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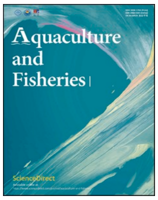

Original research article

Does soak time influence the effect of artificial light on catch efficiency in snow crab (*Chionoecetes opilio*) pot fishery?

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ABSTRACT

In the Barents Sea commercial snow crab (*Chionoecetes opilio*) fishery, an increase in catch efficiency of the conical pots is important for the profitability of the industry. Light emitting diodes (LEDs) have previously been tested for increasing catch efficiency of the snow crab pots. These earlier experiments have shown varying results ranging from large increase in snow crab catches to no significant effect. These experiments have used different pot soaking times; however, the soaking time might affect the impact of LEDs on catch efficiency. In commercial snow crab fishery, the pot soak time is varying which has not been considered in earlier experiments testing the effect of LEDs. Therefore, this study examined whether pot soaking time can explain the observed differences in relative catch efficiency of snow crab pots with and without LEDs with soak times ranging from 2 to 14 days in the Barents Sea snow crab fishery. For target sizes of snow crab (≥95 mm carapace width), results indicated an increase in catch efficiency between 10 and 30% for pots with LEDs with exception of one experiment using six days soak time. However, experimental results were subjected to large uncertainties and, except from one experiment with five days soak time, the estimated increases were nonsignificant. Furthermore, the pot soak time was not found to impact the effect of white LEDs on capture efficiency.

1. Introduction

Snow crab (*Chionoecetes opilio*) is a cold-water species inhabiting areas of Northwest Atlantic and the North Pacific Oceans (Agnalt et al., 2010). In the Barents Sea, the commercial snow crab fishery started in 2012 following the establishment of a snow crab population which was first recorded in 1996 (Kuzmin et al., 1999; Lorentzen et al., 2018; ICES, 2021). Recent studies suggest that the snow crab establishment in the Barents Sea was caused by natural expansion of this species from Alaskan waters (Dahle et al., 2022) either as migration of benthic stages or dispersal of larval stages of snow crab (Huserbråten et al., 2023). Since then, the snow crab population in the Barents Sea has increased rapidly, currently making a valuable commercial fishery.

The snow crab mainly inhabits muddy and sand grounds in the eastern part of the Barents Sea at depths around 200–400 m (Siikavuopio et al., 2019; Solstad et al., 2021; see also Holte et al., 2022 for snow crab range). It mainly feeds on benthic species that are abundant in the area, such as crustaceans, polychaetes, molluscs, echinoderms, and fish (Agnalt et al., 2011). Since snow crab is a relatively newly established species, its presence might have an impact on the composition of benthic invertebrate communities as has been observed for the introduced red king crab (*Paralithodes camtschaticus*) (Oug et al., 2018). However, snow crab does not appear to have negative effects on fish stocks (Dvoretsky & Dvoretsky, 2015). The food supply for snow crab in the Barents Sea regarding both the abundance and composition has been assessed favourable for successful long-term development of its population (Zakharov et al., 2021), and thus, the stock size is expected to increase (ICES, 2021). Furthermore, snow crab prefers cold water temperatures (1.0–1.6 °C) (Solstad et al., 2021). Therefore, the spread of the snow crab population is associated to the areas in the eastern, central, and north-western Barents Sea (Danielsen et al., 2019; Hjelset et al., 2019; ICES, 2021; Prozorkevich et al., 2018), i.e., areas that are available for snow crab fishery. Thus, the Barents Sea snow crab fishery has a potential to further provide a significant income for the fishing industry

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because of its high market value (i.e., Norges Råfisklag, 2023), and methods to improve the catch efficiency of snow crab pots are sought.

The snow crab fishery in the Barents Sea uses conical snow crab pots identical to those used off the eastern coast of Canada (Olsen, Herrmann, Grimaldo, & Sistiaga, 2019; Winger & Walsh, 2011). These pots are preferred by the fishers as they are light and stackable onboard the fishing vessels, thus allowing many pots to be transported to the fishing grounds. This is important as the Barents Sea snow crab fishery takes place far off the coast with large factory vessels that are processing the catch onboard. Each vessel deploys from 1000 to 2000 pots per day (Olsen, Herrmann, Grimaldo, & Sistiaga, 2019). The current Norwegian regulations for the fishery in the Barents Sea permit a maximum number of 9000 pots per vessel, maximum pot soaking time of 3 weeks, and a minimum snow crab landing size (MLS) of 95 mm carapace width (CW), with no more than 20% soft-shelled snow crab in the catch (Norwegian Directorate of Fisheries, 2020). Moreover, all snow crab below the MLS must be returned to the sea alive in the best possible condition. The annual quota was set to 6500 tonnes for 2021 and further increased to 6725 tonnes for 2022. A closed season takes place from 1st of July to 30th of September to protect snow crab undergoing moulting from being damaged (Norwegian Directorate of Fisheries, 2020).

Retention of individuals under the MLS should be avoided during the capture process as it both increases the sorting time on board the vessel when the pots are recovered, and questions animal welfare due to handling-related injuries and possible mortality (Winger & Walsh, 2011; Urban, 2015). The snow crab pot fishery involves two subsequent processes. First, an attraction process supported by the bait odour where the crabs enter the pot attracted by bait, such as squid (*Illex* spp.) (Miller, 1990; Olsen, Herrmann, Sistiaga, & Grimaldo, 2019). Second, a size selection process where the smallest snow crabs that entered the pot pass through the pot netting meshes and escape (Olsen, Herrmann, Sistiaga, & Grimaldo, 2019; Olsen, Herrmann, Sistiaga, & Grimaldo, 2019); a process that is assumed to be associated to the loss of bait odour over time of pot soaking (i.e., the duration the pot is deployed) (Olsen, Herrmann, Sistiaga, & Grimaldo, 2019). Thus, when snow crabs are no longer attracted by the bait odour, more crabs attempt escaping the pot. To allow escape of the undersized crabs, the mesh sizes of pots typically used in the Barents Sea vary from 120 to 150 mm (Olsen, Herrmann, Sistiaga, & Grimaldo, 2019). During the escape process, undersized snow crabs need enough time to approach the netting meshes and then position themselves for successful escape (Winger & Walsh, 2007). Therefore, the size selection potential of the pots can only be fully utilized when they are deployed for a certain time. However, in the commercial snow crab fishery, the pot soak time varies due to operational conditions.

In the Barents Sea commercial snow crab fishery, an increase in catch efficiency of the conical pots is important since the number of pots used by each vessel is restricted. The use of artificial lights in addition to bait to increase catch efficiency has been applied in different pot fisheries (i.e., Bryhn et al., 2014; Humborstad et al., 2018). The response behaviour of the target species to artificial light is species, size, and context dependent. Previous experiments using LEDs in snow crab pots have shown varying results. Specifically, a significant increase in catch efficiency in snow crab fishery both off the east coast of Canada and in the Barents Sea has been observed (Cerbule et al., 2021; Nguyen et al., 2017, 2019; Nguyen & Winger, 2019a). In Canada, an increase in catch per unit of effort (CPUE) by up to 77% has been reported when using white LEDs (Nguyen et al., 2017). In the Barents Sea, however, adding white LEDs have given mixed results, i.e., an increase in catch efficiency of 52–53% (Cerbule et al., 2021), while no significant increase in CPUE was observed by Nguyen et al. (2019). However, experiments in these studies used different pot soak times that might have affected the catch efficiency. Therefore, more studies are required for assessing the prospect of using white LEDs to increase snow crab catch efficiency in the Barents Sea while considering different soaking times. Thus, the aim of this study is to address the following research questions:

- Is there any size-dependent effect on the catch efficiency of snow crab when using white LEDs in addition to bait in the snow crab pots?
- Does the effect of white LEDs on snow crab capture efficiency depend on pot soak time?

2. Materials and methods

2.1. Pots and LEDs

The pots used in these experiments were identical to those used in the commercial fishery for snow crab in the Barents Sea and along the east coast of Canada (Olsen, Herrmann, Grimaldo, & Sistiaga, 2019; Winger & Walsh, 2011). The pot frame consisted of a lower ring (Ø130 cm, Ø14 mm steel bar) and a top ring (Ø70 cm, Ø12 mm steel bar) connected by steel bars (Ø12 mm) to give a pot height of 60 cm. The top diameter of the plastic entrance cone located in the center of the top ring was 55 cm. The weight of each pot was approximately 12.5 kg. The pot frames were covered with a diamond mesh netting with a 140 mm mesh size made of Ø4 mm single braided polyethylene twine. The 140 mm mesh size in the pot netting provides a 50% probability for legal-sized snow crab for escaping or being retained (CW50) since the CW50 for snow crab in such pots is estimated to be approximately 95 mm (Herrmann et al., 2021).

An acorn-shaped LED fishing lights (DYP-200, Dongyang Engineering Co., Ltd.) emitting white, continuous light were chosen to enhance the attraction of snow crabs to the test pots. The housing of the DYP-200 light contains one LED that emits light through the cap. The light can be turned on manually or automatically when submerged in water. It is positively buoyant, suggesting a vertical position under water with the light beam directed upwards. It has a maximum operation depth of 700 m, and a battery life of approximately 300 h. The scalar irradiance spectrum of the LED was measured using a hyperspectral radiometer (Ramses ASC VIS, TriOS GmbH, Germany) (Fig. 1).

