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RESEARCH ARTICLE **ARAŞTIRMA MAKALESİ**

Estimating gillnet selectivity of Bluefish (*Pomatomus saltatrix*) by morphology

Lüferin (*Pomatomus saltatrix*) morfolojisiyle galsama ağı seçiciliğinin tahmini

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Abstract: The dataset of the study consists of total length, fork length, head girth, maximum girth and weight measurements of 136 bluefish. The relationship between the total length and fork length of the product was TL=1.1348×FL−0.8184; the relationship between the total length and weight was W=0.0103×$L^{2.97}$. The relationships between the total length and head girth and between the total length and maximum girth of the sample were linear: the relationship of the total length and head girth was G_{gill}=0.5092×TL−0.0874; the relationship of the total length and maximum girth was G_{max}=0.5989×TL−0.8540. The statistical relationship between length and girth was used to obtain a theoretical gillnet selectivity equation for the species. In conclusion, a relationship of $S(l)$=Φ[(C−G_{gill})/0.4952]×[1−Φ((C−G_{max})/0.4255)] was determined between the stretched size of the mesh used in bluefish fishing and the catch rate. Using this equation, and considering the legal length and length at first maturity, the minimum mesh size of the gillnet for sustainable fishery was determined.

Keywords: *Direct estimation, Sechin method, length-girth relationship, length-length relationship, length-weight relationship*

Öz: Çalışmanın veri setini, 136 adet lüfer balığı üzerinde yapılan; total boy, çatal boy, operkulum çevresi, vücut çevresi ve ağırlık ölçümleri oluşturmaktadır. Türün total boyu ile çatal boyu arasında TL=1,1348×FL−0,8184, total boyu ile ağırlığı arasında ise W=0,0103×$L^{2.97}$ şeklinde bir ilişki olduğu tespit edilmiştir. Örnekleme ait total boy-operkulum çevresi ve total boy-vücut çevresi arasında ise sırası ile G_{gill}=0,5092×TL−0,0874 ve G_{max}=0,5989×TL−0,8540 şeklinde doğrusal bir ilişkinin olduğu hesaplanmıştır. Boy ile çevre arasında kurulan istatistiksel ilişkiler kullanılarak, türe ait kuramsal uzatma ağı seçicilik denklemi elde edilmiştir. Sonuç olarak, türün avcılığında kullanılabilecek ağın tam göz boyu ile yakalanma oranları arasında $S(l)$=Φ[(C−G_{gill})/0,4952]×[1−Φ((C−G_{max})/0,4255)] şeklinde bir ilişkinin olduğu tespit edilmiştir. Elde edilen bu denklemden faydalanılarak, türün yasal ve ilk üreme boyları dikkate alınarak, sürdürülebilir bir avcılık için kullanılacak sade uzatma ağının minimum tam göz boyunun ne olması gerektiği belirlenmiştir.

Anahtar kelimeler: *Direkt tahmin, Sechin metodu, boy-çevre ilişkisi, boy-boy ilişkisi, boy-ağırlık ilişkisi*

INTRODUCTION

Bluefish (*Pomatomus saltatrix* Lin., 1766), the only member of the Pomatomidae family (Whitehead et al., 1986), is a rapidly migrating, pelagic and predatory species (Haimovici and Krug, 1996). Their distribution extends to a wide area including the Atlantic, Pacific and Indian Oceans, and they inhabit the continental shelves of warm and temperate seas (Wilk, 1977). They have a high commercial value around the world (Froese and Pauly, 2016). In Turkey, in addition to gillnets and hooks (Hoşsucu, 2000), they are also caught with purse seine and trawl. According to the statistics from the General Fisheries Commission for the Mediterranean (GFCM), the average fish production of Turkey in the last decade was 7,252.8±1,355.6 tons and the majority of the production was from the Black Sea and the Marmara Sea ($\bar{x}$±SE) (FAO, 2016).

