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# Performance of artificial neural networks and traditional methods in determining selected growth parameters of *Alburnus sellal* Heckel, 1843

by

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**Abstract**

In this study, predictions were made on the growth performance of *Alburnus sellal* Heckel, 1843 from the Munzur River using back propagation artificial neural networks and ANN algorithms. Statistical growth models used in fish biology and results obtained from artificial neural networks were compared. A total of 239 samples were used in this comparison. It was determined that the population is distributed across age groups 0–VII. The relationship between length and weight was calculated as $W = 0.0046L^{3.198}$ for all individuals. The von Bertalanffy growth parameters were calculated for all individuals: $L_t = 21.93\ [1 - e^{-0.158\ (t\ +\ 2.11)}]$; $W_t = 102.29\ [1 - e^{-0.158\ (t\ +\ 2.11)}]^{3.198}$. The growth performance index (Φ′) value was 1.880 for all individuals. The condition factor varied between 0.479 and 1.115 for females and between 0.533 and 1.076 for males. The Mean Absolute Percent Error (MAPE) statistic was used, which is a widely used method to measure the accuracy of the predictions made. It was determined that ANNs MAPE (%) values were better than MAPE values calculated for the length–weight relationship and von Bertalanffy growth function models for *A. sellal*. This study shows that ANNs can be used as an alternative useful method for predicting population parameters. ANN models are therefore an effective tool to describe fish growth parameters. They have been found to be a useful predictive tool. The developed models can be used to predict future sustainable fish management.

**Key words:** *Alburnus sellal*, artificial neural networks, growth parameters, MAPE (%), Munzur River

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## 1. Introduction

*Alburnus sellal* Heckel, 1843 from the Cyprinidae family has a wide distribution area in Turkey. According to some molecular systematic and phylogeographic studies conducted in recent years (Mohammadian-Kalat et al. 2017; Bektaş et al. 2020; Çiçek et al. 2020; Jouladeh-Roudbar et al. 2020; Freyhof et al. 2021), *Alburnus mossulensis* Heckel, 1843 described from the Euphrates–Tigris River System was revised and reported as a synonym of *A. sellal* Heckel, 1843 (Düşükcan et al. 2022).

Research on fish biology, age determination and growth, length–weight relationship and condition factor, growth characteristics, systematic and zoogeographic features, population dynamics, bio-ecological features, and nutrition biology is carried out as part of reproductive biology and growth biology. Some studies cover a few features of a species, while others cover all of its species characteristics. Until the species represented in a water source are identified, no significant results can be obtained in this area. The growth rate of each fish species varies within the limits of maximum and minimum growth. Since fish only grow in one direction, not only length growth, but also weight gain is taken into account to calculate the growth rate (Bellido et al. 2000). Most population analyses are related to growth rate (increase in length and weight per unit time), rather than fish size at different ages. According to Nikolsky (1963), growth in fish is a change in mass over time, defined as an increase in length or weight depending on nutrition. Growth in length is high in the first years of a fish's life and then continues at a decreasing rate. Weight growth, on the other hand, does not show a smooth increase over time, as in the case of the length growth curve. However, it still manifests itself as a function of time. The weight growth curve is sigmoidal – the growth is slow in the first years of fish's life, then accelerates and continues at a decreasing rate after a certain period of time (Erkoyuncu 1995).

With the development of computer technologies, human beings base almost all their operations on these innovative technologies and enable them to find new methods. Artificial neural networks, the concept of artificial intelligence, is a subtitle created as part of a project that has become the focus of researchers. Artificial neural networks can learn and generalize by experimenting with data. Therefore, it has a nonlinear structure. Linear networks have also been found to give better results compared to other methods (Türeli Bilen et al. 2011; Benzer et al. 2015; Benzer & Benzer 2016; Benzer et al. 2017; Benzer & Benzer 2018; Ozcan & Serdar 2018; Ozcan & Serdar 2019; Ozcan 2019; Sangün et al. 2020; Bulut 2023). In most of these studies, ANNs performed better than classical linear and nonlinear modeling methods (Brosse et al. 1999). LWRs and VBGF statistical methods used in many studies may be insufficient for scientific work (Maravelias et al. 2003). ANNs is an alternative method in nonlinear predictive modeling cases (Joy & Death 2004).

The objective of this study was to compare selected growth characteristics of *A. sellal* living in the Munzur River using traditional growth models and artificial neural networks. Data obtained with the networks were compared.

## 2. Materials and methods

The Munzur River takes its origin in many branches on the southern slopes of the hills in the central part of the Munzur Mountains. These branches join in the Ovacık depression area, which is the largest plain of the province. The Munzur River joins the Pülümür River within the limits of the city center of Tunceli (Saler & Haykır 2011). The Uzunçayır Dam Lake is located there, which was created on the Munzur River to generate energy (Saler et al. 2014; Bulut et al. 2021).