The sensitivity of the sensor was 6 × 10–4 mW m^{-2} nm^{-1} @ 500 nm. For comparison of light levels, a second light source, ProGlow (Fishtek Marine Ltd., UK), previously used in Cerbule et al. (2021), was also measured. The ProGlow housing contains one LED and has a shape of a rounded, flat rectangular cuboid. It is turned on automatically when submerged in water. This light is negatively buoyant, has a maximum operation depth of 1200 m, and a battery life of approximately 500 h. A distance of 30 cm between the LED and the sensor was chosen to obtain measurements of both light sources.

The scalar irradiance was measured for each 3.3 nm. Both lights were measured with the axis of the radiation lobe of the diode angled 0°, 45°, and 90° relative to the longitudinal axis of the radiometer (Fig. 1a–c). In the 0° position, measurements were also made in 1 h intervals for 14 days, i.e., the maximum soak time during which the lights were employed during the fishing trials. All measurements were conducted in air in a dark room at 4 °C, which corresponds to the expected water temperature at the seabed (Townsend, 2012, pp. 112–149) where the fishing takes place. A baseline measurement was made to document the light level of the dark room without any illumination from the tested light sources.

The spectrums of DYP-200 (used in this study) and ProGlow (used in Cerbule et al. (2021)) were similar in their wavelength distributions (Fig. 2). Both had a peak wavelength of 450 nm and a second peak at 540–547 nm. The irradiance of DYP-200 was, however, two orders of magnitude higher (max value: 5.0 mW m^{-2} nm^{-1}) than for ProGlow (max value: 0.023 mW m^{-2} nm^{-1}). Both light types gave different levels of irradiance at different angles relative to the sensor, which were related to their different degree of directionality. DYP-200 positioned at 45° and 90° relative to the sensor gave similar irradiance levels (peak value: 0.8 mW m^{-2} nm^{-1} and peak value: 0.4 mW m^{-2} nm^{-1}, respectively) that were lower than when positioned at 0° (peak value: 5.0 mW m^{-2} nm^{-1}), while the ProGlow, which had a wider beam spread, gave similar irradiance levels when positioned 0° (peak value: 0.023 mW m^{-2} nm^{-1}) and 45° (peak value: 0.019 mW m^{-2} nm^{-1}) relative to the sensor,

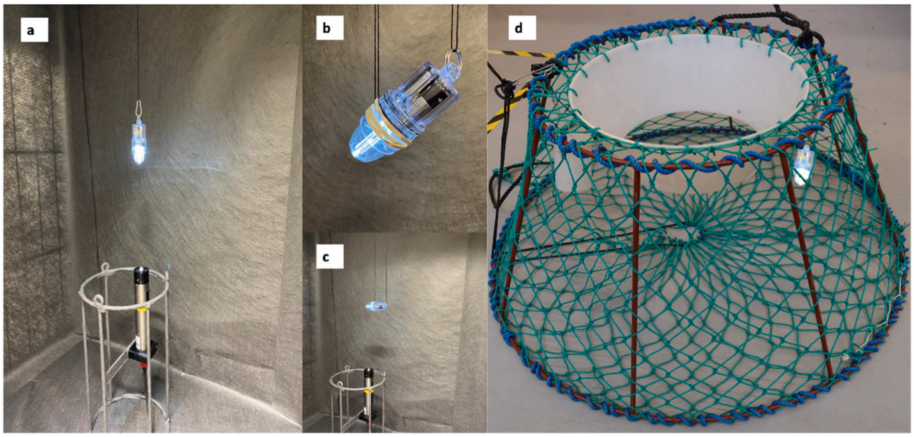

Fig. 1. Experimental setup during the scalar irradiance spectrum measurements (**a-c**) and experimental setup for attaching the light in the snow crab pots (**image d**). The LEDs were measured with the axis of the radiation lobe of the diode angled 0° (**image a**), 45° (**image b**), and 90° (**image c**) relative to the longitudinal axis of the radiometer.

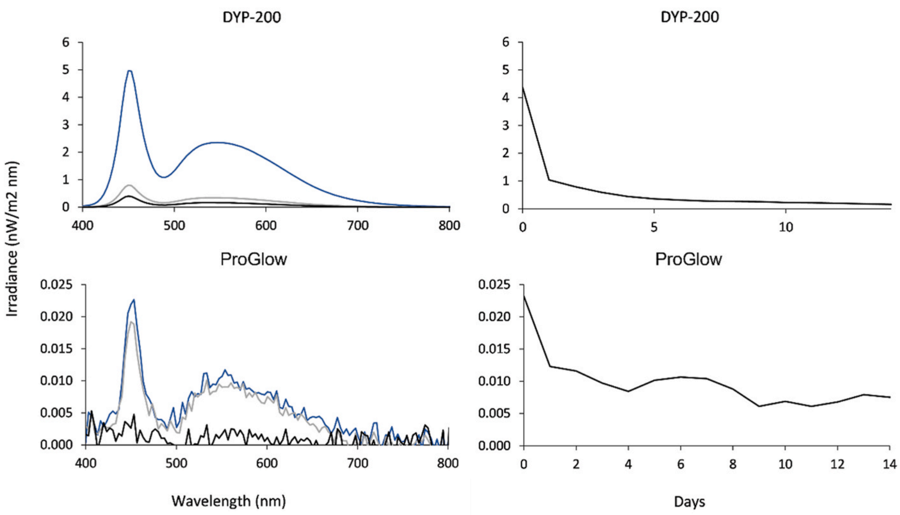

Fig. 2. Irradiance and change in peak irradiance of the two white LED sources. **Left:** The irradiance of DYP-200 (upper plot) and ProGlow (lower plot). The light sources were positioned at three different angles relative to the sensor with 0° (black line), 45° (grey line), and 90° (blue line). **Right**: the change in peak irradiance (450 nm) over a period of 14 days of DYP-200 (upper plot) and ProGlow (lower plot).

and these where higher than when positioned at 90° (peak value: 0.005 mW m^{-2} nm^{-1}). The irradiance of both light types dropped over the 14-day observation period when deployed at 4 °C. The reduction was largest during the first 24 h, and larger for DYP-200 (3.3 mW m^{-2} nm^{-1}) than ProGlow (0.01 mW m^{-2} nm^{-1}). Nevertheless, the irradiance level of DYP-200 remained higher than that of the ProGlow throughout the 14 days of observation.

2.2. Sea trials and data collection

Sea trials were conducted on board the commercial fishing vessel "Northeastern" (55.2 m LOA and 2250 HP) operating 9000 pots, with a capacity of deploying and retrieving up to 2000 pots per day. Comparative fishing experiments were conducted from 7th to 25th of October 2020 in the Barents Sea (latitude between N76°10.80 and N76°49.10; longitude between E36°21.50 and E37°58.70). The depths of the fishing grounds varied between 220 and 278 m.

The pots were attached on longlines by a quick-link system with a 30 m distance between each pot. To compare the catch efficiency of baited pots and test pots with inserted LEDs in addition to bait, herein called baseline and test pots, respectively, they were attached to the same longline where each test pot was followed by two or three baseline pots (Fig. 3). This deployment pattern was used to ensure that test and baseline pots were exposed to the same abundance and size structure of the fished snow crab population during the experiments (i.e., Olsen, Herrmann, Sistiaga, & Grimaldo, 2019; Cerbule et al., 2021).

Six experiments (series) with different soak times were conducted during the sea trials. The soaking time of those six series varied between 2 and 14 days. Each series consisted of one longline with test and baseline pots, except the Series six which consisted of two longlines in the same fishing area (Fig. 3b). Series four and five were deployed in different areas and at different times; therefore, they were considered separately even though both series had the same pot soak time. As the trials took place in a commercial fishery, additional baseline pots were added to Series six to increase the commercial catches (Fig. 3b). Such additional pots (i.e., 65 pots for both lines in Series six) were excluded from the analysis of this study when comparing the test and baseline pots due to possible differences in snow crab abundance and size of the population present at the particular pot position.

