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Macro-elements Prediction in the Tissues of *Carassius gibelio* (Bloch, 1782) using Adaptive Neuro-Fuzzy Inference Systems

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Abstract: The Prussian carp represents a valuable food resource in Danube Delta, and also, it is a well-known bioindicator for monitoring the pollution of the aquatic environment. The aim of the present paper is to apply the neuro-adaptive techniques, to obtain fast and economic sustainable results for the prediction of magnesium (Mg) and calcium (Ca) concentrations in the muscle and hepatic tissues of *Carassius gibelio*. Adaptive Neuro-Fuzzy Inference Systems (ANFIS) require validated data sets for the development of intelligent models. Thus, within this paper the prediction of Ca and Mg in the muscle tissue of the Prussian carp has been generated. Model training, testing and validation was realized based on results obtained after samples analysis in the laboratory. The results registered in this study confirm the efficiency of ANFIS models use for the fast prediction of macro-elements in fish tissues. Further investigation is required in order of optimize the prediction methodology.

Keywords: ANFIS; prussian carp; calcium; magnesium

1. Introduction

The continuous development of human societies exerts a high anthropic pressure on the environment, through the generation of wastes from different human activities (industry, agriculture, wastewater discharge). The macro-elements calcium (Ca) and magnesium (Mg) are important indicators of water quality and their concentrations in the aquatic ecosystems influences the toxicity of other pollutants such as heavy metals. Besides of being an important food source, fish are known to be useful bioindicators for the identification of different pollutants present in the water environment (Bănăduc *et al.*, 2016);(Simionov *et al.*, 2019). The fish species *Carassius gibelio* (Bloch, 1782) is a valuable food resource for the local human population of Danube Delta, Romania and from the food safety perspective it is important to determine the macro-elements concentrations in the tissues (Simionov *et al.*, 2021). Several studies have been conducted to determine the profile of macro-elements in the *C. gibelio* (Jovanovic *et al.*, 2019). However, studies for the prediction of Ca and Mg in fish tissues are scarce.

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Therefore, the present study aims to develop an Adaptive Neuro-Fuzzy Inference System, by applying the neuro-adaptive techniques, for the prediction of Ca and Mg in the muscle and liver tissues of *C. gibelio.*

Adaptive Neuro-Fuzzy Inference System (ANFIS) represents an instrument which is part of the Fuzzy Logic Toolbox. It was introduced by (Jang, 1993) and currently is considered one of the most visible soft computing methodologies (Walia, Singh and Sharma, 2015). ANFIS is based on techniques of neuro-adaptive learning, which allows the modelling of a data set by applying fuzzy rules such as "if-then". Also, the learning mechanism of ANFIS uses back-propagation or a combination of back-propagation and least square estimation for prediction of membership functions parameters (Jang, Sun and Mizutani, 1997). The neuro-adaptive learning techniques are based on a learning method similar to the neuronal networks. Nevertheless, this technique has the advantage of generating new information based on a data set and through fuzzy modelling.

2. Materials and Methods

The biological material (fish specimen) was collected from 3 lakes adjacent to the Aquatic Complex Dranov, Danube Delta, Romania. It was taxonomically identified as *Carassius gibelio* (Bloch 1782), known by its common name as the prussian carp. All individuals were placed in polyethylene bags and transported to the laboratory. Samples of muscle and liver were collected from each fish and all samples were digested using the TopWave digestion system. The concentrations of macro-elements calcium (Ca) and magnesium (Mg) were quantified in samples using the flame atomic absorption spectrometry (FAAS) technique and the ContrAA 700, Analityk Jena equipment. After analysis, the registered values were used as the data set for the development of ANFIS model.

In order to generate a realistic model, the correlation between data was identified. Thus, the hypostasis that the liver accumulates higher concentrations of Ca and Mg, compared to the muscle, was assumed.

The data base used in the present study for the development of ANFIS model is consisted of 119 values, which was divided as it follows: 60 values were used for model training and the rest were used for model testing and validation. The process of data selection is represented in Figure 1.

