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Original Article

Effect of light-emitting diodes (LEDs) on snow crab catch rates in the Barents Sea pot fishery

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Snow crab (*Chionoecetes opilio*) has become an important species for the Norwegian seafood industry since its first commercial harvest in 2012. However, periodically catch rates can be low, causing a financial strain on the fishery. Thus, improving the catch rate of existing pot designs has the potential to significantly improve the profitability of fishing enterprises. In this study, we investigated whether the addition of low-powered purple and white light-emitting diode (LED) fishing lights inside the pots could improve catch rates of snow crab in the Barents Sea. Results showed that pots with purple lights harvested a 12.8% higher catch per unit effort (CPUE; number of crab per pot) of legal-sized crab, which was significantly more than the control pots ($p = 0.035$); pots with white lights did not catch significantly more crab ($p > 0.05$). Pots equipped with only light (no bait) caught very few crabs and were not considered a viable alternative. Although purple LEDs increased snow crab capture, the economic benefits of using underwater lights in pots remains unclear given the high capital investment required.

Keywords: Barents Sea snow crab fishery, catchability, invasive species, LEDs, underwater fishing light

Introduction

Snow crabs (*Chionoecetes opilio*) are a subarctic and arctic species belonging to the family *Oregoniidae*. Snow crabs have a wide distribution and have been found in cold waters of the Sea of Japan, the Bering Sea, the West Coast of Greenland, and along the East Coast of Canada from Nova Scotia to Labrador (Puebla *et al.*, 2008). They live in a wide range of depths between 20 and 2000 m on sandy or muddy substrates. Since smaller crabs are found in shallower depths, large crab are targeted commercially at deeper depths, but typically <350 m (Comeau *et al.*, 1998; Morris *et al.*, 2018; Mullowney et al., 2018). As a stenothermal species, their temperature range is −1.5 to 11°C, but prefer temperatures below 5°C (Hardy *et al.*, 1994; Siikavuopio *et al.*, 2017; Mullowney et al., 2018). Males can reach a maximum size of 150 mm carapace width (CW), while females do not exceed 95 mm CW (Mullowney et al., 2018). Snow crab grow by moulting their exoskeleton, and stop growing after a terminal moult, which typically occurs between instars 9–14 for males (size range of 40–150 mm CW) and 9–11 for females (size range of 30–95 mm CW). After their terminal moult, adult crabs can live up to 8 years under optimal conditions (Dawe *et al.*, 2012).

In 1996, snow crabs were first discovered in the Barents Sea as an invasive species, and are now permanently settled (Kuzmin *et al.*, 1999; Alvsvåg *et al.*, 2009; Agnalt *et al.*, 2011). Although the population has not been fully assessed, the stock size of the Barents Sea continental shelf population (including Norway and Russia) has been estimated at 19 million individuals (Bakanev and Pavlov, 2009), and predicted to grow to 370 million individuals, with a total estimated biomass of 188 260 mt in the near future (Dvoretsky and Dvoretsky, 2015). In order to adapt to this situation, a substantial number of studies have been conducted during the last few years to understand snow crab biology, distribution, and habitat (Alvsvåg *et al.*, 2009; Agnalt *et al.*, 2010, 2011; Siikavuopio *et al.*, 2017; Mullowney et al., 2018). Several studies on commercialization have been conducted, i.e. management, fishing, processing, and storage (e.g. Agnalt *et al.*, 2011; Hansen, 2016; Siikavuopio *et al.*, 2017).

The Norwegian snow crab commercial pot fishery started in 2012, and has become an important economic contributor to the seafood industry, with total landings of 5300 mt, accounting for ∼$40 million USD in 2016 (Lorentzen *et al.*, 2018). The main exports are cooked and frozen products sent to Japan, South-Korea, and USA markets. The quota was set at 4000 mt for 2018, with a closure from mid-June to mid-September to protect the crabs during moulting. The fishery targets only adult male crab, with a minimum legal landing size of 100 mm CW. Small Japanese-style conical pots baited with squid and arranged in fleets (line of connected pots), similar to the East Coast of Canada (Winger and Walsh, 2011; Morris *et al.*, 2018), have become the industry norm in the Barents Sea fishery. Baited pots are a traditional fishing method used in demersal fisheries around the world. Compared with other fishing technologies, baited pots tend to produce less bycatch, effective species and size selectivity, limited benthic habitat disturbance, and require smaller vessels and energy consumption (Miller, 1990; Furevik and Løkkeborg, 1994; Suuronen *et al.*, 2012). Finding methods to improve catching efficiency has the potential to significantly improve the profitability of fishing enterprises. For snow crab, several studies have been undertaken during the last two decades to improve pot design (Hébert *et al.*, 2001), study crab behaviour around baited pots (Winger and Walsh, 2011), and evaluate various bait compositions (Cyr and Sainte-Marie, 1995; Grant and Hiscock, 2009; Araya-Schmidt, 2017).