On each longline, test pots with bait and LEDs were deployed in alternated order with baseline pots that were using the bait only (Fig. 3a). Each pot (both test and baseline pots) was baited with

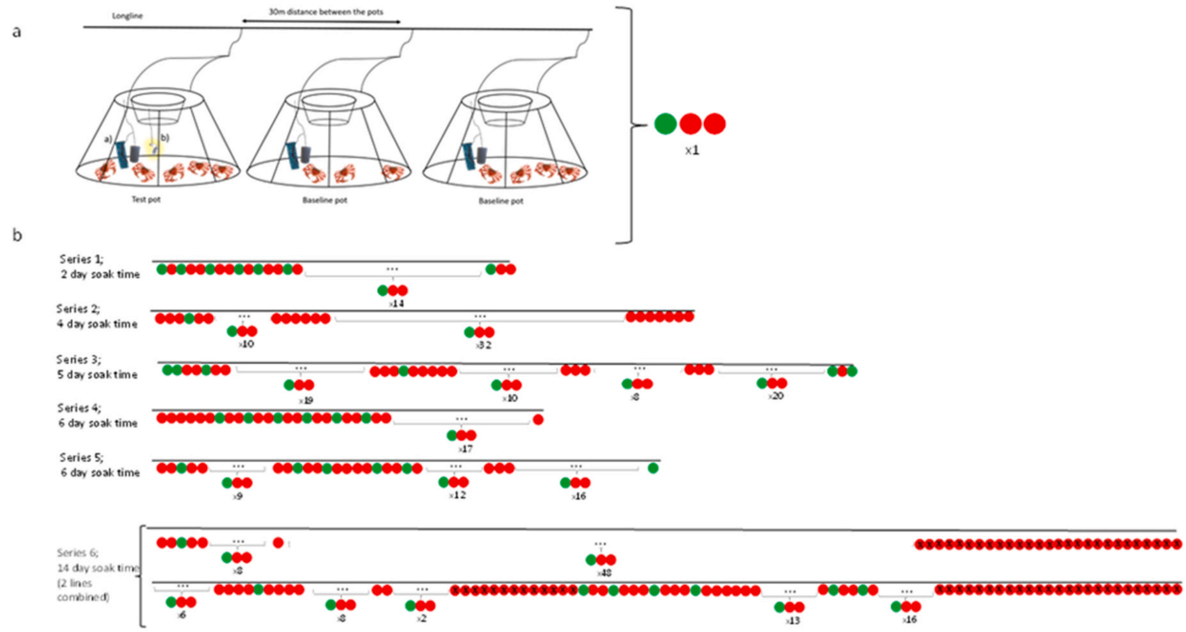

Fig. 3. Experimental setup. **Image a**: Each test pot was equipped with a) bait (bait container and bait bag) and b) a LED (DYP-200). Test pots were alternated with pots using bait only (baseline pots). The distance between the pots on the longline was kept to approximately 30 m. **Image b**: arrangement of test (green circles) and baseline (red circles) pots on the longline in each of the six series. Crossed red circles in Series 6 mean pots that have been excluded from the analysis (65 pots in total). Series 6 consisted of pots deployed on two longlines with same deployment time and fishing area.

approximately 1 kg whole squid (*Illex* spp.) using one small mesh bait bag and a plastic bait container. Therefore, the bait was distributed with 0.5 kg squid in the bag and 0.5 kg in the bait container following the configuration used in the commercial snow crab fishery (Araya-Schmidt et al., 2019).

When the pots were hauled on board, they were emptied separately on a sorting board. Snow crab was measured for their CW according to Jadamec et al. (1999) for individuals with CW sizes from 75 mm. The catch was measured in 1 cm wide size classes, which is often used in fishing gear selectivity and catch efficiency studies (Herrmann et al., 2017; Wileman et al., 1996). The number of pots that did not retain any snow crab was also recorded.

2.3. 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 snow crab 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.

2.4. Estimation of the effect of artificial light on the snow crab catch efficiency

2.4.1. Estimation of the mean number of snow crab captured in each test and baseline pot

The capture efficiency of pots with and without the use of artificial light was assessed for the six series. To compare the catch performance between the test and baseline pots, we first estimated the mean number of snow crab captured (expressed as capture per unit effort (CPUE) per deployment) in each treatment pot with use of artificial light and baseline pot that did not contain the LED in each of the six series separately by:

$$CPUE_t = \frac{\sum_{i=1}^{Kt} nt_i}{Kt} \qquad CPUE_b = \frac{\sum_{i=1}^{Kb} nb_i}{Kb} \tag{1}$$

In Eq. (1), *nt* is the number of snow crab in test pots while *nb* is the number of snow crab retained in the baseline pots. *Kt* and *Kb* are the number of pots on test and baseline mainlines in each of the six series, respectively.

Uncertainties are obtained using a nested bootstrap approach (Efron, 1982) as described below. First, in an outer resampling loop, the groups of test and baseline pots, respectively, was resampled separately. Second, each time a specific pot i was drawn in the outer resampling, its catch in terms of number crab nt_i or nb_i was resampled with replacement in an inner resampling. This nested resampling procedure led to a set of values for $\sum_{i=1}^{Kt} nt_i$, $\sum_{i=1}^{Kb} nb_i$, which by applying (1), led to a set of values for $CPUE_t$ and $CPUE_b$. Repeating this resampling scheme 1000 times led to a population of 1000 results for $CPUE_t$ and $CPUE_b$, which were applied to obtain Efron 95% percentile confidence intervals (CI) for each of those performance parameters (Efron, 1982). Specifically, the 1000 values for each parameter were sorted and ranked after their value. Based on this, the lower bound value for the 95% confidence limit was obtained by inspecting the value that was the 25th lowest value. Similarly, the upper bound confidence limit was the one with the 975th lowest value. We used the statistical software SELNET for the analysis of the data (Herrmann et al., 2012).

2.4.2. Modelling the relative size-dependent catch efficiency between pots with and without LED

Contrary to estimating the absolute catch efficiency (i.e., the $CPUE_t$

and $CPUE_b$ as described in 2.3.1.), the relative catch efficiency between test and baseline pots can be estimated based on catch data from the experimental fishing (i.e., Olsen, Herrmann, Grimaldo, & Sistiaga, 2019; Cerbule et al., 2021). This approach, in contrast to CPUE, does not depend on the size-dependent availability of snow crab on the fishing grounds, thus providing a result that is of broader relevance than when estimating the case-specific total catch rate (Olsen, Herrmann, Grimaldo, & Sistiaga, 2019). To use this approach, the test and baseline pots for each of the six series were deployed simultaneously on the same fishing grounds with same soaking time and bait.

In this study, we used the relative size-dependent catch efficiency between the test and baseline pots to isolate and quantify the effect on catch efficiency of adding LEDs to baited snow crab pots. Estimation of the relative catch efficiency is a well-established method used for comparing catch efficiency in passive fishing gears (Brčić et al., 2017; Herrmann et al., 2017) and has been applied in a previous study estimating the effect of LEDs on snow crab catch efficiency (Cerbule et al., 2021).

The relative size-dependent catch efficiency between pots with and without LEDs was independently estimated for each of the six series applying the same approach as in Cerbule et al. (2021) using an unpaired catch comparison and catch ratio analysis (Herrmann et al., 2017). We were interested in the size-dependent catch comparison rate values summed over the deployments carried out using test and baseline pots in each series. During the sea trials, the catch data obtained for test and baseline pots were not collected in pairs, nor did they have the same total number of deployments as each test pot was mainly followed by two or three baseline pots on each longline in each of the six series (Fig. 1b). Hence, to estimate the functional form of the summed catch comparison rate (the experimental rate being expressed by Equation (3) for test against baseline pots), the catch data from the deployments of both types of pots were summed and compared with the summed data of the pot deployments by minimizing the following expression:

$$-\sum_{w}\left\{\sum_{i=1}^{tq}\left[nt_{wi}\times ln(CC(w,\boldsymbol{v}))\right]+\sum_{j=1}^{bq}\left[nb_{wj}\times ln(1.0-CC(w,\boldsymbol{v}))\right]\right\} \tag{2}$$

In the Expression (2), $\boldsymbol{v}$ is a vector representing the parameters of the function describing the catch comparison curve defined by $CC(w, \boldsymbol{v})$. nt_{wi} and nb_{wj} are the numbers of snow crab measured in each CW size class w for test and baseline pots, respectively. In Expression (2), tq and bq are the number of deployments carried out with test and baseline pots. The inner summations in the equation represent the summations of the data from the deployments, and the outer summation in the expression is the summation over the size classes w. Minimizing Expression (2) is equivalent to maximizing the likelihood for the observed data based on a maximum likelihood formulation for binominal data (Herrmann et al., 2013). The experimental summed catch comparison rate, CC_w, is given by:

$$CC_w=\frac{\sum_{i=1}^{tq}nt_{wi}}{\sum_{i=1}^{tq}nt_{wi}+\sum_{j=1}^{bq}nb_{wj}} \tag{3}$$

The experimental CC_w is often modelled by the function $CC(w, \boldsymbol{v})$ (Krag et al., 2014):

$$CC(w,\boldsymbol{v})=\frac{exp(f(w,v_0,\ldots,v_k))}{1+exp(f(w,v_0,\ldots,v_k))} \tag{4}$$

In Equation (4), f is a polynomial of order k with coefficients from v_0 to v_k. We considered f of up to an order of 4 with parameters $v_0 \ldots v_4$. Leaving out one or more of the parameters $v_0 \ldots v_4$ led to 31 additional models. These were also considered as potential models for the catch comparison $CC(w, \boldsymbol{v})$ between test and baseline pots. Among these models, estimations of the catch comparison rate were made using a multi-model inference to obtain a combined model (Burnham & Anderson, 2002; Herrmann et al., 2017).

The ability of the combined model to describe the experimental data was evaluated based on the p-value. This value quantifies the probability of obtaining by coincidence at least as big a discrepancy between the experimental data and the model as observed. The p-value, 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 (Wileman et al., 1996).

