Location, orientation, and economic performance of low-powered LED lights inside snow crab traps in eastern Canada

Khanh Quoc Nguyen Corresp., [1] , **Paul D Winger** [1]

[1] Fisheries and Marine Institute, Memorial University of Newfoundland, St. John's, NL, Canada

Corresponding Author: Khanh Quoc Nguyen
Email address: Khanh.Nguyen@mi.mun.ca

This study investigated the effect of installing underwater Light-Emitting Diode (LED) lights in different locations and orientations inside baited traps targeting snow crab *Chionoecetes opilio* off the coast of Newfoundland and Labrador, Canada, as well as the economic performance associated with using lights in this fishery. Our results showed no significant differences in catch per unit effort (CPUE) for both legal and sublegal-sized crab among the different experimental treatments, however all of the experimental (illuminated) traps harvested significantly more crab (+53% on average) than control traps (without lights). Longer soak time did not affect the catch rate of the control traps, however it significantly increased the catch rate for the illuminated traps. The proportion of legal-sized and sublegal-sized crab accounted for 73% and 27%, respectively for both control and illuminated traps. In addition, there were no significant differences in crab size distributions between pairwise comparisons. In terms of economic feasibility, we show that an investment in LED lights by a fishing enterprise will require additional variable costs, however our analysis reveals the financial break-event point can be reached after approximately two years. A profit of $164,920 CDN per vessel was predicted during the life cycle of a typical light (e.g. 14 years), compared to traditional capture methods (without lights). This gain was proportional with crab prices and allocated quota level. These results suggest that fishing enterprises can increase their profitability by using LED lights in the snow crab fishery.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Location, orientation, and economic performance of low-powered LED lights inside snow crab traps in eastern Canada

Khanh Nguyen Quoc [1,2], and Paul Winger D[1]

[1]Fisheries and Marine Institute
Memorial University of Newfoundland
St. John's, NL, Canada

[2]Nha Trang University
Nha Trang, Khanh Hoa, Vietnam

Corresponding author:
Khanh Nguyen[1]
55 Ridge Road, St. John's, NL, Canada, A1C 5R3
E-mail address: khanh.nguyen@mi.mun.ca

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Abstract

This study investigated the effect of installing underwater Light-Emitting Diode (LED) lights in different locations and orientations inside baited traps targeting snow crab *Chionoecetes opilio* off the coast of Newfoundland and Labrador, Canada, as well as the economic performance associated with using lights in this fishery. Our results showed no significant differences in catch per unit effort (CPUE) for both legal and sublegal-sized crab among the different experimental treatments, however all of the experimental (illuminated) traps harvested significantly more crab (+53% on average) than control traps (without lights). Longer soak time did not affect the catch rate of the control traps, however it significantly increased the catch rate for the illuminated traps. The proportion of legal-sized and sublegal-sized crab accounted for 73% and 27%, respectively for both control and illuminated traps. In addition, there were no significant differences in crab size distributions between pairwise comparisons. In terms of economic feasibility, we show that an investment in LED lights by a fishing enterprise will require additional variable costs, however our analysis reveals the financial break-event point can be reached after approximately two years. A profit of $164,920 CDN per vessel was predicted during the life cycle of a typical light (e.g. 14 years), compared to traditional capture methods (without lights). This gain was proportional with crab prices and allocated quota level. These results suggest that fishing enterprises can increase their profitability by using LED lights in the snow crab fishery.

Keywords

Fishing with light, snow crab harvesting, inshore fishery, economic analysis, operating cost reduction

1. Introduction

Snow crab *Chionoecetes opilio* is a commercially important species on the east coast of Canada, in particular the provinces of Quebec, New Brunswick, Nova Scotia, and Newfoundland and Labrador (Hébert et al., 2001; Dawe & Mullowney, 2016; DFO, 2016). This fishery has been the world's largest snow crab fishery for the last few decades, with total landings of 93,519 mt annually (Dawe & Mullowney, 2016; DFO, 2015). This fishery targets only adult male crabs with a minimum landing size of 95 mm carapace width (CW). The fishery is managed using individual quota allocations, effort controls (trap and trip limits), gear restrictions (trap type and mesh size), and time/area closures in order to achieve conservation and management objectives (DFO, 2016).