For hundreds of years, above-water lights have been used to improve the catch efficiency of fishing gears. These lights can gather and concentrate fish to the surface, which can then be harvested using a surrounding net (e.g. purse seines, drop net, and lift net), baited hooks (e.g. tuna handlining and hairtail angling), or jigging devices (e.g. squid jigging) (see review by Nguyen and Winger, 2019). Over time with technological advancement, especially the development of light-emitting diode (LED) fishing lights, the use of underwater light in fishing applications has grown substantially. Several studies have investigated their use in reducing bycatch in gillnets, shrimp trawls, and setnets (e.g. Hannah *et al.*, 2015; Ortiz *et al.*, 2016; Lomeli *et al.*, 2018; Virgili *et al.*, 2018), improving the catch efficiency of baited pots for fish and crustaceans (Bryhn *et al.*, 2014; Nguyen *et al.*, 2017; Humborstad *et al.*, 2018; Ljungberg and Bouwmeester, 2018), and studying basic fish behaviour in response to lights (Marchesan *et al.*, 2005; Larsen *et al.*, 2017, 2018; Grimaldo *et al.*, 2018; Melli *et al.*, 2018). A new approach using underwater LED fishing lights to improve the catch rate of pots was recently developed in Canada. An incidental discovery showed that unbaited pots targeting flatfish equipped with a low-powered LED fishing light captured occasional snow crab as bycatch (Murphy, 2014). This was the first evidence that underwater LED fishing lights might be an effective stimulus for capturing snow crab. Subsequent work by Nguyen *et al.* (2017) showed that attaching purple (peak wavelength of 446 nm) and white (peak wavelength of 456 nm) LED fishing lights into the pot significantly increased the catch per unit effort (CPUE) of legal-sized crab.

The purpose of this study was to extend recent findings in Canada (Nguyen *et al.*, 2017) to the snow crab fishery in the Barents Sea. In particular, we investigated whether the addition of low-powered LED fishing lights inside baited pots could improve catch rates of snow crab. Thus, the catch rate and size selectivity from experimental pots was compared to the control pots without lights during two field experiments in the Barents Sea.

Methods

Gear description

Small Japanese-style conical pots with a volume of 1.7 m^3 were used in the experiment, which are typical for harvesting snow crab in the Barents Sea and the East Coast of Canada (Winger and Walsh, 2011; Araya-Schmidt, 2017; Lorentzen *et al.*, 2018). The dimensions and additional details of the pots are shown in Figure 1. The pot frame was made from round-stock steel with a diameter of 12 mm for the top ring and vertical portions, and 15 mm for the bottom ring. The pot was covered by orange polyethylene netting with 135 mm stretched mesh that allowed sublegal-sized and female snow crabs an opportunity to escape capture through the mesh openings, and a single top-mounted, conical white plastic entrance. The pots were connected to a ground line (fleet) at an interval of 25 m by a polypropylene rope (branch line) of ∼3.5 m length. For each treatment, pots were randomly selected for inspection to ensure that they were identical.

Sea trials

The study was carried out onboard the commercial fishing vessel *M/S Tromsbas*, 68.1 m LOA, which operated 24 h per day, carried 10 000 pots, and had the capacity of retrieving and deploying an average of 2000 pots per day. Comparative fishing experiments were conducted in June 2017 and February 2018, in the Barents Sea, along the Norwegian continental shelf (Latitude between 74°04′N and 76°09′N, Longitude between 33°48′E and 37°59′E; Figure 2). Depth at the fishing sites ranged between 190 and 290 m. The seabed temperature was between 0.3 and 0.9°C measured by electronic temperature loggers. The experiment was conducted using Electralume® fishing lights manufactured by Lindgren Pitman (Pompano Beach, FL, USA). Purple and white

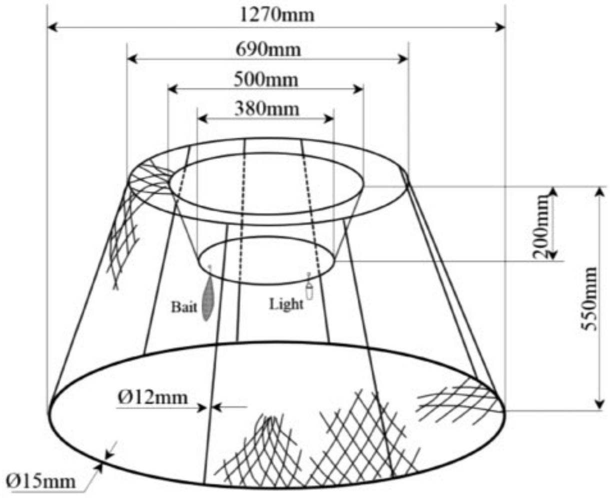

Figure 1. Schematic drawing of a conical snow crab pots used in this experiment.