Further, based on the estimated catch comparison function $CC(w, \boldsymbol{v})$ (Equation (4)), we obtained the relative catch efficiency (also named catch ratio) $CR(w, \boldsymbol{v})$ between the test and baseline pots as follows (Herrmann et al., 2017):

$$CR(w,\boldsymbol{v})=\frac{qb\times CC(w,\boldsymbol{v})}{qa\times(1-CC(w,\boldsymbol{v}))} \tag{5}$$

The catch ratio $CR(w, \boldsymbol{v})$ value represents the ratio between catch efficiency of pots with and without the use of LEDs (i.e., test and baseline pots). Since we used the same type of pots for the test and baseline, any difference in the catch ratio would be a result of adding LEDs to the test pots. Thus, if the catch efficiency of both pot types is equal, $CR(w, \boldsymbol{v})$ should always be 1.0 meaning that there is no effect of adding LEDs on the catch efficiency of the pots, whereas a 70% increase in catch efficiency by using LEDs would be shown if $CR(w, \boldsymbol{v}) = 1.7$. The CIs for the catch comparison curve and catch ratio curve were estimated using double bootstrapping (i.e., Herrmann et al., 2017; Cerbule et al., 2021).

To identify sizes of snow crab with significant difference in catch efficiency, we checked for snow crab CW size classes in which the 95% CI for the combined catch comparison curve did not contain value of $tq/(tq + bq)$ and value of 1.0 for the catch ratio curve. We used the statistical software SELNET for the analysis of the data (Herrmann et al., 2012).

2.4.3. Estimation of size-integrated catch ratio between test and baseline pots

In addition to modelling the relative size-dependent catch efficiency between pots with and without lights, we used a size-averaged value to estimate the effect of adding white LEDs on the snow crab catch efficiency. In contrast to the size-dependent evaluation of the catch ratio, $CR_{average}$ is specific for the snow crab population structure encountered during the experimental sea trials, and it cannot be extrapolated to other scenarios in which the size structure of the snow crab population may be different because of different time period and fishing area (Olsen, Herrmann, Sistiaga, & Grimaldo, 2019). The size-integrated average values (in percentage) for the catch ratio ($CR_{average}$) were estimated directly from the experimental catch data using the following equation:

$$\begin{aligned}
CR_{average} &= 100\times\frac{qb\times\sum_{w}\sum_{i=1}^{tq}nt_{wi}}{qa\times\sum_{w}\sum_{j=1}^{bq}nb_{wj}}\\
CR_{average-} &= 100\times\frac{qb\times\sum_{w<mw}\sum_{i=1}^{tq}nt_{wi}}{qa\times\sum_{w<mw}\sum_{j=1}^{bq}nb_{wj}}\\
CR_{average+} &= 100\times\frac{qb\times\sum_{w\geq mw}\sum_{i=1}^{tq}nt_{wi}}{qa\times\sum_{w\geq mw}\sum_{j=1}^{bq}nb_{wj}}
\end{aligned} \tag{6}$$

In Equation (6), the outer summations include the CW size classes of the snow crab in the catch that are under ($CR_{average-}$) and over ($CR_{average+}$) the MLS ($mw = 95$ mm CW) of snow crab.

2.5. *Modelling the size-dependent catch efficiency between baseline pots*

The baseline pots in each series were deployed with 30 m or ≥60 m distance from the test pots in Series two, three and Series six while in other series each test pot was followed by only two baseline pots with few exceptions (Fig. 1b). It is not known if the 30 m distance between the pots as used in commercial fishery is sufficient to avoid light pollution, or if some light at the test pots reaches neighbouring baseline pots (Cerbule et al., 2021)and the light level that can attract snow crab is unknown. To estimate whether there is a difference in catch efficiency between the baseline pots located close to the test pots (with a 30 m distance) and further away from the LEDs (≥60 m), we used the same method by estimating catch comparison rate and catch ratio between the two types of baseline pots (Cerbule et al., 2021; Herrmann et al., 2017). Further, we used the same approach for estimating CIs for the catch comparison and catch ratio curves (Cerbule et al., 2021; Herrmann et al., 2017).

2.6. *Estimating the effect of changing pot soak time*

2.6.1. *Estimating the effect of changing the soak time on the catch ratio*

To infer the effect of changing pot soak time between series with different soak times (i.e., Series 1 with soak time of 2 days (A) to Series 2 with 4 day soak time (B), etc.) on the catch ratio curve $CR(w, \boldsymbol{v})$ where both catch ratio curves are obtained against the same baseline (i.e., baited snow crab pots without light), the size-dependent change $CR_{A/B}(w,\boldsymbol{v})$ in the values was estimated by (Cerbule et al., 2022; Jacques et al., 2021):

$$CR_{A/B} = \frac{CR_A(w,\boldsymbol{v})}{CR_B(w,\boldsymbol{v})} \tag{7}$$

where CR_A $(w, \boldsymbol{v})$ and CR_B $(w, \boldsymbol{v})$ are catch ratio values for Series with different soak time. Efron 95% percentile CIs were obtained based on the two $CR_{A/B}$ $(w, \boldsymbol{v})$ bootstrap populations of results (1000 bootstrap repetitions in each) for both CR_A $(w, \boldsymbol{v})$ and CR_B $(w, \boldsymbol{v})$ (Herrmann et al., 2017). As they were obtained independently, a new bootstrap population of results was created by:

$$CR_{A/B}(w)_i = \frac{CR_A(w,\boldsymbol{v})_i}{CR_B(w,\boldsymbol{v})_i} \quad i \in [1 \ldots 1000] \tag{8}$$

where i is the bootstrap repetition index. As the bootstrap resampling was random and independent for the two results, it is valid to generate the bootstrap population of results for the difference based on Equation (8) using the two independently generated bootstrap files (Herrmann et al., 2018).

2.6.2. *Effect of soak time on average catch ratio*

To investigate the effect that the pot soak time (ST) has on the size-integrated catch ratio ($CR_{average}(ST)$), Equation (10) was calculated for individual soak times without the summation over different Series (Grimaldo et al., 2020). This was applied individually for $CR_{average+}$ and $CR_{average-}$. Based on this equation, we tested whether the value for $CR_{average}$ changed linearly with different soaking time using the following equation:

$$CR_{average}(ST) = \alpha \times ST + \beta \tag{9}$$

The last part of the analysis using model (9) was conducted using the linear model function (lm) in the statistical package R (version 2.15.2; www.r-project.org).

3. Results

The six experimental series contained between 21 and 110 test pots and 39 to 236 baseline pots (Table 1).

The number of snow crab in test and baseline pots varied between the six series. In total, 1361 snow crabs were measured for the test pots and 2587 for the baseline pots; therefore, CW size measurements of total 3948 snow crab were included in this study.

Table 1

Experimental data sets of six series. Corresponding soak time and start position of the lines, depth, number of test and baseline pots used for captured snow crab carapace width measurements, and the number of snow crab retained in test and baseline pots in each series. In Series 6, the starting position represents the start position of the first of the two longlines.

	Series 1	Series 2	Series 3	Series 4	Series 5	Series 6
Pot soak time (days)	2	4	5	6	6	14
Position of deployment at the start of the line	N 76 ^{O} 13.90 E 37 ^{O} 37.10	N 76 ^{O} 18.40 E 37 ^{O} 19.40	N 76 ^{O} 49.10 E 37 ^{O} 58.70	N 76 ^{O} 17.00[E 37 ^{O} 25.00	N 76 ^{O} 24.40 E 36 ^{O} 21.50	N 76 ^{O} 15.31 E 37 ^{O} 58.12
Depth (m)	270	278	220	270	273	262
Number of test pots (*tq*)	21	44	64	22	43	110
Number of baseline pots (*bq*)	39	104	134	49	91	236
Crab in test pots (*nt*)	160	142	480	101	186	292
Crab in baseline pots (*nb*)	247	310	738	197	403	692

3.1. *Mean number of snow crab captured in each pot in pots with and without artificial light*

Results in Table 2 and Fig. 4 show that in five of the six experiments there was no significant difference between the mean number of crabs captured in each pot when pots with and without LEDs were compared. Specifically, in Series 3, the $CPUE_t$ for the test pots was 7.50 (CI: 6.62–8.42) while it was 5.51 (CI: 5.07–6.00) for the baseline pots ($CPUE_b$). For the remaining five series, no significant differences were observed (i.e., Series 1–2 and Series 4–6) as test and baseline pots did not capture significantly different amounts of snow crab.

However, the mean number of captured snow crab differed significantly between the series conducted in different locations (Fig. 4). The CPUE estimation depends on the spatial and temporal size-dependent availability of snow crab on the specific fishing grounds as shown in Fig. 4.

Therefore, the results of the CPUE estimation cannot be generalized to other locations and different seasons. Further, the absolute catch for each pot type depends on soak time in an unknown way (Olsen, Herrmann, Sistiaga, & Grimaldo, 2019). Specifically, the capture process in pots involves an attraction/entry process and a subsequent but overlapping size selection process, where some of the crabs that have entered a pot can escape, affecting the total catch in the snow crab pots.

Table 2

Results with mean number of snow crab captured in test (*CPUEt*) and baseline pots (*CPUEb*) with and without attached LEDs, respectively. Numbers in parentheses are 95% confidence intervals.

