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Research Article

Estimation of gillnet mesh size for Narrow-barred Spanish mackerel (*Scomberomorus commerson* Lacépède, 1800) using girth measurements, Northwest Persian Gulf

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Abstract

This research was conducted in the fishing ground of Bushehr Province in the northern Persian Gulf from October 2018 to June 2019. *Scomberomorus commerson* specimens were caught using common multifilament drift gillnet with mesh sizes of 130, 140, 150 mm (STR). The main purpose was to determine the proper gillnet mesh size for the prohibition of catching non-adult fish using girth measurements. Fork length, girths were measured at the preopercle (POG), opercula (OG), and first (DF1G) and second dorsal (DF2G) fins. Overall, 1230 specimens were caught during the autumn, winter, and spring seasons. The percentages of immature Narrow-barred Spanish mackerel caught by gillnets with the mesh sizes of 130, 140, and 150 mm (STR) were 69.2 %, 66.5 %, and 60.3 %, respectively. The estimated equations between fork length and girths were POG=0.2285FL+5.4836 (R^2=0.8366), OG=0.2477FL+6.8582 (R^2=0.8006), DF1G=0.2851FL+7.0874 (R^2=0.8566), and DF2G= 0.3191FL+8.1031 (R^2=0.8316). Pearson correlation analysis also showed a positive correlation between the measured girths and fork length (p<0.01). Two-way ANOVA results showed that the effect of mesh size on fork length and girths were significant (p<0.05). Based on the fork length of first sexual maturity (83.6 cm), the use of the estimated mesh size based on the DF2G (17.39 cm) will be essential to reduce the catch of non-adult fish and having sustainable fishing in the future.

Keywords: *Scomberomorus commerson*, Gillnet, Recommended mesh size, Persian Gulf

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Introduction

The increasing human need for protein resources as a result of rapid population growth has increased the human tendency to consume more seafood. Accordingly, countries with marine resources are making more efforts to catch fish species (Mytilineou and Sarda, 1995; Sadough Niri *et al*., 2020). Developments in fishing technology and the use of well-equipped vessels have led to overfishing, which has caused extensive damage to the stocks and resources of many commercial species. Due to the increase in fishing fleets and economic issues, the populations of many fish species in the Persian Gulf are currently subjected to the overexploitation (Hosseini, 2016; Sadough Niri *et al*., 2018; Sadough Niri *et al*., 2020). The favorable environmental conditions in the Persian Gulf have made this aquatic zone the habitat of numerous tropical and subtropical aquatic species (Carpenter *et al*., 1997).

Due to the high economic value of *Scomberomorus commerson* (Narrow-barred Spanish mackerel), it is considered as one of the most economically favored fish in the Persian Gulf and the Oman Sea (Jayabalan *et al*., 2011). This fish is one of the largest epipelagic and neritic species of the tuna fish family, which is the target of commercial, recreational, and traditional fishermen throughout the Pacific and western Indian Ocean (Grandcourt *et al*., 2005). This species inhabited in shallow coastal waters (depths less than 100 m) and often is associated with reefs and shoals (Collette and Nauen, 1983). Mostly, it is comprised of small schools with long-shore migrations, even though permanent dweller inhabitants have also been reported (Collette, 2001). Recent genetic analyzes of *S. commerson* have shown that there is only one stock of this fish in the Persian Gulf and Oman Sea (Hoolihan *et al*., 2006). Narrow-barred Spanish mackerel is caught by various types of fishing gears such as gillnet, midwater trawler, trolling, and long lines in coastal waters (Collette, 2001). The fishing vessels include fiberglass boats and wooden dhows with different sizes and capacities are used in the coastal waters of Bushehr. Gillnet fishing method has a special place among the people of Iran due to the high catch rate, lower fuel consumption, and energy usage compared to fishing methods such as trawling. The average catch of *S. commerson* in Iran has been reported to be around 24194 tons in the last 4 years. The highest catch amount was about 25507 tons in 2018 (Eighani *et al*., 2020).

