Research Article *http://dx.doi.org/10.4314/mejs.v17i1.6* ***Open Access***

Developing an Artificial Neural Network (ANN) to Estimate Growth Model of Narrow-Clawed Crayfish (*Pontastacus leptodactylus)* in Yenice Reservoir (Çanakkale, Türkiye)

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ABSTRACT

This study aims to develop an artificial neural network (ANN) to estimate the growth model of the narrow-clawed crayfish (*Pontastacus leptodactylus*). A total of 546 (255 males and 291 females) narrow-clawed crayfish individuals were collected monthly between July 2007 and June 2008 by using fyke nets (34 mm mesh size) from Yenice Reservoir, Çanakkale, Türkiye. Total length (TL) and total weight (TW) were measured, and the relationship between TL and TW was modeled using both the traditional length-weight relationship (LWR) and ANN approaches. The performance of both models was evaluated, and the ANN developed in this study yielded superior results when compared to the traditional LWR method. The R-value was found 0.95077. This value indicates that the model developed using ANN provides better results than traditional growth forecasting models. The present study demonstrates that ANNs can be used as a novel and effective approach to estimating the growth of narrow-clawed crayfish. The ANN approach can provide useful information for sustainable and successful fisheries management.

Keywords: Artificial neural networks, Crayfish, Length-weight relationship, Growth models.

1. INTRODUCTION

Narrow-clawed crayfish (*Pontastacus leptodactylus*) holds significant economic importance in Türkiye due to its widespread distribution (Berber et al., 2011). Consequently, extensive research efforts have focused on various aspects of this species, particularly its reproductive and biological aspects (Balık et al., 2005; 2006; Berber and Balık, 2006; Berber et al., 2010, 2024; Harlıoğlu et al., 2012; Deniz Bök et al., 2013; Bolat and Kaya, 2016; Harlıoğlu et al., 2018; Kale et al., 2020, 2021; Acarlı et al., 2023; Boyalık et al., 2023), fisheries technology (Balık et al., 2002, 2003; Bolat et al., 2010), population dynamics (Bolat, 2001; Berber et al., 2012; Yüksel et al., 2013), and genetics (Akhan et al., 2014).

Submitted: 27th April 2024 Accepted: 29th October 2024 Published: 6th February 2025

Globally, the production of freshwater crayfish involves both aquaculture and fisheries methods with techniques varying depending on the species. These techniques include monoculture, alternating cultivation, extensive practices, and intensive approaches (Kale and Berber, 2020).

Diler (2013) emphasized the use of rotation strategies in freshwater crayfish production to bolster natural or individual stocks in reservoirs. In Türkiye, the predominant production method exclusively relies on harvesting crayfish from natural aquatic habitats. However, continuous exploitation of these natural stocks poses a risk of overfishing, exerting pressure on the available populations. Recognizing this concern, Kale and Berber (2020) conducted an assessment of production trends related to narrow-clawed crayfish in Türkiye. They also developed forecasting models using various trend analysis methods. The authors observed a declining production trend, predicting its continuation in the future. Consequently, there is a pressing need to enhance narrow-clawed crayfish stocks and explore alternative production methods. The paddy crayfish alternating breeding system is a new and promising method for the production of narrow-clawed crayfish. However, there is little research on crayfish-rice polyculture in Türkiye (Berber and Kale, 2018; Berber et al., 2019).

Accurately determining and estimating growth models for narrow-clawed crayfish is critical for crayfish culture methods. The traditional length-weight relationship (LWR) equation serves as a widely employed method for growth estimation, with several authors relying on it (Harlioğlu, 1999; Berber et al., 2012, 2020; Klassen et al., 2014). The LWR is commonly used to assess the condition of freshwater species and to determine whether somatic growth is allometric or isometric, as described by Ricker (1975). Additionally, LWR proves useful for converting length equations into weight equations, facilitating their application in stock assessment models (Lindqvist and Lathi 1983). Similarly, Verdiell-Cubedo et al. (2006) have emphasized the utility of LWR in estimating stock biomass from limited samples.

