these sets is expressed with a membership function. There is no limit to what form and how many membership functions can be. The number of membership volumes varies according to the knowledge and experience of the specialist. The most commonly used membership function types are trapezoidal, Gaussian, and triangular.

Triangle membership function

The triangle membership function is used to specify the input and output variables in fuzzy logic-based systems. This membership function is determined by three variable real numbers such as p, q and r and its equation is as follows;

$$\mu(x;p,q,r) = \max\left\{\min\left\{\frac{x-p}{q-p}, \frac{r-x}{r-q}\right\}, 0\right\}$$

Trapezoidal membership function

The trapezoidal membership function is used to define the input and output variables, similar to the triangular membership function, and is defined as follows;

$$\mu(x;p,q,r) = \max\left\{\min\left\{\frac{x-p}{q-p}, 1, \frac{r-x}{r-q}\right\}, 0\right\},$$

where p, q, r and s are real numbers;

Implementation of the fuzzy inference system

The fact that it is close to human logic and easy to create has made the Mamdani-type fuzzy inference system very popular in natural sciences such as physics, chemistry and biology recently (Ermiş et al, 2022; Putti, 2017; Şahiner, 2015; Şahiner, 2016; Şahiner, 2018; Şahiner, 2022; Şahiner, 2023). In this study, we used the Mamdani-type fuzzy inference system to guide the fuzzy logic models that are planned to be used in future biology studies.

Determine and predict the *P. potamios* crab population according to various climatic conditions on a personal computer with Intel(R) Core(TM) i7 (2.81 GHz) configuration on the MATLAB R2015a platform, we constructed mathematical model using the Mamdani-type fuzzy inference system, the steps of which are given below. Our Mamdani inference mechanism has six inputs and one output value. The input variables are months, annual average temperature (°C), dam volume (*hm*³), altitude (dam water height (*m*)), annual average wind speed (*m/sec*) and annual average precipitation (*kg/m²*). The output variable is the population of *P. potamios* crab.

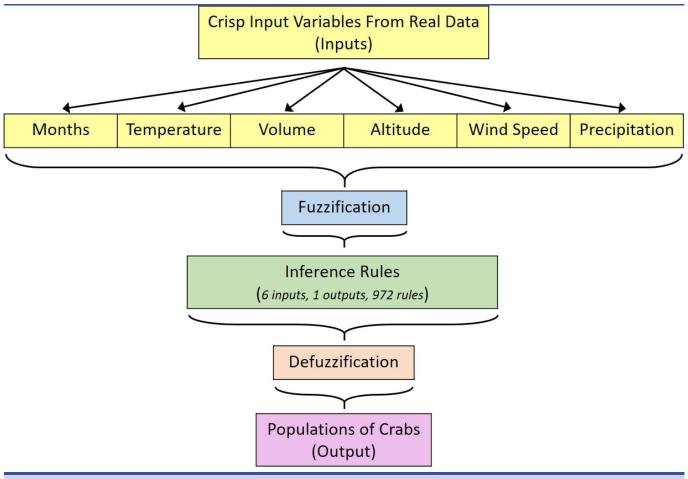

Figure 5. General Structure of the Mamdani Fuzzy Inference System.

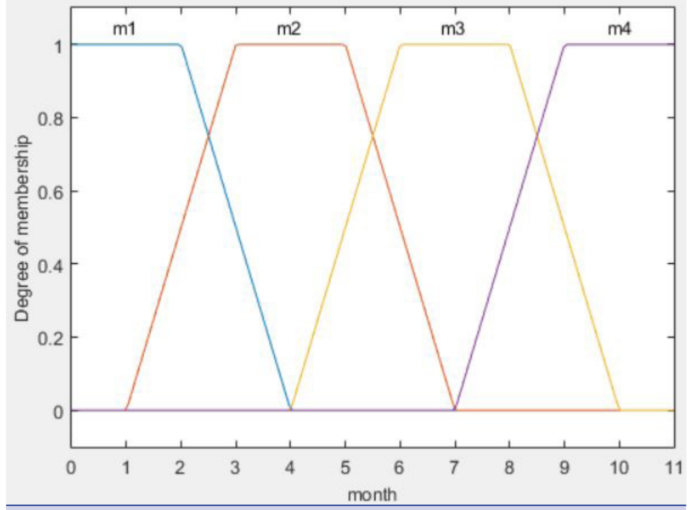

Figure 6. Membership functions for months.