In Newfoundland and Labrador, the commercial fishery for snow crab began in the 1960s (Dawe & Mullowney, 2016). Landings were initially low, but dramatically increased from approximately 10,000 mt in 1970 to 69,000 mt in 1999 (Dawe & Mullowney, 2016; DFO, 2016). However, landings have gradually decreased from 53,500 to 47,000 mt between 2009 and 2015 (DFO, 2016). In 2017, a further 22% reduction in the overall quota was experienced, with a total quota of 35,419 mt shared among 2600 license holders (DFO, 2016, 2017). This has resulted in the year over year shrinking of individual quotas allocated to fishing enterprises, and this trend is expected to continue for the foreseeable future (Wassmann et al., 2011). While market prices for snow crab are currently high and thus mitigating significant financial impact on fishing enterprises, this trend may not continue. Finding methods to improve the profitability of fishing enterprises is a worthwhile approach as it can improve business viability when quotas are low. Past approaches have included 1) methods to improve size-selectivity to minimize labour associated with “picking” through the catch (Winger & Walsh, 2011), 2) the development of novel baits to reduce bait costs (Grant & Hiscock, 2009), and 3) the use of novel stimuli such as low-powered LED lights to increase the catch rates of baited traps (Nguyen et al., 2017).

Fishing with artificial lights is a well-developed method of increasing the catch rate in recreational and commercial fisheries (Yami, 1976; Stone & Dixon, 2001; Hazin et al., 2005; Breen & Lerner, 2013, Solomon & Ahmed, 2016). Using artificial light as a stimulus to attract and concentrate fish prior to harvest has a long history over thousands of years, starting soon after men discovered fire, and this has led to the development of fishing with light in many parts of the world (Yami, 1976; Sokimi & Beverly, 2010; An, 2013; Breen & Lerner, 2013; Solomon & Ahmed, 2016). While initially developed for above-water applications in pelagic fisheries, the use of artificial light has now spread to underwater applications for deep-water species such as cod, swordfish, and snow crab (Stone & Dixon, 2001; Hazin et al., 2005; Tüzen et al., 2013; Bryhn et al., 2014, Nguyen et al., 2017).

Nguyen et al. (2017) demonstrated that attaching a low-powered light emitting diode (LED) light inside a baited trap significantly increased the Catch Per Unit Effort (CPUE) of snow crab compared to similar traps without lights. However, our understanding of why underwater lights attract and concentrate marine animals confronts us with many competing hypotheses. A common understanding is that animals are simply attracted to the light (Yami, 1976; Ito et al., 1998). However, for other species the mechanism could be more complicated. In some cases, fish appear to be attracted to the light to feed on prey which are themselves attracted by the light (Yami, 1976; Marchesan et al., 2005; An, 2013; Bryhn et al., 2014). It could also be possible that underwater lights better enable animals to see and find structure or refuge in an otherwise dark and barren landscape. Or perhaps underwater lights help individual animals identify conspecifics already inside a baited trap, thereby encouraging entry through social facilitation (Winger et al., 2016). Or perhaps underwater lights help animals detect trap entrances when approaching traps. These questions highlight that much is unknown regarding the mechanisms determining animal behaviour in response to artificial light. In many cases, we still do not know how certain animals even perceive light, and we do not fully understand their response to light stimuli (Bryhn et al., 2014; Nguyen et al., 2017).

For trap and pot fisheries, bait plays a key role in attracting targeted animals (Dawe & Mullowney, 2016; Winger et al., 2016; Jørgensen et al., 2017). Underwater observations have shown that animals usually travel up-current to seek the chemical odour source that has spread down-current from bait (Zhou & Shirley, 1997; Winger & Walsh, 2011; Winger et al., 2016; Jørgensen et al., 2017). The shape and size of the odour plume determines the area/volume of water under influence by the trap, and thus the number of animals that are vulnerable to capture. If the velocity of the water current is low, then the area/volume of attraction will be small. Adding LED lights to baited traps offers a unique stimuli that is able to travel in all directions and is not dependent on water current (Nguyen et al., 2017). This has the potential to increase the effective swept area (i.e., area of influence) of a trap. However, due to the shape of many underwater light housings, it is difficult to illuminate a trap in a truly omni-directional fashion. This means lights tend to throw light unevenly around the trap. How this affects attraction of target and non-target species remains unknown.

