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Investigation of the Relationship between Body Length and Live Weight of the Pikeperch (Sander *Lucioperca* Linnaeus, 1758) in Beyşehir Lake Population

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ABSTRACT
The aim of this study is to examine the relationship between the total length and standard lengths with live weight of the freshwater pikeperch growing in the Beyşehir Lake population using four mathematical models. 50 female fish materials of marketable size limit age were used. The data obtained were divided into two groups: estimation (70%) and test (30%). The applied models are exponential decay, exponential and Wood models, and in such research generally preferred power model. R^2, R^2adj, RMSE, AIC, BIC and MAPE values were used as goodness of fit tests and comparison criteria of the models. According to the study results, the total length gives more accurate estimates than a standard length in the estimating live weight. As a result, it was concluded that other models might provide better results than the power model, and they were suggested to be used in estimating the live weight of pikeperch fish.

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Beyşehir Gölü Populasyonundaki Sudak (Sander *Lucioperca* Linnaeus, 1758) Balıklarının Vücut Uzunluğu ile Canlı Ağırlıkları Arasındaki İlişkilerin Matematiksel Modellerle İncelenmesi

ÖZET
Bu çalışmanın amacı, Beyşehir Gölü popülasyonunda yetişen tatlı su levreklerinin total boy ve standart boylarının canlı ağırlık ile ilişkisini dört matematiksel model kullanarak incelemektir. Bunun için pazarlabilir boy limiti çağında bulunan 50 dişi balık materyali kullanıldı. Elde edilen veriler tahmin (%70) ve test (%30) verileri olmak üzere iki gruba ayrıldı. Uygulanan modeller üstel azalma, üstel ve Wood modelleri olmakla birlikte bu tür araştırmalarda genellikle tercih edilen güç modelidir. Modellerin karşılaştırma kriterleri ve uyum iyiliği testleri olarak R^2, R^2adj, RMSE, AIC, BIC ve MAPE değerleri kullanılmıştır. Çalışma sonuçlarına göre, total boy, canlı ağırlık tahmininde standart boydan daha doğru tahminler yapmaktadır. Sonuç olarak, diğer modellerin güç modelinden daha iyi sonuçlar verebileceği sonucuna varılmış ve su levreklerinin canlı ağırlığının tahmininde kullanılması önerilmiştir.

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INTRODUCTION

Many climates and ecosystems worldwide negatively affected by the increase of global warming. The changes in the ecosystem cause a rapid depletion of natural resources and therefore, humans seek new nutrition resources. The most valuable and expensive structures in the human diet are proteins and fats which sometimes they could be insufficient in the diet. The important thing in human nutrition is consuming foods that contain high amounts of essential amino acids and fat profiles. Fish have become a strategic product in human nutrition as a food source due to their high amount of protein, unsaturated fatty acids, essential amino acids and fatty acids contents (Tekinşen & Gökmen, 2007). Fish contain 64-84%

water, 15-24% protein, 0.1-22% oil, 0.8-2% mineral substance, and around 1% carbohydrate (glycogen) (Nettleton, 2000).

Türkiye is surrounded by sea on three sides and the presence of many fresh water, ponds and dams, makes it very suitable for natural and artificial aquaculture. Commercially important fish species are vaccinated, especially in inland ponds.(Numann, 1958). In the largest freshwater source of Turkey, namely Beyşehir Lake six different fish species are observed and one of them is pikeperch, which is commercially important (Sander lucioperca Linnaeus, 1758) (Numan, 1958). The vaccination of pikeperch fish was made in 1978 (Tümgelir, et al., 2007).

It is important to know the relationship between length and live weight for fish hunt. In the official newspaper of the Ministry of Agriculture and Rural Affairs in 2008, fish caught in inland and sea waters were specified by fishing season and the lengths of the fish. In this context, the minimum total length for the fishing of pikeperch (S. Lucioperca) was determined as 26 cm, and their fishing was prohibited in all regions between 15 March - 30 April (Anonymous, 2008). In terms of hunters, the mathematical modeling of the relationship between length and live weight for pikeperch fish is of economic importance (Anderson & Neumann, 1996).

