Simple pot modification improves catch efficiency and species composition in a tropical estuary mud crab (*Scylla serrata*) fishery

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Abstract

Pots are widely used fishing gear type for targeting different crustacean and fish species. Pot entrance size and design are among the most important technical parameters that influence the catch efficiency of certain species. An optimal pot entrance design should allow an efficient entry for the target species while preventing subsequent escape. The tropical estuary pot fishery targeting mud crab (*Scylla serrata*) in Vembanad Lake, India, employs rectangular pots with rectangular-shaped entrances. Low catch rates for target species and high bycatch rates are observed in this fishery. This study was carried out to investigate if a simple pot modification by extending the entrance of the traditional pots, can improve the catch efficiency of mud crab. Further, we estimated and compared the catch composition in this small-scale fishery using the traditional and modified entrance pots. The results showed that the catch efficiency for all sizes of mud crab is on average more than six times higher with the modified entrance pots compared to the traditional pots (622% (CI: 344-1867%)). However, significant quantities of juvenile crabs are caught in modified pots. Further, the bycatch ratio was significantly reduced for modified compared to the standard entrance pots in this fishery. These results show that such pot modifications have potential to significantly improve the catches in mud crab pot fisheries without increase in capture of bycatch species. However, additional mechanisms for excluding undersized crabs from pot catches should be investigated.

Keywords: Pot entrance, pot fisheries, mud crab, catch efficiency, catch composition

1. Introduction

Pots are low impact fishing gear, which is widely used to capture different species of crustaceans and fish (Jennings and Kaiser, 1998; Thomsen et al., 2010). Pots are designed as enclosures that attracts target animals to enter the gear through one or more entrances, often following the bait odour, while preventing or limiting their subsequent escape (He et al., 2021). Globally, a wide range of pot designs are used depending on such factors as morphological and behavioural characteristics of the target species (Slack-Smith, 2001; Gabriel et al., 2005).

Pots are widely used in the inland fisheries sector, due to low gear costs and low energy requirements required for operation of them, thus providing sustenance to small-scale fisheries sectors in many countries (Suuronen et al., 2012; Swathilekshmi, 2018; Petetta et al., 2021). One of such small-scale pot fisheries is the fishery targeting mud crab (*Scylla serrata*) which is one of the economically most important species in coastal regions due to the growing demand (Sen and Homechaudhuri, 2017; Apine et al., 2019). Specifically, the mud crab fishery contributes significantly to the overall catches of the Vembanad lake, which is one of the most important brackish water lakes in India (Asha et al., 2014; Ajay, 2021). In this area, the pots form a major fishing gear type used in the southern and eastern zones of the lake, with an estimated CPUE of 0.26 kg/h (Asha et al., 2014). The total landing from the Vembanad lake fishery is reported to be around 4300 tonnes. In this fishery, the major pot design used to target mud crab along the southern and eastern stretches of the Vembanad lake are traditional rectangular pots (Asha et al., 2014). This type of pots is used for targeting mud crab throughout the year with highest catch rates from June to November.

However, the capture rates for mud crabs in these pots are generally low for all sizes of mud crab. There is no minimum legal size for mud crab in this fishery; however, the length at first sexual maturity (LFM) for the species is reported to be around 95 mm carapace length (CL)

(Prasad and Neelakanda, 1989; Ali et al., 2020). Furthermore, although in this fishery the main target species is the mud crab, catches of a large number of other non-targeted species such as *Etroplus maculatus*, *Arius subrostratus, Mystus oculatus* are common (Asha, 2014; Ajay, 2021).

One of the solutions for increasing the pot catch efficiency is to equip the gear with optimal entrances. Such pot entrance design should provide an easy entrance for the target species, thus increasing the entry probability while further preventing them from escape or loss during pot retrieval (Miller, 1990; Li et al., 2006; Cerbule et al., 2022a). Therefore, the entrance size and design are factors which are critical to determine catch efficiency in a pot fishery. Various pot entrance designs are used in different fisheries, including fisheries for mud crab (Chacko et al., 1954; Mahesh Raj, 1992; Broadhurst et al., 2018). For example, many studies have explored to increase the ingress in pots by modifying the mouth entrance (Luckhurst and Ward, 1985; Bjordal and Furevik, 1998; Fuwa et al., 1995). It has been observed that complex, two-bend designs resembling horse-neck funnels were found to be most effective in increasing the ingress. Furthermore, use of non-return structures in the mouth entrance, are found to be effective (Hughes et al., 1970; Carlile et al., 1997); however, a few studies reported decrease in catch rates (i.e., Munro, 1972). Two successive entrances, the first with wider opening, followed by a smaller opening, is found to increase entrance efficiency in other pot fisheries (Furevik and Løkkeborg, 1994). Such complex pot entrance designs are more useful in some fisheries with long pot deployment time (soak time) exceeding 24 hours since they do not experience a reduction in catch rates after prolonged soaking (Sheaves, 1995). However, in fisheries with short soak times (i.e., with soak time less than 24 hours), simpler pot entrance modifications such as increase in entrance length into the pot can be applied to increase the catch efficiency of the gear.

In this study, we compared the catch efficiency of standard mud crab pots as used in the small-scale fisheries in the tropical estuary fishery in Vembanad lake with that of pots with modified entrance design. We also estimated the catch composition in this fishery using the standard pots and compared it with the catch composition retained by the modified gear. Specifically, the present study was aimed to answer the following research questions:

- How does increasing the entrance funnel length in rectangular pots affect the length-dependent catch efficiency of mud crab?
- What is the catch composition in small-scale mud crab pot fisheries, and can modifications in pot entrance design change the catch composition in this fishery?

