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Original research article

Square mesh codend improves size selectivity and catch pattern for *Trichiurus lepturus* in bottom trawl used along Northwest coast of India

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ABSTRACT

The size selectivity and catch pattern of *Trichiurus lepturus* in 40 mm diamond and square mesh codends were investigated in this study. A 34 m high opening trawl was used, which is a common design used by fishermen operating along the northwest coast of India, and the cover codend method was employed to determine codend selectivity. Along with the changes in the length at 50% retention rate for *Trichiurus lepturus* with the usage of the square and diamond mesh codends, indicators to understand the exploitation pattern of this species in the fishery were assessed based on the total number of individuals and on total weight of the catch. The mean selection length increased and discard fraction is reduced when 40 mm square mesh codends are used in place of diamond meshes, however, it is observed that individuals at commercial length are also lost. The results demonstrate that mandatory use of legal mesh sizes alone will be insufficient to aid in the sustainable harvest of this species, given its estimated length at first sexual maturity of 61.2 cm. This is the first study to compare the size selection of this species in 40 mm diamond and square mesh codends along Northwest coast of India. Results of the study will help as a baseline for gear-based regulations in the region.

1. Introduction

The Northwest coast of India is an important fishing ground along the Indian coast contributing about 35% of the total marine catches from India. The annual average catches of *Trichiurus lepturus* Linnaeus, 1758 (Largehead hairtail), during 2015–2019 was 0.21 mT, which is 5.8% of the total marine landings of the country (Central Marine Fisheries Research Institute (CMFRI), 2019). *T. Lepturus* contributes the bulk of the ribbonfish fishery, with two other species, *Lepturacanthus savala* Cuvier 1829 (Savalai hairtail) and *Eupleurogrammus muticus* Gray 1831 (Smallhead hairtail), occurring occasionally in the catches. The biomass of this resource along the Northern Arabian Sea is estimated at 236939 t and the fishable biomass as 165346 t (Ghosh et al., 2014). This fish is an apex predator and hence has high ecological significance in maintaining the levels of prey species in the ecosystem (Koya et al., 2018). *Trichiurus lepturus* forms an important fishery along Gujarat coast with a little more than 100 thousand tonnes caught annually, which forms about 13 percent of the total landings from the state of Gujarat. Trawlers contribute more than 50% of the total fleet in Gujarat and land more than 60% of the total catch from the state. Majority of the catches of *T. lepturus* are landed by trawlers that undertake multi-day fishing operations and the rest is contributed by gillnets (Ghosh et al., 2014). The species captured in the fishery range in length from 42.5 cm to 103.8 cm, with the average length at capture being 66.7 cm. From the north Arabian Sea, the estimated mean length at first sexual maturity (LFM) for this species is 61.2 cm, and gonadal development begins at a length of 45 cm (Ghosh et al., 2014). The issue of trawl bycatch has been reported from Gujarat waters by different authors (Zynudheen et al., 2004; Madhu et al., 2015) in which juveniles of *T. lepturus* forms a major constituent (Azeez et al., 2021). The use of trawl codends with illegal mesh sizes, which often ranges from 15 to 30 mm, is one of the reasons attributed for the high incidence of bycatch (Azeez et al., 2021; Mohamed et al., 2010).

Use of selective fishing gears, can regulate the length of capture, reduce discards of juveniles and hence increase the yield per recruit of the target species (MacLennan, 1992). Therefore, understanding the

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selectivity of commercially used gears is critical for effective monitoring, governance, and sustainable resource harvesting. Gear based technical measures which includes the use of selective fishing gears, are widely used in trawl fisheries and among these measures, square meshes are found to be very effective in improving selectivity of trawls (Broadhurst et al., 2004). Several experimental studies carried out in India using square mesh codends have highlighted the efficacy of using square meshes (Madhu, 2018).

The selectivity estimates of trawl codends are mostly derived by covered codend method from multiple hauls, but the variations in the estimates when multiple hauls are conducted for deriving the parameters are not considered in most of the studies reported from the Indian waters (Madhu, 2018). For optimization of mesh size for the fishery, particularly in multi-species fisheries, the variance associated during multi-haul analysis, needs to be considered and included in the estimations (Macbeth et al., 2005; Millar et al., 2004).

The works related to deriving the selection properties of trawl codends, carried out along the Indian coast, was reviewed by Madhu (2018). Rajeswari et al. (2013) have reported the selectivity estimates of *T. lepturus* along Vishakapatnam, northeast coast of India, however the variance estimates nor the effect of using the different codends on catch profile is not reported. Apart from the study mentioned above, there are no other studies on the trawl codend selection properties of this significant species along the Indian coast.

