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Short Communication

Increased catches of snow crab (*Chionoecetes opilio*) with luminescent-netting pots at long soak times

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ABSTRACT

Luminescent netting increases the catch rate of snow crabs (*Chionoecetes opilio*) over short soak times (1 d), however the commercial fishery often requires longer soak periods, up to1 week. Building on previous research, this study investigated the catch efficiency and size selectivity of pots with luminescent netting over long soak times (144–336 h) in the inshore snow crab fishery of Newfoundland, Canada. A total allowable catch and individual quota allocation management system for snow crab is regulated in Canada and using luminescent netting to increase catch rates would reduce the carbon footprint of the fishery by reducing days fished. Our results showed that luminescent pots had a 21.6 % and 18.3 % higher catch-per-unit-effort (CPUE; number of crabs per pot) of legal-sized crab and sub-legal sized crab, respectively, than control pots; with no difference for soft-shelled crab. Additionally, no significant differences were shown for size selectivity over the range of carapace widths observed between luminescent and control pots. Little other bycatch (female snow crab and unwanted species) were caught in either pot treatments. This study shows that luminescent netting increases the efficiency of the snow crab fishery, which provides economic and environmental benefits.

1. Introduction

The use of lights in demersal fisheries has rapidly increased worldwide with the aim to either increase catching efficiency or reduce non-target species capture (Nguyen and Winger, 2019a). Recently, light-emitting diodes (LED) lights and luminescent twine is being used at depth to alter the capture of demersal fishing gears (Bryhn et al., 2014; Humborstad et al., 2018; Lomeli et al., 2018). This phenomenon has particularly affected snow crab (*Chionoecetes opilio*) fisheries. Several studies have shown snow crab catch rate increases in Newfoundland (Nguyen et al., 2017; Nguyen and Winger, 2019b) and the Barents Sea (Nguyen et al., 2019a) when using LED lights in pots. Additionally, another study showed that pots with luminescent netting also increase snow crab catch rates (Nguyen et al., 2019b).

The snow crab pot fishery has the highest value of any fishery in Newfoundland, valued at $325 million CAD in 2017 (DFO, 2018). The fishery targets only adult male crabs with a minimum landing size of 95 mm carapace width (CW) using Japanese-style, top-entry pots with a minimum stretched mesh size of 135 mm (DFO, 2018). Pots are set in longlines (*i.e.* fleets) and typically baited with squid (*Illex illecebrosus*) or a mixture of squid and herring (*Clupea harengus*). The Newfoundland snow crab fishery is managed with individual quotas (DFO, 2018); therefore, using lights to increase capture rates reduces the carbon footprint of the fishery by reducing days fished. Additionally, the added attraction of snow crab to pots with lights could reduce the amount of bait used and the associated use of fossil fuels needed to capture bait, which is both fuel intensive and high quality (*i.e.* food-grade; Nguyen and Winger, 2019a).

Luminescent netting in snow crab pots could be a promising alternative to LED lights, which include (1) lower initial costs given that a pot with luminescent netting costs $10 CND more than the traditional pots, versus LED lights that typically are priced at CND $60 (Nguyen et al., 2019b); (2) LED lights require batteries, which are costly, and require regular changing; and (3) are easily tossed into the ocean as litter. LED lights also are potential plastic litter, whereas pots with luminescent netting do not add any more plastics than a traditional pot

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(Nguyen and Winger, 2019a). Conversely, luminescent netting requires only the regular charging by ultraviolet light from the sun. “Charging” refers to exposing luminescent fibers to the sun or ultraviolet light to enable luminescence, which decreases over time (Nguyen et al., 2019b). While fishing luminescent pots over short soak times (≤ 1 d), pots are often in-and-out of the water and get the required time on deck to be charged by sunlight. However, this is potentially problematic when long soak times are the normal fishing practice, which often occurs due to low catch rates or bad weather.

