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Original research article

Gillnet colour affects catch efficiency in pearlspot (*Etroplus suratensis*) tropical estuary fishery

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ABSTRACT

Gillnets are one of the most commonly used fishing gears in both marine and inland waters. Different colour filament nettings are often used in gillnets. However, the effect of gillnet colour on catch efficiency is unclear for most fisheries. Therefore, in this study we investigated the effect of gillnet colour on the catch efficiency in pearlspot (*Etroplus suratensis*) fishery in Vembanad lake, India. Gillnet colours tested were transparent, green and blue. Results showed that in this fishery, the catch efficiency of gillnets of the three colours tested differed significantly. The highest catch efficiency of pearlspot was shown by green gillnets compared to transparent or blue netting. Specifically, green gillnets on average were estimated to be 74% more efficient compared to transparent gillnets. For the green compared to the blue gillnets, the catch efficiency was estimated to be higher by 81%. These results demonstrate that gillnet colour can be an important factor significantly affecting the catch efficiency of this fishing gear.

1. Introduction

Gillnets are efficient and relatively inexpensive fishing gear, which, therefore, is one of the most commonly used gears by commercial and artisanal fishing fleets in all oceanic, estuarine and freshwater environments (Blalbolil et al., 2016; Brandt, 2005; FAO, 2016). Due to the ease of operation, low costs, and easy maintenance, gillnets are most widely used fishing gear in different fisheries (Valdemarsen, 2001), including in estuarine environments by small-scale fishers.

Gillnets are available in several colours and colour intensities (Hanamseth et al., 2018). The choice that fishermen often make in selecting colours and their intensities may be dependent on such factors as costs, availability of the material, netting colour contrast for easier removal of the fish from the net after gear retrieval (Grimaldo et al., 2019), and assumed catch efficiency of the gear (Hanamseth et al., 2018). Specifically, in some fisheries, coloured gillnets are favored over transparent ones, assuming that certain gillnet netting colours are better at reducing the contrast between the gillnets and their background in the water column (Grimaldo et al., 2019). This, therefore, could result in an increase in gillnet catch efficiency since the fish would be less likely to notice the netting before encountering the gear (Cui et al., 1991). On the other hand, for example, the European Union gillnet standard for sampling in freshwater environments recommends gillnets to be light grey in colour (CEN, 2015). The visibility of gillnets with different colours depends on natural light intensities in the water where the fishing takes place (Cui et al., 1991). Some comparative studies using gillnets of different colours and their effect on the catches are reported (Koike et al., 1958; Jester, 1973; Steinberg, 1985; Tweddle & Bodington, 1988; Balik & Çubuk, 2001; Wanner et al., 2010). However, these results are specific for the particular conditions since the visibility of the gillnets depends on different aspects such as the brightness contrast with the background (Fridman, 1973, p. 489), flexibility and thickness of the twine (Hamley, 1975; Pauly, 1991) and on the other characteristic reflection properties of the twine used (Wardle et al., 1991).

A review by Murphy and Westerman (2022) shows that significant variation exist on how organisms perceive and process light signals. Specifically, fish are able to distinguish between colours and lights of various intensities (Hurst, 1953), and several fish species have a broad

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range of spectral sensitivity to light (Douglas and Djamgoz, 1990). Furthermore, many fish species are often being captured into gillnets during peaks of higher activity during dusk and dawn where light intensity is reduced (Prchalová et al., 2010). Many teleost fish also have vision that is adapted for ultraviolet light, making the visual aspects of fish behavior difficult to understand (Losey et al., 1999). Therefore, since the principle of capturing fish in gillnets is based on fish swimming into the deployed gear without noticing, gillnets in some colours may be more efficient compared to the others.

In this study, we collected data from Indian pearlspot (*Etroplus suratensis*) gillnet fishery taking place in Vembanad lake, Kerala to test whether changes in gillnet colour could improve the catch efficiency in this fishery when the gillnets are constructed using netting filaments of particular colour. Pearlspot is an indigenous species which inhabits fresh and brackish water environments in peninsular India (Jhingran & Natarajan, 1969). Studies regarding the major fishing gear used in the Vembanad lake (Ajay, 2021) and Muvattapuzha river (Renjith Kumar et al., 2016), show that gillnets are the major fishing gear type used in fisheries in this area, contributing to more than 80% of the catches in the region. Pearlspot is one of the species with high economic importance and contributes significantly to the fisheries in the area (Roshni et al., 2017). The total catches of pearlspot from the inland waters of Kerala during 2021–22 are estimated to 2137 tonnes, which increased from 1708 tonnes recorded during 2020–21 (Provisional data Govt. of Kerala). For this species, 50% length of maturity (ml) is estimated as 150 mm total length (Talwar & Jhingran, 1991). However, the Government of Kerala has recently implemented a Minimum Legal Size (MLS) of 100 mm for pearlspot in the state to prevent capture of juvenile fish in the estuaries of the state (Gazette, Govt. of Kerala, 2021).