Gillnets are extensively used by small scale fishing fleets to catch benthic, pelagic, and demersal fish species (Fabi *et al*., 2002). A gillnet is selective for a certain length range, and paying attention to this feature is very important in fisheries management (Carol and Garcı´a-Berthou, 2007; Cilbiz *et al*., 2014). The mesh size and morphological characteristics of the fish, including the length and perimeter of the fish's body, are influencing factors on gillnet fishing (Santos *et al*., 2006). Determining the appropriate mesh size for species or target groups is the most important requirement for designing gillnets. Therefore, any mesh size mismatch with fish size reduces catch and causes failure in fishing operations (Hosseini *et al*., 2017). In recent years, numerous studies have been conducted on the growth, reproduction, and fishing of *S. commerson* in the Persian Gulf and the Oman Sea (Hoolihan *et al*., 2006; Sadeghi *et al*., 2009; Taghavi Motlagh and Shojaei, 2009; Kaymaram *et al*., 2010; Fakhri *et al*., 2011; Niamaimandi *et al*., 2015; Eighani *et al*., 2018; Herrmann *et al*., 2018). However, few studies have been conducted to determine and introduce suitable gillnet mesh sizes for this species (Grandcourt *et al*., 2005; Darvishi, 2008; Hosseini *et al*., 2016). Therefore, based on the reported fork length (83.6 cm) at first sexual maturity by previous studies (Kaymaram *et al*., 2010), the purpose of this study was to determine the proper mesh size by measurement of girth and fork length of *S. commerson* to reduce the number of non-adult fish to have sustainable fishing in the Persian Gulf.

Materials and methods

Study Design

This study was done monthly in the fishing ground of Bushehr waters situated in the Persian Gulf (latitude 29° 18′ to 28° 40′ N; longitude 50° 04′ to 50° 32′ E) from October 2018 to June 2019 (Fig. 1).

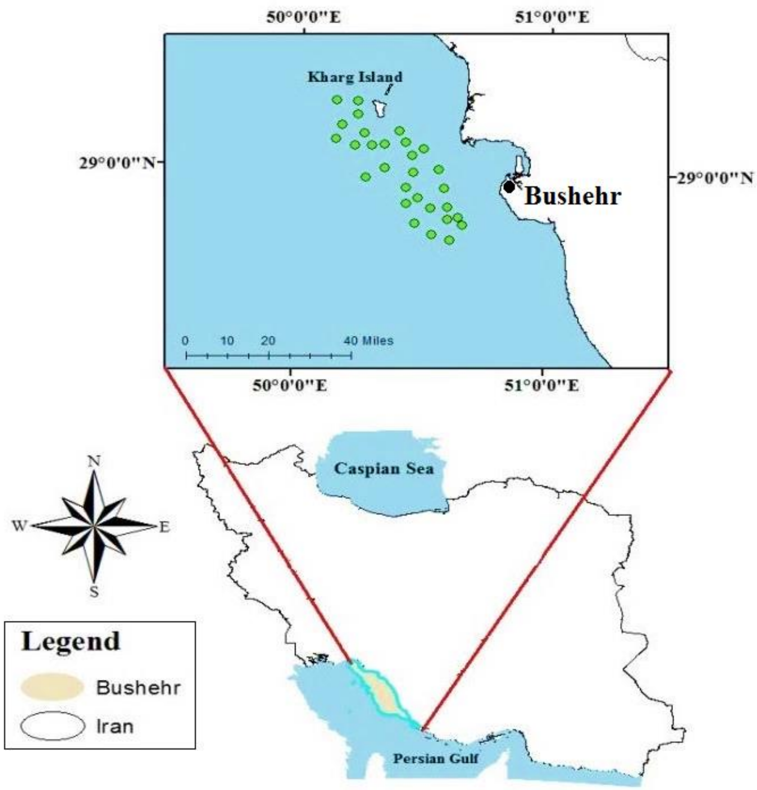

Figure 1: The geographical location of fishing grounds in the northwest Persian Gulf (2018-2019).

The Narrow-barred Spanish mackerel specimens were caught using multifilament drift gillnet with mesh sizes of 130, 140, 150 mm (STR) operated by the artisanal fiberglass dhows (In the summer, the fishing dhows use shrimp trawl nets, and their fishing operations by gillnets is limited in comparison with other fishing seasons). The nets were deployed from 4 to 6 PM and afterward were retrieved at midnight. Then, *S. commerson* specimens were collected from the net. Morphological characteristics including fork length (FL), preopercle (POG), opercule (OG), first (DF1G), and second (DF2G) dorsal fins girths were measured to the nearest cm (Fig. 2). The proper mesh size.