In this study, 239 *A. sellal* specimens were collected from the Munzur River between 2019 and 2021 (Fig. 1). The caught fish were brought to the laboratory immediately and their total length was measured on a measuring board with an accuracy of ± 1 mm. Weight was recorded using an electronic analytical balance with an accuracy of ± 1 g. The sex of the fish was determined by opening their abdomen and examining the gonads. Those with milky-white and smooth surface gonads were determined as males, those with greenish-yellow and granular surface gonads as females (Lagler et al. 1977). In smaller fish, sex was


**Figure 1**
Munzur River (URL-1 2023).

determined using a microscope. To determine age, 10–15 scales were taken from the left side of the fish between the lateral line and between the operculum and the anterior side of the dorsal fin. The scales were usually placed in paper envelopes with non-adhesive seal flaps. Dirty scales were washed in warm water. A few drops of glycerin were placed on the slides with the rough surface upward and the age was determined by reading the scales (Türkmen et al. 2005) under a Nikon ECLIPSE Ci microscope.

Length and weight distribution graphs were prepared using fish length and weight values. Average length and weight values for each age group were calculated. The length–weight relationship was determined using the regression method according to the following formula (Sparre & Venema 1998):

$$W = a \times L^b$$

where *W* – total weight, *L* – total length, *a* and *b* – regression constants.

The Index of Average Percentage Error (IAPE) was used to check whether there was a difference between age readings according to the following formula (Beamish & Fournier 1981):

$$IAPE = \frac{1}{N}\sum\left(\frac{1}{R}\right)\sum\left(\frac{xij - xj}{xj}\right)$$

where *N* is the number of fish for which age was determined, *R* is the number of readings, *xij* is the mean age calculated for the jth fish, *xij* is the ith age determination for the jth fish).

The von Bertalanffy weight and length growth formula were used in the mathematical calculation of length and weight growth (von Bertalanffy 1938):

$$L_t = L_\infty\ [1-e^{-k(t-to)}]; \quad W_t = W_\infty\ [1-e^{-k(t-to)}]^b$$

where $L_\infty$ is the infinity length (cm), $W_\infty$ is the infinity weight (g), k is Brody's growth coefficient (year$^{-1}$), $L_t$ is the length of t-year-old fish (cm) and to is the age of fish at hatching (year).

The condition factor, which is an indicator of the nutritive capacity of the environment in which the fish live, was calculated with the following formula:

$$condition\ factor = \frac{body\ weight}{fish\ size} \times 100 \quad \text{(Le Cren 1951).}$$

The von Bertalanffy growth performance was used to compare the growth rate in different environments. The growth performance index (Φ′) was calculated using the following formula:

$$\Phi' = log_{10}(k) + 2log_{10}(L_\infty) \quad \text{(Gayanilo \& Pauly 1997).}$$

### 2.1. Artificial Neural Networks (ANNs)

Artificial neural networks (ANNs) are new features of the human brain through learning capabilities, such as acquiring information, creating and discovering new information, to enable these activities to be performed automatically without any assistance of developed computer systems. In the case of artificial neural networks, inspired by the human brain, the effort resulted in a mathematical process of modeling learning. Biological nerve cells communicate with each other through synapses. Nerve cells send the information they process to other cells via their axons. Similarly, artificial nerve cells collect information from outside via aggregate function and activation. They produce output by passing it through the function and send to other cells through network connections (to process the elements). It has different summation and activation functions. The values of the connections connecting artificial neural networks are called weight values (Öztemel 2012).

ANNs consist of three layers: input, hidden and output layers. In the input layer, data from the set or sensors are transferred to the network. In the hidden layer, information from the input layer is transferred to the output layer by multiplying by weight coefficients and passing through the activation functions. The output layer uses error calculation functions with output values previously given to the ANNs. The error value between the values produced by the ANNs is calculated. If the error value is not at the desired rate, the weight coefficients used in the network are updated again (Emeksiz et al. 2016). The aim of artificial neural networks is to find the weight and bias values that will produce the best result for the established model. Weights and biases are updated at each epoch. The process of calculating these values is called learning.

The structural model of the system is shown in Figure 2. A feed-forward backprop propagation algorithm is used for system training.

Weight and bias values, the mathematical equation of the neuron model (Krenkel et al. 2011) are given in the following equations:

$$w : w - \varepsilon \frac{\partial C}{\partial w}$$

$$b: b - \varepsilon \frac{\partial C}{\partial b}$$

$$y(k) = F(\sum_{i=0}^{m} wi(k).xi(k) + b)$$

where *yi(k)* is the output value in discrete time *k*, *F* is the transfer function, *wi(k)* is the weight value in discrete time *k*, where *i* ranges from 0 to *m*, *xi(k)* is the input value in discrete time *k*, where *i* ranges from 0 to *m*, and *b* is the bias.

The MAPE (%) equation was used to compare ANNs and other methods. The closeness of the estimated values to the actual data is proportional to the smallness of the MAPE value (Benzer et al. 2017).

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{ei}{Yi}\right| \times 100$$

where *Yi* is the actual observation value, *ei* is the difference between the actual data and the estimation data, and *n* is the number of total observations.