LED fishing lights, with a peak wavelength of 446 and 456 nm, respectively, were used. The intensity (irradiance, $\text{mW m}^{-2}\text{nm}^{-1}$) of the two different light sources was measured using a Trios RAMSES ACC hyperspectral radiometer (sensitivity at $4.0 \times 10^{-7}\ \text{W m}^{-2}\text{nm}^{-1}$). The light sources were positioned 100 cm from the light metre with the strongest beam pointing towards the sensor on the radiometer. Measurements where done in air in a dark room. The purple light and white light had an integrated intensity of 0.90 and $2.85\ \text{mW m}^{-2}\text{nm}^{-1}$, respectively [see Nguyen *et al*., (2017) for other technical specifications].

In 2017, we evaluated five experimental treatments:

(1) Baited pot (B) for control;

(2) Purple light-baited pot (BP)—similar to (1), with addition of a purple LED fishing light;

(3) White light-baited pot (BW)—similar to (1), with addition of a white LED fishing light;

(4) Unbaited purple light pot (P)—pot equipped with only a purple LED fishing light (no bait);

(5) Unbaited white light pot (W)—pot equipped with only a white LED fishing light (no bait),

Based on the results of the first experiment, we designed a comparative experiment in 2018, however, only baited treatments (1, 2, and 3) were tested due to very low catch rates in the two unbaited treatments (4 and 5) in the first year.

For both sea trials, pots were baited with 0.5 kg of frozen squid (*Illex illecebrosus*). To prevent scavenging of the bait by non-targeted animals, the bait was placed in a polyethylene bait protection bag, typical for the crab fishery in the Barents Sea. The bait bags were green, 40 cm long, had a diamond mesh shape, and a stretched mesh size of 21 mm.

The lights were mounted under the entrance of the pot directly opposite the bait bag in the manner similar to Nguyen *et al.* (2017; Figure 1). In 2017, each fleet consisted of 200 pots. In order to sample more sites, we modified the experiment in 2018 so as to use only half a fleet (100 pots) for experimental purposes, with the remaining pots in the fleet not recorded. All experimental pots were randomly attached within a fleet for comparative purposes. A total of five fleets in 2017 and ten fleets in 2018 were successfully deployed and retrieved. The total numbers of pots sampled by treatments (1–5) were 710, 400, 433, 141, and 133, respectively (Table 1).

The soak time varied between 43 and 268 h (Table 1). Upon the retrieval of each pot, all crabs were counted and the number of crab per pot was defined as the CPUE. Bycatch of non-targeted species were recorded simply as count data (numbers of individuals per species for each treatment). Only legal-sized male crabs were retained for commercial purposes. In cases where uncertainty was noted (e.g. light malfunction, broken meshes, pots appeared damaged, upside down pot, or missing bait bag), the data was excluded from analysis. The total number of non-functional pots was 162 (excluded from the analysis), and the average per fleet was 10.8 (± 1.54 s.e.). For each treatment of B, BP, and BW, we randomly collected pots to measure CW of all crabs in the selected pots using a Vernier caliper with an accuracy of 0.1 mm. A total of 1618 crabs were measured during the experiment (Table 1).

Statistical analysis

Differences between the two sea trials, i.e. seasonality, were tested and found not to be significant. We estimated the effect of pot treatments on CPUE of crab using a generalized linear mixed-effect model (GLMM) based on the Poisson regression, following procedure outlined in Zuur *et al.* (2016). A generalized modelling approach was used because our catch data violated many of the assumptions needed for parametric tests. The Poisson regression considers CPUE as count data in which CPUE values could only be non-negative integers, where integers were counts rather than ranks. Additionally, mixed-effect models were used to measure variability between fleets. Each model was determined to have overdispersion, dispersion parameter for the quasipoisson family >1 (1.96 for legal-sized crab and 2.43 for sublegal-sized crab), thus the negative binomial distribution was used. Residuals met the assumptions for homogeneity, normality, and independence. The GLMM was fit using the "`glmmadmb`" function based on packages "`R2admb`," and 95% confidence intervals (CIs) were generated by using the "`confint`" function. The model structure was as follows (M1):

```
M1 = glmmadmb(CPUE∼Treatment + offset(log(
soaktime)) +(1|FleetID), family="nbinom",
zeroInflation=TRUE, data = dat)
```

where the response variable is CPUE, the explanatory variable is Treatment, soak time is used as an offset, and fleet number (FleetID) is the random effect. The percent change in catch between pot light treatments was compared to the control by:

$$\mathrm{PC} = 100[\exp(E)\text{–}1]$$

where PC is the percentage change, E is the estimated value obtained from the fitted model. This analysis was conducted separately for legal-sized crab and sublegal-sized crab.