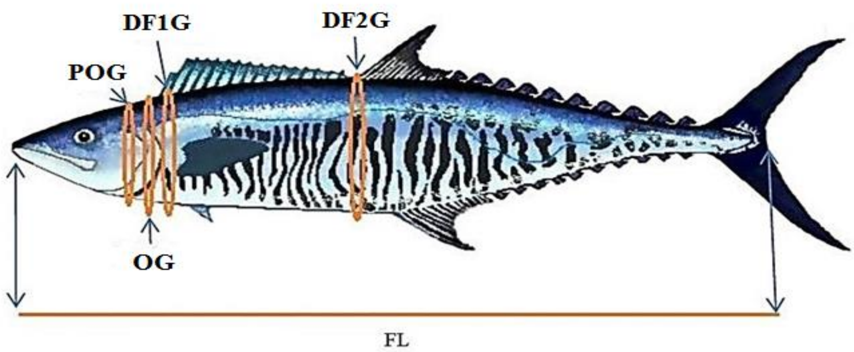

Figure 2: Locations of girth measurements of Narrow-barred Spanish mackerel (*Scomberomorus commerson* Lacépède, 1800).

Analysis of size measurements

Sturges formula was used to determine fork length interval that would have stable class size frequencies (Zar, 2010). That is,

R = (Max-Min) + 1

K = 1 + 3.3 log n

C = R ÷ K

Where R is the range of the measured fork lengths, K is the number of categories based on a sample size of n, and C is the class width.

Estimation of recommended mesh size

Correlation between fork length and measured girths was investigated by linear regression fitted by the least-squares method, and Pearson correlation. The linear relationships were as follows:

$G = \alpha + \beta$ FL where G denotes the girth measurement and FL is fork length, α is the intercept, and β is the slope of the line.

The size of the proposed mesh size was calculated based on the fork length of 83.6 cm corresponded to the length at the first sexual maturity in the Persian Gulf (Kaymaram *et al*., 2010) according to Pet *et al*. (1995):

$G_{pred} = \alpha + \beta \times 83.6$ cm

The recommended mesh size is chosen to have a mesh perimeter equal to G_{pred}. If *m* is the inside mesh length from knot to adjacent knot then the mesh perimeter is 4*m* (Hameed and

Bupendaranat, 2000). Hence, the recommended value of m is

$m = G_{pred} / 4$

Corresponding to stretched mesh size of

$2m = G_{pred} / 2$.

Based on the measured girths and the equations used, a mesh size will be selected that prevents the catch of immature fish under the size at the first sexual maturity and allows them to survive, grow and reproduce in the future.

Data analysis

The normality and homogeneity of variance assumptions of the size measurements were verified by Kolmogorov-Smirnov and Leven tests. One-way ANOVA was used to determine whether there are any statistically significant differences between the means of measured fork length and girths. Duncan's multiple comparisons test was also used to compare the means of measured girths. Two-way ANOVA was used to consider the significance of mesh size effects on catch size (Zar, 2010). All statistical tests were performed in SPSS version 21 and Microsoft Office Excel 2010 software.

Results

Totally, 1230 specimens of *S.commerson* were measured during the study period. The percentages of immature fish in gillnets with mesh sizes of 130, 140, and 150 mm were 69.2 %, 66.5 %, and 60.3 %, respectively (Fig. 3).

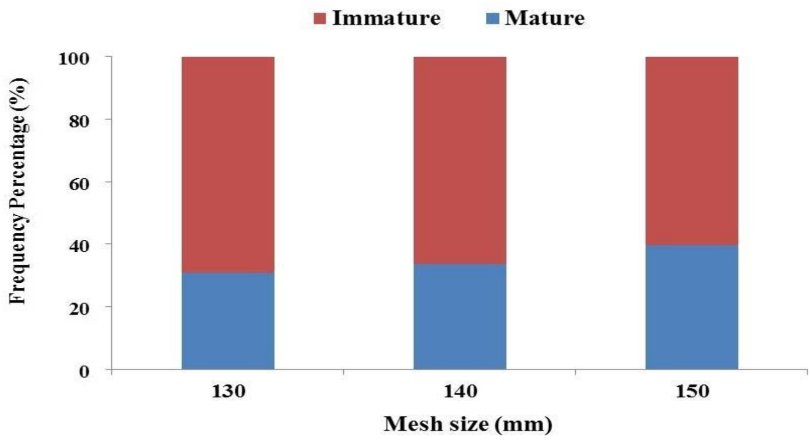

Figure 3: Mature and immature percentages of *Scomberomorus commerson* caught by drift gillnet in the fishing grounds of the northwest Persian Gulf (2018-2019).

