

Effect of twine thickness on size selectivity and catch efficiency of gillnets used in Prussian carp (*Carassius gibelio*) fisheries

Sade uzatma ağlarında farklı ip kalınlığındaki sade ağ kullanımının gümüşü havuz balığı (*Carassius gibelio*) avcılığında boy seçiciliği ve av verimi üzerindeki etkileri

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Abstract: This study evaluated the effects of twine thickness and mesh size on the size selectivity and catch efficiency of gillnets used to control the invasive Prussian carp, *Carassius gibelio* (Bloch, 1782) population in the Karakaya Dam Lake, Türkiye. A total of 1.675 individuals ranging from 17.0 to 31.2 cm in length were captured. Among the tested configurations, the gillnet with 84 mm mesh size and 0.23 mm twine thickness demonstrated the highest catch efficiency, accounting for 50.4% of the total catch, whereas the 76 mm mesh with 0.18 mm twine yielded only 17.9%. Statistical analysis confirmed that mesh size significantly influenced the average length of captured fish ($p < 0.05$), with larger mesh sizes capturing longer individuals. Seasonal variation was notable, with peak catches observed in December (375 specimens) and January (316 specimens), aligning with the winter schooling behaviour of the species that enhances catchability. The SELECT method was used to model size selectivity, and the lognormal model provided the best fit across all twine thicknesses. Modal lengths of 20.59 cm (0.23 mm), 20.97 cm (0.20 mm), and 21.64 cm (0.18 mm) were estimated, indicating minimal variation due to twine thickness. Although twine thickness did not significantly affect selectivity, it enhanced catch efficiency, particularly for larger individuals. These findings suggest that gillnets with thicker twine and larger mesh sizes are more effective for managing *C. gibelio* populations, especially during winter months. Moreover, the use of durable gear contributes to reduced gear loss and increased operational lifespan, supporting the socioeconomic sustainability of local fisheries. This research provides a scientific foundation for developing seasonally optimized and gear-specific strategies for managing invasive species in Turkish inland waters.

Keywords: Invasive species management, catch efficiency, gillnet selectivity, twine thickness

Öz: Bu çalışmada, Karakaya Baraj Gölü'ndeki (Malatya, Türkiye) istilacı gümüşü havuz balığı, *Carassius gibelio* (Bloch, 1782) popülasyonun avcılık ile kontrol edilebilmesine yönelik olarak, farklı ip kalınlığı ve ağ göz açıklığındaki sade uzatma ağı kullanımının avın boy seçiciliği ve verimliliği üzerindeki etkileri araştırılmıştır. Çalışmada 17,0-31,2 cm toplam boy aralığında 1.675 birey yakalanmıştır. Test edilen konfigürasyonlar arasında, 84 mm ağ gözü açıklığına ve 0,23 mm ip kalınlığına sahip sade ağ, toplam avın %50,4'ünü oluşturarak en yüksek av verimliliğini göstermiş; buna karşın 76 mm ağ gözü açıklığına ve 0,18 mm ip kalınlığına sahip ağ yalnızca %17,9 verim sağlamıştır. İstatistiksel analiz, ağ gözü açıklığının yakalanan balıkların ortalama uzunluğunu önemli ölçüde etkilediğini ($p < 0,05$) ve daha büyük ağ gözü açıklıklarının daha uzun bireyleri yakaladığını doğrulamıştır. Mevsimsel farklılık dikkat çekici olup, en yüksek av Aralık (375 örnek) ve Ocak (316 örnek) aylarında elde edilmiştir. Bu durum, türün avlanabilirliğini artıran kış dönemi sürü oluşturma davranışı ile uyumludur. Ağların boy seçiciliğinin modellenmesinde SELECT yöntemi kullanılmış ve lognormal model, tüm ip kalınlıkları için en iyi uyumu sağlamıştır. İp kalınlığından kaynaklanan minimum varyasyonu gösteren model uzunluklar sırasıyla 20,59 cm (0,23 mm), 20,97 cm (0,20 mm) ve 21,64 cm (0,18 mm) mm olarak tahmin edilmiştir. İp kalınlığı seçiciliği önemli ölçüde etkilemeye de, özellikle daha büyük bireyler için av verimliliğini artırmıştır. Bu bulgular, daha kalın ipli ve daha büyük ağ gözü açıklığına sahip sade ağların, özellikle kış aylarında *C. gibelio* popülasyonlarını avlamada daha etkili olduğunu göstermiştir. Ayrıca, dayanıklı av araçlarının kullanılması, av aracı kaybının azalmasına ve operasyonel ömrün uzamasına katkıda bulunarak yerel balıkçılığın sosyoekonomik sürdürülebilirliğini desteklemektedir. Bu araştırma, Türkiye iç sularındaki istilacı türlerin yönetimi için mevsime göre optimize edilmiş ve av aracına özgü stratejiler geliştirilmesi adına bilimsel bir temel sunmaktadır.

Anahtar kelimeler: İstilacı tür yönetimi, av verimliliği, ağ seçiciliği, ip kalınlığı

INTRODUCTION

Inland aquatic ecosystems in Türkiye possess high biodiversity and play a critical role in both ecological sustainability and economic productivity. However, intensified anthropogenic pressures and global environmental changes are increasingly threatening these ecosystems. The spread of invasive species is a significant threat. These species, which are typically introduced through human activities and are not part of the native fauna, compete with native species for food,

habitat, and reproductive space. Consequently, they disrupt the ecological balance, reduce native population sizes, and pose a serious risk to overall biodiversity (Tarkan et al., 2012; Çiçek et al., 2018).

Carassius gibelio (Prussian carp), one of the most widespread invasive fish species in the inland waters of Türkiye, is distinguished by its high reproductive capacity,

gynogenetic reproduction ability, and remarkable tolerance to environmental stressors. These biological traits facilitate rapid adaptation to new habitats and enable the species to become dominant within invaded ecosystems (Erdem et al., 2014; Aydın, 2021). Due to these characteristics, *C. gibelio* has rapidly spread into new habitats and established dominance in invaded ecosystems. In large reservoirs such as Karakaya Dam Lake, its population density has reached levels that pose a significant threat to native species, exerting considerable pressure on the ecosystem balance. This discrepancy is thought to arise similarly from species-dependent morphological differences (Dürhani et al., 2023).