The bluefish is a symbol for various non-governmental organizations committed to preserving marine life in Turkey; it is used in many campaigns regarding this issue. Discussions on its legal catch length have always reached an impasse and as a natural consequence of these long-lasting discussions, the legal length has undergone many changes: The first legal length was determined to be 15 cm fork length (FL) during the fishing season in 1986-1987; over time, the legal length reached 18 cm (FL) and 20 cm (TL). Until today, the lowest legal length was 14 cm (TL) during the 11-year long fishing season beginning in 2000; no length ban was implemented during the 1999-2000 fishing season. The length ban for the current fishing season is 18 cm total length (Anonymous, 2016).

In Turkey, in addition to its high economic value, bluefish is historically and traditionally highly valued. Few species that are similarly valued are also given names based on their lengths: bluefish are named "defneyaprağı" (<10 cm), "çinekop" (10-20 cm), "sarıkanat" (20-25 cm), "kofana" (35-40 cm) and "sırtıkara" (>40 cm TL) (Deveciyan, 1915; Türgan, 1959).

In this study, the theoretical catch rate of gillnet was determined by utilizing the morphological structure of bluefish, and by considering this rate mesh sizes of gillnet for fishing above the legal length and length at first maturity were calculated.

MATERIALS AND METHODS

The material of the study consists of morphological measurements obtained from 136 bluefish. The samples were collected from different fishing gears (line and net fishing) intended for sampling with large length range. Total length (TL), fork length (FL), head girth (G_{gill}) and maximum girth (G_{max}) of individual fish were measured at 0.1 mm and the total body weight was recorded at 0.01 g sensitivity.

Linear regression was used to determine the relationships between total length and fork length (TL-FL), total length and head girth (TL-G_{gill}), and total length and maximum girth (TL-G_{max}) of the samples:

$$y = b \times x + a$$

In the equation, x represents the independent variable, y represents the dependent variable, a and b represent the regression intercept and slope. The relationship between length and weight of the species was calculated with:

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

In the equation, W represents the weight at each L length, while a and b represent the regression coefficient (Ricker, 1973). The intercept and slope parameters of the relationships were estimated by linear regression analysis on log-transformed length and weight data.

Growth type of the species was determined using the Student's t-test. The power of the correlation between established relationships was determined with the determination coefficient (R^2).

A theoretical selectivity model, which is based on the relationship between the fish length and girth, and is also known as the Sechin method, was used to estimate the selectivity parameters and selectivity curve (Sechin, 1969; Kawamura, 1972). This model is suited to species with a morphology that allows for gilled and wedged; and the model is based on determining two length groups ($G_{gill} \leq C \leq G_{max}$);

a) Determination of length groups small enough to get their heads into the mesh,

b) Determination of length groups large enough to be retained by the mesh.

In the study, the equations that were modified from Sechin (1969) by Reis and Pawson (1999) by simplifying and applying the equations to commercial fishery data were adopted:

$$P^{retained} = P\{G_{max} \geq C\} = 1 - \Phi\left(\frac{C - G_{max}}{\sigma_{max}}\right)$$

$$P^{passing} = P\{G_{gill} \leq C\} = \Phi\left(\frac{C - G_{gill}}{\sigma_{gill}}\right)$$

$$S(l) = P^{retained} \times P^{passing}$$

In the equations, S represents the estimated catch rate at each l length, C represents the mesh size (stretched mesh size×2), G_{max} and G_{gill} represent the maximum girth and head girth for each l fish length; Φ represents the cumulative normal standard distribution function, σ_{gill} and σ_{max} represent the standard deviation of the relationships between fish length-head girth and fish length-maximum girth. Using these equations, a normal distribution curve is obtained from two transverse sigmoid curves' combination. All calculations were carried out using MS-Excel® functions.

RESULTS

In the study, the total length of the smallest sample was 16.5 cm, whereas the total length of the largest sample was 35.3 cm. The average length of the samples was 23.25 cm and the standard error was ±0.34 cm. A relationship, W=0.0103×$L^{2.97}$ (R^2=0.987) was determined between the weight and length of the species. At 95% confidence interval, standard error of b (slope) value of this relationship was ±0.07, and therefore the growth type of the species was determined to be isometric (t-test). The linear and strong relationship between the fork length (FL) and total length (TL) of the samples was determined as TL=1.1348×FL−0.8184 (R^2=0.999).

