Research in Marine Sciences
Volume 5, Issue 2, 2020
Pages 699 - 708

Mesh size selectivity of drift gillnets for skipjack tuna (Katsuwonus pelamis) in Gulf of Oman

Seyed Abbas Hosseini[1,*], and Mohammad Reza Mirzaei[1]

[1]Offshore Fisheries Research Center, Iranian Fisheries Science Research Institute, Agricultural Research Education, and Extension Organization (AREEO), Chabahar, Iran

Received: 2020-03-27 *Accepted: 2020-05-12*

Abstract

In this study, gillnet selectivity of skipjack tuna (*Katsuwonus pelamis*) is determined for the data came from Oman sea in south-east coast of Iran during 2017-2019. For this purpose, girth measurements for opercular (OP) and front of dorsal fin (D_1) of the nets with stretched mesh sizes of 140 and 146mm were incorporated into the theoretical selection curves based on cumulative function of standard normal distribution. Analysis of covariance (ANCOVA) showed that girth at D_1 is determined as a maximum girth of skipjack tuna. Data on capture process showed that most fish is enmeshed by the nets, and hence it justifies the use of the selectivity model. The selectivity curves were in consistent with length distributions and the optimum selection length was estimated at 53 and 55 cm for 140 and 146 mm nets, respectively. The findings of the present papers suggest that the commonly used drift gillnets are not destructive for skipjack in terms of size selection, as most fish are allowed to spawn at least once before capturing. More issues on skipjack fishery management in Indian Ocean are discussed.

Keywords: Skipjack tuna; drift gillnets; selectivity; Oman Sea; Optimum length.

1. Introduction

Gillnet selectivity is an important parameter describing the capacity and efficiency of the fishing gear in capturing fish (Kitahara, 1971). The parameters derived from the gillnet curves are fundamental information in fisheries stock assessment and management. These can also be used directly in comparative performance of different types of mesh sizes of the nets in developing management strategies for rational and sustainable fisheries (Millar and Holst, 1997). One of the main aspects of studying fishing gear technology is to minimize the

*Corresponding Author's email: ab_hossaini@yahoo.com

catch of juveniles of a given species and also non-targeted fish species (i.e. bycatch). This can be achieved by a good understanding of selectivity of different mesh sizes of gillnets for the same species of different sizes or different species under field operations (Millar and Holst, 1997). Gillnets are known as a high selective gear for capturing fish of a given species or certain sizes of the same species in large in quantities (Hamley, 1975). In general, mesh size and fish shape are the main factors affecting gillnet selectivity (Hamley, 1975; Petrakis and Stergiou, 1995), as well as (a) the elastic stretching of the net; (b) the hanging ratio; (c) the strength and flexibility of the twine; (d) the visibility of the twine; (e) fish behavior and swimming speed being the other factors. The most commonly used method in selectivity of gillnets is the indirect method, which determines the selectivity by comparing the length distributions of fish from different mesh sizes of the nets (Millar and Fryer, 1999). Although many studies were conducted in selectivity of gill nets in various parts of the world (McCombie and Berst, 1969; Regier, 1969; Kawamura, 1972; Winters and Wheeler, 1990; Reis and Pawson, 1992; Millar and Holst, 1997; Hosseini *et al.*, 2017), this is not the case of the skipjack tuna.

Skipjack tuna (*Katsuwonus pelamis*) belonging Scombridae family is a highly migratory species and distributed throughout tropical, subtropical waters and warm temperate waters of all Oceans (Collette and Nauen, 1983). This species perform spawning activities several times in a year where the sea surface temperature is higher than 24^0C (Matsumoto *et al.*, 1984). Skipjack is the major species of tropical tunas in world wild; constituting more than 50% of the total tuna catches (Macfadyen, 2016). In Indian Ocean, average annual catches of the tuna species during 2014-2018 were reported to be around 490,000 tonnes, with a contribution of nearly 34% to total catches of tunas, and of around 49% to tropical tunas during the period (IOTC, 2019a). Several fishing gears are employed for skipjack tuna, but the species is mostly caught by industrial purse seiners (≈49%), followed by gillnet (≈18%), and pole and line (≈16%), (IOTC, 2019b). The six main countries catching skipjack tuna in Indian Ocean are Spain from EU by purse seine (17%), Indonesia by coastal purse seine, troll line, gillnet (17%), Maldives by pole-and-line (17%), Seychelles by purse seine (11%), Sri Lanka by gillnet-long line (10%), and Iran by drift gillnets (9%), (IOTC, 2019b).

