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Illuminating square meshed panels with white-coloured LED ropes to stimulate escape of undersized fish in beam trawl fisheries

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ABSTRACT

The Belgian beam trawl mixed-species fishery is associated with high bycatch and discard rates. Research on the effects of Square Mesh Panels (SMPs) and artificial light to improve the size selectivity of demersal trawls are relevant for ecosystem health as well as compliance with minimum conservation reference size (MCRS) requirements. This study was conducted as comparative fishing trials during five fishing campaigns in different areas. The influence of artificial illumination on the escape rates of undersized species was tested by placing white-coloured LED ropes on either a square mesh discard release panel (DRP) in the back of the net or a square mesh benthic release panel (BRP) in the belly of the net with a mesh size of 180 mm. Results showed that commonly discarded undersized European plaice (*Pleuronectes platessa*), escaped significantly more frequently through illuminated SMPs than through reference SMPs. The highest reduction was achieved in the clear waters of the Belgian part of the North Sea (BPNS) during daytime, where only 34 % of undersized plaice were found in the illuminated gear and 66 % in the reference gear. Cover codend catches showed that plaice mainly escaped through the BRP either when the BRP or the DRP were illuminated with LED ropes. Although the effect of a LED-DRP and a LED-BRP were evaluated on different fishing trials, the results suggest a greater reduction of undersized plaice when using a LED-BRP. In this study, no significant differences in catches of the other species were observed when SMPs were illuminated. This research shows that the use of LED rope as a Bycatch Reduction Light (BRL) offers opportunities to reduce bycatch of plaice in beam trawling, a mixed-species fishery where the options for reducing bycatch are otherwise very limited.

1. Introduction

The beam trawl fishery is a mixed species fishing method that is very efficient for catching flatfish (Van Marlen, 2003). The vessels tow paired trawls fixed to rigid beams (Revill et al., 2013) which make direct physical contact with the seabed to ensure adequate capture rates of different target species (Van Marlen, 2003). Belgian fisheries have been predominantly using beam trawls since the 1960s. During the last decade a slow but steady diversification has started, but beam trawl is still the main fishing technique used in the Belgian fishery (Lenoir et al., 2023). The Belgian beam trawlers mainly target common sole (*Solea solea*), representing 43 % of the landing value, followed by cephalopods and plaice (*Pleuronectes platessa*), representing 10 % and 8 % of commercial landing values, respectively (Scherrens, 2023). Effects of beam trawls on the marine environment are reductions in biomass, production and diversity of benthic fish and benthic communities. In addition, beam trawls are associated with considerable bycatch and discard rates due to their poor selectivity (Soetaert et al., 2016). In 2013, the European Parliament and the Council on the Common Fisheries Policy (CFP) adopted the Regulation (EU) No 1380/2013, which introduced a landing obligation (commonly referred to as the “discard ban”) by requiring the landing of all fish subject to quota that does not fall under the “high survival” exemption, regardless of size (European Union, 2013).

The aim of this directive is to stimulate commercial fisheries to generate technical solutions for more selective fishing and eventually phase out discards in European fisheries (Santos et al., 2016). Despite the current challenges regarding implementation of the landing obligation, this policy measure shows potential to become an efficient measure for eliminating or reducing bycatch (NSAC, 2023). Reducing discards of total allowable catch (TAC) species below minimum

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conservation reference size (MCRS) remains an important goal in Belgian beam trawl fisheries.

Historically, the selective properties of beam trawls have been adapted by altering the size selection in the codend, either by changing the codend mesh size or the mesh geometry (Glass, 2000; Brčić et al., 2016). For example, in the Belgian beam trawl fishery targeting common sole the codend minimum mesh size (80 mm) was adapted to the 50 % retention length of sole (MCRS of 24 cm), but this mesh size still has poor selectivity for co-occurring species.

In recent years, considerable research has been done on enhancing the selectivity of fishing gears to avoid the capture of unwanted fish, notably by either developing alternative fishing methods or through technical modifications other than altering codend mesh sizes (Soetaert et al., 2016). Many trawl bycatch reduction devices (BRDs), such as separator grids, guiding panels, square-mesh panels (SMPs), capture avoidance designs and codend modifications have been developed and studied (Melli et al., 2019). Square-mesh panels can be positioned on either the lower panel of the net (Benthic Release Panel (BRP)) or on the upper panel of the net (Discard Release Panel (DRP)). According to Fonteyne and Polet, (2002), SMPs fitted to the aft belly of a beam trawl successfully release benthic organisms, such as crustaceans, echinoderms, bivalves, gastropods and other benthic species and fish that

Table 1
Overview of the different trial details, experimental design and summary of mean (± SD) of the key technical and environmental variables collected aboard the R/V Belgica during the comparative fishing trials. The number of fish catches per investigated species and trial are also reported.

