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RESEARCH PAPER

Size-Selectivity of Trammel Nets for Two Herbivorous Fish Species in Coral Reef Fisheries of Jeddah, Saudi Arabia

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Abstract

Size-selectivity of monofilament trammel nets for two important herbivorous species. *Acanthurus sohal* and *Siganus rivulatus* in Jeddah fisheries was investigated using three different inner-panel mesh sizes: 50, 56, and 62 mm. The SELECT method was used to calculate selectivity parameters. Five models were fitted to estimate the selectivity curves, namely: normal location, normal scale, lognormal, gamma and bi-modal. In addition, length-girth (G_{max}) and length-weight relationships were determined. Based on the lowest deviance/degrees of freedom ratio, the log-normal model provided the best fit for *S. rivulatus* catch, with modal lengths of 18.3, 20.5, and 22.7 cm, whereas the bi-modal model provided the best fit for *A. sohal* catch, with modal lengths of 19.30, 21.62, and 23.93 cm for 50, 56 and 62 mm mesh sizes, respectively. The length-girth relationship could be described by the linear equation: $G_{max} = 0.69+0.67\times TL$ for *S. rivulatus* and $G_{max}=1.32+0.712\times TL$ for *A. sohal*. The length-weight relationship could be described by the power equation: $W=0.024\times TL^{2.81}$ for *A. sohal* and $W=0.015\times TL^{2.99}$ for *S. rivulatus*. We recommend using trammel nets with a minimum inner-panel mesh size of 62 mm for the rational exploitation of the two species.

Introduction

Species of the two fish families: Acanthuridae and Siganidae are herbivores which are of the main grazing groups in the Indo-Pacific coral reefs (Vincent *et al.*, 2011). They are considered as a keystone guild because they play a significant role in limiting the establishment of macroalgae and hence maintaining healthy coral reefs by controlling their benthic community structure (Hatcher, 1981; Lewis and Wainwright, 1985; Carpenter, 1986; Carpenter, 1990).

However, many studies reported that the artisanal fishing techniques, even under low fishing activity, can decrease the species richness and abundance of the target species (Dulvy *et al.*, 2004; Goetze *et al*., 2011) resulting in changes in the community structure, the degree of which depends on the fishing intensity and the selective nature of the fishing gear (May, 1984). For predicting responses of fish species to fishing intensity, the length-based life history traits, particularly the maximum length (Taylor *et al*., 2014) and the average individual body weight (Vallès *et al*., 2015) can be used as indicators.

In fisheries management, the regulation of the mesh size of the fishing gear is one of the technical conservation measures to protect undersized juvenile fish and get the maximum sustainable yields (Gulland, 1983; Wileman *et al.*, 1996; Cochrane and Garcia, 2009). To determine the optimum mesh size of gillnets and trammel nets required to catch the optimum fish sizes of the target species, the size-selectivity parameters are usually estimated through selectivity studies (Trent and Pristas, 1977; Petrakis and Stergiou, 1996; Balik, 1999; Fujimori and Tokai, 2001; Fabi *et al.*, 2002; Dincer and Bahar, 2008; Kalayci and Yesilcicek, 2012).

In Saudi Arabia, gillnet and trammel net fishing is one of the most important and widely used fishing methods in the traditional fisheries along the Red Sea coast. This is due to the low cost, the ease of handling, and the efficiency with which gillnets and trammel nets catch more valuable species (Valdes-Pizzini *et al.*, 1992; Acosta and Appeldoorn, 1995).

Despite their ecological and economic importance of the two herbivorous species, there is no previous study to assess the size-selectivity of monofilament trammel nets used in Jeddah coral reef fisheries. So, the current research aims to assess the size-selectivity parameters of trammel nets used to catch *Siganus rivulatus* Forsskål and Niebuhr, 1775 (Marbled spinefoot) and *Acanthurus sohal* (Forsskål, 1775) (Sohal surgeonfish) for the first time in Jeddah coral reef fisheries, in addition to determining the length-weight and length-girth relationships for the two species, to recommend the optimum mesh size for catching the optimum fish size (length and weight) of the two species.

Materials and Methods

The fishing operations using trammel nets were carried out in the same shallow (1-2 m depth) coral reef areas exploited by local fishermen as a small-scale fishery in Jeddah fisheries in the Red Sea (Figure 1). The most commonly used trammel nets in Jeddah fisheries are of the monofilament nylon (polyamide). Local fishermen usually use trammel nets of 56 mm inner-panel mesh size (stretched), and occasionally use trammel nets of 50 and 62 mm mesh sizes. Trammel nets having the three different inner-panel mesh sizes were used in the fishing operations during the present study.

Nine trammel net units were used in each fishing operation; each three units have one of the three inner-panel mesh sizes used. The design of each unit is shown in Figure 2. The trammel net units were tied to each other end-to-end in an alternative order of inner-panel mesh sizes (50-56-62 mm). At the beginning of each experiment, two fishermen, on a wooden fishing boat of 6-7 m length provided with outboard engine of 25 - 40 HP, throw the net into the water, leave it for about one hour and then start frightening the fishes in the area around the net to escape into (drive-in) the net direction and finally caught except fishes small enough to escape through the inner-panel meshes. Lastly, fishermen start hauling the trammels into the fishing boat to collect caught fishes. This fishing operation was repeated three times a day in different locations in the same fishing ground.

The retained catch of *A. sohal* and *S. rivulatus* from each trammel net was collected separately, and brought to the laboratory for morphometric measurements. The total fish length (L) and maximum body girth (G_{max}) were measured to the nearest 0.1 cm, and the total body weight (W) was measured to the nearest 0.1 g.

The power equation: $W=a\ L^{b}$ was used to describe the length-weight relationship, where a is the intercept and b is the slope of the regression analysis. The following equation suggested by Pauly, 1984 (Pauly's t-test) was used to test whether the value of the exponent 'b' is significantly different from 3:

$$t = \frac{s.d._x}{s.d._y} \times \frac{|\,b - 3\,|}{\sqrt{1-r^2}} \times \sqrt{n-2}$$

Where, $s.d._x$ is the standard deviation of $\log_e L$ values, $s.d._y$ is the standard deviation of the $\log_e W$, r^2 is the determination coefficient, n is the number of specimens used in the regression analysis. If t value is greater than the critical t values (t-distribution in statistical tables) for 'n-2' degrees of freedom, the b value is different from 3 (i.e., the growth is not isometric).