Soak time, defined as the amount of time a pot was fished, is an important factor that affects catch efficiency and size selectivity (Winger and Walsh, 2011; Araya-Schmidt et al., 2019; Olsen et al., 2019). Animals targeted with pots need enough time to locate and enter the pot. Moreover, the selective properties of the netting are not fully utilized when pots are retrieved before small animals escape (Winger and Walsh, 2011; Olsen et al., 2019). Several studies showed that catch-per-unit-effort (CPUE; number of legal crabs per pot) of snow crabs with baited pots increased as soak times increased (Nguyen et al., 2017; Araya-Schmidt et al., 2019), however the relationship changes as pots become saturated (Miller, 1990). For the snow crab fishery in Eastern Canada, pots are often soaked for periods of several days to weeks depending on the weather and catch rates (Nguyen and Winger, 2019b). Nguyen et al. (2019b) hypothesized that after a few hours, once luminescence decreased, luminescent pots fished no better than traditional pots which rely on bait.

Nguyen et al. (2019b) suggested that catch rates increased with luminescent netting over short soak times 1 d, but did not when fished for long soak times (8 d). However, this change in catch rate could have been due to an effect of area, given that the short soak-time trials took place inshore and long soak-time trials took place offshore, but, more specifically, this difference likely could have been due to saturation. Saturation occurs when a pot's present catch reduces its potential for additional catch (Miller, 1990). In Nguyen et al. (2019b), the inshore trials had low catch rates and the offshore trials had a very high catch rate. Pot saturation likely occurred in the offshore trials where catch rates and soak times were both high, leading to pots with a large number of crabs. The large number of crabs likely reduced catch rate once the saturation level was met (Miller, 1990), making a comparison between treatments not possible.

The objective of this study was to compare the catch rates and size selectivity of luminescent snow crab pots versus commercial pots. The location was specifically chosen to have low catch rates and the fishers used long soak times (> 6 d); this enabled an effective way to determine if soak time had an effect on snow crab capture with luminescent pots while avoiding pot saturation.

2. Methods

2.1. Fishing experiment

Sea trials were undertaken in Conception Bay, on the east coast of Newfoundland (Fig. 1), during the annual commercial fishery, between April and May 2019. The trials were conducted onboard the commercial, inshore fishing vessel *F/V Four Seas*. The pots used were Japanese-style conical pots with a bottom diameter of 102 cm, top diameter of 55.5 cm, height of 44 cm, and mesh size of 135 mm (Fig. 2). Two pot types, luminescent (experimental) and conventional (control) pots, were newly purchased (Fig. 2). The only difference between the pot types was the netting that contained luminescent fibers in the experimental pots (EuroGlow netting from Euronete Company, Maia, Portugal, Nguyen et al., 2019b). Fishermen use both orange and green pots for commercial fishery (see photographs from Winger and Walsh, 2011; Olsen et al., 2019). To our knowledge, no scientific literature showing catch rate differences between green and orange pot has been documented. We assumed that netting colour does not affect catch efficiency and size selectivity. The pots were deployed in longlines by alternating treatments every ten pots. Each longline consisted of 50 pots, with 30 luminescent pots and 20 control pots, spaced at intervals of 46 m. Each pot was baited with 1 kg of Northern shortfin squid, with half of the bait in a bait jar and the rest hung under the entrance on a hook. To ensure the luminescent pots were fully charged, pots were deployed during the day, and considered fully charged during the steam to fishing grounds, which was at least 1 h per fishing cycle.