	Test pots (*CPUEt*)	Baseline pots (*CPUEb*)
Series 1	7.62 (6.33–9.05)	6.33 (5.10–7.61)
Series 2	3.23 (2.73–3.75)	2.98 (2.61–3.39)
Series 3	7.50 (6.62–8.42)	5.51 (5.07–6.00)
Series 4	4.59 (3.54–5.59)	4.02 (3.33–4.75)
Series 5	4.33 (3.44–5.35)	4.43 (3.86–5.01)
Series 6	2.65 (2.32–3.01)	2.31 (2.13–2.51)

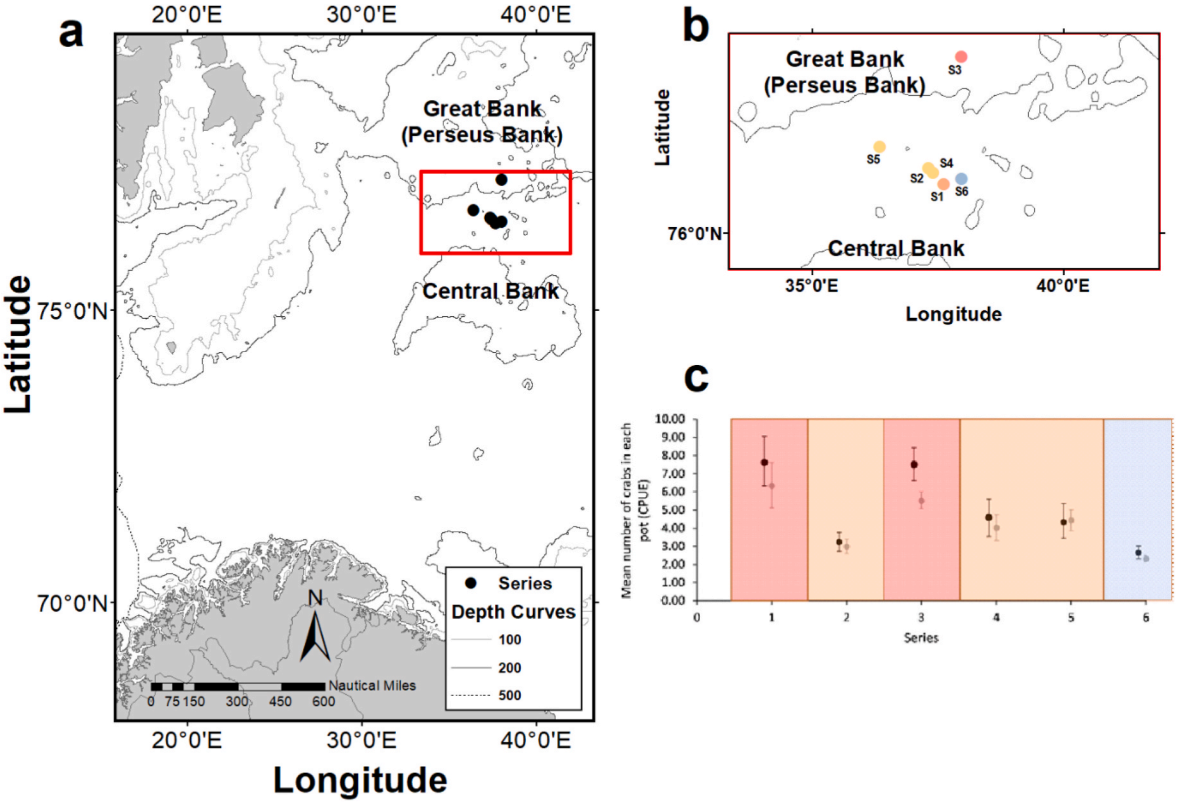

Fig. 4. Illustration of the area where the fishing trials were conducted and the mean number of snow crab in each pot (CPUE) captured in the six series. **Image a** and **image b** show the location and depth (m) for each of the six series. **Image c** shows the plot with mean number of crabs in treatment (black) and baseline (grey) pots with and without artificial light, respectively. Colours in **b** and **c** visualize the observed mean number of crabs observed in the locations where the experiments were conducted.

3.2. Relative size-dependent catch efficiency between pots with and without LEDs

To account for spatial and temporal differences in snow crab abundance, we further estimated the size-dependent relative catch efficiency between test and baseline pots in each series.

The length distribution of snow crab showed that both test and baseline pots retained a large proportion of individuals between 75 mm and 95 mm CW, thus below the MLS of 95 mm CW (Fig. 5).

The *p*-values for three of six series were below 0.05 (Table 3) (Series 2, 3 and 5). Therefore, the deviations between the experimental catch comparison points and the fitted curve (Fig. 6) were examined for these cases to determine whether the deviations were due to structural problems in describing the experimental data by the modelled catch comparison curve or due to data overdispersion. As no clear pattern in the deviation between the experimental points and fitted curves were detected, we assumed that the low *p*-values were to be associated to overdispersion in the data (Wileman et al., 1996). Therefore, we

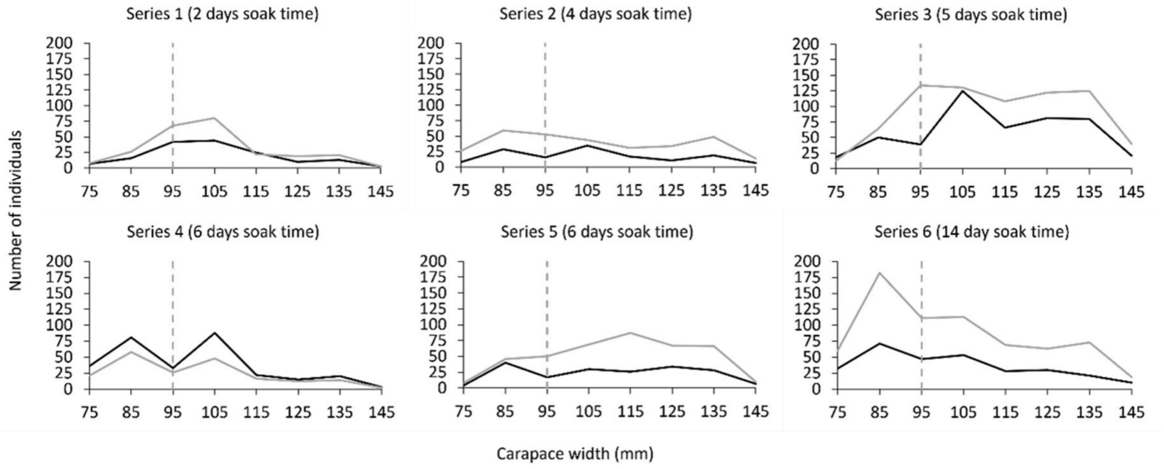

Fig. 5. Population caught in test pots using LEDs (black line) and baseline pots (grey line). Grey stippled vertical line represents the minimum landing size of the snow crab (95 mm carapace width). The comparison of capture rates between test and baseline pots in the individual lines needs to further account for difference in number of test and baseline pots in each series.

Table 3
Catch ratio results (%) and fit statistics for pots with added LEDs versus the baseline pots for each series. Values in parentheses represent 95% confidence intervals. DOF = degrees of freedom.

	Series 1	Series 2	Series 3	Series 4	Series 5	Series 6
Pot soak time (days)	2	4	5	6	6	14
p-value	0.1405	0.0168	<0.001	0.087	0.0433	0.1982
DOF	3	3	5	3	3	4
Deviance	5.47	10.22	38.19	11.65	8.13	6.01
$CR_{average}$	120.30 (92.53–156.67)	114.19 (83.94–149.28)	136.18 (116.53–158.97)	108.27 (88.45–129.92)	97.67 (74.66–124.02)	115.08 (98.33–133.57)
$CR_{average-}$	125.63 (43.85–259.45)	102.89 (58.64–159.37)	184.90 (111.25–287.23)	107.13 (62.27–172.03)	172.44 (95.28–284.72)	116.08 (86.45–149.44)
$CR_{average+}$	119.45 (87.60–157.20)	110.30 (85.22–139.41)	130.50 (107.76–156.84)	118.91 (67.23–187.02)	86.11 (60.95–120.59)	114.54 (90.16–141.70)

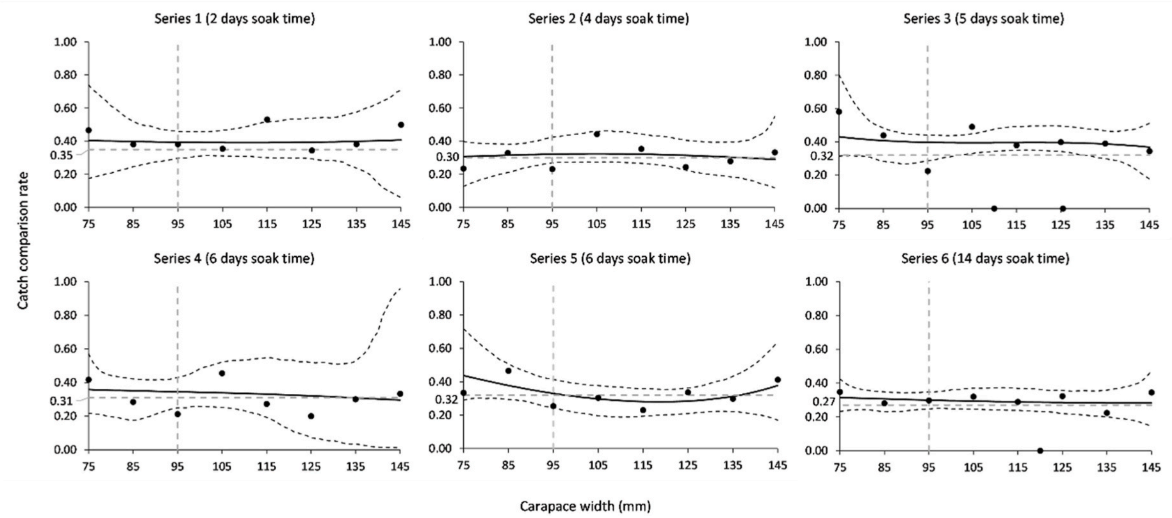

Fig. 6. Catch comparison rates for baseline pots against test pots using white LEDs. Circle marks represent experimental catch comparison rate. Black solid line represents the mean estimated curve and the stippled lines represent the 95% confidence intervals. Horizontal stippled grey lines represent baseline for no significant effect of adding artificial lights on catch comparison rate. Grey stippled vertical line represents the minimum landing size of the snow crab (95 mm carapace width).

assumed the model can be used to assess the effect on catch efficiency by adding artificial lights to standard commercial pots.