The Neural Network Toolbox from MATLAB Ver. R2016a was used for ANNs estimations. The operations in MATLAB consist of three parts: training (70%), testing (15%) and validation (15%) (Benzer & Benzer 2018).

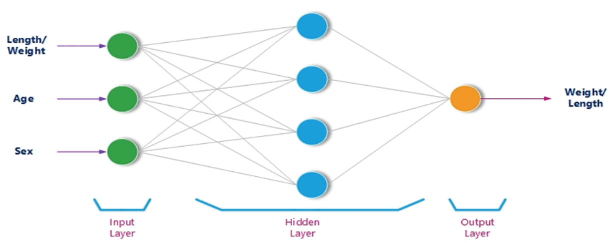


**Figure 2**

Representation of an ANN.

## 3. Results

The total length and weight of the samples were 7.6–17.9 cm and 4.5–47.5 g in females, and 9.0–17.3 cm and 5.0–42.1 g in males, respectively. Of the 239 samples, 116 samples were females and 123 samples were males. The female-to-male ratio was calculated as 1:0.943. Total length frequency distribution and weight frequency distribution of *A. sellal* individuals are shown in Figure 3.

The length–weight relationship of *A. sellal* was calculated as $W = 0.0051L^{3.154}$ for females, $W = 0.0038L^{3.267}$ for males and $W = 0.0046L^{3.198}$ for all individuals from the Munzur River. The growth type is positive allometric for females, males and all individuals of *A. sellal* from the Munzur River ($b > 3$). The $R^2$ value is 0.846 for females, 0.884 for males and 0.863 for all individuals ($P < 0.001$; Table 1; Figure 4). The condition factor for *A. sellal* from the Munzur River varies between 0.479 and 1.115 for females and from 0.533 to 1.076 for males.

The age groups of the examined samples ranged from 0 to VII. While IV years constitute the most dominant age group in the population, 0 years represent the smallest age group (Figure 5). The longest specimen was 17.9 cm and belonged to a VII-year-old female individual.

The Index of Average Percentage Error is a percentage error index determined from age reading by two independent age readers, unaware of each other. If the rate is between 5% and 15%, the reading is considered reliable (Duman & Başusta 2013). In this study, age readings for *A. sellal* from the Munzur River resulted in the IAPE of 8.1%.

The von Bertalanffy growth parameters were as follows: $L_t = 22.67 [1 - e^{-0.143 (t + 1.99)}]$; $W_t = 111.17 [1 - e^{-0.143 (t + 1.99)}]^{3.154}$ for females, $L_t = 20.35 [1 - e^{-0.196 (t + 1.24)}]$; $W_t = 114.80 [1 - e^{-0.196 (t + 1.24)}]^{3.267}$ for males and $L_t = 21.93 [1 - e^{-0.158 (t + 2.11)}]$ (Fig. 6); $W_t = 102.29 [1 - e^{-0.158 (t + 2.11)}]^{3.198}$ for all individuals. The Φ› value was 1.866, 1.909 and 1.880 for females, males and all individuals, respectively.

The graph showing how the error values of the training, validation and test sets changed in each iteration as a result of the ANNs training conducted in MATLAB is provided in Figure 7. As can be seen in the graph, the training of the network reached the optimum result in 10 iterations, and it can be concluded that increasing the number of epochs does not benefit the system. The training was completed when the best validation performance in epoch 4 was 0.00083535 and the validation error reached 10 epochs. If the training mean square error is in a decreasing state, this indicates good training. Validation controls for training neural networks were calculated as 6 in epoch 10 and gradient = 0.00010533 in epoch 10 (Fig. 8).

The regression graph obtained after learning in MATLAB is shown in Figure 9. Regression values are used to validate the network's performance. The regression graphs in Figure 9 show the network outputs. They evaluate the training-validity-test groups separately according to their target values. If the network performance is desired to be increased, the network can be retrained. The linear regression line shows the best fit between the targets and the outputs. ANNs were used randomly as follows: 70% in training (167), 15% in testing (36) and 15% in validation (36) for *A. sellal*. According to Figure 9, the targeted output R value was 0.87275 for training, 0.96297 for validation, 0.94942 for testing and 0.90697 for all. The lowest value belongs to the training set and is 0.87275.

