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Mesh Selectivity of Drift Gillnet for *Caranx sexfasciatus* and *Caranx tille*

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The gear selectivity and fishing power of different mesh sizes (13.5, 14, 14.5 and 15 cm) were investigated using experimental catch data of carangids *Caranx sexfasciatus* and *Caranx tille*. The selectivity and residual curves were generated using four different individual uni-normal (normal scale, normal location, gamma and log-normal) and bi-normal functions with four different mesh sizes. Selectivity parameters were estimated using the SELECT (Share Each LEngth Class Total) model which has been implemented in the software called GILLNET (Generalized Including Log-Linear N Estimation Technique). Model deviance, Dispersion parameter and Residual plots were used to determine the best fit of the data. The results demonstrated that bi-normal model and uni-normal log-normal yielded good fit for *C. Sexfasciatus* and *C. tille* respectively. Mesh sizes 14 and 14.5 cm performed better than the modeled in both the catch data. Modal length increased with mesh sizes. Bi-normal model yielded narrow selection range while log-normal model was of wider range. Shape and size of the selectivity curves were identical and uniform in size. Over dispersion was common in all selectivity models which in turn showed lack of fit irrespective of the models.

Key words: Gillnet, selectivity, SELECT, fishing power, carangids

Gillnets with mesh size optimized for target species are highly selective in nature. Species specific and location specific optimization of mesh size is important to improve the selectivity of gillnets. Information on mesh selectivity is essential for responsible harvesting and management of fisheries resources. In India, several attempts were made in optimizing the mesh sizes for commercial exploitation of different marine fishes (Joseph & Sebastian, 1964; Sreekrishna *et al.*, 1972; Kartha & Rao, 1991; Kunjipalu *et al.*, 1994; Varghese *et al.*, 1996; Kunjipalu *et al.*, 2001; Neethiselvan *et al.*, 2001; Boopendranath & Pravin 2005).

Species of the family Carangidae constitute a significant quantum of catch in the artisanal fishery of Kanyakumari coast of south India. *Caranx sexfasciatus* and *Caranx tille* are the most dominant species caught by large mesh drift gillnets in the Kanyakumari coast of Tamil Nadu. However, no mesh selectivity study has been carried out for optimizing the mesh size for this fishery. The mesh size and shape of fish determine the quantity of catch and its composition (Sparre & Venema, 1992).

The relative efficiency of defined mesh size is expressed by a selectivity curve (Jensen, 1995). In this paper, SELECT model (Millar, 1992) is used for estimating selectivity parameters for carangid species taken by large mesh drift gillnets. This model estimates the parameters under two assumptions of equal fishing power and fishing power in relation to mesh size.

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Materials and Methods

The study was carried out in Kanyakumari coast of Tamil Nadu, India from September 2002 to April 2004. Out of the four experimental gillnets, two were made of polyamide multifilament twine (R-tex 737) and mesh sizes 13.5 and 14.0 cm (stretched). Another two nets were of R-tex 786 with 14.5 and 15.0 cm mesh sizes (stretched). All were similar in construction to those used by local fishermen. However, fishermen used only 14.0 cm mesh size for catching the large carangids. The experimental fleet which was 2,700 m long consisted of randomly arranged gillnet units of selected mesh sizes. A total of 36 gillnet units were incorporated in one fleet and each unit was 1000 meshes in length and 80 meshes in depth. Nets were operated by local fishermen from FRP boats of 8.4 m L_{OA} in traditional fishing grounds, located about 13 nautical miles off Kanyakumari in the depth range of 30-60 m. The hanging ratio of the nets varied from 0.50 to 0.56. A total of 288 PVC floats of 100 mm dia and 20 mm thickness were attached to the double lined head rope of 6 mm dia polpropylene. Thermocole floats of size 280x280x190 mm (LxBxH) were attached at both ends of each unit. After every operation, mesh panels were rearranged randomly in order to minimize the bias and sampling error. Nets were allowed to drift along with the boat for 4-6 h during the night and lifted before sunrise. After lifting the nets, the catch were segregated species-wise and mesh-wise. The targeted species *Caranx sexfasciatus* and *Caranx tille* were stored separately in a container. After bringing the catch to the shore, morphometric measurements like Total length (TL), Fork length (FL), Gill girth (Gg), Gilled girth (Gr), Maximum girth (Gmax), individual weight and total weight of the catch were recorded. The length and girth were measured to the nearest cm and mm respectively and weight to the nearest gram.