There was an indication that the estimated catch efficiency for the pots using artificial light was larger than that of the baseline pots using only the bait (Tables 3 and 4; Fig. 6). The results averaged over size classes for crab over the MLS, showed that the test pots retained from 10 to 30% ($CR_{average+}$) more snow crab than the baseline except for Series 5, where the test pots retained 13% less snow crab compared to the

Table 4
Catch ratio (*CR* (*w*)) (%). Values in parentheses represent 95% confidence intervals.

	CR (*w*) (%) to baseline pot					
	Series 1	Series 2	Series 3	Series 4	Series 5	Series 6
Pot soak time (days)	2	4	5	6	6	14
***w* (mm)**						
75	126.22 (9.15–495.78)	104.88 (45.16–167.80)	158.22 (0.00–736.60)	124.37 (45.57–279.60)	164.52 (42.75–495.72)	125.34 (77.14–195.46)
85	123.10 (61.50–201.98)	109.09 (68.03–150.76)	144.03 (90.40–202.79)	120.47 (59.87–175.33)	128.60 (76.27–206.86)	120.53 (84.83–148.85)
95	120.92 (83.23–162.20)	121.13 (80.96–168.74)	137.92 (97.74–179.15)	117.30 (75.27–169.27)	104.34 (66.31–147.61)	116.61 (90.13–146.03)
105	119.75 (84.32–163.05)	113.24 (76.76–187.47)	136.44 (104.85–172.30)	114.03 (58.31–225.70)	89.56 (53.33–129.81)	113.40 (85.34–157.04)
115	119.75 (84.32–163.05)	120.89 (76.66–179.56)	136.94 (101.23–190.87)	110.07 (37.46–253.24)	82.80 (52.34–119.68)	110.82 (81.53–154.62)
125	119.69 (73.54–191.38)	108.68 (68.28–160.39)	136.65 (97.04–192.63)	105.18 (16.34–239.49)	84.12 (55.16–119.51)	108.84 (75.63–149.83)
135	123.51 (49.32–243.66)	103.33 (57.29–158.65)	132.37 (89.38–182.97)	99.47 (15.71–255.22)	96.38 (54.64–156.57)	107.57 (69.41–153.42)
145	127.88 (0.00–417.85)	96.86 (16.78–272.56)	121.70 (50.45–224.51)	93.69 (0.00–93.69)	128.55 (23.54–354.13)	107.23 (36.30–236.81)

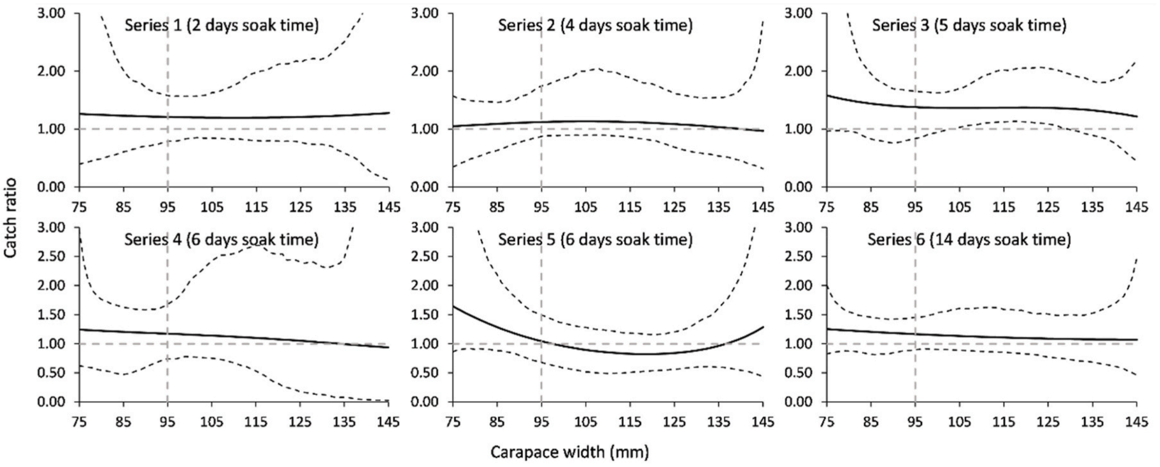

Fig. 7. Catch ratio results for test pots using LEDs versus the baseline pots. Black solid lines represent the mean estimated curves and the stippled lines represent the 95% confidence intervals. Horizontal stippled lines represent baseline for no significant effect of adding artificial lights. Grey vertical stippled lines represent the minimum landing size of snow crab (95 mm carapace width).

baseline pots for snow crab above the MLS ($CR_{average+}$ = 86.11 (CI: 60.95–120.59)) (Table 4). However, these results were only statistically significant for one of the six series (Series 3; $CR_{average+}$ = 130.50 (CI: 107.76–156.84); Table 3). For undersized snow crab (i.e., snow crab <95 mm CW), the test pots retained more snow crab compared to the baseline pots. However, these results were not significantly different from the number observed in the baseline pots on average in all series (Tables 3 and 4).

The catch comparison and catch ratio curves showed that both test and baseline pots retained a large proportion of snow crab under MLS of 95 mm CW (Fig. 7). The difference between test and baseline pots were not statistically significant in any of the series.

3.3. Size-dependent catch efficiency between baseline pots with different distance to test pots with LEDs

The fit statistics for the relative size-dependent catch efficiency estimation between baseline pots showed that the *p*-value for one of the series (Series two) was below 0.05 (Table 5). However, as no clear pattern in the deviation between the experimental points and fitted curves were detected (Fig. 8), we assumed that the low *p*-value for Series two was associated to overdispersion in the data (Wileman et al., 1996). Therefore, we assumed the model described the data sufficiently well.

The catch efficiency between the two sets of baseline pots in Series two, three and six deployed 30 m and ≥60 m from the test pot with LED, respectively, did not show any significant differences. Specifically, the baseline pots without LEDs pots deployed ≥60 m away from the light source (i.e., test pot) compared to those 30 m from the test pots showed similar catch efficiency for all sizes of snow crab observed (Fig. 8). This result further suggests that the effect from the LEDs (test pots) is not extending to the nearest baseline pots which are deployed on the same mainline with 30 m distance (Table 5; Fig. 8). Thus, we can be more confident about our results when comparing the test and baseline pots in the described experimental setup (Fig. 3).

3.4. Effect of changing pot soak time

3.4.1. Effect of changing pot soak time on catch ratio

The size-dependent change in catch ratio between pots of different soak time ($CR_{A/B}(w, \mathbf{v})$) did not show significant difference in capture of snow crab except one instance comparing Series 2 and Series 5 for snow crab with CW size of 105–125 cm (Fig. 9). In that instance, more snow crab was retained in pots in Series 2 with 4 days soak time compared to Series 5.

Table 5
Fit statistics and average catch ratio results ($CR_{average}$) (%) obtained for baseline pots with ≥60 m distance from the test pots with LEDs against baseline pots with 30 m distance from the LED. DOF = degrees of freedom.

