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Improving dolnet selectivity by assessing square mesh performance for covered codend experiment

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Abstract

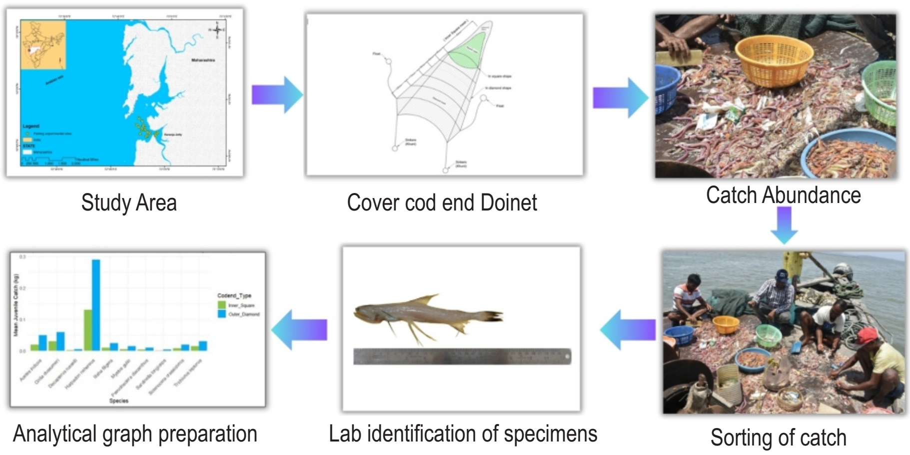
Aim: The present study aimed to evaluate the impact of squaremesh modifications on juvenile escapement in dolnets.

Methodology: The study was conducted in Karanja, Raigad district of Maharashtra, India, from April 2024 to March 2025, involving 15 sets of experimental dolnet hauls with fish targeted dolnet with square mesh codend modifications. Catch composition, size selectivity and bycatch were assessed through standardised fishing operations and morphometric measurements, with statistical analyses performed using R software to evaluate the efficiency of gear modifications.

Results: The cover codend experiment conducted at a depth of 15–20 m during pre- and post-monsoon season at Karanja, Raigad district, Maharashtra, India, revealed that dolnet catches were dominated by *Harpadon nehereus* (63.4% ± 6.4) and juvenile anchovies *Coilia dussumeri*, (13.7% ± 9.0). Frequent retention of juveniles in the codend was observed with 32.4% ± 4.7 of juvenile biomass recorded there and juvenile anchovy escapement reaching up to 47.8% ± 6.2. Selectivity analysis showed the 40 mm square mesh codend had an L_{50} of ~32 mm, allowing smaller fish to escape. Statistical tests confirmed reduced juvenile retention and improved selectivity in the square mesh design, supporting sustainable fisheries management.

Interpretation: The 40 mm square mesh codend improved the size selectivity by releasing juveniles, reducing bycatch and supporting sustainable dolnet fisheries in Maharashtra.

Key words: Catch composition, Codend experiment, Dolnet fisheries, Juvenile escapement, Square mesh selectivity



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Introduction

The north-west coast of India contributes about 32% of the India's total marine fish landings (CMFRI, 2024). Moreover, this coastal area is not only crucial for the sustenance of local fishing communities, providing a vital source of livelihood and familial support, but it also plays a significant role in ensuring food security across India. In the context of small-scale fisheries, a study by Iburahim *et al.* (2017) highlighted the application of bagnets, locally known as dolnets, along the western coast of India. This fishing gear is also employed in various other Asian countries including Bangladesh, Indonesia, Malaysia, Myanmar and Thailand (Akerman, 1986). The design and functional attributes of these nets vary regionally, adapting to local marine conditions, target species and fishing practices. The nomenclature of these bagnets varies across different coasts of India. On the north-east coast, they are referred to as Behundi jal, while names like Dolnet, Bokshi jal or Kavi jal are common on the north-west coast (Akerman, 1986; Iburahim *et al.,* 2017).

These nets are versatile in their operation, capable of capturing fish from various depths, including near to seabed, mid-water column and a few feet below the surface. The complexity inherent in the configuration, rigging and operation of these gears is noteworthy (Bapat, 1970). Remarkably, many of the fishermen lacking formal education have incrementally improved the efficiency of these gears through indigenous knowledge of oceanographic parameters such as wave patterns, tidal movements and current flows (Pratiwi *et al.,* 2023). For instance, in the high tide phase, these bagnets are effectively used to capture species such as Bombay duck, sardines, *Acetes* sp. and anchovies. Dol net fishery is a traditional stationary bag net system along India's coast, commonly operated in estuarine and nearshore waters. Its functioning depends on the tidal currents and lunar cycle. This gear is designed with fine mesh codend, which provides high efficiency in capturing pelagic species. However, this design also leads to a major drawback, *i.e.,* juvenile bycatch. Immature fishes are unintentionally caught in large numbers, which poses risk of reducing future fish populations and biodiversity (Pradhan *et al.,* 2019; Dineshbabu *et al.,* 2022).