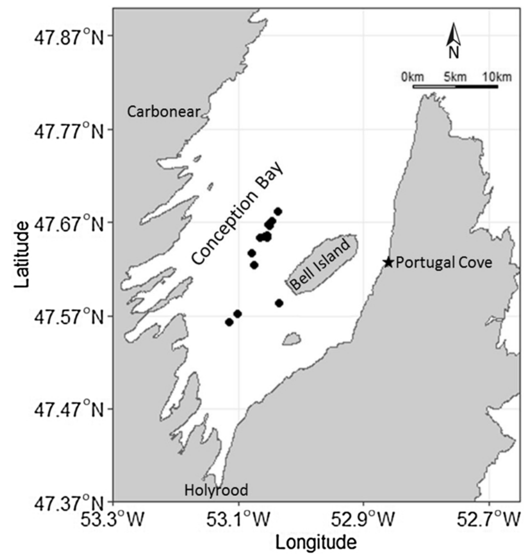

Fig. 1. Map of the study site in Conception Bay (Newfoundland, Canada) showing all locations fished (black points).

Pots were hauled aboard one-by-one and emptied on the sorting table. Numbers of legal-sized crabs and bycatch were counted. Bycatch included any non-snow crab species and sublegal-sized, soft-shelled, and female snow crab. Randomly chosen pots of each treatment and each longline were sampled to measure CW of all crabs in the pot to the nearest mm using Vernier calipers. Only legal-sized male crabs were retained for commercial purposes. All other individuals were immediately returned alive to the ocean.

2.2. Statistical analysis

The CPUE was considered count data and was analyzed for differences between treatments with Generalized Linear Mixed Models (GLMMs) using R statistical software (R Development Core Team, 2019) in the *lme4* package (Bates et al., 2015). The dependent variable was CPUE, the independent variable was pot treatment, and the random effect was longline on the intercept. Data was initially fit with a Poisson distributed model and dispersion was estimated with the *DHARMa* package (Hartig, 2017) which approximates dispersion *via* simulations. The Poisson model was determined to be overdispersed (dispersion = 1.2647, $p < 0.001$), thus the data were fit with a negative binomial distributed model which can handle overdispersion. The difference in CPUE between treatments was determined by a likelihood ratio test where the test statistic (χ^2) is the difference in deviance $d_o - d_a$, where d_a is the deviance of the full model and d_o is the deviance of the constrained model (Bates et al., 2015). Model fit and confidence intervals were estimated with bootstrapping *via* the *bootmer* function in *lme4* and *boot.ci* function in the *boot* package (Canty and Ripley, 2017) with 1,000 simulations deriving 95 % confidence intervals using the predict function.

Snow crab CW was analyzed by comparing the proportion retained of the catch between treatments at each length class following the methods of Eighani et al. (2020). The logit [luminescent/(luminescent + control)] of the catches-at-length were estimated by low-order polynomial GLMMs (degree 0–3) and the data were modelled with a

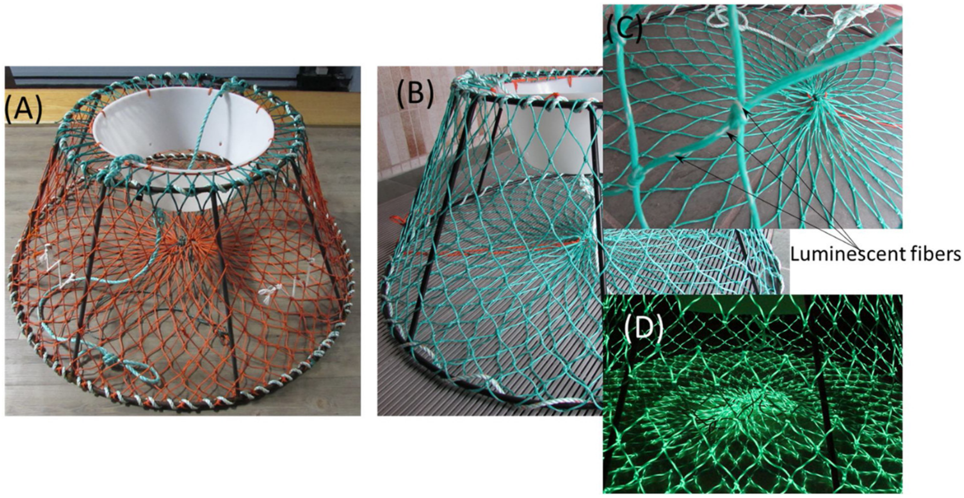

Fig. 2. Traditional pots (A) and luminescent pots (B), indicating luminescent fiber (C), and its emission (D), used in sea trials.