	Series 2 (4-day soak time)	Series 3 (5-day soak time)	Series 6 (14-day soak time)
p-value	0.0269	0.3731	0.3045
Deviance	9.18	5.36	6.02
DOF	3	5	5
$CR_{average}$	102.08 (77.54–129.55)	86.59 (63.98–110.34)	108.12 (92.45–130.41)

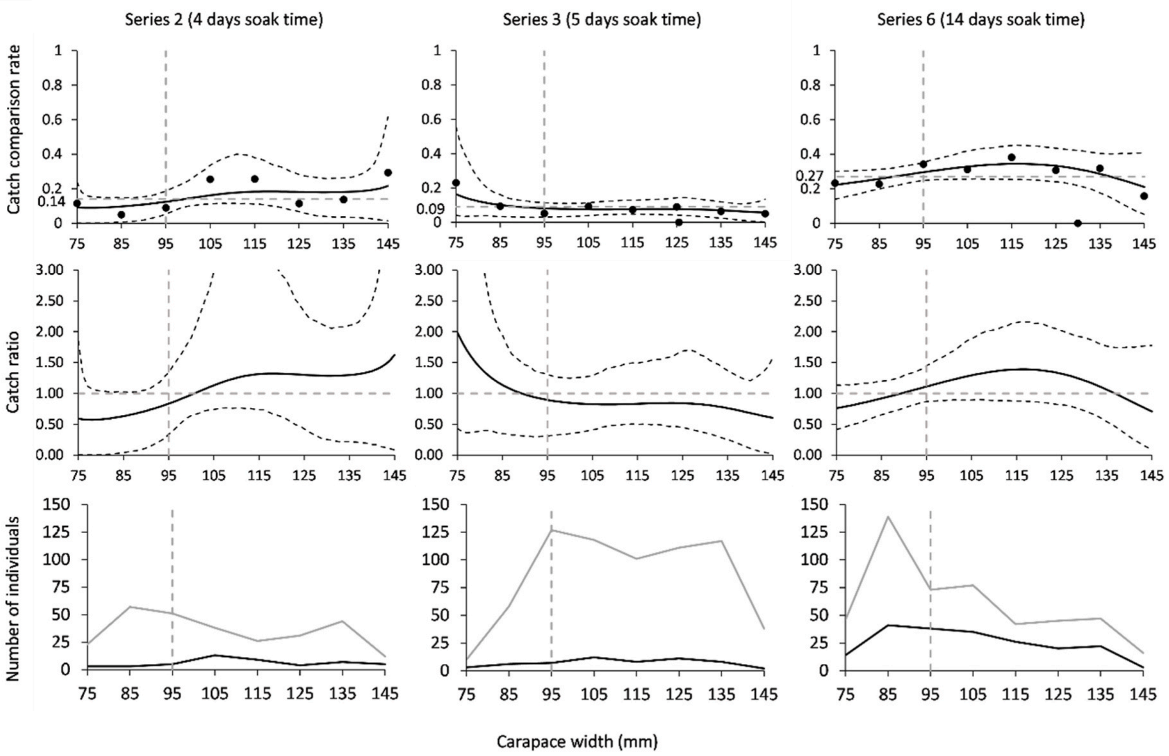

Fig. 8. Catch comparison rate (upper row), catch ratios (middle row) and population caught in baseline pots deployed with ≥60 m distance from the light source against baseline pots alternated with test pots with a 30 m distance from the light source (left column – Series two with 4 days soak time; middle – Series three with 5 days soak time; right – Series six with 14 days soak time). Circle marks represent experimental catch comparison rates. The black solid curve in catch comparison and catch ratio plots represents the mean estimated curve and the stippled curves represent the 95% confidence intervals. Horizontal stippled grey curves represent the baseline for the absence of any significant effect of distance from the LED source on the catch comparison rate and catch ratio of the baseline pots.

3.4.2. *Effect of soak time on the average catch ratio between test and baseline pots*

Further, we used results of linear regression to determine whether there is a significant difference of pot soaking time on size-integrated catch ratio ($CR_{average}$) of test pots on snow crab above and below the MLS of 95 mm CW (Fig. 10). The results on the analysis (parameter α) did not show a significant effect of pot soak time for either $CR_{average+}$ (p-value = 0.758) and $CR_{average-}$ (p-value = 0.307) (Table 6).

4. Discussion

In the present study, we investigated the influence of pot soak time on the effect of using white LEDs in addition to bait for increasing the catch efficiency in the commercial snow crab fishery in the Barents Sea. Artificial lights have been applied in active and passive fishing gears for both increasing the catch efficiency of target species (i.e., Bryhn et al., 2014; Humborstad et al., 2018; Nguyen & Winger, 2019a, b; Susanto et al., 2022) and reducing bycatch (i.e., Grimaldo et al., 2018; Lomeli et al., 2018; Melli et al., 2018; Senko et al., 2022) depending on the behaviour of the species and the particular fishery. In the snow crab fisheries in Canada and the Barents Sea, the use of differently coloured LEDs has been reported to have varying results, including a significant positive effect on the catch efficiency of snow crab (Cerbule et al., 2021; Nguyen et al., 2017, 2019, 2020). Such increase in catch efficiency is important to maintain the profitability in this fishery.

Both the results of the absolute catch efficiency (i.e., *CPUEt* and *CPUEb*) and relative catch efficiency estimation showed an indication of improved catch efficiency averaged over all sizes of snow crab by inserting white LEDs to baited snow crab pots. However, the use of the CPUE method is strongly affected by the snow crab abundance, which may vary between locations (Fig. 4). Therefore, we applied the catch comparison analysis (Cerbule et al., 2021; Olsen, Herrmann, Grimaldo, & Sistiaga, 2019) to be able to generalize the observed results of this study since this method is not affected by changes in size-dependent abundance of snow crab and different soak times between the series to the same extent as the CPUE analysis.

The results of the catch comparison analysis indicated that using white LEDs have a positive effect on the catch efficiency of snow crab pots; however, it did not result in a significant increase in catch efficiency in most instances (Fig. 7). In an earlier study in the Barents Sea snow crab fishery, Cerbule et al. (2021) reported a statistically significant 52–53% increase in catch efficiency for target sized snow crab when using white lights and further a 76% increase when green lights were used. In this study, however, the experimental results were subject to large uncertainties and, except from the experiment with five days soak time (Series three), the estimated increases were nonsignificant.

The size-depended catch efficiency results showed that for the snow crab above 95 mm MLS ($CR_{average+}$; Table 3), the estimated catch efficiency increased by 10.3–30.5 % in five of the six series when using white LEDs. However, this increase in the estimated catch efficiency was only statistically significant in one out of six series (i.e., Series 3). For the undersized snow crab (under 95 mm CW), no significant difference in catch efficiency was observed between test and baseline pots. A large proportion of undersized snow crab was retained in both test and baseline pots in all six series. The amount of retained undersized snow crab in both types of pots was higher than in the previous study using white LEDs in the snow crab pots with 8-, 14-, and 17-days soak time (Cerbule et al., 2021). This result might be caused by differences in the snow crab distribution at the different locations and seasons when the studies were conducted. However, since we did not use non-selective (small-meshed) pots to collect data on the entire population structure regarding both, abundance and size distribution, it is unknown whether this result was related to a larger abundance of small snow crab (i.e., under 95 mm CW) in the area where this and the earlier sea trial took