In fisheries research, artificial neural networks (ANNs) have consistently delivered superior results and higher accuracy compared to traditional methods (Suryanarayana et al., 2008). Various artificial intelligence approaches, including ANNs, adaptive neuro fuzzy inference systems (ANFIS), fuzzy logic, and other machine learning techniques have been applied in different investigations within fisheries and aquatic sciences (Benzer and Benzer, 2016; Sonmez et al., 2018; Arslan et al., 2020; Kale, 2020, 2024a, 2024b, 2024c; Gültepe et al., 2024). Several studies have employed ANNs to determine the growth characteristics of various freshwater species (Benzer and Benzer, 2015, 2016, 2018a, 2018b, 2019, 2020, 2022; Benzer et al., 2017a, 2017b; Ozcan, 2019; Ozcan and Serdar, 2018, 2019). However, there has been no study investigating the length-weight relationship and the development of a growth estimation model for crayfish in Yenice Reservoir, Çanakkale, Türkiye. Therefore, this study is aimed to develop an artificial neural network to estimate the growth model of the narrow-clawed crayfish in Yenice Reservoir, Çanakkale, Türkiye.

2. MATERIALS AND METHODS

2.1. Study Area

Yenice Reservoir (Fig 1) was constructed along the Kurudere Creek with the primary purpose of providing accessible water for agricultural and animal husbandry needs. It encompasses a substantial 1330-hectare irrigation area, a total surface area of 0.328 km^2, and a water volume of 3,730,000 m^3 (Berber et al., 2011). Selvi et al. (2017a, 2017b) conducted an evaluation of metal contamination risk in the reservoir and reported that there was no significant concern in this regard. Furthermore, Berber et al. (2011) observed that the reservoir's water level fluctuations are primarily driven by irrigation activities. Yenice Reservoir supports a diverse fish fauna, comprising species such as *P. leptodactylus, Tinca tinca, Squalius cephalus, Cyprinus carpio,* and *Gobio gobio*.