The linear equation: $G_{max}=c+d\ L$ was used to describe the length-girth relationship, where c is the intercept and d is the slope of the regression analysis.

The length frequency of *A. sohal* and *S. rivulatus* for each trammel net was prepared. The Kolmogorov-Smirnov test, implemented in the 'Statistix' software (version 8.1) was used to test if there are significant differences between length frequencies or not. The SELECT (Share Each Length's Catch Total) method, described in Millar (1992) and its application on gillnets is described in Millar and Holst (1997) and Millar and Fryer (1999) was used to estimate the selectivity curves of the different trammels by fitting five selectivity models, implemented in the Pasgear 2 software version 2.5 (Kolding and Skålevik, 2011), to the length frequency data.

The number of fish ' Y_{ji} ' belonging to a given length class ' j ' that encounter mesh size ' i ' are considered as observations of independent Poisson variables;

$$Y_{ji}=Po(p_i\lambda_j)$$

Where p_i is the relative fishing intensity of the net of mesh size i, λ_j is the abundance of fish in length class j. The relative selectivity (retention probability) of length class j fish in mesh size i are denoted by $s_i(j)$. The number of length j fish caught in gillnet i is then Poisson distributed

$$N_{ji}=Po(p_i\lambda_j\ s_i\ (j))$$

The five selectivity models are described by the following equations:

1- Normal Location:

$$\exp\left(-\frac{(L_j - k.m_i)^2}{2\sigma^2}\right)$$

2- Normal scale:

$$\exp\left(-\frac{(L_j - k_1.m_i)^2}{2(k_2.m_i)^2}\right)$$

3- Log normal:

$$\frac{1}{L_j}\exp\left[\mu_1 + \log\left(\frac{m_i}{m_1}\right) - \frac{\sigma^2}{2} - \frac{\left(\log(L_j) - \mu_1 - \log\left(\frac{m_i}{m_1}\right)\right)^2}{2\sigma^2}\right]$$

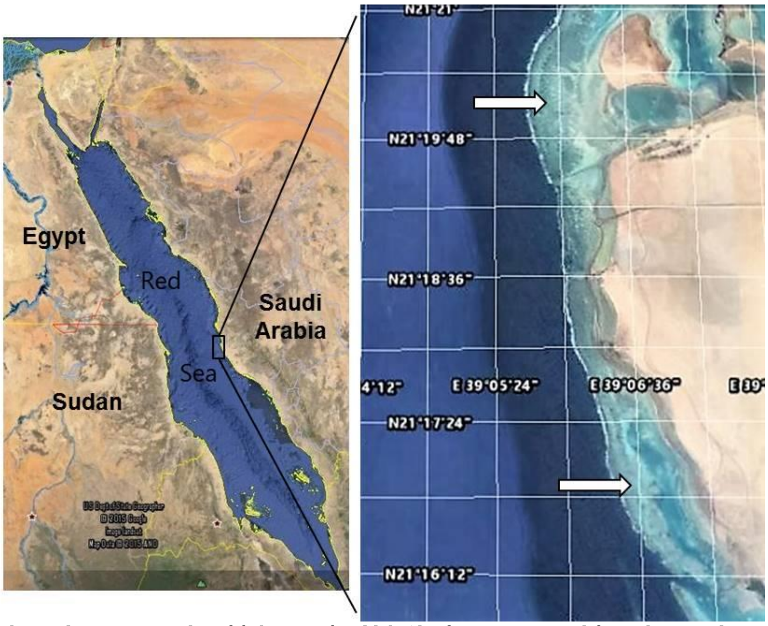

Figure 1. Map showing the study area in coral reef fisheries of Jeddah (the frames are saved from the Google Earth software, and arrows refer to the coral reef areas).

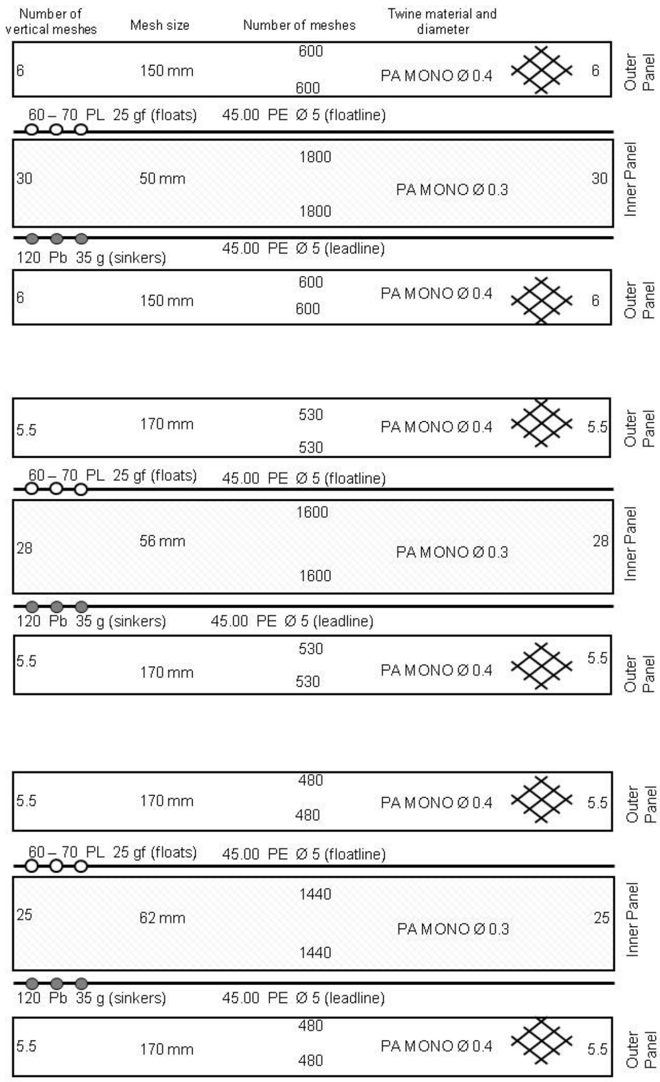

Figure 2. Specifications of trammel nets used in the fishing operations.