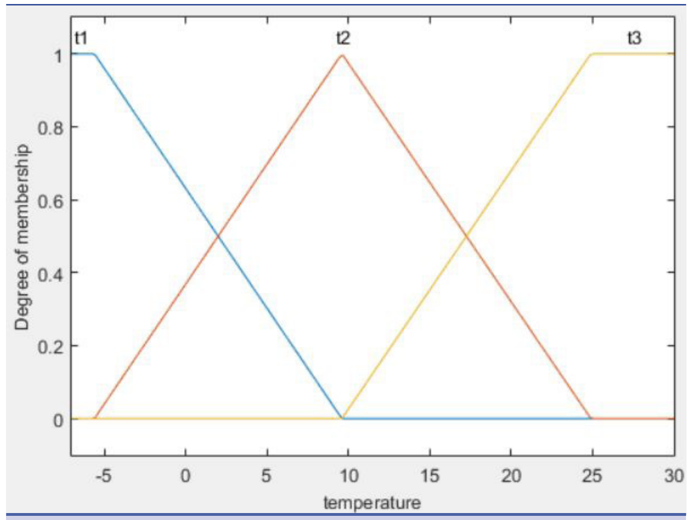

Figure 7. Membership functions for the temperatures.

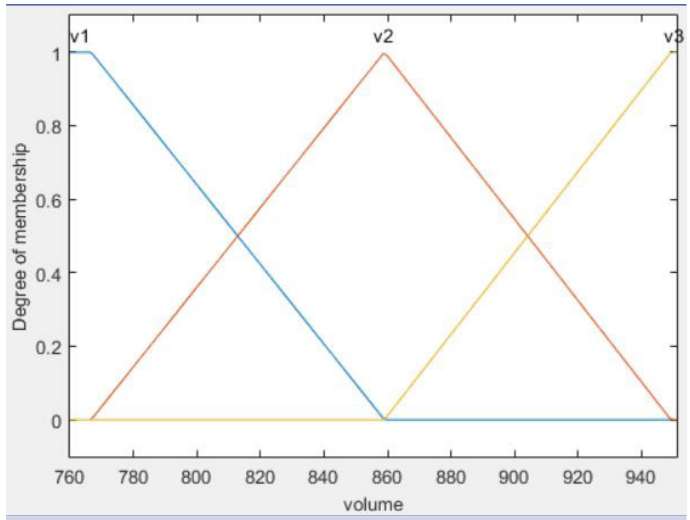

Figure 8. Membership functions for volumes.

Fuzzification

In this step, we determined the membership degrees by converting the input and output values to values between with the help of the membership functions. Thus, by the fuzzification of our input and output variables through membership functions, we have turned precise numerical values into linguistic variables. As a result, based on our experience and expertise, we have made our output data interpretable according to these verbal evaluations. In Figure 6, months are labelled as follows; *0 = February, 2 = March, 3 = April, 4 = May, 5 = June, 6 = July, 7 = August, 8 = September, 9 = October, 10 = November, 11 = December.* Also, t1, t2, and t3 represent low, medium, and high temperatures, respectively, in Figure 7. Similarly, linguistic labelling of low, medium and high is used in Figures 8, 9, 10, 11 and 12.

Inference rules

In the previous step, we the input variables of our model into fuzzy input. In this step, we created fuzzy rules using logical operations such as "if-then", "and", "or", "not" by taking expert opinions. Then, we obtained fuzzy outputs by processing fuzzy inputs according to these rules. Briefly, we transformed verbal/linguistic input and output variables into mathematical form. For this, we defined the rules as much as the multiplication of the membership function numbers we defined for each input value while determining the rules. That is, since there are input variables in our model and 4,3,3,3,3,3 defined membership functions