2. Materials and methods

2.1. Experimental design and data collection

Experimental trials were conducted in a small-scale mud crab fishery along the eastern stretch of the Vembanad lake, adjoining the Kumbalangi Island (Figure 1) at Cochin, Kerala from June to November 2022.

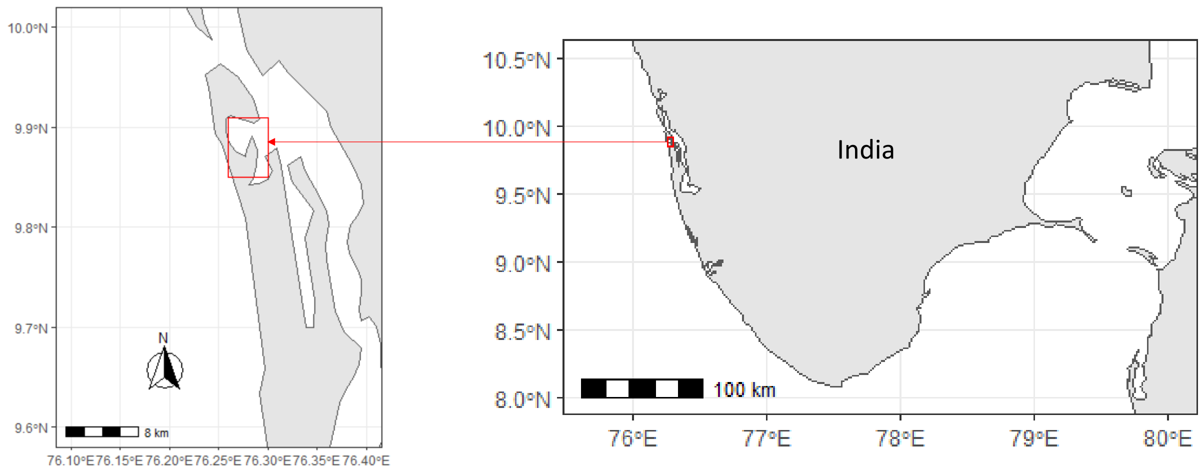

Figure 1. Map of the positions where pots were deployed.

During the trials, we used the standard commercial mud crab pots as employed by the fishing boats in the region as the baseline, against which we tested pots with modified entrance design (test pots). The baseline pots in this mud crab fishery are rectangular-shaped pots with dimensions of 1000 mm × 400 mm, made of galvanised iron rod and covered using 35 mm knotted polyamide (PA) webbing. The entrance sizes for such pots are 120 mm × 100 mm. The test pots in this study were equipped with an entrance extension of 100 mm towards the inside of the pot facing downwards. Therefore, in the modified test pot design, all the other characteristics were similar, except for the extension part which was attached to the pot entrance (Figure 2). The hypothesis for testing this type of modification in the entrance of rectangular pots is that such entrance design would make it difficult for crabs that had fallen into the pots to escape the gear through this rather complex entry.

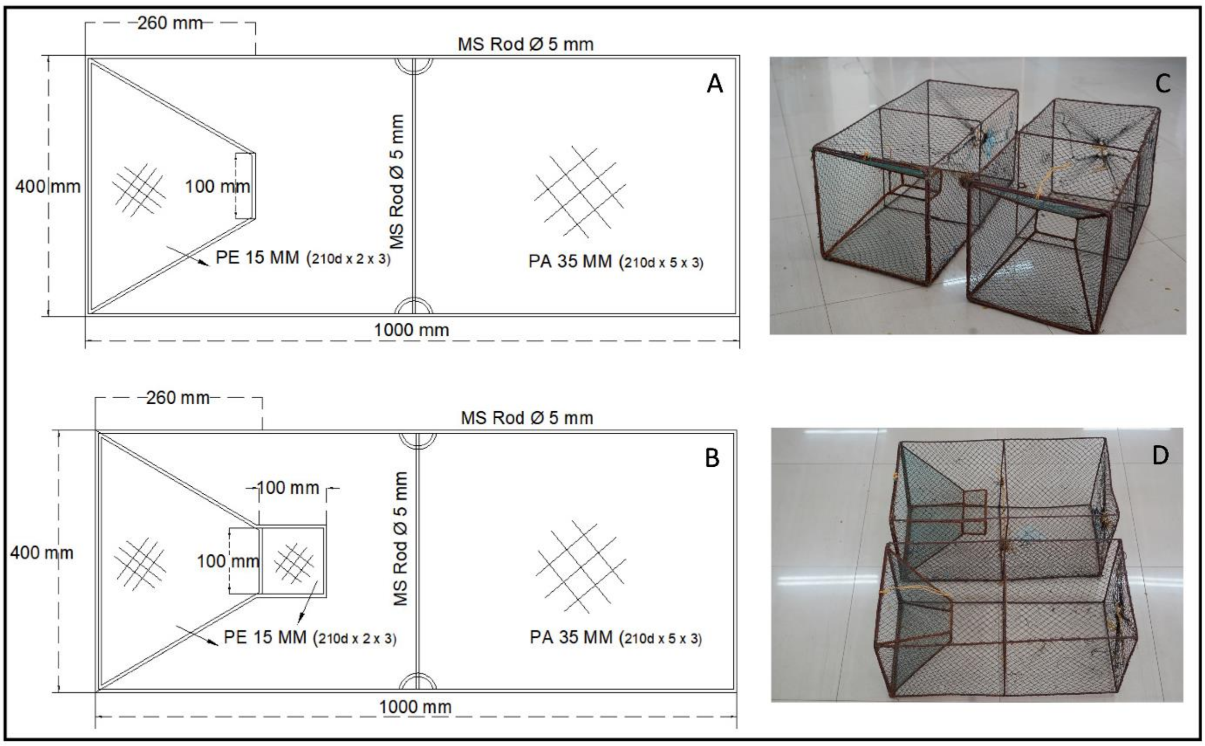

Figure 2. Experimental design of comparing baseline pots (A) used in mud crab pot fishery in Vembanad lake, India and test pots with extended pot entrance (B). The photographs (C and D) show the entrance of the baseline and tests pot from different angles.