The selection parameters of *Caranx sexfasciatus* and *Caranx tille* were estimated applying the SELECT (Share Each LEngth Class Total) model (Millar, 1992) using GILLNET (Generalized Including Log-Linear N Estimation Technique) software (CONSTAT, 1998). This software contains five different functions, *viz.*, Normal location (where model length is proportional to mesh size but with fixed spread of the curve), Normal scale, Log-normal, Gamma and Bi-normal (Table 1). All the models follow Baranov's principle of geometric similarity (Baranov, 1948) except normal location curve. The data were fitted twice to the above functions based on the assumption of equal fishing power and the fishing power proportional to mesh size (Millar & Holst, 1997). Apart from the selection curves, the residual plots were also obtained by plotting mesh size against length class. Model deviances (D) or likelihood ratio for each fit were calculated for corresponding degrees of freedom. Degrees of freedom (DF) was calculated by number of length class multiplied by number of mesh sizes used minus number of length class and number of parameters involved (Millar & Fryer, 1999). The deviance statistics and residual plots were used to assess fit of the selectivity models.

After fitting all the models, the goodness of fit was evaluated using model deviance (D) (McCullagh & Nelder, 1989). The model, which had less deviance value, was considered as better fit. The Deviance was also evaluated in relation to DF and further it was referred to the chi-square distribution D ~ c^2 (DF) to study the significant differences between models (Wileman *et al.*, 1996). Dispersion parameter was calculated for all the models fitted to catch data of both the species to study the kind of dispersion or spread or variance of the selectivity curve. After assessing the fits with above-mentioned statistical tools, the better-fit model for both the species, were further inspected from residual plots. A good fit of plot was regarded based on appearance of residuals in the plots. The better-fit model, which showed lack of fit, was further extended to bi-normal model to

Table 1. Uni-modal and Bi-modal selectivity models used in the selectivity studies

Model	Selection curve
Normal location constant spread (k, s):	$\exp\left(-\frac{(l-k.m_j)^2}{2s^2}\right)$ where k = Location of the mode of the selection curve; s = Spread of the selection curve; m_j = mesh size of j^{th} gear; l = length of the fish.
Normal scale (k_1, k_2):	$\exp\left(-\frac{(l-k_1.m_j)^2}{2k_2^2.m_j^2}\right)$ where k_1 = Location of the mode of the selection curve; k_2 = Spread of the selection curve; m_j = mesh size of j^{th} gear; l = length of the fish.
Lognormal (m, s):	$\frac{1}{l}\exp\left[m-\frac{s^2}{2}-\frac{(\log(l)-m)^2}{2s^2}\right]$ where m = Location of the mode of the selection curve; s = Spread of the selection curve; l =length of the fish.
Gamma (α , β):	$\left(\frac{l}{(\alpha-1).\beta}\right)^{\alpha-1}\exp\left(\alpha-1-\frac{l}{\beta}\right)$ where α = Location of the mode of the selection curve; β = Spread of the selection curve; l = length of the fish.
Bimodal or Binormal (a_1, b_1, a_2, b_2, ω):	$\exp\left(-\frac{(l-a_1.m_j)^2}{2b_1^2.m_j^2}\right)+\varpi\exp\left(-\frac{(l-a_2m_j)^2}{2b_2^2}\right)$ where a_1 = Location of the first mode of the selection curve; a_2 = Location of the second mode of the selection curve; b_1 = Spread of the first mode of the selection curve; b_2 = Spread of the second mode of the selection curve; ω = Scaling constant relation to the height of the first and second modal length of the fish; m_j = mesh size of j^{th} gear; l =length of the fish.

get an improved fit. The better fit model obtained for the catch data of *Caranx sexfasciatus* and *Caranx tille* was subjected to approximation of bi-normal or bi-modal model to find out the best fit of the data as suggested by Holst *et al.* (1994). Deviance, degrees of freedom, dispersion parameter and residual plots were also estimated and validated as done in the case of uni-normal models in order to find out the best fit of the selectivity data for both the species studied.