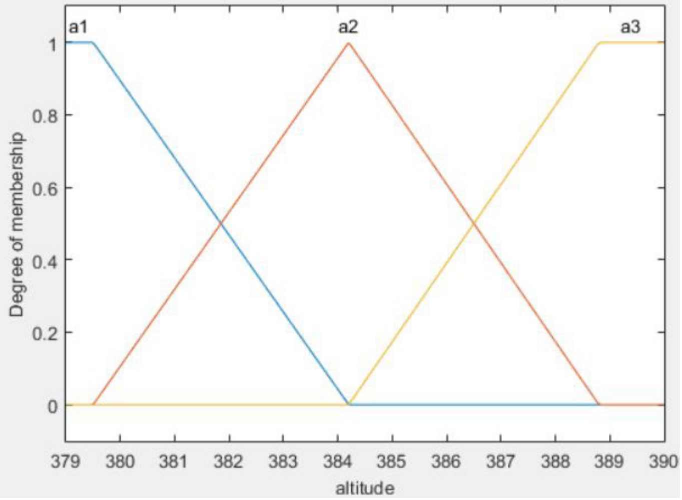

Figure 9. Membership functions for altitudes.

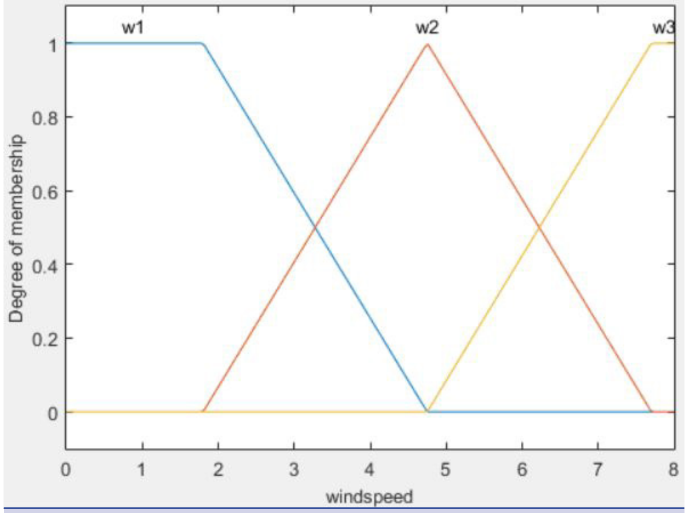

Figure 10. Membership functions for the wind speeds.

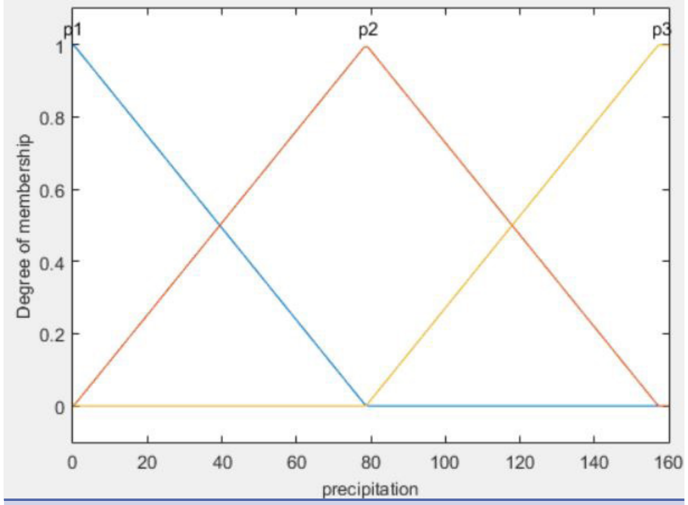

Figure 11. Membership functions for precipitation.

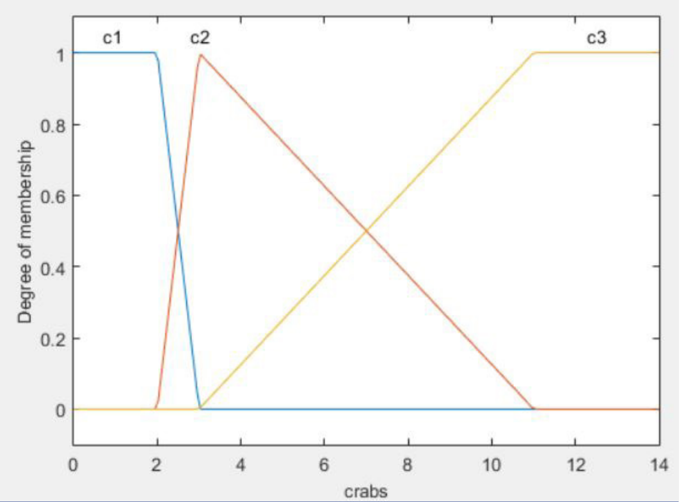

Figure 12. Membership functions for a population of crabs.