Evidence from multiple studies highlights the seriousness of this problem. In the Hooghly-Matlah estuary, juveniles of finfishes and shellfishes form upto 90% of the total bagnet landings during winter migratory season (Krishnan and Talwar, 2021). Similarly, in the hilsa fishery, about 80% of the individuals captured are juveniles (Prajith *et al.,* 2017). Other reports also document high proportions of juveniles in bagnet fisheries (Islam *et al.,* 1993). This practice disrupts marine biodiversity and interferes with the life cycles of several species (Boehlert, 1996; Pradhan *et al.,* 2019). Despite this drawback, dolnets are often environmentally sustainable over trawl nets because trawling operations are more damaging to the marine environment because they disturb benthic habitats, consume more fuel and create high ecological stress. Square mesh nets are helpful for reducing juvenile bycatch because they are more selective (Kunjipalu *et al.,* 2001). The square shape of the mesh allows smaller, younger fish to escape, while still catching the bigger, mature fish (Prakash *et al.,* 2022). A 2012 study in Indonesia investigated the impact of square mesh panels on shrimp trawl nets. The researchers found that using square mesh significantly reduced the capture of juvenile fish up to 60% compared to traditional diamond mesh nets (Broadhurst *et al.,* 2009). Most of the existing studies are restricted to square mesh modifications in trawl gears, while systematic evaluations of square mesh modifications in dolnets are still lacking. Therefore, this study investigates the efficiency of square mesh modifications in dolnet fisheries for reducing juvenile bycatch and promoting sustainable fishing practices.

Materials and Methods

Study area and period: The study was conducted in the coastal waters of Karanja (Lat: 18°50'49.2"N, Long: 72°57'00.0"E) in the Raigad district of Maharashtra, India (Fig. 1). This area is a significant landing centre with extensive dolnet operations, particularly targeting Bombay duck and other commercially important fish (Iburahim *et al.,* 2017). Experimental fishing operations were carried out from April 2024 to March 2025.

Experimental design: A total of 15 experimental hauls were conducted during the study period at Karanja, Maharashtra. The experiment aimed to assess the selectivity of square mesh codends inserted within traditional dolnets, with gear modifications tailored according to the target species. Modified dolnet configurations were employed 40 mm square mesh cover codend as per Bahamon *et al.* (2006) was used in dolnets targeting fish species. Traditional dolnets themselves comprised a range of mesh sizes of 130 mm at the mouth to 12 mm at the codend. However, the experimental square mesh cover codend inserted inside the dolnet consisted of a single, uniform mesh size specific to the target fish species, *i.e, Harpadon nehereus*, as shown in Fig. 2. For hauls targeting fish, a dolnet equipped with an internal square mesh panel of 40 mm was considered to enhance the size and species selectivity.

Experimental fishing operations: Each experimental haul was conducted in accordance with the standard dolnet fishing practices employed in the Karanja region, using 20 Hp diesel engine-powered vessels of 6 m LOA for uniformity, with an exposure duration of 120 ± 20 min. Haul duration, net placement and deployment method sapart from the experimental codend modification were standardized across all trials to ensure consistency and minimize operational variability as shown in Table 1. After each fishing operation, the dolnet was retrieved and the catch from both the outer codend and the inner square mesh codend was carefully sorted, identified using standard taxonomic references. (Day, 1889; Fischer, 1984; Talwar and Kacker, 1984; Van Der Laan *et al.,* 2014) and authentic google websites such as FishBase (Froeseand Pauly, 2025) and weighed separately (Prakash *et al.,* 2022). This approach facilitated the assessment of size selectivity and catch composition through cover codend