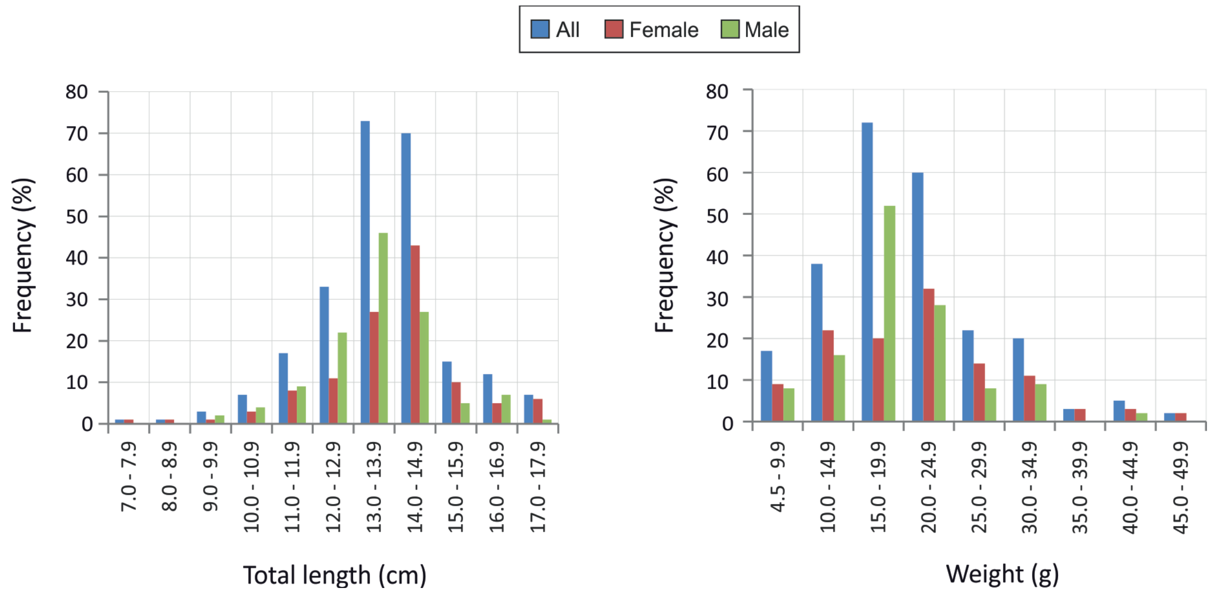


**Figure 3**

Total length–frequency and weight–frequency distribution of individuals of *A. sellal* in the Munzur River.

**Table 1**

Length–weight relationship parameters and condition factor for *A. sellal* in the Munzur River.

| Sex | n | Length-weight relationship parameters | | | | Condition factor |
|---|---|---|---|---|---|---|
| | | *a* | *b* | %95 Confidence interval | $R^2$ | |
| Female | 116 | 0.0051 | 3.154 | 3.016 – 3.395 | 0.846 | 0.479 – 1.115 |
| Male | 123 | 0.0038 | 3.267 | 3.055 – 3.330 | 0.884 | 0.533 – 1.076 |
| All | 239 | 0.0046 | 3.198 | 3.016 – 3.395 | 0.863 | 0.479 – 1.115 |

Thus, the learning process was carried out with great success. Since the R values obtained with ANNs are close to 1, it can be concluded that the training accuracy is highly accepted.

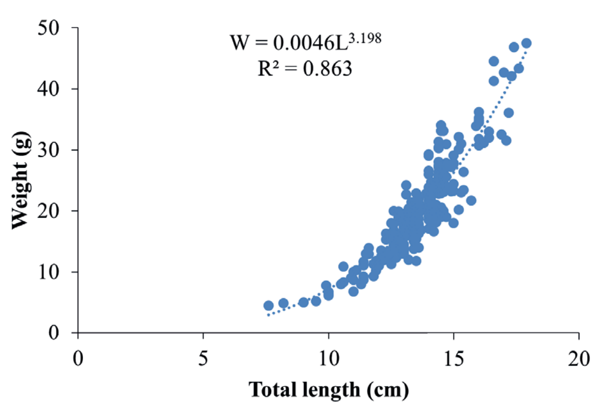


**Figure 4**

Total length–weight relationship for all individuals of *A. sellal* from the Munzur River.

The actual values, ANNs, LWRs and VBGF data of *A. sellal* by sex and age are given in Table 2. The table was obtained by comparison with *A. sellal* ANNs, LWR and VBGF. The mean Absolute Percent Error (MAPE) statistic was used, which is a widely used method to measure the accuracy of the predictions made. ANNs MAPE (%)

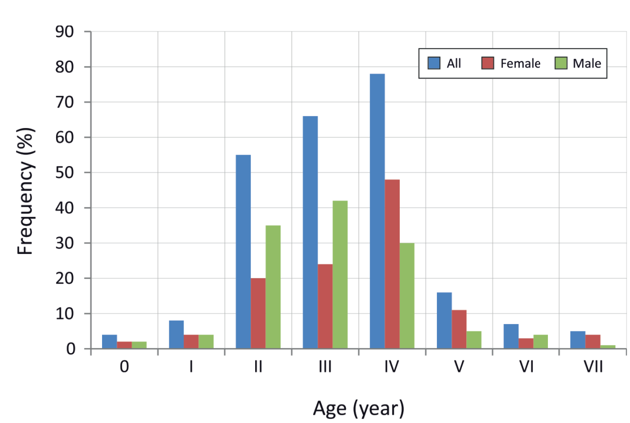


**Figure 5**

Age–frequency of *A. sellal* from the Munzur River.