4- Gamma:

$$\left(\frac{L_j}{(\alpha-1).k.m_i}\right)^{\alpha-1}.\exp\left(\alpha-1-\frac{L_j}{k.m_i}\right)$$

5- Bi-modal:

$$\exp\left(-\frac{(L_j-k_1.m_i)^2}{2(k_2.m_i)^2}\right)+\omega.\exp\left(-\frac{(L_j-k_3.m_i)^2}{2(k_3.m_i)^2}\right)$$

where;

μ_i=mean length of fish caught in mesh size *i*

σ_i=standard deviation of the length of fish in mesh size *i*

L_j=mean length of fish in length class *j*

All models were fitted under the assumption of equal fishing effort, because all nets have the same number of settings, panel area and time set. So, in Pasgear software, the relative fishing intensities is simply considered equal.

Results

The total number of retained specimens was 318 represented by 86 (27.04%), 127 (39.94%) and 105 (33.02%) for *A. sohal* and 656, represented by 232 (35.4%), 221 (33.7%) and 203 (30.9%) *S. rivulatus* caught in the trammel nets of 50, 56 and 62 mm inner-panel mesh sizes, respectively. Figure 3 shows the observed and estimated (fitted) length frequencies and the mean length of *A. sohal* and *S. rivulatus* caught by the different trammel nets used in the present study as obtained from Pasgear 2 software.

The number of specimens, length range, mean length, mean weight and standard deviations are given in Table 1. The results of the pairwise Kolmogorov-Smirnov test comparisons revealed that length frequencies of *A. sohal* and *S. rivulatus* caught with the different trammel nets are significantly different ($P < 0.05$, H_0 is rejected) except that of *A. sohal* caught with 50 and 56 mm (Table 2).

The selectivity parameters estimated by the five different selectivity models are given in Table 3. Based on the lowest ratio of deviance to degrees of freedom and largest P-value, the bi-modal model provided the best fit having the lowest ratio of 0.49 and the largest P-value of 0.999 for *A. sohal***,** while the log-normal model provided the best fit for *S. rivulatus* having the lowest ratio of 0.8406 and the largest P-value of 0.758. The modal lengths and spread values estimated using the best fit model for each trammel net are listed in Table 4. The results obtained indicated that both the modal lengths and spread values increase with increasing the inner-panel mesh size of the trammel net. Selectivity curves estimated by the best fit selectivity model for the different trammel nets are shown in Figure 4.

Based on total length, maximum girth and total weight measurements of 318 specimens of *A. sohal* and 656 specimens of *S. rivulatus*, the length-girth relationship, shown in Figure 5, could be described by the linear equation: G_{max}=1.32+0.712×TL (R^2=0.96) for *A. sohal* and G_{max}=0.69+0.67×TL (R^2=0.90) for *S. rivulatus*, while the length-weight relationship, shown in Figure 6, could be described by the power equation: W=0.024×$TL^{2.81}$ (R^2=0.98) for *A. sohal* and W=0.015×$TL^{2.99}$ (R^2=0.97) for *S. rivulatus*. Pauly's t-test revealed that the growth of *A. sohal* is negative allometric (t=8.41, critical t value=1.968 for P=0.05), whereas the growth of *S. rivulatus* is isomtric (t=0.47, critical t value=1.964 for P=0.05).

From the linear relationship between the maximum girth and total fish length, shown in Figure 6, we could estimate the maximum girth corresponding to the modal length for each mesh size; 150.6, 167.1, and 183.6 mm maximum girth corresponding to 19.3, 21.62 and 23.93 cm modal lengths for *A. sohal* and 128.7, 143.4 and 158.0 mm maximum girth corresponding to 18.3, 20.5 and 22.7 cm modal length for *S. rivulatus* caught by 50, 56, and 62 mm inner-panel mesh size, respectively. The ratio of the maximum body girth to the mesh perimeter was found to be 1.5 for *A. sohal* and 1.3 for *S. rivulatus* caught with the three inner-panel mesh sizes of the trammel nets.

Discussion

It has been reported that the inner-panel mesh size is responsible for the size selectivity of trammel nets (Losanes *et al.*, 1992; Erzini *et al.*, 2006; Stergiou *et al.*, 2006). Results of the present study confirmed this fact and indicated that a slight increase in the inner-panel mesh size resulted in a significant difference in length distributions of both *A. sohal* and *S. rivulatus* (Table 2), with the overlapping over the majority of length classes (Figure 3), and the mean observed total length of the retained fish increased from 20.4 to 23.9 cm for *A. sohal* and from 19.1 to 21.2 cm for *S. rivulatus* with the slight increase in the inner-panel mesh size from 50 to 62 mm (Table 1).

The SELECT method used to estimate the selectivity parameters in the present study is one of the methods which apply the principle of geometric similarity, described by Baranov (1948), to compare catches in the same length group retained by different gears, under the assumption of equal fishing power for all used mesh sizes (Millar and Holst, 1997; Millar and Fryer, 1999; Millar, 2000; Carol and Garcia-Berthou, 2007).