	TRIP 1	TRIP 2	TRIP 3	TRIP 4	TRIP 5
Date	Dec 2019	Feb 2020	Oct 2020	Dec 2020	Feb 2021
Number of successful hauls	17	29	30	23	22
Average gear deployment duration (min)	88.24 (± 23.53)	84.31 (± 16.68)	80.07 (± 16.66)	84.65 (± 16.39)	66.27 (± 25.70)
Experimental design	LED - BRP	LED - BRP	LED - BRP + DRP	LED - DRP + BRP	LED - BRP
Panel cover position	-	-	DRP	DRP	BRP
Location	Southeast UK	English Channel Southeast UK	English Channel North Sea Southeast UK	English Channel North Sea	North Sea
Mean depth (m)	-	-	41.2 (± 8.64) - 25.9 (± 5.92)	37.3 (± 4.15) 35.1 (± 4.63)	31.0 (± 6.12)
Mean seawater temperature (°C)	-	-	16.7 (± 0.07) - 15.5 (± 0.39)	12.8 (± 0.39) 12.3 (± 0.07)	8.02 (± 0.34)
Mean turbidity levels (NTU)	-	-	16.0 (± 1.69) - 57.2 (± 23.7)	21.3 (± 3.90) 18.1 (± 1.02)	19.5 (± 7.67)
Investigated species					
Limanda limanda					
Number in Standard codend	212	930	335	97	2070
Number in Experimental codend	199	934	359	101	1791
Number in Standard panel cover codend	-	-	118	7	2695
Number in Experimental panel cover codend	-	-	102	8	4842
Total	411	1864	914	213	11398
Solea solea					
Number in Standard codend	784	676	1251	219	200
Number in Experimental codend	825	683	1111	170	168
Number in Standard panel cover codend	-	-	213	13	524
Number in Experimental panel cover codend	-	-	232	8	661
Total	1609	1359	2807	410	1553
Pleuronectes platessa					
Number in Standard codend	325	7679	2716	5144	2353
Number in Experimental codend	358	6096	1566	4505	1602
Number in Standard panel cover codend	-	-	78	153	1860
Number in Experimental panel cover codend	-	-	75	94	3211
Total	683	13775	4435	9896	9026
Trisopterus luscus					
Number in Standard codend	508	447	606	578	56
Number in Experimental codend	500	385	589	608	50
Number in Standard panel cover codend	-	-	32	216	58
Number in Experimental panel cover codend	-	-	20	157	131
Total	1008	832	1247	1559	295
Merlangius merlangus					
Number in Standard codend	637	962	525	183	565
Number in Experimental codend	625	919	538	184	548
Number in Standard panel cover codend	-	-	147	70	387
Number in Experimental panel cover codend	-	-	177	67	712
Total	1262	1881	1387	504	2212
Chelidonichthys spp					
Number in Standard codend	0	216	114	645	42
Number in Experimental codend	3	191	73	533	44
Number in Standard panel cover codend	-	-	7	45	105
Number in Experimental panel cover codend	-	-	4	14	87
Total	3	407	198	1237	278

would otherwise show high discard mortality rates. Another BRD that has recently received increasing attention is artificial light (Bycatch Reduction Light (BRL); Yochum et al., 2024). Artificial light can induce a positive or negative phototactic response or enhance the visual perception of gear components (Yochum et al., 2024). Previous studies showed the potential to influence catch composition in bottom trawl fisheries by combining LED lights with BRDs. LED lights can significantly reduce release efficiency of blue whiting (Cuende et al., 2020), trigger evasion response in haddock (Grimaldo et al., 2018) or influence the behaviour of cod, whiting, haddock, lemon sole, plaice and *Nephrops* (Melli et al., 2018). An extensive summary of studies evaluating BRLs in bottom trawls was recently published by Yochum et al. (2024).

The objective of the current study was to investigate whether LEDs fitted on SMPs of a beam trawl net could increase the selective properties of those SMPs by further reducing the bycatch of undersized commercial species while maintaining commercial catch levels. An experimental study was performed, where comparative fishing trials were used to test nets equipped with and without artificial light. We looked at the length distribution of catches in these paired trawl experiments and studied the escape rate through the SMPs using panel cover codends. We also identified whether the light interacted with other variables, such as environmental, biological and technical factors.

2. Material and methods

2.1. Data collection

Sea trials were carried out on board the R.V. BELGICA (50.9 m L.O.A., 1154 kW) from 2019 to 2021. A complete overview of the different sea trials is shown in Table 1. Fishing grounds were located in the Belgian Part of the North Sea (BPNS), the outer Thames Estuary (TE) and the Eastern English Channel (EEC) (Fig. 1). Five fishing trials were performed, each lasting three to five days. The number of hauls varied between 17 and 30 hauls per trial. Tow durations varied from 15 to 127 minutes with an average of 88 minutes. To account for the influence of time of day and light availability on flatfish catch rates (De Groot, 1971; Rijnsdorp et al., 2000), hauls were conducted during day- and nighttime. Hauls conducted completely(shoot until haul) before sunrise and after sunset were categorized as night hauls, hauls conducted at least partially between sunrise and sunset were categorized as day hauls.

2.2. Fishing gear

Unlike commercial beam trawlers, the R.V. BELGICA is not equipped

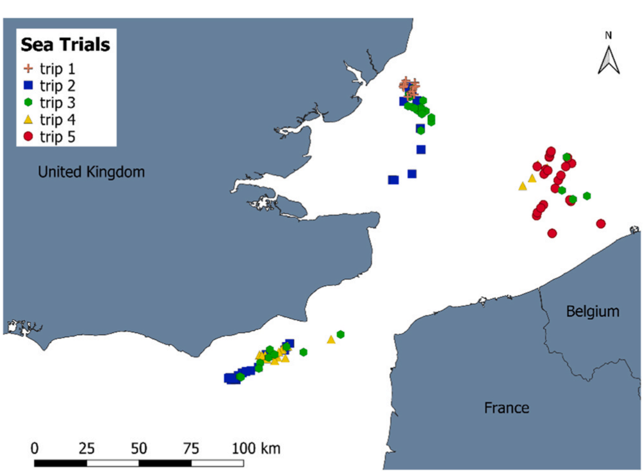

Fig. 1. Map of the fishing grounds where sea trials were conducted. The symbols represent the trawl locations by campaigns. Map developed using QGIS software (3.14.16-Pi version).

with derrick booms for towing two separate beam trawls simultaneously. To enable simultaneous fishing with a standard and an experimental net (Fig. 2), two 4 m nets were attached next to each other on an 8 m beam, with an extra trawl head in the middle. Trials were performed with rectangular chain mats. Both nets were constructed in polyethylene (PE) netting with diamond shaped meshes of 120 mm mesh size. The codends were constructed of PE netting with a mesh size of 81 $\pm$ 3 mm, corresponding to the codend minimum mesh size of the beam trawl fishery (Bayse et al., 2016). Both nets were equipped with a square meshed BRP made of single braided polyethylene (Fig. 3A), measuring 1.20 $\times$ 1.80 m with a mesh size of 178 $\pm$ 5 mm, positioned at a distance of 10 meshes (1.20 m) in front of the codend. In addition to the BRPs, we equipped both nets with DRPs in the same material and of the same dimensions as the BRPs on fishing trial 3 and 4. The DRPs were inserted in the back of the net, at a distance of 10 meshes in front of the codend, immediately above the BRPs (Fig. 2).