Among the fork length classes of caught fishes by the mesh size of 130 mm, the fork length class of 76.6-81.4 cm with 84 fish specimens had the highest frequency. Also, among the fork length classes of caught fishes by the mesh sizes of 140 and 150 mm, the fork length class of 81.5-86.3 cm with 98 and 86 fish specimens showed the highest frequency, respectively (Fig. 4). Descriptive statistics for measured fish characteristics are presented in Table 1.

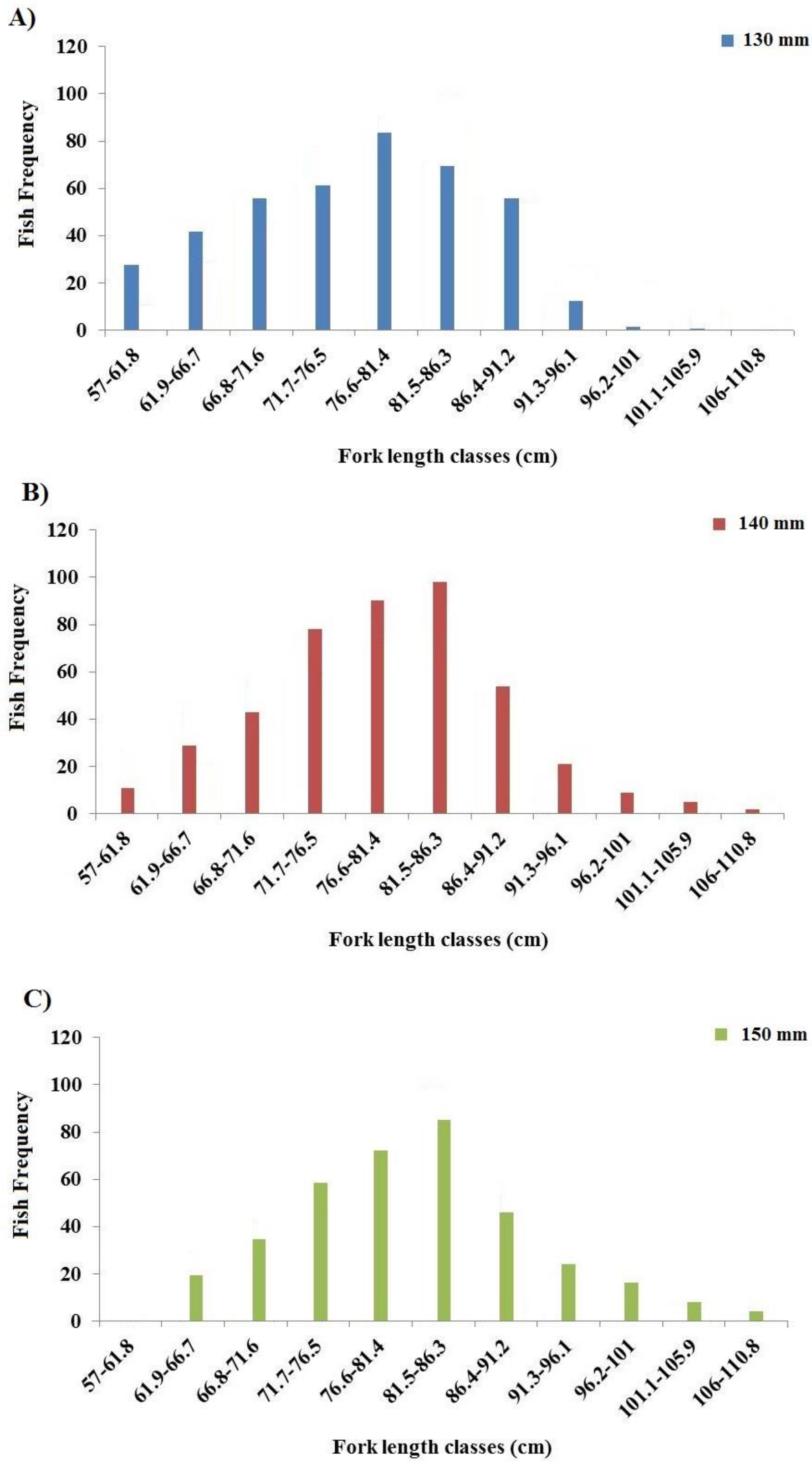

Figure 4: Distribution of fork length classes of *Scomberomorus commerson* caught by drift gillnet with stretched mesh sizes of A) 130 mm, B) 140 mm, and C) 150 mm in the fishing grounds of the northwest Persian Gulf (2018-2019).

