EVALUATION OF GROWTH IN PIKE (*Esox lucius* L., 1758) USING TRADITIONAL METHODS AND ARTIFICIAL NEURAL NETWORKS

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(Received 22nd Apr 2015; accepted 24th Mar 2016)

Abstract. The present study was performed to assess the population structure and growth of pike in Mogan Lake using length-weight relationships, von Bertalanffy equations and artificial neural networks between February 2013 and March 2014. The age of *Esox lucius* caught in Mogan Lake ranged between I to VII years. The fork length of the fish ranged from 27.5 cm to 70.0 cm, and the body weight of the fish ranged from 200 g to 2820 g. The von Bertalanffy growth lengths were 130.30 for females, 122.70 for males and 126.50 for all individuals. The von Bertalanffy growth weights were 18889 for females, 14881 for males and 16688 for all pike. The results obtained using the artificial neural networks and regression technique were compared to those obtained using the growth rate of the fish caught from the natural environment and von Bertalanffy growth model. Artificial neural networks are an alternative to von Bertalanffy growth models.
Keywords: *growth, artificial neural networks, Esox lucius, von Bertalanffy, Mogan Lake*

Introduction

Pike (*Esox lucius* L., 1758) is a widely distributed species of fish in Turkey and one of the most valuable fish in inland waters (Çubuk et al., 2005). It is an essential element of the ecosystem as a piscivore and can tolerate a wide range of environmental conditions (Casselman and Lewis, 1996). This species is of high economic importance in the fisheries of Mogan Lake. Despite its importance, few studies have been conducted on the pike population in Mogan Lake.

There is a large body of literature regarding the growth properties of pike in various water reservoirs. Tanyolaç and Karabatak (1974) examined its growth properties in Mogan Lake, Aksun (1987) in Karamık Lake, Karabatak (1993) Akşehir in Lake, Treer et al. (1998) in Croatian Reservoir, Altındağ et al. (1999) in Kesikköprü Dam Lake, Lorenzoni et al. (2002) in Trasimeno Lake, Küçük and Güçlü (2004) in Çapalı Lake, Çubuk et al. (2005) in Karamık Lake, Gaygusuz et al. (2006) in Terkos Dam Lake, Erdem et al. (2007) in Uluabat Lake, Uysal et al. (2008) in Işıklı Lake, Yağcı et al. (2009) in Işıklı Dam Lake, Ziliukiene and Ziliukas (2010) in Lake Rubikiai, and Moslemi-Aqdam et al. (2014) in Anzali Wetland.

Much research has been performed regarding the prediction of future data using artificial neural networks (ANNs) because they exhibit better results than traditional methods found in the literature (Hill et al., 1996; Hamzacebi and Kutay, 2004;

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1402_543554

Suryanarayana et al., 2008; Türeli Bilen et al. 2011; Christiansen et al., 2014; Benzer, 2014). These studies showed that neural network models are significantly better than traditional statistical and human judgment methods when forecasting monthly and quarterly data (Desilets et al., 1992).

The present study investigated the growth of *Esox lucius* and provides information regarding the population structure (age, growth and sex ratio) of pike in Mogan Lake between February 2013 and March 2014.

Materials and methods

Study site

Mogan Lake is located approximately 20 km south of Ankara, the capital of Turkey, and lies within the coordinates 39º44'40" N and 39º47'45" N latitudes and 32º46'30" E and 32º49'30" E longitudes (*Figure 1*). It is near Gölbaşı town, which has become economically and socially developed and has had an increasing population and settlement in recent years. A large number of commercial establishments, such as restaurants, social clubs, and tea gardens, as well as summer resorts, have been built around the lake, which has become a popular site for sports, fishing, sailing, and rowing (Anonymous, 1989).