Recently, skipjack catches in Indian Ocean have increased sharply and in 2018 reached a level of 600,000t (around 100,000t more than in 2017), with around 18% driven by gillnet fishery (IOTC, 2019a). Therefore, research studies are needed to assess the selectivity of gillnets to determine the appropriate mesh sizes of the nets for its sustainable exploitation.

2. Materials and methods

Data required for size selectivity of gillnets came from the two types including transverse morphometric (i.e. girth measurements) and length data sampled from drift gillnet fisheries of three landing sites of Tang, Konarak and Beris in south-east coast of Iran during 2017-2019 (Figure 1). Regarding the girths data, measurements at different positions of the fish body such as Opercular girth (OP) and girth at the beginning of first dorsal fin (D_1) (Figure 2) as well as fork length (FL) were collected for two presently used gillnets in stretched mesh sizes of 140 and 146 mm (Table 1). During sampling fish retained by the nets were also recorded for the data on capture process marked on the girths by the mesh sizes. These additional girth data are: Eye (EY), POP (Pre-opercular), and front of second dorsal fin (D_2) (Figure 2).

Girth measurements were made with a loop of non-stretchable synthetic twine at five positions along the fish body. Moreover, during landing visits, the inside mesh sizes in opposite knots were measured in the dry state for the mean of 20 randomly selected meshes by inserting a steel ruler using light hand force to stretch the mesh. These mesh sizes measured at the field were considered as input data for the selectivity model. As shown in Table 1, the difference between measured mesh sizes and nominal mesh sizes from manufacturer was between 1 to 2 mm.

Least square regression (Zar, 1999) was used for determining the relationship between the length data with girth measurements, in which the strength of the relationship is defined by the determination of coefficient (R^2) at a significant level of p=0.05. In order to determine the significant differences between transverse morphometric data, analysis of covariance (ANCOVA) was used by comparing the slopes of length-girth relationships.

Gillnet selectivity was estimated indirectly by inferring data on maximum girth and head girth measurements, known as Sechin model (1969). This approach is based on the assumption that a fish, once swimming into the net, is caught if its head girth is smaller but maximum girth larger than the mesh perimeter. On this basis, girth among any particular length class of fish is normally distributed, with a common variance for all length classes. The Sechin model used here is defined by the cumulative function of standard normal distribution as below:

$$S_j = \phi\left(\frac{(2M - K_g G_{gj})}{\sqrt{\sigma_{gj}{}^2 + \sigma_m{}^2}}\right) \times \left[1 - \phi\left(\frac{(2M - K_{max} G_{maxj})}{\sqrt{\sigma_{maxj}{}^2 + \sigma_m{}^2}}\right)\right]$$

where, S_j is the probability of retention of fish of size-class j, ϕ is the cumulative function of

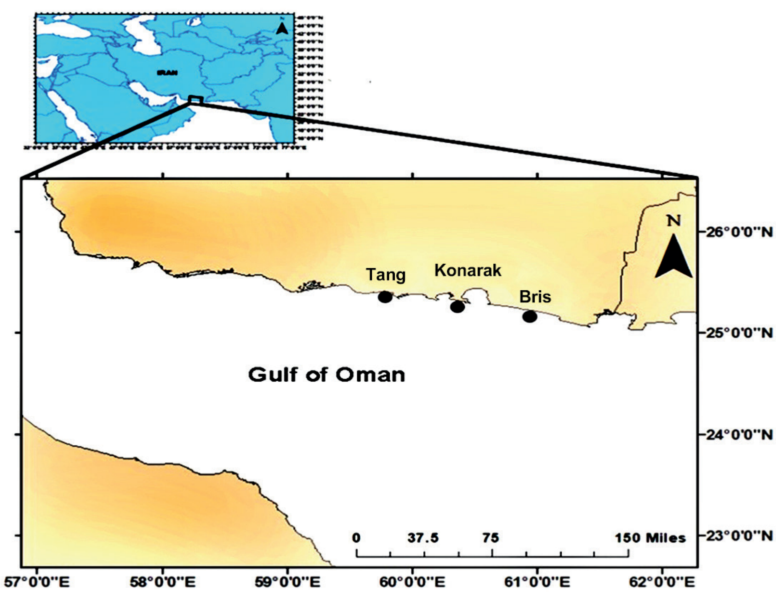

Figure 1. Maps indicating the landing sites for sampling with closed circles of black dots, Gulf of Oman, Iran

