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Could green artificial light reduce bycatch during Barents Sea Deep-water shrimp trawling?

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ABSTRACT

The Nordmøre grid is widely used in shrimp trawls to reduce the bycatch of fish species. However, small-sized fish species and juveniles still pass through the grid and enter the codend, along with the targeted shrimp. This bycatch of small fish has a negative impact on the ecosystem due to increased fish mortality, and leads to additional sorting work onboard. Some small-sized fish that enter the trawl avoid entering the codend by escaping through the outlet above the grid, without making contact with the grid itself. Design changes that promote this behavior could potentially reduce bycatch in shrimp trawl fisheries. Light-emitting diodes (LEDs) mounted around the escape outlet have previously been found to have either a negative effect, or no effect at all, on fish bycatch species. This study investigates the effect of mounting green LEDs on the lower part of a Nordmøre grid, to determine if their presence would encourage bycatch fish to rise towards the escape outlet prior to contacting the grid. Experimental fishing trials were conducted to assess the size selective properties of a 19 mm bar spaced Nordmøre grid with and without LEDs, mounted on a bottom trawl targeting Deep-water shrimp (*Pandalus borealis*). For the four bycatch species investigated, 51–100% of small fish passed through the Nordmøre grid. The addition of green LEDs to the Nordmøre grid did not significantly affect the escape probability or the size selectivity of any of the investigated species. Very few Deep-water shrimp were found to escape through the escape outlet independent of the presence of the LEDs mounted on the grid.

1. Introduction

The Nordmöre grid is widely used in shrimp trawls to reduce fish bycatch (Broadhurst, 2000; He and Balzano, 2011). However, substantial quantities of small fish species and juveniles can pass through the grid and enter the small-meshed codend along with the targeted shrimp (He and Balzano, 2007). This is a problem also in the Norwegian trawl fishery targeting Deep-water shrimp (*Pandalus borealis*) in the Barents Sea (Larsen et al., 2017). The Deep-water shrimp is a commercially important species, and has been fished since the beginning of the 20th century in all Nordic countries. The international trawl fishery in the Barents Sea is often associated with a juvenile fish bycatch problem (Gullestad et al., 2015), mainly due to the small codend mesh size used in the fishery (minimum 35 mm). Bycatches of juvenile and undersized fish from various species of commercial interest can be significant during periods of the year in the Norwegian Deep-water shrimp fishery. These catches can have a negative effect on the ecosystem and represent an unintended ecosystem impact of the fishery (Gullestad et al., 2017). The Nordmøre grid was initially developed to exclude jellyfish from catches, but is also efficient in excluding bycatch fish species during shrimp trawling (Isaksen et al., 1992). Legislation introduced in Norway in 1991, and internationally in 1993, requiring the use of the Nordmøre grid eliminated the issue of larger sized fish in bycatch. However, smaller fish, often juveniles, are still able to pass through the 19 mm bar spaced grid into the codend, together with the targeted shrimp. The Nordmøre grid system as used in Norway consists of a section with guiding panel, a sorting grid and a fish escape opening in front of the grid (Norwegian Directorate of Fisheries, 2017).

The current regulations in the Northeast Atlantic shrimp fishery allow the retention of low numbers of juveniles of commercially important species. A fishing area is closed if the authorities register that a fishing vessel is catching more than eight individuals of cod (*Gadus morhua*), 20 haddock (*Melanogrammus aeglefinus*), three redfish (*Sebastes* spp.), or three Greenland halibut (*Reinhardtius hippoglossoides*)

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Table 1
Overview of the 16 hauls with dates (day and month), hour and minute for the start of the hauls, towing time by minutes and number of length measurements obtained for fish and shrimp. The values in brackets represent the sampling factors (% in weight measured). Length measurements were taken for all fish caught. * indicates that data were not collected due to damage, making length measurement impossible. *nC* is the number of individuals in the codend and *nG* is the number of individuals in the grid cover. Hauls 5–12 were made with LED lamps.

Haul ID	Date	Start haul	Towing time	Redfish		American Plaice		Cod		Haddock		Deep-water Shrimp	
				nC	*nG*	*nC*	*nG*	*nC*	*nG*	*nC*	*nG*	*nC* (% measurd)	*nG* (% measured)
1	19.11.	05:31	70	15	77	55	74	29	45	14	11	210 (8.18)	264 (54.50)
2	19.11.	07:44	120	328	627	58	97	149	72	67	94	227 (5.30)	40 (65.24)
3	19.11.	14:43	136	56	125	35	132	23	32	5	16	213 (6.92)	0 (100)
4	19.11.	17:51	121	29	86	92	95	50	51	18	10	212 (6.39)	7 (39.66)
5 LED	20.11.	15:13	119	67	250	84	100	27	19	14	36	202 (9.31)	35 (100)
6 LED	20.11.	18:05	101	19	137	148	187	15	18	17	16	269 (9.22)	167 (100)
7 LED	20.11.	23:45	99	37	125	214	162	46	43	19	19	293 (4.08)	46 (56.25)
8 LED	21.11.	02:22	121	22	197	205	194	70	47	15	18	240 (7.74)	33 (66.67)
9 LED	21.11.	05:41	114	62	249	188	212	107	53	13	21	268 (3.50)	159 (76.62)
10 LED	21.11.	08:25	181	423	576	107	123	179	53	46	53	226 (2.44)	70 (56.59)
11 LED	21.11.	12:17	101	43	290	55	118	50	32	16	20	212 (2.32)	18 (39.95)
12 LED	21.11.	19:54	36	29	347	164	215	20	24	16	17	215 (2.73)	93 (56.54)
13	22.11.	00:52	87	11	146	87	148	24	23	10	11	212 (3.23)	*
14	22.11.	04:07	89	21	102	30	111	53	36	6	4	191 (3.92)	*
15	22.11.	06:20	89	37	115	98	190	85	68	4	9	226 (5.54)	27 (63.37)
16	22.11.	10:36	40	154	106	23	33	90	22	14	25	230 (2.67)	8 (59.76)