Table 1: Descriptive statistics for POG, OG, DF1G and DF2G, and FL of *Scomberomorus commerson* caught by drift gillnet in the fishing grounds of the northwest Persian Gulf (2018-2019).

Parameters	Minimum (cm)	Maximum (cm)	Mean±SE (cm)
POG	18.20	32.00	23.5±0.07
OG	20.20	35.80	26.38±0.07
DF1G	23.00	40.20	29.55±0.08
DF2G	26.40	45.80	33.25±0.09
FL	57.00	110.00	78.8±0.3

The ANOVA results showed significant differences among the measured morphological characteristics in different seasons ($p<0.05$). The mean comparison of measured girths showed that there were significant differences between the measured girths of caught fish by different used mesh sizes in different seasons ($p<0.05$) (Table 2).

Table 2: Seasonal mesh size performance comparison (Mean±SE) of POG, OG, DF1G, DF2G, and FL of *S. commerson* caught by drift gillnet in the fishing grounds of the northwest Persian Gulf (2018-2019). Differences in uppercase letters indicate a significant difference between mesh size within the season ($p<0.05$).

Season	mesh sizes	POG (cm)	OG (cm)	DF1G (cm)	DF2G (cm)	FL (cm)
Autumn	13	23.6±0.2 ^{b}	26.5±0.2 ^{b}	29.1±0.2 ^{b}	32.7±0.3 ^{b}	76.9±0.8 ^{c}
	14	23.8±0.2 ^{b}	26.8±0.2 ^{b}	29.4±0.2 ^{b}	33±0.2 ^{b}	78.4±0.7 ^{b}
	15	24.4±0.2 ^{a}	27.5±0.2 ^{a}	30±0.3 ^{a}	34.1±0.3 ^{a}	82.4±0.8 ^{a}
Winter	13	22.6±0.2 ^{b}	25.1±0.2 ^{a}	28.5±0.3 ^{b}	31.7±0.3 ^{b}	76.1±0.7 ^{b}
	14	23.2±0.2 ^{a}	25.5±0.3 ^{a}	28.9±0.3 ^{b}	32.5±0.3 ^{a}	77.8±0.8 ^{b}
	15	23.1±0.2 ^{a}	25.4±0.2 ^{a}	29.3±0.2 ^{a}	32.6±0.2 ^{a}	79.1±0.6 ^{a}
Spring	13	23.2±0.2 ^{a}	26.1±0.2 a	29.2±0.2 ^{c}	33.1±0.3 ^{b}	78.1±0.9 ^{c}
	14	23.9±0.2 ^{a}	26.9±0.2 ^{a}	30.2±0.2 ^{b}	34.2±0.2 ^{a}	80.4±0.9 ^{b}
	15	23.3±0.2 ^{a}	26.7±0.2 ^{a}	31±0.2 ^{a}	34.6±0.3 ^{a}	82.3±0.6 ^{a}

The results of seasonal mean comparison also showed that there were significant differences between measured girths during different seasons ($p<0.05$) (Table 3).

Two-way ANOVA test results showed that the effect of mesh size on fork length and measured girths were significant ($p<0.05$). The relationship between the fork length and the measured girths are shown in Figures 5 and 6. The regression equations showed that there is a strong linear relationship between the fork length and the girths (Figs. 5 and 6). Accordingly, the obtained equations were POG=0.2285FL+5.4836 (R^2=0.8366), OG=0.2477FL+6.8582 (R^2=0.8006), DF1G=0.2851FL+7.0874 (R^2=0.8566), and DF2G= 0.3191FL+8.1031 (R^2=0.8316), respectively (Table 4).

The Pearson correlation analysis also showed that there is a positive correlation between measured parameters and fork length ($p<0.01$) (Table 5). Based on the fitness coefficient (K) obtained by fork length of caught fish at first sexual maturity, the stretched mesh size for the preopercle (POG), opercule (OG), first and second dorsal fin girths (DF1G, DF2G) calculated 12.29, 13.78, 15.46, and 17.39 cm, respectively (Table 6).