Controlling invasive species is a fundamental requirement for sustainable fisheries management and the preservation of aquatic ecosystem health. In this context, passive fishing gears designed to increase harvest pressure are among the most effective and practical methods for reducing the population density of invasive species (Erdem et al., 2014; Rytwinski et al., 2019). Technical specifications of gillnets, particularly mesh

size and twine thickness, play a critical role in the effectiveness of control strategies for invasive fish species. The literature has extensively examined the influence of these parameters on gear selectivity and catch efficiency, yielding valuable insights into optimal net configurations for suppressing invasive populations (Cilbiz et al., 2014a; Aydın et al., 2018).

MATERIALS AND METHODS

Study area

The study was conducted in the 3rd and 4th fishing zones of Karakaya Dam Lake. The 3rd zone falls under the jurisdiction of the S.S. Adagören, Ağilyazı, Kuluşağı, and İmamlı Fisheries Cooperative, while the 4th zone is managed by the S.S. Hasırcı, Boran, and Toygar Fisheries Cooperative. These areas were selected based on discussions with cooperative presidents and members, who confirmed that *C. gibelio* is widely caught in these regions. The study utilized gillnets commonly employed by these cooperatives. Figure 1 illustrates the research area and sampling coordinates.

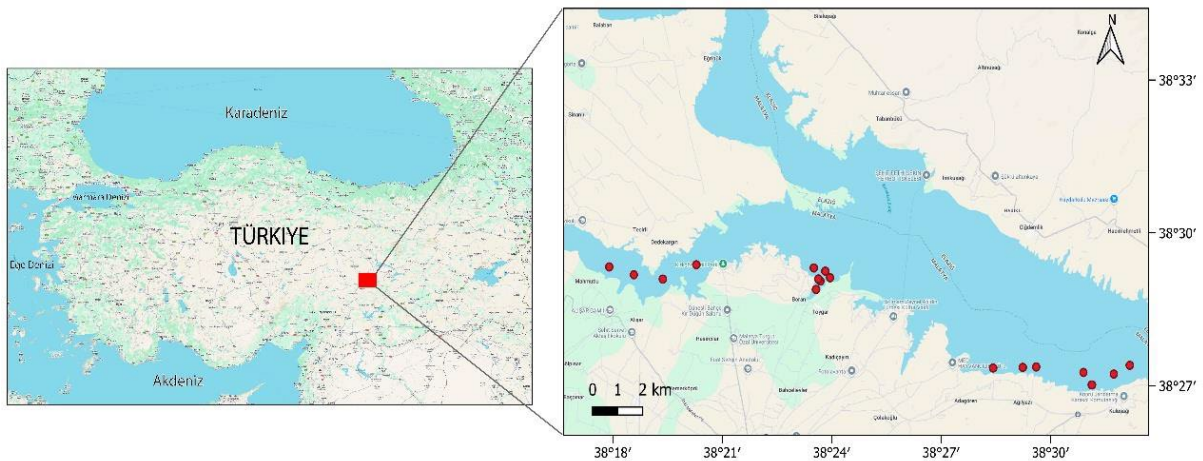


Figure 1. Map of Karakaya Dam Lake showing the sampling stations for Prussian carp (*Carassius gibelio* Bloch, 1782).

Data collection

This study evaluated the selectivity characteristics of gillnets for controlling the population of the invasive species *C. gibelio* in Karakaya Dam Lake. Fishing trials were conducted using nets with varying mesh sizes and twine thicknesses to analyze the species' population structure, catch efficiency, and seasonal distribution. The results revealed that nets with an 84 mm mesh size and 0.23 mm twine thickness yielded the highest catch efficiency. This finding provides a novel contribution by linking gear selectivity with the seasonal behavior of invasive species, particularly their tendency to form schools during winter months, which can be strategically targeted in removal efforts. The outcomes of the study support the development of scientifically grounded, locally applicable, and sustainable fisheries management strategies for invasive species control. Furthermore, the inclusion of recreational fishers in these efforts is recommended to enhance public engagement in ecosystem conservation.

Size selectivity of gillnets

The SELECT (Share Each Length's Class Catch Total) method was used to estimate selectivity indirectly (Millar, 1992; Millar and Fryer, 1999; Millar and Holst, 1997). Data were analyzed using RStudio software with R codes developed by Millar (2015, 2017). The length selectivity for each mesh size was described using five different models within the SELECT method: normal location [I], normal scale [II], gamma [III], lognormal [IV], and bi-normal [V] (Millar and Fryer, 1999; Park et al., 2011). The most suitable model was selected based on the lowest deviance value. The equations for each model are as follows:

$$\text{Normal Location} \quad \exp\left(-\frac{(L-k.m_j)^2}{2\sigma^2}\right) \quad \text{I}$$

$$\text{Normal Scale} \quad \exp\left(-\frac{(L-k_1.m_j)^2}{2k_2^2.m_j^2}\right) \quad \text{II}$$

$$\begin{aligned}
 \text{Log-Normal} & \quad \frac{1}{L} \exp\left(\mu + \log\left(\frac{m_j}{m_1}\right) - \frac{\sigma^2}{2} - \frac{(\log(L) - \mu - \log(\frac{m_j}{m_1}))^2}{2\sigma^2}\right) & \text{III} \\
 \text{Gamma} & \quad \left(\frac{L}{(\alpha-1)k.m_j}\right)^{\alpha-1} \exp\left(\alpha - 1 - \frac{L}{k.m_j}\right) & \text{IV} \\
 \text{Bi-normal} & \quad \exp\left(-\frac{(L-k_1.m_j)^2}{2k_1^2.m_j^2}\right) + c.\exp\left(-\frac{(L-k_2.m_j)^2}{2k_2^2.m_j^2}\right) & \text{V}
 \end{aligned}$$