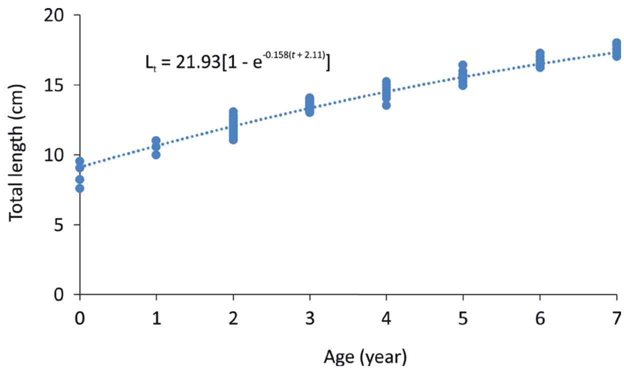


**Figure 6**

Age–total length relationship for all individuals of *A. sellal* from the Munzur River.

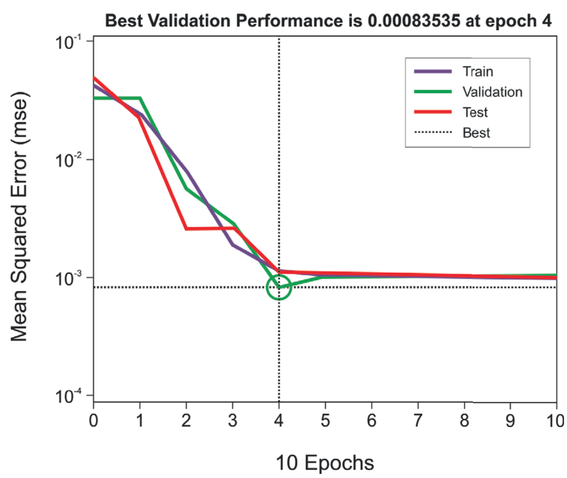


**Figure 7**

Demonstration of the best validation performance in a neural network model.

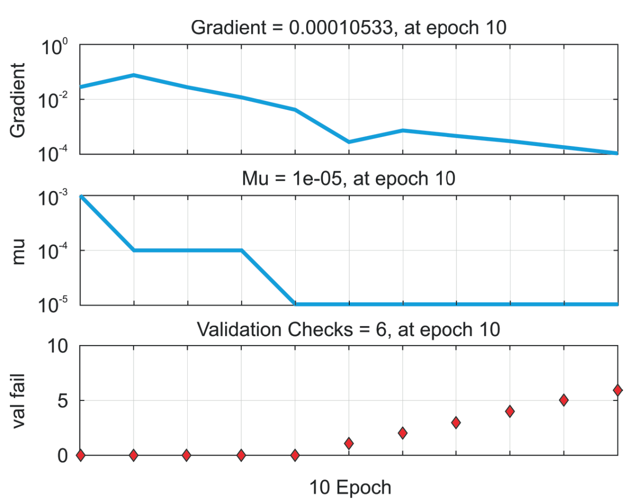


**Figure 8**

Artificial neural networks training state.

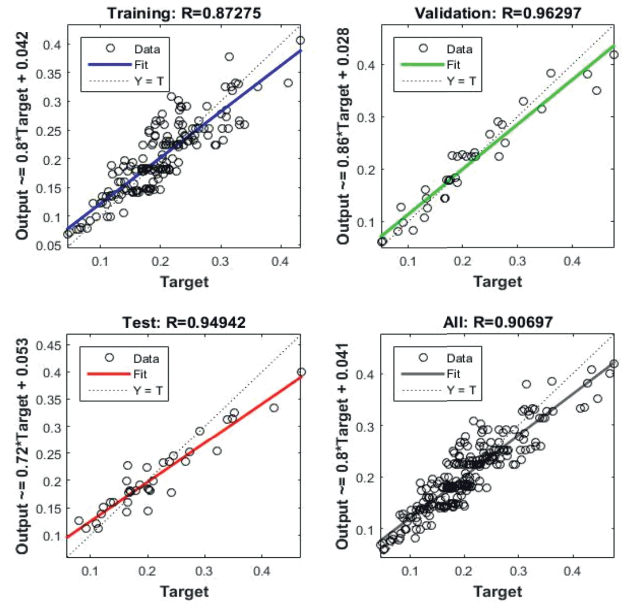


**Figure 9**

Training, validation, testing and all data results of artificial neural networks.

values were calculated better than the MAPE values calculated in *A. sellal* length–weight relationship and von Bertalanffy growth function models.

## 4. Discussion

The total length and weight of the samples were 7.6–17.9 cm and 4.5–47.5 g for females, 9.0–17.3 cm and 5.0–42.1 g for males, respectively. Of the 239 samples, 116 samples were females and 123 samples were males. The length and weight ranges of this species obtained in studies conducted in different regions are given in Table 3. The differences between the length and weight values may be caused by the sampling method and time of sampling, the region where the samples were collected, the total length or fork length values taken into consideration, and ecological factors (Suiçmez et al. 2011). The female-to-male ratio was calculated as 1:0.943. The female-to-male ratio determined by Türkmen & Akyurt (2000) was 1:0.93, by Yıldırım et al. (2003) 1:1.08, by Çiçek (2013) 1:0.18, and by Yakut (2019) 1:0.82.