The Gujarat government has mandated that all trawlers operating out of the state use a 40 mm square mesh codends (Anonymous, 2003, p. 21). However, adoption of these codends is relatively low, and the majority of trawlers targeting ribbonfish use diamond mesh codends with mesh sizes ranging from 25 to 30 mm (Azeez et al., 2021). The mesh size used for targeting other species like squids and carangids ranged from 15 to 30 mm depending on the season of operation. Although commercial operations have been conducted with 40 mm square mesh codend nets (Mohamed et al., 2010), fishermen are frequently hesitant to use square mesh codend nets out of fear of losing their catch and continue to use diamond meshes. There are also no reports on the estimates of selectivity either for diamond or square mesh codends for this species along the northwest coast of India. The comparative estimates based on weight, due to the use of different shaped meshes (Sala et al., 2015; Yang et al., 2021) is also not available, which would be much required information to convince the fishers for using legal mesh shapes/sizes in the fishery. Therefore, this study was conducted to compare the selection properties of square and diamond mesh codends, to evaluate the selection properties and exploitation pattern of these codends, and to quantify and compare their usability. This will help in devising further management strategies for this fishery including regarding mesh size or shape of the legal codends stipulated for trawlers operating along the northwest coast of India.

2. Materials and methods

2.1. Field experiments

Departmental fishing vessel MFV Sagar Kripa (15.5 m LOA, 124 hp Stern trawler) was used for the field trials, in the depth range of 15–35 m, which is the commercial trawling ground off Veraval, Gujarat. A 34 m high opening bottom trawl (HOBT) was used for the experimental trawling and all the fishing trails were conducted during the daytime. The portions from the wings to the square of the net were fabricated using 200 mm meshes and the length of the codend was 8 m with a circumference of 170 meshes (Figure of Trawl- Appendix 1). Throughout the study, V-shaped otterboards (1.36 × 0.79 m), weighing 80 kg each were used. The length of the bridle and the sweep length were 10 m and 20 m respectively and was not changed during the sea trials. The square and diamond mesh codends were constructed using 1.5 mm diameter twine, while the cover was constructed using 20 mm polyamide (PA) netting (RTex 630). To avoid the masking effect, the cover was approximately 1.5 times the length and width of the codend, and small plastic kites (8 in total) were used in addition (Lök et al., 1997; Grimaldo et al., 2009). The speed of hauling was maintained between 1.2 and 1.4 ms^{-1} which is the normal speed maintained by the commercial trawlers in this ground (Edwin et al., 2014, p. 276). The towing duration for the hauls were fixed as 1 h and the net was hauled after this stipulated time. For each haul, fishing depth, tow duration and towing speed were recorded. After each haul, only the codend was changed, and the square and diamond mesh codends were alternated. For diamond mesh codends, the mesh size was determined (40 meshes from various areas of the codend) using a wedge-shaped measurement device with a 2 kg weight attached, and the bar length was determined for square mesh codends, to ascertain changes in the mesh size, prior to each tow. All tows were shot and retrieved in the same manner and at the end of each tow, the catches from the codend and cover were kept separate, and, after sorting, lengths were measured using standard methods to the nearest millimetre. A subsample from the total catch were taken for length frequency measurements if the catches were large to be measured entirely.

2.2. Modelling and estimation of the size selection in the codends

Each codend was analyzed separately using the same method described below. The experimental design used to test the codends enabled the collection of catch data to be analyzed as binominal data, in which individuals retained by the codend cover or by the codend itself are used to estimate the size selection in the codend (i.e., length-dependent retention probability). Between hauls with the same codend, the size selectivity is expected to vary (Fryer, 1991). We were interested in the averaged size selection over hauls in this study because it would provide information about the average consequences of the size selection process when the codend is applied in the fishery. We tested different parametric models $r_{codend}(l, \boldsymbol{v_{codend}})$ for the codend size selection. $\boldsymbol{v_{codend}}$ is a vector consisting of the parameters of the model. Assuming that all individuals entering the codend undergo same selection process (Wileman et al., 1996), we selected four basic selectivity models to describe $r_{codend}(l, \boldsymbol{v_{codend}})$, for both codends. The four models tested were: Logit, Probit, Gompertz, and Richard (Eq. (1)). The first three models are completely described by the two selection parameters L50 (length of fish with a 50% probability of being retained) and SR (length difference between fish with a 75% and 25% probability of being retained, respectively), whereas the Richard model requires an additional parameter (1/δ) to describe the curve's asymmetry.