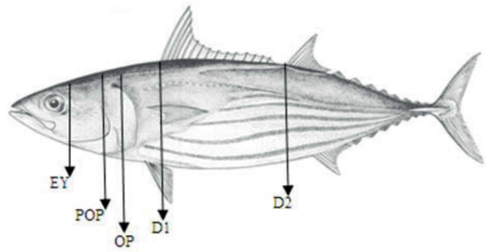

Figure 2. Body profiles of skipjack tuna with different girth positions at capture along the fish's body are indicated by lines (EY, Eye; POP, Pre-opercular; Op, Opercular; D_1, front of first dorsal fin; D_2, front of second dorsal fin).

Table 1. Technical features of sampled drift gillnets used during the study. Mesh sizes are given in mm and inch (")

Stretched mesh size in mm (inch)		Netting material	Twine No. (210D/Ply)	Depth (No. meshes)	Stretched length (Yards)
Nominal mesh size	Measured mesh size				
140 (5 $^1/_2$″)	142 (5.59″)	Multifilament	24,33,36	120,150	200
146(5 $^3/_4$″)	147 (5.79″)	" "	" "	" "	" "

standard normal distribution, G_{gj} is the mean opercular girth for fish of size-class j, K_g is the measured girth/mesh perimeter at meshing mark in gill (opercular) position, σ_{gj} is the standard deviation of opercular girth of size-class j, σ_m is the standard of mesh perimeter, G_{maxj} is the mean maximum girth for fish of size-class j, K_{max} is the measured girth/mesh perimeter ratio at meshing mark in maximum position, σ_{maxj} is the standard deviation of maximum girth of size-class j, 2M is the mesh perimeter. Also, in this model the correction coefficients of compressibility at retention girth and twine elasticity due to mesh size variations, known as k-factor, are considered in the selectivity curves.

3. Results

422 and 194 specimen of skipjack tuna was collected for the determination of length-girth relationship at opercular (OP) and at front of first dorsal fin (D_1) body positions, respectively. The regression equations showed a significant relationship between the girths and length data, with R^2 obtained as 0.88 and 0.90 for OP and D_1, respectively (Table 2). Results of one-way ANCOVA for the fork length (FL) and girth measurements at OP and D_1 positions indicated statistically a significant difference (Table 3; F = 13.16, p = 0.000). This difference is also indicated by the estimated linear regression between two girth measurements at the same length based on Figure 3, and hence the body position at D_1 was considered as a maximum girth of skipjack for the selectivity model.

An investigation of body positions of skipjack marked by the meshes of the nets indicated

Table 2. Summary of the results of regression equations fitted to the girth measurements and length data for skipjack tuna. The values of mean and range are related to the girth data, and are given in centimeter

Regression equation	SE± Mean	Range	Number	(R^2)
*OP = 0.5563FL+3.9287	0.20±36.8	24.1-51.3	422	0.88
+D_1=0.6165FL+3.5924	0.45 ±41.3	29-56.7	194	0.90

*Op, Girth at operculum; + girth at front of first dorsal fin

Table 3. Analysis of covariance (ANCOVA) between girths at opercular (OP) and first dorsal fin (D_1) with fork length data of skipjack tuna