Because of the ability of trammel nets to catch large fish by entanglement or trammeling, the length distributions of *A. sohal* and *S. rivulatus* caught with the different trammel nets in the present study are skewed to the right (Figure 3), deviating from the

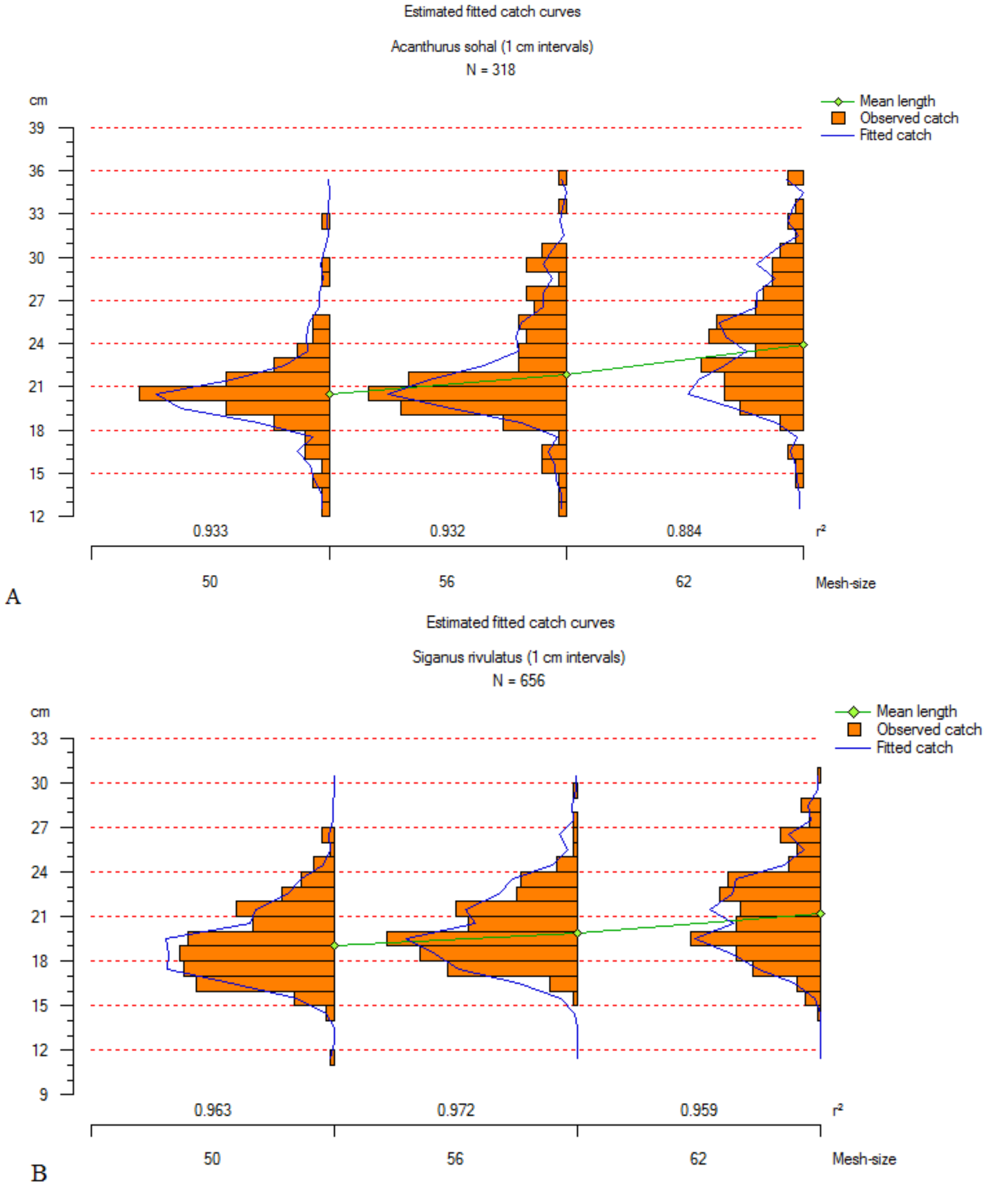

Figure 3. Length frequency distributions (observed and fitted) and the mean length of *A. sohal* (A) and *S. rivulatus* (B) caught with 50, 56, and 62 mm inner-mesh sizes in Jeddah fisheries (Pasgear 2 software output).

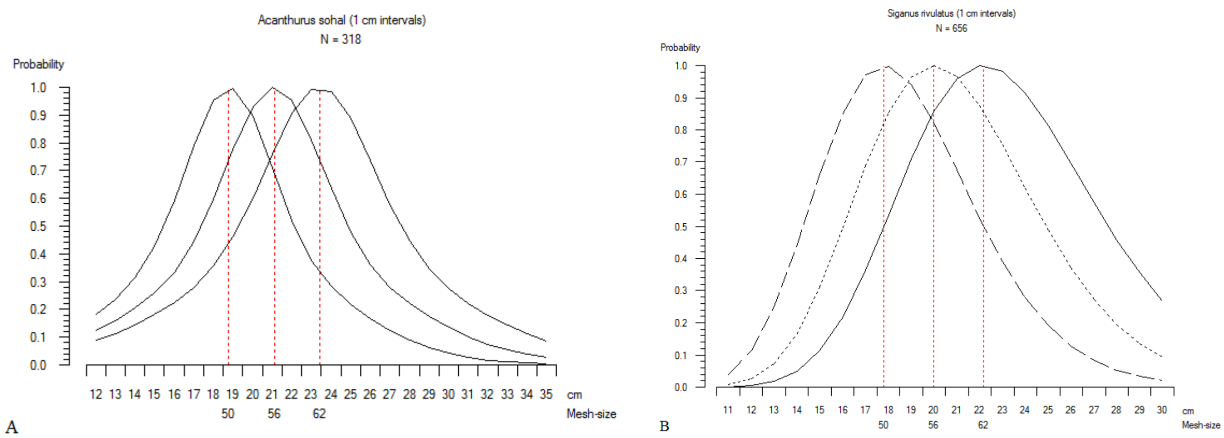

Figure 4. Selectivity curves of 50, 56, and 62 mm inner-panel mesh sizes trammel nets, estimated by the best fit bi-modal model for *A. sohal* (A) and log-normal model for *S. rivulatus* (B) in Jeddah coral reef fisheries (Pasgear 2 software output).