Table 3: Seasonal mean comparison (Mean±SE) of POG, OG, DF1G, DF2G, and FL of *S. commerson* caught by drift gillnet in the fishing grounds of the northwest Persian Gulf (2018-2019). Differences in uppercase letters indicate a significant difference between treatments (p<0.05).

Parameter	Autumn	Winter	Spring
POG (cm)	23.9±0.1 [a]	22.9±0.1 [b]	23.5±0.1 [a]
OG (cm)	26.9±0.2 [a]	25.3±0.1 [b]	26.6±0.1 [a]
DF1G (cm)	29.6±0.1 [a]	28.9±0.2 [b]	29.9±0.2 [a]
DF2G (cm)	33.2±0.2 [a]	32.3±0.2 [b]	33.8±0.2 [a]
FL (cm)	78.7±0.5 [b]	77.9±0.4 [c]	79.9±0.5 [a]

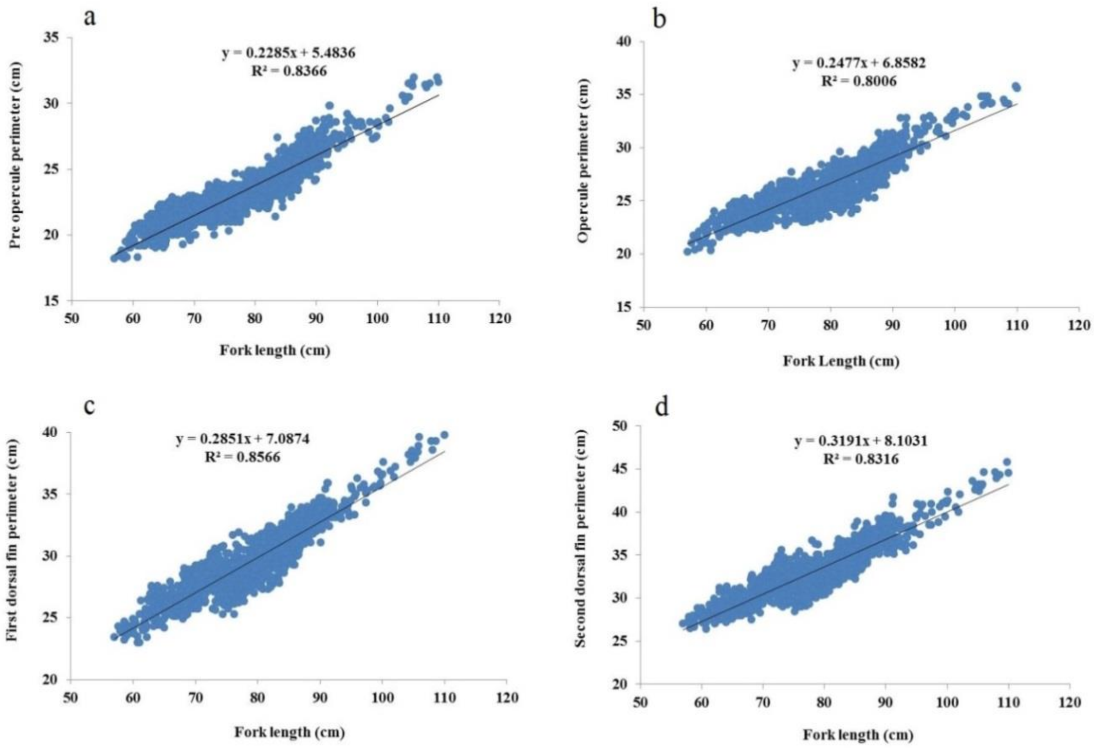

Figure 5: Regression between (a) POG, (b) OG, (c) DF1G, and (d) DF1G of *S. commerson* caught by drift gillnet in the fishing grounds of the northwest Persian Gulf (2018-2019).

Table 4: Two-way ANOVA analysis of POG, OG, DF1G, DF2G, and FL of *S. commerson* caught by drift gillnet in the fishing grounds of the northwest Persian Gulf (2018-2019).