Lomeli (2019) describes the formulas for the four selection models as well as additional information on this aspect. CLogit and DLogit (details in Cheng et al., 2019) were considered as additional models (Eq. (1)) for estimating the codend size selection.

$$r_{codend}(l,\boldsymbol{v_{codend}}) = \begin{cases} Logit(l, L50, SR) \\ Probit(l, L50, SR) \\ Gompertz(l, L50, SR) \\ Richard\left(l, L50, SR, \frac{1}{\delta}\right) \\ CLogit(l, C, L50, SR) \ = \ 1.0 - C + C \times Logit(l, L50, SR) \\ DLogit(l, C_1, L50_1, SR_1, L50_2, SR_2) = C_1 \times Logit(l, L50_1, SR_1) + (1.0 - C_1) \times Logit(l, L50_2, SR_2) \end{cases} \quad (1)$$

The ability of the model to describe the data adequately is based on calculating the corresponding p-value, which expresses the probability of obtaining at least as large a discrepancy between the observed experimental data and the fitted model by coincidence. Thus, for the fitted model to be considered a candidate for modelling the size selection data, the *p*-value cannot be less than 0.05 (Wileman et al., 1996). In the case of a poor fit ($P < 0.05$), the residuals were examined to determine whether the poor fit was caused by structural issues when modelling the experimental data with the various selection curves or by data over-dispersion (Wileman et al., 1996). The best model among the four considered in (1) is determined by comparing the AIC values of the different models. The model with the lowest AIC value is chosen (Akaike, 1974). The purpose of the analysis is to determine the values of the parameter $\boldsymbol{v_{codend}}$ that maximize the likelihood of observing experimental data (averaged overhauls). This was accomplished by minimizing the following expression, which corresponds to maximizing the likelihood of the observed experimental data:

$$-\sum_{j=1}^{m}\sum_{l}\left\{\frac{nR_{jl}}{qR_j}\times ln(r_{codend}(l,\boldsymbol{v_{codend}}))+\frac{nE_{jl}}{qE_j}\times ln(1.0-r_{codend}(l,\boldsymbol{v_{codend}}))\right\} \quad (2)$$

where the outer and inner summations are over *m* hauls conducted with a particular codend in a particular tow and over *l* length classes, respectively. The terms nRj_l and nEj_l are the number of fish of length class *l* measured in codend and cover in haul *j*, respectively. Sampling factors are denoted by the letters qR_j and qE_j for the fraction of fish measured for length from the codend and cover, respectively.

Following the identification of the specific size selection model for a given codend, bootstrapping was used to estimate the confidence intervals (CI) for the average size selection. For the size selection analysis, we used the software tool SELNET (Herrmann et al., 2012) and the double bootstrap method implemented in this tool was used to obtain CI for the size selection curve and associated parameters. This bootstrapping technique is similar to that described by Millar (1993), in that it accounts for both within-haul and between-haul variation, and the total hauls of each codend were defined as a group. To account for variation between hauls, the procedure included an outer bootstrap resample with replacement from the group of hauls. To account for within-haul variation within each resampled haul, the data for each length class were bootstrapped using an inner bootstrap with replacement and each bootstrap produced a "pooled" set of data that was then analyzed using the identified selection model. Each bootstrap run produced an average selection curve, and 1000 bootstrap repetitions were used to estimate the Efron percentile 95% CI for each species analyzed (Herrmann et al., 2012). Additionally, each fitted curve was plotted against the experimental length-dependent catch comparison rates to acquire a visual representation and reflect the trend in the data.

2.3. Estimation of difference in size selectivity between codends

The difference (delta) in size selectivity $\Delta r(l)$ between the two codends was estimated by:

$$\Delta r(l) = r_{square}(l) - r_{diamond}(l) \quad (3)$$

The 95% confidence intervals for $\Delta r(l)$ were calculated using the results of two bootstrap populations, $r_{diamond}(l)$ and $r_{square}(l)$. Since they were obtained independently of each other, a new bootstrap population of results for $\Delta r(l)$ was created using (Larsen et al., 2018):

$$\Delta r(l)_i = r_{square}(l)_i - r_{diamond}(l)_i \ i \in \ [1\ldots1000] \quad (4)$$

Finally, as described previously, Efron 95% percentile confidence limits for $\Delta r(l)$ were determined using the bootstrap population. If the 95% CIs for the length classes did not overlap 0.0, there were significant differences in size selection between codends.