Table 1. Number of specimens, total length range, mean length (± standard deviation, SD) and mean body weight (Wt) (± SD) of *A. sohal* and *S. rivulatus* caught with monofilament trammel nets (by mesh sizes) in Jeddah fisheries

Species	Mesh Size (mm)	n	Length range	Mean TL & SD (cm)	Mean Wt & SD (gm)
	50	86	12.6–32.9	20.4±3.0	119±49.8
A. sohal	56	127	12.9–35.0	21.9±3.9	154±81.9
	62	105	14.3–35.6	23.9±4.1	193±107.3
	50	232	14.7–26.5	19.1±2.4	105±44.4
S. rivulatus	56	221	11.7–29.2	19.9±2.2	119±44.1
	62	203	14.6–30.2	21.2±3.1	145±60.3

Table 2. Kolmogorov-Smirnov test results for the comparisons between length distributions of *A. sohal* and *S. rivulatus* caught with the different inner-panel mesh sizes

Species	Inner-panel mesh sizes compared				Two-tailed K-S - Statistic	P-value
	m1	n1	m2	n2	N1< > N2	(Smirnov's Chi-Square Approx.)
	50	86	56	127	0.16	P>0.05 , H_0 is not rejected
A. sohal	50	86	62	105	0.46	P<0.05 , H_0 is rejected
	56	127	62	105	0.33	P<0.05 , H_0 is rejected
	50	232	56	221	0.18	P<0.05 , H_0 is rejected
S. rivulatus	50	232	62	203	0.28	P<0.05 , H_0 is rejected
	56	221	62	203	0.23	P<0.05 , H_0 is rejected

Table 3. Trammel net selectivity parameters estimated using the SELECT method for the different models applied for *A. sohal* and *S. rivulatus* caught with the different inner-panel mesh sizes

Species	Model	Parameters	D	P-value	d.f	D/d.f
	Normal location	(k, sigma)=(0.397, 3.589)	32.704	0.995	56	0.58
	Normal scale	(k1, k2)=(0.408, 0.066)	34.875	0.988	56	0.62
A. sohal	Log-normal	(mu, sigma)=(3.009, 0.164)	33.066	0.994	56	0.59
	Gamma	(k, alpha) = (0.011, 38.645)	32.896	0.997	56	0.59
	Bi-modal	(k1, k2, k3, k4, w) = (0.386, 0.041, 0.387, 0.104, 0.736)	25.916	0.999	53	0.49
	Normal location	(k, sigma) = (0.367, 3.729)	35.327	0.757	42	0.8411
	Normal scale	(k1, k2) = (0.376, 0.068)	38.787	0.613	42	0.92
S. rivulatus	Log-normal	(mu, sigma)=(2.940, 0.183)	35.304	0.758	42	0.8406
	Gamma	(k, alpha) = (0.012, 31.163)	35.698	0.743	42	0.85
	Bi-modal	(k1, k2, k3, k4, w) = (0.351, 0.051, 0.441, 0.057, 0.467)	34.576	0.672	39	0.89

Table 4. Modal lengths and spread values for the best fitting model of trammel net selectivity curves for *A. sohal* and *S. rivulatus* caught with the different inner-panel mesh sizes

Species	Model	Inner-Panel Mesh Size					
		50 mm		56 mm		62 mm	
		Modal Length	Spread	Modal Length	Spread	Modal Length	Spread
A. sohal	Bi-modal	19.30	2.05	21.62	2.30	23.93	2.54
S. rivulatus	Log-normal	18.29	3.55	20.49	3.98	22.68	4.40

typical (normal) bell-shaped selectivity curve of gillnets (Hamely, 1975; Millar and Fryer, 1999). Hence, the skewed bi-modal selectivity model was found to be the most appropriate one of the five models, implemented in Pasgear software, providing the best fit to length distributions of *A. sohal*, and the skewed unimodal log-normal selectivity model providing the best fit to length distributions of *S. rivulatus* based on the lowest ratio of model deviance to degrees of freedom and highest P-value (Table 3). Moreover, the value of the ratio of the model deviance to degrees of freedom is less than unity in all models which means that there is no over-dispersion of data (i.e. the assumption of the underlying Poison distribution is not violated) (Holst *et al.*, 1998).

However, It is well known that different species of the same length have different body shapes and girths, which are closely related to (and hence

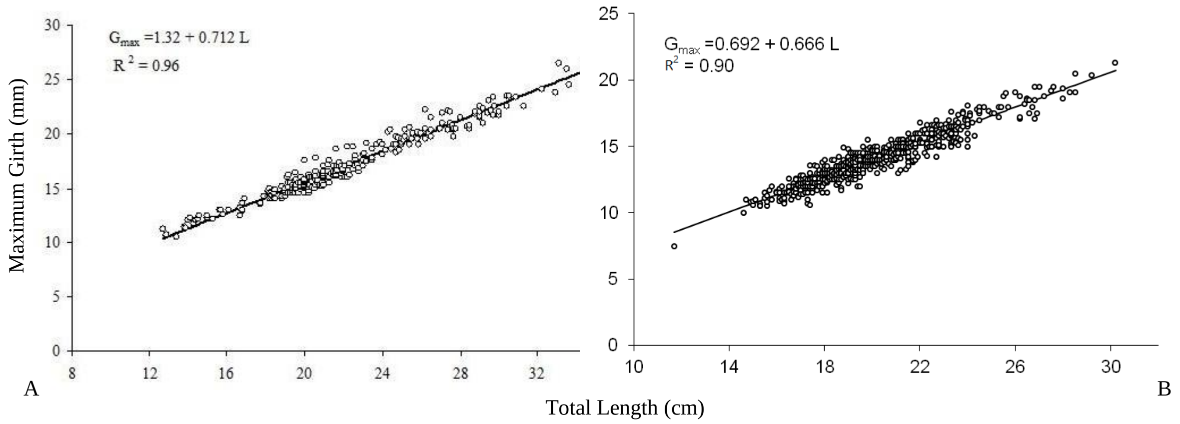

Figure 5. Length-Girth relationship of *A. sohal* (A) and *S. rivulatus* (B) caught withmonofilament trammel nets in Jeddah coral reef fisheries.