Results and Discussion

The total catch of *Caranx sexfasciatus* obtained from four mesh sizes was 1205 numbers. Of the total number, 410 specimens were caught in mesh size 13.5 cm, 301 in 14 cm, 324 in 14.5 cm and 170 in 15 cm. The total catch of *Caranx tille* obtained in four mesh sizes was 1571 numbers. Of them, 375 specimens were caught in mesh size 13.5 cm, 425 in 14 cm, 419 in 14.5 cm and 352 in 15 cm. Length frequency distributions of the species studied are given in Fig. 1. Length frequency distribution of both the species caught from gillnets were uni-modal in shape.

The range of fork length of *Caranx sexfasciatus* and *Caranx tille* caught was 29.4 - 69.6 cm and 36.5 - 97.4 cm, respectively. The estimated selectivity parameters for all uni-normal models including deviance statistics and the corresponding degrees of freedom for every model under the assumption of equal fishing power and fishing power proportional to mesh size are given in Table 2.

While evaluating the model deviances obtained from different uni-normal models, log-normal model yielded smaller deviance compared to other models in both the species. The models which had high deviance value were rejected since it expressed poor fit of data. Further, a small difference was observed between model deviances obtained from both the assumptions in normal scale and normal location function except with log-normal and Gamma function. It showed that fishing power did not influence the deviance value in latter models. There was no significant difference between models except with normal scale ($p < 0.005$) in both species. Other better fits followed by log-normal model based on deviance value were normal location under the assumption of fishing power proportional to mesh size, gamma and normal scale under the assumption of equal fishing power.

The Dispersion parameter (DP) was worked out to evaluate the degree of variance of the selectivity curve. The DP varied greatly among the uni-normal models. The better-fit log-normal model yielded the lowest DP among the other uni-normal models fitted for both the species catch data. However, the estimated DP was greater than one in the better fit models of both the species *C. sexfasciatus* (5.65) and *C. tille* (5.04) since the deviance was higher than the degrees of freedom. The selection curves are given in Fig. 2.

Residual plots of all the models for the species *C. sexfasciatus* (Fig. 3) under both the assumptions of equal fishing power and fishing power proportional to mesh size

Table 2. SELECT model parameter estimates for gillnet selectivity in respect of *Caranx sexfasciatus* and *Caranx tille*

S.No.	Species	Model		Degrees of Freedom	Equal fishing power			Fishing power α mesh size		
					Parameters	SD	Model Deviance	Parameters	SD	Model Deviance
1	*Caranx sexfasciatus*	Normal location	Fixed spread	61	(k,s) = (3.4695, 3.694)	0.0196, 0.0914	345.5	(k,s) = (3.4889, 3.7034)	0.0197, 0.0918	344.8
		Normal scale	spread α mj	61	(k1,k2) = (3.5071, 0.2556)	0.0194, 0.0060	380.51	(k1,k2) = (3.5259, 0.2549)	0.0194, 0.0060	380.74
		Lognormal	spread α mj	61	(m,s) = (3.8429, 0.0763)	0.0059, 0.0018	344.73	(m,s) = (3.8488, 0.0763)	0.0059, 0.0018	344.73
		Gamma	spread α mj	61	(k,a) = (0.0196, 177.4954)	0.0009, 8.1807	350.66	(k,a) = (0.0196, 178.4954)	0.0009, 8.2139	350.66
		Bimodal	spread α mj	58	(a1,b1) = (3.4333, 0.2229)	0.0198, 0.0074	335.02	(a1,b1) = (3.4479, 0.2224)	0.0201, 0.0074	335.06
					(a2,b2) = (3.7531, 0.3296)	0.0881, 0.0232	335.02	(a2,b2) = (3.7832, 0.3281)	0.0882, 0.0229	335.06
					w = 0.0468	0.0276,	335.02	w = 0.0511	0.028898	335.06
2	*Caranx tille*	Normal location	Fixed spread	91	(k,s) = (4.7205, 4.2649)	0.0168, 0.0862	467.75	(k,s) = (4.7394, 4.2716)	0.0168, 0.0866	466.6
		Normal scale	spread α mj	91	(k1,k2) = (4.7485, 0.2986)	0.0167, 0.006	510.58	(k1,k2) = (4.7674, 0.298)	0.0166, 0.0060	510.8
		Lognormal	spread α mj	91	(m,s) = (4.1518, 0.0642)	0.0037, 0.0013	458.56	(m,s) = (4.156,0.0642)	0.0036, 0.0013	458.56
		Gamma	spread α mj	91	(k,a) = (0.0192, 246.2453)	0.0008, 9.9843	469.95	(k,a) = (0.0192, 247.2453)	0.0008, 10.0328	469.95
		Bimodal	spread α mj	88	(a1,b1) = (4.7485, 0.2986)	0.0167,0.006	510.58	(a1,b1) = (4.7674, 0.2980)	0	510.8
					(a2,b2) = (23.2, 1.28)	0	510.58	(a2,b2) = (23.814, 0.3858)	0	510.8
					w = 0.111	0	510.58	w = 0.1174	0	510.8