Source of Variation	df	SST	F	Significance
OP	420	898.4	13.17	0.000
D_1	192	743.8		

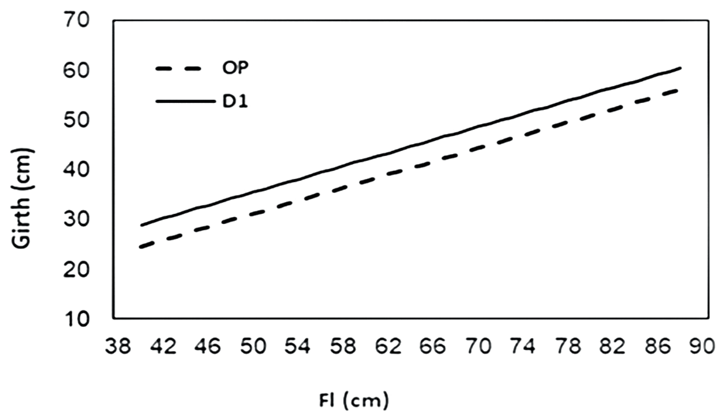

Figure 3. Predicted girth relationships with length for skipjack tuna whish was performed by the linear regressions presented in Table 2. The values of girths at OP (opercular) are higher than D_1 (at first dorsal fin).

that more fish were captured by the opercular, contributing to 50% and 56% of the all fish captured for the nets of 140 and 146 mm, respectively (Figure 4). After that, the fish caught by D_1 (28%) in the 140 mm mesh size and by HD (29%), Eye and Pre-opercular girths, in the mesh size of 146 mm were ranked next in abundance. When we compare the capture processes in details by fish size we can observe that fish at 52 cm fork length begin to be captured increasingly by OP (opercular) for the nets of 140 mm mesh size and then the trend decreased at length of 64 cm FL. Fish of larger lengths (70-86 cm) are captured more by HD (Figure 4). On the other hand, fish captured by D_1 are observed for smaller fish, mostly at 43 to 55 cm FL.

The trend of capture process of fish by length for the 146 mm mesh size is almost the same as 140 mm nets, but its frequency for OP position was peaked at larger length of 58 cm.

When we pooled the data on capture process for two body positions, i.e. Entangled (fish captured by head, pre-opercular) and enmeshed

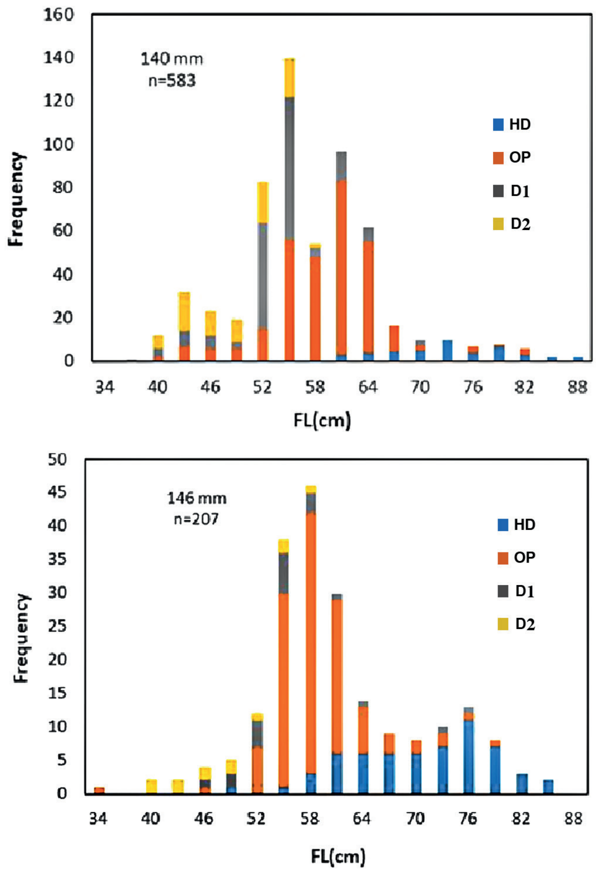

Figure 4. Length distributions for various capture processes (HD. Head including Eye and Pre-opercular girths; Op, Opercular girth; D_1, girth at first dorsal fin; D_2, girth at first dorsal fin) in two mesh sizes in mm. n, represents the number of specimen sampled.

Table 4. Proportion (%) of two different capture processes of skipjack tuna taken by mesh size. Entangled includes fish captured by head, pre-opercular, and enmeshed represents individuals captured by opercular, D_1 and D_2.

Mesh size (mm)	Entangled	Enmeshed
140	7.6	92.4
146	28.5	71.5

(individuals captured by opercular, D_1 and D_2) we find that, for both mesh sizes of 140 and 146 mm, mostly fish are retained by enmeshing (Table 4).