For Canadian fishing enterprises, using LED lights to increase CPUE of snow crab traps permits the opportunity to catch individual quotas (IQ) with greater efficiency. This means potentially fewer days on the water and the possibility of reduced operating costs (e.g., less bait, fuel, labour), thereby improving the financial viability of thousands of small owner-operated businesses. Several studies have already demonstrated the economic benefits of using artificial light in other fisheries (e.g., Matsushita et al., 2012; Nguyen & Tran 2015; An et al., 2017; Susanto et al., 2017). These studies have shown that a key challenge in adopting artificial lights is the financial burden of the initial capital investment. Higher catch rates would theoretically balance this additional cost, with fishing enterprises eventually achieving a return on investment (ROI) and thereafter increased profit. However an economic analysis of this business opportunity is currently lacking for the snow crab fishery in Canada, making it difficult for fishing enterprises to make informed decisions.

Building on the previous research by Nguyen et al. (2017) and the research gaps mentioned above, this study investigated two additional aspects: a) the effect of light location and orientation on catch rates of target and non-target species, and b) the economic performance of a typical fishing enterprise that has elected to use LED lights as part of their regular fishing activity.

2. Methods

2.1. Experimental design and data collection

Experimental fishing was carried out utilizing the 11.89 m LOA snow crab fishing vessel, *F/V The Flat Rock Byes,* register number 154021, from May to June, 2017. The experiment was conducted in the nearshore waters of Newfoundland, directly east from the town of Pouch Cove (Latitude between 47°43'30"N and 47°47'48"N, Longitude between 52°25'15"W and 52°37'24"W) (see Fig.1). The average depth of fishing was approximately 190 to 200 m. Small Japanese-style conical traps which are typical for this fishery were used (see Winger & Walsh, 2011 for further description). All traps, including control and experimental traps, were identical in every manner. Baiting was standardized, with each trap receiving 1362 g of whole squid hung in the entrance of the trap using a snap shackle. Traps were deployed in fleets, with each fleet containing a total of 60 traps spaced at intervals of 36.6 m. The fleets were soaked for several days and haphazardly retrieved between 4-15 days, depending on the weather.

Lindgren-Pitman LED Electralume® fishing lights (white) were used in this experiment. See Nguyen et al. (2017) for technical specifications. Like many commercially available underwater LED lights, this product does not disperse light evenly in all directions. Designed primarily for pelagic longlines targeting swordfish, they work particularly well at dispersing light horizontally and downward with very little light travelling in the upward direction. Thus, we hypothesized that location and orientation of the light in a trap could affect how it is perceived by snow crab and the resulting catchability of the trap. To test this hypothesis, we evaluated five experimental treatments:

(1) Control trap - traditional baited trap without light;

(2) High Upright - traditional baited trap with a light suspended in the upright orientation, higher off the seabed;

(3) High Upside Down - traditional baited trap with a light suspended in the upside down orientation, higher off the seabed;

(4) Low Upright - traditional baited trap with a light suspended in the upright orientation, close to the seabed; and

(5) Low Upside Down - traditional baited trap with a light suspended in the upside down orientation, close to the seabed.

Figure 2 illustrates the subtle differences in light dispersion using the different locations and orientations. In treatments where the light was in the upright orientation, the seabed is accentuated by the light emitted. By comparison, treatments where the light was in the upside down orientation tended to accentuate the plastic collar by the light emitted. Distance from the seabed to the light was 23 cm for the high location and 9 cm for the low location. All lights were hung in the entrance of the trap directly opposite the bait.

Each fleet of traps consisted of all five experimental treatments randomly placed throughout the fleet for comparative purposes. A total of 11 fleets were successfully deployed and retrieved during the study, containing a total of 216 experimental traps and 364 control traps. In some cases, serious disturbance of a trap was observed upon haul-back (e.g., light malfunction, broken meshes, or upside down) and these traps were omitted from the analysis. We also omitted the first and last three traps in each fleet as our experience indicates these “end” traps tend to “dance” with the upward pull of the vertical down-ropes, lowering their fishing performance (Bungay at al., 2015).

For each trap hauled, the number of legal-sized and sublegal-sized crabs were separated, counted and recorded as the catch per unit effort (CPUE). A random selection of crab were taken for each treatment and measured to determine crab size, measured as the carapace width (CW) to the nearest mm using Vernier calipers. Animals with CW ≤ 94 mm were recorded as sublegal-sized, and animals with CW ≥ 95 mm were recorded as legal-sized. A total of 296 crabs were measured during the experiment. Non-targeted animals (e.g., female crab and other species) were also counted and measured for size. Only legal-sized male crabs were retained for commercial purposes and placed in the hold of the vessel. All other individuals were immediately returned alive over the side of the vessel into the sea.