Catch efficiency

Length-dependent catch comparison and catch ratio analyses were conducted to compare the catch efficiency between commercial and experimental gillnet configurations (Cerbule et al., 2021; Fakioglu et al., 2023; Lomeli et al., 2020; Lomeli et al., 2021). The length-dependent catch comparison rate, $CC(l,v)$, and catch ratio, $CR(l,v)$, were estimated for *C. gibelio* to investigate potential differences in catch efficiency for each configuration. We used Equation [IX] to assess the relative length-dependent catch comparison rate (CC) of changing from one net configuration to another (Lomeli et al., 2021; Cerbule et al., 2021; Fakioglu et al., 2023). The modelled catch comparison rate, $CC(l,v)$, experimentally expressed by Eq. [VI], was obtained using maximum likelihood estimation by minimizing Expression [VII] (Lomeli et al., 2021; Fakioglu et al., 2023). The experimental CC was modeled by the function $CC(l,v)$ using Equation [VIII] (Fakioglu et al., 2023). The catch ratio $CR(l,v)$, defined in Equation [IX], was used to provide the direct relative value of catch efficiency between the compared panels (Lomeli et al., 2021; Cerbule et al., 2021; Fakioglu et al., 2023). The double bootstrapping method with 1,000 repetitions was used to estimate the Efron 95% confidence intervals (CIs) (Efron, 1982) for both catch comparison and catch ratio. The equilibrium points for catch efficiency were 0.5 for the catch comparison rate and 1.0 for the catch ratio (Fakioglu et al., 2023). The statistical software SELNET was used for the relative catch efficiency analysis (Herrmann et al., 2017; Herrmann et al., 2012).

$$CC_l = \frac{\sum_{j=1}^h \left\{ \frac{nd_{lj}}{qd_j} \right\}}{\sum_{j=1}^h \left\{ \frac{nd_{lj} + ns_{lj}}{qd_j + qs_j} \right\}} \quad \text{VI}$$

$$-\sum_{j=1}^h \sum_l \left\{ \frac{nd_{lj}}{qd_j} x \ln[CC(l,v)] + \frac{ns_{lj}}{qs_j} x \ln[1.0 - CC(l,v)] \right\} \quad \text{VII}$$

$$CC(l,v) = \frac{\exp[f(l,v_0, \dots, v_k)]}{1 + \exp[f(l,v_0, \dots, v_k)]} \quad \text{VIII}$$

$$CR(l,v) = \frac{CC(l,v)}{[1 - CC(l,v)]} \quad \text{IX}$$

RESULTS

Catch composition

During the research period, 1,675 specimens of *C. gibelio* were captured, ranging in total length from 17.0 to 31.2 cm and in total weight from 105.3 to 356.3 g. When evaluated based on twine thickness, nets with 0.23 mm twine were the most efficient, accounting for 50.4% of the catch, while those with 0.18 mm twine were the least efficient, accounting for 17.9%. Similarly, regarding mesh size, the 84 mm mesh size was found to be the most efficient, whereas the 76 mm mesh size was the least efficient. An increase in mesh size resulted in a statistically significant increase in the average length of the captured fish (Table 1).

Table 1. Catch numbers and total length distribution of Prussian carp (*Carassius gibelio* Bloch, 1782) caught by experimental gillnets

Twine thickness (mm)	Mesh size (mm)	N	Min–Max	Mean ± SE	CI (%95)
0.18	76	51	17.0–26.0	^a 22.127±0.285 ^x	0.572
	80	69	17.3–28.1	^{bcd} 23.641±0.240 ^y	0.480
	84	130	20.4–26.9	^{bcd} 24.163±0.144 ^{yz}	0.284
	88	50	20.7–26.8	^{bcd} 24.524±0.193 ^z	0.389
0.20	76	72	18.0–27.5	^a 22.132±0.242 ^x	0.482
	80	105	17.5–29.8	^b 23.497±0.221 ^y	0.439
	84	240	17.2–31.2	^{ce} 24.553±0.132 ^z	0.260
	88	114	17.5–30.2	^{cde} 24.489±0.195 ^z	0.386
0.23	76	124	17.0–28.7	^a 22.266±0.199 ^x	0.394
	80	138	17.4–29.8	^{bd} 23.680±0.222 ^y	0.438
	84	385	17.1–29.8	^{bcd} 24.201±0.113 ^y	0.222
	88	197	18.5–28.9	^e 24.748±0.142 ^z	0.280

^aDifferent letters in the same column indicate statistical differences in total lengths ($p < 0.05$). The letters x, y, and z represent comparisons within the same twine thickness, while a, b, c, d, and e represent the overall means. CI: 95% confidence interval of the means.

The number of *C. gibelio* specimens captured per sampling period showed statistically significant differences based on both twine thickness ($X^2 = 29.7$, $p = 0.040$) and mesh size ($X^2 = 233.14$, $p < 0.001$). Overall,

catch efficiency was much higher during winter than during other seasons (Table 2). Similarly, the average fish lengths varied significantly according to the month of capture ($p < 0.05$) (Figure 2).

Table 2. Number of caught Prussian carp (*Carassius gibelio* Bloch, 1782) by sampling months, twine thickness, and mesh size

Months	N	Twine thickness (mm)			Mesh size (mm)			
		0.18	0.2	0.23	76	80	84	88
January	316	75	96	145	25	58	165	68
February	212	46	61	105	8	24	111	69
March	133	14	33	86	11	12	86	24
April	-	-	-	-	-	-	-	-
May	-	-	-	-	-	-	-	-
June	-	-	-	-	-	-	-	-
July	112	14	39	59	31	37	34	10
August	92	14	28	50	28	22	33	9
September	71	8	27	36	22	9	34	6
October	115	16	43	56	32	17	44	22
November	249	45	79	125	21	49	116	63
December	375	68	125	182	69	84	132	90