for each input variable, we have defined 4×3×3×3×3×3=972 rules. Some of these rules are as follows;

- If month is m1, temperature is t2, volume is v3, altitude is a1, wind speed is w2, and precipitation is p2, then population is c1,
- If the month is m4, temperature is t3, volume is v2, altitude is a3, wind speed is w1, and precipitation is p3, then population is c3,
- If the month is m4, temperature is t1, volume is v1, altitude is a2, wind speed is w3, and precipitation is p1, then the population is c2.

Defuzzification

In the previous step, after we input values to fuzzy numbers under the membership functions, we fuzzy output values under the rules we defined. However, since these values are the values of the fuzzy set, they must be turned into crisp values to be processed. In this sense, in this step where we reversed the fuzzification process, the crisp values obtained by the fuzzification process were made comparable with the classical systems.

RESULTS AND DISCUSSION

In this study, real data have been converted into fuzzy values under the rules created with linguistic values, and then a fuzzy inference system has been built, in which crisp values can be obtained again by fuzzification of these fuzzy values. Our model results are crisp numbers from the cluster [0,14], the population scale of *P. potamios*. Estimation of the number of P Potamios populations is accomplished by outputs from the "if...then" rule base, where input values are entered. For example, the input variables month=8, annual average temperature=1.7, dam volume=828, altitude (dam water height)=389, dam water height=3.4, and annual average precipitation=58 are not observed in the real data. If one enters these input data into our fuzzy inference system as [8,1.7,828,389,3.4,58], it is obtained that the output value is 4.5, which is *the P. potamios* population number (see Figure 13). Accordingly, it can be easily obtained that the number of populations in these input variables should be at least 4 and at most 5.

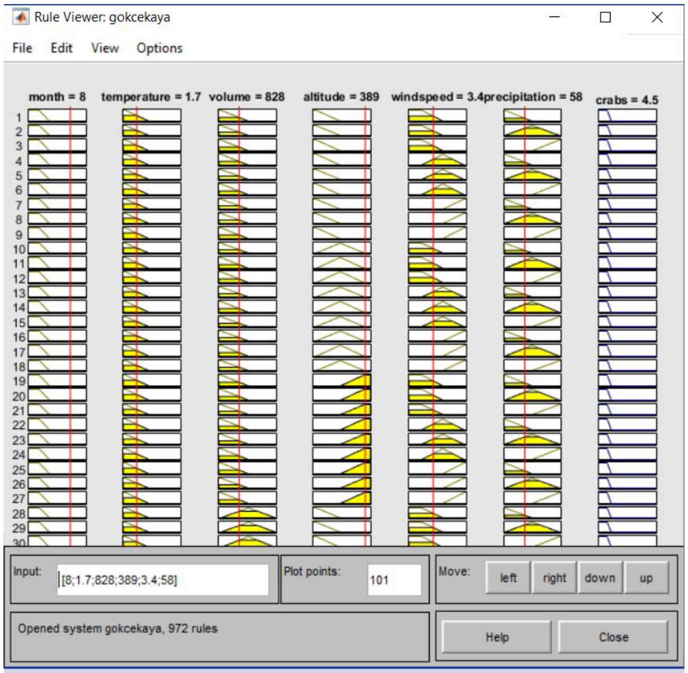

Figure 13. Rule-based fuzzy inference system.