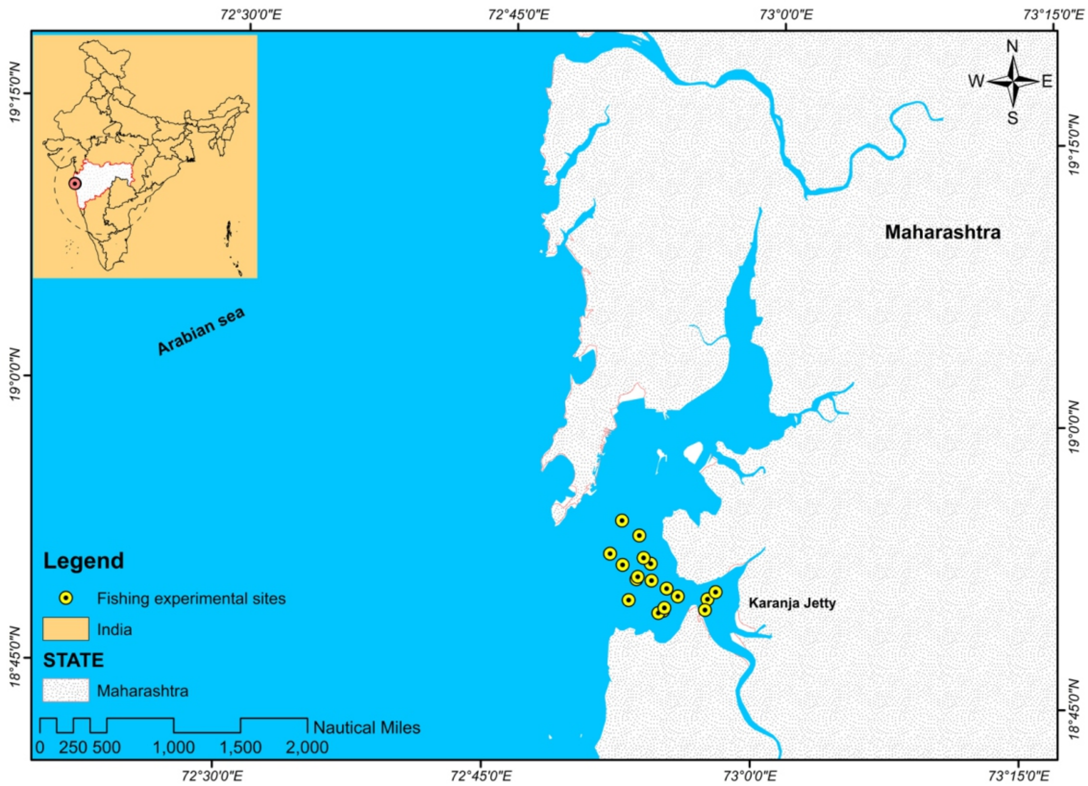

Fig. 1: Map showing the geographical location of the study area.

Table 1: Operational and catch related data of cover codend dolnet trials at Karanja, Raigad, Maharashtra, India

Trial date	Hauling time (24 hr format)	Total Catch (in Kg)	Outer codend Catch (in Kg)	Inner cod end Catch (in Kg)	Bycatch (in Kgs)
08/04/2024	07:00	27.7	6.7	20.9	5.8
23/04/2024	13:45	29.7	5.4	24.3	3.2
07/05/2024	13:00	43.7	21.6	22.5	4.9
27/05/2024	09:50	41.4	20.5	20.8	4.5
06/08/2024	12:30	40.8	22.4	18.4	3.6
20/08/2024	10:47	39.7	20.9	18.7	5.4
12/09/2024	15:30	42.0	14.2	27.8	3.7
16/10/2024	09:40	49.8	20.6	29.2	3.0
19/11/2024	18:11	25.0	7.3	17.6	3.3
10/12/2024	08:05	12.0	4.0	8.0	4.4
30/12/2024	07:51	10.5	4.2	6.3	5.1
17/01/2025	15:06	45.2	23.8	21.3	2.9
13/02/2025	07:51	43.9	15.4	28.5	4.2
05/03/2025	11:25	24.7	13.2	11.4	2.6
24/03/2025	18:50	20.2	10.1	10.1	3.8

experiment. For all commercially significant fish species, a total of 30 specimens from each species were sampled to ensure adequate representation for statistical analysis. Comprehensive morphometric data, including total length (TL in cm) wasmeasured with Vernier Calliper (0-150 mm; Resolution: 0.1 mm; Accuracy: ± 0.02 mm) and body weight (BW in gm) recorded using a accurate weighing machine (Model: Digitone DGT5), were systematically collected during each haul.

Statistical analyses: All collected data, encompassing catch composition, species-specific morphometric measurements and bycatch, were subjected to comprehensive statistical analyses