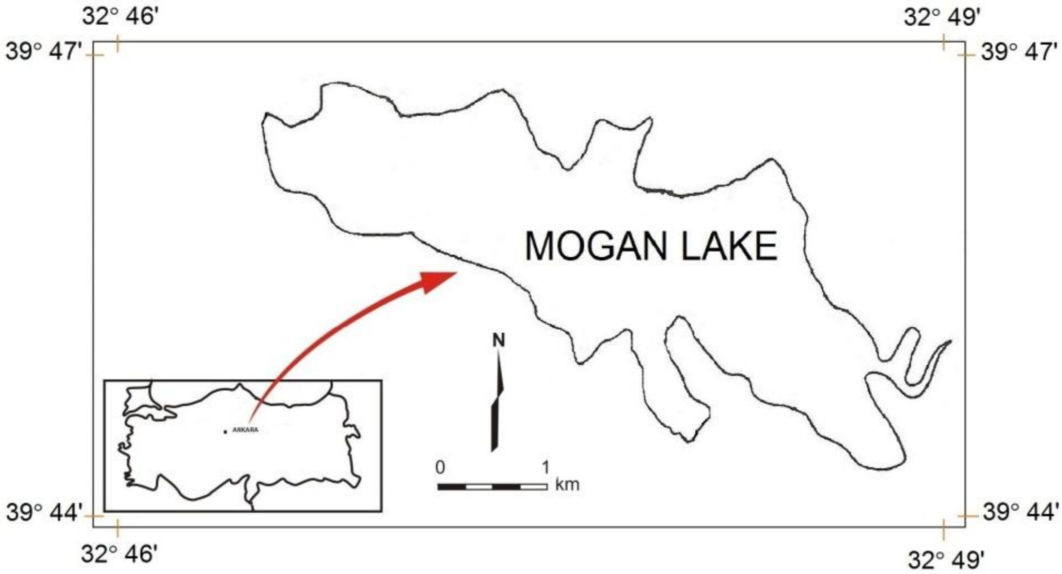

Figure 1. *Map of Mogan Lake*

Sampling / Data Collection

Fish samples (*Esox lucius* L., 1758) were collected from Mogan Lake. During the study, 431 fish specimens were caught between February 2013 and March 2014. The fish obtained from the lake were immediately transported to the laboratory. The length and weight (min-max) of the fish were 275 – 700 mm and 200 – 2820 g, respectively. Scales were sampled from each specimen to identify their age according to the method of Lagler (1966).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1402_543554

Length-weight relations

The length-weight relationships were estimated from the formula W = a L^b, where W is total body weight (g), L is the total length (mm), and a and b are the coefficients of the functional regression between W and L (Ricker, 1973). The equation was log transformed to estimate the parameters 'a' and 'b'. When b is equal to three (3), an isometric growth pattern occurs, but when b is not equal to 3, an allometric growth pattern occurs, which is positive if >3 or negative if <3.

Von Bertalanffy equations

Growth was estimated using the von Bertalanffy growth curve model (Eq.1 and Eq.2) according to Sparre and Venema (1992).

$$L_t = L_\infty[1 - e^{-K(t-t_0)}] \text{ for length} \qquad \text{(Eq.1)}$$

$$W_t = W_\infty[1 - e^{-K(t-t_0)}]^b \text{ for weight} \qquad \text{(Eq.2)}$$

where L_t = the fork length (cm) at age t, L_∞= the asymptotic length (theoretical maximum length), k = the Brody growth coefficient (proportional to the rate at which L_∞ is reached), t = the age (years), t_0 = the age at zero length, e is the base of natural log (2.71828), W_t is the weight of the fish in g at age t, W_∞ is the asymptotic weight of (theoretical maximum weight) the fish in g and b is the constant in the length–weight relationship. The von Bertalanffy growth parameters were estimated for males and females independently, as well as for both sexes combined.

Artificial Neural Networks

The ANN provides a better model because it produces better predictions for lower values, and the normality of the residuals and their independence from the predicted variables are also improved. Several authors reported greater performances of ANNs compared to linear regressions (Sun et al., 2009). ANNs have another advantage in that the ANN modelling approach is fast and flexible (Brosse et al., 1999). In this study, the ANN is a new and alternative approach for predicting the growth and weight of pike compared to traditional methods.

ANNs are computational systems that simulate biological neural networks and can be defined as a specific type of parallel processing system based on distributional or connectionist methods (Hopgood, 2000). They appear to be more functional for predicting the future. ANNs can reveal the power relationships between unknown and unidentified data. By contrast, ANNs are simulations of biological nervous systems using mathematical models. They are networks with simple processor units, interconnections, adaptive weights and scalar measurement functions (e.g. summation and activation functions) (Rumelhart et al., 1986).