Thus, based on the climatic and topographic characteristics of the geographical region where this dam is located, a mathematical model was created to determine the population number of *P. potamios* using a fuzzy logic approach. Thanks to this model, the number of *P. potamios* populations in the Gökçekaya Dam can be estimated by entering the previously unobserved and unmeasured climatic and geographical data into the rule base of our fuzzy logic model. The rule base we have constructed in the Mamdani inference system method has been created by using all of the 132 dam data obtained from the study carried out by Phd. Tuğrul Öntürk between 2011-2021 on Gökçekaya Dam (in Turkey) and benefiting from the experience and opinions of the experts. Regression analysis is used to measure the relationship between two or more quantitative variables. Regression analysis was performed to demonstrate the success and accuracy of the created model. The results obtained in the model were compared with the real data, and it was shown that the results in this model were 91% compatible (see Figure 14).

As a result, this mathematical model, which we created using the Fuzzy Logic Toolbox of the MATLAB platform, can determine the *P. potamios* population number with great accuracy. Therefore, our study may guide future academic studies on *P. potamios* population dynamics in this area.

CONCLUSION

The mathematical model we have created will not only predict the number of *P. potamios* population with great accuracy under future climatic changes but will also enable the effects of the re-

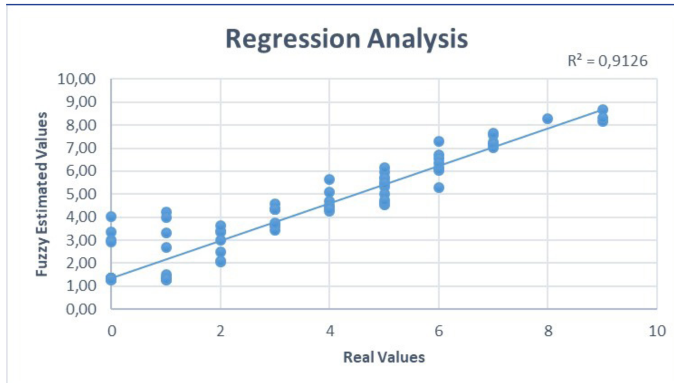

Figure 14. Regression analysis.

lationships between input parameters on the dynamics of the *P. potamios* population to be interpreted quite simply, similar to the comments below.

During the data analysis, the number of individuals in June was ignored in all years. Because of the climate zone in which the research area is located, the mating and breeding period may start at the end of May. The hatched individuals of the *P. potamios* species are carried and fed by the female in the abdomen for a while until they pass the larval stage. This is seen in many crab species.

Therefore, female individuals carrying eggs and larvae in June generally do not leave their nests for protection. They only feed in a close environment without leaving the nest to meet their nutritional needs. Accordingly, the June were ignored as they showed variability compared to other summer months.

Our findings have shown us that; The height of the air temperature, the height of the water level, the excess amount of precipitation and the wind speed have a direct positive effect on the population density.

For crustaceans such as shrimp and crabs, the water temperature is an important survival-related environmental factor that not only directly influences their metabolism, growth, moulting, and survival but also affects other environmental parameters (e.g., dissolved oxygen).

Therefore, the temperature has become an essential factor that restricts shrimp and crab culture (Ren et al, 2021).

As the air temperature increases, the water temperature also increases. Since this affects the living conditions of *P. potamios* positively, it will start the spawning and mating period and increase the number of individuals. However, depending on the increase in temperature, there will be an increase in the amount of food, as the number of plankton and other monocellular invertebrates in the water body will also increase. More food means more individuals survive (see Figure 15).

The amount of precipitation is important to maintain the water level at a certain height. Depending on the sufficient rainfall, the dam water level will remain at a sufficient level. Thus, hiding in

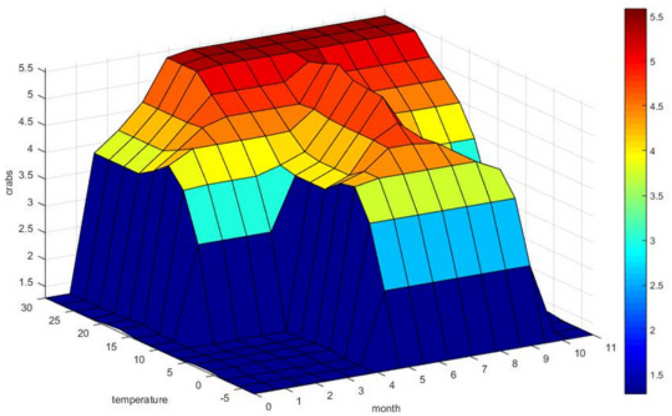

Figure 15. The population of crabs depends on the months and temperature.