The analysis of catch proportion at each length class for crab retained from B pots and experimental baited pots was performed using the GLMM procedure outlined in Holst and Revill (2009). In this procedure, the GLMM was used to plot the relationship between proportions of catch in illuminated pots with bait vs. B pots at each length class. The statistical model used catch proportion as a response variable, which was calculated by $n_{L,\ \mathrm{exp}}/(n_{L,\ \mathrm{exp}} + n_{L,\ B})$, where $n_{L,\ \mathrm{exp}}$ is the number of crab of length L from the experimental pot and $n_{L,\ B}$ is the number of crab of length L from the B pot(see M2 below), CW as the explanatory variables (fixed effect), and subsample ratio and soak time were used as offsets. We included the fleet number (FleetID) as a random effect. The analysis was preceded by fitting the highest order polynomials followed by subsequent reductions until all terms showed a significance ($p < 0.05$), with removal of one term at each step to determine the best-fit model. Analyses were performed separately for different treatments using RStudio for Windows via the "`glmmPQL`" function from the "`MASS`" package.

```
M2 = glmmPQL[(expt/(expt +ctr)) ∼1 +
CW + I(CW^2) + I(CW^3) + offset(log(
q.expt/q.ctr)) + offset(log(soaktime)),
random=∼1|FleetID, family=binomial,
weights=(expt+ctr), data=CWdata]
```

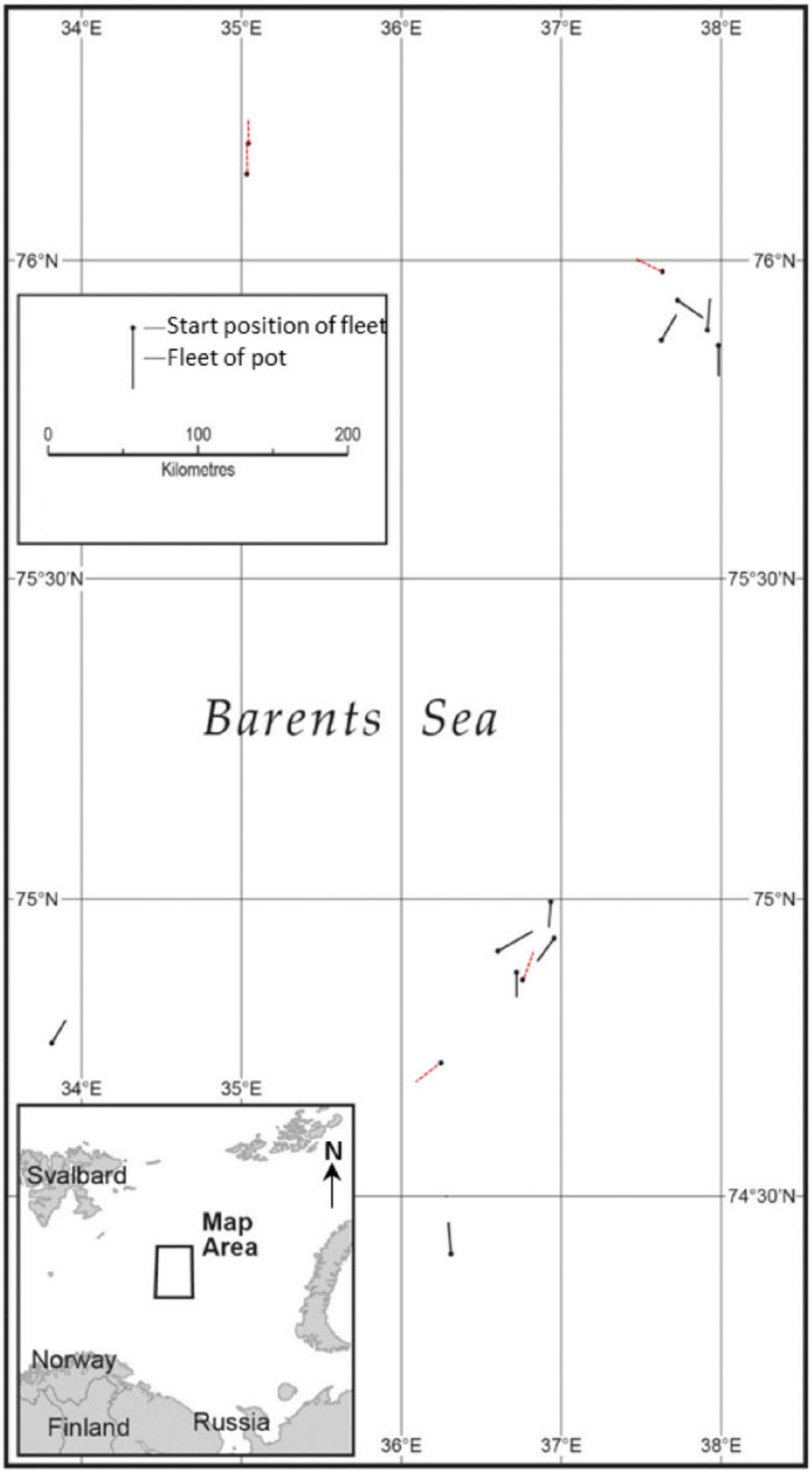

Figure 2. Map of the study sites, located in international waters along the Norwegian continental shelf. Lines and symbols indicate the position and orientation of each fleet of pots. Red dotted lines indicate fleet from 2017 and black solid lines indicate fleets from 2018.

where *expt* is the number of crab at each CW class measured for the experimental pot and *ctr* is the number of crab at each CW class measured for the B pot.