2.4. Estimation of exploitation pattern and catch efficiency indicators

To evaluate how each of the two codends performed in the specific fishery, three exploitation pattern indicators *nP*–, *nP*+, and *dnRatio* were estimated. *nP*– and *nP*+ quantify the retention efficiency of fish below and above the LFM (in percentages), respectively, whereas *dnRatio* represents the discard ratio in numbers and denotes the percentage of codend catch that is undersized. These indicators can be used to summarize catch patterns for a particular type of gear in a particular fishery. The size selection properties provide information that is independent of the population size structure encountered by the gear during the fishing process, whereas these indicators are directly dependent on the population size structure, providing additional information to aid in evaluating the performance of the codend system (Wienbeck et al., 2014). These indicators are given by:

$$\begin{aligned} nP- &= 100\times\frac{\sum_j\sum_{l<LFM}\left(\frac{nR_{jl}}{qR_j}\right)}{\sum_j\sum_{l<LFM}\left(\frac{nR_{jl}}{qR_j}+\frac{nE_{jl}}{qE_j}\right)} \\ nP+ &= 100\times\frac{\sum_j\sum_{l>LFM}\left(\frac{nR_{jl}}{qR_j}\right)}{\sum_j\sum_{l>LFM}\left(\frac{nR_{jl}}{qR_j}+\frac{nE_{jl}}{qE_j}\right)} \\ nDRatio &= 100\times\frac{\sum_j\sum_{l<LFM}\left(\frac{nR_{jl}}{qR_j}\right)}{\sum_j\sum_{l}\left(\frac{nR_{jl}}{qR_j}\right)} \end{aligned} \quad (5)$$

where *j* is the sum of hauls and *l* is the sum of length classes. Ideally, for a

Table 1
Overview of the hauls conducted during the sea trials showing codend configuration, haul number, number of *T. lepturus* caught in the codend (nR), cover codend (nE), sampling ratio (qR and qE), tow duration and depth of operation.

Codend	Haul ID	Sample number		Sampling ratio		Towing Duration (min)	Maximum towing Depth (m)
		Codend (nR)	Cover (nE)	Codend (qR)	Cover (qE)		
Diamond	1	73	237	0.77	0.31	65	18
	2	30	63	1.00	1.00	55	16
	3	28	72	0.71	1.00	62	19
	4	21	33	1.00	1.00	60	23
	5	74	119	1.00	0.73	65	19
	6	79	117	1.00	0.86	60	25
	7	88	177	0.86	0.62	58	22
	8	95	265	0.76	0.56	55	21
	9	58	89	0.58	0.52	60	20
	10	34	52	1.00	1.00	62	22
	11	50	78	1.00	1.00	55	23
Square	1	57	171	1.00	0.21	58	19
	2	57	176	1.00	0.59	63	16
	3	21	133	1.00	0.72	70	20
	4	70	117	1.00	0.45	50	22
	5	120	290	0.42	0.28	60	20
	6	95	240	1.00	0.18	65	25
	7	90	165	1.00	0.53	55	22
	8	65	126	1.00	0.65	45	21
	9	25	54	1.00	1.00	65	18
	10	47	109	1.00	1.00	60	23
	11	30	74	1.00	1.00	50	24
	12	33	90	1.00	1.00	62	23

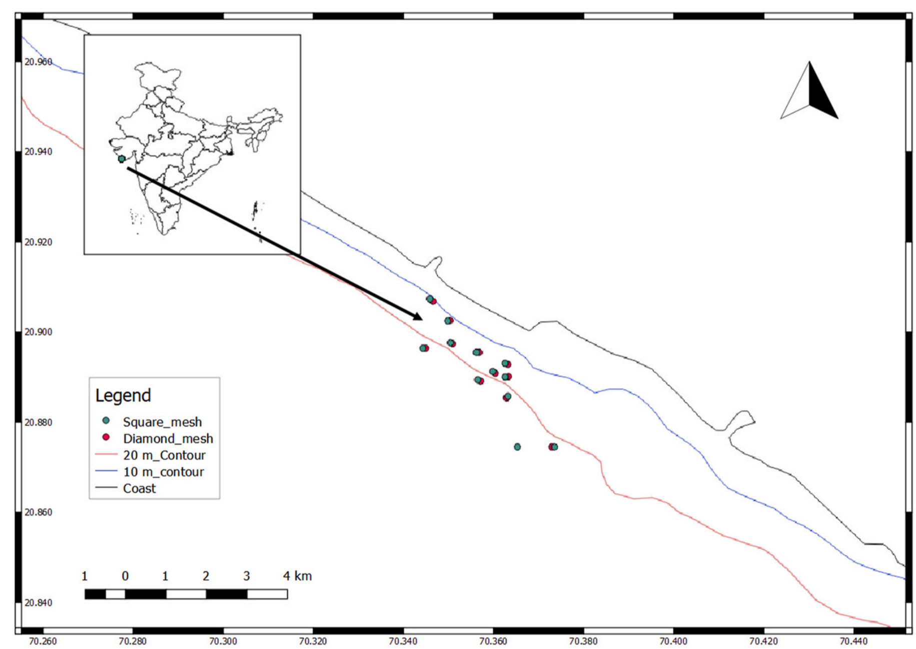

Fig. 1. Fishing locations: green points indicate the beginning of diamond mesh tows, while red points indicate the start of square mesh hauls. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Akaike information criterion (AIC) used to determine the model fit for each codend. The highlighted model is the one that was chosen.