During the trials, a paired experimental design was used with each pair consisting of two baseline pots and two test pots fished simultaneously. This configuration was fished several times during the experiments. The pots were deployed in the depth range of 2-3 meters, in the traditional mud crab fishing grounds of the estuary. Before deployments, each pot was baited with approximately 40-50 grams of spotted catfish (*Arius maculatus*). The pots were soaked for approximately 24 hours during each deployment, which corresponds to the pot soak time used in the commercial mud crab fishery in the region.

Once each pot was lifted, the catch was emptied into separate containers for following length and weight measurements. The catch was sorted by species and the numbers and weights of all species were recorded for each pot separately. Further, mud crab carapace length measurements were taken using a measuring scale to the nearest cm. After the measurements, the pots were re-baited and re-deployed; ensuring that the position was changed for each deployment.

2.2. Modelling the length-dependent catch efficiency between the test and baseline pots

To assess the change in relative length-dependent catch efficiency for mud crab between the test and baseline pots, we used the method described in Herrmann et al. (2017). The method models the length-dependent catch comparison rate (CC_l) summed over pot deployments for the full deployment period. CC_l is expressed by:

$$CC_l = \frac{\sum_{j=1}^{m}\{nt_{lj}\}}{\sum_{j=1}^{m}\{nt_{lj}+nb_{lj}\}} \qquad (1)$$

In Equation (1), nt_{lj} and nb_{lj} are the numbers of mud crab caught in each carapace length class l for the test pots and the baseline pots, respectively, in deployment j of the paired design with two baseline and two test pots. m is the number of deployments conducted with the paired design where the catch contained mud crab. The functional form for the catch comparison rate $CC(l, \boldsymbol{v})$ was obtained using maximum likelihood estimation by minimizing:

$$-\sum_l\left\{\sum_{j=1}^{m}\left\{nt_{lj} \times ln\big(CC(l,\boldsymbol{v})\big) + nb_{lj} \times ln\big(1.0 - CC(l,\boldsymbol{v})\big)\right\}\right\} \qquad (2)$$

where $\boldsymbol{v}$ represents the parameters describing the catch comparison curve defined by $CC(l, \boldsymbol{v})$. The outer summation in Expression (2) is the summation over the mud crab carapace length classes l. When the catch efficiency of test and baseline pots is similar, the expected value for the summed catch comparison rate would be 0.5, thus applying this baseline allow to judge whether or not there is a difference in catch efficiency between the two pot designs. The experimental CC_l was modelled by:

$$CC(l,\boldsymbol{v}) = \frac{exp\big(f(l,v_0,\ldots,v_k)\big)}{1+exp\big(f(l,v_0,\ldots,v_k)\big)} \qquad (3)$$

In Equation (3), f is a polynomial of order k with coefficients v_0 to v_k. The values of the parameters $\boldsymbol{v}$ were estimated by minimizing the Expression (2) which was equivalent to maximizing the likelihood for the observed catch data. In Equation (3), we considered f of up to an order of 4 with parameters v_0, v_1, v_2, v_3, and v_4. Leaving out one or more of the parameters $v_0 \ldots v_4$ led to 31 additional models that were considered as potential models for the catch comparison rate $CC(l, \boldsymbol{v})$. Among these models, estimations of the catch comparison rate were made using multi-model inference to obtain a combined model (Burnham and Anderson 2002; Herrmann et al., 2017).

The ability of the combined model to describe the experimental data was evaluated based on the p-value. The p-value, which was calculated based on the model deviance and the degrees of freedom, should not be <0.05 for the combined model to describe the experimental data sufficiently well, except for cases in which the data exhibited over-dispersion (Wileman et al., 1996; Herrmann et al., 2017).

Based on the estimated catch comparison function $CC(l, \boldsymbol{v})$, we estimated the relative catch efficiency, also named catch ratio, $CR(l, \boldsymbol{v})$ between the two pot designs using the following equation:

$$CR(l, \boldsymbol{v}) = \frac{CC(l,\boldsymbol{v})}{(1 - CC(l,\boldsymbol{v}))} \qquad (4)$$

The relative catch efficiency $CR(l, \boldsymbol{v})$ provides a direct relative value of the catch efficiency between test and baseline pots. If the catch efficiency of test and baseline pots is equal, $CR(l, \boldsymbol{v})$ should always be 1.0. $CR(l, \boldsymbol{v}) = 1.5$ would mean that the test pots catch 50% more mud crab with carapace length l compared to the baseline pots. By contrast, $CR(l, \boldsymbol{v}) = 0.8$ would mean that test pots catch only 80% of the mud crab with carapace length l compared to the baseline pots.