The length–weight relationship of *A. sellal* was calculated as $W = 0.0051L^{3.154}$ for females, $W = 0.0038L^{3.267}$ for males and $W = 0.0046L^{3.198}$ for all individuals from the Munzur River. The length–weight relationships of *A. sellal* obtained in studies conducted in different regions are given in Table 3. These growth parameters in fish can vary from species to species,

**Table 2**

Actual and calculated values by age and sex for *A. sellal* ANNs, LWRs and VBGF.

| Sex | Age | Actual Data | | ANN modeling (MATLAB) | | ANN MAPE (%) | | LWRs Relationships | | LWRs MAPE (%) | | von Bertalanffy | | von BertalanffyMAPE (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L | W | L | W | L | W | L | W | L | W | L | W | L | W |
| ♀ | 0 | 7.90 | 4.7 | 7.92 | 5.01 | 0.253 | 6.595 | 8.12 | 4.43 | 2.785 | 5.744680851 | 7.61 | 4.40 | 3.670886076 | 6.382978723 |
| ♂ | | 9.25 | 5.1 | 9.32 | 5.18 | 0.756 | 1.568627451 | 8.96 | 5.37 | 3.135135135 | 5.294117647 | 8.99 | 4.85 | 2.810297297 | 4.901960784 |
| ♀ | 1 | 10.35 | 7.95 | 10.30 | 8.03 | 0.483 | 1.006289308 | 10.18 | 8.15 | 1.642512077 | 2.51572327 | 9.88 | 7.86 | 4.541062802 | 1.132075472 |
| ♂ | | 10.28 | 7.85 | 10.22 | 7.48 | 0.584 | 4.713375796 | 10.19 | 7.94 | 0.875 | 1.146496815 | 10.23 | 8.35 | 0.486381323 | 6.369426752 |
| ♀ | 2 | 12.16 | 12.92 | 12.06 | 12.74 | 0.822 | 1.393188854 | 12.01 | 13.51 | 1.233552632 | 4.566563467 | 11.85 | 12.94 | 2.549342105 | 0.154798762 |
| ♂ | | 12.30 | 14.52 | 12.25 | 14.76 | 0.406 | 1.652892562 | 12.34 | 14.19 | 0.325203252 | 2.272727273 | 11.56 | 15.57 | 6.016260163 | 7.231404959 |
| ♀ | 3 | 13.36 | 17.52 | 13.36 | 17.67 | 0.000 | 0.856164384 | 13.12 | 18.34 | 1.796407186 | 4.680365297 | 12.56 | 17.65 | 5.988023952 | 0.742009132 |
| ♂ | | 13.36 | 18.44 | 13.37 | 18.36 | 0.075 | 0.433839479 | 13.36 | 18.34 | 0.000 | 0.542299349 | 12.48 | 19.53 | 6.586826347 | 5.911062907 |
| ♀ | 4 | 14.40 | 24.1 | 14.36 | 23.84 | 0.278 | 1.078838174 | 14.49 | 23.08 | 0.625 | 4.232365145 | 14.04 | 25.02 | 2.500444444 | 3.817427386 |
| ♂ | | 14.36 | 23.13 | 14.37 | 23.05 | 0.070 | 0.345871163 | 14.33 | 23.15 | 0.208913649 | 0.086467791 | 14.06 | 24.24 | 2.089 | 4.798962387 |
| ♀ | 5 | 15.55 | 28.21 | 15.54 | 28.12 | 0.064 | 0.319035803 | 15.23 | 29.87 | 2.057877814 | 5.884438143 | 15.32 | 30.07 | 1.456 | 6.593406593 |
| ♂ | | 15.92 | 31.64 | 15.95 | 31.81 | 0.188 | 0.537294564 | 15.81 | 32.16 | 0.690954774 | 1.643489254 | 15.36 | 29.72 | 3.518 | 6.068268015 |
| ♀ | 6 | 16.97 | 37.37 | 17.01 | 38.14 | 0.235 | 2.060476318 | 16.66 | 39.39 | 1.826753094 | 5.405405405 | 16.44 | 36.82 | 3.12391043 | 1.471768799 |
| ♂ | | 16.53 | 34.48 | 16.63 | 34.46 | 0.601 | 0.05800464 | 16.26 | 36.20 | 1.633393829 | 4.988399072 | 15.42 | 33.98 | 6.715063521 | 1.450116009 |
| ♀ | 7 | 17.48 | 45.08 | 17.24 | 44.12 | 1.372 | 2.129547471 | 17.701 | 43.30 | 1.2584.3021 | 3.948535936 | 16.4 | 43.28 | 6.178489703 | 3.992901508 |
| ♂ | | 17.30 | 42.1 | 17.37 | 41.37 | 0.402 | 1.733966746 | 17.32 | 41.88 | 0.115606936 | 0.522565321 | 16.3 | 40.02 | 5.780346821 | 4.940617577 |
| Average MAPE (%) | | | | | | 0.349 | 1.655 | | | 1.267 | 3.342 | | | 4.000 | 4.122 |