	Models					
Codend	Logit	Probit	Gompertz	Richard	DLogit	CLogit
Diamond	1562.9	1562.3	1632.7	1553.1	**1546.6**	1564.9
Square	2757.15	2753.2	2817.3	2752.4	**2709.4**	2759.2

target species, *nP–* and *nDRatio* should be small (close to zero), whereas *nP+* should be large (close to 100%), retaining all individuals above the LFM (61.2 cm) that enter the codend.

As with usability indicators that use numbers of fish, the overall performance of the codend can be supplemented and summarised by usability indicators that use weight instead of cover codend data (Sala et al., 2015).

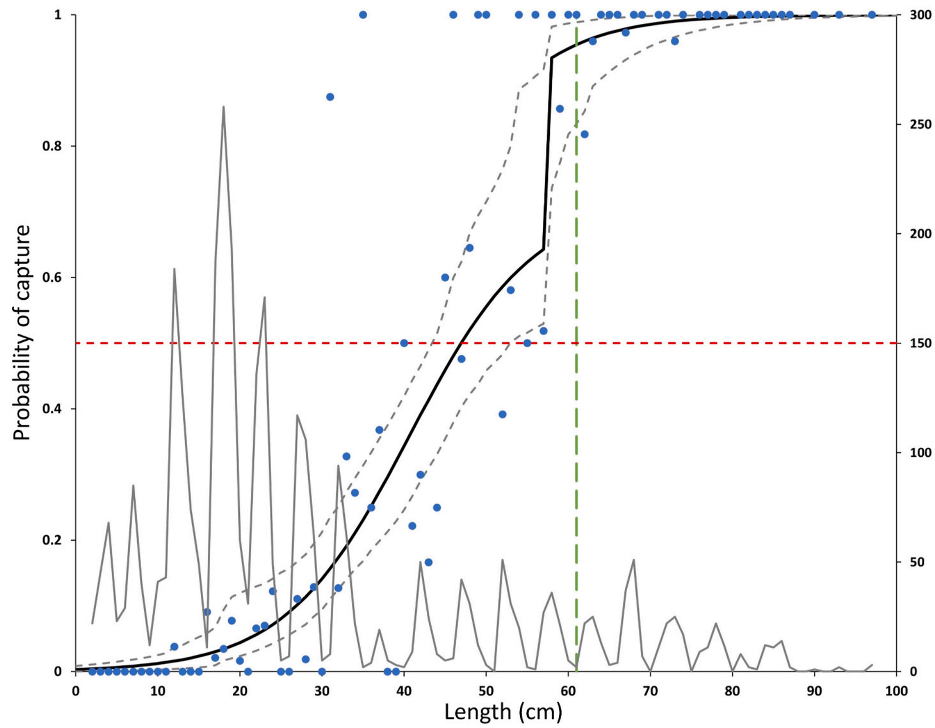

Fig. 2. Selection curve of *Trichiurus lepturus* in Diamond mesh codend. The black dashed line indicated 95% CI for the selection curve. The blue dots are observed proportions. The vertical green line indicates LFM (61.2 cm), and the red horizontal dashed line is proportion at 50% retention. The grey curve is the total population encountered. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