The confidence intervals (CIs) for $CC(l, \boldsymbol{v})$ and $CR(l, \boldsymbol{v})$ were estimated using a double bootstrapping method (Herrmann et al., 2017). The bootstrapping method accounts for between- and within pot variability in catch efficiency accounting for uncertainty due to the limited number of crab caught in each pair. However, contrary to the double bootstrapping method (Herrmann et al., 2017), the outer bootstrapping loop used in the current study (accounting for the variability between deployments) was carried out in pairs to take full advantage of the experimental design of deploying test and baseline pots simultaneously (Grimaldo et al., 2019). By using multi-model inference in each bootstrap iteration, the method also accounted for the uncertainty in model selection. We performed 1000 bootstrap repetitions and calculated the Efron 95% (Efron, 1982) confidence limits. To identify the sizes of mud crab with significant differences in catch efficiency between pots, we checked for length classes in which the 95% confidence limits for the catch ratio curve did not contain 1.0 (Herrmann et al., 2017).

The length-integrated average catch ratio ($CR_{average}$) value was estimated directly from the experimental catch data using (Grimaldo et al., 2019):

$$CR_{average} = 100 \times \frac{\sum_{l}\sum_{j=1}^{m}\{nt_{lj}\}}{\sum_{l}\sum_{j=1}^{m}\{nb_{lj}\}} \qquad (5)$$

where the outer summation covers the carapace length classes of the mud crab in the catch during the experimental fishing period. Further, the $CR_{average}$ values were estimated from the experimental catch data for mud crab below ($CR_{average-}$) and above ($CR_{average+}$) length at first sexual maturity (LFM) of 95 mm carapace length. Values for $CR_{average-}$ and $CR_{average+}$ were estimated by using:

$$\begin{aligned} CR_{average-} &= 100 \times \frac{\sum_{l<LFM}\sum_{j=1}^{m}\{nt_{lj}\}}{\sum_{l<LFM}\sum_{j=1}^{m}\{nb_{lj}\}} \\ CR_{average+} &= 100 \times \frac{\sum_{l\geq LFM}\sum_{j=1}^{m}\{nt_{lj}\}}{\sum_{l<\geq LFM}\sum_{j=1}^{m}\{nb_{lj}\}} \end{aligned} \qquad (6)$$

In cases when $CR_{average}$, $CR_{average+}$ or $CR_{average-}$ do not include the value 100% in the CIs, the relative catch efficiency between the two pot types will be significantly different when averaged over all sizes of mud crab or for mud crab below or above the LFM, respectively.

2.3. Quantification of catch composition

To quantify the species composition observed in test and baseline pots, respectively, we used species dominance estimation (Herrmann et al., 2022; Cerbule et al., 2022b; Petetta et al., 2022). This estimate considers all observed species in the catch and measures how much is the dominance of each species in the sample (Maurer & McGill, 2011). Specifically, this shows how the different species are distributed within the catches of test and baseline gear (Cerbule et al., 2022b). In this study, we estimated the catch composition for test and baseline pots separately by estimating the dominance patterns of species observed in our samples averaged over pot deployments. We used cumulative dominance plots to assess the cumulative proportional abundances of the species (i.e., species dominance) (Warwick et al., 2008) and compared between the pots with test and baseline pot entrance.

We first examined the species dominance patterns in catch composition retained by test and baseline pots separately, by (Herrmann et al., 2022; Cerbule et al., 2022b):

$$dn_i = \sum_{j=1}^{m} \left\{ \frac{n_{ij}}{\sum_{i=1}^{Q} \{n_{ij}\}} \right\} \qquad (7)$$

where n_{ij} is the count numbers for each species with i being predefined species ID where n stands for nt or nb when test and baseline pots, respectively, are being investigated. We kept fixed species ranking with mud crab as the target species having species ID 1, which was then followed by the bycatch species. Q represents the total number of species observed and j is the pot deployment. m is number of pairs that have some catch in the specific type of pot (test or baseline).

Further, the cumulative species dominance was estimated (Herrmann et al., 2022; Cerbule et al., 2022b):

$$Dn_I = \sum_{j=1}^{m} \left\{ \frac{\sum_{i=1}^{I} n_{ij}}{\sum_{i=1}^{Q} n_{ij}} \right\} \quad with \quad 1 \leq I \leq Q \qquad (8)$$

In Equation (8), I is the species ID summed up in the nominator (Herrmann et al., 2022; Cerbule et al., 2022b). Following the approach in Herrmann et al. (2022) and Cerbule et al. (2022b), we kept a fixed species ranking for species in all catches in the cumulative dominance curves. This approach allows comparison of the steepness of the cumulative dominance curves, where steeper sections will imply some species being more dominant than other species in the sample while horizontal parts show that the particular species are not abundant (Herrmann et al., 2022; Cerbule et al., 2022b).

We applied the same approach for uncertainty estimation for the observed catch compositions as in Herrmann et al. (2022) and Cerbule et al. (2022b). Specifically, Efron percentile 95% confidence intervals were used to provide the uncertainty of the values of dominance patterns obtained following the procedure described in Herrmann et al. (2022). This procedure enables estimation of the uncertainty around the dominance values induced by the limited sample sizes for the individual deployments for the pairs of pots as well as for the between deployment variation in species dominance. Furthermore, the difference Δd in species dominance d between test (t) and baseline (b) pots was estimated by (Herrmann et al., 2022; Cerbule et al., 2022b):

$$\Delta d = d_t - d_b \qquad (9)$$

CIs for Equation (11) were obtained based on separate bootstrap populations for d_t and d_c similar as in Cerbule et al. (2022b). When inferring for significance, we inspected if the CIs for the difference contained the value 0.0. If 0.0 value was within the CIs, no significant difference was detected (Herrmann et al., 2022; Cerbule et al., 2022b).