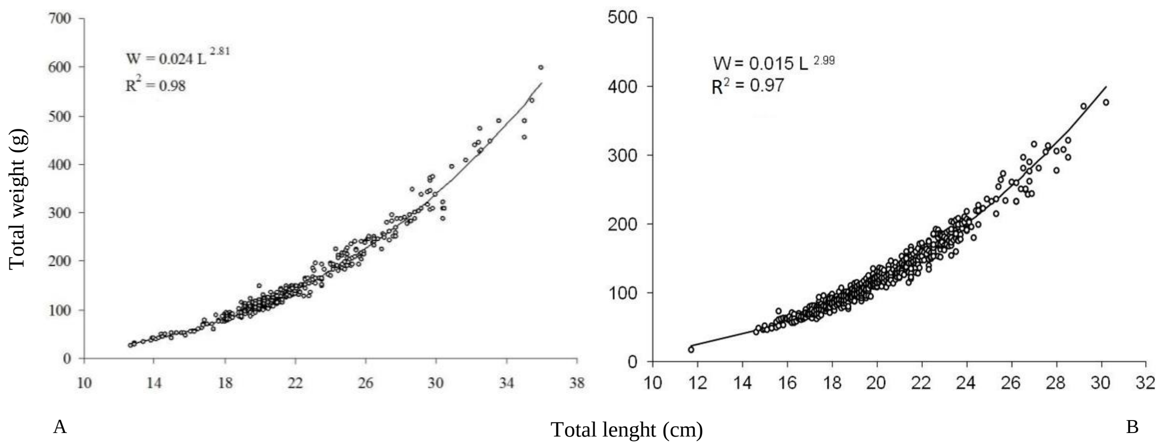

Figure 6. Length-weight relationship of *A. sohal* (A) and *S. rivulatus* (B) caught with monofilament trammel nets in Jeddah coral reef fisheries.

affecting) mesh size selectivity due to the fact that fish to be retained by a mesh, the girth at the point of capture has to be equal or slightly higher than mesh perimeter (Hamely, 1975; Reis and Pawson, 1999). Thus, the species-specific length-girth relationship is very important to be determined to allow the estimation of the girth of fish of known length which is easier to be measured (Stergiou and Karpouzi, 2003; Santos *et al.*, 2006).

Reis and Pawson (1999) concluded that efficient capture of fish by gillnets (i.e., the majority of fish being gilled or enmeshed) will be when the fish's girth at capture position slightly exceeds the mesh perimeter (girth/mesh perimeter ratio ranges from 1.0 to 1.1, regardless of body shape). They also predicted that it is sufficient to measure maximum girth to represent girth at capture position. In the present study, the ratio of the maximum girth of mean selection length to the mesh perimeter was found to be 1.5 for *A. sohal* and 1.3 for ***S.*** *rivulatus* for all trammel nets. The smaller ratio (1.3) indicates that the bulk of the catch of *S. rivulatus* in the present study may be retained by being gilled and/or wedged through the inner-panel meshes (Koura and Shaheen, 1969, Reis and Pawson, 1999), while some proportion of (large) fish are caught by entanglement or trammeling forming the right side skewness in the catch curve. The larger ratio (1.5) for *A. sohal* means that a larger proportion of individuals of this species are caught by entanglement or trammeling resulting in the best fit by the bi-modal selection model.

In the present study, the length-weight relationship of *A. sohal* in Jeddah fisheries was estimated for the first time, where there is no previous data on length-weight relationships for this species in the electronic database website, FishBase (Froese and Pauly, 2010). The exponent ' b' value was 2.81, and this means that there is a negative allometric growth where the ' b' value is significantly smaller than the exponent '3' in the cube law of the isomtric growth.

For *S. rivulatus*, there are many published results on the length-weight relationship of this species at different locations in the Red Sea and Mediterranean (Table 5). The parameter a of the different length-

Table 5. Parameters of the length weight-relationship of *Siganus rivulatus* in the Red Sea and Mediterranean

Area	a	b	r	n	Size range (cm)	Authors
Red Sea (Saudi Arabia)	0.0108	3.071	-	898	11.0 – 30.0	Hashem(1983)
Red Sea (Egypt)	0.012	3.020	-	425	9.4 – 33.7	Mehanna and Abdulla (2002)
Red Sea (Saudi Arabia)	0.013	2.990	0.96	200	15.0 – 27.0	Tharawt and Al- Owafair 2003)
Red Sea (Saudi Arabia)	0.015	2.990	0.98	656	11.7 – 30.2	The present study
Mediterranean (Egypt)	0.012	2.934	0.99	-	-	Mohamed, (1991)
Mediterranean (Egypt)	0.016	2.872	-	1126	11.0 – 28.0	El - Okda, (1998)
Mediterranean (Lebanon)	0.010	3.037	0.99	781	12.4 – 26.7	Bariche *et al*. (2005)
Mediterranean (Turkey)	0.007	3.179	0.95	521	10.7 – 24.1	Bilecenoglu and Kaya (2002)
Mediterranean (Libya)	0.023	2.818	0.96	1672	6.2 – 27.4	Shakman *et al*. (2008)
Mediterranean (Egypt)	0.023	2.783	0.93	1217	8.6 – 25.9	El – Far (2008)

weight relationships ranged between 0.007 and 0.023, with an average of 0.0142 and 95 % confidence limits of 0.010 and 0.018. The parameter b ranged between 2.783 and 3.18, with an average of 2.97 and 95 % confidence limits of 2.883 and 3.056. It is clear that the overall growth pattern of the species is isometric, because the 95 % confidence limits include the value 3.0 characteristic to the isometric growth (Froese, 2006), and the Pauly's t-test indicated that the b value is not significantly different from 3 of the cube law. This means that *S. rivulatus* keeps its body shape with growth, keeping linearity of maximum girth to fish length. So, it is expected that the size selection by the given mesh size will be normally distributed (Koura and Shaheen, 1969; Froese, 2006).