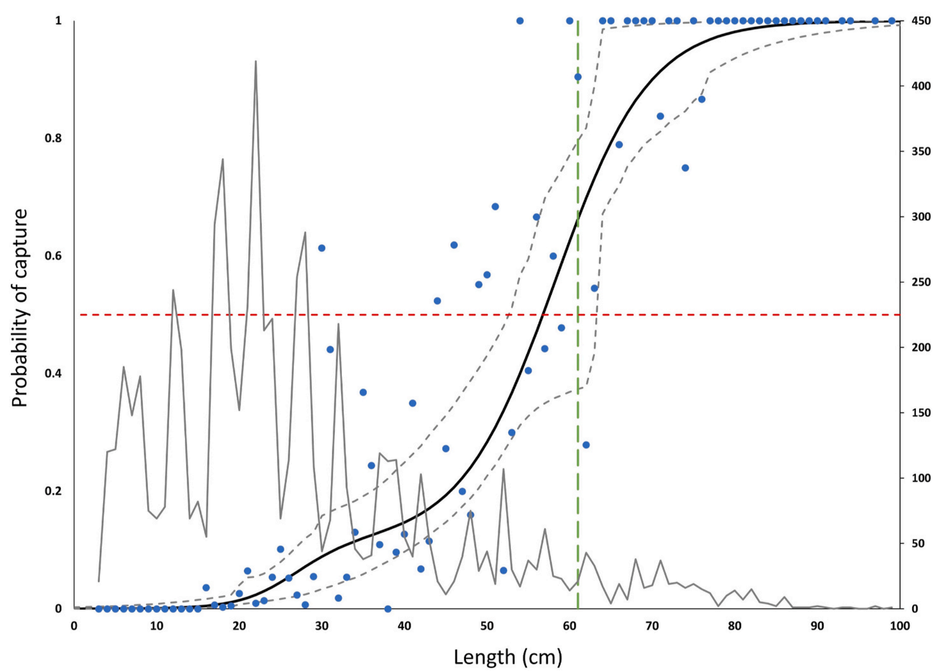

Fig. 3. Selection curve of *Trichiurus lepturus* in square mesh codend. The black dashed line indicated 95% CI for the selection curve. The blue dots are observed proportions. The vertical green line indicates LFM (61.2 cm), and the horizontal red dashed line is proportion at 50% retention. The grey curve is the total population encountered. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Selectivity results showing the L50, SR, and exploitation pattern indicators for the two codend configurations tested, including the weight and value analysis. Values in parentheses represent 95% Efron CI's. The fit statistics in terms of the *P*, deviance, and DOF.

Codend	Diamond (Efron 95% CI)	Square (Efron 95% CI)
L50 (cm)	46.95 (43.32–52.94)	56.75 (52.67–63.69)
SR (cm)	21.55 (12.83–25.43)	15.07 (9.56–24.17)
nP -	13.50 (10.71–18.36)	7.02 (4.77–10.10)
nP+	98.29 (94.48–99.66)	87.82 (80.94–93.98)
nDRatio	61.66 (52.72–70.46)	48.35 (36.92–58.59)
wP-	50.98 (45.58–58.61)	31.28 (22.67–41.73)
wP+	98.83 (96.14–99.82)	92.65 (86.96–98.29)
wDRatio	27.02 (21.76–34.29)	19.50 (12.76–26.55)
Model	DLogit	DLogit
DoF	80	88
Deviance	187.4	409.9
P	<0.001	<0.001

$$wP- = 100 \times \frac{\sum_{j}\sum_{l<LFM}\left(\frac{nR_{jl}}{qR_j} \times a \times l^b\right)}{\sum_{j}\sum_{l<LFM}\left(\frac{nR_{jl}}{qR_j} \times a \times l^b + \frac{nE_{jl}}{qE_j} \times a \times l^b\right)}$$

$$wP+ = 100 \times \frac{\sum_{j}\sum_{l>LFM}\left(\frac{nR_{jl}}{qR_j} \times a \times l^b\right)}{\sum_{j}\sum_{l>LFM}\left(\frac{nR_{jl}}{qR_j} \times a \times l^b + \frac{nE_{jl}}{qE_j} \times a \times l^b\right)} \quad (6)$$

$$dwRatio = 100 \times \frac{\sum_{j}\sum_{l<LFM}\left(\frac{nR_{jl}}{qR_j} \times a \times l^b\right)}{\sum_{j}\sum_{l}\left(\frac{nR_{jl}}{qR_j} \times a \times l^b\right)}$$

Where a (= 0.000058129) and b (= 3.61631) are the parameters of the length-weight equation for the species (Avinash et al., 2014).

The Efron 95% percentile CIs for the indicator values were estimated using the double bootstrap method described in the preceding section. The CIs considered the effects of variation in both between-haul selection and the population entering the gear, as well as the uncertainty in individual hauls due to the finite number of fish caught in each haul.

3. Results

3.1. Fishing operations and catch data

The trials at sea resulted in a total of 28 hauls, among which data from three hauls using diamond mesh and two hauls using square mesh codends could not be used, since damage was observed in the codend. Hence for the analysis data from 11 hauls using the diamond mesh codend and 12 hauls using square mesh codend were considered (Table 1, Fig. 1). The depth of the operations ranged from 10 to 25 m, with most of the hauls carried out at an average depth of about 21 m. Diamond mesh codends had an average mesh size of 40.1 ± 0.1 mm, while square mesh codends had an average bar length of 20.0 ± 0.1 mm. The duration of each tow ranged from 50 to 72 min and averaged at 59 min. The total catch in the different hauls ranged from 20 to 80 kg, which is the typical catch obtained by single day operating trawlers in the fishing ground. Ribbonfish dominated the catches since the post-monsoon season (September–October) has the most abundance of this species along this coast. Sciaenids and squids were other major species that were caught. Two hauls were carried out in a single day, in the same fishing ground, by alternating the codends alone and keeping all other operational parameters as consistent as possible.

3.2. Selectivity results

The DLogit model was chosen as the best for both codends tested based on the lowest AIC values (Table 2). Overall, the models selected seem to follow the main trends observed in the experimental retention rates fairly well (Figs. 2 and 3), despite their *P* being less than 0.05 (Table 3). Therefore, the low *P* obtained were assumed to be caused by overdispersion in the experimental rates which is often observed to be the case when dealing with pooled estimates of subsampled size selectivity data as in this case (Sistiaga et al., 2019).