Traditionally the fishers in this region use gillnets with colourless filament netting due to the easy market availability in the region. However, the studies carried out in the Indian waters related to the colour of the netting material and its possible effect on the catches are limited (George et al., 1975; Kunjipalu et al., 1984; Narayanappa et al., 1977; Rao et al., 1980). A recent study conducted by Mohanan et al. (2022) examined the use of different colour gillnets (green, blue and transparent) in the fishery targeting pearlspot. These results, quantified as catch per unit of effort (CPUE) (in weight), indicated that there could be potential differences in catch rates by gillnets of different colours. Specifically, these results found that more pearlspot could be captured by green compared to blue or transparent gillnets (Mohanan et al., 2022). However, CPUE estimates are dependent on abundance and size distribution at time and location where the experiments are conducted and, therefore, cannot be generalized to other fishing situations (Cerbule et al., 2021; Olsen et al., 2019). Further, since a MLS has been introduced in this fishery, the effect of gillnet colour on catch efficiency depending on fish length is important to address. Additionally, the effect of gillnet colour could potentially depend on fish size. Therefore, the results presented in Mohanan et al. (2022) should be followed with investigations that can provide results which are both, independent on absolute pearlspot abundance and population size structure and that are able to provide length dependent estimates of relative catch efficiency for gillnets of different colours. In the present study, we estimated the relative length-dependent catch efficiency of transparent gillnets as traditionally used in pearlspot fishery and compared it to gillnets made of blue and green filament netting to examine whether there were significant differences in catch efficiency between gillnets of these different colours. Earlier studies in different fisheries suggest a potential difference in fishing efficiency of gillnets with different colour netting both in freshwater (i.e., Tweddle & Bodington, 1988; Balik & Çubuk, 2001) and marine (i.e., Kunjipalu et al., 1984; Cui et al., 1991; Gladston et al., 2018) environments. Furthermore, based on earlier results presented in Mohanan et al. (2022) the assumption for this study is that the gillnet colour can significantly effect catch efficiency in Indian pearlspot fishery which could be explained by the optical properties of different colour netting.

Therefore, this study was designed to answer the following questions:

- Can netting colour affect the relative length-dependent catch efficiency in a gillnet fishery?
- Can the optical properties explain differences in the relative catch efficiency between different colour gillnets?
- Can potential differences in mechanical properties such as tensile strength and elongation of break for gillnets of different colours cause variations in catch efficiency?

2. Materials and methods

2.1. Experimental gillnets

During the sea trials, we deployed three fleets of gillnets, each containing three gillnet sheets of different colour. Specifically, the gillnets in each fleet were made of different colour netting, i.e., one gillnet sheet made of blue, green and transparent netting, respectively, based on the initial results obtained by Mohanan et al. (2022) (Fig. 1). The size of each gillnet sheet was 150 m length and 2.5 m depth. All gillnets were made of polyamide monofilament twine of 0.2 mm diameter with mesh sizes of 65 mm (knot to knot). A total of 75 floats (50/20 mm), were attached at an interval of 2 m to the headline made of 4 mm diameter polypropylene rope. The sinkers used were sheathed aluminium wires, which is a common practice among the gillnet fishers in this region to avoid the use of lead sinkers which are relatively costly. During the experiments, the gear characteristics and operational methods were same as practised by fishers using commercial gillnets except for the colour of the netting used (Fig. 1). The craft used for the operations was a wooden canoe (6 m LOA) fitted with a 4.5 HP outboard petrol engine for propulsion. The gillnets were operated at depths ranging from 5 to 12 m in the tropical estuary. The salinity ranged from 3 to 10 ppt during the study.

2.2. Fishing trials and data collection

The fishing trials were conducted during the pre-monsoon season (February–May) 2022 by deploying the gillnets simultaneously and in the same fishing area in Vembanad lake, Kerala (Fig. 2). The Vembanad lake is the second largest brackish water system in South India (Asha et al., 2016). Due to its ecological diversity, the lake is home to a variety of fish species, and a total of 150 species belonging to 56 families have been recorded in the estuary (Ajay et al., 2022; Roshni et al., 2021). Among them, pearlspot and black clam (*Villorita cyprinoids*) are considered two of the most valuable species in this lake and the mouth of the rivers that join the lake (Ajay et al., 2022). The area corresponds to the commercial fishing grounds for pearlspot.

In this study, the gillnet deployment time for the entire fleet was approximately 25–30 min after which the nets were soaked for 6 h (approximately 0500–1100 h). The order of hauling the nets was based on the order of deployment, with first net deployed to be hauled first. The catches from each gillnet were collected and kept separately in different bins, and the total length of each pearlspot was measured to the nearest centimetre below (total length).

2.3. Modelling the length-dependent catch efficiency between gillnets of different colours

The estimations of the absolute catch efficiency (i.e., CPUE) for gillnets of different colours (as, for example, showed in Mohanan et al. (2022)) are dependent on abundance and size distribution at time and location where the experiments are conducted. Therefore, such results cannot be generalized to other fishing situations (Cerbule et al., 2021; Olsen et al., 2019). In contrast, the relative length-dependent catch efficiency provides results that can be generalized to other scenarios with