3. Results

During the experiment, a total of 69 mud crabs were captured during the 39 paired deployment of the pots, with 11 crabs in the baseline (traditional) and 58 crabs captured in the test (modified entrance) pots (Supplementary material 1). The soaking time ranged from 23 to 25 hours during the trials.

3.1. Catch efficiency of test versus baseline pots

The fit statistics of the catch comparison analysis showed that the *p*-value was 0.3025 (Table 1). Therefore, the fit statistics showed that the model described the experimental data sufficiently well.

Table 1. Catch ratio results ($CR(l)$) (%), and fit statistics observed in pots with two designs. Values in parentheses represent 95% confidence intervals. DOF = degrees of freedom.

Length (cm)	Test vs baseline
4	379.57 (125.38-2519.13)
5	420.26 (140.10-2486.37)
6	461.73 (176.11-2388.08)
7	502.86 (233.91-2113.17)
8	544.02 (253.74-1963.67)
9	587.69 (266.75-2440.03)
10	637.93 (255.37-3202.83)
11	699.28 (267.55-4218.88)
12	774.53 (357.68-7695.04)
13	860.23 (411.90-11488.83)
14	941.94 (380.67-16864.81)
15	996.04 (304.12-25737.08)
$CR_{average}$	622.22 (331.25-1900.00)
$CR_{average-}$ (<95 mm CL)	720.00 (322.22-2500.00)
$CR_{average+}$ (≥95 mm CL)	500.00 (144.44-1800.00)
p-value	0.3025
Deviance	4.85
DOF	4

The carapace lengths of mud crab observed in these experiments ranged from 4 to 15 cm in both pot designs. The results showed that test pots with modified entrance openings using extension had significantly increased catch efficiency of mud crab (Table 1, Fig. 3). Specifically, the test pots captured six times more mud crab on average compared to the baseline pots with standard entrance design ($CR_{average}$ = 622.22 (CI: 331.25-1900.00); Table 1). This difference in catch efficiency was significant for all size of mud crab (Fig. 3) since the catch efficiency was significantly increased for both mud crab above and under the (LFM) of 95 mm carapace length (Table 1).

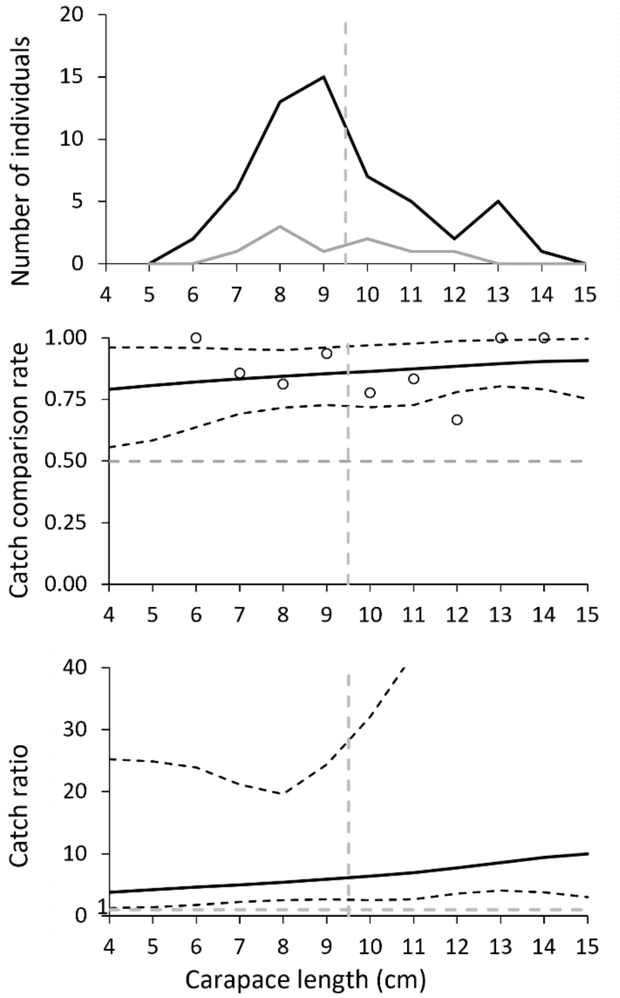

Figure 3. Catch comparison and catch ratio analysis. Upper graph: the length frequency distribution of mud crab captured with test pots with modified entrances (black line) and baseline pots (grey line). Vertical stippled lines show the carapace length at first sexual maturity for mud crab. Middle: the modelled catch comparison rate. Circles represent experimental rate. Bottom: the estimated catch ratio curves. Black stippled lines in both graphs are 95% confidence intervals. The grey stippled lines at 0.5 and 1.0 represent the point at which test and baseline pots would have an equal catch rate.

3.2. Species dominance patterns in catch compositions

During the experimental fishing, a total of six different species were observed as captured by test and baseline pots (Table 2).

Table 2. List of species and corresponding species ID, number of individuals and weight captured during the experiments with baseline pots and test pots with modified entrance.