the nest, which is also seen in *P. potamios* and many crab species, will continue. As the water level decreases, the nests will remain on the surface and in the dry area, which can cause the death of the individual and the offspring (see Figure 16). Because both the individuals emerging from the larva and the female and male individuals provide of their nutritional needs from the water. What is more important than all these is that the individuals that hatch from the eggs can only survive in water until they become adults. Systems to meet the oxygen needs in the external environment have not been developed (see Figure 16). Therefore, they cannot live in dry and arid areas (Buck et al, 2003).

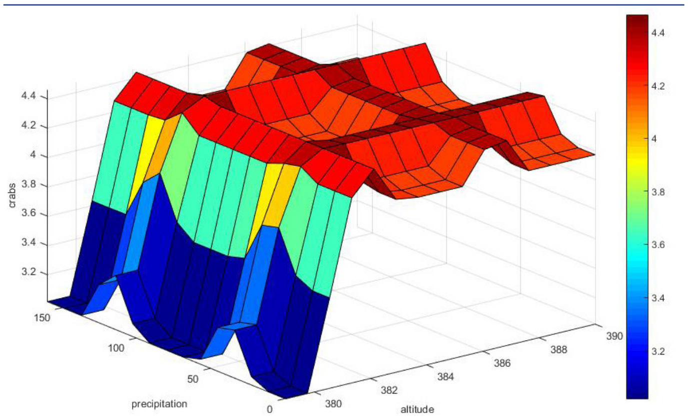

Figure 16. The population of crabs depends on the rainfall and water level.

Crabs feed on fish eggs or newly hatched fish fry. Therefore, with this study, the population density can be determined based on climatic data. Thus, the negative impact on the fish population can be kept in balance and the healthy growth of the fish population can be ensured by taking the necessary precautions in the regions where fishing is the livelihood.

In addition to all environmental variables, we think that the structure of the mountains around the research area, the forested area, and height are effective on temperature and rainfall. In general, due to the height of the Gökçekaya Dam and the southern part of the southern part, it takes snow and rainfall above seasonal norms in winter. This maintains the amount of water in the dam lake. Consequently, the crab population is positively affected. The height map of the Gökçekaya Dam and its surroundings is given in Figure 17.

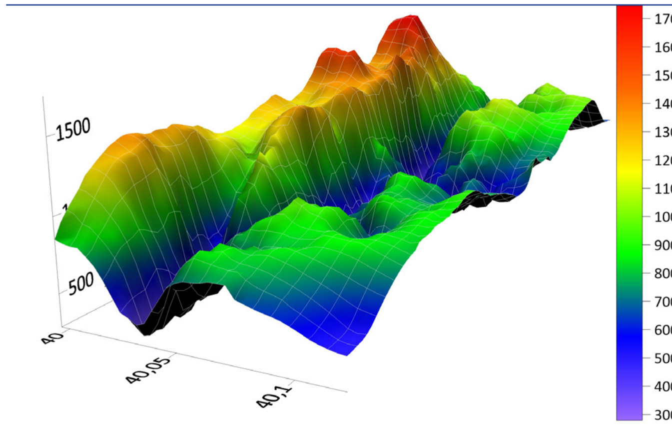

Figure 17. The height map of the Gökçekaya Dam and its surroundings.

The population dynamics of Potamon potamios can be accurately predicted using a mathematical model based on fuzzy logic, and a prediction accuracy of over 90% is achieved under various climatic conditions. Thus, the population dynamics of Potamon potamios can be accurately predicted with the climate data to be obtained in the coming years.

This model not only predicts the P. potamios population with high accuracy under varying climatic conditions but also provides a framework for studying the impact of climate change on similar aquatic species.

Declarations: -

Ethical Approval: Not applicable because this article does not contain any studies with human or animal subjects

Conflict of Interest: The author declare that they have no competing interests.