2.2. Analysis

Non-parametric Wilcoxon Rank-Sum Test was used to compare the mean CPUE of legal and sublegal-sized crab between control and experimental treatments, including the effects of light location, light orientation, and soak time. A generalized linear model (GLM) based on the Poisson ANCOVA was used to estimate the effects of light location and orientation at different soak times on CPUE without an interaction term. The number of crab per trap (CPUE) was considered the response variable (i.e. count data without negative values), while different treatments (i.e. nominal scale) and soak times (i.e. ratio scale) were explanatory variables. The model was defined as:

$$\text{CPUE} = e^{\mu} + \varepsilon_{\text{Poisson distribution}} \qquad (1)$$

$$\mu = \beta_0 + \beta_{Tr}Tr + \beta_{ST}ST \qquad (2)$$

where, β_0 is the intercept (constant); β_{Tr} and β_{ST} is the coefficients for the trap treatments and soak time, and Tr and ST is the treatment and soak time variables. However, evidence suggested that the data were overdispersed – noted by the dispersion parameter for quasipoisson family greater than 1 (3.26 for legal-sized and 3.13 for sublegal-sized crab) thus a negative binomial distribution was used. Analyses were carried out using RStudio for Windows. The R code for the model was *m = glm.nb(CPUE ~ Treatment+Soaktime, data = Data)* based on package of *"MASS"*, where CPUE is the count of number of crab per trap; Treatment consists of control, high upright, high upside down, low upright and low upside down, and Soaktime contains three values of 4 days, 6 days and 15 days. All analyses were calculated at a confidence level of $p < 0.05$.

Comparison of the mean CW of crab caught by different treatments was conducted using ANOVA. Post-hoc comparisons were carried out using Tukey's SHD method. Size frequency distributions were compared using Kolmogorov-Smirnov two-sample Z test. To compare the selectivity ratio of crabs caught by control and experimental traps, we used the generalized linear mixed-effect model (GLMM) in which the fleet number was used as a random effect (see Holst and Revill 2009). The purpose of the model was to evaluate the effects of fixed factors (light location and orientation) on CW at each size class. Analyses were done using RStudio for Windows via the *glmmPQL* function based on package of *"MASS"*.

2.3. Economic feasibility

We analyzed the economic performance of a typical small coastal snow crab fishing enterprise based on simulating data from the *F/V Flat Rock Byes* in which we assumed two scenarios: i) the vessel harvests snow crab using the traditional method (bait only), and ii) the vessel harvests snow crab using both bait and LED light. Field data from treatments 1 (control) and 2 (high upright light) were chosen for the economic comparison because these treatments are operationally the simplest for fishermen. Total revenue or gross revenue (TR) was defined as the entire year's vessel revenue using the negotiated landed price for snow crab. The fishing enterprise had a quota of 9.979 mt (Skipper of the *F/V Flat Rock Byes*, St. John's, Canada, personal communication). The landed price of crab in the year of 2017 was \$9.7/kg CND (*\$1 CND = \$0.788 USD*) (see BCAN 2017; FFAW 2017). Thus, TR of the *F/V Flat Rock Byes* was therefore \$96,580 CND in 2017. Due to the management regime and fixed price structure in this fishery, TR is relatively fixed and known at the beginning of the fishing season (assuming the fishing enterprise harvests its full quota).

Income was defined as the difference between total revenue and variable costs, which is calculated by the following equation:

$$IC_T = TR - VC_T \qquad (3)$$

$$IC_L = TR - VC_L \qquad (4)$$

where IC_T, IC_L are the incomes using traditional and light fishing methods, respectively; TR is total revenue which is the same in both scenarios; VC_T and VC_L are the variable costs using traditional and light fishing methods, respectively, which is described below.

We assume that the use of lights incurs additional costs of LED lights and batteries. This increase in equipment costs must be balanced by a decrease in variable costs in order for the fishing enterprise to reach a break-even point on the investment. In order to evaluate the economic benefits of using LED lights, we start with comparing the profit of the traditional fishing method against the light fishing method. The annual profit is the difference between total revenue and total costs as represented by the following equations:

$$P_T = TR - TC_T \qquad (5)$$

$$P_L = TR - TC_L \quad (6)$$

where P_T and P_L are the annual profit of the traditional and light fishing methods, respectively; TC_T and TC_L are the total costs of the traditional and light fishing methods in a year, respectively, and total cost includes fixed costs and variable costs represented by the following equation:

$$TC_T = FC_T + VC_T \quad (7)$$

$$TC_L = FC_L + VC_L \quad (8)$$

where FC_T and FC_L are the fixed costs of the traditional and light fishing methods respectively, which are defined as the costs the vessel owner must pay annually including vessel maintenance, depreciation, quota application, license, loan interest, insurance, taxes, gear investment, and harbour fees. In this analysis, fixed costs were treated similarly between the traditional fishing method and light fishing method ($FC_T = FC_L$). VC_T and VC_L are the variable costs of the traditional and light fishing methods, respectively. VC_T is defined as the variable cost of the vessel for each trip times the number of trips per year including fuel, bait, ice, and crew labour. An additional cost of purchasing LED lights would be compensated (paid back) by any increase in catch rate, and variable cost reduction for each year. Time until Return on Investment (ROI) is determined by the break-even point which is calculated by the difference in variable costs between the traditional and light fishing methods (D) that is represented by the following equation:

$$D = P_L - P_T = VC_T - VC_L \quad (9)$$

The break-even point occurs when the cumulative variable costs of the light fishing method minus traditional fishing method equals zero (D=0). In other words, this is when a fishing enterprise has earned-back the investment it made in purchasing the lights and can begin

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

generating revenue on that investment. As each subsequent year passes, D represents the financial gain realized using the light fishing method, compared to the traditional method.

3. Results

3.1. Light placement and orientation

Figure 3 illustrates the CPUE observed for the different experimental treatments for both legal and sublegal-sized snow crab. Mean CPUE for legal-sized crab ranged from 13.3 to 21.2 crab/trap for the different treatments (Table 1). No significant differences in CPUE among the four light treatments were detected, however each of these treatments produced significantly higher CPUE compared to the control traps (Table 1). Mean CPUE for undersized crab retained in the control, high upright, high upside down, low upright, and low upside down trap was 4.91, 6.94, 7.52, 7.45, and 7.98 respectively (Table 1). No significant differences in CPUE among the four light treatments were detected, however each of these treatments also produced significantly higher CPUE of sublegal crab compared to the control traps (Table 1).

Combining the light treatments together, the results indicate that traps equipped with LED lights harvested significantly higher CPUE of both legal and sublegal snow crab than control traps (W = 59672, p-value < 0.001 for legal-sized and W = 52682, p-value < 0.001 for sublegal-sized crab). Figure 4 illustrates the catch rate of control traps and illuminated traps for both legal and sublegal crab. Regardless of light positions (i.e. high and low), the Wilcoxon Rank-Sum test revealed that there were no significant differences in CPUE of both legal and sublegal-sized crab between high positions (i.e. high upright and high upside down combined) and low position (i.e. low upright and low upside down combined) (W = 6086.5, p-value = 0.475

for legal sized and W = 5434.5, p-value = 0.475 for sublegal sized crab). Figure 5 shows CPUE of crab caught by high and low light placements. Similar results were observed in the light orientations (i.e. upright and upside down) using the Wilcoxon Rank-Sum test. No significant differences in CPUE were detected between upright (including high upright and low upright combined) and upside down (including high upside down and low upside down combined) traps (W = 6643, p-value = 0.076 for legal-sized and W = 5700.5, p-value = 0.778 for sublegal sized crab) (Figure 6).

Soak time did not affect the CPUE of the control trap for legal-sized crab (Figure 7). Pairwise comparisons showed no statistical difference between four and six days (Wilcoxon rank sum test, W = 8483, p-value = 0.607), no statistical difference between four and 15 days (Wilcoxon rank sum test, W = 7318.5, p-value = 0.688), and no statistical difference between six and 15 days (Wilcoxon rank sum test, W = 5928, p-value = 0.5638) (Table 2). In contrast, longer soak times produced significantly higher CPUE in the illuminated traps for legal-sized crab (Figure 7). Illuminated traps soaked for 15 days harvested the highest catch, producing a mean CPUE of 23.2 crab/trap, followed 20.1 crab/trap when soaked six days, and finally 18.4 crab/trap when soaked four days (Table 2). For sublegal-sized crab, the mean CPUE decreased with increasing soak time (see Figure 7). The number of sublegal crab decreased from 5.9 and 9.1 crab/trap when soaked 4 days, down to 2.8 and 4.8 crab/trap when soaked 15 days, for control and illuminated traps respectively. Pairwise comparisons for the different soak times are shown in Table 2.