Species ID	Species name	Common name	Number of individuals		Weight (g)	
			Test	Baseline	Test	Baseline
1	*Scylla serrata*	Mud crab	58	11	7630	2070
2	*Arius maculatus*	Spotted catfish	0	14	0	1200
3	*Macrobranchium rosenbergii*	Giant river prawn	8	5	420	260
4	*Etroplus suratensis*	Pearlspot	0	5	0	390
5	*Etroplus maculatus*	Orange chromid	0	6	0	185
6	*Leptomelanosoma indicum*	Indian threadfish	0	2	0	670

The species dominance values (Table 3) and species cumulative dominance patterns (Fig. 4) showed that the catches by mud crab pots in this fishery is largely dominated by the target species. However, in the baseline pots, catches of five other non-target bycatch fish species were recorded. These species were observed and contributed to the catches to the extent as shown by the dominance values in Table 3. Thus, some species were recorded in only few deployments. Significant differences in dominance values between test and baseline pots were observed for both number of individuals in each species and also when the species dominance values were expressed by weight of observed species (Table 3). Specifically, significantly lower species dominance by spotted catfish, Pearlspot (*Etroplus suratensis*) and orange chromid (*Etroplus maculatus*) were observed when the pot entrance was extended in the test pots. However, the dominance of mud crab was significantly increased from 25.58% (CI: 10.20 – 42.50%) in baseline pots to 87.88% (CI: 77.92 – 96.87%) in the test gear when number of individuals were considered and from 43.35% (CI: 17.57 – 63.24%) to 94.78% (CI: 89.39 – 98.86%) when dominance values were estimated for the weight of the species (Table 3). No significant differences for giant river prawn (*Macrobranchium rosenbergii*) and Indian threadfish (*Leptomelanosoma indicum*) were observed between the two pot designs as the pairwise difference in dominance values included 0.0 within the obtained CIs (Table 3).

Table 3. Species dominance values (in %) for number of individuals and weight of each species in test pots with modified entrance and baseline pots, respectively, and pairwise difference in dominance values (delta) between them. Values in parentheses represent 95% confidence intervals. Significant differences are highlighted in bold.

Species	Dominance values for number of individuals (%)			Dominance values for weight (%)		
ID	Test	Baseline	Delta (test-baseline)	Test	Baseline	Delta (test-baseline)
1	87.88 (77.92 – 96.87)	25.58 (10.20 – 42.50)	**62.30 (41.72 – 80.95)**	94.78 (89.39 – 98.86)	43.35 (17.57 – 63.24)	**51.43 (31.12 – 77.34)**
2	00.00 (00.00 – 00.00)	32.56 (17.39 – 47.50)	**-32.56 (-47.50 – -17.39)**	00.00 (00.00 – 00.00)	25.13 (11.86 – 43.27)	**-25.13 (-43.27 – -11.86)**
3	12.12 (03.12 – 22.08)	11.63 (02.44 – 23.68)	00.49 (-14.76 – 13.96)	05.22 (01.14 – 10.61)	05.44 (01.07 – 12.49)	-00.23 (-08.24 – 06.67)
4	00.00 (00.00 – 00.00)	11.63 (02.33 – 22.50)	**-11.63 (-22.50 – -02.33)**	00.00 (00.00 – 00.00)	08.17 (01.59 – 18.17)	**-08.17 (-18.17 – -01.59)**
5	00.00 (00.00 – 00.00)	13.95 (04.44 – 26.19)	**-13.95 (-26.19 – -04.44)**	00.00 (00.00 – 00.00)	03.87 (01.00 – 09.02)	**-03.87 (-09.02 – -01.00)**
6	00.00 (00.00 – 00.00)	04.65 (00.00 – 12.50)	-04.65 (-12.50 – 00.00)	00.00 (00.00 – 00.00)	14.03 (00.00 – 33.15)	-14.03 (-33.15 – 00.00)

The species cumulative dominance in test and baseline mud crab pots is shown in Figure 4 with horizontal parts of the cumulative dominance curve showing species that were not represented in the samples by the test pots. The catch composition differed significantly between the test and baseline pots (Fig. 4) with significantly less bycatch species observed in pots with extended pot entrance for both, cumulative dominance in number of individuals captured for each species and weight.

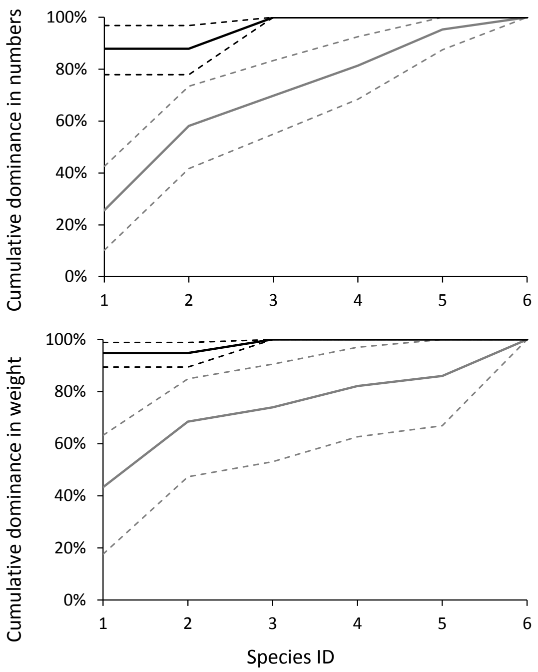

Figure 4. Upper graph: Cumulative dominance in number of individuals captured per species for test pots with modified entrance (black) and baseline pots with standard entrance design (grey). Lower graph: Cumulative dominance in weight per species for pots test (black) and baseline (grey) pot designs.