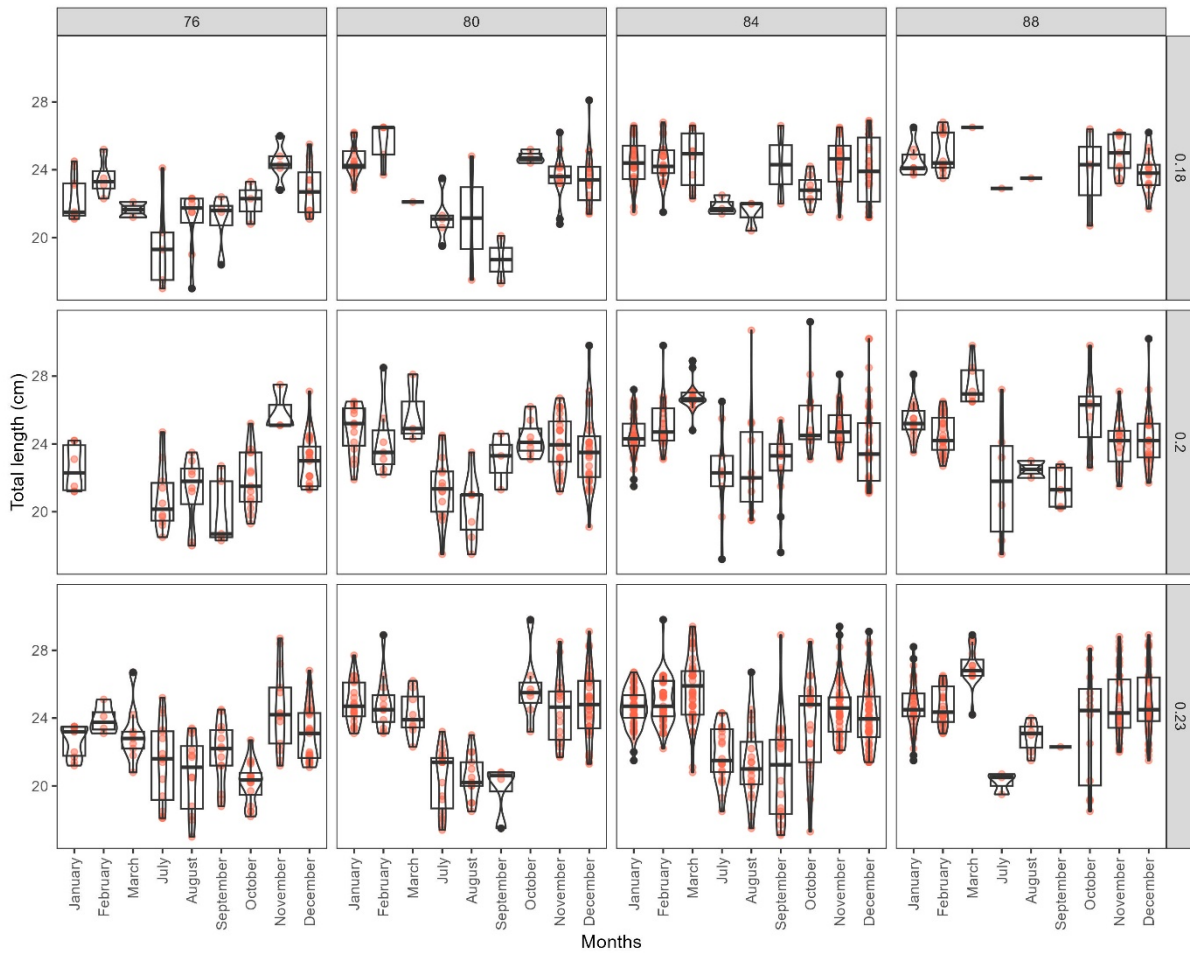


Figure 2. Length distribution of Prussian carp (*Carassius gibelio* Bloch, 1782) by sampling months, twine thickness, and mesh size

Size selectivity of gillnets

Table 3 presents the estimated selectivity parameters for the gillnet with a mesh size of 76 mm and a twine thickness of 0.18 mm, based on different models. The lognormal model, which yielded the

lowest deviation, was determined to be the most suitable for the dataset. Accordingly, the estimated modal length for *C. gibelio* captured by this gillnet was 21.64 cm, with a spread of 2.02 cm.

Table 3. Selectivity model parameters of Prussian carp (*Carassius gibelio* Bloch, 1782) for gillnets with a 76 mm mesh size and 0.18 mm twine thickness

Model	Parameters	Equal fishing power						
		Estimates	Mode 1	Spread 1	Mode 2	Spread 2	Deviance	df
Normal location	k	2.86(0.03)	21.71(0.22)	2.17(0.16)	-	-	78.77	34
	σ	2.17(0.16)						
Normal scale	k ₁	2.87(0.02)	21.83(0.22)	2.01(0.15)	-	-	78.07	34
	k ₂	0.07(0.01)						
Lognormal	μ_1	3.04(0.01)	21.64(0.22)	2.02(0.15)	-	-	76.91	34
	σ	0.12(0.01)						
Gamma	k	0.02(0.01)	21.71(0.23)	2.01(0.15)	-	-	77.04	34
	α	118.35(17.96)						
Bi-normal	k ₁	-	-	-	-	-	-	-
	k ₂							
	k ₃							
	k ₄							
	c							

Model	Parameters	Fishing power α mesh size						
		Estimates	Mode 1	Spread 1	Mode 2	Spread 2	Deviance	df
Normal location	k	2.88(0.03)	21.90(0.22)	2.17(0.16)	-	-	78.37	34
	σ	2.17(0.16)						
Normal scale	k ₁	2.89(0.02)	22.01(0.22)	2.00(0.15)	-	-	78.08	34
	k ₂	0.06(0.01)						
Lognormal	μ_1	3.05(0.01)	21.83(0.22)	2.04(0.15)	-	-	76.90	34
	σ	0.12(0.00)						
Gamma	k	0.02(0.01)	21.89(0.22)	2.02(0.15)	-	-	77.04	34
	α	119.35(17.96)						
Bi-normal	k ₁	-	-	-	-	-	-	-
	k ₂							
	k ₃							
	k ₄							
	c							

Table 4 presents the estimated selectivity parameters for the gillnet with a mesh size of 76 mm and a twine thickness of 0.20 mm, based on different models. The gamma model, yielding the lowest

deviance, was determined to be the most suitable for the dataset. Accordingly, the modal length for *C. gibelio* captured by this gillnet was estimated to be 20.97 cm, with a spread of 2.38 cm.