binomial distribution. The GLMMs were fit by maximum likelihood using the *glmer* function of the *lme4* package. The dependent variable was the logit of the retained catch proportion per length class, the independent variable was length class, the random effect was longline on the intercept, and subsample ratio was considered as an offset. The best model was selected based on the minimum AICc value, a version of the Akaike information criterion with a correction for small sample sizes using the function *AICctab* from the *bblme* package (Bolker, 2017). Per length class, if the proportion retained equals 0.5, then there is no difference in catch-at-length between treatments. For example, if catch proportion equals 0.75, then 75 % of snow crab at the particular length class were captured by the luminescent pot and 25 % by the control pot. The significance between treatments is determined by confidence intervals. If 0.5 is contained within the confidence intervals, then there is no difference between treatments at the particular length class.

3. Results

A total of 14 longlines over 5 daily trips were successfully deployed and retrieved. A total of 395 luminescent and 278 control pots were fished, and 4,420 and 2,727 snow crabs including legal-sized, sublegal-sized, soft-shelled, and female crabs, were captured by the luminescent and control pots, respectively. Additionally, 28 and 25 pots were randomly selected for CW measurements for the luminescent and control treatment, respectively. Pots which appeared to have broken meshes, were set flipped over, or lost the bait jar were removed from the analysis (27 pots). Longlines of pots were soaked between 144 h and 336 h with a mean ± standard deviation of 211 ± 72 h (~9 days). Fishing depths varied between 135 and 255 m. The number of snow crabs caught in the experimental and control pots varied from 1 to 31, and from 0 to 29, respectively (*i.e.* including legal-sized, sublegal-sized, soft-shelled, and female crabs).

Very little bycatch of non-targeted species was caught throughout the experiment. Bycatch included spider crab (*Hyas araneus*; $n = 54$), common whelk (*Buccinum undatum*; $n = 23$), green sea urchin (*Stronglyocentrotus droebachiensis*; $n = 3$), and mud star (*Ctenodiscus crispatus*; $n = 20$). Only 2 female crabs were caught by the experimental pots, and 0 were captured by the control pots. A GLMM revealed no significant differences in catches between pot treatments for bycatch species ($p > 0.05$ for all comparisons).

Catch rates were low for each treatment. The luminescent pot had a CPUE of 3.1 (95 %CI: 2.2–4.5) and captured 21.6 % more legal-sized crab than the control pot (CPUE of 2.6, 95 %CI: 2.0–3.3), which was statistically significant ($\chi^2 = 14.770$, $p < 0.001$; Fig. 3). The CPUE of sublegal-sized crab was 4.0 (95 %CI: 3.1–5.1) with luminescent pots, which was 18.3 % higher than the control pots (CPUE of 3.4, 95 %CI: 2.9–3.9; $\chi^2 = 10.830$, $p < 0.001$; Fig. 3). No significant difference in CPUE was detected for soft-shelled crabs, where the CPUE was 2.7 (95 %CI: 1.4–4.9) and 2.5 (95 %CI: 1.5–4.2) for the luminescent and control pots, respectively (8.0 % catch increase; $\chi^2 = 2.080$, $p = 0.150$; Fig. 3).

A total of 591 snow crabs (335 for luminescent and 256 for control pots) were measured for CW. Carapace width ranged from 72 to 132 mm. The best fit model for snow crab CW analysis was the third-order polynomial (Fig. 4). Modelled catch proportion of snow crab CW was near 0.5 for most length classes and the confidence interval contained 0.5 over the range of snow crabs observed. Therefore, there was no significant difference in crab size between treatments (Fig. 4).