REFERENCES

Brandis, D., Storch, V., Türkay, M. (2000). Taxonomy and zoogeography of the freshwater crabs of Europe, North Africa, and the Middle East (Crustacea, Decapoda, Potamidae), Biologica 80, 5-56, 2000.

Brandis, D. (2001). On the taxonomy and biogeography of Potamon atkinsonianum (Wood-Mason, 1871) and Potamon (Potamon) emphysetum (Alcock, 1909), Hydrobiologia 452, 89?100, 2001.

Buck, T. L., Breed, G. A., Pennings, S. C., Chase, M. E., Zimmer M. and Carefoot, T. H. (2003). Diet choice in an omnivorous salt-marsh crab: different food types, body size, and habitat complexity, Journal of Experimental Marine Biology and Ecology 292(1), 103-116, 2003.

Ermiş, E., Ermiş, T., Şahiner, A. (2022). Synthesis, characterization of (E)-3-((2?hydroxy-5-(thiophen-2-yl) benzylidene)amino) benzonitrile and optimization of its energy by fuzzy logic modelling, Journal of Molecular Structure 1262, 133056, 2022.

Giller, P. S., Malmqvist, B. (2000). The biology of streams and rivers, Oxford University press, New York, page 296, 2000.

[Kennish(1996)] R. Kennish, Diet composition influences the fitness of the herbivorous crab Grapsus albolineatus, Oecologia 105(1), 22-29, 1996.

Öntürk, T. (2018). Examination of population and reproductive characteristics of freshwater crab (Potamon potamios (Olivier 1804) in Sakarbaşı(Çifteler), Research Journal of Biology Sciences 11(1): 5-7, 2018.

Özbek, M., Ustaoglu, M. R. (2006). Check-list of Malacostraca (Crustacea) species of Turkish inland waters, E.U. Journal of Fisheries Aquatic Sciences, 23, 229–234, 2006.

Özbek, M., Ustaoglu, M. R. (2005). Göller bölgesi iç sular?n?n Malacostraca (Crustacea-Arthropoda) faunasının taksonomik açıdan incelenmesi, E.U. Journal of Fisheries Aquatic Sciences, 22, 357-362, 2005.

Putti, F. F., Filho, L. R. A. G., Gabriel, C. P. C., Neto, A. B., Bonini, C. S. B., Reis, A. R. (2017). A Fuzzy mathematical model to estimate the effects of global warming on the vitality of Laelia purpurata orchids, Mathematical Biosciences 288, 124-129, 2017.

Ren X, Wang Q, Shao H, Xu Y, Liu P and Li J (2021). Effects of Low Temperature on Shrimp and Crab Physiology, Behavior, and Growth: A Review. Front. Mar. Sci. 8:746177. doi: 10.3389/fmars.2021.746177

Sternberg, R. V., Cumberlidge N., and Rodriguez, G. (1999). On the marine sister groups of the freshwater crabs (Crustacea: Decapoda: Brachyura), Journal of Zoological Systematics and Evolutionary Research, 37, 19-38, 1999.

Şahiner, A., Yılmaz, N., Demirözer, O. (2015). Mathematical modeling and an application of the filled function method in entomology, International Journal of Pest Management 60(3), 232-237, 2015.

Şahiner, A., Ucun, F., Kapusuz, G., Yılmaz, N., (2016). Completed optimised structure of threonine molecule by fuzzy logic modelling, Zeitschrift für Naturforschung A 71(4), 381-386, 2016.

Şahiner, A., Bedir, F., Yılmaz, N. (2018). Application of modern and classical optimization techniques in abrasion of Al-Cu-SiCp and Al-Cu-B4Cp composites, Journal of Multidisciplinary Modeling and Optimization 1(1), 23-32, 2018.

Şahiner, A., Ermiş, T., Ermiş, E. (2022). Optimization of energy surface of thiophene-benzothiazole derivative Schiff base molecule with fuzzy logic modelling, Computational and Theoretical Chemistry 1211, 113680, 2022.

Şahiner, A., Ermiş, T., Karakoyun, M. H., Awan, M. W. (2023). Determining the most effective way of intervention in forest fires with fuzzy logic modeling: the case of Antalya/Türkiye, Natural Hazards 116, 2269?2282, 2023.