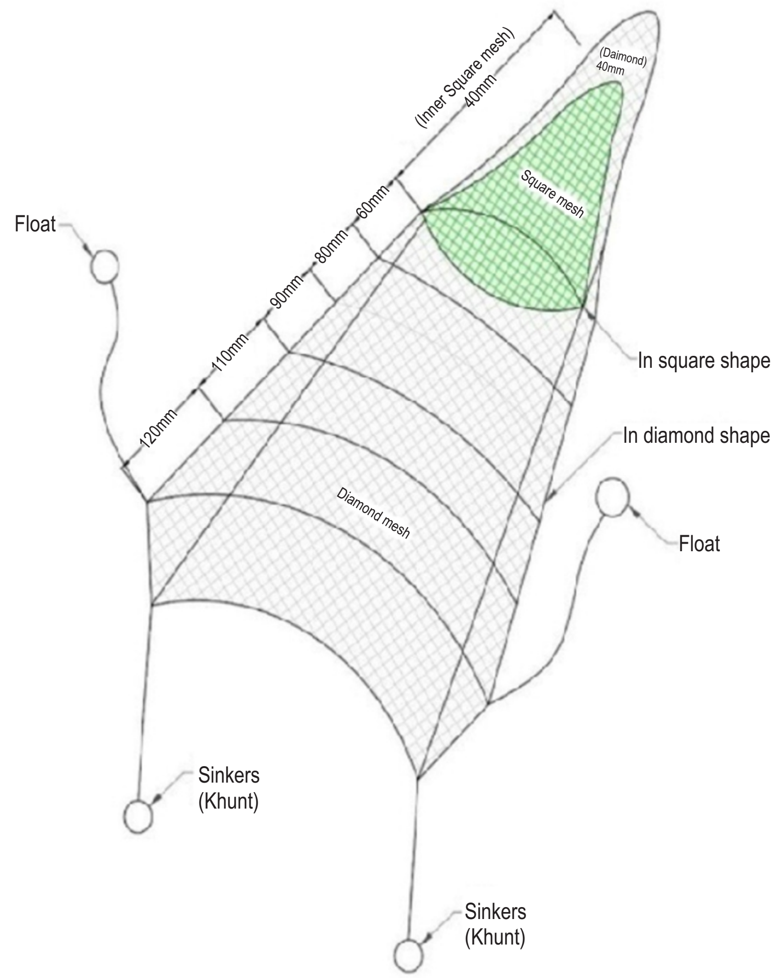

Fig. 2: Design of dolnet for cover codend experiment

utilizing R statistical software (version 4.5.0) using Lafaye De Micheaux *et al.* (2013). Size selectivity for fish, corresponding to 40 mm square mesh codends, were rigorously analysed through the application of logistic regression models. Key selectivity parameters, such as length at 50% retention (L_{50}) and selection range (SR), were estimated using the Sicejar package in R according to Caglar *et al.* (2018). Furthermore, catch per unit effort (CPUE) for target species and bycatch was meticulously calculated and subsequently compared across the experimental codends. Descriptive statistics (mean, standard deviation, range) were computed to summarize the collected catch data. Comparison of mean lengths, weights and catch rates were statistically assessed using paired t-test.

Shapiro-Wilk test was used to examine the normality of paired differences before applying paired t-tests and where normality assumptions were not satisfied, the non-parametric Wilcoxon signed-rank test was employed. A significance level of $\alpha = 0.05$ was adopted for all hypothesis testing and effect sizes (Cohen's d) were calculated for paired comparisons to assess the magnitude of differences between codend designs. Also, to complement the length-based selectivity analysis, an escape ratio (ER) was calculated to quantify the proportion of fish that successfully escaped through the codend meshes. The escape ratio was defined as:

$$ER = \frac{\text{Catch in Outer codend}}{\text{Catch in Inner codend+Catch in outer cod end}}$$

Escape ratios were calculated for each haul and averaged seasonally to assess variability.

Results and Discussion

The catch was over whelmingly dominated by the Bombay duck (*Harpadon nehereus*), which constituted an average of 63.4% ± 6.4 of the total biomass. A substantial portion of the remaining catch, 13.7% ± 9.0, consisted of juvenile anchovies (*Coilia dussumeri*). In contrast, the croaker

Table 2: Proportion of fish retained in 40 mm square mesh codend across the length interval

Length Class (cm)	Total Fish	Retained	Proportion Retained
25–29	30	0	0.00
30–34	45	32	0.71
35–39	42	36	0.86
40–44	28	28	1.00
45–49	12	12	1.00
50–54	6	6	1.00
55–59	4	4	1.00

Pseudosciaena diacanthus represented a minor component at 0.5% ± 0.4. A significant concern identified was the frequent capture of juvenile *H. nehereus* and *C. dussumieri,* especially individuals in the 20 to 40 mm range. On average, 32.4% ± 4.7 of the juvenile biomass was recorded in the cod net, with this figure for juvenile anchovies reaching as high as 47.8% ± 6.2 in some instances. The presence of postlarval *H. nehereus* (30-40 mm) with undeveloped fins suggest they were being passively forced through the net mesh by strong tidal currents. These results underscore the pressing need for modifications to dolnet designs to minimize bycatch. The recorded catch per unit effort (CPUE), ranging from 1.8 to 6.5 kg per haul in the present study, is consistent with values reported in previous studies for this region (Pradhan *et al.,* 2019), thereby affirming the representation of the observed fishing operations.