4. Discussion

This study examined how long soak times affected the catch rates of snow crabs with luminescent pots versus traditional pots in the Newfoundland fishery. Soak time directly affects the size selectivity of snow crab pots, where increased soak time leads to increased size selectivity, *i.e.* more undersized snow crabs escape (Winger and Walsh, 2011; Olsen et al., 2019). However, when only considering catch rates of legal-sized snow crabs, *i.e.* individuals that are too large to escape through meshes or escape mechanisms, only the capture process should be examined since size selectivity measures associated with soak time do not affect them. Prior research concluded that luminescent pots were only effective at increasing snow crab catch rates when used in conjunction with short soak times, taking advantage of the relatively short time that the pots illuminate (3–4 h; Nguyen et al., 2019b). Although, when considering if an increase in legal-sized snow crab was really a result of the luminescent pot, a similar increase in catch rate should be observed prior to pot saturation, the point when catch rate decreases with increasing with soak times.

Our results showed that luminescent pots do increase catch rates when compared to traditional pots at long soak time, which was inconsistent with Nguyen et al. (2019b). Some differences were shown between studies, Nguyen et al. (2019b) had a higher increase between treatments (55 % versus 22 %), and this study had much higher bycatch of sub-legal and softshell crab. The higher catches of sub-legal snow crab over long soak times is contradictory to expectations (Winger and Walsh, 2011; Olsen et al., 2019), and the catches of softshell crab was very unusual for the fishery and particular to the season and area fished (pers. comm. Captain C. Parsons, *F/V Four Seas*). However, due to catch rates varying between this study and previously published literature, these differences are likely due to annual and local changes in density of the different groups of snow crab.

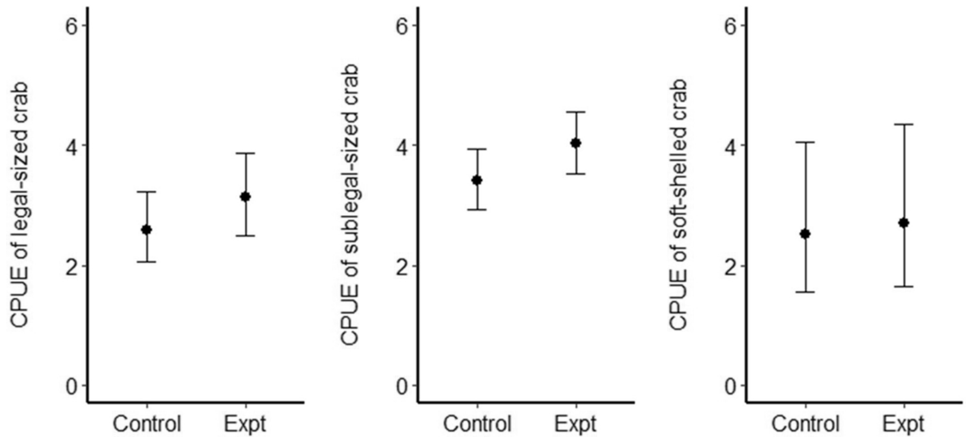

Fig. 3. Modelled mean CPUE (number of crab per group per pot) of classified crab caught by control and experimental (Expt) pots with standard errors.