**Table 3**

Selected growth parameters of *A. sellal* that were previously measured in different regions.

| Habitat | Researcher(s) | Sex | Length distribution (cm) | Weight distribution (g) | Length–weight relationship parameters | | Condition factor |
|---|---|---|---|---|---|---|---|
| | | | | | *a* | *b* | |
| Karasu River | Türkmen & Akyurt 2000 | Female | 8.5 – 18.5* | 5.1 – 79.5 | 0.008 | 3.082 | 0.56 – 1.48 |
| | | Male | 8.9 – 18.1* | 3.6 – 79.5 | 0.01 | 2.828 | 0.58 – 1.55 |
| Atatürk Dam Lake | Başusta & Çiçek 2006 | All | 8.38 – 24.20 | - | 0.00395 | 3.313 | - |
| Karakaya Dam Lake | Alkan Uçkun & Gökçe 2015 | Female | 10.8 – 18.6* | 16.87 – 56.57 | 0.206 | 2.065 | 0.54-1.96 |
| | | Male | 12.5 – 19.0* | 18.32 – 45.90 | 0.119 | 2.138 | 0.51 – 1.31 |
| Gamsiab Dam Lake, İran | Hedayati et al. 2016 | All | 3.1 – 11.59 | 0.224 – 12.55 | 0.007 | 3.135 | - |
| Lower Euphrates | Keskin 2016 | All | 3.3 – 16.5 | 0.22 – 47.96 | 0.0078 | 3.032 | 0.53 – 1.10 |
| Hamzeh-Ali District | Radkhah 2016 | All | 1.92 – 7.41 | 0.05 – 2.93 | 0.00006 | 3.09 | - |
| Bibi-Sayyedan River | Keivany et al. 2017 | Female | 4.5 – 16.80 | 0.72 – 55.67 | 0.0061 | 3.175 | 0.61 – 0.84 |
| | | Male | 4.6 – 14.10 | 0.91 – 30.91 | 0.0084 | 3.036 | 0.49 – 0.98 |
| Karasu River | Serdar et al. 2017 | Female | 7.5 – 19.9 | 5.0 – 62.2 | 0.0131 | 2.80 | - |
| | | Male | 8.0 – 21.4 | 5.3 – 71.2 | 0.0125 | 2.82 | - |
| Azad Dam Lake, İran | Fazlı et al. 2019 | All | 7.5 – 17.5* | 4.3 – 48.1 | 0.00005 | 2.743 | 0.93 – 1.82 |
| Murat River | Ozcan 2019 | Female | 8.7 – 19.9 | 5.0 – 40.60 | 0.0097 | 2.812 | 0.43 – 0.91 |
| | | Male | 7.2 – 19.6 | 3.24 – 38.70 | 0.0168 | 2.599 | 0.46 – 0.98 |
| Keban Dam Lake | Yakut 2019 | Female | 10.4 – 17.8 | 6.5 – 59.5 | 0.0018 | 3.555 | 0.56 – 1.15 |
| | | Male | 9.5 – 18.2 | 5.4 – 56.8 | 0.0042 | 3.213 | 0.41 – 1.05 |
| Pülümür River | Özcan & Serdar 2021 | Female | 6.7 – 22.7 | 3.5 – 74.3 | 0.0105 | 2.86 | 0.456 – 1.237 |
| | | Male | 7.0 – 22.1 | 3.6 – 70.2 | 0.0160 | 2.70 | 0.474 – 1.304 |
| Tigris River | Yüksel et al. 2021 | Female | 13.8 – 19.0 | 27.2 – 71.62 | 0.0129 | 2.925 | 0.707 – 1.259 |
| | | Male | 13.3 – 19.5 | 19.66 – 83.3 | 0.0076 | 3.091 | 0.480 – 1.217 |
| Munzur River | This study | Female | 7.6 – 17.9 | 4.5 – 47.5 | 0.0051 | 3.154 | 0.479 – 1.115 |
| | | Male | 9.0 – 17.3 | 5.0 – 42.1 | 0.0038 | 3.267 | 0.533 – 1.076 |

*Fork length

as well as between individuals of the same species living in different habitats. In addition, it is known that seasonal changes can be observed depending on the amount of food and reproduction in the environment (Yakut 2019). Differences between "b" values can be caused by various factors, such as habitat, season, number of samples, hunger and satiety status, gonad maturity, sex, health status, sampling method and length values used in calculations (Tesch 1968; Wootton 1998; Suiçmez et al. 2011).