The L50 value estimated as 46.95 (43.32–52.94) cm for the diamond mesh codend increased by 9.8 cm–56.75 (52.67–63.69) cm, in square mesh codend Fig. 2 (Fig. 3; Table 3).

This is corroborated by the delta plot (Fig. 4) which shows that the

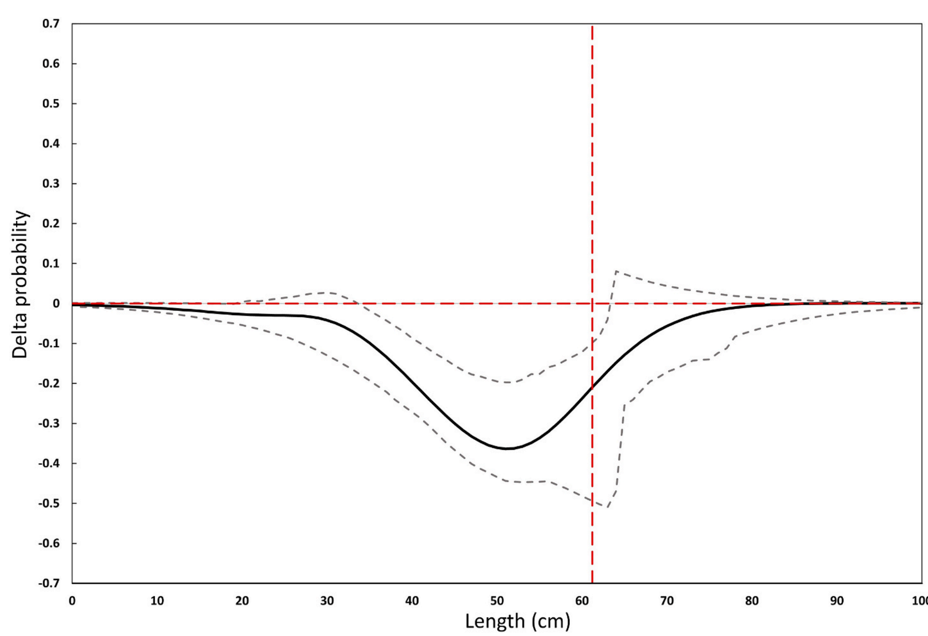

Fig. 4. Delta retention probability curve between the diamond and square mesh codend. The fitted Delta curve is indicated by the thick black curve; the stipple curves indicate the 95% CI for the curves; the vertical stipple line represents the LFM (61.2 cm) for ribbonfish (*Trichiurus lepturus*).

diamond mesh codend has higher retention probability for *T. lepturus* both above and below the LFM. This indicates that using square mesh codends instead of diamond mesh would significantly reduce the probability of retention for fish measuring 34.0 cm–64.0 cm in length.

3.3. Exploitation pattern results

The value of the indicators (Table 3) demonstrated that the use of square mesh codend as alternative to the diamond mesh codend affects the exploitation pattern. Specifically, the capture efficiency of fish below the LFM (*nP*-) was estimated to 13.50% (CI: 10.71%–18.36%) for the diamond mesh codend, and 7.02% (CI: 4.77%–10.10%) for the square mesh codend. However, the capture efficiency for fish larger than LFM (*nP*+) was higher in the diamond mesh codend with 98.29% (CI: 94.48%–99.66%) when compared to 87.82% (CI: 80.94%–93.98%) for the square mesh codend. This demonstrates that there would be loss of target catch or a lower efficiency when using the square mesh codend. The *nDRatio* which quantifies the percentage of discards, were 61.66% (CI:52.72%–70.46%) and 48.35% (CI: 36.92%–58.59%) respectively for the diamond and the square mesh codends.

The exploitation pattern considered in terms of weight, showed similar trend like the number-based analysis, with diamond mesh codend retaining 50.98% (CI: 45.58%–58.61%) of the total weight of species below the LFM (*wP*-), whereas the same value for square mesh was 31.28% (CI: 22.67%–41.73%). The total weight of catch comprising of individuals above LFM (*wP* +) in terms of percentage in diamond mesh codend was 98.83% (CI: 96.14%–99.82%), which was less in square mesh codend 92.65% (CI: 86.96%–98.29%), indicating a potential loss in weight when square mesh codends are used. The *wDRatio* which indicates the percentage weight of catch below LFM, in diamond mesh codend was 27.02% (CI: 21.76%–34.29%), which was only 19.50% (CI: 12.76%–26.55%) in case of square mesh codend.