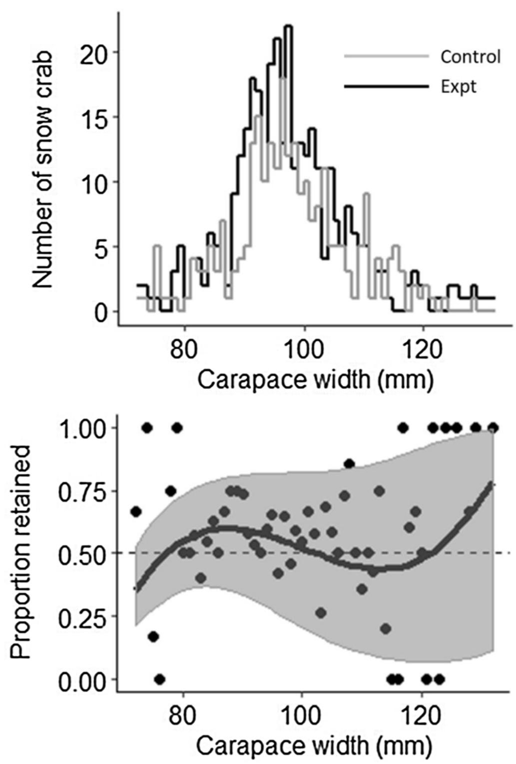

Fig. 4. GLMM results for the catch-at-length for the snow crab caught during the experiment based on carapace width (CW). Top panel represents the number of crabs at each length class for the experimental and control pots. Bottom panel represents the proportion of the total catch retained by experimental pots. The horizontal dashed line at 0.5 determines equal efficiency of both pot treatments (bottom panel). A proportion greater than 0.5 indicates more crab were 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 control. The solid black line represents the mean CW predicted by the model. Where confidence intervals (the gray shaded areas) overlap 0.5, there is no statistically significant difference in catch-at-length between experimental and control pots at the given length class.

The use of LED lights in snow crab pots continues to increase catch rates even after the bait has run out, which can produce positive effects if pot saturation is not met (Nguyen et al., 2017), however luminescence pots likely only have an increased catch rate during the initial hours of deployment (Nguyen et al., 2019b). For the traditional pots, the olfactory stimulus from the bait has a pivotal role in the first few days of soaking, after which the crab remains in the pot, unable to escape. Therefore, in spite of an overall increase in catch rate, a lower catch rate per day was observed with increasing soak times (Araya-Schmidt et al., 2019). Generally, increased soak times promote escape which improves pot size selectivity. For example, Olsen et al. (2019) demonstrated that baited pots started to significantly reduce sublegal-sized animals after 5-day of soak time (*i.e.* 85 %).

Pot saturation is the decline in catch rate with increasing catch, or once a pot reaches its saturation level (Miller, 1979, 1990), and is the likely explanation for Nguyen et al.'s (2019b) lack of observed differences between luminescent and control pots at long soak times. The combination of high catch rates and long soak times would have likely decreased entry rates as the combination of limited space, competition, and a reduced bait plume limited snow crab entry (Bacheler et al., 2013). Other studies conducted in the offshore Newfoundland snow crab fishery have had difficulties comparing fishing gear treatments when catch rates had a CPUE > 20 due to pot saturation (pers. comm. M. Donovan), and pot saturation is generally a problem for abundance assessments in pot fisheries (Bacheler et al., 2013). Pot saturation level is currently unknown for snow crab in conical pots, however, in the current study mean catch rates are safe to assume to be below saturation thresholds given the low catch rates, which explains why we could observe an effect of luminescent netting on catch rate over long soak times.

Marine animal's attraction to light has been known for thousands of years, and using lights to increase catch rates dates back for a long period of time (Nguyen and Winger, 2019b). At this time, the underlying mechanism that attracts snow crab to pots with lights is unknown. While some species are simply attracted to light, others are attracted to the prey which are attracted to the light (Humborstad et al., 2018). Although the function of snow crab photoreceptors remains unclear, other crustaceans, such as crayfish (*Orconectes immunis*), blue crab (Callinectes sapidus), estuarine shrimp (*Palaemonetes paludosus*), spiny lobster (*Panulirus argus*), and shallow-water crabs (*Palaemonetes vulgaris*) are sensitive to ambient light, in particular to flash bioluminescence (Frank and Widder, 1994; Warrant and Locket, 2004). The sensitivity and spatial resolution of deep-sea crustacean eyes, including snow crabs, are well matched for vision at the depths which they are found (Warrant and Locket, 2004). Snow crab have been shown to react similarly to light as many pelagic fish species which respond by moving or orienting toward the source of light, *i.e.* positive phototaxis behaviour (Nguyen et al., 2017; Nguyen and Winger, 2019b). Phototaxis behaviour is also exploited in other pot fisheries besides snow crab (*i.e.* cod and shrimp) where animals are attracted to pots with lights (Bryhn et al., 2014; Humborstad et al., 2018; Utne-Palm et al., 2018).