During three trials, a panel cover codend made of diamond shaped meshes with a mesh size of 48 $\pm$ 3 mm (Fig. 2) was placed on either the DRP or BRP of both nets (Table 1). This setup allowed us to quantify the escape rate of fish and analyse their length and numbers during each experiment. The panel cover codends provided insights into the behaviour of the different species towards light and the SMP.

The mesh size of the panels and cod-ends was determined at the end of each sea trial with an omega mesh gauge, following the protocol described by Fonteyne (2005). Fishing gear was checked for damage after each haul.

2.3. BRL properties

To test the effect of artificial light, a flat 10 m LED strip (12 VDC; 9,6 W; 1020 lm; 120 LEDs/m; IP20) emitting a white colour (4000 K) was fitted inside a transparent plastic water hose with a diameter of 2 cm. The water hose was filled with paraffin oil to avoid compression due to pressure (Fig. 3B). The LED rope was attached to either the BRP or the DRP (Table 1) of both the starboard and portside net and connected to a battery pack installed on the net near the headrope (Fig. 3B and C).

The LED ropes were alternately turned on (at least every 3 hauls) on the starboard and port side to eliminate possible side-specific effects of the beam trawl nets. The BRP and DRP were located at 15 m behind the beam, so it is safe to assume that the artificial light did not affect the catch entering the control net. We also assume that the LED rope did not influence fish behaviour around the BRP and DRP in the control net due to the very high amount of suspended material at this location in the net.

Because little is known about the spectral sensitivity to which the different bycatch animals have maximum spectral sensitivity, trials were conducted with white light, covering a broad range of wavelengths to maximize detection. The normalised spectral irradiance of the LED rope fitted in the water hose with paraffin oil was measured with a spectroradiometer (JETI specbos 1211–2) in a dark room. The light energy emitted by the LED rope covers a broad range of wavelengths with a first narrow peak of blue light at 453 nm, which is expected to be in the range of the peak wavelength of the inhabited environment. The light energy furthermore shows a second lower and broader peak of orange light (around 600 nm) (Fig. 4).

2.4. Environmental data

Knowledge of the environmental conditions in which an animal experiences the BRL is important for interpreting the results (ICES, 2018; Yochum et al., 2024). Environmental variables were therefore recorded during the third, fourth and fifth trial using a Wisens TBD data logger measuring turbidity, pressure and temperature. The data logger was placed on top of the headrope of the beam trawl. Measurements from the TBD data logger were taken once per minute of the haul then aggregated per haul over the entire period that the net was in contact with the sea floor.