The length range of skipjack tuna sampled by gillnets, irrespective of mesh size, was varied from 34 to 86 cm FL with an average of 56.0±0.46. Although, the length distribution of the species captured by each mesh size was in the same range (Table 5), the mean length was higher for mesh size of 146 mm (59.6±0.71) when compared to the nets of 140 mm (56.2±0.35).

Examining the size selectivity curves of the nets and their comparison with length frequency of skipjack indicated that for both mesh sizes of

Table 5. Length parameters of skipjack tuna captured by mesh sizes of drift gillnet (N, number of fish samples)

Mesh size (mm)	N	Min	Max	Mean ±SE
140	581	37	86	56.2±0.35
146	208	34	85	59.6±0.71

Table 6. Size selectivity parameters of skipjack tuna estimated for each mesh size of gillnets

Mesh size (mm)	Optimal length (cm)	K factor OP	K factor D_1
140	53	0.794	0.787
146	55	0.801	0.792

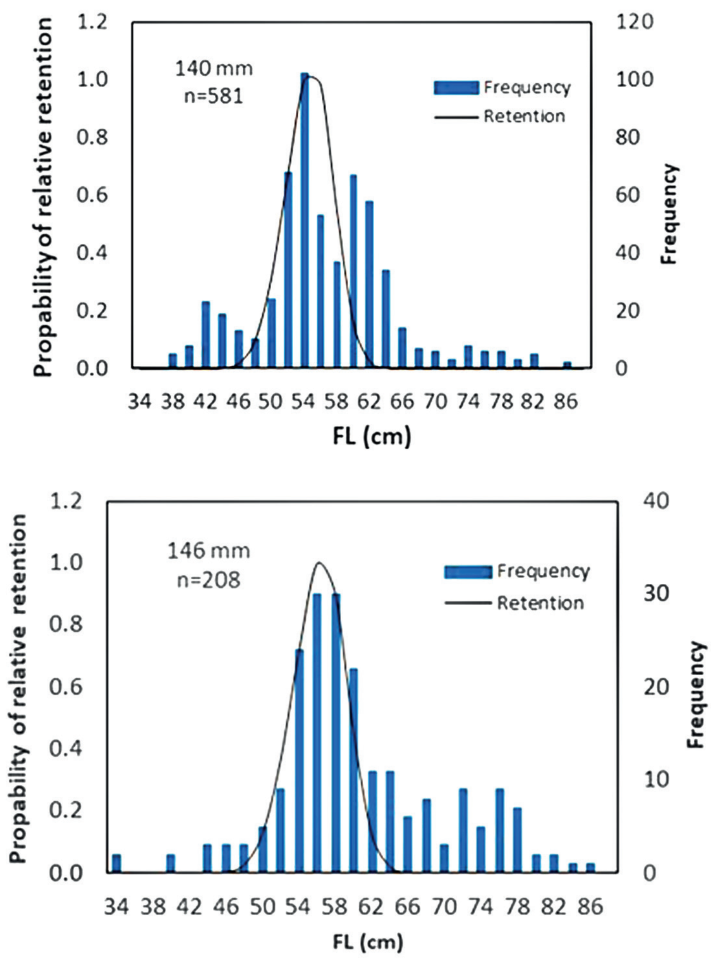

Figure 5. Mesh size selectivity curves (lines) of skipjack tuna in drift gillnets by mesh size compared with size frequency distributions (bars), and n is the number of specimen sampled.

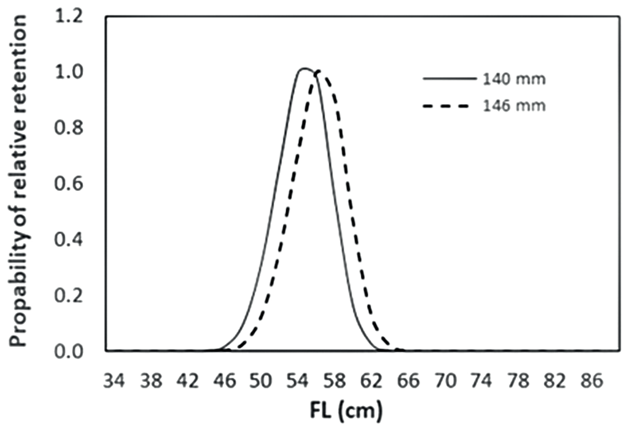

Figure 6. Estimated size selectivity curves of skipjack tuna in drift gillnets by mesh size derived from the corresponding selectivity model