4. Discussion

Among the various technical measures tried in India for bycatch and juvenile catch reduction, square mesh codends are the most popular and have been incorporated into the marine fisheries regulations of four states. Though the use of square mesh codends is legally mandated in these states, there is still concern among fishermen that legal square mesh codends would reduce catches and make operations unprofitable, thereby limiting their adoption in these states. The codend selectivity parameters have been estimated for about 20 species, along the Indian coast (Madhu, 2018). However, most of these studies have not considered the different selectivity models that are commonly used and would fit the data, nor considered the variance between hauls, which is especially important in selectivity studies (Wileman et al., 1996). Moreover, this is the first time that exploitation indicators, were ever derived for a species in the Indian scenario. The Dlogit model fitted the experimental data best. This is because it considers more than one selection process that takes place for example, one during the towing and another during haul-back or at the surface, which is not considered in other models.

The study showed that changing the shape of mesh from 40 mm diamond to 40 mm square, increased the L50, however there was a decrease in the efficiency of the codend by letting some portion of the marketable fish to escape. The L50 values estimated as 46.95 cm and 56.75 cm respectively for diamond and square mesh codend in this study were higher, compared to 33.4 cm in diamond and 36.2 cm in square mesh codend reported for this species by Rajeswari et al. (2013), in a study conducted along the east coast of India. The results of this study cannot be directly compared due to difference in geographical location and since it has considered only the logistic model without considering the variance component due to between haul variations.

However, the exploitation pattern indicators reveal that utilizing square mesh codend has a more beneficial advantage, with only 7.02% (CI: 4.77%–10.10%) of fish held below LFM compared to 13.5% (CI: 10.71%–18.36%) in diamond mesh codend. When diamond mesh codend is used, 61.66% (CI: 52.72%–70.46%) of the fish caught have been discarded, compared to only 48.35% (CI: 36.92%–58.59%) when square mesh codend is used. It can also be seen that there is a reduction of about 10% in number of fish above LFM in case of square mesh codend with a value at 87.82% (CI: 80.94%–93.98%) when compared to the diamond mesh codend with a value at 98.29% (CI: 94.48%–99.66%). However, when the retained percentage in terms of weight caught is considered, the values come down to about 6%, which would be more intuitive, since the profit is solely based on the weight of the fish, rather than number.

The morphology of fish determines its capture in the gear, and it has been reported that dorso-ventrally and laterally flattened fishes have low selection in square mesh codends, when compared to diamond mesh codend (Fonteyne & M'Rabet, 1992; Perez-Comas et al., 1998; Sala et al., 2008).

At present there is no minimum legal mesh size (MLS) stipulated for the *T. lepturus* along Gujarat coast, and the analysis is based on the LFM for this species reported from the coast by Ghosh et al. (2014). However, MLS has been estimated for this species in state of Maharashtra (45 cm) and stipulated as 46.0 cm in Kerala, two states of India, where square mesh codends are legally mandated. The MLS for this species has been specified based on criteria of size at sexual differentiation into male and female, based on the premise that this species has high reproductive potential and hence biomass are not significantly affected by high fishing pressure (Mohamed et al., 2014). However, a recent study on the analysis of the stock status of this species along the Gujarat waters shows that this species is overfished (Sathianandan et al., 2021), which cautions the need for high conservation status for this species. Hence, as a precautionary measure, it would be better to maintain the MLS same as that of LFM, for this species till the stock status improves. In addition to mesh size/shape regulations, temporal regulations to restrict fishing during season of high juvenile abundance also would be important. Trawl selection is a complex process, influenced by a large number of factors (Wileman et al., 1996), and only the shape of the mesh is considered in this study. Hence further studies taking into consideration many of these factors in the experimental setup would be required, and also regional optimization would be required, since the LFM or MLS is reported to be different for different regions along the Indian coast. Nevertheless, the results point towards the positive benefits of using square mesh codend for improving selectivity and population parameters for *T. lepturus* which is an importance resource targeted by trawlers along Gujarat coast.

There are many ways by which the gear restrictions, can be circumvented if they are made mandatory and fishers often do not voluntarily adopt a responsible fishing gear (Eayrs & Pol, 2019). Therefore, an effective uptake of legal codends would happen only with the active support of the fishers. Consultations with stakeholders and prolonged studies in commercial conditions, using the legal gear, and constant dialogues between the researcher and fisher, prior to implementation of regulations could help in better adoption of the legal codends in the fishery.

CRediT authorship contribution statement

Madhu Vettiyattil: Conceptualization, Methodology, Investigation, Formal analysis, Writing – review & editing. **Bent Herrmann:** Methodology, Formal analysis, Writing – review & editing. **Meenakumari Bharathiamma:** Conceptualization, Resources, Writing – review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aaf.2021.12.015.

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