A linear relationship, G_{max}=0.5989×TL−0.8540 (R^2=0.968, σ_{max}=0.4255) was determined between the total length and maximum girth of the bluefish. In addition, a linear relationship, G_{gill}=0.5092×TL−0.0874 (R^2=0.942, σ_{gill}=0.4952) was determined between the total length and head girth of the species (Figure 1).

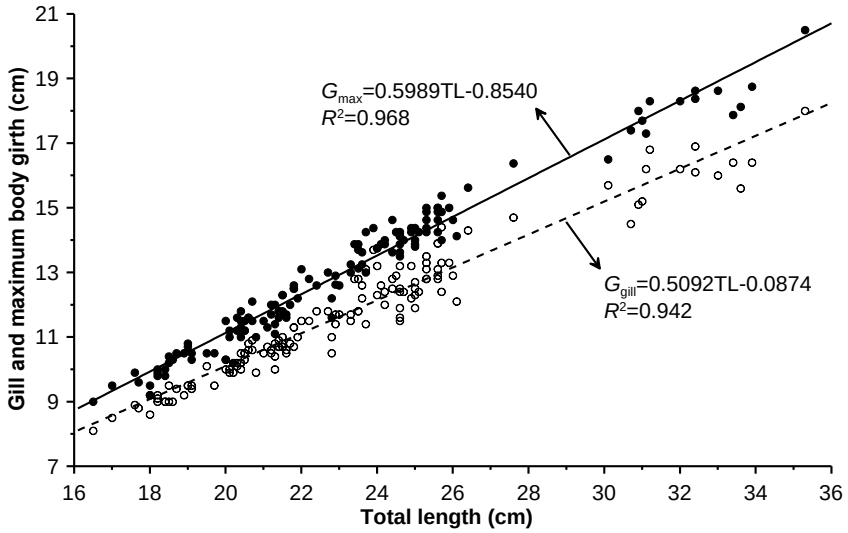

Figure 1. Total length-head girth and total length-maximum girth relationships of the bluefish (*Pomatomus saltatrix*) (● and |: TL-G_{max}; ○ and ¦: TL-G_{gill}).

The morphometric relationship between the length, head girth and maximum girth revealed the following relationship between the stretched mesh size and catch rate:

$$S(l)=\Phi\left(\frac{C-(0.5092\times \mathrm{TL}-0.0874)}{0.4952}\right)\times\left[1-\Phi\left(\frac{C-(0.5989\times \mathrm{TL}-0.854)}{0.4255}\right)\right]$$

This relationship showed that the stretched mesh size of the gillnet that allows for fishing above the 18 cm legal length was 55 mm. This mesh size, the probability of catching individuals at 18 cm legal length was 6‰, optimum catch length was 20.75 cm total length and catch rate at optimum catch length was 77.8% (Figure 2).

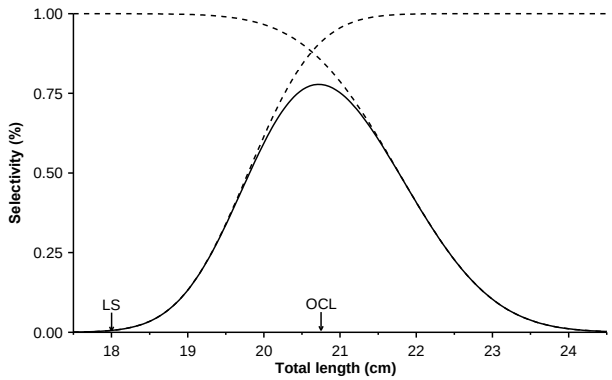

Figure 2. Estimated gillnet selectivity of 55 mm stretched mesh size for the bluefish (*Pomatomus saltatrix*) (LS: Legal size, OCL: Optimum catch length)

In Turkey, the length at first maturity was reported as 25.4 cm fork length (Ceyhan et al., 2007). Total length measurements are accepted as the main measurement standard in legal regulations; therefore, this value should be converted to total length for practical use. The relationship equation obtained in this study for total length and fork length revealed that the length at first maturity was 28.0 cm total length for bluefish. A gillnet with an 85 mm stretched mesh size allowed for fishing above the length at first maturity. Theoretically, with this mesh size, 5‰ of the individuals at first maturity length were caught, optimum catch length was 31.45 cm and the catch rate for individuals at optimum catch length was 97.5% (Figure 3).