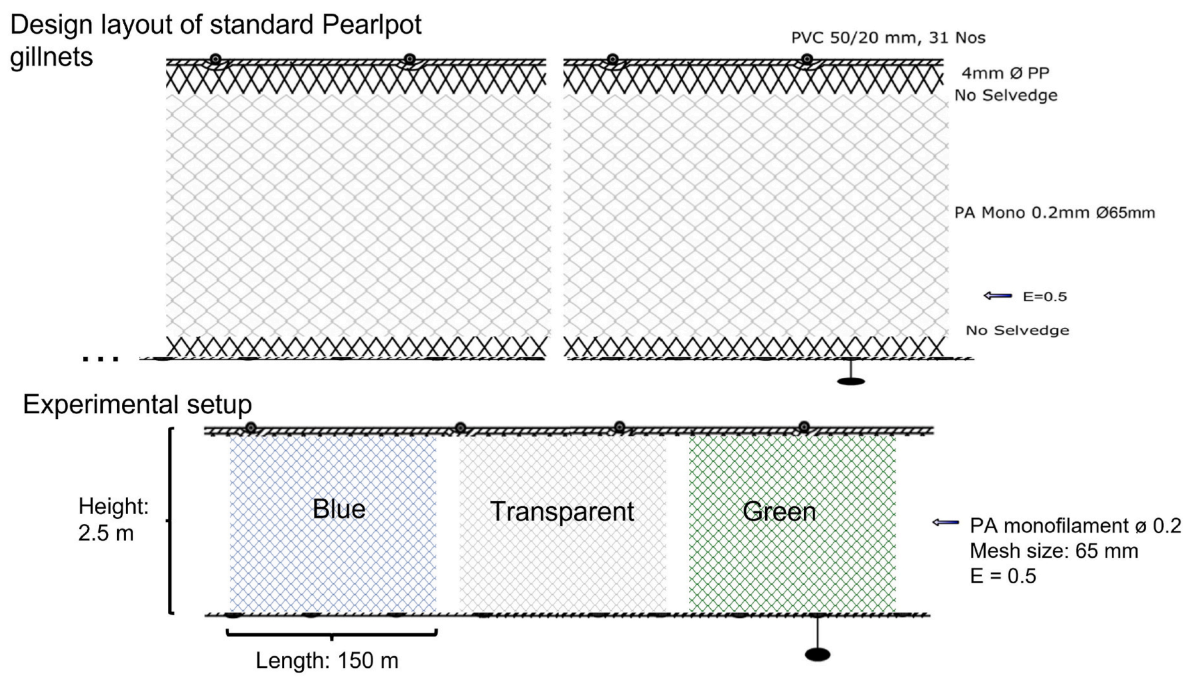

Fig. 1. Design setup for standard pearlspot gillnets (upper image) and experimental setup (lower image) showing one gillnet fleet used during the fishing trials with blue, transparent, and green gillnets. E = hanging ratio.

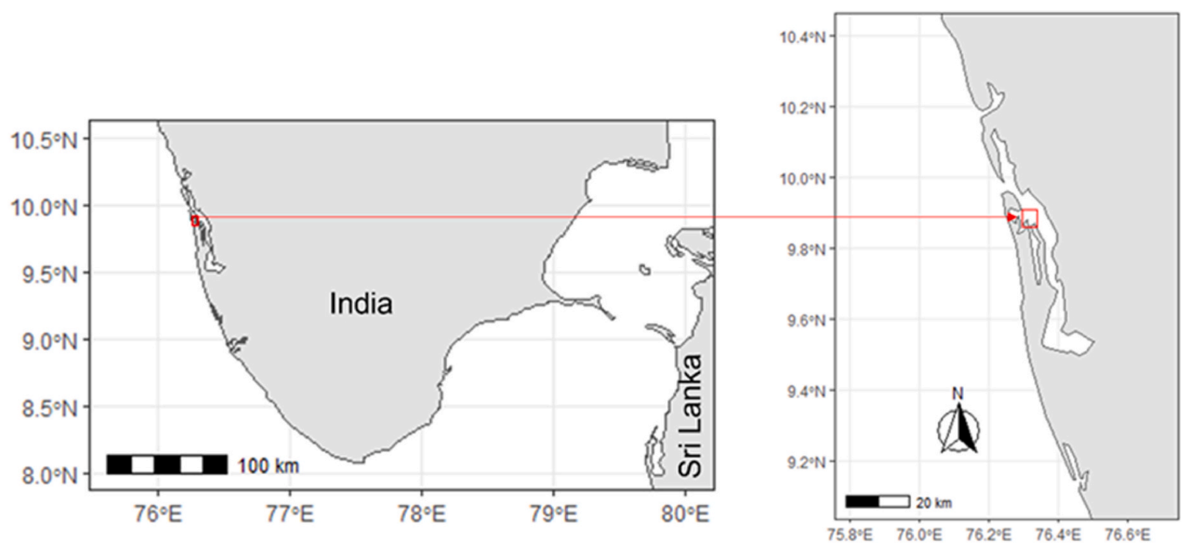

Fig. 2. Map showing the location where the gillnets were deployed during the sea trials in Vembanad lake, Kerala.

different abundance and size distribution of pearlspot which is a considerable advantage of applying this method. In addition, the length-dependent results allows estimation of catch efficiency for different sizes of pearlspot. This provides an additional information, i.e., regarding the catch efficiency of pearlspot below and above the ml of 150 mm or MLS of 100 mm total length which, for example has not been possible when estimating the CPUE in this fishery (Mohanan et al., 2022).

Therefore, in this study we used the relative length-dependent catch efficiency between the gillnets to isolate and quantify the effect of gillnet netting colour. To estimate the relative length-dependent catch efficiency between the three gillnets (transparent, blue and green), they should be deployed simultaneously in the same fishing ground with the same deployment time. Estimation of the relative catch efficiency is a well-established method that has been widely used for comparing catch efficiency of passive fishing gear (for example, Herrmann et al., 2017; Grimaldo et al., 2019; 2020; Cerbule et al., 2021; 2022a; 2022b).

To assess the change in relative length-dependent catch efficiency when changing colour of the gillnet netting from colour *A* to colour *B* (green, blue or transparent, respectively), we used the method described in Herrmann et al. (2017) and compared the catch data for the three different gillnet colours. This was done in three separate analyses: first comparing blue gillnets with green gillnets, second – blue with transparent, and third – green with transparent. The method models the experimental catch comparison rate (CC_l) summed over gillnet deployments for the full deployment period (Grimaldo et al., 2019, 2020):

$$CC_l = \frac{\sum_{i=1}^{h}\{nA_{li}\}}{\sum_{i=1}^{h}\{nA_{li} + nB_{li}\}} \tag{1}$$

where nA_{li} and nB_{li} are the numbers of pearlspot caught in each length class l for the gillnet A (green, blue or transparent) and the gillnet B (green, blue or transparent, respectively) in deployment i. h is the number of deployments carried out. The functional form (the analytical/parametric description) for the length dependent catch comparison rate $CC(l, \boldsymbol{v})$ was obtained using maximum likelihood estimation by minimizing the following expression (Krag et al., 2014):

$$-\sum_{l}\sum_{i=1}^{h}\{nA_{li} \times ln(CC(l,\boldsymbol{v})) + nB_{li} \times ln(1.0 - CC(l,\boldsymbol{v}))\} \tag{2}$$