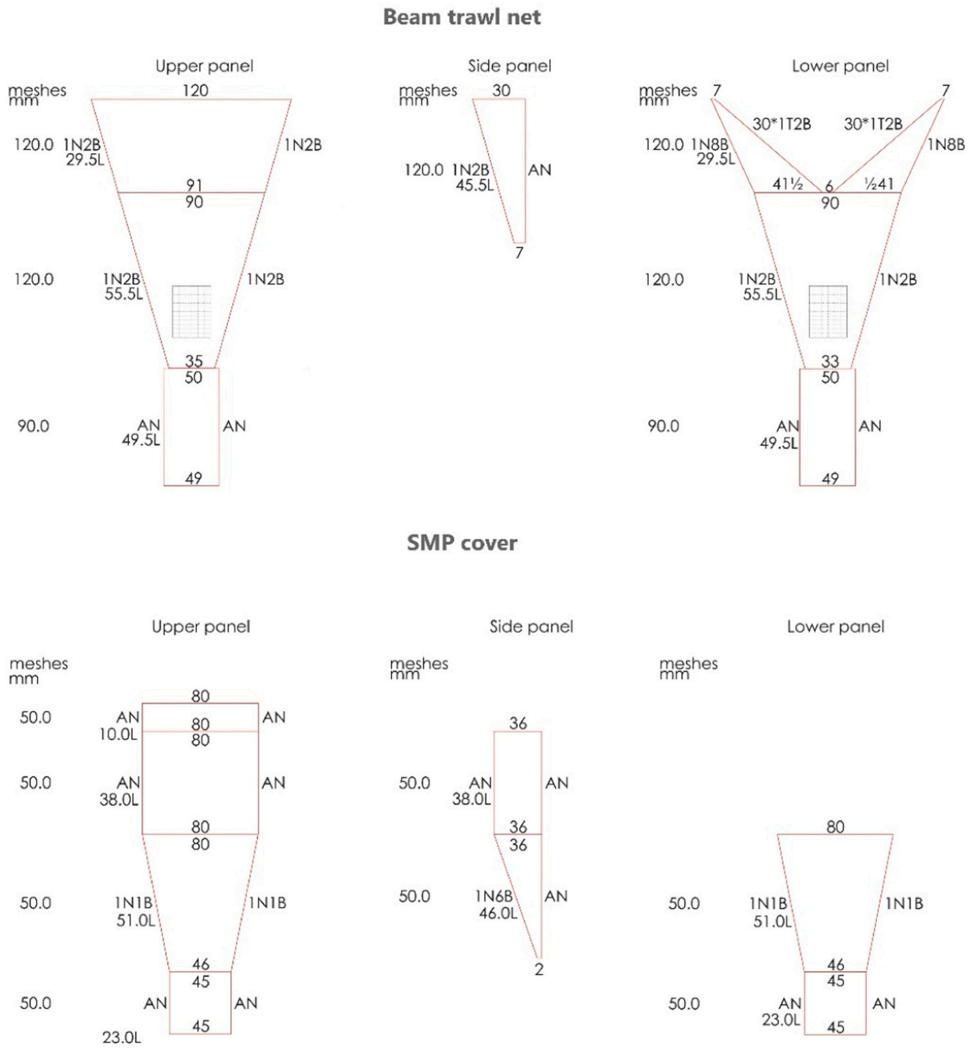

Fig. 2. Net drawing of the beam trawl net (top) and panel cover (bottom) used in this study. The two nets were identical with the SMPs placed in the exact same area of the net, either in the upper panel (DRP), lower panel (BRP), or both. Panel cover codends were placed on either the DRP or BRP of both nets. Stretched length of the meshes (mm), number of meshes in width and cutting rate are indicated for each part of the net.

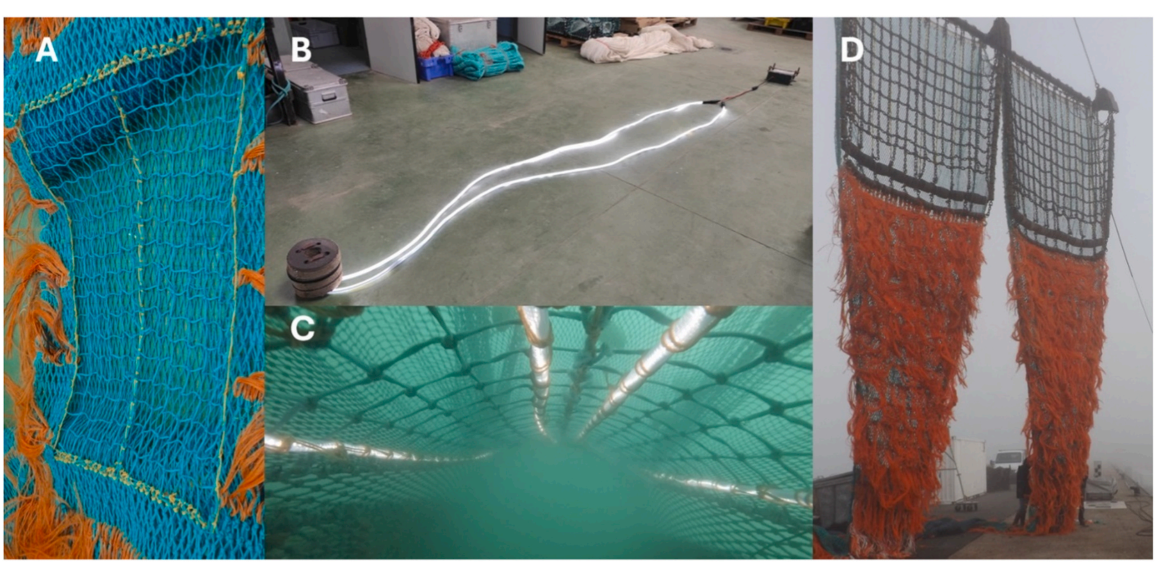

Fig. 3. Picture of the BRP (A), the LED rope with battery pack (B), the LED rope attached to the DRP (C) and two 4 m nets attached next to each other to an 8 m beam (D).

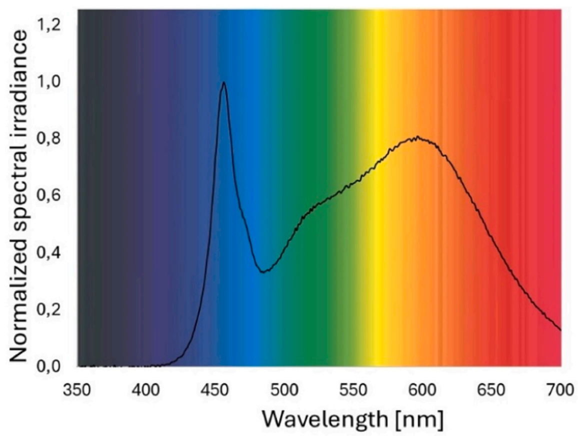

Fig. 4. The normalised spectral irradiance measured with a spetroradiometer JETI specbos 1211–2 (right).

2.5. Catch sampling

Once the nets were hauled on board, the catches of the starboard and portside codends and cover codends were analysed separately. All commercial fish species were sorted, counted and measured to the nearest mm. If more than 150 fish of the same species were present in one catch fraction, 150 were measured and the remainder were counted and used to raise the number of this species at each length (raised number at length = measured number at length*(measured in total + counted in total)/measured in total). All the fish were weighed by species. After measurement, all caught fish were thrown back into the sea as soon as possible.

2.6. Video recordings

In preparation of the fishing trials, underwater video recordings were made with GoPro Hero 4 cameras on board of the R.V. Simon Stevin (36 m L.O.A., 1040 kW). The cameras were mounted at different positions of the net to evaluate functioning of the LED ropes, the position of the of the cover codends and the possible effect on the release efficiency of bycatch through the SMPs.

2.7. Statistical analysis

We selected six commercial fish species, each with at least 1500 individuals caught in total and - except for gurnard - at least 150 individuals present in each trial. All the statistical analyses were performed using R, version 2021.09.1, Build 372.