Length based selectivity analysis was conducted using grouped length frequency data, with fish lengths binned into 5 mm class intervals as shown in Table 2. The observed proportion of fish retained in the codend increased with length, showing a clear sigmoid pattern indicative of logistic selectivity behaviour (Ghosh *et al.,* 2024). A logistic model was fitted to the mid-length data using non-linear regression. The fitted curve estimated the length at 50% retention (L_{50}) as 32.7 mm, with a selection range (SR) of 4.1 mm. This suggests that fish approximately loss than 30 mm had a high probability of escapement, while those above 40 mm were almost entirely retained (Madhu, 2018). The curve closely matched the observed proportions, reinforcing the square mesh's ability to allow juvenile escapement while retaining marketable sizes. For instance, no fish in the 25-29 mm bin were retained, while full retention was observed for size classes above 40 mm (Fig. 3). These findings demonstrate the efficiency of 40 mm square mesh codend in enhancing size selectivity and reducing the capture of undersized individuals. These results are in agreement with the previous studies employing similar mesh sizes, supporting the adoption of square mesh codends as a practical strategy for sustainable fisheries management (Millar and Fryer, 1999).

The goodness of fit analysis confirmed a strong model fit, with an R^2 value of 0.976, indicating that 97.6% of the variation in retention proportion was explained by the logistic model. The root mean square error (RMSE) was calculated as 0.053, suggesting minimal deviation between observed and predicted values. These metrics support the reliability of logistic selectivity curve for representing the retention characteristics of the 40 mm square mesh codend. The escape ratio analysis revealed clear seasonal differences in the performance of the square mesh codend depending upon the seasonal catch composition in dolnet catches (Table 3). The highest escapement was observed during the monsoon season (mean ER = 0.47), when strong tidal currents and high hydrodynamic turbulence likely forced smaller individuals, especially juveniles, through mesh openings.

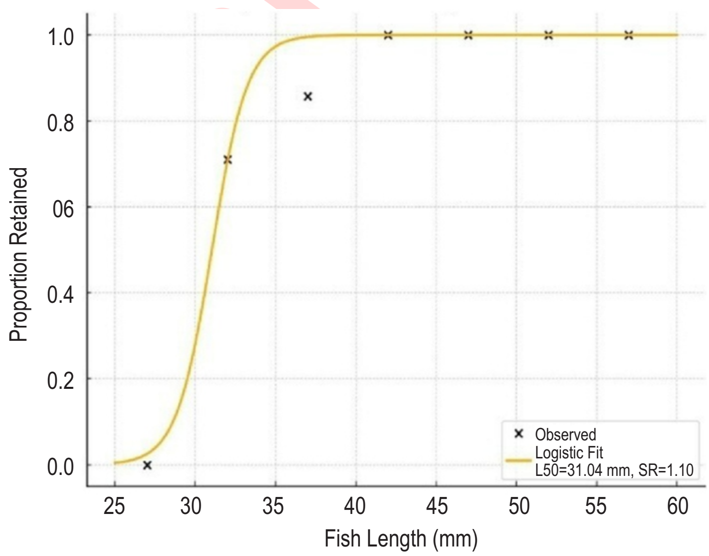

Fig. 3: Fish retention probability in 40 mm square mesh codend.

Table 3: Seasonal variation in escape ratio (ER) of dolnet bycatch

Season	Mean ER	SD	Min	Max
Pre-monsoon (Feb-May)	0.40	0.14	0.18	0.54
Monsoon (Jun-Sep)	0.47	0.12	0.34	0.55
Post-monsoon (Oct-Jan)	0.39	0.09	0.29	0.53

Table 4: Catch composition in outer vs inner codend using 40 mm square mesh

Species Names	Weight of catch in outer codend (in kg)	Weight of catch in inner codend (in kg)
Harpadon nehereus	0.42 ± 0.2	1.24 ± 0.3
Coilia dussumieri	0.08 ± 0.05	0.22 ± 0.1
Acetes indicus	0.06 ± 0.02	0.20 ± 0.05
Trichiurus lepturus	0.04 ± 0.01	0.12 ± 0.03
Ilisha filigera	0.03 ± 0.01	0.10 ± 0.02
Solenocera crassicornis	0.01 ± 0.005	0.05 ± 0.01
Mystus gulio	0.005 ± 0.002	0.03 ± 0.01
Pseudosciaena diacanthus	0.015 ± 0.01	0.05 ± 0.02
Decapterus russelli	0.002 ± 0.001	0.01 ± 0.005
Sardinella longiceps	0.004 ± 0.002	0.015 ± 0.005