4. Discussion

The results of this study show that significant improvement in the catch efficiency was achieved by modifying the pot entrance opening design by adding an entrance extension to the baseline mud crab pots. Specifically, the catches of mud crab increased six times when using the test compared to the baseline pot design. In the baseline design, it is speculated that the low catch efficiency can be related to subsequent escape of the crab that enter the gear through the pot entrance. Adding such entrance modification is a simple measure to limit the escape of individuals that have entered the gear and thus captured in the pots.

The incidence of bycatch of different fish species was reduced significantly in the test gear. The catch composition analysis showed that a total of six species were observed in the test pots, four of them contributing to bycatch in this fishery. However, the test pots showed a significantly higher species dominance by the targeted mud crab compared to the baseline pots. The other species observed in the pot catches were species with low commercial value and, therefore, considered as non-target bycatch. The exception is giant river prawn which has a high commercial value in this fishery (about INR 150-400 per prawn depending on the size), and thus provides an additional revenue for fishers (Nair and Salin, 2012). However, no significant difference of giant river prawn in catch composition between the two pot designs was observed.

Earlier studies have shown that modifications in the pot entrance often can significantly alter both size and species selectivity (Bjordal and Furevik, 1988; Li et al., 2006; Salthaug, 2002; Cerbule et al., 2022a). This study provides one example of such case. Crabs have complex behaviour mechanisms and often are forthcoming in exploring crevices and other complex structures (Archdale et al., 2006; Webley et al., 2009). In this study, the pot entrance modification which was an extension attached to the simple horizontal opening in the baseline pot makes it difficult for crabs that had fallen into the pots to escape out of this rather complex entry. Simultaneously, it may be speculated that bycatch fish species has a rather cautious approach to the entry into the pot as observed in other studies (Furevik, 1994; Hirayama et al., 1999). Specifically, the fish species mostly encountered in the estuary were pearlspot, catfishes, and others (Roshni et al., 2021), which do not prefer rock crevices or uneven terrain as their habitat. Therefore, the lower dominance by the bycatch species in this study could be explained by a general avoidance of this relatively complex opening of the test pots.

Therefore, in this multi-species fishery, the pot modification has significantly reduced the total bycatch of fish, with significant increase in the retention of mud crab. These results showing the potential at improving the fishing efficiency in a pot fishery are relevant for the pot fisheries since pots are seen as a sustainable fishing gear worldwide (Suuronen et al., 2012; Petetta et al., 2020, 2021). Thus, studies demonstrating the potential to increase the economic viability of pot fisheries are useful for possible implementation into commercial fisheries. The lower mud crab catch rates in the baseline pot could be explained by the subsequent escapement, since size of the pot is inversely proportional to finding the entrance (Munro, 1974). Since the pots used are comparatively small, escapement would have been higher in the baseline pots. The ingress is also found to vary depending on such factors as the motivation state of the individual (Stoner, 2003) and various environmental conditions (i.e., Stoner et al., 2006). However, the site of the experiment and the timing of operations were the same throughout the study for test and baseline pots; therefore, the environmental factors could not have influenced the results.

However, even though there was significant improvement in the mud crab catch efficiency by the test entrance pots, the carapace length of the crabs captured ranged from 50 mm to 150 mm. Compared to Australian mud crab fishery where strong regulations are in place for commercial and recreational fisheries on the minimum size of the mud crab (150 mm carapace width)

(Apine et al., 2019), no such regulations are present in India. However, the LFM of this species is estimated to be around 95 mm carapace length. Thus, the capture of individuals below this size could further reduce the recruitment of the mud crab and have potential negative consequences for the fishery. This result clearly indicates that even though the species selection was significantly improved by capturing less non-target species in this fishery, the size selection of the test pots is low. While there are no official quantitative data available on changes in the mud crab population in India, the population decline has been detected which is potential related to overexploitation of the species due to large catches of juvenile crab and berried female crabs (Thampi Samraj et al., 2015; Apine et al., 2019). Small mud crabs have less demand and are not preferred for consumption; therefore, they are typically released. Although survival estimates are unavailable, it can be presumed that they survive in the wild, which is another advantage of pot fisheries over other methods.

The baseline pots that are normally used in the fishery are covered with a 35 mm mesh size netting which means that undersized mud crab are not able to utilize the mesh openings in order to escape the gear. Use of larger mesh size in the pot netting or escape vents to allow escapement of undersized individuals that entered the gear can significantly reduce unnecessary catches of small individuals (Butcher et al., 2012). Although use of larger mesh size would be a simple measure for reduction of undersized mud crab in pot catches, use of large meshes would not be accepted in the fishery, which is inherently traditional and due to the fishermen's assumption that significant catch losses would result (Eayrs and Pol, 2018). Increasing the mesh sizes could also lead to smaller fishes in the area gaining access into the pot, and feeding on the bait, which could prove counterproductive or result in need for further pot modifications. In addition, it is reported that in case of fishes, increasing mesh size could have lower attraction when compared to small mesh pots (Luckhurst and Ward, 1985); however, this is not proved in case of mud crab.

Strategically placed escape vents matching the morphology of the mud crab of certain carapace length size could be a viable option to improve size selectivity of such mud crab pots without major changes in the pot design being used by the fishers (i.e., Broadhurst and Millar, 2018). Therefore, this could potentially lead to better adoption of the measure by this specific fishery. Regulations in many pot fisheries now require one or more escape gaps included in pot designs to allow small individuals to escape the gear during pot deployment. Such mechanisms often also include use of degradable materials to prevent continues fishing in cases when the pots are lost, abandoned or discarded (He et al., 2021). Specifically, pots that are abandoned, lost or discarded, especially those that do not have an escape vent, have the potential to continue catching fish and self-baiting for an extended period. In many pot fisheries, biodegradable materials or devices are built into the pot in order to reduce its catching function after it has been abandoned, lost or discarded (He et al., 2021). The dimensions and location and number of the escape vents in each mud crab pots need to be determined by in-situ studies followed by field trials, considering the LFM of the target species and also for eliminating the possibility of smaller fishes feeding on the baits in the pot.