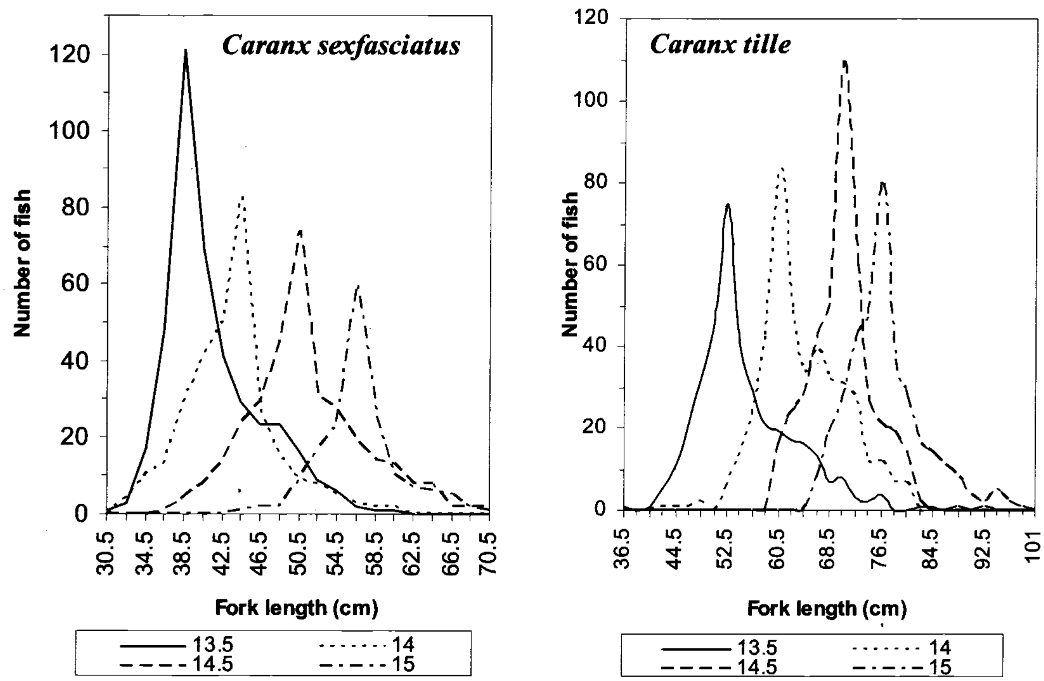

Fig. 1. Length frequency of carangid fishes caught by gillnets with mesh sizes of 13.5, 14.0, 14.5 and 15.0 cm

revealed that the mesh size of 14.5 cm performed better followed by 14 cm and 13.5 cm. It was inferred by the presence of a large number of positive residuals. Fishing powers were almost equal in both normal scale and gamma model by the presence of equal number of positive residuals in respective mesh sizes. Similarly fishing power of normal location was same with normal scale and gamma except in the mesh size 13.5 cm. Residual plots showed that smaller length group of fish were caught from mesh size of 14 cm (32.5 to 46.5 cm). However, the mesh size 14.5 cm captured wider range of smaller and larger fishes (42.5 to 70.5 cm) and overlapping of catch were also observed in these mesh sizes. Mesh size of 13.5 cm captured all size groups of fish.