Whereas the post-monsoon period recorded the lowest mean ER = 0.39, which coincided with calmer hydrodynamic conditions. Such reduced turbulence likely decreased the assistance provided by water flow, increasing the retention of smaller fish. Thereby, lowering escapement levels (Wileman *et al.,* 1996; Broadhurst, 2000). The pre-monsoon (0.40) values were intermediate, reflecting moderate levels of escapement under relatively stable environmental conditions. Similar seasonal effects have been documented in Mediterranean bottom trawl fisheries, where fluctuations in the environmental conditions and fishing effort significantly influenced catch rates (Sbrana *et al.,* 2003). For each species, paired catch weight data from the outer and inner codends were analysed (Table 4). Shapiro Wilk test was used to evaluate normality of paired differences, followed by paired t-tests to assess statistical significance. All ten species showed a statistically significant difference ($p < 0.05$) in catch weights between the outer and inner codends. Normality was tested using the Shapiro-Wilk test; where assumptions were not met, Wilcoxon signed-rank tests were applied, yielding consistent outcomes. All comparisons were significant ($p < 0.05$, $\alpha = 0.05$), with effect sizes (Cohen's d ≈ 0.69 for overall catch) indicating moderate to large practical differences. These results align with the reports of Lucchetti (2008), who reported improved size selectivity and reduced undersized catch using square meshes, highlighting their role in enhancing retention efficiency and promoting selective fishing.

The inner codend consistently retained a higher biomass, as indicated by selectivity ratios exceeding 2.5 for most species. For instance, *A. indicus, C. dussumieri* and *I. filigera* showed selectivity ratios of 3.27, 3.30 and 3.49, respectively. *H. nehereus,* the dominant species in the catch, exhibited a selectivity ratio of 2.66. The highest selectivity ratio was recorded for *D. russelli* (4.26), suggesting effective retention of smaller individuals by the inner codend. These results confirm that the square mesh modification significantly improves retention efficiency and reduces escapement, especially of small and slender bodied species (Fujimori *et al.,* 2000; Moussa *et al.*, 2025). Paired comparisons of species-wise catch weights revealed significantly higher retention in the inner codend across all ten studied species ($p < 0.05$) as shown in Fig. 4 and Table 5. Selectivity ratios (inner: outer catch weight) ranged from 2.66 in *H. nehereus* to 4.26 in *D. russelli,* indicating enhanced capture efficiency and reduced

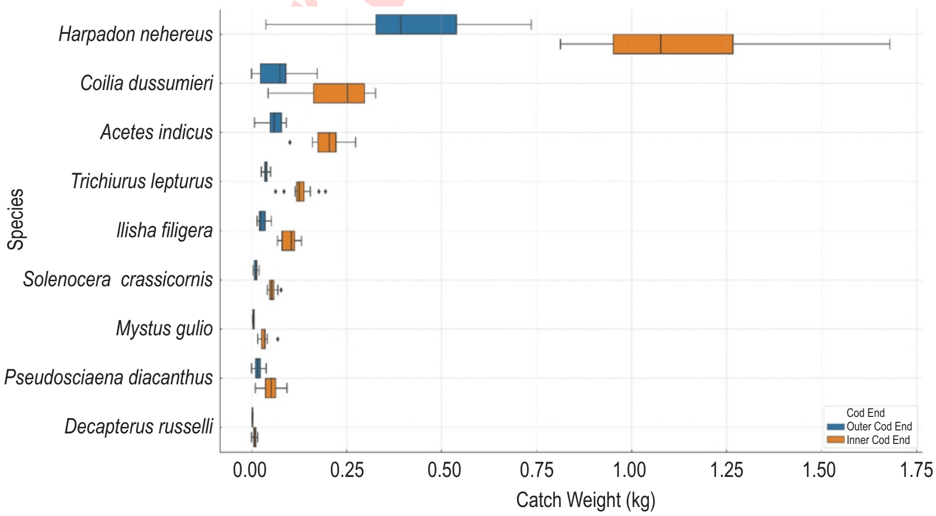

Fig. 4: Species-wise comparison of catch weights between outer and inner codends in a double codend dolnet fitted with a 40 mm square mesh panel.

Table 5: Descriptive analysis of outer and inner codend catches in modified Dolnet

Statistics	Outer codend (Diamond mesh)	Inner codend (Square mesh)
Total Trails	15	15
Mean weight (kg)	14.02	19.05
Standard Deviation	7.29	7.30
Minimum weight (kg)	4.0	6.3
Maximum weight (kg)	23.8	29.2
Median	14.2	20.8
25th Percentile	7.0	14.5
75th Percentile	20.75	23.4

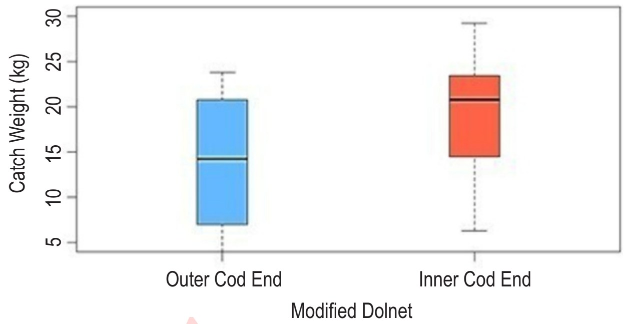

Fig. 5: Comparison of catch weights in outer (diamond) and inner (square) codends of modified dolnets.