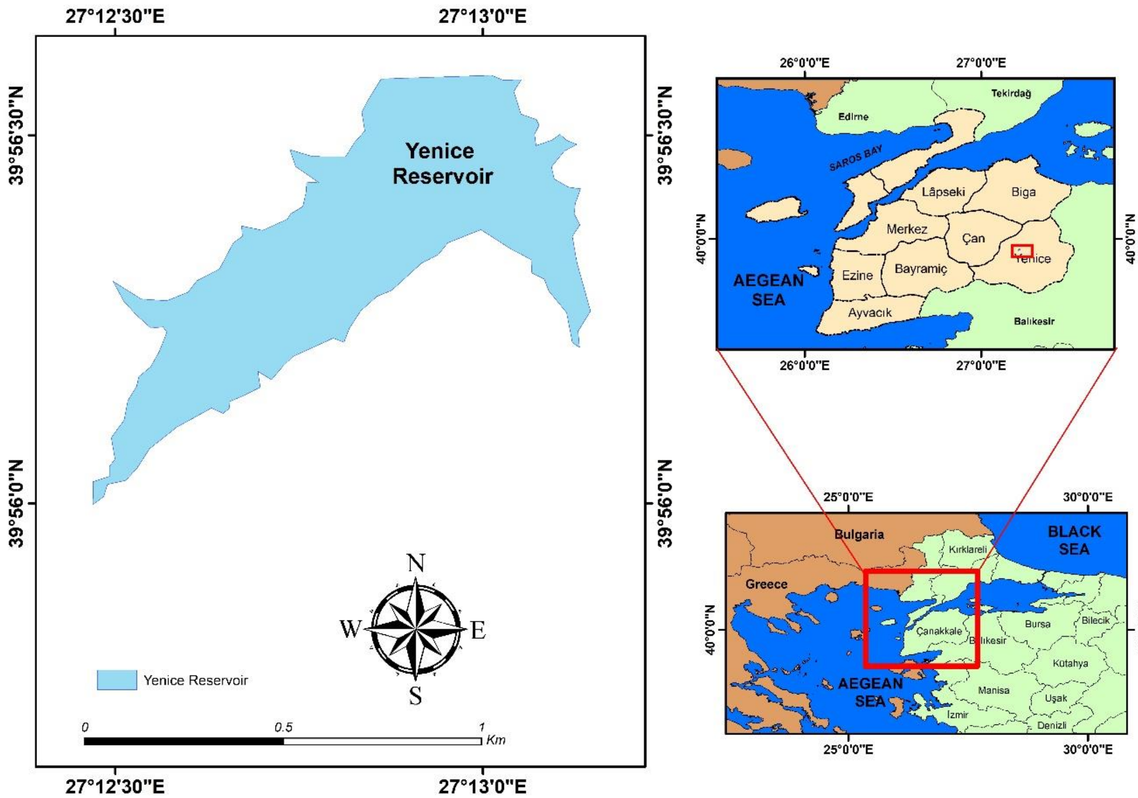

Figure 1. Map of Yenice Reservoir in Çanakkale, Türkiye.

2.2. Sampling

Specimens were collected monthly from Yenice Reservoir in Çanakkale, Türkiye, between July 2007 and June 2008 using fyke nets with a 34 mm mesh size. The fyke nets were placed at a depth of 2-3 meters on the reservoir bottom in the late afternoon and retrieved the following morning. This timing was chosen because narrow-clawed crayfish generally seek shelter during the daytime and are more active at night. A total of 546 individuals (255 males and 291 females) were captured during the sampling.

2.3. Data Analysis

2.3.1. Traditional Length-Weight Relationship (LWR)

All specimens were weighed to the nearest 0.1 g and total lengths of individuals were measured to the nearest 0.1 cm with a digital caliper. In order to determine the relationship between the length and weight of crayfish individuals, the formula given in equation (1), suggested by Le Cren (1951) and developed by Ricker (1973), was used.

$$W = aL^b \qquad (1)$$

In this equation, *W* is the total weight (g), *L* is the total length (cm), *a* is the cut-off point and *b* is the slope. The exponential distribution regression equation was used to determine the relationship between length and weight. The degree of relationship between the variables is determined by the coefficient of determination (R^2).

The parameter "b" indicates whether the growth is isometric or allometric. If b=3, growth is isometric, b<3 indicates negative allometric growth and b>3 indicates positive allometric growth. The growth status was checked using Pauly's t-test (Pauly 1984). For this, the equation (2) was used:

$$t = \frac{SD_{\log L}}{SD_{\log W}} \frac{|b-3|}{\sqrt{(1-r^2)}} \sqrt{n-2} \qquad (2)$$

In this equation, SD_{logL} is the standard deviation of the logarithm of length values, SD_{logW} is the standard deviation of the logarithm of weight values, *n* is the number of individuals used in the calculation. The value of *b* is different from 3 if the *t* value is greater than the *t* values listed in a table for n-2 degrees of freedom (Pauly 1984).

2.3.2. Artificial Neural Networks (ANNs)

The development of the artificial neural network model for this study was carried out using the MATLAB 2020a software package. Specifically, the model was created utilizing the 'nntool' tool within the Deep Learning Toolbox of MATLAB. The learning algorithm employed in the artificial neural network model was 'Levenberg-Marquardt,' with the performance evaluated based on the mean squared error (MSE).

It is important to note that there are no fixed rules for determining the optimal number of hidden layers or neurons within artificial neural network models. These parameters are typically identified through a process of trial and error, configurations that give the lowest mean square error and the highest performance are selected. In this study, the number of hidden layers and the quantity of neurons in each hidden layer were determined through this trial-and-error approach, ultimately resulting in the selection of the network structure that exhibited the best performance. The artificial neural network models were developed using a linear activation function and the differential descent algorithm. Following the approach proposed by Sonmez et al. (2018), 70% of the dataset was allocated for training purposes in machine learning. Additionally, 15% of the available data was designated for testing, while the remaining 15% was reserved for validation. The learning rate was set to 0.01, and the training process was iterated for a total of 1000 cycles.