per 10 kg of shrimp (Norwegian Directorate of Fisheries, 2011). These strict bycatch rules have led to frequent closures of large shrimp fishing grounds in the Northeast Atlantic in recent years. Closures can last for weeks or months, often resulting in huge operational problems and increased costs for the fishing fleet, i.e. longer distances between potential fishing grounds due to area closures. The bycatch of juvenile fish also causes practical problems, such as increased catch sorting time onboard fishing vessels.

Underwater observations have shown that some small fish avoid entering the codend by seeking the escape outlet in the upper panel in front of the Nordmøre grid without making contact with the grid (Larsen, pers. comm.). Therefore, apart from the obvious effect of changing the grid bar spacing (Grimaldo and Larsen, 2005), other changes in the grid section design that affects the ratio of juvenile fish seeking the outlet without contacting the grid could reduce the bycatch of small-sized fish.

The use of light-emitting diodes (LEDs) can have an effect on fish behavior (Hannah et al., 2015). In a recent study using various colors of Lindgren-Pitman Electralume® LEDs, Nguyen et al. (2017) found that lights in the lower luminescence spectra, at peak wavelengths 464 and 519 nm (blue and green, respectively), and white LEDs, significantly increased the catch of Snow crab (*Chionoecetes opilio*) during field experiments. During trials on cod pots in the Baltic Sea, Bryhn et al. (2014) found that green light resulted in significant increases in both the number and size of fish caught. A number of studies have demonstrated the potential for this type of stimulation to influence the selective properties of trawl gear. For example, Rose and Hammond (2014) found that attaching green Lindgren-Pitman Electralume LEDs to the footrope of a survey trawl resulted in an increased escape rate for Southern Rock sole (*Lepidopsetta bilinetata*). Hannah et al. (2015) reported that attaching LEDs to shrimp trawl footgear and illuminating the escape path under the net resulted in a bycatch reduction of 50–90% depending on the fish species. The authors also attached similar LEDs close to the Nordmøre grid, resulting in a significant increase in the bycatch of eulachon (*Thaleichthys pacificus*). Despite this negative effect, the authors discuss the possibility that illumination of the grid face by artificial light may help other small fish to escape (Hannah et al., 2015). LEDs mounted around the Nordmøre grid escape outlet have been tested to determine if they could promote bycatch escape through the outlet, avoiding grid contact, in Northeast Atlantic shrimp fishery (Larsen et al., 2017). A significant reduction in the probability of seeking the escape outlet was reported for haddock, but not for other species. However, the study had a small sample size, leading to wide confidence intervals in the results for the species investigated. Based on the results obtained by Larsen et al. (2017), it can be speculated that fish are scared by the LEDs in the upper part of the grid section and therefore discouraged from escaping through the outlet. Following on from this, the current study investigated the effect of mounting green LEDs on the lower part of the Nordmøre grid to examine if this would encourage bycatch species to rise towards the outlet and escape without contacting the grid.

2. Materials and methods

2.1. Experimental design

Fishing trials were performed on board the research trawler (R/V) "Helmer Hanssen" (63.8 m overall length and 4080 HP) during 19th – 22nd of November 2016. The study area was located in the Northeast of the Barents Sea and the experiments were made within an area of 17 × 5 nautical miles (N75°30′-E30°10′ to N75°13′-E29°50′). The location for the trials is with sun below horizon in the period 29th October to 7th February and with a depth of 363–381 m we therefore assumed darkness at the fishing depth any time of the day. The fishing trials were carried out using an Egersund Polar 2800# trawl and a pair of Injector Scorpion doors (8 m^2, 3100 kg). The trawl and doors were linked by 40 m long double sweeps. The ground-gear attached to the fishing line was a 19.2 m long rockhopper constructed of three sections with Ø53 cm rubber discs. In Table 1 it is explained how we executed the hauls with and without artificial lights.

The trawl was equipped with a four-panel Nordmøre grid section, equivalent in dimensions and construction to the two-panel standard Nordmøre grid section (Norwegian Directorate of Fisheries, 2017), which is used by the Norwegian coastal fleet targeting shrimp. The grid was made of stainless steel (1.50 m high and 0.75 m wide) and was mounted to maintain an angle of 45° ± 2.5° while fishing. The bar spacing in the Nordmøre grid was measured using a caliper following the guidelines in Wileman et al. (1996), and recorded as 18.73 ± 0.14 mm (mean ± standard deviation). A triangular escape outlet was cut out of the top panel of the grid section. It measured 35 meshes long (by 52 mm mesh length) and 70 meshes wide equaling a triangle ca. 1.6 m long and 0.75 m wide, reinforced with a Ø10 mm PE rope (Fig. 1A). To collect fish and shrimp escaping through the escape outlet before reaching the grid, a small meshed cover (mesh size

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