where $\boldsymbol{v}$ represents the parameters describing the catch comparison curve defined by $CC(l, \boldsymbol{v})$. The outer summation in expression (2) is over length classes l. When the catch efficiency of the gillnets with netting colours A and B is similar, the expected value for the summed catch comparison rate is 0.5. Therefore, this baseline can be applied to judge whether or not there is a difference in catch efficiency between the gillnets with different netting colours. The experimental CC_l was modelled by Grimaldo et al. (2019):

$$CC(l,\boldsymbol{v}) = \frac{exp(g(l, v_0, \ldots, v_m))}{1 + exp(g(l, v_0, \ldots, v_m))} \tag{3}$$

where g is a polynomial of order m with coefficients v_0 to v_m. The values of the parameters $\boldsymbol{v}$ describing $CC(l, \boldsymbol{v})$ were estimated by minimizing expression (2) being equivalent to maximizing the likelihood for obtaining the observed experimental catch data. We considered g of up to an order of 4 with parameters v_0, v_1, v_2, v_3, and v_4 as experience from prior studies (Krag et al., 2015; Santos et al., 2016; Sistiaga et al., 2018) have demonstrated that this provides a model that can sufficiently describe the catch comparison curves between two fishing gears (Lomeli et al., 2021). Leaving out one or more of the parameters $v_0 \ldots v_4$ led to 31 additional models that were also 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 & Anderson, 2002; Grimaldo et al., 2019; Herrmann et al., 2017). Detailed information on how the individual models are weighted in predictions for the combined model can be found in 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 overdispersion (Wileman et al., 1996; Herrmann et al., 2017; Lomeli et al., 2021). Specifically, Lomeli et al. (2021) provides details on how deviance residuals are calculated and used in cases with p-values < 0.05 to examine for overdispersion in data. Based on the estimated catch comparison function $CC(l, \boldsymbol{v})$, we obtained the relative catch efficiency (or catch ratio) $CR(l, \boldsymbol{v})$ between the two gillnet types using the following equation:

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

$CR(l, \boldsymbol{v})$ quantifies the relative catch efficiency between the gillnet with netting colour A and that of the netting colour B. Thus, if the catch efficiency of two compared gillnets with different netting colours is equal, $CR(l, \boldsymbol{v})$ will be 1.0. If the gillnets with colour A catches 50% more fish with length l than the gillnet with netting colour B, $CR(l, \boldsymbol{v})$ will be 1.5. In contrast, a value of 0.8 for $CR(l, \boldsymbol{v})$ would imply that the gillnet with colour A catches only 80% of the pearlspot with length l compared to the gillnet with netting colour B.

The 95% confidence limits 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-deployments variability (uncertainty in the estimation resulting from set deployment variation of catch efficiency in the gillnets and in the spatial-temporal availability of fish) as well as within-deployment variability (uncertainty due to limited amount of fish captured in the individual deployments). 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 gillnets with different netting colours simultaneously. 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 pearlspot with significant differences in catch efficiency between gillent with different netting colours, we checked for length classes in which the 95% confidence limits for the catch ratio curve did not contain 1.0 (Grimaldo et al., 2019).

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

$$CR_{average} = 100 \times \frac{\sum_{l}\sum_{i=1}^{h}\{nA_{li}\}}{\sum_{l}\sum_{i=1}^{h}\{nB_{li}\}} \tag{5}$$

where the outer summation covers the length classes in the catch during the experimental fishing period.

Further, $CR_{average}$ values were estimated from the experimental catch data for individuals below ($CR_{average-}$) and above ($CR_{average+}$) the 50% length of maturity (ml) for this species which is 150 mm total length (Talwar & Jhingran, 1991) and the newly suggested MLS of 100 mm (Gazette, Govt. of Kerala, 2021) by using the following equation:

$$\begin{aligned} CR_{average-} &= 100 \times \frac{\sum_{l<ml}\sum_{i=1}^{h}\{nA_{li}\}}{\sum_{l<ml}\sum_{i=1}^{h}\{nB_{li}\}} \\ CR_{average+} &= 100 \times \frac{\sum_{l\geq ml}\sum_{i=1}^{h}\{nA_{li}\}}{\sum_{l<\geq ml}\sum_{i=1}^{h}\{nB_{li}\}} \end{aligned} \tag{6}$$

2.4. Mechanical properties of the gillnets

To ensure that the potential differences in catch efficiency are related to the gillnet colour and not to differences in the mechanical properties of the netting, we additionally measured the tensile strength and elongation of break of all gillnets. Specifically, the differences in tensile strength and elongation could lead to variations in catch efficiency that is not related to the gillnet colour since such mechanical properties affect when the netting breaks at the point of tension due to the presence of fish. As a result, in such case, fish potentially being able to break the gillnet netting and escape (Cerbule, Herrmann, et al., 2022) resulting in a lower catch efficiency for a particular gillnet that would not be related to the colour of the monofilament. Therefore, we tested the tensile strength and elongation at break of twines used for transparent, blue and green gillnets were performed using a 10 KN universal testing machine (AGIS 10 KN, Schimatzu, Autograph, Japan) equipped with a load cell with 1000 N rated force (N). Ten replications were performed for each type of twine according to the procedure described by the IS 6359 (Bureau of Indian Standards, 2018a) and IS 5815 (Part 4) (Bureau of

Indian Standards, 2018b). Tensile strength was defined as the stress needed to break the twine sample (Grimaldo et al., 2020). Elongation at break was defined as the length of the gillnet twine sample after it had stretched to the breaking point. Elongation is given as a percentage relative to the initial twine length (Grimaldo et al., 2020).