During the training of the network, the input data and input-output relationship between the learning of the network is provided. This method, generally called supervised learning, is a preferred method (Haykin, 1999). The supervised learning method trained with the network structure (back-propagation networks) was used to solve problems in this study.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1402_543554

The sum squared error (SSE) and mean absolute percentage error (MAPE) were used in the study as the two performance criteria (Matlab, 2006). SSE was used as a criterion to determine training during the training of the network. In addition, comparisons were made involving more than one method because the MAPE of each provides information about the average relative size of their errors.

SSE and MAPE are described by equations Eq.3 and Eq.4, respectively.

$$SSE = \sum_{i=1}^{n} e_i^2 \tag{Eq.3}$$

$$MAPE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{e_i}{Y_i} \right| * 100 \tag{Eq.4}$$

where Y_i is the actual observation value, e_i is the difference between the actual value and the prediction value, and n is the number of total observations.

Data and identification models

The Neural Network Toolbox of MATLAB was used for the ANN calculations. This study was performed using 431 *Esox lucius* (157 females, 235 males and 39 immature individuals) caught between February 2013 and March 2014 in Mogan Lake. The data were divided into three equal parts, training, validation, and test sets. The MATLAB functions were used for "training", "testing", and "validation". They were used randomly, with 70% for training, 15% for testing, and 15% for the validation of fish.

Results

There were 36.43 % females, 54.52 % males and 9.05 % immature fish. The differences among different age groups were not statistically significant ($p > 0.05$). The age ranged between I to VII years.

The male:female ratio was 1.49:1 for the general population. The prevailing climatic conditions during the study were predicted to affect the sexual maturity, breeding, breeding time, egg development, and egg hatching (Hellawell, 1971).

Most of the samples studied in this study belonged to the III-year age group (*Table 1*). The females were longer and heavier than the males in the III, IV and VI-year age groups.

Table 1. *Age structure, parameters of the length–weight relationship (a and b), growth (L_∞, K, t_0) and CF of Esox lucius.*

Authors			Length Min-max	Age Range	a	b	r^2	L_∞ (cm)	W_∞ (g)	K ($year^{-1}$)	t_0 (year)	CF
Karabatak (1993)	♀	L	33.66-67.10	1-7	2.71	3.38	-	136.46	320.88	0.062	-3.59	0.83
	♂	cm			2.22	3.08		160.46	379.00	0.048	-4.06	0.81
Treer et al. (1998)	♀♂	-	-	-	-	-	-	142.0	-	0.140	0.500	-
Altındağ et al.(1999)	♀	L	25.2-53.4	0-5	2.59	3.36	-	114.76	21942.81	-0.075	-3.349	0.863-
	♂	cm			2.21	3.10		145.49	31915.62	-0.056	-3.318	1.005

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Lorenzoni et al. (2002)	♀♂	FL cm	-	-	-	3.04	0.99	162.76	-	0.089	0.291	-
Küçük And Güçlü (2004)	♀♂	-	-	-	0.226	2.719		48.84	-	0.416	1.449	0.877
Çubuk et al. (2005)	♀ ♂ ♀♂	FL cm	22.50-50.0	1-5	0.0060 0.0063 0.0059	3.10 3.07 3.10	-	117.0 123.1 121.6		0.089 0.098 0.092	0.74 0.74 0.75	-
Gaygusuz et al. (2006)	♀♂	SL cm	28.9-54.1	-	2.8931	1.0489	-	-	-	-	-	-
Erdem et al. (2007)	♀♂	FL cm	30.11-54.85	1-5	-	-	-	-	-	-	-	0.90
Uysal et al. (2008)	♀ ♂	FL cm	23-49.4	1-6	-	-	-	117.8 118.0	18003 21983	0.067 0.067	2.36 1.97	-
Ziliukiene and Ziliukas (2010)	♀♂	-	26.50-107.0	2-12	0.06	3.02	-	131.7	14870	0.150	0.040	-
Moslemi-Aqdam et al. (2014)	♀♂	FL cm	18.00-72.50	-	0.0037	3.21	0.98	-	-	-	-	0.949-1.106
Kahraman et al. (2014)	♀♂	Tl cm	40.2-70.3	-	0.0659	2.481	-	-	-	-	-	-
Present Study	♀ ♂ ♀♂	FL mm	29.23-63.50	1-7	0.00009 0.00007 0.00010	2.59 2.64 2.58	0.92 0.97 0.94	130.30 122.70 126.50	18889 14881 16688	0.039 0.043 0.044	0.77 0.69 0.65	0.8408 0.8113 0.8359