2.3.3. Performance Evaluation Criteria

To assess the accuracy of predictions generated by the artificial neural network model developed in this study, five distinct accuracy measures were employed. These measures include mean absolute deviation (MAD), mean squared error (MSE), root mean square error (RMSE), mean absolute percentage error (MAPE), and mean absolute error (MAE). These are all metrics that gauge the degree of deviation or error between the actual and predicted values. The evaluation of prediction accuracy by the neural network model was performed separately for the training data, validation data, and the complete dataset.

2.3.4. Mean Absolute Deviation (MAD)

Mean absolute deviation is a measure that quantifies accuracy in the same units as the data and helps evaluate the amount of error. Equation (3) is used to compute the mean absolute deviation:

$$MAD = \frac{\sum_{t=1}^{n} |y_t - \hat{y}_t|}{n} \tag{3}$$

In this equation, y_t represents the current value, $\hat{y}_t$ represents the forecasted value, and n is the total number of observations.

2.3.5. Mean Squared Error (MSE)

Mean squared error is one of the most commonly employed error measurements. It penalizes larger errors more severely, as squaring larger values increases their impact compared to smaller values. MSE is calculated as the sum of squared errors divided by the total number of observations, as shown in equation (4):

$$MSE = \frac{\sum_{t=1}^{n} (A_t - F_t)^2}{n} \tag{4}$$

In this equation, n represents the total number of observations, A_t denotes the true value, and F_t represents the predicted value at observation t.

2.3.6. Root Mean Square Error (RMSE)

The root mean square error is a measure of how closely a model's predictions align with the actual values, taking into consideration the magnitude of errors. RMSE is calculated by taking the square root of the mean squared error, as expressed in equation (5):

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(A_t - F_t)^2}{n}} \quad (5)$$

In this equation, n represents the total number of observations, A_t stands for the true value, and F_t represents the predicted value at observation t.

2.3.7. Mean Absolute Percentage Error (MAPE)

In the calculation of the mean absolute percentage error, accuracy is expressed in terms of percentages, making it easier to comprehend compared to other statistics. This measurement evaluates the percentage of error. MAPE is determined using equation 6.

$$MAPE = \sum_{t=1}^{n} \frac{\left|\frac{y_t - \widehat{y_t}}{y_t}\right|}{n} \times 100 \quad (6)$$

In this equation, y_t represents the current value, $\hat{y}_t$ is the forecasted value, and n is the number of observations.

2.3.8. Mean Absolute Error (MAE)

The mean absolute error calculates the absolute deviations from the original data, regardless of the sign. Equation (7) is used to compute MAE:

$$MAE = \frac{1}{n}\left(\sum_{t=1}^{n}|A_t - F_t|\right) \quad (7)$$

In this equation, A_t represents the true value, F_t stands for the predicted value, and 'n' denotes the number of observations.

3. RESULTS AND DISCUSSION

The results of the traditional LWR are presented in figure 2. Figure 3 displays the regression coefficients of the artificial neural network model employed in this study. The R-values in the figure illustrate the relationship between the input and output data. The R-value was calculated as 0.94828 during the training of the neural network model. For testing, the R-value was determined as 0.96254, while for validation, it reached 0.95365. The R-value for all input and output data was computed as 0.95077. This value indicates that the model developed using artificial neural networks provides better results than traditional growth forecasting models.

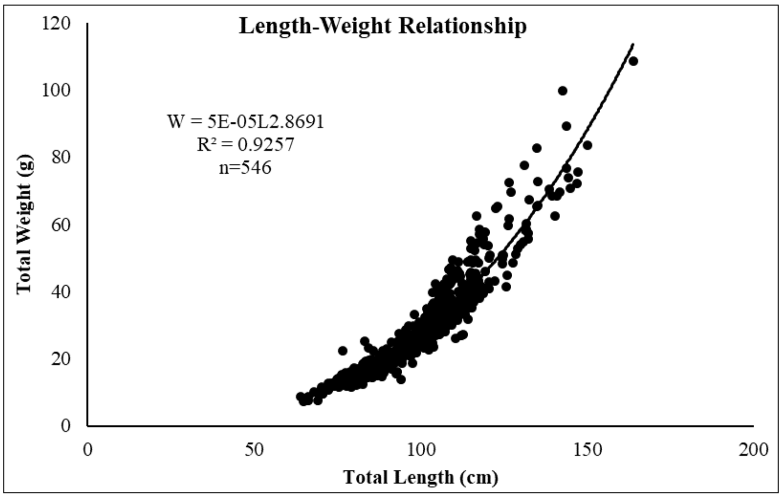

Figure 2. Traditional length-weight relationship.