In this model, a proportion of 0.5 indicates no difference in catch between experimental pots and B pots at each length class, while a proportion >0.5 indicates more crab caught by experimental pots, and *vice versa*, i.e. a value of 0.75 means that 75% of crabs were caught by the experimental pot and 25% by the B pot. Where CIs overlap 0.5, there is no statistically significant difference in catch-at-length between experimental and B pots at the specific length class.

Table 1. Summary details for the comparative fishing experiment.

		B				BP				BW				P		W	
FleetID	**St**	**Np**	**CPUE**	**Nc**	**SSR**	**Np**	**CPUE**	**Nc**	**SSR**	**Np**	**CPUE**	**Nc**	**SSR**	**Np**	**CPUE**	**Np**	**CPUE**
1	43	74	99	98	0.61	29	22	22	0.12	31	31	31	0.17	32	7	28	0
2	71	80	111	110	0.62	30	37	30	0.17	27	47	47	0.32	29	1	24	0
3	165	65	65	65	0.37	30	24	21	0.13	28	5	5	0.05	29	1	30	3
4	95	85	132	NA	NA	30	53	NA	NA	33	56	NA	NA	24	0	24	0
5	265	77	232	131	0.73	27	115	54	0.31	29	112	64	0.31	27	7	27	5
6	118	28	85	36	0.15	27	53	28	0.15	27	47	37	0.19	NA	NA	NA	NA
7	122	29	46	34	0.19	27	58	33	0.19	31	59	35	0.2	NA	NA	NA	NA
8	121	31	114	39	0.22	27	77	23	0.13	28	69	53	0.3	NA	NA	NA	NA
9	135	24	34	19	0.11	23	56	44	0.25	31	55	36	0.21	NA	NA	NA	NA
10	109	44	170	25	0.14	19	120	34	0.19	27	124	25	0.14	NA	NA	NA	NA
11	261	29	31	31	0.18	27	43	31	0.18	27	42	36	0.21	NA	NA	NA	NA
12	268	31	33	27	0.15	27	54	20	0.11	30	51	29	0.17	NA	NA	NA	NA
13	205	47	119	32	0.18	23	59	25	0.14	25	60	29	0.17	NA	NA	NA	NA
14	219	34	95	33	0.19	27	80	31	0.18	31	100	30	0.17	NA	NA	NA	NA
15	220	32	83	33	0.19	27	79	28	0.15	28	100	24	0.14	NA	NA	NA	NA
Total		710	1449	713		400	930	424		433	958	481		141	16	133	8

B, control pot; BP, purple light-baited pot; BW, white light-baited pot; P, unbaited purple light pot; W, unbaited white light pot; St, soak time (h); Np, number of valid pots in a fleet; Nc, number of crab measured; SSR, sub-sampling ratio; NA, not applicable.

Results

Effects of artificial light on catch rates

Generally, the CPUE of crab was low throughout the experiment, indicating a low abundance of snow crab in the Barents Sea during experimental fishing. CPUE ranged from 0 to 14 individuals per pot (Figure 3). The baited purple light pots (BP pots) harvested a 12.8% higher CPUE of legal-sized crab than control pots (B pots), and this difference was significantly different from the control ($p = 0.035$; Table 2). The baited white light pots (BW pots) caught 2.0% more legal-sized crab than B pots, but this result was not significantly different ($p = 0.732$). Unbaited purple light pots (P pots) and unbaited white light pots (W pots) caught significantly less crab than B pots (>89.1% less than the control for each treatment). The modelled catch rate of legal-sized crab was 0.31 for B pots, 0.35 for BP pots, 0.32 for BW pots, 0.01 for P pots, and 0.01 for W pots. There were no significant differences in CPUE of sublegal-sized crabs between BP pots and B pots ($p = 0.620$), as well as BW pots and B pots ($p = 0.510$; Table 3). The modelled catch rate of sublegal-sized crab for B pots, BP pots, and BW pots was 0.03, 0.3, and 0.8, respectively. The proportion of sublegal-sized crab occupied 32%, 33%, and 31% of B, BP, and BW pots, respectively.

Figure 4 shows the CPUE of legal-sized crab for each fleet ($n = 15$). Values above the 1:1 line indicate the experimental pots caught more crab than B pots, which was particularly noticeable for the BP pots.