To assess whether the catch efficiency for the different species at length (to the nearest cm) was different in the experimental net compared to the reference net we performed a comparison analyses of paired hauls with the R package "selfisher" (Brooks et al., 2022). Hauls nested within trips were considered as random effects. We tested different models using both polynomials and splines. The best fitting model for each species was selected based on the Akaike Information Criterion (AIC). This method was performed on the catches of both main codends and panel cover codends. Model output resulted in a continuous curve with a 95 % confidence band, where a catch ratio of 1 indicates equal catches in both codends, values above 1 indicate higher catches in the experimental codends.

To evaluate the effect of light on the number of fish from each species, GLMMs were performed using a logistic regression with logit link. The response variable was the catch of each species as a number of individuals, with fixed covariates landing category (legally sized/undersized), daytime (night/day) and location (BPNS/TE/EEC) and all relevant 2-way interactions. Trial and haul numbers were considered as random effects. The model was fitted using the 'glmer' function of the 'lme4' package. Data from sea trials with a LED-BRP (trials 1, 2, 3 and 5) were analysed separately from the trial with a LED-DRP (trial 4). Least square mean values of 0.5 indicate no effect of the LED rope, values above 0.5 indicate higher catches in the net with the LED rope. For each species, non-significant interactions were removed from the final model. In the model for plaice, the significant interactions "location*landing" category and "daytime* landing" category were retained. We found no significant interactions for the other species and did not retain them in the final models.

Turbidity, depth and temperature were only measured on trial 3, 4 and 5 (Table 1). All three of these variables showed strong correlation with the trials and fishing locations, thus their inclusion in the model was not recommended.

3. Results

Underwater video recordings showed that the cover codends did not block the meshes of the SMPs and that the LED ropes functioned properly (Fig. 3C).

Six species were selected for investigation: common dab (*Limanda limanda*), common sole (*Solea solea*), European plaice (*Pleuronectes platessa*), pouting (*Trisopterus luscus*), whiting (*Merlangius merlangus*) and gurnard (*Chelidonichthys lucerne* and *Eutrigla gurnardus* were pooled during processing on board). Plaice had the highest catch numbers (Table 1). The proportion and length frequency distributions of the different species caught in the codends of the trials that compared the LED-BRP net (experimental net) with the BRP net (reference net) are represented in Fig. 5. The experimental net caught significantly less undersized plaice (less than 27 cm length). The largest differences were observed for the smallest individuals while no significant difference was found for the legally sized individuals (27 cm and larger). It is noted that the increasing catch difference with size suggested by the model for the largest plaice, is based on a low number of individuals and is not significant. No significant differences were found for the five other species. The trial with the LED-DRP showed similar results, being the increased escape rate of only undersized plaice due to the presence of the LED rope.

To infer the behaviour of the different species towards light and the SMPs, small mesh cover codends were used in three sea trials. Catches of plaice in the cover codends are represented in Fig. 6, together with the catches in the main codends of the corresponding sea trials. No commercial plaice was lost through the either the illuminated or the reference SMPs during these experiments. It is noted that the mesh size of the cover codends was smaller than the mesh size of the main codends; therefore, the smallest plaice that were retained in the cover codends could therefore also have escaped through the main codends if no SMPs had been present. DRP cover codends contained only small amounts of plaice compared to the main codends in both the trial with the LED-BRP and the trial with the LED-DRP. The DRP cover codends of the illuminated nets contained less plaice than the DRP cover codends of the reference net. The BRP cover codends contained high numbers of undersized plaice, with the cover codend of the illuminated nets containing significantly more plaice than those of the reference net (63 % in the LED-DRP cover codend and 37 % in the reference cover codend on average). No significant effects were observed for the five other species.

The effect of the LED rope in a BRP on the catches of plaice depended significantly on landing category, location and day- vs. nighttime. Least-square means of the final GLMMs are represented in Fig. 7. The effect of the LED rope on bycatch was largest during daytime in the BPNS, where only 34 % of the undersized plaice was found in the illuminated net. In the turbid waters of the Thames Estuary, the LED-BRP did not influence the catches. The reduction in bycatch was always larger during daytime compared to nighttime. The GLMM showed no effect of light on catches of any other species.