The age groups of the examined samples ranged from 0 to VII. In previous studies, the age groups were determined as follows: I–VI by Türkmen & Akyurt (2000) in the Karasu River (Aşkale locality); I–VII by Yıldırım et al. (2003) in the Karasu River; III–IX by Çiçek (2013), in the Tigris River; 0–IV by Keskin (2016) in the Lower Euphrates Basin; I–VII by Yakut (2019) in the Keban Dam Lake; II–VI by Yüksel et al. (2021) in the Tigris River. It can be thought that different physical, chemical and biological structures of the fishing environment, the sampling location, the time and shape of the fishing gear, the population structure, the number of fish used and nets used in fishing are different in age ranges.

The von Bertalanffy growth parameters were as follows: $L_t = 22.67\ [1 - e^{-0.143\ (t + 1.99)}]$; $W_t = 111.17\ [1 - e^{-0.143\ (t + 1.99)}]^{3.154}$ for females, $L_t = 20.35\ [1 - e^{-0.196\ (t + 1.24)}]$; $W_t = 114.80\ [1 - e^{-0.196\ (t + 1.24)}]^{3.267}$ for males and $L_t = 21.93\ [1 - e^{-0.158\ (t + 2.11)}]$; $W_t = 102.29\ [1 - e^{-0.158\ (t + 2.11)}]^{3.198}$ for all individuals. The growth performance index (Φ') value was 1.866, 1.909 and 1.880 for females, males and all individuals, respectively. Türkmen & Akyurt (2000) reported $L_\infty = 21.59$ cm, k = 0.19 for females and $L_\infty = 20.41$ cm, k = 0.24 for males of *A. mossulensis* in the Karasu River (Aşkale locality). Yıldırım et al. (2003) reported $L_\infty = 21.87$ cm, k = 0.16 for females and $L_\infty = 19.58$ cm, k = 0.18 for males of *A. mossulensis* from the Karasu River. Çiçek (2013) calculated $L_\infty = 20.97$ cm, k = 0.16 for females and $L_\infty = 17.55$ cm, k = 0.35 for males of *A. mossulensis* from the Tigris River. Yakut (2019) reported the following von Bertalanffy growth parameters for *A. mossulensis* from the Keban Dam Lake: $L_\infty = 22.97$ cm for females and $L_\infty = 22.05$ for males. Yüksel et al. (2021) found $L_\infty = 29.02$ cm and $W_\infty = 253.83$ g for *A. sellal* from the Tigris River. Mohamed et al. (2015) reported that the growth performance index for *A.mossulensis* from the Euphrates River (Iraq) was 2.16. Keskin (2016) found the growth performance index to be 2.06 for *A.mossulensis* from the Lower Euphrates Basin. Yakut (2019) found the growth performance index to be 4.15 and 4.35 for females and males of *A. mossulensis* from the Keban Dam Lake, respectively.

As can be seen in Figure 7, the training of the network reached the optimum result in 10 iterations, and it can be concluded that increasing the number of epochs does not benefit the system. Ozcan (2019) found that training the network reached the optimum result in 20 iterations for *A. mossulensis* in the Murat River.

According to Figure 9, the targeted output R value was 0.87275 for training, 0.96297 for validation, 0.94942 for testing and 0.90697 for all. When the R value is between 0.95 an 1, further education is more successful (Ekici & Aksoy 2009). Ozcan (2019) found that the targeted output R value was 0.98418 for training, 0.99014 for validation, 0.98131 for testing, 0.98485 for all *A. mossulensis* individuals from the Murat River. The network results are along the 45° line, which indicates that they are close to the targets, and the distribution of the data indicates a very good fit (Saleem et al. 2017). Since the R values obtained with ANNs are close to 1, it can be said that the training accuracy is highly accepted. In the literature, the MAPE statistic expresses estimation errors in percentages, so it has a meaning on its own, more accepted in practice than other methods (Akgül 2003). In the study, the MAPE values for length and weight were calculated as 0.349 and 1.655 for ANNs, 1.267 and 3.342 for LWRs, 4.000 and 4. 122 for the von Bertalanffy growth function, respectively. Based on these results, it can be concluded that the prediction values made by the ANNs model are reliable and consistent in both training and testing phases. Ozcan (2019) found that MAPE values for length and weight of *A. mossulensis* from the Murat River were calculated as 1.118 and 1.866 for ANNs, and 2.001 and 4.949 for LWRs. Forecast models with MAPE values below 10% are defined as "high accuracy" models, models with values between 10% and 20% are defined as "correct" models (Witt & Witt 1992). Similarly, Lewis defines models with a MAPE value of less than 10% as "very good", models with a MAPE between 10% and 20% as "good". Models between 20% and 50% are "acceptable" and models with more than 50% are "wrong and faulty" (Lewis 1982; Çuhadar et al. 2009).

## 5. Conclusion

Especially in recent years, the growing interest in artificial neural networks in the field of fisheries is due to the fact that close estimates are made on artificial neural networks. In this study, the results obtained with artificial neural networks are quite close to actual values compared to other methods. Thus, ANNs have been proved to be a reliable alternative method for evaluating growth characteristics. Artificial neural networks are important in fisheries management in terms of making accurate predictions and evaluating growth characteristics.

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