Selectivity and bycatch

The CW ranged from 66.5 to 158.5 mm across three treatments of B, BP, and BW pots. Figure 5 illustrates CW frequency distribution of male crab (top panels) and the size selectivity analysis of male crab for the different pot treatments (lower panels). The logit-quadratic curves were the best fit for the BP pots and the BW pots (Table 4). The GLMMs showed that the BP pots caught more crab at CWs <78 mm and >127 mm than the B pot (Figure 5); no size selectivity differences were observed for medium sizes. For BW pots, the model showed that no size selectivity was found for crabs ≥82 mm, but crabs <82 mm were caught more by the BW pot (Figure 5). A large variation of catch proportion was found at the extreme end of crabs measured for BP and BW pots.

Bycatch of non-targeted species was low throughout the experiment. Table 5 shows the numbers of individuals captured by species and treatment, including wolffish (*Anarhichas sp.*), Dover sole (*Microstomus pacificus*), and Atlantic cod (*Gadus morhua*). The majority of wolffish were observed in B pots. In addition, 11 female snow crab were recorded during the experiment (three for B pot, six for BP pot, and two for BW pot).

Discussion

Adding LED fishing lights to a pot was shown to increase the CPUE of snow crab in the Barents Sea for BP pots, but not BW pots or non-baited pots with light. These results build on a study in the Newfoundland and Labrador snow crab fishery where pronounced increases in CPUE by using artificial light (47–77%) were observed.

Our results indicated that the purple LED fishing light was more efficient than the white LED fishing light. This finding is inconsistent with Nguyen *et al.* (2017) who found that both purple and white LED fishing light could improve the catch rate of snow crab pots, but white light performed better than purple light (increase of 77% for white LED fishing light vs. 47% for purple LED fishing light). We speculate that there were several explanations for these differences. Although both studies were conducted at comparable depths (200–300 m), it is likely that the bottom characteristics of the two sites (e.g. substrate, current, temperature, salinity, transparency, habitat, and benthic condition) may be different (Petrie and Anderson, 1983; Agnalt *et al.*, 2011; Dvoretsky and Dvoretsky, 2015). Moreover, snow crab abundances are different in the two regions. For example, the average catch rate of traditional pot in the eastern Canada was over 13 crabs per pot, while this number was approximately two crabs per pot in the Barents Sea (Nguyen *et al.*, 2017; Morris *et al.*, 2018; Olsen *et al.*, 2019). These differences might explain the contradictory results. It is well known that marine animal vision and

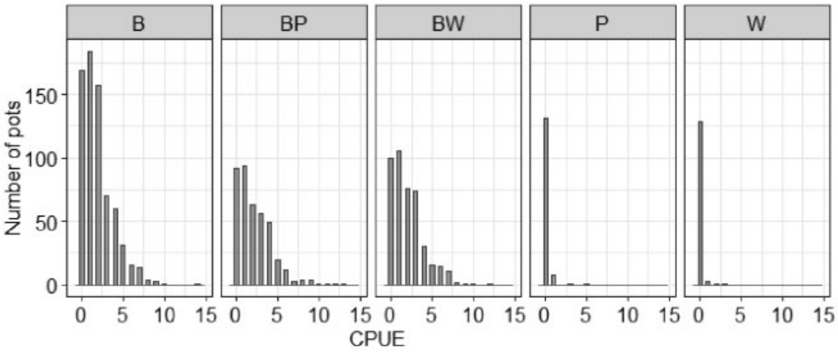

Figure 3. The CPUE of legal-sized crab for the different treatments. B represents the control pot; BP represents the purple light-baited pot; BW represents the white light-baited pot; P represents the unbaited purple light pot; and W represents unbaited white light pot.

Table 2. Parameter estimates, fit statistics, and variation from the random effect of a GLMM model for legal-sized snow crab using fleetID as a random factor ($n = 15$).

Treatment	Estimate	s.e.	z-value	95% CI	p-value
(Intercept)	−1.17	0.15	−7.90	0.23–0.41	<0.001
BP	0.12	0.05	2.11	1.00–1.25	0.035
BW	0.02	0.05	0.34	0.92–1.13	0.732
P	−2.67	0.28	−9.60	0.04–0.12	<0.001
W	−3.30	0.36	−9.16	0.02–0.08	<0.001
Random effect			**Variable**	**SD**	**Variance**
FleetID			Intercept	0.56	0.31

Number of pots were 1 817.
s.e., standard error of the estimate; SD, standard deviation; BP, purple light-baited pot; BW, white light-baited pot; P, unbaited purple light pot; W, unbaited white light pot.

Table 3. Parameter estimates, fit statistics, and variation from the random effect of a GLMM model for sublegal-sized snow crab using fleetID as a random factor ($n = 15$).