The use of linear models prevents accuracy in live weight estimation because living beings' characteristics are generally non-linear. Mathematical modeling of body length and live weight relationships can usually be done more accurately with the help of nonlinear modeling. Determining the relationship between body length and live weight provides essential information about the ecology of a species (Anderson & Neumann, 1996).

Today, with the development of technology and computer programs, the live weights of the fish have been estimated by using different input variables by researchers. For example, other body measurements and images could be used as input variables in live weight estimations (Fisher et al., 1996; Çınar et al., 2006; Daniela et al., 2015).

This study aims to explain the relationships between the total and standard lengths with the live weight of the pikeperch fish caught in Beyşehir Lake with mathematical models.

MATERIAL and METHOD

Data Set

The sampling was done in Beyşehir Lake, which is located within the borders of Beyşehir district of Konya province (Figure 1). Beyşehir Lake is Turkey's largest freshwater resources (Çınar et al., 2006). It is located between the coordinates of 37° 33′-37° 59′N, 31° 19′-31° 44′E, has an 650 km² surface area approximately, 1115 m altitudeabove sea level, and has a length of 45 km and a maximum width of 25 km,

Figure 1. The study area, Beysehir Lake

Şekil 1. Çalışma alanı, Beyşehir Gölü

The research material was obtained from the fishermen who caught pikeperch fish (Sander lucioperca Linnaeus, 1758) in the 2018 fishing season from Beyşehir Lake with their nets. The age of the fish was determined by considering the age of the marketable length limit, while the sexes of the fish were defined according to the fin tips and vent structure (Anonymous, 2008). The study material consists of the total length, standard length, and live weight data of 50 female pikeperch fish of the marketable size limit age (Figure 2).

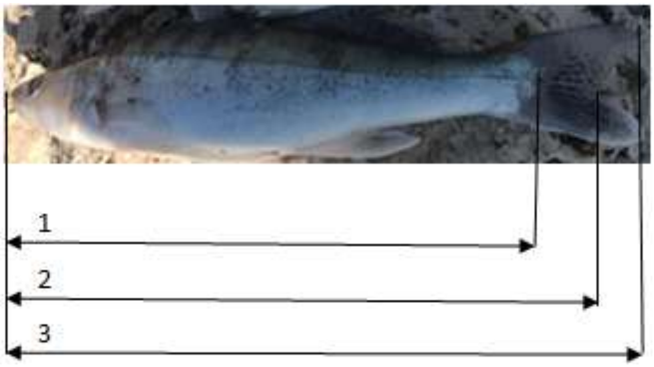


Figure 2. Body measurements (1 – Standard length, 2 – Fork length, 3 – Total length)

Şekil 2. Boy ölçüleri (1- Standart boy, 2- Çatal boy, 3- Total boy)

Mathematical Models

We used the power and exponential functions (Archontoulis & Miguez, 2015) and Wood function (Wood, 1967) to describe the weight-length relation Eq (1-4):

Power function: $W = aX^b$ (1)

Exponential (decay) function: $W = ae^{(-bX)}$ (2)

Exponential (gives rise to maximum) function:
$W = a\left[1 - e^{(-bx)}\right]$ (3)

Wood function: $W = aX^b e^{(-cx)}$ (4)

In the study, these models were widely preferred in the growth curves created using live weight. Where W is the standard weight in g, and X is the length of fish in cm, such as total length (TL) and standard length (SL), a, b and c parameters define the shape of the curve and the magnitude of the W value.

For parameter estimation Levenberg-Marquardt algorithm (Levenberg, 1944; Marquardt, 1963) was used.

Model Selection Criteria

Different statistical criteria can be used to find the best model. The following criteria (Eq. (5) -Eq.(10)) were used to compare the above models (Burnham & Anderson, 2002; Mendenhall & Sincich, 2012; Archontoulis & Miguez, 2015; Gök et al., 2019).