Table 4. Selectivity model parameters of Prussian carp (*Carassius gibelio* Bloch, 1782) for gillnets with a 76 mm mesh size and 0.20 mm twine thickness

Model	Parameters	Equal fishing power						
		Estimates	Mode 1	Spread 1	Mode 2	Spread 2	Deviance	df
Normal location	k	2.85(0.02)	20.98(0.27)	2.59(0.16)	-	-	138.20	43
	σ	2.16(0.16)						
Normal scale	k ₁	2.87(0.02)	21.12(0.29)	2.46(0.17)	-	-	132.64	43
	k ₂	0.07(0.01)						
Lognormal	μ_1	3.05(0.01)	20.89(0.26)	2.38(0.15)	-	-	133.61	43
	σ	0.11(0.007)						
Gamma	k	0.04(0.004)	20.97(0.27)	2.38(0.15)	-	-	132.62	43
	α	79.09(10.961)						
Bi-normal	k ₁	-	-	-	-	-	-	-
	k ₂							
	k ₃							
	k ₄							
	c							

Model	Parameters	Fishing power α mesh size						
		Estimates	Mode 1	Spread 1	Mode 2	Spread 2	Deviance	df
Normal location	k	2.88(0.02)	21.26(0.26)	2.61(0.17)	-	-	137.48	43
	σ	2.17(0.16)						
Normal scale	k ₁	2.89(0.02)	21.40(0.27)	2.45(0.17)	-	-	132.65	43
	k ₂	0.07(0.01)						
Lognormal	μ_1	3.06(0.01)	21.15(0.25)	2.41(0.15)	-	-	133.61	43
	σ	0.11(0.007)						
Gamma	k	0.04(0.004)	21.45(0.25)	2.40(0.15)	-	-	132.62	43
	α	80.10(10.61)						
Bi-normal	k ₁	-	-	-	-	-	-	-
	k ₂							
	k ₃							
	k ₄							
	c							

Table 5 presents the estimated selectivity parameters for the gillnet with a mesh size of 76 mm and a twine thickness of 0.23 mm, based on different models. gamma model, yielding the lowest deviance, was

determined to be the most suitable for the dataset. Accordingly, the modal length for *C. gibelio* captured by this gillnet was estimated to be 20.59 cm, with a spread of 2.56 cm.

Table 5. Selectivity model parameters of Prussian carp (*Carassius gibelio* Bloch, 1782) for gillnets with a 76 mm mesh size and 0.23 mm twine thickness

Model	Parameters	Equal fishing power						Deviance	df
		Estimates	Mode 1	Spread 1	Mode 2	Spread 2			
Normal location	k	2.85(0.02)	20.62(0.26)	2.75(0.14)	-	-	178.69	40	
	σ	2.16(0.16)							
Normal scale	k ₁	2.87(0.02)	20.74(0.29)	2.67(0.16)	-	-	173.58	40	
	k ₂	0.07(0.01)							
Lognormal	μ_1	3.04(0.01)	20.49(0.25)	2.55(0.13)	-	-	174.14	40	
	σ	0.12(0.007)							
Gamma	k	0.04(0.004)	20.59(0.26)	2.56(0.13)	-	-	173.03	40	
	α	66.71(7.63)							
Bi-normal	k ₁	-	-	-	-	-	-	-	
	k ₂	-							
	k ₃	-							
	k ₄	-							
	c	-							

Model	Parameters	Fishing power α mesh size						Deviance	df
		Estimates	Mode 1	Spread 1	Mode 2	Spread 2			
Normal location	k	2.88(0.02)	21.93(0.25)	2.77(0.14)	-	-	177.75	40	
	σ	2.17(0.16)							
Normal scale	k ₁	2.89(0.02)	21.85(0.26)	2.65(0.15)	-	-	173.62	40	
	k ₂	0.06(0.01)							
Lognormal	μ_1	3.05(0.01)	20.80(0.24)	2.58(0.13)	-	-	174.14	40	
	σ	0.12(0.007)							
Gamma	k	0.04(0.004)	20.91(0.24)	2.57(0.13)	-	-	173.03	40	
	α	67.72(7.63)							
Bi-normal	k ₁	-	-	-	-	-	-	-	
	k ₂	-							
	k ₃	-							
	k ₄	-							
	c	-							

Figure 3 displays the fitted selectivity curves and the corresponding deviance residuals. The selectivity curves for gillnets with different twine thicknesses were very similar. These curves, characterized by a single peak, indicate that the catch was generally retained by gilling or wedging. For all three twine thicknesses, positive residuals were prominent for individuals exceeding 24 cm in total length with the 84 mm mesh size, whereas negative residuals were observed for other mesh sizes. The fishing power of the 76, 80, and 88 mm mesh sizes was lower than that of the model (indicated by negative residuals).

Catch efficiency

Table 6 presents the results of the catch efficiency analysis for gillnets with a 76 mm mesh size, based on twine thickness. The experimental data fit for the modeled catch comparison rates was evaluated as poor for the 0.18 mm vs. 0.20 mm comparison, as the estimated p-value was below 0.05. No statistically significant differences were observed in length classes or catch comparisons for gillnets with the 76 mm mesh size.

Table 7 presents the results of the catch efficiency analysis for gillnets with an 80 mm mesh size, based on twine thickness. The experimental data fit for the modeled catch comparison rates was evaluated as poor for the 0.18 mm vs. 0.20 mm comparison, as the estimated p-value was below 0.05. There were no statistical differences in length classes or comparisons for gillnets with the 80 mm mesh size.

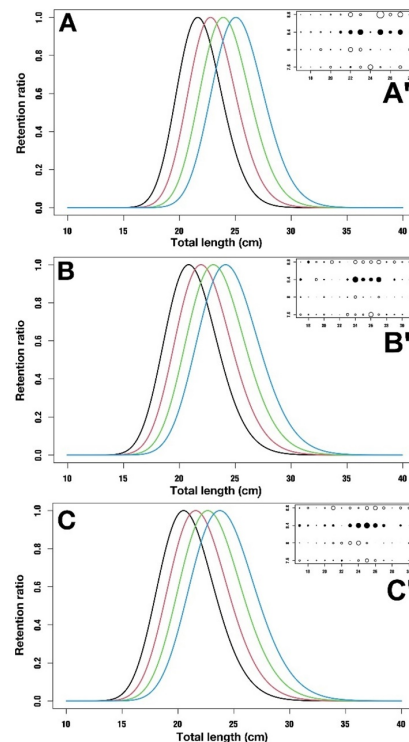


Figure 3. Selection curves (A, B, C) and deviance residual plots (A', B', C') of gillnets for Prussian carp (*Carassius gibelio* Bloch, 1782)

Table 6. Catch ratio (CR) results (in %) at different lengths and fit statistics for the catch comparison analysis of Prussian carp (*Carassius gibelio* Bloch, 1782) for three mesh sizes (76 mm). Values in brackets represent the 95% confidence limits.