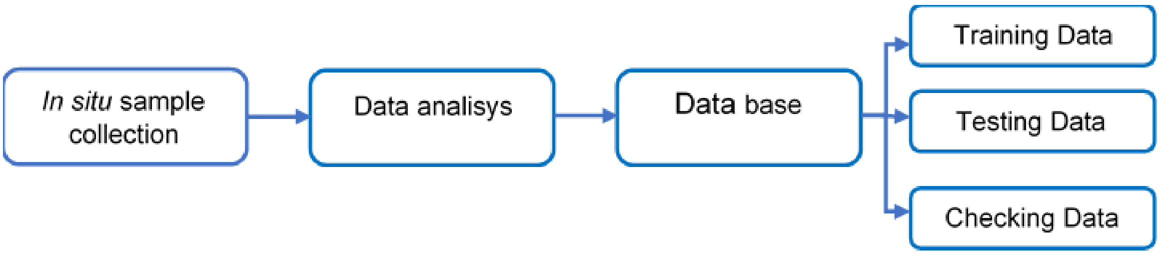

Figure 1. Data Selection Process

Also, the descriptive statistics for the parameters used in the present study for the prediction of Ca (Ca_l – liver calcium, Ca_m – muscle calcium) and Mg (Mg_l - liver magnesium, Mg_m – muscle magnesium) are presented in Table 1.

Table 3. Descriptive Statistics for the Parameters Used in this Study

Parameters	Unit	Min	Max	Mean
Ca_l	$\mu g/g$	425.4011	472.6704	451.496
Mg_l	$\mu g/g$	229.5616	263.1168	244.0578
Ca_m	$\mu g/g$	254.1428	296.524	272.3614
Mg_m	$\mu g/g$	212.445	238.8689	221.4392

3. Results and Discussions

The development of ANFIS model was realized by using the Neuro-Fuzzy Designer interactive application, integrated in the Fuzzy Logic toolbox. The procedure for ANFIS model development is represented in Figure 2.

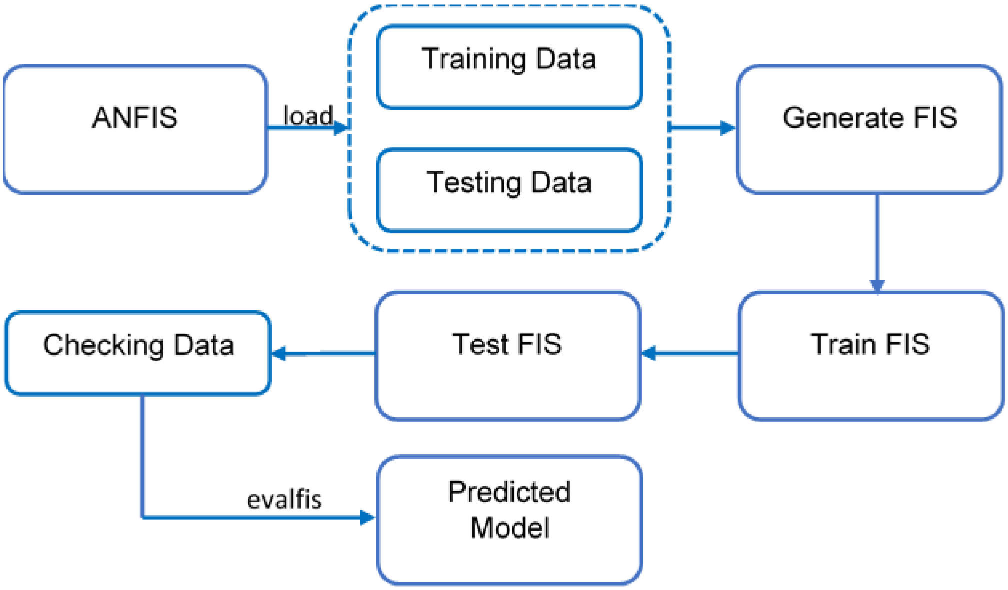

Figure 2. Diagram of the ANFIS Model

In the present paper two ANFIS models were developed: the first model predicted Ca concentration in the muscle and the second predicted Mg concentration in the muscle.