Coefficient of Determination: $R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \tilde{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$ (5)

Adjusted Coefficient of Determination:
$R^2_{adj} = 1 - (1 - R^2)\frac{n-1}{n-p}$ (6)

Root Mean Squared Error: $RMSE = \sqrt{\frac{\sum_{i=1}^{n}(\mathbf{y_i} - \hat{\mathbf{y}}_i)^2}{n-p-1}}$ (7)

Mean Absolute Percentage Error:
$MAPE = \frac{100\%}{n}\sum_{i=1}^{n}\left|\frac{y_i - \hat{y}_i}{y_i}\right|$ (8)

Akaike Information Criteria:
$AIC = \ln\left[\frac{1}{n}\sum_{i=1}^{n}(y_i - \tilde{y}_i)^2\right] + \frac{2p}{n-(p+1)}, \left(\frac{n}{p} < 40\right)$ (9)

Bayes Information Criteria:
$BIC = \ln\left[\frac{1}{n}\sum_{i=1}^{n}(y_i - \tilde{y}_i)^2\right] + \frac{p}{n}\ln n$ (10)

In the above-given Eq.1-6; n: is the number of samples, p: is the number of parameters in the model, y_i: shows the standard weight of i^{th} sample, $\bar{y}$: shows average standard weight, $\tilde{y}_i$: shows estimated standard weight. The highest value of the R^2 and R^2_{adj} and the lowest value of the others were considered in determining the best model.

In the study, Excel 2013 package for Windows was used for the data preparation and STATISTICA 13.2 statistical package was used to estimate the parameters included in the models.

RESULTS and DISCUSSION

Before the models were applied, the data set was divided into two groups an estimation and test data using the cross-validation method (Table 1). After the models were applied to the estimation data set, the parameters were found for the models. Then by using these models, the live weight was estimated according to the test data. In Table 1, descriptive statistics of estimation (n=35), test (n=15), and all (n=50) data sets were given. The average live weight (W) of the studied fish was 343.40 ± 15.36 g, total length (TL) 34.12 ± 0.52 cm and standard size (SL) 28.22 ± 0.42 cm.

Table 1. Data sets used for mathematical models
Çizelge 1. Matematiksel modeller için kullanılan veri seti

Data	N	Descriptive Statistics	Total Length (cm)	Standard Length (cm)	Live Weight (g)
Estimation	35	Mean±SE	34.01±0.59	28.15±0.47	340.90±17.36
		Std. Deviaton	3.50	2.78	102.70
		Minimum	28.00	23.50	195.00
		Maximum	40.50	33.50	540.00
Test	15	Mean±SE	34.37±1.11	28.40±0.91	349.30±32.30
		Std. Deviaton	4.29	3.53	125.10
		Minimum	28.00	23.00	170.00
		Maximum	41.00	33.50	565.00
Total	50	Mean±SE	34.12±0.52	28.22±0.42	343.40±15.36
		Std. Deviaton	3.71	2.99	108.60
		Minimum	28.00	23.00	170.00
		Maximum	41.00	33.50	565.00

Table 2 shows the prediction models and parameters obtained after the application of the models to the estimation data set. As seen in Table 2, Wood model has three parameters, while power, exponential decay, and exponential models have two parameters. Parameters a, and b obtained for the power model using the total length as predictor are respectively; 0.000013 and 2.886. In this study, the a and b parameter values for power model were similar to the parameters obtained by Fisher et al., (1996). Fisher et al., 1996 investigated the relationship between the total length and standard weight of burbot fish (lota lota) in North American populations. The parameters of the power model were also similar to the power model parameters applied to pikeperch fish by Çınar et al., 2006. The power model was also used by Daniela et al., 2015, for the estimation of the length-weight relationship of the endemic barbus tyberinus bonaparte fish and the parameters were found as a = 0.138×10^{-4}, b = 2.940.