Crab carapace width results revealed no significant differences between treatments. However, generally the logits for each length class were higher for the luminescent pots indicating higher catch rates across all lengths, which follows results of higher catches of legal and sublegal snow crab. Similarly, Nguyen et al. (2019b) carapace width results also indicated higher catches of legal-sized crab, but results were not significant. However, catches of sub-legal crab indicated lower catches, matching results comparing CPUE (Nguyen et al., 2019b). These results indicate that higher sample sizes of length measured snow crab would likely lead to statistical significances for the carapace width analyses, which would match results found comparing CPUE. However, working on commercial vessels, measuring a large number of crabs can be challenging.

In summary, our results clarify that luminescent pots can increase catch rates with long soak times if catch rates do not lead to pot saturation. If fishers are concerned with the costs of using LED lights or their potential for increased ocean litter, luminescent pots could be an alternative, regardless of soak time. Additionally, we show that luminescent pots can increase catches of sublegal snow crab if they are in abundance in the area fished, mirroring results from prior work that reported similar trends but lacked statistical significance (Nguyen et al., 2017, 2019a, 2019b).

CRediT authorship contribution statement

1. Khanh Q. Nguyen conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, approved the final draft.

2. Shannon M. Bayse conceived and designed the experiments, analyzed the data, contributed reagents/materials/analysis tools, authored or reviewed drafts of the paper, approved the final draft, provided supervision and advice throughout the study.

3. Meghan Donovan performed the experiments, editorial reviews of the manuscript, and approved the final draft.

4. Paul D. Winger contributed to the research proposal, the experimental design, field work arrangement, supervision, and advice throughout the study, aided with the data interpretation, editorial reviews of the manuscript, and approved the final draft.

5. Svein Løkkeborg participated in data analysis, provided editorial reviews of the manuscript, and approved the final draft.

6. Odd-Børre Humborstad participated in data analysis, provided editorial reviews of the manuscript, and approved the final draft.

Declaration of Competing Interest

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

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References

Araya-Schmidt, T., Olsen, L., Rindahl, L., Larsen, R.B., Winger, P.D., 2019. Alternative bait trials in the Barents Sea snow crab fishery. PeerJ 7, e6874. https://doi.org/10.7717/peerj.6874.

Bacheler, N.M., Schobernd, Z.H., Berrane, D.J., Schobernd, C.M., Mitchell, W.A., Geraldi, N.R., 2013. When a trap is not a trap: converging entry and exit rates and their effect on trap saturation of black sea bass (*Centropristis striata*). ICES J. Mar. Sci. 70 (4), 873–882.

Bates, D., Mächler, M., Bolker, B.M., Walker, S.C., 2015. Fitting Linear Mixed-effects Models Using lme4. https://cran.r-project.org/web/packages/lme4/index.html.

Bolker, B., 2017. Package Bbmle. https://cran.r-project.org/web/packages/bbmle/bbmle.pdf.

Bryhn, A.C., Königson, S.J., Lunneryd, S.-G., Bergenius, M.A.J., 2014. Green lamps as visual stimuli affect the catch efficiency of floating cod (*Gadus morhua*) pots in the Baltic Sea. Fish. Res. 157, 187–192.

Canty, A., Ripley, B., 2017. Package 'boot'. (Accessed 26 November 2019). https://cran.r-project.org/web/packages/boot/boot.pdf.

DFO, 2018. Assessment of Newfoundland and Labrador (Divisions 2HJ3KLNOP4R) snow crab. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep 2018/024.