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Mesh	POG	43.632	2	21.816	4.096	0.017
	OG	80.116	2	40.058	6.430	0.002
	DF1G	194.748	2	97.374	12.229	0.000
	DF2G	240.165	2	120.083	11.934	0.000
	FL	2396.151	2	1198.075	14.153	0.000

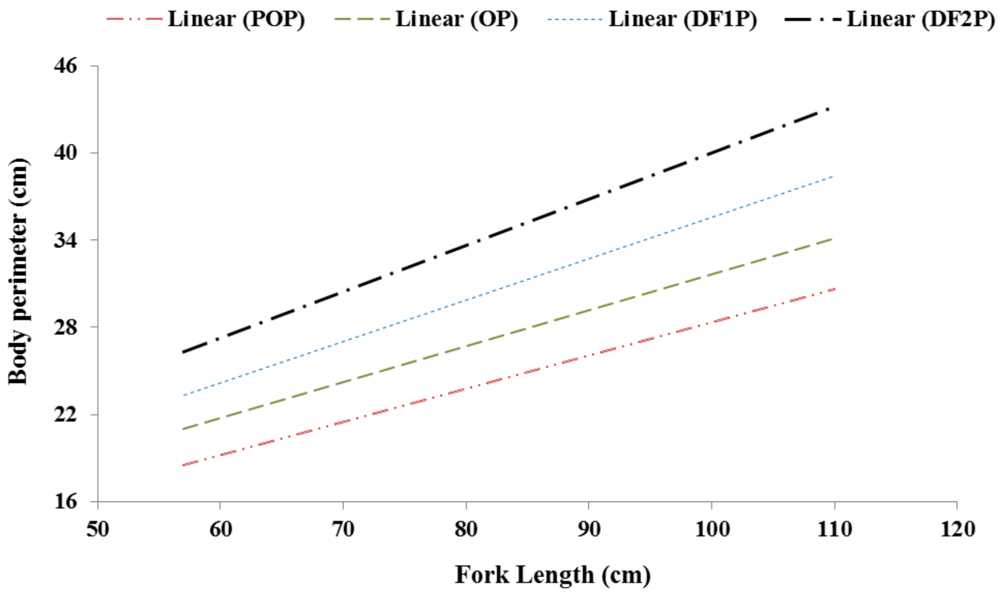

Figure 6: Regression between fork length and girths of *S. commerson* caught by drift gillnet in the fishing grounds of northwest Persian Gulf (2018-2019).

Table 5: Pearson correlation analysis of POG, OG, DF1G, DF2G, and FL of *S. commerson* caught by drift gillnet in the fishing grounds of the northwest Persian Gulf (2018-2019).

Pearson Correlations		POG	OP	DF1P	DF2P	FL
POG	Correlation	1				
	Sig. (2-tailed)					
OG	Correlation	0.953**	1			
	Sig. (2-tailed)	.000				
DF1G	Correlation	0.934**	0.952**	1		
	Sig. (2-tailed)	0.000	0.000			
DF2G	Correlation	0.922**	0.940**	0.966**	1	
	Sig. (2-tailed)	0.000	0.000	0.000		
FL	Correlation	0.915**	0.895**	0.926**	0.912**	1
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	

**Correlation is significant at the 0.01 level (2-tailed).

Table 6: Determination of *S. commerson* girths at the size of first maturity G_{pred}, and recommended mesh size *m* by drift gillnet in the fishing grounds of the northwest Persian Gulf (2018-2019).

Parameter	FL (cm)	G_{pred}	*m* (cm)	2*m* (cm)
POG	83.6	24.59	6.14	12.29
OG	83.6	27.56	6.89	13.78
DF1G	83.6	30.92	7.73	15.46
DF2G	83.6	34.78	8.69	17.39

Discussion

Similar to the length-weight relationship, the length-girth relationship can be used to manage and assess fisheries' resources (Mendes *et al*., 2006). The use of this relationship is very important in the indirect selectivity of gillnets because fish morphology strongly influences retention by fishing gear (Mendes *et al*., 2006; Hoseini, 2016; Sadough Niri *et al*., 2020). Girth and its related dimensions including width and height have been investigated as critical factors in the gear selection process (Reis and Pawson, 1992). In this study, there was a linear relationship between fork length and different measured girths of caught fish. The results showed that at similar lengths, the girth at the beginning of the second dorsal fin was greater than the beginning of the first dorsal fin. Therefore, the beginning of the second dorsal fin was considered as the maximum girth of this fish. Other researchers also have reported a strong linear relationship among the fork length and the different girths for *S. commerson* and determined the maximum girth at the beginning of the second dorsal fin for *S. commerson*, which is consistent with the results of this study (Dudley *et al*., 1992; Grandcourt *et al*., 2005; Darvishi, 2008; Hosseini *et al*., 2016). The determination of the maximum girth of the fish depends on the fish species and body shape (Hameed and Bupendaranat, 2000). The relationship between the girth and mesh size is one of the factors that determine the optimal mesh size (Hameed and Bupendaranat, 2000). Regardless of the species, other factors such as behavior and reaction of fish around the net, net structure, hanging ratio, elongation of the mesh, and fish visibility influence the length distribution of fish caught in the gillnet (Holst *et al*., 1998).