The length of a pike with known weight and the weight of a pike with known length were calculated with the logarithmic length-weight relationship using the regression coefficient of length and weight ($W = a\ L^b$) (*Table 2* and *Figure 2*).

Growth equations for the length of a pike at any age were calculated with the Von Bertalanffy growth equation using the age-length relationship growth data according to sex and length (*Table 3*). The proportional growth in both sexes and the age-length relationship curves are shown in *Figure 3 - 4*.

Table 2. *Length-weight relationship parameters, equations and correlation coefficients*

Sex	Length-weight relationship parameters	Correlation coefficients (R)
Female	$W = 0.00009657 \times L^{2.5926}$ $\text{Log } W = -4.0152 + 2.5926 \text{ Log } L$	0.92
Male	$W = 0.00007 \times L^{2.6389}$ $\text{Log } W = -4.1549 + 2.6389 \text{ Log } L$	0.97
Female + Male	$W = 0.00010328 \times L^{2.5773}$ $\text{Log } W = -3.986 + 2.5773 \text{ Log } L$	0.94

Table 3. *von Bertalanffy growth parameters and equations*

Sex	Growth parameters			
	L_∞	W_∞	K (year^{-1})	t_o
Females	130.30	18889	0.039	-0.772
Males	122.70	14881	0.043	-0.693
Females + Males	126.50	16688	0.044	-0.654