Treatment	Estimate	s.e.	z-value	95% CI	p-value
Intercept	−5.17	0.60	−8.62	0.01–0.02	<0.001
BP	−0.13	0.26	−0.50	0.52–1.47	0.620
BW	0.16	0.24	0.66	0.73–1.89	0.510
Random effect			**Variable**	**SD**	**Variance**
FleetID			Intercept	1.95	3.8

Number of pots were 1 543. Because of negligible sublegal-sized crab caught by the unbaited purple light pot and unbaited white light pot, these treatments were excluded from the model.
s.e., standard error of the estimate; SD, standard deviation; BP, purple light-baited pot; BW, white light-baited pot.

their behaviour in response to artificial light is dependent on their living environment, and for some species the mechanism could be more complicated (Marchesan *et al.*, 2005). Contrary results have also been demonstrated for shrimp trawl fisheries carried out in different fishing sites. For example, attaching low-powered LED fishing lights along the fishing line of a bottom trawl targeting ocean shrimp (*Pandalus jordani*) off the Coast of Newport, Oregon, USA significantly reduced bycatch of fish (Hannah *et al.*, 2015; Lomeli *et al.*, 2018), which is contrary to what was observed in the Barents Sea (Larsen *et al.*, 2017, 2018).

Functional explanations for why LED fishing lights increase the CPUE of snow crab in baited pots remains unknown at this time. The light could directly concentrate animals, or indirectly stimulate crab to enter the pot by attracting potential prey, or facilitate crabs to find the entrance to the pot (Nguyen *et al.*, 2017). For example, attaching a green LED fishing light inside a baited cod pot significantly increased the CPUE of Atlantic cod (*G. morhua*) by 74% (Bryhn *et al.*, 2014), however, it appeared that cod did not respond to artificial light, but rather swam into the pot to feed on krill (*Thysanoessa inermis*), which were attracted to the light (Humborstad *et al.*, 2018; Utne-Palm *et al.*, 2018).

The catchability of baited fishing gear is known to depend on various conditions, such as animal density, satiation level, bait quantity and type, soak time, fishing season, pot design, and oceanographic conditions (e.g. Cyr and Sainte-Marie, 1995; Hébert *et al.*, 2001; Winger and Walsh, 2007, 2011; Grant and Hiscock, 2009). Our results support the previous research by Nguyen *et al.* (2017) that novel stimuli in the form of artificial light can increase the CPUE of snow crab pots. However, our results show that in order to increase the *vulnerability* of crab to capture, they must also be present and available to the fishing gear. We speculate that LED fishing lights have a low effect on CPUE when population abundance is low and a strong effect in places which have high crab densities (i.e. eastern Canada). This suggests that the effective application of LED fishing light in the commercial fishery will be dependent on the availability of crabs to capture, and that this may vary with colour of light, fishing location, season, and year.

The proportion of sublegal-sized crab recorded in this study was high, accounting for 32% of the CPUE. Given that the selectivity of snow crab pots is influenced by mesh size and soak time (Hébert *et al.*, 2001; Winger and Walsh, 2011; Olsen *et al.*, 2019), we recommend fishing vessels either increase their mesh size, soak time, or both. Another alternative is to decrease the minimum landing size from 100 mm CW to 95 mm CW, similar to Canada, which would have increased the landings of this study by 11%. However, LED fishing light had no effect on the CPUE of sublegal-sized snow crab in this study.

For size selectivity, small differences were observed for small crabs for both baited-light treatments, and for the largest crabs for the BP treatment. These differences should be considered with caution as the number of crab captured at these lengths was relatively low. When considering length classes not at the extreme ends of crabs captured, there was no difference in size

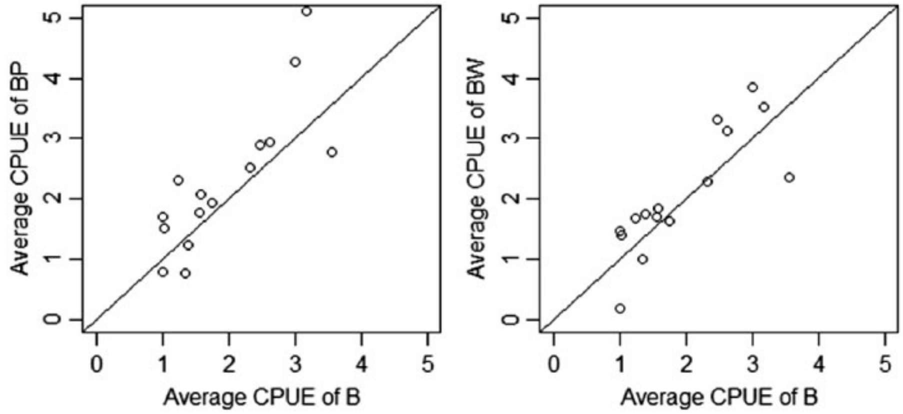

Figure 4. Comparison of CPUE of legal-sized crab for 15 fleets of pots. The left panel represents a comparison between the control pot and the purple light pot. The right panel represents a comparison between control pot and the white light pot. B represents the control pot. BP represents the purple light-baited pot. BW represents the white light-baited pot. Average CPUE of the control pot is plotted on the *x*-axis, and average CPUE of the experimental pot is plotted on the *y*-axis. Each point represents the mean from one fleet. The solid 1:1 lines show the same CPUE between control pot and experimental pots (either purple light pot or white light pot). Points above the 1:1 line indicates the experimental pot captured more than control pot in the same fleet, and *vice versa*.