The mean tensile strength S of transparent, blue and green gillnets was estimated from the 10 individual measurements for each. Uncertainties were quantified in terms of Efron 95% confidence limits that were obtained by bootstrapping using 1000 resamples. The same procedure was applied to estimate the mean elongation (E) at break for the three materials.

Further, to estimate the differences in tensile strength (S) and elongation (E) between gillnets A and B with different netting colour, we estimated the percentage difference following the procedure in Brinkhof et al. (2018). By applying this approach, the bootstrap population with 1000 results for the difference was obtained using the 1000 bootstrap results for the mean tensile strength (S) and elongation (E) for individual nettings by using the following equation:

$$relS_i = \frac{SA_i - SB_i}{SB_i} \times 100 \quad i \in [1 \ldots 1000]$$
$$relE_i = \frac{EA_i - EB_i}{EB_i} \times 100 \quad i \in [1 \ldots 1000] \tag{7}$$

where SA_i, EA_i and SB_i, EB_i are the mean tensile strenght and elongation for A and B gillnets, respectively obtained for bootstrap repetition i. Since the samplings for S and E were random and independent for the three gillnet types, it is valid to generate the bootstrap population of results and calculate the Efron 95% CIs for the difference based on (7) using the independently generated bootstrap files for transparent, blue and green gillnets (Brinkhof et al., 2018; Herrmann et al., 2018; Larsen et al., 2018). If the 95% CIs for the percentage effect of tensile strength and relative percentage effect of elongation does not contain 0.0%, there is a significant difference between the two compared gillnets in tensile strength or elongation, respectively (Brinkhof et al., 2018).

The above described estimations were performed in the analysis software SELNET (Herrmann et al., 2012), version date 23 February 2023.

2.5. Estimation of colour absorbance values

To investigate if differences in optical properties between the different coloured gillnets could explain potential differences in catch efficiency values for colour absorbance was measured. Specifically, twines taken from the same gillnets used in the experimental trials were analysed. The samples, which were around 5 mm long, were first sonicated for 5 min in distilled water. After sonication, the samples were removed, wiped dry, and kept in a polythene zip bag until further testing. The materials were chopped into very small pieces of about 2 mm length and submerged in distilled water in the cuvette for examination. The colour absorbance was measured in a 10-cm quartz cuvette against distilled water using a Shimadzu™ double-beam UV-2450 spectrophotometer spanning the spectral range of 200–700 nm at 1-nm resolution.

3. Results

During the experiments, a total of thirty simultaneous deployments of the gillnets were conducted. In total, 185 Pearlspot were caught during 30 gillnet deployments and included in the analysis of this study, with 87, 48, and 50 fish caught in the green, blue and transparent gillnets, respectively (Table 1).

Table 1
Number of Pearlspot caught in gillnets with different netting colours.

Deployment	Number of fish		
	Green	Blue	Transparent
1	2	2	2
2	3	2	2
3	5	2	2
4	2	2	2
5	4	2	3
6	3	3	2
7	2	2	3
8	3	2	1
9	2	2	3
10	3	2	2
11	5	1	4
12	2	3	3
13	3	1	0
14	3	1	0
15	2	2	1
16	2	0	1
17	3	0	1
18	3	0	2
19	3	2	1
20	4	2	1
21	2	1	1
22	3	2	1
23	4	2	2
24	3	2	2
25	2	2	1
26	5	2	1
27	3	1	2
28	1	1	2
29	3	0	0
30	2	2	2
Total	87	48	50

3.1. Catch efficiency between gillnets of different colours

The fit statistics of the catch comparison analysis showed that the p-value was smaller than 0.05 for all three comparisons with transparent, blue and green gillnets (p-value < 0.001; Table 2). However, the modelled catch comparison curve represented the trends in experimental data well in all three cases (Fig. 3). Therefore, the low p-values in these three comparisons were assumed to be due to over-dispersion in the data. To further examine this, the residual plots (Supplemental file 1) were checked. The results from the residual plots supported that low p-values observed here could be caused by the over-dispersion in the experimental data.

The size of the captured fish ranged between 8 and 28 cm total length in all gillnets. There were significant differences in catch efficiency when gillnets of green netting were compared with those made of blue or transparent colour filaments. The catch efficiency with both, blue and transparent gillnets, were lower compared to that of the green gillnets. Specifically, the catch efficiency was increased significantly by 81.3% (Table 2) when green and blue gillnets were compared and by 74.0% (Table 2) when green and transparent gillnets were compared (Table 2, Fig. 3). However, the results did not show significant differences for small individuals (8–11 cm total length) when green and blue and green and transparent gillnets were compared (Table 2). Specifically, the average value for catch ratio for fish below the 50% length of maturity ($CR_{average\text{-}(<150\ mm)}$) did not show significant difference for gillnets of green and transparent colours (Table 2). This was also the case for pearlspot under the MLS of 100 mm ($CR_{average\text{-}(<100\ mm)}$) (Table 2). However, the result was significantly different for large fish (Table 2). This was also the case for comparison between green and blue gillnets (Table 2). Further, when blue and transparent gillnets were compared, the results did not show any significant differences in catch efficiency for any of the length classes of pearlspot (Table 2, Fig. 3).

3.2. Mechanical properties of the gillnets

The average tensile strength of the transparent gillnet was 22.8 N (CI:

Table 2
Catch ratio results (in %) according to length class (cm) and fit statistics for gillnets with different netting colours. Values in parentheses represent 95% confidence intervals. DOF = degrees of freedom. Significant values are marked in bold.