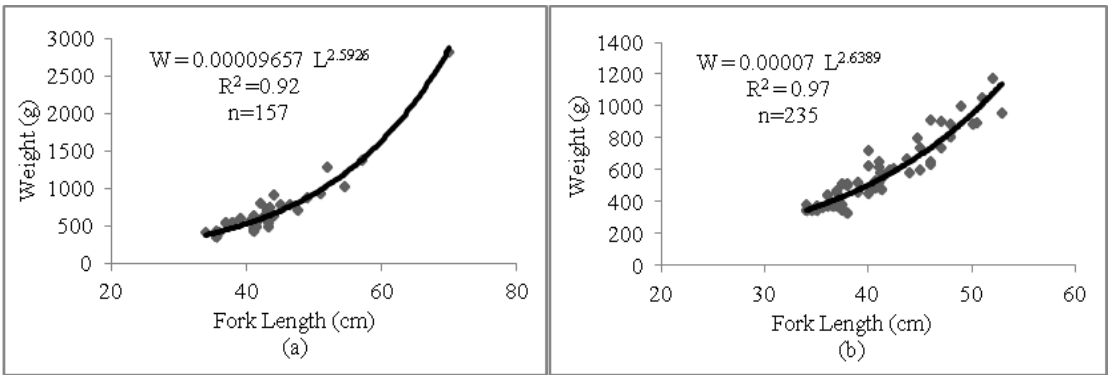

***Figure 2**. Length–weight relationships in females (a) and males (b)*

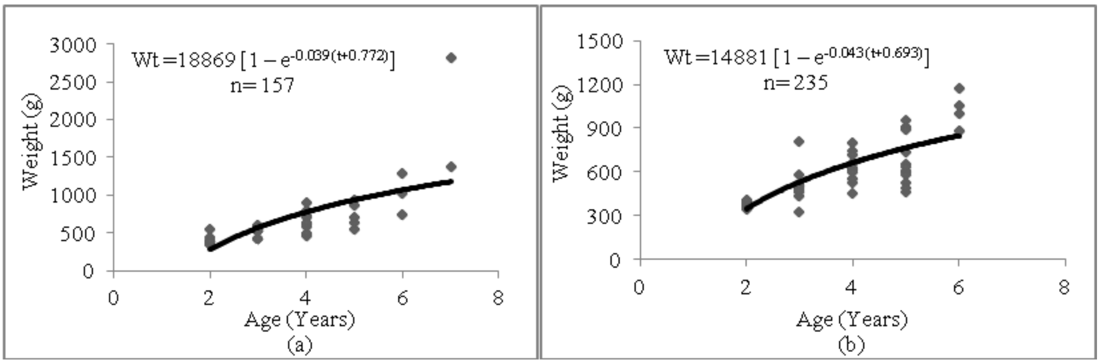

***Figure 3.** Age–weight relationships in females (a) and males (b)*

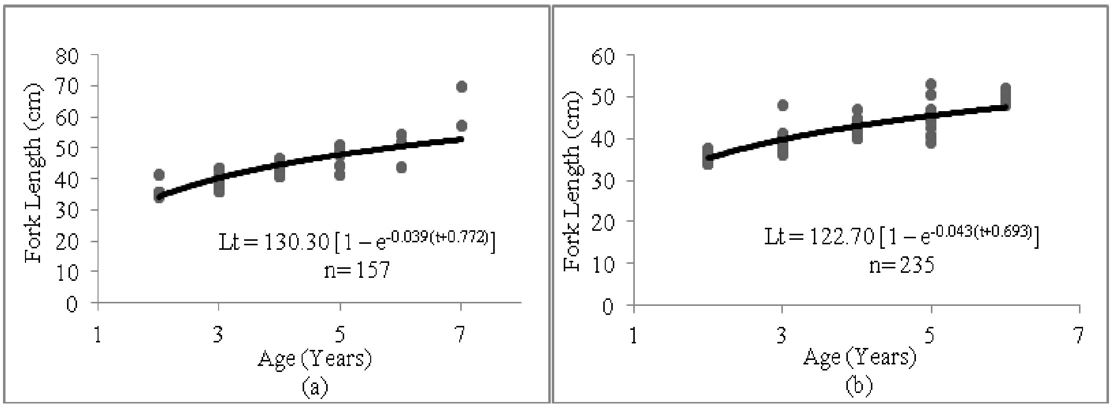

***Figure 4.** Age–length relationships in females (a) and males (b)*

A multilayer feed-forward neural network was used for the ANN. A schematic representation of a typical ANN is shown in *Figure 5* and consists of 4 interconnected layers of ‘nodes’ or ‘neurons’, including an input layer containing 1 node per independent variable (i.e. ages, length, weight and sex of pike), a hidden layer, and

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1402_543554

finally, an 'output layer' with 1 node (i.e. the weight or length of the fish samples). *Figure 6* shows a graphical presentation of the fit between the actual and predicted values.

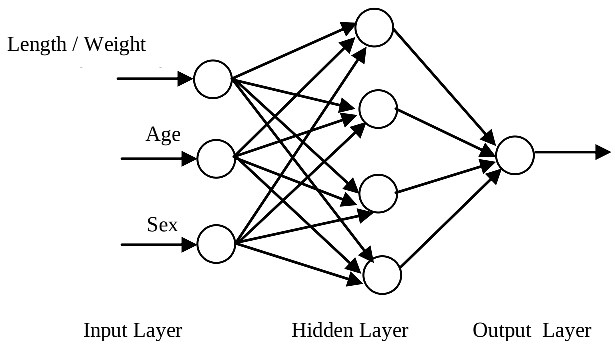

Figure 5. *An ANN consisted of an input layer with 3 nodes, a hidden layer, and an output layer with 1 node to be predicted*