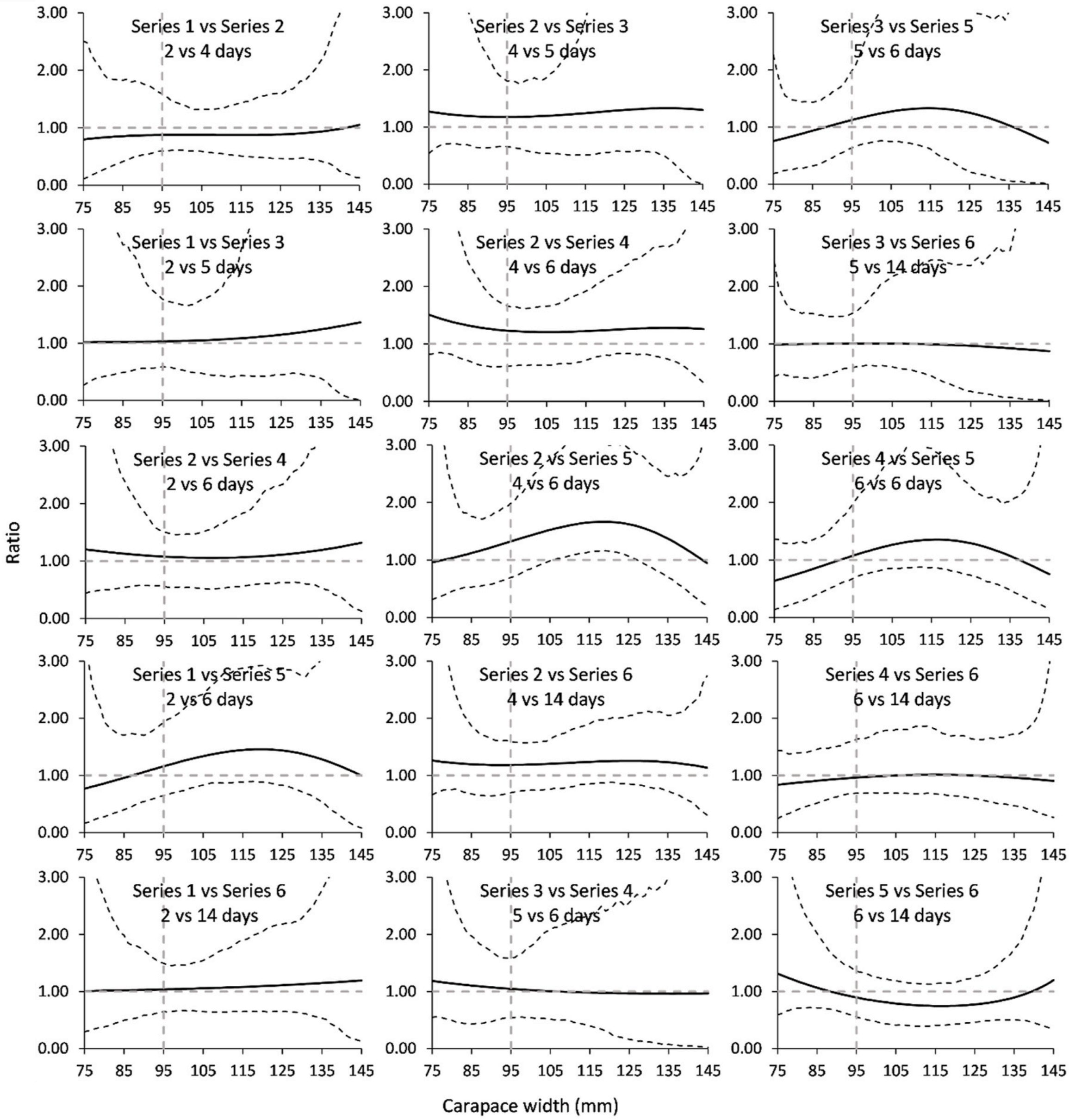

Fig. 9. The size-dependent change in catch ratio between pots of different soak time between pots of different soak time regarding catch efficiency of snow crab. Black curve represents the estimated catch ratio curve with 95% confidence intervals (black stippled curves). Horizontal stippled line at 1.0 represents the point at which both gears have an equal catch rate.

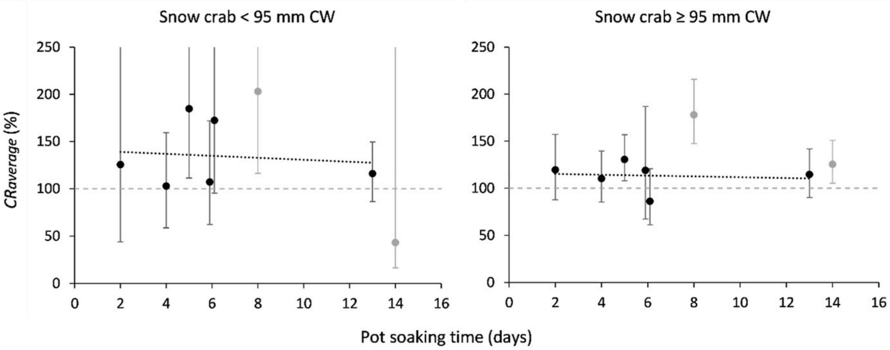

Fig. 10. Fit of the linear model (stippled black line) testing the effect of pot soaking time on the catch ratio (i.e., the size-dependent relative average catch efficiency between test and baseline pots) for undersized snow crab ($CR_{average-}$; left plot) and for snow crab above the minimum landing size of 95 mm carapace width ($CR_{average+}$; right plot). At 100%, both test and baseline pots have equal catch efficiency. The black dots represent mean values of $CR_{average}$ and the bars are the 95% confidence intervals. Grey dots represent values from previous experiments using white LEDs (Cerbule et al., 2021).

Table 6
Results from linear modelling of the effect of pot soaking time on the catch ratio (i.e., the size-dependent relative average catch efficiency between test and baseline pots, $CR_{average-}$ and $CR_{average+}$). α = the effect of pot soaking time on the size-integrated catch ratio.

	Parameter	Value	Standard error	Significance (*p*-value)
$CR_{average-}$	α	−1.058	04.589	0.307
	β	141.20	37.91	0.004
	R^2-value	0.171		
$CR_{average+}$	α	−0.434	02.483	0.758
	β	115.91	20.51	0.001
	R^2-value	0.012		

place.

The snow crab inhabits benthic habitats which can range between 200 and 400 m depth (Alsvåg et al., 2009). The habitat preference can depend on snow crab life-stage with adult males dominating deeper areas while shallower areas are being occupied by females and juveniles (Holte et al., 2022; Zakharov et al., 2021). However, the abundance may also differ due to various other factors such as seasonality and water temperature (Solstad et al., 2021) where adults prefer lower seawater temperature (up to 3 °C) compared to earlier life stages (up to 4.5 °C) (Brethes et al., 1987; Dionne et al., 2003; Huserbråten et al., 2023; Tremblay, 1997). Food availability of different infaunal organisms such as annelids, sipunculids, and bivalves in a particular area can further affect the snow crab distribution (Agnalt et al., 2011; Holte et al., 2022). Variation in food habitats in a fishing area can influence the snow crab abundance of different genders and sizes, and thus the associated fishery. Juveniles and females are found in areas dominated by bivalves, and males in areas with polychaetes and crustaceans (Zakharov et al., 2021).

No statistically significant effect of white LEDs on snow crab capture efficiency above the MLS depending on pot soak time was detected except in one instance when comparing Series 2 and Series 5 (4- and 6-days soaking time, respectively). This was the case also for undersized snow crab where the indication of capturing more undersized individuals in the test pots did not differ significantly depending on the soak time. An earlier experiment on pot soak time in snow crab fishery has resulted in a significant difference among the tested soak times (Olsen, Herrmann, Sistiaga, & Grimaldo, 2019). However, the pot soak time in most instances of this study did not have an influence on the effect of white LEDs on the catch efficiency.

The observed indication of improved catch efficiency in this and the significant increased catch in earlier trials by adding LEDs to snow crab pots might be explained by the fact that the light underwater better enables the crabs to see and locate the structure of the pot or helps to detect the pot entrances when approaching the pot attracted by the bait odour. For pot fisheries, bait is important for attracting target animals over a large distance in water and depends on the water current while vision is having an effect over very short ranges at sea (Westerberg & Westerberg, 2011). The visual range for an animal depends on the water turbidity, depth, and sensitivity of its eyes (Warrant & Adam Locket, 2004). Therefore, this range differ from species to species and depends on the habitat. Since the behaviour in relation to visual stimuli is species dependent (Nguyen & Winger, 2019b), the capture efficiency of the pots is to a large extent related to the behaviour of the target species and must have the optimal characteristics to attract the crabs (i.e., an optimal bait and light combination). Furthermore, other factors, such as the ability of snow crab to perceive different light properties (e.g., colours and light levels), need further investigations.

The comparison of the white light used in this study (DYP-200) and Cerbule et al. (2021; ProGlow) showed that the light level of available LEDs with similar wavelength distribution can vary between different producers and, in this case, it differed by two orders of magnitude. The relatively low light level of ProGlow had a markedly effect on the catch efficiency in Cerbule et al. (2021), and so it seems that a higher light level is not needed to attract snow crabs to the pots. In contrast, it cannot be concluded that the higher light level of DYP-200 caused the observed inconclusive results on the catch efficiency obtained in this study since it was conducted at a different season and in a different fishing area. The lower energy requirement of the ProGlow light can have positive handling and environmental implications. Therefore, further investigations should be conducted to reveal the optimal light level of LEDs for attracting snow crab to the pots. It was also noted that the DYP-200 light was positively buoyant and had a narrower beam width compared to the ProGlow light. The area illuminated is, therefore, more sensitive to how DYP-200 are mounted in pots. As the lights were not fixated in the test pots, it cannot be excluded that there have been a variation in the illuminated area that might have contributed to the variability in the catch efficiency.

In this study as in Cerbule et al. (2021), we deployed the pots following practice in the commercial snow crab fishery where the distance between individual pots on the mainline is 30 m. Alternating test and baseline pots with and without LEDs, respectively, may question the independency between them due to possible light contamination from the test to baseline pots and as the optimal light level that attracts snow crab is unknown. The results of comparing the baseline pots that were deployed next to the test pots with 30 m distance and baseline pots further away from the test pots (≥60 m) did not show any difference on the average catch efficiency between them. This result suggests that since both types of baseline pots fish equally, the artificial light emitted from the test pots may not extend further towards the baseline pots when 30 m distance between them is kept. During these and earlier experiments testing the application of LEDs in snow crab fishery (i.e., Cerbule et al., 2021), the pots were equipped with both bait and a LEDs simultaneously to attract snow crab towards the pots. However, further experiments could assess the catch efficiency of pots equipped only with the LEDs and separated from the odour effect from the squid bait to better understand the catch mechanism.

Based on the results from this study and the significantly increased catch observed in earlier experiments (Cerbule et al., 2021; Nguyen et al., 2017, 2019, 2020), LEDs can have positive effect on the catch efficiency of snow crab pots. However, the associated costs of LEDs (i.e., 40 USD per unit), batteries (i.e., 4 USD per pair), and increased labour and operation time to handle the setting and removal of LEDs, must have a positive cost-benefit effect to be relevant for uptake in the commercial snow crab fisheries. Therefore, further research is needed to verify the effectiveness and overall profitability of using LEDs in snow crab fisheries in addition to increase the knowledge on how snow crab responds to artificial light characteristics.

CRediT authorship contribution statement

Kristine Cerbule: Conceptualization, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Bent Herrmann:** Conceptualization, Software, Validation, Writing – original draft, Writing – review & editing. **Eduardo Grimaldo:** Conceptualization, Writing – original draft. **Leif Grimsmo:** Conceptualization, Data curation, Writing – original draft. **Junita D. Karlsen:** Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review &

editing.

Declaration of interests

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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