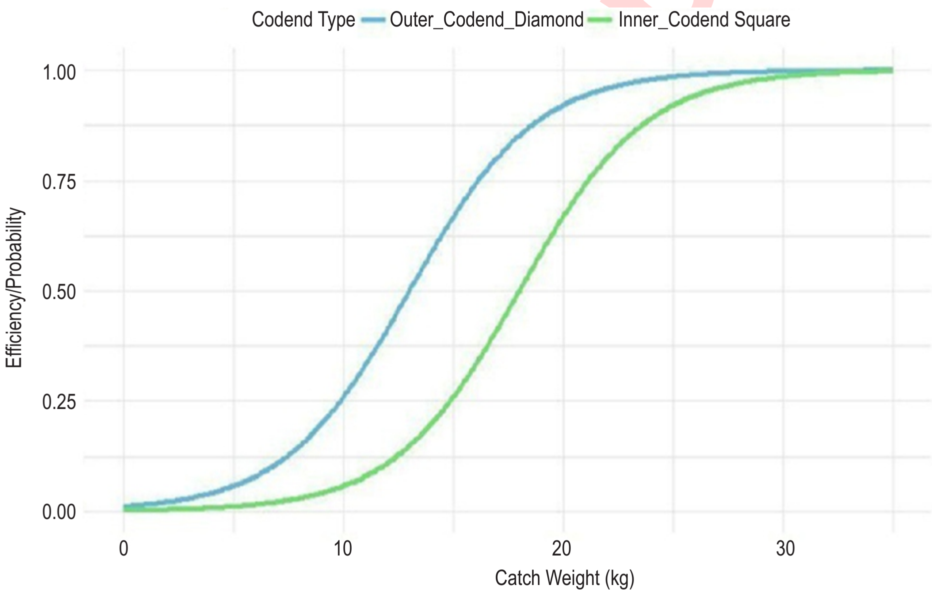

Fig. 6: Catch efficiency profiles of modified codend design.

escapement. Boxplot visualizations confirmed this pattern, with consistently higher medians and narrower interquartile ranges observed in the inner codend. These findings suggest that the square mesh modification effectively improves gear selectivity and contributes to sustainable fishing practices.

The distribution pattern showed a higher central tendency and narrower interquartile range in the inner codend, suggesting that the square mesh was more effective in selectively retaining fish while allowing smaller or non-target individuals to escape through the outer section. This selectivity aligns with the functional design of square meshes, which maintain constant mesh opening dimensions under tension, in contrast to the collapsing nature of diamond meshes. Such structural differences are particularly advantageous in reducing juvenile retention and improving catch quality. Similar patterns were reported by Prajith *et al.* (2017), where square mesh codend resulted in significantly higher escapement of juvenile thread fin breams and ribbon fishes, along with a 22-35% reduction in undersized catch and a marked improvement in the proportion of marketable fish. Additionally, the observed consistency across hauls suggests operational stability and practical feasibility of the modified design. The enhanced performance of the inner codend supports its adoption as a selectivity improvement measure in dolnet fisheries along the north-west coast of India, contributing towards resource sustainability and improved sorting efficiency at landing centres. The inner codend exhibited a higher median catch weight, indicating superior efficiency in retaining fish. Moreover, the narrower interquartile range (IQR) in the inner codend reflects more consistent catch outcomes across hauls, whereas the wider IQR observed in the outer codend denotes greater variability in performance (Fig. 5). The higher median