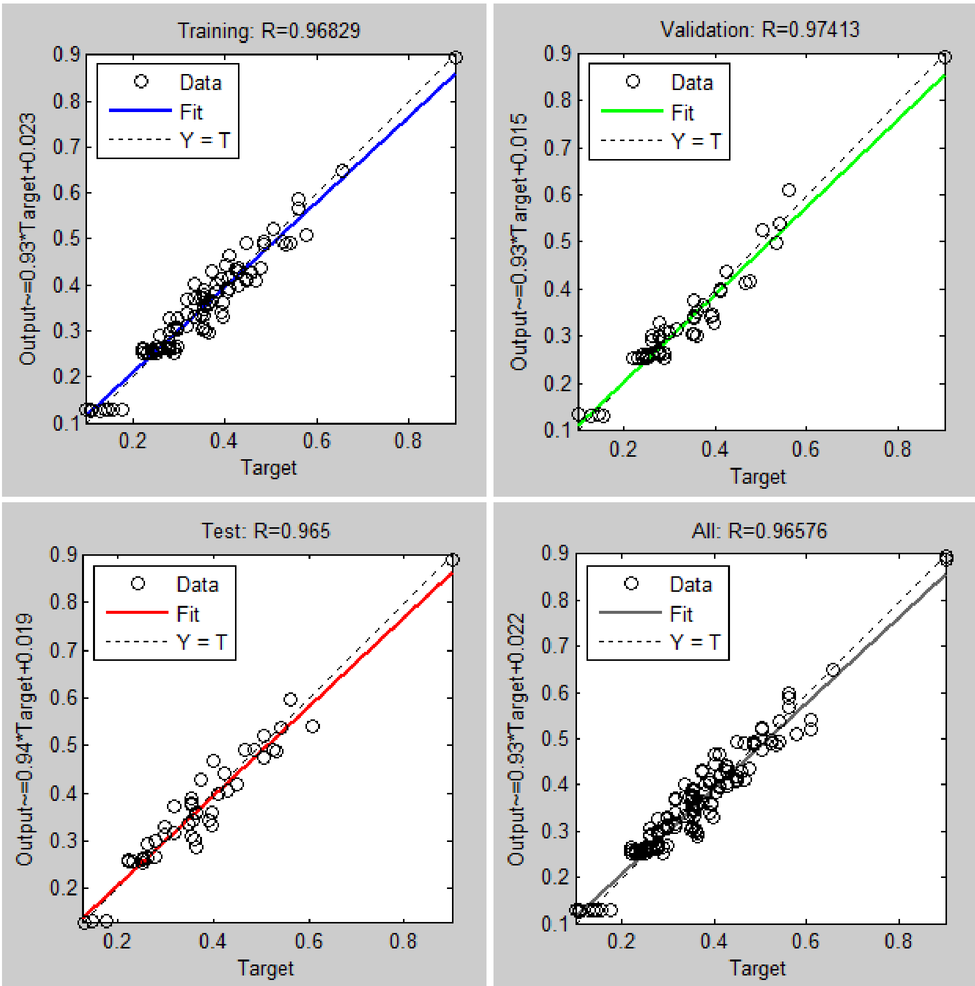

Figure 6. *Relationship between the actual data and forecast values for length.*

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DOI: http://dx.doi.org/10.15666/aeer/1402_543554

The length-weight relationships for the *Esox lucius* living in Mogan Lake were $W = 0.00009657 \times L^{2.5926}$ for females, $W = 0.00007 \times L^{2.6389}$ for males and $W = 0.00010328 \times L^{2.5773}$ for females+males. The b value for the female-male group was 2.5773. The von Bertalanffy growth equations were $L_t = 130.30\ [1 - e^{-0.039\ (t+0.772)}]$ for females, $L_t = 122.70\ [1 - e^{-0.043\ (t+0.693)}]$ for males and $L_t = 126{,}50\ [1 - e^{-0{,}044\ (t+0{,}654)}]$ for all pike.

The condition factor (CF) of *Esox lucius* varied from 0.6014 to 1.1250 in males, from 0.6152 to 1.0798 in females and from 0.06014 to 1.1250 in all pike. The CF in both sexes was 0.8359 (*Table 1*).

Discussion

There were 36.43 % females, 54.52 % males and 9.05 % immature fish. The ages of the pike caught from Mogan Lake ranged between I to VII years. According to Nikolskii (1980), the age distribution is affected by various ecological factors and the prime factor is the availability of food. Factors such as the mortality rate and hunting pressure also play an important role. The age distribution in Mogan Lake is similar to that found by Tanyolaç and Karabatak (1974) in Mogan Lake.

The male:female ratio was 1.49:1 for the general population. This ratio was 1.22:1 in Kesikköprü Dam Lake (Altındağ et al., 1999), 1.10:1 in Apolyont (Uluabat) Lake (Erdem et al., 2007), 1.76:1 in Trasimeno Lake (Lorenzoni et al., 2002) and 1.68:1 in Işıklı Lake (Uysal et al., 2008). The climatic conditions during the study likely affected the sexual maturity, breeding, breeding time, egg development and egg hatching (Hellawell, 1971).