Table 2. Estimated model parameters by estimation data
Çizelge 2. Tahmin verilerine göre tahmini model parametreleri

Models	Mathematical expression	X is the total length			X is the standard length		
		Parameters			Parameters		
		a	b	c	a	b	c
Power	$W = aX^b$	0.000013	2.886	-	0.000019	2.921	-
Exponential decay	$W = ae^{(-bX)}$	0.019857	-0.082	-	0.019413	-0.100	-
Exponential	$W = a[1 - e^{(-bx)}]$	-0.026199	-0.077	-	-0.025423	-0.093	-
Wood	$W = aX^b e^{(-cx)}$	0.01208	0.162	-0.080	4.55	-2.36	-0.18

Evaluation criteria for the models used in the study are given in Table 3. It could be stated that the best model for estimation data is the power and Wood model. Considering that the number of model parameters are different, it could be observed that the adjusted determination coefficient is more efficient than the coefficient of determination. The highest R^2 value is found in the Wood model, but in R^2adj, the power model and the Wood model are evaluated similarly. The Wood model could be chosen for all model goodness-of-fit criteria (R^2adj, RMSE, AIC, and BIC) (Table 3). In the test data, the exponential decay model and the exponential model gave the best results in evaluatingall data (Table 3).

Table 3. Selection criteria for each model based on total length as predictor
Çizelge 3. Tahmin edici olarak total boya dayalı her model için seçim kriterleri

Model	p	R^2	R^2_{adj}	RMSE	MAPE	AIC	BIC
Estimation n=35							
$W = aX^b$	2	0.9599	**0.9587**	**0.0212**	2.6850	**-7.6715**	**-7.5933**
$W = ae^{(-bX)}$	2	0.9540	0.9526	0.0227	2.8804	-7.5350	-7.4568
$W = a[1 - e^{(-bx)}]$	2	0.9555	0.9542	0.0223	2.8163	-7.5685	-7.4903
$W = aX^b e^{(-cx)}$	3	**0.9611**	**0.9587**	**0.0212**	**2.6408**	-7.6337	-7.5225
Testing n=15							
$W = aX^b$	2	0.9548	0.9513	0.0287	**1.3540**	-6.9894	-6.9617
$W = ae^{(-bX)}$	2	**0.9570**	**0.9537**	**0.0280**	1.5980	**-7.0391**	**-7.0114**
$W = a[1 - e^{(-bx)}]$	2	0.9569	0.9536	**0.0280**	1.5436	-7.0380	-7.0103
$W = aX^b e^{(-cx)}$	3	0.9569	0.9498	0.0293	1.5420	-6.8262	-6.8300
Overall n=50							
$W = aX^b$	2	0.9161	0.9144	0.032	4.907	-6.853	-6.781
$W = ae^{(-bX)}$	2	0.9540	0.9531	**0.024**	3.4467	-7.4545	-7.3832
$W = a[1 - e^{(-bx)}]$	2	0.9546	**0.9536**	**0.024**	3.4674	**-7.4661**	**-7.3948**
$W = aX^b e^{(-cx)}$	3	**0.9551**	0.9532	**0.024**	**3.4127**	-7.4320	-7.3277

When the standard length is used as the predictor, it gives the best result as the power model for estimation data, exponential decay for the test data, and power model for all the data (Table 4). However, the total length had better results than the standard length as a predictor in weight estimation.

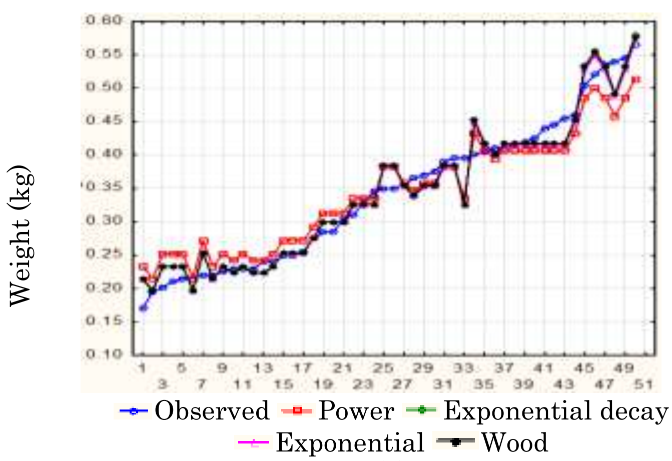
In Figure 3, line plots of live weight predicted by total length and standard length with overall, estimation and testing data were drawn.