In the case of *C. tille*, residual plots (Fig. 3) of all models tested revealed that the fishing powers of 14 cm and 14.5 cm were greater than modeled with the occurrence of predominance of positive residuals. However, in log-normal model, fishing power was equal in both 13.5 and 15 cm. Fishing powers were almost equal in both the normal location and gamma model by the presence of equal number of positive residuals in respective mesh sizes except in the mesh size 13.5 cm. Residual plots were almost similar in all the models. Plots showed capture of middle-sized length group (54.5 - 80.5 cm) from the mesh size of 14 cm and this mesh size overlapped with the mesh of 14.5 cm by capturing the same size group of fish (60.5 - 80.5 cm). However, 15 cm mesh captured larger fishes (82.5 - 98.5 cm). Deviance residuals were equal for both the equal fishing intensity and fishing power proportional to mesh size in all the uni-models. As the model deviance, DP and Residual Plot of the better fit model showed poor fit in both the species catch data, the better fit model was extended to bi-normal model to get best fit of the data.

Model deviance of the bi-normal model was slightly reduced to 335.02 from the better fit log-normal model (344.73) in *C. sexfasciatus* catch data under equal fishing power (Table 2). The DP obtained from the extended bi-normal model for the catch data of *C. sexfasciatus* was 5.78 while it was 5.65

in better fit log-normal model. In the case of *C. tille*, it was 5.8 and 5.04 in bi-normal and log-normal model, respectively. However, the estimated DP for both the catch data were higher in bi-normal model than better fit log-normal model and indicated the over dispersion of the data. Significant difference ($p < 0.05$) was observed between the model deviance of bi-normal and log-normal model in the catch data of *C. sexfasciatus*. As deviance value obtained from bi-normal model was greater than better fit log-normal model in the case of *C. tille*, further analysis was not carried out and better fit log-normal was considered as the best fit for the catch data. In all uni-normal and bi-normal models, the deviance value was smaller in constant fishing power than when fishing power is assumed to be proportional to mesh size.

Among the uni-normal models tested, log-normal model provided better fit for the selectivity data of both the species. However, extended bi-normal model under equal fishing power was found as best fit for the catch data of *C. sexfasciatus* since the estimation yielded the model deviance, dispersion parameter and good residuals arrangement. The bi-normal model selection curve was proved as ideal curve for gillnet selectivity (Hovgard, 1996a; Fujimori & Tokai, 2001; Park *et al.*, 2004) as the fishes may be caught by several capture mechanisms including gilling, wedging and tangling. In the case of *C. tille*, uni-normal log normal model was found as best fit. It might be due to predominance of gilling in the capture process which accounted for 75.9 % and remaining by wedging. Huse *et al.* (1999) suggested that log-normal selection curve was the appropriate one for the gillnet selectivity. Yokota *et al.* (2001) and Holst *et al.* (2002) opined that twine thickness has no significant effect on catching efficiency of gillnets. However, tangling might be facilitated depending on the mesh size, when hanging coefficient (Riedel, 1963; Hamley & Regier, 1973) or twine thickness and material (Pycha, 1962) are favourable. In this study, less than 1% tangling was observed and hence the selection curve appeared with a single mode.

Modal length and spread of the bi-normal model increased with mesh size. However, the spread was lesser than better fit log-normal model in both the catch data. Modal length (46.4 to 51.5 cm) appeared similar for each mesh size in both better fit uni normal and best fit bi-normal models in the catch data of *C. sexfasciatus*. Modal length for *C. tille* obtained from best fit log-normal model ranged from 63.3 to 70.3 cm