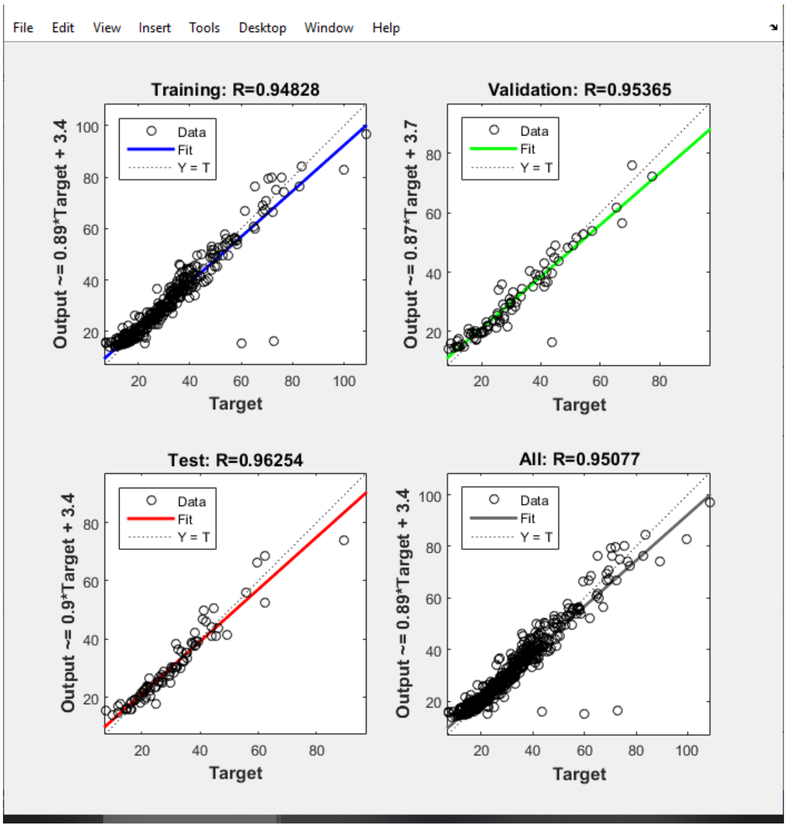

Figure 3. Regression coefficients of the artificial neural network model used in the study.

Figure 4 illustrates the comparison between the predicted weight values from the neural network model and the actual calculated weight values.

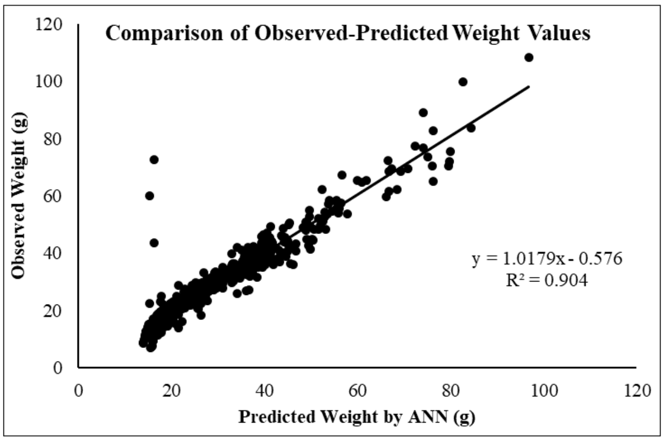

Figure 4. Comparison of the weight values predicted using the artificial neural network model used in the study and the weight values actually calculated.

Additionally, figure 5 presents a comparison between the weight data predicted by artificial neural networks and the weight data measured in the laboratory.