	Catch ratio (%)		
Length (cm)	Green vs blue	Green vs transparent	Blue vs transparent
8	49.9 (4.1–104.9)	126.5 (60.7–274.5)	171.0 (72.0–901.5)
9	59.4 (8.8–111.8)	129.8 (63.5–268.5)	156.3 (70.8–761.6)
10	71.5 (17.8–125.5)	133.6 (68.7–263.1)	141.5 (70.9–559.0)
11	86.7 (35.5–139.9)	137.9 (74.2–256.9)	127.8 (71.4–379.3)
12	105.0 (59.7–163.6)	142.7 (84.5–246.6)	115.9 (68.7–256.7)
13	126.7 (83.2–197.3)	147.9 (95.0–241.4)	106.0 (64.3–194.4)
14	**151.5 (112.5–243.4)**	**153.7 (106.5–231.8)**	98.0 (54.8–155.1)
15	**179.1 (139.4–289.0)**	**159.9 (117.2–223.8)**	91.5 (50.9–133.7)
16	**208.8 (159.0–330.2)**	**166.5 (123.9–227.2)**	86.2 (47.2–125.9)
17	**239.6 (171.7–394.5)**	**173.3 (127.4–244.1)**	82.1 (44.7–125.3)
18	**269.9 (180.8–477.7)**	**180.4 (129.3–275.8)**	78.8 (42.6–126.2)
19	**297.9 (183.2–566.2)**	**187.4 (128.9–315.0)**	76.3 (40.2–133.9)
20	**321.6 (174.8–645.8)**	**194.3 (125.6–350.6)**	74.4 (35.9–145.1)
21	**338.9 (166.2–710.5)**	**200.8 (126.3–377.1)**	73.1 (30.7–168.0)
22	**347.9 (155.8–734.8)**	**206.7 (123.2–404.0)**	72.2 (26.9–214.3)
23	**346.8 (159.0–734.9)**	**211.7 (122.8–437.4)**	71.5 (23.5–332.0)
24	**334.8 (156.6–768.3)**	**215.5 (117.4–504.9)**	71.1 (22.1–417.0)
25	**311.4 (150.5–832.1)**	**217.6 (115.9–709.9)**	70.7 (18.6–645.8)
26	**277.5 (128.4–947.2)**	**217.6 (108.1–897.8)**	70.4 (14.7–1093.4)
27	235.4 (85.8–1341.4)	214.8 (92.8–1388.1)	70.0 (10.9–1615.3)
28	189.5 (0.0–1906.5)	208.9 (71.4–2564.3)	69.5 (7.9–2236.4)
$CR_{average}$	**181.3 (145.8–227.7)**	**174.0 (130.9–226.3)**	96.0 (72.6–125.9)
$CR_{average-}$ (<150 mm)	84.6 (45.8–137.5)	137.5 (62.6–274.1)	162.5 (66.8–360.3)
$CR_{average+}$ (≥150 mm)	**295.5 (189.1–442.3)**	**191.2 (131.7–278.2)**	64.7 (36.0–105.6)
$CR_{average-}$ (<100 mm)	40.0 (0.0–141.9)	100.0 (6.3–264.5)	250.0 (0.0–786.2)
$CR_{average+}$ (≥100 mm)	**197.7 (154.0–257.0)**	**177.1 (142.3–221.7)**	89.6 (69.1–112.8)
p-value	<0.001	<0.001	<0.001
Deviance	37.6	65.6	38.1
DOF	14	14	11

22.2–23.2 N) which was not significantly different from the average tensile strength of the material of green and blue gillnets (Table 3). The average elongation at break was 28.1% (CI: 26.9%–29.3%) for transparent gillnet material and 28.4% (CI: 27.4%–29.8%) and 28.9% (CI: 27.6%–29.9%) for green and blue gillnet materials, respectively (Table 3).

The relative percentage difference in breaking strength and elongation at break ranged between 0.9% and 2.7% when comparing the gillnets used in these experiments. Furthermore, no significant differences in tensile strength and elongation at break were detected when comparing the relative percentage difference between any of the gillnet materials (Table 3).

3.3. Colour absorbance

The absorbance values of green coloured netting were higher compared to the absorbance values recorded for the blue and transparent twines at all wavelengths measured (i.e., from 190 nm to 700 nm) (Fig. 4).

4. Discussion

In this study, we assessed whether change of the gillnet material colour could have an effect on catch efficiency. Specifically, we compared the catch efficiency of transparent, blue and green gillnets in the Indian pearlspot fishery. Our results showed a significant increase in catch efficiency for green gillnets which on average captured 74% more fish compared to transparent gillnets that are normally used in this fishery without affecting the catches of undersized fish (i.e., pearlspot under the ml and MLS). Further, the green colour net was 81% more efficient at capturing pearlspot compared to the blue gillnet. The results regarding mechanical properties of the gillnets used in these experiments showed no significant differences in tensile strength and elongation between the materials of transparent, blue and green nets. Therefore, the observed differences between the compared gillnets regarding the catch efficiency cannot be explained by factors other than the gillnet material colour.

Since the results of this study demonstrate that the catch efficiency in green colour gillnets were significantly higher than the other two nets, this suggests that the green colour netting might be generating a lower contrast under water compared to the other two colours tested. This, therefore, would result in increasing the probability of fish encountering the green coloured gillnets. The constrast produced by the gear against a background is an important factor that affects the visibility of a gillnet, and thereby its capture potential. Our results suggest that the transparent or blue netting did not merge sufficiently well with the surroundings during the deployment compared to the green nets in the slightly turbid waters, where the study was undertaken. These results are consistent with earlier results showing that transparent gillnets were visible at a depth of 10 m and remained so down to 90 m while the green monofilament net was hardly visible (Angelsen & Huse, 1979). Similar results were obtained when visually comparing the nets at the bottom where the green netting was less visible compared to the light netting (Angelsen & Huse, 1979).