Although Altındağ et al. (1999), Erdem et al. (2007), and Uysal et al. (2008) found that most of the samples were in the II-year age group, Çubuk et al. (2005) found that most of the samples were in the I-year age group in their study site.

Uysal et al. (2008) found that females were longer than males in the I, II and III year ages groups, whereas females were heavier than males in the I, II, III and V-year age groups. Erdem et al. (2007) found that females were longer than males in the I, II, IV and V-year age groups, whereas males were longer than females in the III-year age group. It was found that females were heavier than males in the I, II, III and IV-year age groups (Erdem et al., 2007). Çubuk et al. (2005) and Küçük and Güçlü (2004) found that females were longer than males in all age groups.

The length-weight relationships for the *Esox lucius* living in Mogan Lake were $W = 0.00009657 \times L^{2.5926}$ for females, $W = 0.00007 \times L^{2.6389}$ for males and $W = 0.00010328 \times L^{2.5773}$ for females+males. The b value for the female-male group was 2.5773. The b values determined by different researchers were generally larger than the values determined in this study (*Table 1*). Kahraman et al. (2014) reported similar b values (2.481).

The slope (b) value of the length–weight relationship in both sexes was 2.58. The b value is often 3.0 and generally between 2.5 and 3.5. As the fish grows, the changes in weight are relatively greater than the changes in length due to approximately cubic relationships between fish length and weight. The b values in fish are species specific and vary with sex, age, seasons, physiological conditions, growth increment and nutritional status of the fish (Ricker, 1975; Baganel and Tesch, 1978).

Variations in fish growth in terms of length and weight can be explained as an adaptive response to different ecological conditions (Nikolsky, 1963). The von Bertalanffy growth equations were $L_t = 130.30\ [1 - e^{-0.039\ (t+0.772)}]$ for females, $L_t =$

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122.70 [1 - $e^{-0.043\ (t+0.693)}$] for males and L_t = 126,50 [1 - $e^{-0,044\ (t+0,654)}$] for all pike. The "K" value, known as the Brody coefficient, was 0.0772 in females and 0.043 in males. Munro and Pauly (1983) state that the "K" value is an indicator of the growth performance of the species. L_∞ was similar to that of Çubuk et al. (2005) and Ziliukiene and Ziliukas (2010), but was different from other studies (Karabatak, 1993; Treer et al., 1998; Altındağ et al., 1999; Lorenzoni et al., 2002; Küçük and Güçlü, 2004, Uysal et al., 2008).

The condition factor (CF) of *Esox lucius* varied from 0.6014 to 1.1250 in males, from 0.6152 to 1.0798 in females and from 0.06014 to 1.1250 in all pike. The CF in both sexes was 0.8359 (*Table 1*). The results are consistent with several earlier reports (Karabatak, 1993; Küçük and Güçlü, 2004), although they differed from studies performed by Altındağ et al., 1999 and Erdem et al., 2007. The condition factor provides important information about the effect of feeding habits and the population density of the fish on their growth and gonad development (Weatherley, 1972).

Gutierrez-Estrade et al. (2004), Türeli Bilen et al. (2011) and Benzer (2014) performed similar studies. Traditional growth models were also used for predictions together with ANN. The values obtained for the actual, ANNs, W-L relationship and von Bertalanffy data are presented in *Table 4*.

Traditional methods of statistical analysis (i.e. linear regression models, both single and multiple) may be inadequate for quantification (Maravelias et al., 2003). ANNs offer a promising alternative to traditional statistical approaches for predictive modelling when non-linear patterns exist (Joy and Death, 2004). Recently, ANNs have been used in biology and various disciplines of aqua-cultic ecology more than in physical or chemical sciences. Most of these studies demonstrated that ANNs perform better than classical linear regression and generalized additive models (Brosse et al., 1999).