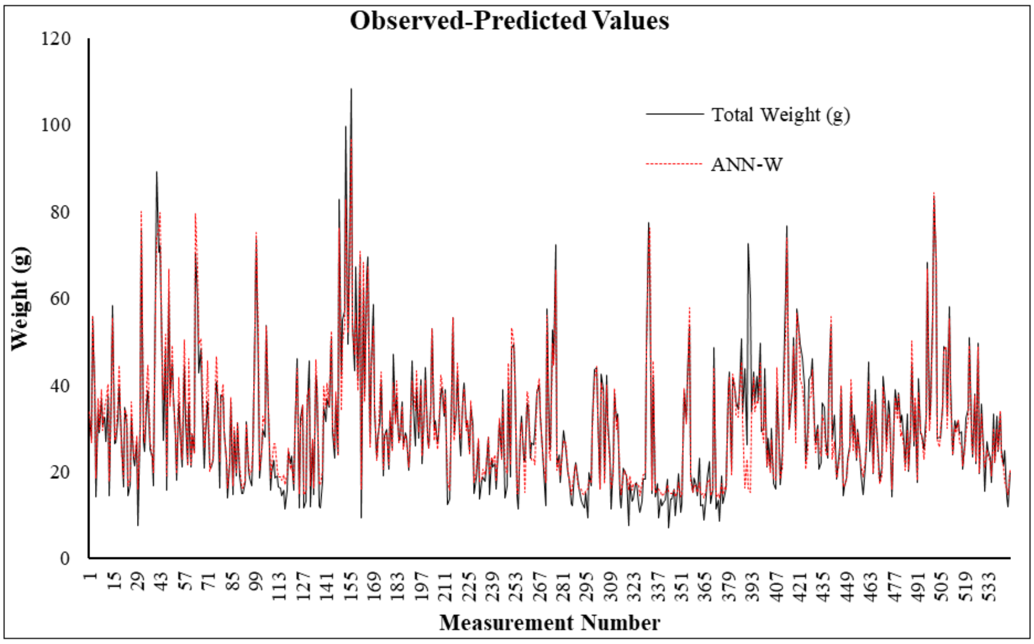

Figure 5. Comparison of measured weight data and weight data predicted using artificial neural networks.

MAE performance values were considered to compare the models. The performance results calculated for all individuals are given in table 1.

Table 1. Performance results of predictions for all individuals.

Dataset	***MAD***	***MSE***	***RMSE***	***MAPE***	***MAE***
Training	1.75952891	8.50097683	2.91564347	7.77313765	0.07773138
Validation	0.86311607	13.14229872	3.62523085	2.42077269	0.02420773
Total	2.62264499	21.64327555	4.65223339	10.19391033	0.10193910

The artificial neural networks developed in this study yielded superior results when compared to the traditional length-weight relationship method. Consequently, our research underscores the potential of artificial neural networks in predicting the length-weight relationship and growth patterns of crayfish (*P. leptodactylus*) species in Yenice Reservoir with greater precision than conventional methods.

Traditional methodologies often assume data normality (Sarı 2016) and rely on the linearity of relationships in regression analysis (Bahçecitapar and Aktaş, 2017). However, as frequently observed in forecasting studies, artificial neural network analysis tends to provide more accurate results when these assumptions are not met (Benzer, 2014; Benzer et al., 2015, 2017; Benzer and Benzer, 2015, 2016, 2017, 2020). Additionally, ANN models have proven effective in addressing problems involving non-linear relationships among multiple variables (Tureli Bilen et al., 2011).

In the literature, several studies have employed artificial neural networks to estimate length-weight relationships and growth patterns in various species. Benzer and Benzer (2018a, 2019) used ANNs to forecast the growth features and length-weight relationships of *Atherina boyeri*, while Benzer and Benzer (2016) did the same for *Esox lucius*. Ozcan and Serdar (2018) applied this approach to *Oxynoemacheilus tigris*, Ozcan (2019) for *Alburnus mossulensis*, and Ozcan and Serdar (2019) for *Capoeta umbla* and *Barbus lacerta*. These studies consistently demonstrated that ANNs are a valuable and successful alternative for assessing the growth characteristics of these species.