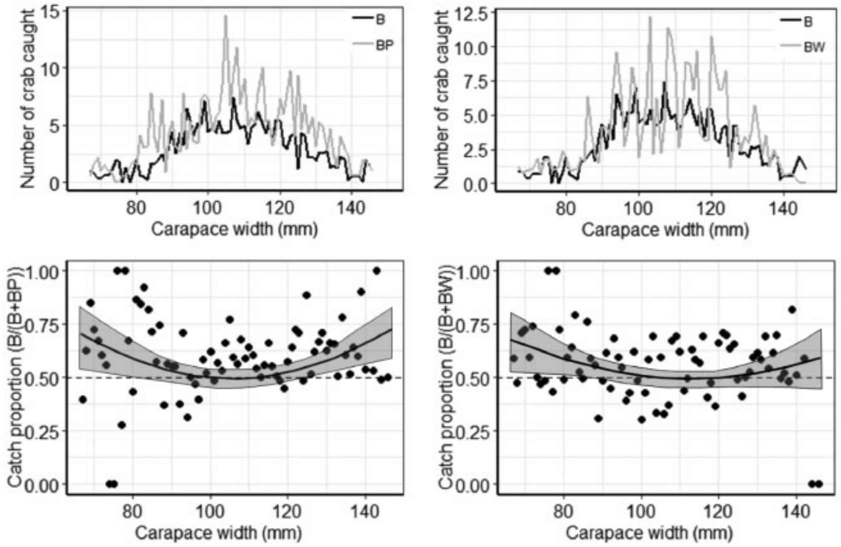

Figure 5. Length-frequency curves for snow crab in the control and purple light-baited pot (top-left panel), and control and white light-baited pot (top-right panel). A GLMM comparison of the proportion of crab captured at each size class between the purple light and the control pot (down-left panel), and the white light pot and the control pot (down-right panel). B is the control pot, BP is the purple light pot, and BW is the white light pot. A value of 0.5 indicates that catch was the same between the experimental and control pots (no size-based selectivity). For example, a value of 0.25 indicates that at the specific length class, 25% of crabs were captured by the experimental and 75% of crabs were captured by control pots. The solid bold lines show the modelled means, while the grey area are the 95% confidence interval.

Table 4. GLMM parameters for pot treatment comparison.

Treatment comparison	Model	Parameter	Estimate	s.e.	df	*t*-value	*p*-value
B vs. BP	Quadratic	β_0	6.39	2.30	563	2.78	0.006
		β_1	−0.13	0.04	563	−2.89	0.004
		β_2	0.01	0.01	563	3.04	0.003
B vs. BW	Quadratic	β_0	5.51	1.96	572	2.81	0.005
		β_1	−0.10	0.04	572	−2.66	0.008
		β_2	0.01	0.01	572	2.54	0.011

s.e., standard error of the estimate; df, degree of freedom; B, control pot; BP, purple light-baited pot; BW, white light-baited pot.

Table 5. Summary of all bycatch species caught during the experiment.

Categories	B (710)	BP (400)	BW (433)
Wolffish (*Anarhichas sp.*)	3.1	1.0	0.9
Dover sole (*Microstomus pacificus*)	1.1	1.3	0.9
Atlantic cod (*Gadus morhua*)	0.1	0.3	0.0

Values shown are percent of individual per pot and total number of pots in brackets for the different treatments.

B, control pot; BP, purple light-baited pot; BW, white light-baited pot.

selectivity between the control pots and the baited-light treatments.

In conclusion, this study has shown that equipping baited pots with artificial light improved the CPUE of snow crab. Pots equipped with purple LED fishing lights caught 12.8% more crab than the control pots, however, the catch rate of snow crab in the Barents Sea can be low at times and the purchase/operation of lights can be costly. Thus, the economic performance for the fishery to switch to using lights is uncertain due to the high cost of LED fishing lights (∼$50 USD each) and the lights are suggested to be used with lithium batteries, which cost $15 per light. Widespread use of LED fishing lights in the commercial fishery must be careful, and future research is recommended to determine the economic benefits of using light in the Barents Sea snow crab fishery. Moreover, a future study with an alternative, less expensive light stimuli that could attract the target species (e.g. luminescent netting) is recommended.

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