The water in the areas where the fishery for the pearlspot is taking place is slightly turbid, due to the movement of water as a result of tidal influence. Furthermore, pearlspot as a bentho-pelagic species (Maitra et al., 2018), is mostly confined to the bottom of the estuary where the water could be more turbid. Therefore, the green netting material would be least visible in such conditions. In this study, we have not used an underwater camera to observe the visibility of the different nets, which could have helped to understand the actual visibility of the different coloured nets in the study area. However, the scanning spectrophotometric analysis of the three gillnet materials showed difference in the absorbance criteria, with green coloured netting having higher absorbance values when compared to the blue and transparent nets. This might explain the difference in capture efficiency observed in this study. Specifically, high light absorptions causes an item to appear darker or opaque to the wavelengths or colours of the incoming wave (Hecht, 2017). Because a substance or object absorbs specific wavelengths or colours of the spectrum, an observer will not perceive these colours in the reflected light. However, if particular wavelengths of colour are reflected from the substance, an observer will see them as well as the material in those colours. With increased absorbance seen in the case of green twines, it can be assumed that the light reflected from green nets would have dissipated considerably faster than that of blue and

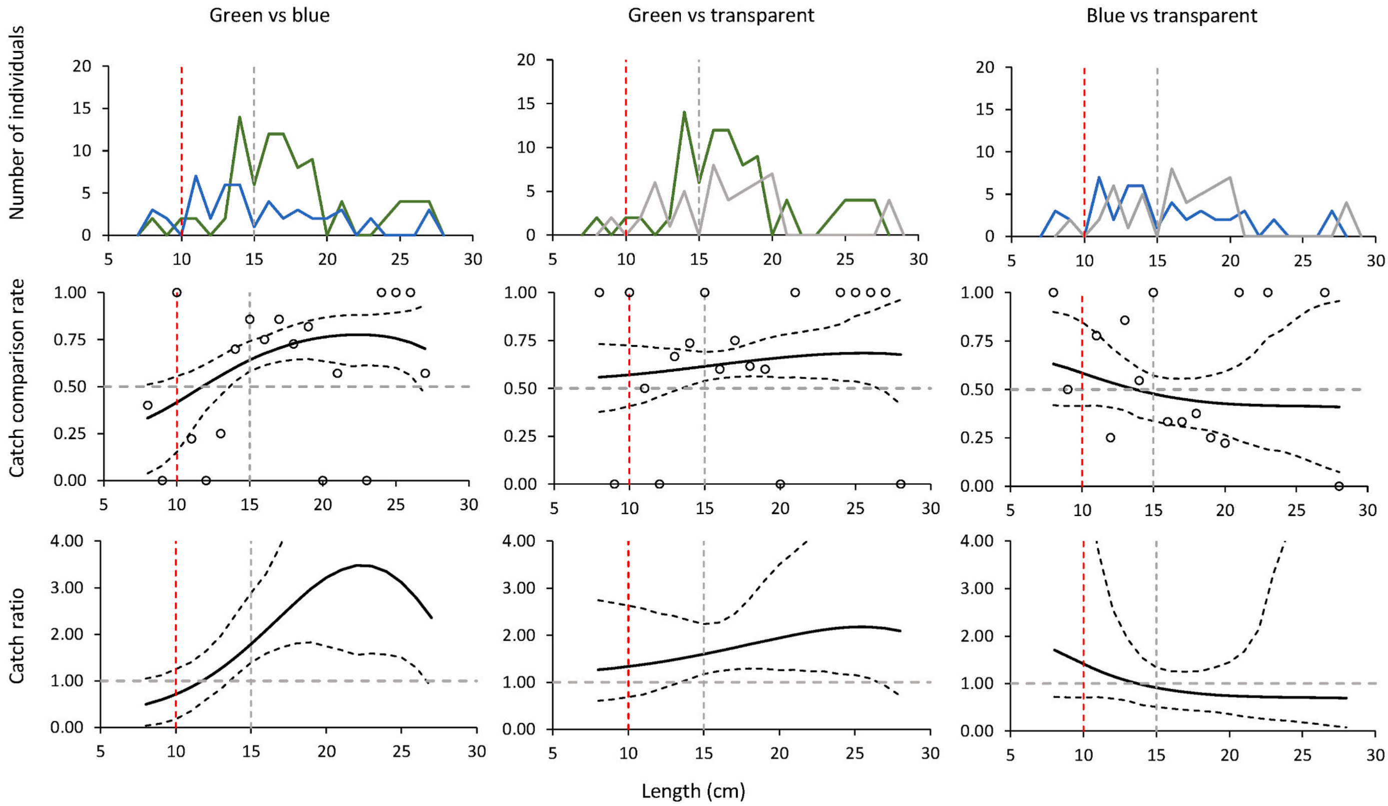

Fig. 3. Size distribution, catch comparison rate and catch ratio for gillnets with different netting colour (from left to right: green vs blue, green vs transparent and blue vs transparent gillnets). Top: size distribution of fish caught with gillnets with different netting colour (line colour representing the netting colour in the experiments). Middle: the modelled catch comparison rate based on all gillnet deployments (black curve) with 95% confidence intervals (black stippled curves). Circles represent the experimental catch comparison rate. Bottom: the estimated catch ratio curve based on all deployments (black curve) with 95% confidence intervals (black stippled curves). The grey stippled horizontal lines at 0.5 and 1.0 represent the baseline at which both types of gillnets fish equally. The grey stippled vertical line at 15 cm represent the 50% length of maturity for this species (Talwar & Jhingran, 1991). The red stippled vertical line at 10 cm represent the new MLS stipulated by the Govt. of Kerala (Gazette, Govt. of Kerala, 2021).

Table 3
Mechanical properties of gillnets with different colours (transparent, green and blue, respectively) with mean values for tensile strength (N) and elongation at break (%), and relative percentage difference in breaking strength and elongation at break (in %). Values in parentheses are 95% confidence intervals.