For fisheries management and ecosystem sustainability, it is important to protect the fish during their maximum growth in weight and maximum reproductive potential. Therefore, Hashem (1983) recommended that the stock of *S. rivulatus* in Jeddah fisheries should be protected till they reach a total body length of 20 cm at which fish will attain a marketable body weight and allowed to give their maximum reproductive potential (high relative fecundity). Moreover, El-Far (2008) estimated the optimum length of this species in the Mediterranean Sea coast of Alexandria (Egypt) to be 20.43 cm.

Based on our results, and considering the fact that *S. rivulatus* in the Red Sea have an isometric growth compared to that of the same species in the Mediterranean, the 62 mm inner-panel mesh size will be the optimum to retain *S. rivulatus* of 22.7 cm (corresponding weight is 170 g) and *A. sohal* of 23.93 cm (corresponding weight is 180 g) mean selection length. Although this mesh size retained less number of individuals, the average body weight of fish was larger than that of fish retained in the smaller sized inner-panel meshes (Table1). Hence, we recommend using trammel nets with a minimum inner-panel mesh size of 62 mm for catching the optimum size of *A. sohal* and *S. rivulatus* and avoiding the undersized fishes in the coral reef fisheries in Jeddah.

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References

Acosta, A.R., and Appeldoorn, R.S. 1995. Catching efficiency and selectivity of gill nets and trammel nets in coral reefs from southwestern Puerto Rico. Fisheries Research, 22 (1995), pp. 175-196. doi: 10.1016/0165-7836(94)00328-T

Balik, I. 1999. Investigation of the Selectivity of Multifilament and Monofilament Gill Nets on Pike perch (*Stizostedion lucioperca* (L., 1758)) Fishing in Lake Beysehir. Turkish Journal of Zoology, 23: 179-183.

Baranov, F. I. 1948. Theory of fishing with gill-nets. Pishchepromizdat, Moscow. Translated from Russian by Ontario Department of Lands, Mafle, Ontario, 45 pp.

Bilecenoglu, M. and Kaya, M. (2002) Growth of marbled spinefoot, Siganus rivulatus, Forsskål, 1775 (Teleostei: Siganidae) introduced to Antalya Bay, eastern Mediterranean Sea (Turkey). Journal of the Fisheries Research, 54 (2): 279-285. doi:10.1016/S0165-7836(00)00296-4

Carol, J., and García-Berthou, E. 2007. Gillnet selectivity and its relationship with body shape for eight freshwater fish species. Journal of Applied Ichthyology, 23(6):654-660. doi: 10.1111/j.1439-0426.2007.00871.x

Carpenter, R.C. 1986. Partitioning herbivory and its effects on coral reef algal communities. Ecological Monograph, 56: 345–365. doi: 10.2307/1942551.

Carpenter, R.C. 1990. Mass mortality of *Diadema antillarum* II. Effects on population densities and grazing intensity of parrotfishes and surgeonfishes. Marine Biology 104:79–86.
doi: 10.1007/BF01313160

Cochrane, K.L., and Garcia, S.M. 2009. A Fishery Manager's Guidebook, 2nd Edition. FAO and Wiley Blackwell Publishers, 518 pp.

Dinçer, A.C., and Bahar, M. 2008. Multifilament gillnet selectivity for the red mullet (*Mullus barbatus*) in the Eastern Black Sea Coast of Turkey, Trabzon. Turkish Journal of Fisheries and Aquatic Sciences, 8: 355-359.

Dulvy, N.K., Polunin, N.V.C. Mill, A.C. and Graham, N.A.J. 2004. Size structural change in lightly exploited coral reef fish communities: evidence for weak indirect effects. Canadian Journal of Fisheries and Aquatic Science. 61: 466–475. doi: 10.1139/f03-169

El-Far, A.M.M. 2008. Artisanal fishery off Al-Exandria coastal area special reference to the fishery biology of *Siganus spp*. MSc. Department of Zoology, Faculty of Science, Zagazig University.

Erzini, K., Gonçalves, J.M.S. Bentes, L., Moutopoulos, D.K., Casal, J.A.H.C., Soriguer, M.C., Puente, E., Errazkin, L.A. and Stergiou, K.I. 2006. Size selectivity of trammel nets in southern European small-scale fisheries. Fisheries Research, 79(1-2): 183-201. doi: 10.1016/j.fishres.2006.03.004.

Fabi, G., Sbrana, M., Biagi, F., Grati, F., Leonori, I. and Sartor, P. 2002. Trammel net and gill net selectivity for *Lithognathus mormyrus* (L., 1758), *Diplodus annularis* (L., 1758), *Mullus barbatus* (L., 1758), in the Adriatic and Ligurian Seas. Fisheries Research, 54: 375-388. doi: 10.1016/S0165-7836(01)00270-3

FAO, 2011-2015. Fisheries and aquaculture software. FishStatJ software for fishery statistical time series. In: FAO Fisheries and Aquaculture Department (online). Rome. Updated 23 June 2015. http://www.fao.org/Fishery/software/fishstatj/en. (Cited 14 July 2015).

Froese, R. 2006. Cube law, condition factor and weight length relationships: history, meta-analysis and recommendations. Journal of Applied Ichthyology, 22: 241-253. doi: 10.1111/j.1439-0426.2006.00805.x

Froese, R., and Pauly, D. 2010. Fish base. World Wide Web electronic publications. URL: http://www.fishbase.org . Reviewed: 10 Feb 2016.

Fujimori, Y., and Tokai, T. 2001. Estimation of gillnet selectivity curve by maximum likelihood method. Fisheries Science, 67(4): 644–654. doi: 10.1046/j.1444-2906.2001.00301.x

Goetze, J.S., Langlois, T.J. and Egli, D.P. 2011. Evidence of artisanal fishing impacts and depth refuge in assemblages of Fijian reef fish. Coral Reefs, 30(2), pp.507–517. doi: 10.1007/s00338-011-0732-8.

Gulland, J.A. 1983. Fish Stock Assessment. A Manual of Basic Methods. FAO/Wiley Series on Food and Agriculture, Vol. 1, FAO, Rome, 223 pp.