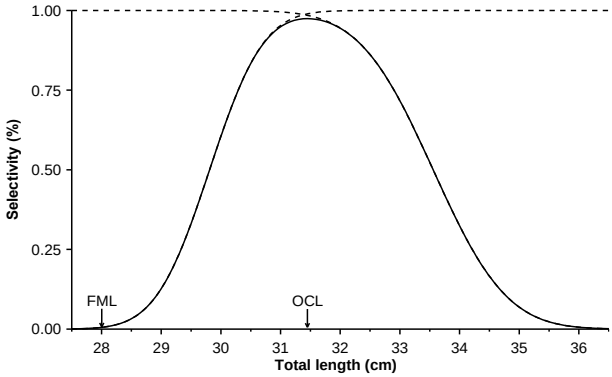

Figure 3. Estimated gillnet selectivity of 85 mm stretched mesh size for the bluefish (*Pomatomus saltatrix*) (FML: Length of first maturity, OCL: Optimum catch length)

DISCUSSION

The total length-fork length relationship established in this study was used to convert previous researchers' findings regarding fork length to the total length. Froese and Pauly (2016) reported that, based on the measurements of pictures of the species, the total length of the species was 1.0834 times the fork length. van der Elst (1976), for individuals inhabiting the South African coast, and Bal et al. (2015), for individuals sampled from the southern Marmara Sea, reported the relationship between the total length and fork length. The

findings of our study were mostly similar to the findings of Froese and Pauly (2016) and Bal et al. (2015), whereas the findings of van der Elst (1976) were considerably different from all of these studies (Table 1).

Table 1. Total length-total weight and total length-fork length relationships of the present and previous studies for the bluefish (*Pomatomus saltatrix*)

L-W	GT	LR	*L-L*	Study
			TL=1.0834×FL+0	Froese and Pauly, 2016
			TL=1.306×FL+3.06	van der Elst, 1976
$W=0.0388\times L^{2.56}$	–A			Erkoyuncu et al., 1994
$W=0.0130\times L^{2.8621}$	–A	13.2-21.7		Kalaycı et al., 2007
$W=0.0325\times L^{2.527}$	–A	10.6-24.0		Bök et al., 2011
$W=0.0107\times L^{2.9574}$	I	12.3-43.7	TL=1.13×FL–0.342	Bal et al., 2015
$W=0.0103\times L^{2.97}$	I	16.5-35.3	TL=1.1348×FL–0.8184	Present study

L-W: Total length-total weight relationships. GT: Growth types (I: Isometry, –A: Negative allometry). LR: Sampled length range (cm, TL). *L-L*: Total length-fork length relationships.

In addition, considering that equations for total length-fork length, total length-head girth and total length-maximum girth would not suffice to draw meaningful conclusions without the weight data of the species, length-weight relationship for the sample was also determined. Although the length-weight relationship determined in this study was similar to the findings of Bal et al. (2015), it completely differed from the findings of Erkoyuncu et al. (1994), Kalaycı et al. (2007) and Bök et al. (2011). The reason for finding negative allometric growth may be that the samples consisted of individuals of smaller sizes (Table 1). Such a result might be obtained if the datasets used for length-weight relationship calculations consist of juveniles that have not reached their mature body shape (Safran, 1992), or consist of old individuals that have lost their body shape due to fat deposition (Froese, 2006), or include an insufficient sample size of individuals with a very narrow length (İlkyaz et al., 2010).