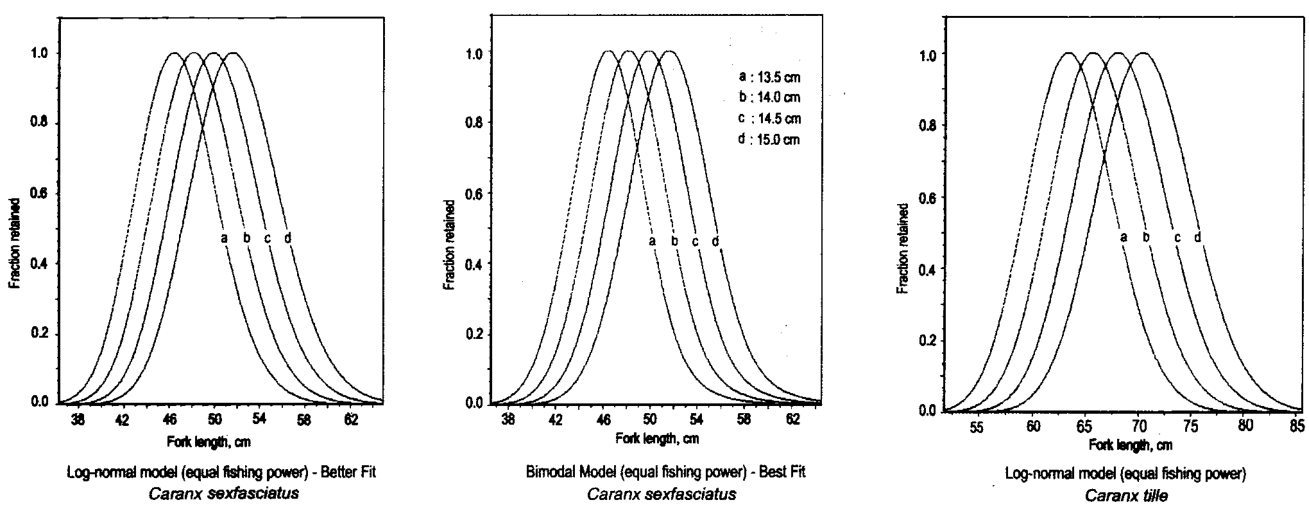

Fig. 2. Selectivity curves of better and best fit models for different mesh sizes for *Caranx sexfasciatus* and *Caranx tille*

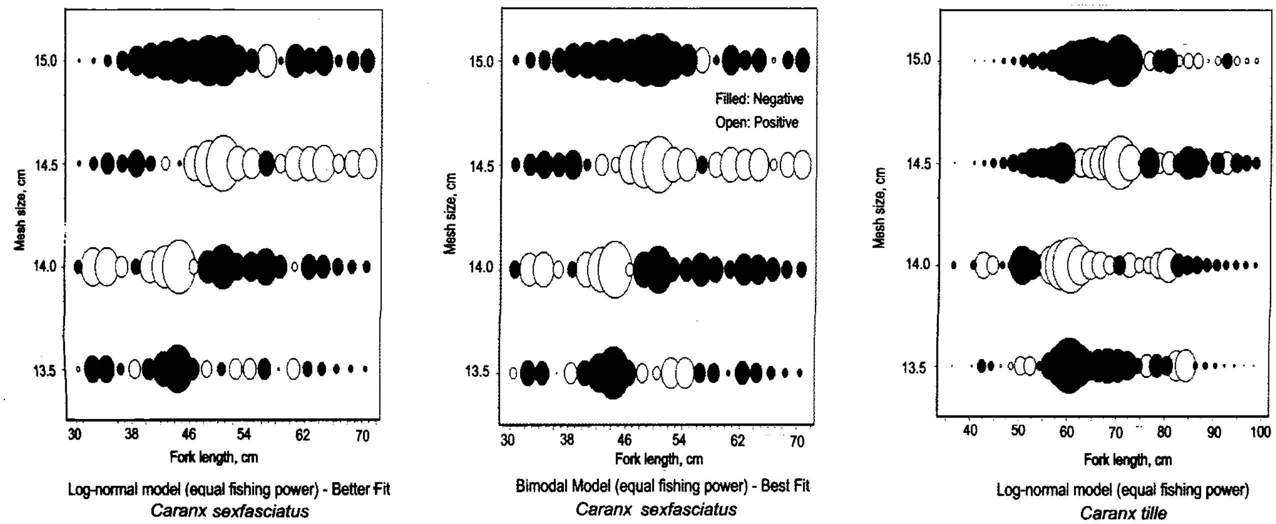

Fig. 3. Residual plots for selectivity curves of better and best fit models for different mesh sizes and fishing powers (area of the square is proportional to square of the residual)

through the mesh size from 13.5 to 15 cm (Table 3). Residual plots of extended model for the catch data of *C. sexfasciatus* showed more number of positive residuals in the mesh sizes of 14.5 and 14 cm which indicated that these meshes performed better than modeled as found in uni-normal better fit log-normal model.