The result showed that mesh size had a significant effect on the measured girths and fork length of caught Narrow-barred Spanish mackerel. Generally, as the gillnet mesh size increases, fishes with larger girth and length are caught, and conversely, as the mesh size decreases, smaller sizes are caught (Gray *et al*., 2005; Kalaycı and Yeşilçiçek, 2014; Ago *et al*., 2014). In addition to the mesh size, seasonal changes cause variations in distribution, migration, reproduction rate, growth, life cycles, and mortality of fish species, which can affect the size of the caught fish (Pondella *et al*., 2002; Liming *et al*., 2006; Stenseth *et al*., 2004).

Choosing the proper mesh size for the target species is one of the most important issues in the design of gillnet. Therefore, mismatching of the mesh size with the target fish size will lead to unsuccessful fishing (Hameed and Bupendaranat, 2000). Caught fish by gill nets may be wedged, gilled, and tangled (De Vries *et al*., 1996). According to the probability of getting caught of fish from different measured girths, four estimated mesh sizes are according to the four girths of *S. commerson* in the first fork length of maturity (83.6 cm). The estimated mesh sizes for preopercle (POG), opercule (OG), and first dorsal fin (DF1G) can catch the immature fish; therefore, these mesh sizes are not suitable for catching. But the estimated mesh size for the second dorsal fin (DF2G: 17.39 cm) is a proper mesh size that can catch adult fish and allows immature fish to escape. Unfortunately, few studies have been conducted on the optimization of drift gillnets of *S. commerson* in the Persian Gulf and there are no reports of the implementation of the proposed mesh sizes. According to the result of Claereboudt *et al*. (2005), different gillnets with mesh sizes of 60 to 160 mm are used for this purpose in the Omani waters, which can catch large numbers of immature fish. They proposed a 171 mm mesh size for the sustainable bio-exploitation of Narrow-barred Spanish mackerel stocks in the UAE using the relationship between fork length and body circumference determined by Dudley *et al*. (1992). The proposed mesh size was designated for the first sexual maturity fork length of 86.3 cm. On the Karnataka coast of India, gillnets with mesh sizes of 65 to 170 mm are used for *S. commerson* (Danishbabu *et al*., 2012). Darvishi (2008) suggested a 152 mm mesh size for *S. commerson* in the Persian Gulf, whereas Hosseini *et al*. (2016) reported a 162 mm mesh size as the best mesh size for catching this species. In the proper management of fishing gear, adult fish are caught and the immature fish are allowed to escape for surviving and reproduction in the future. This can be achieved if a standard fishing net is determined to maximize catches at a sustainable level by controlling and preserving immature fish stocks (Fujimori and Tokai, 2001). Fish mature in a certain length size in different areas. If the length of the first sexual maturity is specified, the mesh size of the net can be determined to avoid damaging the smaller sizes of target fish and allow them to spawn at least once (Carol and García-Berthou, 2007; Sadough Niri *et al*., 2020). The mesh size controls the length size of the regenerative cohort. Also, gillnet fishing efficiency is more related to the physical dimensions of the fish body (Gulland, 1983; Fujimori and Tokai, 2001).

Despite the species diversity of pelagic fish in the waters of the Persian Gulf and the Oman Sea, numerous fish are physically similar to *S. commerson* which are found in the gillnets bycatch composition. Considering the economic value of target species, optimal control, and management should also be done to prevent the overfishing and damaging of non-target species (Haghighatjou *et al*., 2018). There are regulations regarding standard mesh sizes for different species but implementation is problematic and hard in the Persian Gulf. Therefore, according to the results obtained, it should be prohibited to use gillnets with the mesh sizes smaller than 17.39 mm for catching *S. commerson* to preserve the fish stocks for sustainable harvesting in the future. If the target fish are caught below the size of maturity, there will be severe fishing pressure on this valuable species and the fish population will be decreased. Therefore, it is recommended to use the estimated mesh size for *S. commerson* to reduce the catch of non-adult fish and help to the sustainable exploitation of this fish stock in the future.

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