The determination coefficients of the relationships between the total length-head girth and the total length-maximum girth revealed strong relationships between these parameters. These parameters directly affect the accuracy of the results obtained from the theoretical catch probability that forms the method of this study. Therefore, these strong relationships were considered to positively affect the results. In addition, steepness and width of the selectivity curves that were plotted with the model are closely associated with the morphology of species. Curves of fusiform fish species are narrow and steep, whereas curves of compressiform species are broad and flat (Hovgård and Lassen, 2000). This is also directly associated with the catch rate at optimum catch length calculated for the mesh size. In this study, the equation for mesh size length-catch rate generated a characteristic bell-curve suited to the morphology of the species.

van der Elst and Adkin (1991) reported that the length at first maturity for male individuals of the species inhabiting the Natal (South Africa) region was 24 cm, whereas the length at first maturity for female individuals was 25 cm fork length. Kailola et al. (1993) determined this parameter as 30 cm total length at 2 years of age for eastern coasts of Australia. Salerno et al. (2001) reported that the length at first maturity for male individuals of the species inhabiting the coasts of the USA was 33.9 cm, whereas the length at first maturity for female individuals was 33.4 cm fork length. It is expected for this parameter to differ between stocks from different environments and the established length value for the stock in Turkey is one of the lowest among the values established for different geographical conditions. The legal catch length for the species should be supported by scientific findings and indicate mature individuals that have completed their first reproductive cycle. However, the legal catch length implementation in Turkey is considerably below the required length.

In this study, due to the two different catch lengths for bluefish fishing obtained by a legal study and a scientific study, two different catch lengths were used in the calculations for bluefish fishing. By using the mesh size-catch rate equation given in this study, the catch rate of the desired mesh size for any length group can be calculated. Considering the legal catch length, the use of gillnets with a 55 mm stretched mesh size is deemed appropriate, whereas considering the scientific findings, the use of gillnets with an 85 mm stretched mesh size is appropriate. The optimum catch length of the gillnet that allows for fishing above the legal length is notably below the scientifically approved length at first maturity and even the largest fish length that can be captured with this length is below the scientific length (Figure 2). Since different names are used for different sizes in Turkey, individuals at 25 cm or above are called bluefish, however the size that the current legal regulation allows for fishing is “çinekop” (the name of the bluefish with a length between 10 and 20 cm TL). In other words, the fishing length allowed in Turkey is considerably below the fishing length that should be legally implemented for sustainable fishery. Gillnets with an 85 mm stretched mesh should be used to catch bluefish at acceptable sizes; that is, 28.0 cm total length or above.

Although direct estimation methods also allow for estimating gillnet selectivity parameters by using morphometric

measurements of many fish species (Sechin, 1969; Kawamura, 1972) or fishing individuals whose length-frequency information is known (İlkyaz, 2005), indirect estimation methods are mostly preferred for determining these parameters (Hovgård and Lassen, 2000). The direct estimation model ignores coincidentally captured individuals that were caught on other body parts. However, this method is suited to the bluefish with a morphology that allows for gilled and wedged because there are no extremities on the body. In addition, the direct estimation model does not consider whether or not the length groups suited to capture are in the fishing area. In practical environments, the lack of the length size classes can affect the result to a limited extent. On the other hand, Özekinci (2005) showed the similarity of direct and indirect selectivity estimation results.

In Turkey, by using indirect methods, Sümer et al. (2010) studied the selectivity of 40 and 44 mm monofilament and multifilament gillnets, while Acarlı et al. (2013) studied the selectivity of 44, 46, 50 and 56 mm multifilament gillnets. In the studies conducted in other geographical regions, Trent and Pristas (1977) studied gillnets with a mesh size of at least 63 mm in the St. Andrew Bay in Florida, USA, while Lucena et al. (2000) studied a 90 mm mesh size in the southern coasts of Brazil. Compared with the sizes used in these studies, considerably smaller mesh sizes have been used in the studies from Turkey. The reason for choosing smaller mesh sizes in Turkey is commercial fishers' effort to catch smaller individuals, the lack of legal repercussions and the researchers' interest in determining the catch performance of these mesh sizes used in commercial fishing.

In this study, theoretical catch rate of gillnet was determined by utilizing the morphological structure of bluefish, and its relationship with the legal length and length at first maturity in Turkey. In addition, findings on length-length and length-weight of the species were presented.

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