Therefore, for the prediction of Ca in the muscle the data input for Ca concentration in the liver, Mg concentration in the liver and Mg concentration in the muscle was used. Also, for the training process the method of hybrid optimization was used. The use of the hybrid method has the advantage of backpropagation for the parameters associated with the input membership functions, and least squares estimation for the parameters associated with the output membership functions (Meier *et al.*, 2017).

The structure of Ca_m model is represented in Figure 3.

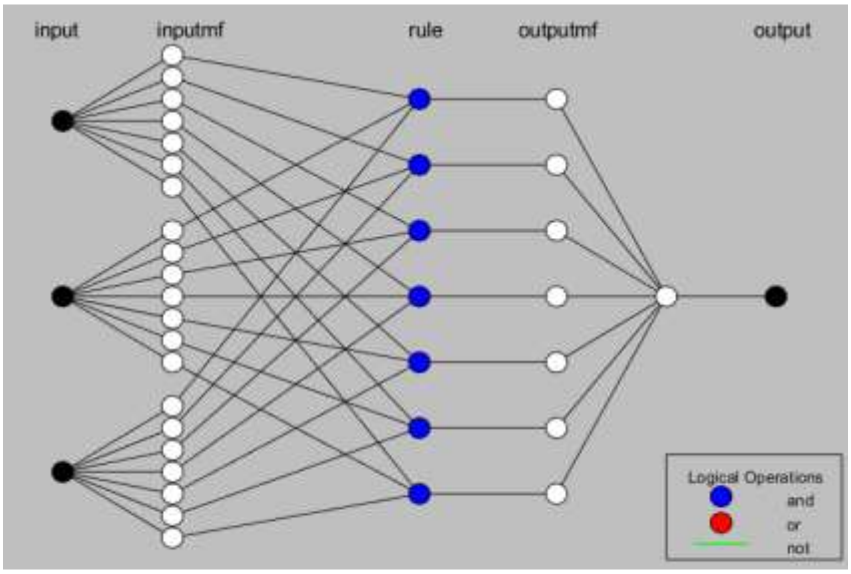

Figure 3. The Structure of the ANFIS Model

As it can be observed, for FIS (Fuzzy Inference System) generation, the Subtractive Clustering method was chosen. Thus, a structure with 7 membership functions, type gbellmf, for each input and a linear member function for output was obtained. The generated FIS contains 7 rules with 70 parameters (42 nonlinear parameters and 28 linear parameters). The fuzzy rules "if-then" were evaluated based on the logic operator "and". The training process for the prediction of Ca concentration in the muscle of the prussian carp was carried out during 330 epochs. The criteria for ending the training process were the error tolerance, due to the lack of knowledge on error behavior. As it can be observed in Figure 4, the simulated data recovers the data periodicity tendency measured with an accurate fitting. The model performance was evaluated based on statistics indicators such as Mean Squared Error (MSE=0.777) and Root Mean Squared Error (RMSE=0.8819).