Eighani, M., Bayse, S.M., Paighambari, S.Y., Broadhurst, M., 2020. Mono- vs multi-filament gillnets: effects on selectivity of the narrow-barred Spanish mackerel *Scomberomorus commerson* in the Persian Gulf. J. Mar. Biol. Assoc. U.K. 100, 285–290. https://doi.org/10.1017/S0025315419001243.

Frank, T.M., Widder, E.A., 1994. Evidence for behavioral sensitivity to near-UV light in the deep-sea crustacean *Systellaspis debilis*. Mar. Biol. 118 (2), 279–284.

Hartig, F., 2017. DHARMa: Residual Diagnostics for Hierarchical (multi-level/mixed) Regression Models [online]. https://cran.r-project.org/web/packages/DHARMa/vignettes/DHARMa.html.

Humborstad, O.-B., Utne-Palm, A.C., Breen, M., Løkkeborg, S., 2018. Artificial light in baited pots substantially increases the catch of cod (*Gadus morhua*) by attracting active bait, krill (*Thysanoessa inermis*). ICES J. Mar. Sci. 75, 2257–2264.

Lomeli, M.J.M., Groth, S.D., Blume, M.T.O., Herrmann, B., Wakefield, W.W., 2018. Effects on the bycatch of eulachon and juvenile groundfish by altering the level of artificial illumination along an ocean shrimp trawl fishing line. ICES J. Mar. Sci. 75, 2224–2234.

Miller, R.J., 1979. Saturation of crab traps: reduced entry and escapement. ICES J. Mar. Sci. 38 (3), 338–345.

Miller, R.J., 1990. Effectiveness of crab and lobster traps. Can. J. Fish. Aquat. Sci. 47, 1228–1251.

Nguyen, K.Q., Winger, P.D., 2019a. Artificial light in commercial industrialized fishing applications: a review. Rev. Fish. Aqua. 27 (1), 106–126.

Nguyen, K.Q., Winger, P.D., 2019b. A trap with light-emitting diode (LED) lights: evaluating the effect of location and orientation of lights on the catch rate of snow crab (*Chionoecetes opilio*). Aqua. Fish. 4 (6), 255–260.

Nguyen, K.Q., Winger, P.D., Morris, C., Grant, S.M., 2017. Artificial lights improve the catchability of snow crab (*Chionoecetes opilio*) traps. Aqua. Fish. 2 (3), 124–133.

Nguyen, K.Q., Humborstad, O.-B., Løkkeborg, S., Winger, P.D., Bayse, S.M., 2019a. Effect of light-emitting diodes (LEDs) on snow crab catch rates in the Barents Sea pot fishery. ICES J. Mar. Sci. 76 (6), 1893–1901.

Nguyen, K.Q., Winger, P.D., Wood, J., Donovan, M., Humborstad, O.-B., Løkkeborg, S., Bayse, S.M., 2019b. Application of luminescent netting in traps to improve the catchability of snow crab. Mar. Coast. Fish. 11, 295–304.

Olsen, L., Herrmann, B., Sistiaga, M., Grimaldo, E., 2019. Effect of gear soak time on size selection in the snow crab pot fishery. Fish. Res. 214, 157–165.

R Development Core Team, 2019. R: a Language and Environment for Statistical Computing. R foundation for statistical computing, Vienna, Austria Retrieved from http://www.R-project.org. Accessed on 26 June 2019.

Utne-Palm, A., Breen, M., Løkkeborg, S., Humborstad, O.-B., 2018. Behavioural responses of krill and cod to artificial light in laboratory experiments. PLoS One 13 (1), e0190918. https://doi.org/10.1371/journal.pone.0190918.

Warrant, E.J., Locket, N.A., 2004. Vision in the deep sea. Biol. Rev. 79, 671–712.

Winger, P.D., Walsh, P.J., 2011. Selectivity, efficiency, and underwater observations of modified trap designs for the snow crab (*Chionoecetes opilio*) fishery in Newfoundland and Labrador. Fish. Res. 109, 107–113.