CONCLUSION

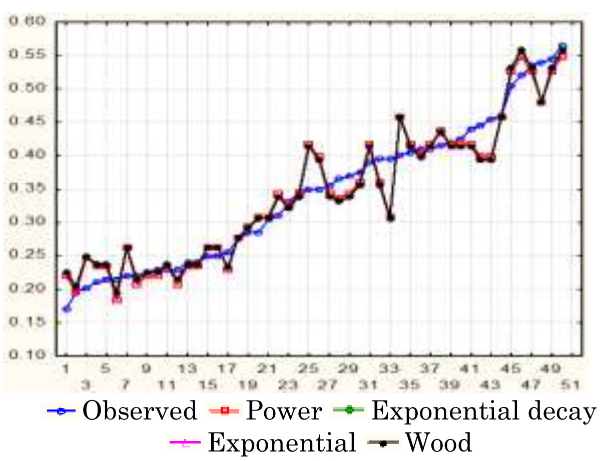
Mathematical modeling of the live weight of fish using their body length enables the estimation of the live weight they will reach throughout their lives. Yield prediction requires a long time and high costs because proper breeding can take many years. Therefore, the estimation method with mathematical models provides time and cost advantages. The power, exponential decay, exponential and Wood models analyzed in the study were evaluated with the goodness of fit criteria such as MAPE, RMSE, R2 and R2adj. The exponential model showed the best fit in all data. Using AIC and BIC model selection criteria also exponential model appears to be the best. As a result, it can be said that the weight of female pikeperch fish in the age of marketable height limit in Beyşehir Lake can be estimated with high accuracy by using their height. The proposed models could also be tested in other fish species.

Table 4. Selection criteria for each model based on standard length as predictor
Çizelge 4. Tahmin edici olarak standart boya dayalı her model için seçim kriterleri

Model	p	R^2	R^2_{adj}	RMSE	MAPE	AIC	BIC
Estimation n=35							
$W = aX^b$	2	0.9246	**0.9223**	**0.0291**	4.1768	**-7.0409**	**-6.9627**
$W = ae^{(-bX)}$	2	0.9173	0.9148	0.0304	4.3116	-6.9485	-6.8704
$W = a\left[1 - e^{(-bx)}\right]$	2	0.9190	0.9166	0.0301	4.2846	-6.9696	-6.8915
$W = aX^b e^{(-cx)}$	3	**0.9264**	0.9218	0.0292	**4.1523**	-6.9959	-6.8847
Testing n=15							
$W = aX^b$	2	0.9151	0.9086	0.0394	1.9476	-6.3598	-6.3321
$W = ae^{(-bX)}$	2	**0.9205**	**0.9143**	**0.0381**	1.9278	**-6.4246**	**-6.3969**
$W = a\left[1 - e^{(-bx)}\right]$	2	0.9198	0.9136	0.0383	1.9242	-6.4159	-6.3882
$W = aX^b e^{(-cx)}$	3	0.9200	0.9067	0.0399	**1.9219**	-6.2072	-6.2111
Overall N=50							
$W = aX^b$	2	**0.9205**	**0.9188**	**0.0313**	4.8489	**-6.9059**	**-6.8345**
$W = ae^{(-bX)}$	2	0.9176	0.9158	0.0319	**4.8081**	-6.8701	-6.7988
$W = a\left[1 - e^{(-bx)}\right]$	2	0.9184	0.9167	0.0317	4.8167	-6.8809	-6.8096
$W = aX^b e^{(-cx)}$	3	0.9181	0.9146	0.0321	4.8123	-6.8315	-6.7272



(a)



(b)