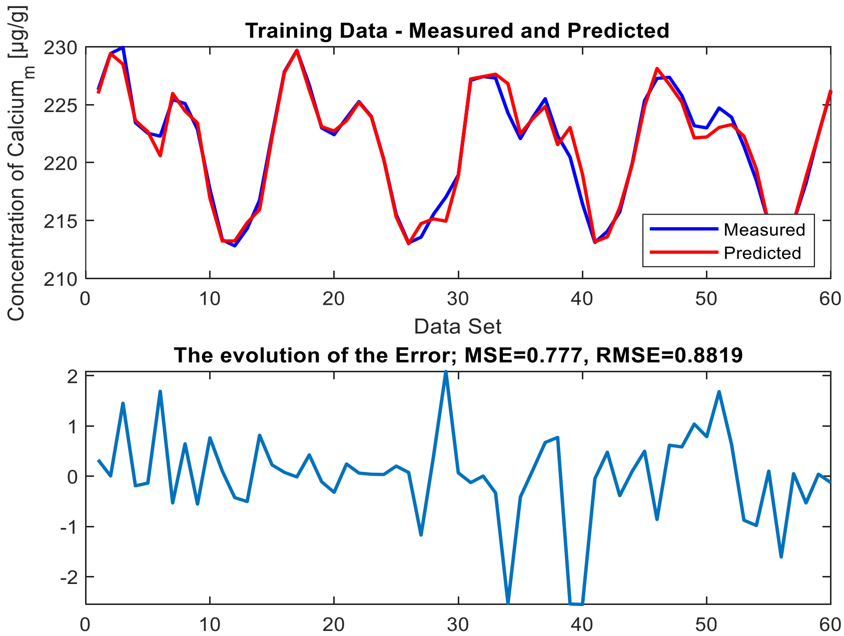

Figure 4. Training Data - Measured and Predicted for Ca; the Evolution of the Error

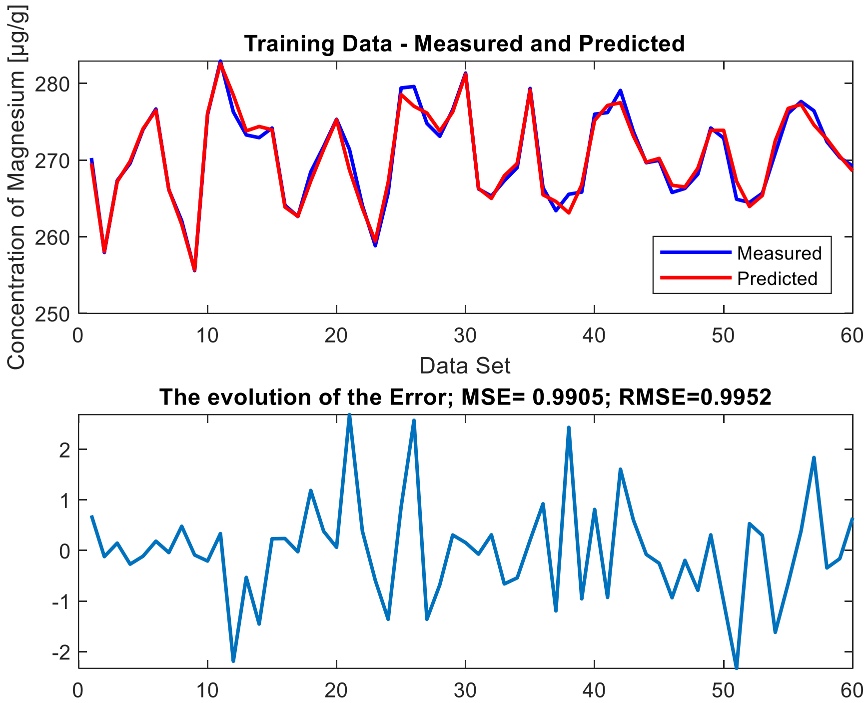

Figure 5. Training Data -Measured and Predicted for Mg; the Evolution of the Error

In case of the prediction of Mg concentration in the muscle of the Prussian carp, the same structure as for the prediction of Ca was used. However, the training process was longer, 786 epochs respectively, due to the criteria of process training ending (error tolerance). As it can be observed in Figure 5, in case of the prediction of Mg concentration in the muscle in the prussian carp, the simulated data manifests the same tendency as the testing data, registering a MSE value of 0.9905 and a RMSE value of 0.9952.

4. Conclusions

The present paper developed two intelligent models based on fuzzy logic which can be used for the estimation of Ca and Mg in the muscle of the prussian carp based on the concentrations of the same elements in the liver.

The obtained results prove that the development of a model based on neuro-fuzzy techniques is a good choice for modelling macro-elements concentrations in *Carassius gibelio*. The use of ANFIS model is a reliable method for a system that lacks experience with data behaviour.

The present models can be expanded and trained using new input data, and therefore, optimizing the prediction accuracy. Also, the developed models can be used to predict other elements with high toxicity potential such as cadmium and lead.

The present study can help improve the economic sustainability of environmental monitoring and the food safety sectors, by implementing a fast and easy to use tool, capable of generating valuable information.

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