140 and 146 mm the range of selectivity curve was agreed well with the uni-modal length distributions of the fish caught by the nets (Figure 5). The optimum selection length (the length with the highest probability of capture) estimated was obtained as 53 and 55 cm FL for the mesh sizes of 140 and 146 mm (Table 6). Results of k-factor (the ratio of the measured girth to mesh perimeter), as a correction factor, revealed that the value was higher at gill position (OP) than at first dorsal fin (D_1) in all mesh sizes of the nets (Table 6). These factors were incorporated into the selectivity model to refine the predicted probability of retention of the fish. Also, the selection range increases with an increase in mesh size as shown in Figure 6.

4. Discussion

The data examined in this paper was taken from gillnets of two mesh sizes of 140 and 146 mm, which are used commonly for skipjack tuna in the region. These kinds of drift gillnets with two mesh sizes are also used for the other tuna species such as yellowfin (*Thunnus albacares*) and longtail tuna (*Thunnus tonggol*) by the local fishermen.

Examining the relationships between the length (fork length) and two parameters of transverse morphometric data including girths at opercular and first dorsal fin positions of skipjack tuna shows that there is a strong linear relationship between them, which is in consistent with the previous studies on the other species (Clarke and King, 1986; Ehrhardt and Die, 1988; Reis and Pawson, 1992).

Depending on the fish morphology and its relation to the perimeter of the mesh size of nets, any fish species can be retained at different body positions (Pet *et al*., 1995). In skipjack tuna, due to the body shape, most of the fish were enmeshed by mesh sizes of 140 and 146mm (92% and 71.5% respectively, indicating selectivity model used here is applicable to the skipjack data captured by the drift gillnets, which is in consistent with the model assumptions (Sechin, 1969).

The k-factor obtained showed that this ratio for D_1 is less than opercular; indicating the body of the skipjack is softer at the front of the first dorsal fin than OP. However, the results suggest that gillnets used in the region have elasticity features and should be considered during the net design.

The results showed that skipjack tuna caught by mesh sizes of 140 and 146 mm nets has a uni-modal length distributions and overlaps with the normal selectivity curves. Optimal selection length of skipjack tuna by 140 and 146 mm mesh sizes were obtained as 53 and 55 cm FL, which are greater than the length at 50% maturity (LM50%) of the species being as 41- 43 cm FL in the western Indian Ocean (Grande *et al*., 2010), suggesting the two types of nets used in Oman Sea are suitable for skipjack fishing. On the other hand, the length distributions of the species caught by the nets also support the findings, as in both nets with mesh sizes of 140 mm and 146 mm, the immature fish accounted for around 2% of the total catches (Figure 5). The proportion of total catches of skipjack by fishing gear in Indian Ocean indicated that most (around 49%) of the species is caught by purse seine and gillnet catches have represented as much as 20% to 30% of the total catches in the recent years (IOTC, 2019a).

Several countries including Sri Lanka, Iran and Pakistan, and Indonesia using gillnets have reported large catches of skipjack tuna in the Indian Ocean. The fishing area for the artisanal gillnets, namely by Iran and Sri Lanka, extends to the high seas, reaching as far as the Mozambique Channel. Although, skipjack tuna caught by Iranian gillnet fishery are not problematic for the stocks in the Oman Sea and/or in Indian Ocean in terms of size selection, it needs to investigate the size selectivity of gillnets used by other fleets, for example by Pakistan, as the Pakistani fishermen use smaller mesh sizes of gillnets (e.g. 13mm stretched mesh size) for the species.

New stock assessment carried out for skipjack tuna in Indian Ocean in 2019 revealed that the historical and current catches are estimated to be below the target point and the stock is determined to be not overfished and is not subject to overfishing (IOTC, 2019a).

Recent purse seine fishery in Indian Ocean shows that more than 90% of the skipjack tuna are caught around Fish Aggregating Devices (FADs), with a larger proportion of the catches consisting of juvenile fish (IOTC, 2019a). It seems that purse seine fishery around FADs is destructive for skipjack tuna in terms of size selection rather than gillnet fishery, and therefore the industrial fishery should be managed in line with the Harvest Control Rule proposed for the skipjack (470,029 tonnes).