Length class (cm)	Twine thickness		
	0.18-0.20 mm	0.18-0.23 mm	0.20-0.23
17	120.30(43.38–592.74)	180.93(63.77–1003.98)	149.96(96.30–1131.58)
18	123.67(39.99–415.53)	188.76(72.30–804.80)	152.03(100.55–630.50)
19	127.19(61.34–311.54)	197.59(87.72–604.93)	154.68(111.84–364.82)
20	130.98(50.37–253.84)	207.81(105.31–442.92)	158.02(127.96–255.87)
21	135.13(39.53–214.75)	219.9(124.54–345.16)	162.2(130.88–257.00)
22	139.76(34.33–227.39)	234.41(148.34–344.17)	167.35(118.59–264.02)
23	145.03(42.75–259.21)	252.05(160.38–364.67)	173.66(103.87–315.02)
24	151.10(39.43–328.43)	273.75(167.88–434.05)	181.33(83.28–363.19)
25	158.19(41.85–411.08)	300.64(161.71–681.95)	190.61(82.66–507.64)
26	166.51(43.03–731.97)	334.02(139.70–1053.66)	201.74(66.41–747.94)
27	176.35(26.40–1323.26)	375.14(120.09–1580.43)	215.01(51.83–1035.50)
28	187.90(22.59–2304.33)	424.73(100.31–2601.09)	230.64(39.43–1586.52)
29	201.28(19.51–3719.61)	482.49(84.48–4375.24)	248.72(29.44–2216.07)
30	216.47(17.02–4649.97)	547.20(71.77–7082.05)	269.14(21.81–6361.41)
31	233.43(15.00–5814.29)	617.18(65.37–10922.22)	291.47(16.27–20095.10)
p-value	0.0447	0.2566	0.2639
Deviance	14.38	10.12	10.02
DF	7	8	8

Table 7. Catch ratio (CR) results (in %) at different lengths and fit statistics for the catch comparison analysis of Prussian carp (*Carassius gibelio* Bloch, 1782) for three twine thickness comparisons with 80 mm mesh sizes. Values in brackets represent the 95% confidence limits.

Length class (cm)	Twine thickness		
	0.18-0.20 mm	0.18-0.23 mm	0.20-0.23
17	187.92(30.40–119598.43)	691.49(67.46–7027.17)	150.49(15.22–1219.22)
18	181.23(52.57–34233.75)	496.57(73.85–3154.29)	139.23(18.32–605.06)
19	173.10(77.63–8570.06)	353.68(80.79–1397.73)	129.61(23.35–353.80)
20	164.68(90.86–2014.41)	258.44(80.51–741.59)	122.59(31.02–213.68)
21	156.88(92.06–533.65)	198.98(84.73–390.46)	118.45(42.37–172.30)
22	150.47(88.83–411.89)	164.85(87.86–380.89)	117.19(70.13–167.01)
23	146.05(77.72–280.73)	149.58(92.23–357.23)	118.9(69.38–171.05)
24	144.20(73.68–266.27)	151.12(98.46–321.20)	123.83(74.63–158.45)
25	145.51(84.16–323.38)	172.83(117.41–306.79)	132.54(77.25–176.10)
26	150.81(91.82–392.11)	227.49(137.69–478.28)	145.91(91.02–227.88)
27	161.15(87.77–595.67)	348.95(162.94–1144.79)	165.14(106.96–327.50)
28	177.68(52.32–2375.85)	622.04(163.00–3571.15)	191.61(102.69–638.39)
29	200.59(23.46–18860.06)	1236.67(169.57–17793.01)	226.07(77.50–1915.31)
30	227.46(17.63–132815.02)	2458.69(144.30–138563.84)	267.24(55.40–5099.70)
31	253.15(15.42–919743.62)	4157.56(124.14–915170.53)	310.57(38.25–11222.57)
p-value	0.0636	0.1258	0.5771
Deviance	16.16	13.90	7.58
DF	9	9	9

Table 8 presents the results of the catch efficiency analysis for gillnets with an 84 mm mesh size, based on twine thickness. The fit of the experimental data for the modelled catch comparison rates was evaluated as poor

for the 0.20–0.23 mm comparison, as the estimated p -value was below 0.05. No statistical differences were observed in length classes or comparisons for gillnets with the 84 mm mesh size.

Table 8. Catch ratio (CR) results (in %) at different lengths and fit statistics for the catch comparison analysis of Prussian carp (*Carassius gibelio* Bloch, 1782) for three twine thickness comparisons with the 84 mm mesh size. Values in brackets represent the 95% confidence limits.

Length class (cm)	Twine thickness		
	0.18-0.20 mm	0.18-0.23 mm	0.20-0.23
17	249.56(50.02–4005.31)	1909.21(218.64–11235.85)	272.66(91.96–2500.51)
18	219.83(55.39–1876.82)	1197.12(214.56–4871.71)	251.13(105.51–1389.08)
19	193.27(59.67–854.32)	757.24(209.89–2347.52)	230.51(120.05–733.63)
20	172.28(67.14.00–442.10)	501.48(206.81–1192.84)	212.28(134.36–414.43)
21	157.93(70.07–280.12)	357.46(207.88–665.38)	196.82(132.40–315.79)
22	150.61(75.86–232.55)	279.09(196.49–440.11)	183.85(133.40–255.05)
23	150.73(85.47–221.64)	241.43(184.71–332.44)	172.82(133.27–229.17)
24	159.51(103.3–218.43)	233.56(194.20–306.25)	163.18(116.65–204.05)
25	179.79(128.13–255.30)	254.98(214.30–342.32)	154.42(108.73–194.05)
26	217.28(158.87–334.66)	317.05(241.68–473.46)	146.13(95.76–189.98)
27	282.66(183.31–603.44)	453.09(288.35–880.23)	137.95(79.55–185.29)
28	394.06(191.71–1624.62)	749.02(331.72–2125.27)	129.59(65.65–189.58)
29	576.58(213.91–5285.76)	1429.18(415.04–6344.73)	120.82(53.76–217.98)
30	850.37(231.51–19373.86)	3071.36(560.86–25619.27)	111.47(39.74–268.08)
31	1207.18(252.96–118099.08)	6922.05(747.56–103914.96)	101.66(25.78–340.11)
p-value	0.1130	0.1899	0.0202
Deviance	14.27	12.43	21.14
DF	9	9	10

Table 9 presents the results of the catch efficiency analysis for gillnets with an 88 mm mesh size, based on twine thickness. The fit of the experimental data for the modelled catch comparison rates was evaluated as poor for the 0.18–0.23 mm

and 0.20–0.23 mm comparisons, as the estimated *p*-values were below 0.05. No statistical differences were observed in length classes or comparisons for gillnets with the 88 mm mesh size.