Selection curve of *C. sexfasciatus* was also with single mode inspite of capture by gilling, wedging and tangling. This indicates that the data fit appropriately with the model though multiple capture process existed (Fryer, 1991). In recent years, many studies revealed that gillnet selectivity curve was asymmetrical in nature (Hamley & Regier, 1973; Wulff 1986). However, in the present study, log-normal and bi-normal model did not match with the catch data due to skewness of the data (Fujimori & Tokai, 2001). Both the best fit curves still do not show good fit. It might be due to over dispersion of the data (McCullagh & Nelder, 1989) which is indicated by greater deviance value than DF, greater DP and systematic

Table 3. Modal length and spread of gillnet selectivity curve

S.No.	Species	Model	Mesh size (cm) 13.5 Modal length (cm) a	b	13.5 Spread a	b	14 Modal length (cm) a	b	14 Spread a	b	14.5 Modal length (cm) a	b	14.5 Spread a	b	15 Modal length (cm) a	b	15 Spread a	b
1	*Caranx sexfasciatus*	Normal location	46.8	47.1	3.69	3.7	48.6	48.8	3.69	3.7	50.3	50.6	3.69	3.7	52	52.3	3.69	3.70
		Normal scale	47.3	47.6	3.45	3.44	49	49.4	3.58	3.57	50.9	51.1	3.71	3.7	52.6	52.9	3.83	3.82
		Lognormal	46.4	46.7	3.58	3.6	48.1	48.4	3.71	3.73	49.8	50.1	3.84	3.86	51.5	51.8	3.97	4.00
		Gamma	46.7	47.0	3.52	3.53	48.4	48.7	3.65	3.66	50.2	50.5	3.78	3.79	51.9	52.2	3.91	3.92
		Bimodal	46.4	46.5	3.01	3	48.1	48.3	3.12	3.11	49.8	50	3.23	3.22	51.5	51.7	3.34	3.34
2	*Caranx tille*	Normal location	63.7	64.0	4.26	4.27	66.1	66.4	4.26	4.27	68.4	68.7	4.26	4.27	70.8	71.1	4.26	4.27
		Normal scale	64.1	64.4	4.03	4.02	66.5	66.7	4.18	4.17	68.9	69.1	4.33	4.32	71.2	72.0	4.48	4.47
		Lognormal	63.3	63.6	4.09	4.11	65.6	66	4.24	4.26	68	68.3	4.39	4.41	70.3	70.6	4.55	4.56
		Gamma	63.6	63.8	4.06	4.07	66	66.2	4.21	4.22	68.3	68.6	4.36	4.37	70.6	71.0	4.51	4.52
		Bimodal	64.1	64.4	4.03	4.02	66.5	66.7	4.18	4.17	68.9	69.1	4.33	4.32	71.2	71.5	4.48	4.47

a : Equal fishing power   b : Fishing power α Mesh size arrangement of residuals in all uni- and bi-normal models.

The spread of the best fit bi-normal selection curve of *C. sexfasciatus* was narrower than the better fit log-normal model around the modal length. However, in the case of *C. tille* the spread was wider since the best fit belongs to uni-normal log normal model as reported by Hovgard *et al.* (1999). Spread variation among the selectivity curves of best fit models could be due to dissimilarity of gear characteristics caused by different operational and capture process as reported by Park *et al.* (2004). Method of capture might have influenced the spread of the curve, as reported by Hovgard *et al.* (1999). The shape of the selectivity curves among uni- and bi-normal curves of the present study was uniform though variations appeared in the amplitude of the curve. However, selection curves for all meshes may have same shape and amplitude as per Baranov's assumption that selectivity would be same for all combination of fish and mesh size for which girth-perimeter ratio is the same (Baranov, 1914).

The fishing process of gillnets is related to the mesh size and twine size (Hamley, 1975; Millar, 1995). Hovgard (1996b) reported that the fishing power would influence the catch rate and sizes, while estimating the selectivity for multi-meshed gillnet. However, in this study, both the better-fit and best-fit models were observed under the assumption of equal fishing power. It indicates that different mesh sizes used in this study had equal catching efficiency for both carangid species of respective selection length as reported by Karunasinghe & Wijeyaratne (1991) and Regier & Robson (1966) for other fishes.

The present study indicates that both uni-normal and bi-normal models fit appropriately for the drift gillnets which are conventionally used by most of the local fishermen in inshore waters of the study area for harvesting large carangids. Modal length increased with mesh size. Uni-normal model yielded wider selection range while the bi-normal model had narrower selection range. Over dispersion was common in all selectivity models which in turn showed lack of fit irrespective of the models.

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