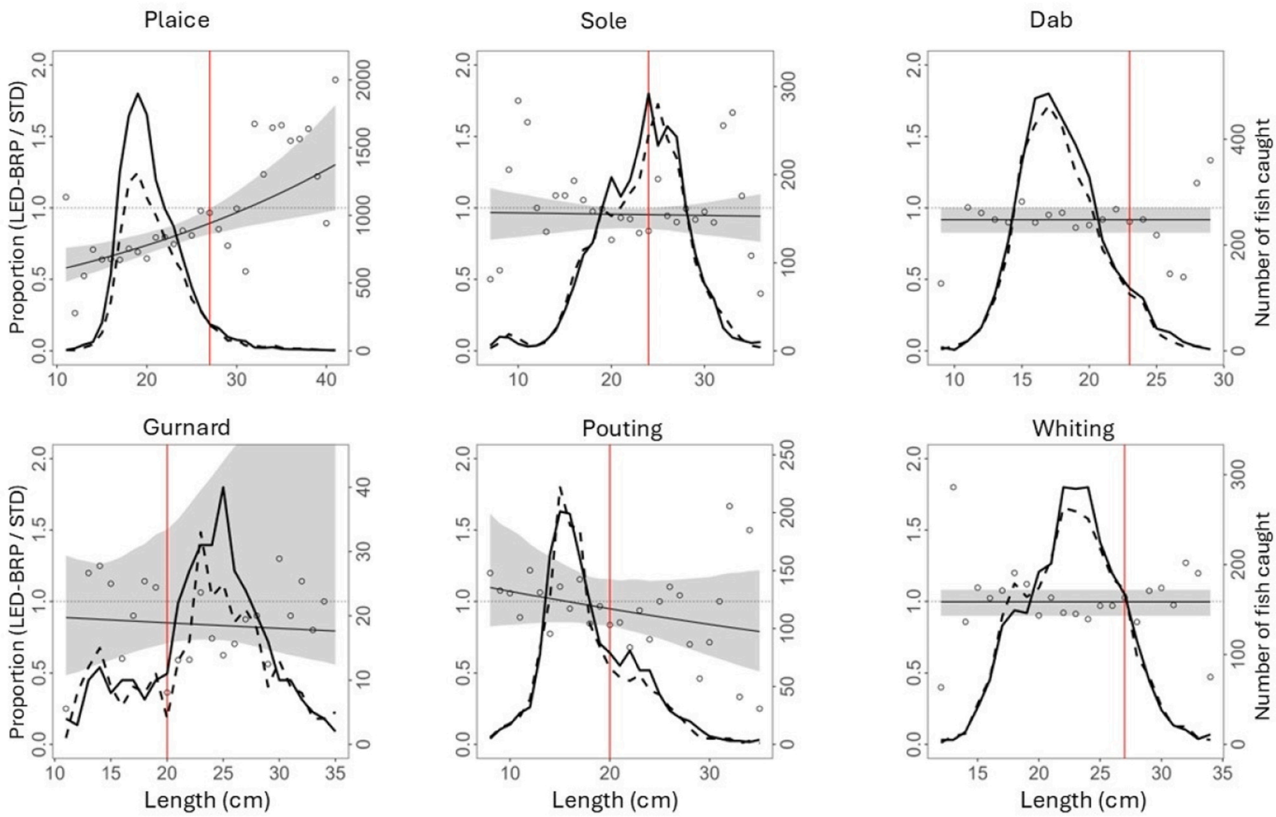

Fig. 5. Catch ratio and length frequency distributions of the species that were caught in the experimental net with a LED-BRP (dotted line) and in the reference net with a BRP (solid line). The left Y-axis shows the catch ratio of fish retained in the experimental net (LED-BRP/STD) per length class and the right Y-axis shows the total number of fish per length class (cm). The horizontal dashed line represents a catch ratio of 1 (no difference between gears). The solid curve showing the modelled mean ratio of fish per length and the grey band indicating the 95 % confidence interval. The MCRS of each species is represented by the red vertical line.

4. Discussion

Before a fish volitionally can escape through the meshes of an SMP, it must first detect it, orient toward it and come into contact with it. The escape thus depends on fish morphology (size, shape, etc.) as well as fish behaviour (Winger et al., 2010; Grimaldo et al., 2018). Several studies have attempted to improve the probability of fish contact with SMPs by inserting devices such as artificial lights, which can induce fish escape behaviour (Parsons et al., 2012; Southworth et al., 2020). Our study confirms for the first time that a white LED rope can enhance the escape of undersized plaice through SMPs in beam trawl fisheries. The LED rope significantly improved the size selection of plaice in catches. Catches of legally sized plaice were not reduced as most of the legally sized individuals cannot easily pass through the SMPs. Catch analysis of the cover codends showed that undersized plaice escape through the belly of the net, regardless of whether the LED rope is attached to the DRP or to the BRP. This means that stimuli received by the fish during the catch process overcome potential phototactic responses at the moment where they encounter the artificial light. As discussed by Karlsen et al. (2021) plaice probably seek the bottom of the gear as an anti-predator response. These results are in accordance with previous findings that showed that small plaice move to the lower part of a *Nephrops* trawl when the lower netting of the trawl funnel is illuminated (Melli et al., 2018). The escape rate of undersized plaice was improved the most when the LED rope was attached to the BRP. It may appear counterintuitive that fish pass through the illuminated BRP as they search for darkness and shelter below them on the seabed, but the only natural source of continuous light in the ocean comes from above. Assuming that most plaice pass the illuminated section of the net with their belly downwards, the LED rope on the DRP shines directly into the eyes of the plaice. When the light is attached to the BRP, it is not directly shining into the eyes. The direct LED light might partially blind the fish. This is not the case when the LED rope is attached to the BRP, likely leaving their visual capacity intact and increasing the chance of a successful escape.

In contrast to previous studies (O'Neill et al., 2022; Melli et al., 2018; Karlsen et al., 2021), the present study showed no significant effect of light on any other investigated species. The harsh conditions inside a beam trawl net can cause physical exhaustion and disorientation, making it difficult for most species to respond to the LED rope. Sole, the most valuable target species in Belgian beam trawl fisheries, is known to be able to actively escape through square mesh panels in beam trawl fisheries (Soetaert et al., 2016). However, no effect of the LED rope on the catch rate for this species was observed. Sole is adapted to low-visibility environments characterised by high turbidity and low light penetration, where image formation by any visual system is challenging (Frau et al., 2020). Detection of prey by sole is primarily olfactory driven, whereas most other flatfish species present in the area rely more on vision for feeding (Harvey, 1996; Frau et al., 2020). Therefore, our data suggest that, in contrast to plaice, the LED rope does not stimulate sole to escape through the SMPs.