The application of artificial neural networks (ANNs) to estimate the length-weight relationship and growth patterns of *P. leptodactylus* species has shown promising results. In a study by Benzer et al. (2015), the growth of crayfish inhabiting Lake Mogan was compared using both the traditional length-weight relationship method and artificial neural networks. The findings indicated that artificial neural networks outperformed the traditional method. Notably, when assessing the accuracy of predictions with MAPE values, the ANN model demonstrated superior accuracy. This observation led to the proposal of artificial neural networks as an alternative method for forecasting crayfish growth.

Benzer et al. (2017a) utilized an artificial neural network (ANN) approach to conduct morphometric analysis on crayfish species in Hirfanlı Dam Lake, analyzing data from 325 individuals for growth estimation. The authors carried out a comprehensive evaluation involving a comparison of total squared error, MAPE, and correlation coefficient values to assess the accuracy of predictions. The results demonstrated that the application of artificial neural networks consistently yielded significantly higher predictive accuracy. In addition, Benzer et al. (2017b) employed the artificial neural network approach to predict the growth patterns of crayfish populations in Lake Eğirdir. Their analysis incorporated data from a total of 222 individuals. Similarly, the assessment considered the MAPE values to gauge the precision of predictions, with the findings underscoring the superior predictive capability of artificial neural networks for crayfish growth in the lake.

Benzer and Benzer (2018a) conducted a comparative analysis between the ANN and the conventional LWR model for forecasting the growth attributes of crayfish in Uluabat Lake. The investigation unveiled that the artificial neural network model, developed based on morphometric measurements collected from a total of 540 individuals, consistently yielded more accurate results in predicting the growth characteristics of crayfish within the lake.

The existing body of literature includes multiple reports from various researchers highlighting the heightened accuracy of artificial neural networks in predicting growth patterns, both in the context of crayfish species and other organisms (Benzer and Benzer, 2015, 2016, 2018b, 2019, 2020; Ozcan, 2019; Ozcan and Serdar, 2018, 2019). The present study also demonstrated that artificial neural networks outperformed traditional growth models, underscoring their efficacy. The utilization of a larger dataset played a pivotal role in achieving these notable results. Artificial neural networks operate by constructing growth models through the application of deep learning algorithms and machine learning techniques, leveraging the information contained within the available data. Consequently, the quantity of data harnessed for machine learning purposes significantly contributes to the overall accuracy of the results obtained.

Future investigations may explore the development of new prediction models using ANNs with different architectures. Additionally, alternative approaches such as fuzzy logic and artificial intelligence techniques trained with deep learning algorithms can be considered. Moreover, the utilization of carapace length, rather than total length, in studies predicting crayfish growth patterns may offer more accurate results, aligning with the biological characteristics of the species. The artificial neural network models developed in this study hold promise for applications in determining length-weight relationships and estimating growth patterns in crayfish populations across diverse water resources.

4. CONCLUSION

The development of an artificial neural network (ANN) model proved instrumental in assessing the growth characteristics of 546 crayfish individuals (*P. leptodactylus*) from Yenice Reservoir in Çanakkale, Türkiye. This model incorporated crucial data including sex, total length, and total weight. Through a rigorous comparison with the traditional length-weight relationship method, the study employed five distinct performance criteria (MAD, MSE, RMSE, MAPE, MAE) to gauge predictive accuracy. The findings unequivocally demonstrated that the ANN model consistently outperformed the traditional LWR method in terms of accuracy. These results have significant implications for sustainable fisheries management, providing valuable insights for monitoring crayfish populations to ensure long-term economic efficiency and periodic enhancement of growth models through comparison and validation processes. This study contributes to advancing responsible fisheries management practices, promoting a more sustainable and efficient approach to resource utilization.

5. ACKNOWLEDGEMENTS

This study was financially supported by Çanakkale Onsekiz Mart University the Scientific Research Coordination Unit (Project number: FHD-2020-3273). An earlier version of this paper was presented at the 6th International Eurasian Conference on Biological and Chemical Sciences in Ankara, Türkiye, October 2023. The authors would like to thank their colleagues for their support during the fieldwork.

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