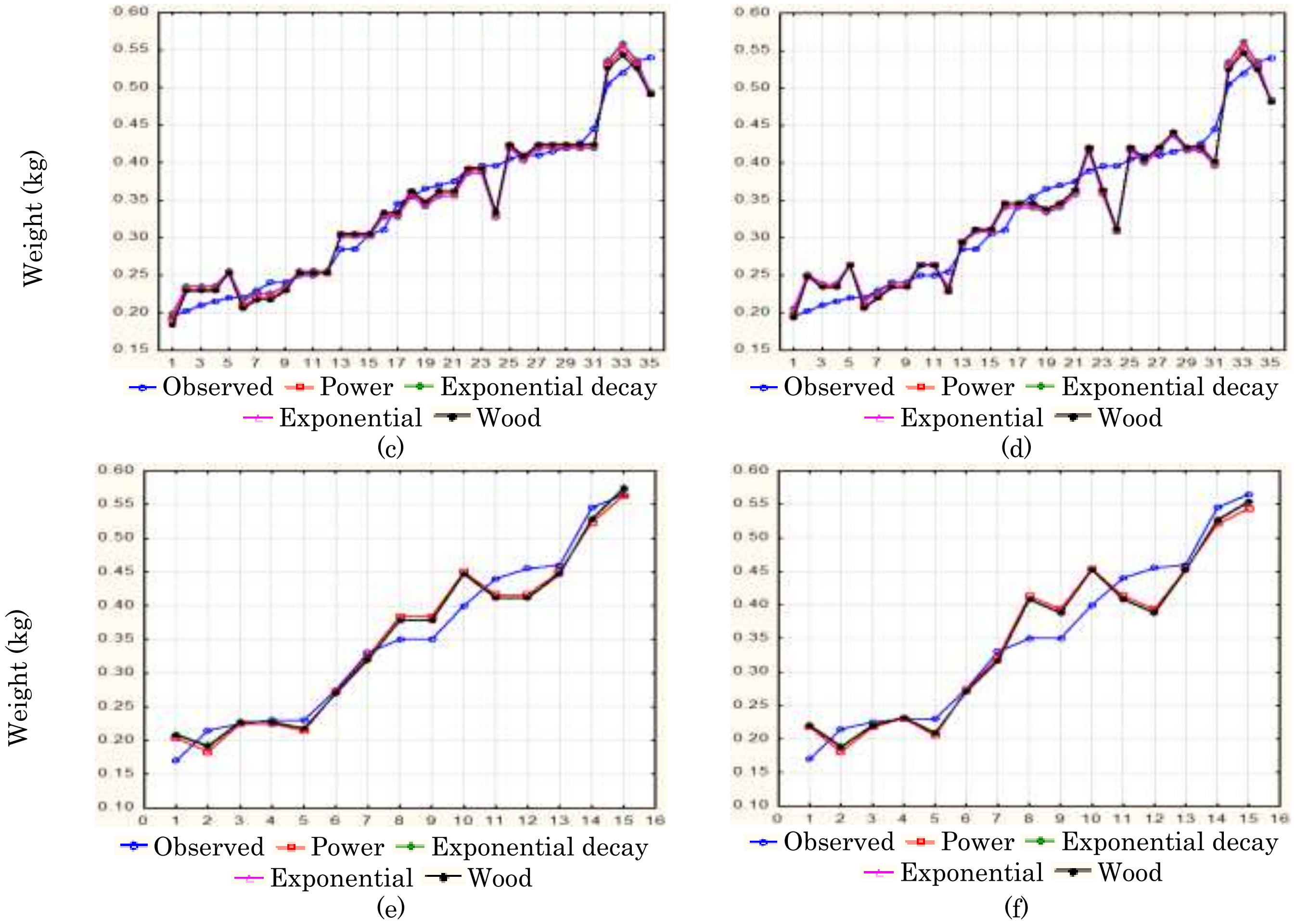


Figure 3. Line plots of live weight predicted by total length (a, c, e) and by standard length (b, d, f) with overall, estimation and testing data

Şekil 3. Total boy (a, c, e) ve standart boy (b, d, f) ile tahmin edilen canlı ağırlığın, tahmin ve test verilerine ait çizgi grafikleri

Author's Contributions

The authors declare that they have equally contributed to the article.

Statement of Conflict of Interest

The authors of the article declare that there is no conflict of interest between them.

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