Table 4. *Predicted and calculated values for ANNs, the length-weight relationship and von Bertalanffy*

Gender	Age	ACTUAL DATA		ANNs FORECAST		ANNs MAPE (%)		W - L Relationship CALCULATED		W - L Relationship MAPE (%)		von Bertalanffy CALCULATED		von Bertalanffy MAPE (%)	
		L	W	L	W	L	W	L	W	L	W	L	W	L	W
A	1	29.23	240.00	29.03	245.56	0.692	2.264	29.51	234.00	0.954	2.500	35.72	291.66	22.186	21.525
F		35.91	395.81	35.96	384.52	0.153	2.936	35.52	406.83	1.072	2.784	41.11	528.62	14.50	33.55
M	2	35.87	369.87	36.25	370.36	1.054	0.132	35.28	386.21	1.639	4.418	39.12	430.33	9.08	16.35
A		35.88	378.36	36.16	380.61	0.772	0.591	35.21	396.98	1.870	4.921	39.62	456.66	10.43	20.69
F		39.54	531.00	39.38	537.92	0.416	1.286	39.79	522.53	0.622	1.595	44.52	676.82	12.59	27.46
M	3	39.31	508.91	39.92	510.94	1.533	0.397	39.82	491.79	1.303	3.364	42.64	624.61	8.48	22.73
A		39.41	518.38	39.67	523.75	0.658	1.025	39.79	505.57	0.967	2.471	43.36	672.22	10.03	29.68
F		42.81	667.38	43.51	677.09	1.613	1.434	43.45	641.81	1.500	3.831	47.80	843.72	11.67	26.42
M	4	41.98	632.10	41.94	584.19	0.100	8.201	43.23	585.05	2.973	7.443	46.01	784.69	9.60	24.14
A		42.41	650.51	42.80	634.86	0.904	2.465	43.45	610.93	2.445	6.084	46.94	852.76	10.68	31.09
F		46.60	740.11	45.01	740.23	3.533	0.016	45.22	799.78	2.961	8.062	50.96	1028.62	9.35	38.98
M	5	47.12	688.47	44.88	710.09	4.980	3.045	44.65	703.37	5.232	2.164	49.24	961.68	4.51	39.68
A		47.96	702.82	44.95	719.61	6.687	2.333	44.78	730.37	6.623	3.920	50.37	1053.34	5.03	49.87
F		50.51	1019.00	52.42	1073.45	3.644	5.072	51.16	959.98	1.287	5.792	53.99	1344.00	6.90	31.89
M	6	49.72	997.80	50.55	1009.60	1.642	1.169	51.39	928.90	3.359	6.905	52.33	1154.45	5.25	15.70
A		50.31	1005.75	51.30	1035.14	1.924	2.839	51.46	934.29	2.280	7.105	53.64	1272.63	6.62	26.54
F	7	63.50	2100.50	62.62	2077.27	1.405	1.118	67.63	1783.97	6.504	15.069	56.91	1573.94	10.37	25.07
A		63.50	2100.50	62.62	2077.27	1.405	1.118	68.48	1728.78	7.843	17.697	56.78	1509.13	10.58	28.15
		Average MAPE				1.840	2.080			2.850	5.900			2.36	9.24

F: Female, M: Male, A: Female+Male, AI: All Individuals

In this study, the application of the ANN was compared to a conventional linear approach. As a result, ANNs can be an alternative to the von Bertalanffy growth

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DOI: http://dx.doi.org/10.15666/aeer/1402_543554

models. By contrast, the estimated growth parameters are model dependent; therefore, model selection uncertainty may be quite high in certain data sets. Ignoring model selection uncertainty may cause a substantial overestimation of the precision and estimation of the confidence intervals of the parameters below the nominal level. This uncertainty has serious implications, particularly when comparing the growth parameters of different fish populations. The set of candidate models should include at least the von Bertalanffy model, one or more sigmoid growth curves, and one or more non-asymptotic models (Katsanevakis and Maravelias, 2008). The von Bertalanffy model can be used to predict the features of a prospective older population from their sample caught when younger. The von Bertalanffy model provides better results with advancing age (Narinc et al., 2010).

In conclusion, the current study demonstrates that ANNs can be an alternative to von Bertalanffy growth models. In addition, it is recommended that the necessary steps should be taken as soon as possible to protect the *Esox lucius* population in the lake after investigating its stock situation and breeding and feeding behaviours.

Acknowledgments. We would like to thank all of the referees, who added value to our paper with their thorough reviews and recommendations.

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