Table 9. Catch ratio (CR) results (in %) at different lengths and fit statistics for the catch comparison analysis of Prussian carp (*Carassius gibelio* Bloch, 1782) for three twine thickness comparisons with the 88 mm mesh size. Values in brackets represent the 95% confidence limits.

Length class (cm)	Twine thickness		
	0.18-0.20 mm	0.18-0.23 mm	0.20-0.23
17	2160.10(220.57–181006.97)	2625.18(306.26–804150.76)	115.64(12.55–587.14)
18	1913.24(210.33–76143.7)	2340.41(313.17–325719.34)	120.94(19.00–535.29)
19	1491.67(192.29–31072.21)	1860.68(312.77–101129.41)	126.87(28.81–394.48)
20	980.52(168.58–11227.29)	1281.37(309.53–32460.99)	133.44(42.91–307.43)
21	572.59(147.08–2991.75)	798.50(288.62–9745.45)	140.66(57.72–288.52)
22	337.25(135.22–1056.11)	500.55(252.74–2323.42)	148.55(87.97–251.81)
23	223.47(132.24–424.36)	349.58(227.83–760.95)	157.11(100.01–245.21)
24	176.97(129.39–243.08)	290.53(211.06–524.74)	166.35(114.62–236.40)
25	172.62(129.02–218.21)	298.60(188.18–566.29)	176.26(128.63–254.87)
26	211.71(133.76–403.01)	389.72(202.05–753.5)	186.81(137.44–268.44)
27	330.96(142.47–1104.64)	656.15(297.19–1708.09)	197.95(143.18–308.63)
28	647.05(153.42–5909.12)	1398.29(415.60–4950.75)	209.55(138.85–370.02)
29	1416.13(175.43–30593.48)	3384.39(472.60–27627.92)	221.39(110.85–496.85)
30	2731.35(194.01–158232.27)	7306.99(537.64–216064.89)	233.10(61.20–697.59)
31	3922.06(197.96–1176494.69)	11664.11(607.03–2132956.16)	244.11(34.97–977.86)
p-value	0.2656	0.0746	0.0074
Deviance	8.82	11.48	20.91
DF	7	6	8

In gillnets with a 76 mm mesh size, an increase in twine thickness enhanced fishing efficiency for larger individuals (Figure 4). For gillnets with an 80 mm mesh size, increasing the twine thickness reduced efficiency for fish in the 17–22 cm length range, but efficiency increased for individuals exceeding 23–24 cm in total length (Figure 4). In 84 mm mesh size gillnets, the 0.18–0.20 mm and 0.18–0.23 mm comparisons showed a similar pattern to the 80 mm nets; however, in the

0.20–0.23 mm comparison, efficiency decreased with increasing lengths due to the increased twine thickness (Figure 4). For 88 mm mesh size gillnets, the 0.18–0.20 mm and 0.18–0.23 mm comparisons exhibited a pattern similar to the 80 mm nets; however, in the 0.20–0.23 mm comparison, the increase in twine thickness led to increased efficiency for larger length classes (Figure 4). Generally, nets made from thicker twine are more effective in catching relatively larger fish.