Gillnet colour	Tensile strength (N)	Elongation at break (%)
Transparent	22.8 (22.3–23.2)	28.1 (26.9–29.2)
Green	22.3 (21.6–22.9)	28.4 (27.4–29.8)
Blue	22.5 (21.9–23.2)	28.9 (27.6–29.9)
Transparent vs green (%)	−02.1 (−05.6 to 01.3)	01.2 (−03.7 to 07.8)
Transparent vs blue (%)	−01.3 (−04.5 to 02.4)	02.7 (−03.3 to 09.0)
Blue vs green (%)	00.9 (−02.9 to 05.1)	−01.4 (−06.4 to 04.6)

transparent netting under slightly turbid circumstances where the experiments were carried out, increasing the probability of fish encountering the green net than the other two nets.

This study demonstrated that changing the colour of gillnet material can significantly increase the catch efficiency for the target species in the specific gillnet fishery. These results are in line with the previous experiments conducted by Mohanan et al. (2022) showing an increase in the absolute catch efficiency when using green compared to transparent nets as commonly used in this fishery or blue gillnets. However, since the study by Mohanan et al. (2022) evaluated catchability of different colour gillnets by using the CPUE (expressed in catch weight) with the associated limitations as explained in this study, these additional experiments provided a more thorough evaluation of length-dependent catch efficiency of different colour gillnets. Therefore, this study demonstrates that there is potential to increase the catch efficiency of target sized individuals (above MLS and ml) in the pearlspot fishery by changing the netting colour used in gillnets from commonly used transparent to green twine. Since the pearlspot is an economically important target species in this region, these results can have considerable implications for this gillnet fishery.

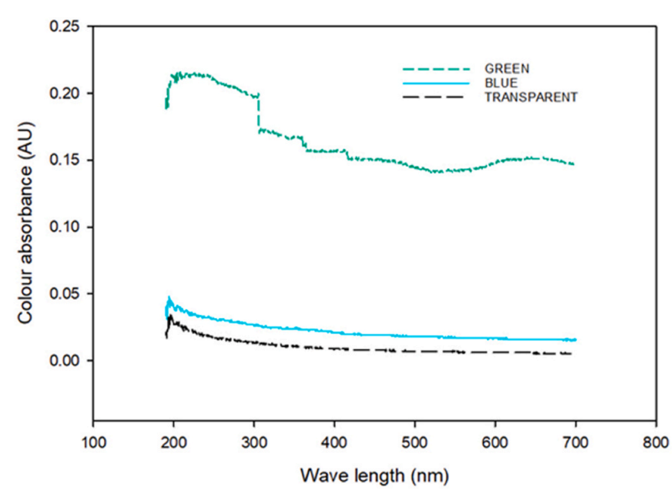

Fig. 4. The absorbance values for the different coloured webbing, studies using UV-VIS spectroscopy.

These highly significant differences observed between gillnets suggest that further assessments of gillnet colour could provide an additional information about the catch efficiency of the gear also in other gillnet fisheries. However, such changes by making gillnets more invisible might affect the catch efficiency not only for the target species but also for the bycatch species which has to be considered in further studies. Last but not least, the use of different netting colours might contribute at explaining differences observed between gillnets when comparing other gillnet parameters, such as mesh size, number of filaments or material type. Therefore, understanding how the colour of the material can impact the gillnet capture effectiveness can be vital. Alternatively, information on how the colour affect the catch efficiency can be applied when designing the gillnets from a material with an increased twine diameter in fishing gear which thus can result in higher visibility of the material. Increased thickness has the potential to decrease the gillnet flexibility (Prchalová et al., 2009); however, increasing the tensile strength and elongation at break of the twine. One such instance is when the diameter of the twine material is increased in order to use new biodegradable materials in fishing gear to prevent plastic pollution and continued fishing caused by lost, abandoned, or discarded non-biodegradable materials (i.e., nylon) fishing gear (Grimaldo et al., 2019; 2020; Cerbule, Gerimaldo, et al., 2022; Cerbule, Herrmann, et al., 2022; Cerbule, Savina, et al., 2022). Gillnets made of the biodegradable material in earlier trials have showed a reduced catch efficiency, probably due to the differences in mechanical properties (Cerbule, Herrmann, et al., 2022). Therefore, in some studies, materials with larger twine diameters are tested to compensate for these differences in mechanical properties (i.e., Cerbule, Grimaldo, et al., 2022). However, it is observed that thicker twines can potentially affect the visibility of the gear to the fish (Herrmann et al., 2017). Therefore, knowledge regarding the effect of colour on catch efficiency is indeed relevant in fisheries where gear invisibility to the target species is desired. Furthermore, such information can also be applied in fisheries using other fishing gear types such as trammel nets and longlines.

The results in our study should be interpreted with caution as they are based on a limited number of gillnet sheets, limited number of deployments and fish captured during one fishing season. However, the time of the year and the area in which the experiments were conducted represent typical conditions for the commercial pearlspot gillnet fishery. Therefore, we consider that our results are representative of a comparable gillnet fishery in the region.

Ethics statement

The authors confirm that the ethical policies of the journal, as noted in the author guidelines page for Aquaculture and Fisheries, have been adhered to. No ethical approval was required for this study as the dataset used for this article consisted of field samples that were collected following a commercial fishing practice in accordance with the local legislation and institutional requirements. No other authorization or ethics board approval was required to conduct this study. The captured animals were not exposed to any additional stress other than that involved in commercial fishing practices, and no further direct or indirect manipulation with fish or other animals were conducted during the trials. Therefore, no information on animal welfare or on steps taken to mitigate fish suffering and methods of sacrifice is provided. This study did not involve endangered or protected species.

CRediT authorship contribution statement

Kristine Cerbule: Conceptualization, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **V.R. Madhu:** Conceptualization, data gathering and, Investigation, Writing – original draft, Writing – review & editing. **Salini Mohanan:** Data gathering and, Investigation, Writing – original draft. **Bent Herrmann:** Conceptualization, Software, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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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.2023.09.002.

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