A species' distinctive reaction to artificial light is affected by environmental conditions, lifestyle and feeding strategies (Marchesan et al., 2005). Environmental factors such as natural light levels, turbidity, temperature and depth are known to influence the fish's behaviour and responses towards the fishing gear, affecting their availability and catchability (Winger et al., 2010). Our results indicated that location had an important effect on the effectiveness of illuminated SMPs. In the turbid waters of the Thames Estuary, plaice had greater difficulty escaping though the SMPs in general, and illuminating the SMPs with a LED rope did not seem to improve their rates of escape. We hypothesise that the LED illuminates the BRP and stimulates escape behaviour, but the high-intensity light may not be required. In turbid conditions, lower

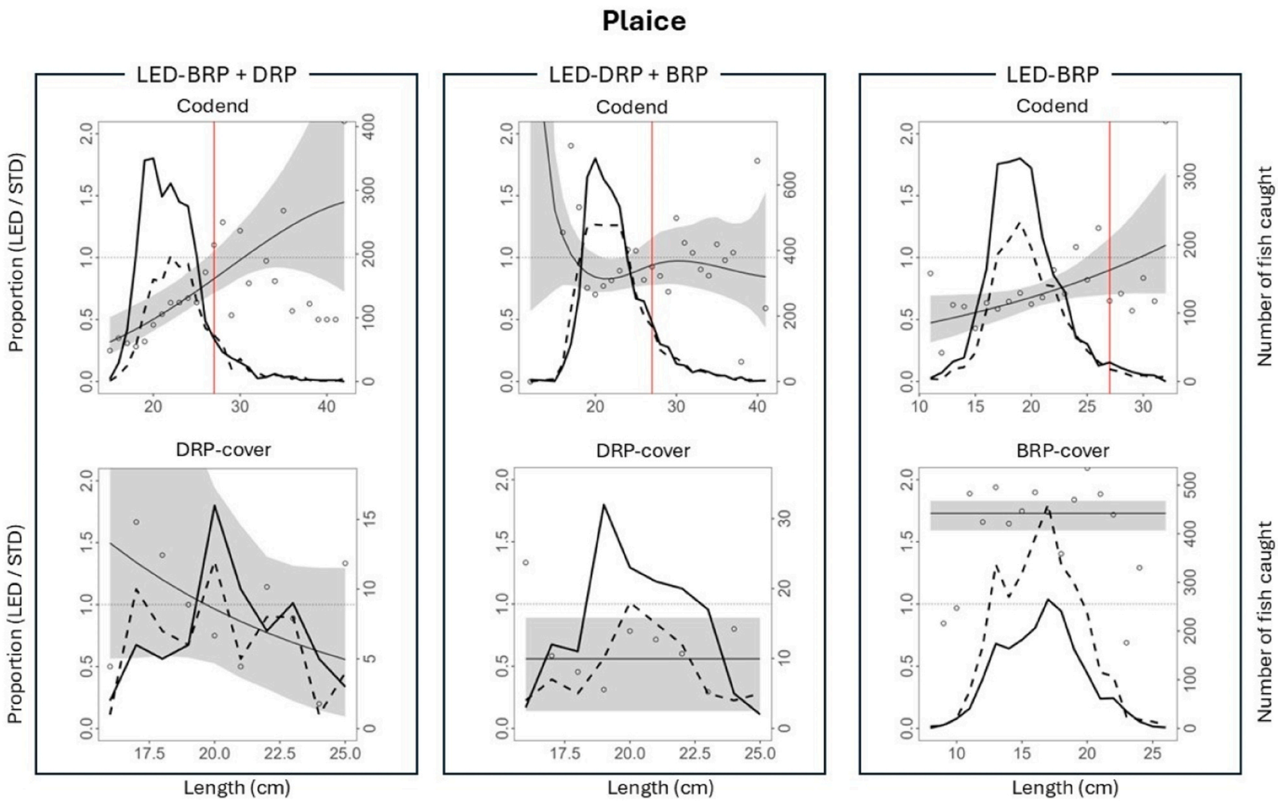

Fig. 6. Catch ratio and length frequency distributions of plaice caught in the experimental nets (dotted line) and in the reference nets (solid line). The left Y-axis shows the proportion of fish retained in the experimental net (LED/STD) per length class and the right Y-axis shows the total number of fish per length class (cm). The horizontal dashed line represents a catch ratio of 1 (no difference between gears). The solid curve showing the modelled mean ratio of fish per length and the grey band indicating the 95 % confidence interval. The MCRS (27 cm) is represented by the red vertical line. Upper graphs show catches in the main codends, catches in the cover codends on the corresponding trials are represented below. Trial 3 (LED-BRP and DRP-cover) at the left, trial 4 (LED-DRP and DRP cover) in the middle, and trial 5 (LED-BRP and BRP cover) at the right.

LED light intensity may even be preferable, as this would reduce the adverse effect of backscattering (Yochum et al., 2022; Benfield and Minello, 1996; Utne-Palm, 2002). Optimizing the LED ropes to the optical properties of the water on the different fishing grounds and taking into account the expected adaptive state of the eyes of the bycatch animals should therefore be considered to improve the efficiency of the LED ropes applied in more turbid fishing grounds (Yochum et al., 2024).

As described by Helfman (1986), the behaviour of many fish species, including demersal species, is affected by the diel cycle. Their activity and position in relation to the sea bottom affects their availability to the bottom trawl (Petrakis et al., 2001). Natural light levels are therefore recognized as an important factor that influences catch composition. In the present study, hauls were conducted during both day- and nighttime to evaluate the effect of time of day in combination with use of a LED rope. We showed that the reduction in bycatch using a LED rope was less pronounced during nighttime. As most other fish, plaice have no eyelids and a fixed pupil size and are incapable of adjusting the optics of the eyes when they are exposed to a BRL during fishing (Yochum et al., 2024). We therefore hypothesise that the fish may be temporarily visually impaired by the strong LED light during nighttime, resulting in a reduced ability to discern the illuminated SMPs (Field et al., 2019). As suggested for use in turbid waters, lower LED light intensity might also help to improve the efficacy of the illuminated escape panels during nighttime. Lower light intensities are also advised for deeper fishing grounds outside our study areas, where the eyes of the bycatch animals are dark adapted and thus have a higher sensitivity to a bright LED light (Yochum et al., 2024).