Hamley, J.M. 1975. Review of gillnet selectivity. Journal of Fisheries Research Board of Canada, 32, 1943–1969. doi: 10.1139/f75-233

Hashem, M.T. 1983. Biological studies on *Siganus rivulatus* (Forsk.) in the Red Sea. Journal of the Faculty of Marine Science, Jeddah, 3: 119-127.

Hatcher, B.G. 1981. The interaction between grazing organisms and the epilithic algal community of a coral reef: a quantitative assessment. Proc 4th Intl Coral Reef Symp 2:515–524.

Holst, R., Madsen, N., Fonseca, P., Moth-Poulsen, T. and Campos, A. 1998. Manual for gillnet selectivity, European Commission, Denmark, 43 pp.

Kalayci, F., and Yeşilçiçek, T. 2012. Investigation of the Selectivity of Trammel Nets Used in Red Mullet (*Mullus barbatus*) Fishery in the Eastern Black Sea, Turkey. Turkish Journal of Fisheries and Aquatic Sciences 12: 937-945. doi: 10.4194/1303-2712-v12_4_21

Kolding, J., and Skålevik, Å. 2011. PasGear 2. A database package for experimental or artisanal fishery data. Version 2.5, available at (http://www.imr.no/forskning/bistandsarbeid/nansis/pasgear2/en).

Koura, R., and Shaheen, A. 1969. Selectivity of gillnets for Nile perch (*Lates niloticus* L.). Studies and Reviews, General Fisheries Commission for the Mediterranean, 39: 1-12.

Lewis, S.M., and Wainwright, P.C. 1985. Herbivore abundance and grazing intensity on a Caribbean coral reef. Journal of Experimental Marine Biology and Ecology 87: 215-228. doi: 10.1016/0022-0981(85)90206-0

Losanes, L.P., Matuda, K., Machii, T. and Koike, A. 1992. Catching efficiency and selectivity of entangling nets. Fisheries Research, 13: 9-23. doi: 10.1016/0165-7836(92)90030-W.

May, R.M. 1984. Exploitation of marine communities. Springer-Verlag, Berlin Heidelbery New York. 367 pp.

Millar, R.B. 1992. Estimating the size-selectivity of fishing gear by conditioning on the total catch. Journal of the American Statistical Association, 87: 962-968. doi: 10.1080/01621459.1992.10476250.

Millar, R.B. 2000. Untangling the confusion surrounding the estimation of gillnet selectivity. Canadian Journal of Fisheries and Aquatic Sciences, 57: 507-511. doi: 10.1139/f99-275.

Millar, R.B., and Holst, R. 1997. Estimation of gillnet and hook selectivity using log-linear models. ICES Journal of Marine Science, 54: 471–477. doi: 10.1006/jmsc.1996.0196

Millar, R.B., and Fryer, R.J. 1999. Estimating the size-selection curves of towed gears, traps, nets and hooks, Reviews in Fish Biology and Fisheries, 9: 89-116. doi: 10.1023/A:1008838220001

Pauly, D. 1984. Fish population dynamics in tropical water: a manual for use with programmable calculators. ICLARM Studies and Reviews 8.

Petrakis, G., and Stergious, K.I. 1996. Gillnet selectivity for four fish species (*Mallus barbatus*, *Pagellus erythrinus*, *Pagellus Acarne* and *Spicara flexuousa*) in Greek waters. Fisheries Research, 27: 17-27. doi: 10.1016/0165-7836(96)00476-6

Reis, E.G., and Pawson, M.G. 1999. Fish morphology and estimating selectivity by gillnets. Fisheries Research, 39: 263–273. doi: 10.1016/S0165-7836(98)00199-4

Santos, M.N., Canas, A., Lino, P.G. and Monteiro, C.C. 2006. Length-girth relationship of 30 marine species. Fisheries Research, 78: 368-373. doi: 10.1016/j.fishres.2006.01.008

Stergiou, K.I., and Karpouzi, V.S. 2003. Length-girth relationships for several marine fishes. Fisheries Research, 60, 161–166. doi: 10.1016/S0165-7836(02)00077-2

Stergiou, K.I., Moutopoulos, D.K., Soriguer, M.C., Puente, E., Lino, P.G., Zabala, C. Monteiro, P., Errazkin, L.A. and Erzini, K. 2006. Trammel net catch species composition, catch rates and metiers in southern European waters: a multivariate approach. Fisheries Research, 79: 170-182. doi: 10.1016/j.fishres.2006.03.003

Taylor, B.M., Houk, P., Russ, G.R. and Choat, J.H. 2014. Life histories predict vulnerability to overexploitation in parrotfishes. Coral Reefs, 33:869–878. doi:10.1007/s00338-014-1187-5

Trent, L., and Pristas, J. 1977. Selectivity of gillnets on estuarine and coastal fishes from the St An drew Bay, Florida. Fishery Bulletin, 75(1): 185-198.

Valdez-Pizzini, M., Acosta, A., Griffith, D.C. and Ruiz-Peres, M. 1992. Assessment of the socio economic impact of fishery management options upon gillnets and trammel nets fishermen in Puerto Rico: An interdisciplinary approach (Anthropology and fisheries biology) for the evaluation of management alternatives. Final report NOAA/NMFS, 96 pp.

Valles, H., Oxenford, H.A. and Gill, D. 2015. Parrotfish size as a useful indicator of fishing effects in a small Caribbean island. Coral Reefs, 34:789–801. doi: 10. 1007/s00338-015-1295-x

Vincent, I.V., Hincksman, C.M., Tibbetts, I.R. and Harris, A. 2011. Biomass and Abundance of Herbivorous Fishes on Coral Reefs off Andavadoaka, Western Madagascar. Western Indian Ocean Journal of Marine Science. Western Indian Ocean Marine Science Association, 10: 83–99.

Wileman, D.A., Ferro, R.S.T., Fonteyne, R. and Millar, R.B. 1996. Manual of methods of measuring the selectivity of towed fishing gears. ICES Cooperative Research Report. (Copenhagen) No. 125, 126 pp.