Some precaution needs to be taken regarding the results obtained in this study since they are based on a limited data collection which leads to uncertainty in the estimated catch ratio curve for the mud crab and on the species dominance results. This needs to be considered when making conclusions based on the results obtained. However, these uncertainties are reflected in the confidence bands around the catch ratio and species dominance curves that are provided along with the results. Therefore, as long as these confidence bands are considered when making conclusions, the limited size of the study should not be a major concern. Considering these confidence bands the results obtained demonstrate despite the study size evidence of a considerable improvement in catch efficiency for the targeted mud crab with the new entrance design as well as significant reduction of bycatch dominance in the catch.

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Supplementary material

Supplementary material 1. Number of individuals of each species observed that had been caught in test pots with modified entrance and baseline pots with standard entrance in each deployment. Corresponding weight (in grams) is given in parenthesis. Species IDs: 1 – mud crab; 2 – spotted catfish; 3 – giant river prawn; 4 – Pearlspot; 5 – orange chromid; 6 – Indian threadfish (Table 2).

	Test						Baseline					
Species ID / Deploym.	1	2	3	4	5	6	1	2	3	4	5	6
1	3 (745)	0	0	0	0	0	2 (450)	1 (105)	0	0	0	0
2	1 (115)	0	0	0	0	0	0	0	0	1 (85)	0	0
3	0	0	0	0	0	0	0	0	0	0	1 (20)	0
4	1 (285)	0	0	0	0	0	1 (280)	0	0	0	0	0
5	1 (95)	0	1 (65)	0	0	0	0	0	1 (55)	0	0	0
6	2 (230)	0	0	0	0	0	0	0	0	0	0	0
7	1 (180)	0	0	0	0	0	1 (75)	0	0	0	0	0
8	2 (195)	0	0	0	0	0	2 (255)	0	0	0	1 (40)	0
9	1 (75)	0	0	0	0	0	0	0	0	0	0	0
10	2 (165)	0	0	0	0	0	0	1 (80)	0	1 (65)	0	0
11	1 (75)	0	1 (50)	0	0	0	0	0	0	1 (90)	0	0
12	1 (175)	0	0	0	0	0	0	1 (100)	1 (60)	0	0	0
13	3 (265)	0	0	0	0	0	0	0	0	0	0	1 (350)
14	3 (180)	0	0	0	0	0	0	2 (160)	0	0	0	0
15	0	0	0	0	0	0	0	1 (95)	0	0	0	0

16	1 (360)	0	0	0	0	0	0	0	0	0	0	0
17	1 (175)	0	2 (95)	0	0	0	0	1 (80)	0	0	0	0
18	1 (175)	0	2 (95)	0	0	0	2 (260)	0	0	0	0	0
19	3 (350)	0	0	0	0	0	1 (420)	0	0	0	0	0
20	1 (185)	0	0	0	0	0	0	0	0	0	1 (35)	0
21	2 (225)	0	0	0	0	0	0	0	0	0	1 (30)	0
22	1 (280)	0	0	0	0	0	0	0	0	0	1 (25)	0
23	1 (80)	0	0	0	0	0	1 (75)	0	0	0	0	0
24	1 (125)	0	0	0	0	0	0	1 (105)	1 (45)	0	0	0
25	1 (115)	0	0	0	0	0	0	1 (75)	0	0	0	0
26	1 (95)	0	0	0	0	0	0	0	0	0	0	0
27	1 (155)	0	0	0	0	0	0	0	0	1 (80)	0	0
28	1 (140)	0	0	0	0	0	0	0	1 (60)	0	0	0
29	1 (65)	0	1 (70)	0	0	0	0	0	0	0	0	0
30	1 (50)	0	0	0	0	0	0	0	0	0	0	0
31	2 (155)	0	0	0	0	0	0	1 (65)	0	0	0	0
32	1 (70)	0	0	0	0	0	0	1 (100)	0	0	0	0
33	1 (65)	0	0	0	0	0	0	0	0	0	0	0
34	3 (670)	0	0	0	0	0	0	0	0	0	0	0
35	1 (85)	0	0	0	0	0	0	1 (75)	0	0	0	0
36	0	0	1 (45)	0	0	0	0	0	0	0	0	1 (320)
37	1 (125)	0	0	0	0	0	1 (255)	0	0	0	0	0
38	1 (140)	0	0	0	0	0	0	0	0	1 (70)	0	0
39	3 (415)	0	0	0	0	0	0	0	1 (40)	0	0	0
40	1 (140)	0	0	0	0	0	0	1 (90)	0	0	0	0
41	1 (135)	0	0	0	0	0	0	0	0	0	0	0
42	1 (65)	0	0	0	0	0	0	0	0	0	1 (35)	0
43	0	0	0	0	0	0	0	1 (70)	0	0	0	0

44	2 (210)	0	0	0	0	0	0	0	0	0	0	0
TOTAL	58 (7630)	0	8 (420)	0	0	0	11(2070)	14 (1200)	5 (260)	5 (390)	6 (185)	2 (670)