In this study, we used SMPs with a mesh size of 178 mm. SMPs of this mesh size lead to escape of commercially sized sole (Soetaert et al., 2016). Our results indicate that catches of sole were not influenced when a LED rope was added to the SMPs. Therefore, we expect that on fishing grounds with large concentrations of small commercial sole, the loss of commercial sole will limit voluntary uptake of (illuminated) SMPs by fishers. Illuminated SMPs with smaller mesh sizes might still allow undersized bycatch of some important bycatch species to escape while limiting the escape of undersized sole. It may therefore be useful to investigate the illumination of the lower section of the large mesh extension piece referred to as the 'Flemish Panel' (Bayse and Polet, 2015). This extension piece is already mandatory in commercial Belgian beam trawl fisheries.

Results of this study confirm that a LED rope can be used as a BRD to reduce catch of undersized plaice in beam trawl fisheries. The present study focused on a steady, bright white LED light. Future research may improve BRD efficiency by adjusting specific light characteristics such as intensity, spectral characteristics and flicker rate (Utne-Palm et al., 2018). The study covers different fishing grounds of Belgian beam trawl fisheries, but all trials were performed during cold winter months. Fishing trials during the other periods can help to better understand the effect of season and seawater temperature on gear selectivity. The design tested here will require optimisation before it will tolerate the rough conditions on board commercial beam trawlers. In contrast to the commercially available LED lights used in commercial and recreational fisheries, our LED ropes were sufficiently robust, but the large and heavy battery pack and long cables used in the present study are not appropriate for use under commercial fishery conditions. An important challenge to encourage broad adaptation of the BRL will be the development of an economically affordable, easy to handle and robust LED rope.

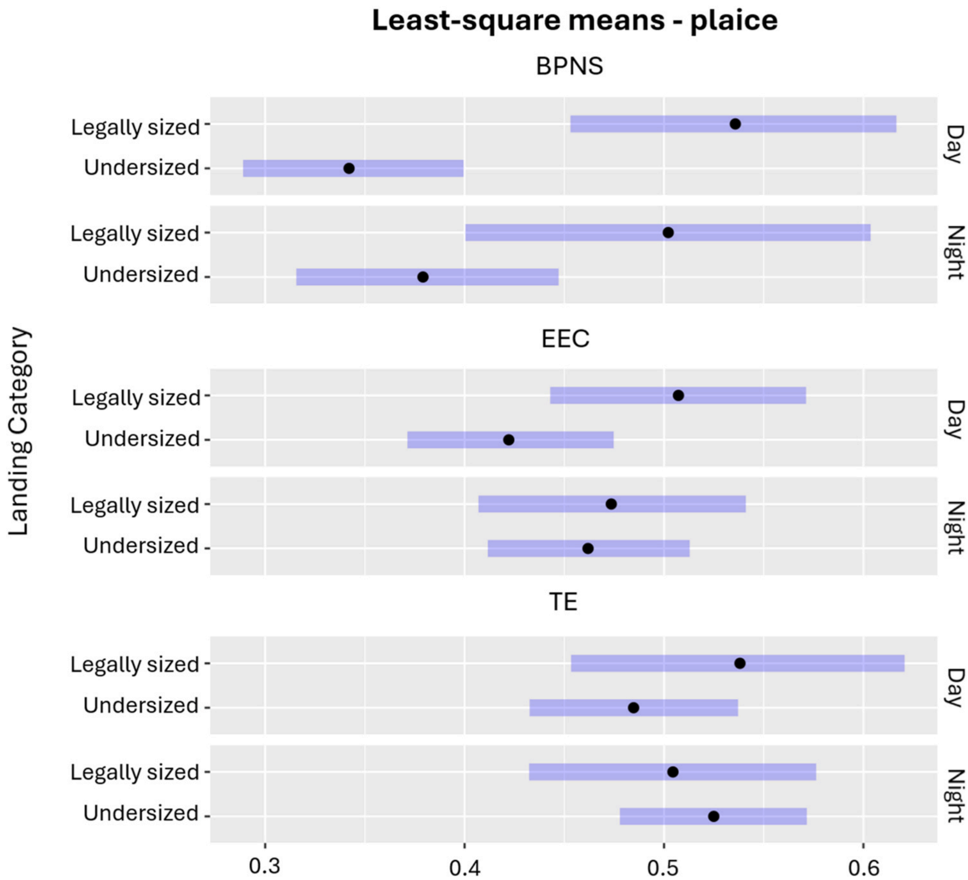

Fig. 7. Least-square means of factors with a significant influence on the effect of light in the GLMM of plaice. BPNS = Belgian Part of the North Sea, TE = the outer Thames Estuary (TE) and EEC = the Eastern English Channel (EEC).

5. Conclusion

The implementation of the landing obligation may stimulate fishers to use different SMPs to reduce bycatch of undersized fish. In this study, we tried to improve the selective properties of SMPs of beam trawls by illuminating them with white LED ropes. The effect on bycatch of six important commercial fish species was investigated. Our results show that a white LED rope illuminating a SMP increases the escape of undersized plaice without affecting the commercial catches. The best results were obtained in nets with an illuminated BRP. The results were heavily affected by fishing location. In the more turbid waters of the Thames Estuary, no reduction in bycatch was observed. The effect of a LED rope on bycatch of plaice was largest during daytime in the clear waters of the BPNS, where 34 % and 66 % of undersized plaice were found in the illuminated and reference gear, respectively. Undersized plaice mainly escapes through the belly of the net in both standard and illuminated trawls, but number of escapes through the belly rise when the net is illuminated. No significant differences in catches of the other species were observed. In the case of sole, we hypothesise that they are not influenced by the LED rope because they rely less on vision compared to most other commercial species in the study area.

CRediT authorship contribution statement

Ampe Bart: Writing – review & editing, Software, Methodology, Investigation. **Page Léonore:** Writing – original draft, Investigation, Data curation. **Van Vlasselaer Jasper:** Writing – review & editing, Investigation. **Van Opstal Mattias:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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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Data Availability

The data that has been used is confidential.

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