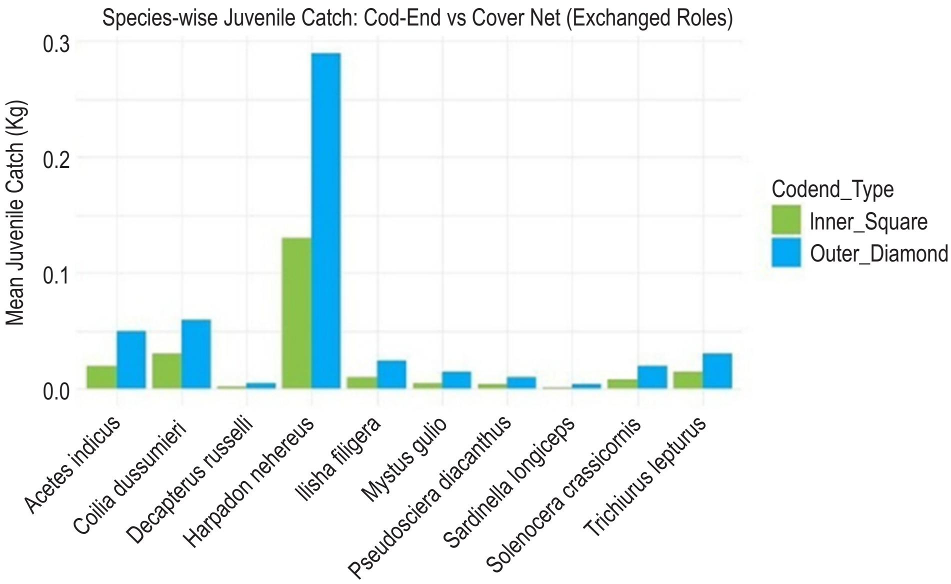

Fig. 7: Species wise juvenile catch comparison in square and diamond mesh.

catch weight and reduced variability collectively highlight the enhanced selectivity and retention efficiency provided by the square-mesh modification. These results are consistent with recent findings by Kamei *et al.* (2024) and Bak-Jensen *et al.* (2023), who demonstrated that square-mesh codends maintain more stable mesh geometry during towing, improve water flow and significantly reduce escape opportunities for smaller individuals, thereby increasing both catch efficiency and the predictability of size-selective performance.

The higher upper range of catch weights in the inner codend highlights efficiency of the square mesh in retaining greater biomass (Fig. 6), which corroborate with the previous studies (Boopendranath *et al.,* 2010; Millar and Fryer, 1999) and can be attributed to the square mesh ability to maintain stable openings under tension, which increases juvenile escapement. (Kunjipalu *et al*., 2001). A similar trend was reported by Ferragut-Perello *et al.* (2023), who documented increased L_{50} values and up to 90 percent escapement of undersized *Merluccius merluccius* with a 52 mm square mesh codend, alongside retention of higher marketable biomass. In comparison, the present results indicate that square mesh codends can achieve both improved selectivity and higher biomass retention, supporting their suitability as a sustainable gear modification in line with system oriented fisheries management approaches highlighted by Lukambagire *et al.* (2023).

Fig. 7 illustrates that the outer diamond mesh codend retained a higher volume of juvenile catch across most species. *Ilisha filigera* showed the highest juvenile retention in the diamond mesh (0.29 kg), more than double that observed in the inner square mesh (0.13 kg). Similar trends were evident for *Harpadon nehereus, Decapterus russelli* and *Coilia dussumeri,* where the diamond mesh consistently captured more juveniles. In contrast, the inner square mesh codend demonstrates a clear reduction in juvenile retention, highlighting its efficiency in facilitating the escape of smaller individuals. These findings are consistent with those of (Rajeshwari *et al.,* 2013; Yan *et al.*, 2023), who also reported improved juvenile escapement with square mesh codend modifications.

The square mesh codend has shown promising results in enhancing size selectivity and reducing juvenile bycatch in dolnet operations. These findings highlight the need for fisheries authorities to promote and implement square mesh technology as a practical measure for sustainable fishing. Future studies should focus on trait-based analyses of escape tendencies to better understand species-specific responses to square mesh configurations. This study also highlights the ecological significance of square mesh codends in dolnet operations by reducing juvenile bycatch of key species such as *Harpadon nehereus*. Allowing undersized fish to escape supports stock recruitment, maintains population structure and protects biodiversity by reducing fishing-induced mortality of non-target species. Improved size selectivity strengthens spawning stock biomass, minimizes discards and enhances catch quality, thereby lowering the risk of stock collapse. Healthier age structures also increase resilience to climate change and habitat stress, aligning with sustainable fisheries management goals and SDG-14.

The study was limited by environmental variability, restricted spatial and temporal coverage and operational constraints that may have influenced net geometry and escapement patterns. Future research should include advanced monitoring (video/acoustic) and evaluation of juvenile survival to strengthen ecological and management relevance.

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Authors' contribution: **S.K. Sharma:** Sample collection, investigation, data analysis, writing original draft; **M.P. Remesan:** Supervision, methodology development, critical review and guidance on fishing technology aspects; **A.T. Landge:** Guidance in fisheries resource management and manuscript revision; **V.R. Madhu:** Assistance in experimental design, statistical analysis; **S. Bhusan:** Laboratory analysis and technical assistance; **P.N. Jha:** Data curation, statistical analysis and support in result interpretation; **K. Ramteke:** Field coordination, logistics and technical support for experimental trials. **S.R. Salunkhe:** Field data collection and data entry.

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