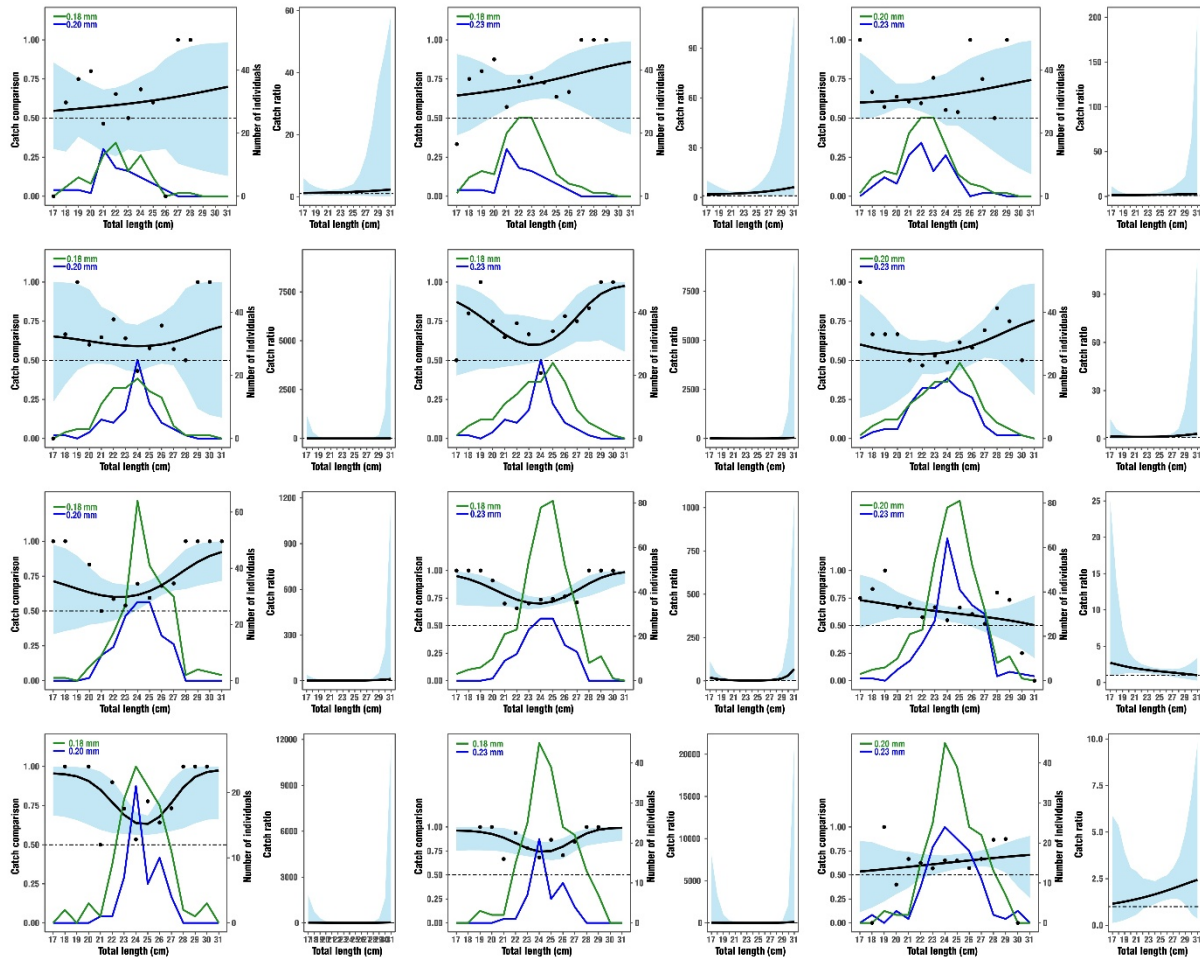


Figure 4. Comparison of the catch rate and catch ratio of Prussian carp (*Carassius gibelio* Bloch, 1782). The curve (solid line) represents the modeled catch efficiency fitted to the experimental points (dots). The soft blue band represents 95% confidence intervals, and the green (standard) and blue (modified) lines represent the length distributions observed in the catch, respectively. The dotted horizontal line at 0.50 indicates equivalence in catch rates between the two configurations. In the small plots, the catch ratio curve (solid line) with 95% confidence intervals (soft blue band) is shown. The dotted horizontal line at 1.00 indicates equivalence in catch rates between the two configurations. Graphs in rows represent 76-, 80-, 84-, and 88-mm mesh sizes from top to bottom. The graphs in the columns represent twine thickness comparisons of 0.18–0.20, 0.18–0.23, and 0.20–0.23 mm from left to right.

DISCUSSION

In the current study, which determined the effects of twine thickness, mesh size, and sampling period on the catch of *C. gibelio* using gillnets, the total length range of *C. gibelio* captured varied between 17.0 and 31.2 cm. In other studies conducted on the same species, the length range was reported as 9.0–33.0 cm fork length in Lake Eğirdir (Isparta, Türkiye) (Balık et al., 2004); 7.9–37.0 cm total length in another study in

Lake Eğirdir (Cilbiz et al., 2014a); 7.8–32.2 cm total length in Lake İznik (Bursa, Türkiye) (Uysal et al., 2014); 8.8–27.5 cm total length in Lake Marmara (Manisa, Türkiye) (Aydın et al., 2018); 10.7–39.6 cm in Demirköprü Dam (Manisa, Türkiye) (Dereci et al., 2021); 10.7–31.0 cm total length in the Seyhan River (Adana, Turkey) (Ergüden, 2015); 5.6–27 cm fork length in Gelingüllü Dam (Yozgat, Türkiye) (Kırankaya and Ekmekçi,

2013); and 21.9–37.0 cm in Chimaditis Lake (northern Greece) (Leonardos et al., 2008). Factors reported to affect the length distributions of the same fish species in different habitats include: (I) environmental factors (such as temperature and salinity (Jaureguizar et al., 2021) and climate change (Tu et al., 2015)); (II) habitat and population density (such as habitat differences (Ferro et al., 2008) and population density and competition (Licht et al., 2015)); (III) fishing and human activities (such as fishing pressure (Tao et al., 2024), water abstraction (Merciai et al., 2017), and gear selectivity (Cilbiz and Ateşşahin, 2024)); and (IV) growth and seasonal variations (Ferro et al., 2008).

In this study, it was clearly determined that twine thickness affects catch efficiency, with thicker nets being more efficient than thinner ones for *C. gibelio* fishing. Increasing the twine thickness of gillnets can enhance their durability without compromising catch performance. A study on the Northeast Arctic cod gillnet fishery showed that a 30% increase in twine thickness did not affect catch efficiency, suggesting that thicker twine can reduce marine litter from damaged and lost gears without negatively impacting catch yield (Brinkhof et al., 2023). The average lengths of catches made by gillnets with the same mesh size but different twine thicknesses did not show a statistically significant difference ($p > 0.05$). Conversely, a study by Ayaz et al. (2011) indicated that thicker twine (0.54 mm) resulted in smaller *Boops boops* catches than thinner twine (0.45 mm), likely due to reduced elasticity and flexibility. This difference is thought to stem from the morphological characteristics of different target species. Compared with *B. boops*, *C. gibelio* is considered to have similar gilling potential across different twine thicknesses due to being larger and relatively stronger. A similar interaction between morphology and gear specifications is observed in recreational fisheries, where hook size has been shown to be the primary determinant of size selectivity for the related cyprinid *Cyprinus carpio*, while bait type drives catch efficiency (Ateşşahin and Dürrani, 2023).

In our study, the estimated modal lengths for *C. gibelio* caught by gillnets with a 76 mm mesh size and twine thicknesses of 0.18, 0.20, and 0.23 mm were found to be quite similar to each other (Tables 3, 4, 5). However, Ayaz et al. (2011) found that twine thickness caused significant differences between modal lengths and SR values. This discrepancy is thought to arise similarly from species-dependent morphological differences. When examining the modal lengths from other studies conducted on the species, Cilbiz et al. (2014a) reported a modal length of 21.92 cm for an 80 mm mesh size in their study using monofilament

gillnets, while Cilbiz et al. (2014b) reported a modal length of 21.84 cm for an 80 mm mesh size in their study using multifilament gillnets. Aydın et al. (2018) reported a modal length of 24.48 cm for an 80 mm mesh size in multifilament gillnets and 25.20 cm in multifilament trammel nets. The reported modal lengths are quite consistent with our findings. Minor differences were attributed to habitat, rigging technique, and net material.

CONCLUSION

In conclusion, fishing is considered a highly effective method for preventing the overpopulation of *C. gibelio*, which has recently entered Karakaya Dam Lake and has no known natural predators. While twine thickness did not have a significant effect on the species' size selectivity, it significantly contributed to catch efficiency. The use of gillnets made from thick twine for fishing this species will increase the chances of control success and extend gear lifespan due to high durability, thereby positively contributing to the socioeconomic sustainability of local fisheries.

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AUTHORSHIP CONTRIBUTIONS

Tuncay Ateşşahin, Conceptualization, methodology, investigation, data collection, writing reviewing and editing. Mahmut İlhan, methodology, investigation, data collection. Mehmet Cilbiz, writing reviewing and editing.

CONFLICT OF INTEREST

The authors declared that there is no conflict of interest.

ETHICS APPROVAL

No specific ethical approval was necessary for the study.

DECLARATION OF AI USE

We have not used AI-assisted technologies in creating this article.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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