This study is the first in which selectivity along with length frequency distributions of skipjack tuna were observed for the gillnet fishery in the Oman Ocean. From the perspective of sustainable fishing, the current gillnets with mesh sizes of 140 and 146 mm are considered as appropriate nets for skipjack tuna because most fish are allowed to spawn at least once before catching.

Acknowledgment

The authors gratefully acknowledge the financial support of the "Iranian Fisheries Science Research Institute" (Project No. 2-78-12-056-961188).

References

Clarke, D., and King, P. 1986. The estimation of gillnet selection curves for Atlantic herring (Clupea harengus L.) using length/girth relations. ICES Journal of Marine Science, 43: 77-82.

Collette, B. B., and Nauen, C. E. 1983. Scombrids of the world: an annotated and illustrated catalogue of tunas, mackerels, bonitos, and related species known to date (v. 2).

Ehrhardt, N. M., and Die, D. J. 1988. Selectivity of gill nets used in the commercial Spanish mackerel fishery of Florida. Transactions of the American Fisheries Society, 117: 574-580.

Grande, M., Murua, H., Zudaire, I., and Korta, M. 2010. Spawning activity and batch fecundity of skipjack, Katsuwonus pelamis, in the Western Indian Ocean. IOTC-2010. AZTI Tecnalia, Portualde z/g.

Hamley, J. M. 1975. Review of gillnet selectivity. Journal of the Fisheries Board of Canada, 32: 1943-1969.

Hosseini, S. A., Kaymarm, F., Behzady, S., Kamaly, E., and Darvishi, M. 2017. Drift gillnet selectivity for indo-pacific king mackerel, Scomberomorus guttatus, using girth measurements in the North of Persian Gulf. Turkish Journal of Fisheries and Aquatic Sciences, 17: 1145-1156.

IOTC, 2019a. Review of the statistical data and fishery trends for tropical tunas. IOTC–2019–WPTT21–08_Rev1.

IOTC, 2019b. Report of the 22nd Session of the IOTC Scientific Committee.. IOTC–2019–SC22–R[E].

Kawamura, G. 1972. Gill-net mesh selectivity curve developed from length-grith relationship. Bull. Jap. Soc. Fish., 38: 1119-1127.

Kitahara, T. 1971. On selectivity curve of gillnet. Nippon suisan gakkaishi, 37: 289-296.

Macfadyen, G. 2016. Study of the global estimate of the value of tuna fisheries-phase 3 report. Poseidon Aquatic Resource Management, Lymington.

Matsumoto, W., Skillman, R., and Dizon, A. 1984. Synopsis of biological data on skipjack tuna, Katsuwonus pelamis. NOAA Technical Report NMFS Circular, no. 451. FAO Fisheries Synopsis (FAO). no. 136.

McCombie, A., and Berst, A. 1969. Some effects of shape and structure of fish on selectivity of gillnets. Journal of the Fisheries Board of Canada, 26: 2681-2689.

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.

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.

Pet, J., Pet-Soede, C., and Van Densen, W. 1995. Comparison of methods for the estimation of gillnet selectivity to tilapia, cyprinids and other fish species in a Sri Lankan reservoir. Fisheries Research, 24: 141-164.

Petrakis, G., and Stergiou, K. 1995. Gill net selectivity for Diplodus annularis and Mullus surmuletus in Greek waters. Fisheries Research, 21: 455-464.

Regier, H. A. 1969. Fish size parameters useful in estimating gill-net selectivity. The Progressive Fish-Culturist, 31: 57-59.

Reis, E., and Pawson, M. 1992. Determination of gill-net selectivity for bass (Dicentrarchus labrax L.) using commercial catch data. Fisheries Research, 13: 173-187.

Sechin, Y. T. 1969. A mathematical model for the selectivity curve of a gillnet. Rbyn. Khoz., 45: 56-58.

Winters, G., and Wheeler, J. 1990. Direct and indirect estimation of gillnet selection curves of Atlantic herring (Clupea harengus harengus). Canadian journal of fisheries and aquatic sciences, 47: 460-470.

Zar, J. 1999. Biostatistical analysis (4th edition), Englewood Cliffs, New Jersey: Prentice- Hall.