Results from the Generalized Linear Model revealed that soak time had a contrary effect on legal and sublegal crab among the illuminated traps. For legal-sized crab, soak time had a positive coefficient, which was statistically significant (Estimate = 0.01, z-value = 2.73, and p-value = 0.006). This means that for each day soak time increases, the expected log CPUE increases by 0.01 (see Table 3). The coefficients for each of the illuminated traps (i.e. high upright, high upside down, low upright, and low upside down) are the expected difference in log CPUE between each of them and the control trap, which were also statistically significant (p-value <0.001 for all comparisons) (Table 3). The expected log CPUE for high upright, high upside down, low upright, and low upside down trap were 0.46, 0.41, 0.45, 0.37 higher than the expected log CPUE for the control trap, respectively (Table 3). For sublegal-sized crab, soak time had a negative coefficient which was statistically significant (Estimate = -0.06, z-value = -9.21, and p-value < 0.001). This means that for each day soak time increases, the expected log CPUE of sublegal crab decreases by 0.06 (Table 4). However, illuminated traps still harvested a higher CPUE of sublegal crab than control traps during longer soak times (p-value < 0.001 for all comparisons). As a result, the expected log CPUE for illuminated traps was still significantly higher than the expected log CPUE for control traps (Table 4).

Legal sized crab dominated the catch in all experimental treatments (Figure 8). Mean CW ranged from 99.01 to 100.95 mm for the different treatments (Table 5). Pairwise comparisons of crab size distribution indicated no significant differences between control traps and illuminated traps, as well as among illuminated traps using Kolmogorov-Smirnov test (p > 0.05 for all pairwise comparisons), except high upright and low upside down comparison (Kolmogorov-Smirnov test, D = 0.3, p-value = 0.023). The illuminated traps had no significant effect on mean CW using ANOVA (F-value = 0.834, p-value = 0.504). Mean size of crab and pairwise comparisons are shown in the Table 5. We also found no effect of light location and orientation on size-based selectivity for snow crab between control and experimental traps ($p > 0.05$ for all comparisons, see Table 6).

3.2. Economic feasibility

Variable costs for the traditional fishing method (VC_T) are shown in Table 7. Total cost for each fishing trip is approximately $7,350 CND with the fishing enterprise needing to conduct about 7 trips to fully harvest its allocated quota. Total VC_T is therefore approximately $51,450 CND per year. This VC_T is assumed to remain constant over a period of 14 years. Table 8 shows the additional financial investment required for the light fishing method over the same 14 year period. We assume that the numbers of LED lights required to equip the *F/V Flat Rock Byes* in Year 1 corresponds with the numbers of the traps onboard (n=240 LED lights). Although the Lindgren-Pitman LED lights have a robust design, a working depth up to 850 m depth (Nguyen et al., 2017), and 10,000 hours of steady state operating time (Farnell 2017), we still observed a few lights broken and lost during our experiment. Thus, we assume a 5% replacement rate of LED lights (n=12) in each subsequent year. Batteries also require replacement every 500 working hours (Nguyen et al., 2017). Assuming the fishing enterprise requires four trips to fully harvest its allocated quota when using the light fishing method, based on the average catch observed in the high upright treatment (see Table 1), this means the batteries will need to be replaced only once during the first year (because they come with batteries when purchased), and twice in each subsequent year (2-14). Thus, the cost to equip and maintain 240 traps would be $17,968 CND in the first year, and $8,650 CND in each of the subsequent thirteen years. The total financial investment in LED lights and batteries for 14 years is therefore $130,423 CND (Table 8).

Cumulative variable costs for the traditional and light fishing methods over a fourteen year period are shown in Figure 9. The location of the intersection of the curves indicates that a fishing enterprise needs approximately two years to reach the break-even point (D=0) on an investment in LED lights, and could begin to realize a savings in variable costs beginning in the third year. Total cumulative variable costs using the traditional fishing method over a fourteen year period is approximately $720,329 CND, compared to only $555,409 CND using the light fishing method. Fishing enterprises could therefore theoretically save approximately $164.920 CND during this time.

Cumulative income depends on input costs (i.e. fuel, bait, labour), output value (i.e. crab price), and the amount of quota allocated. We have estimated the income using both fishing methods over a fourteen year period for varying crab prices (see Figure 10). Total income using the traditional and light fishing methods at the current crab price (i.e. $9.7 CND per kg) is $631,791 and $796,711 CND, respectively. The difference between these two cumulative incomes represents the financial gain that a fishing enterprise can realize when applying LED lights in their traps. Income earned is proportional with increasing crab prices for both traditional and light fishing methods, as defined by the equations: Income = 106.14 x (crab price) - 228.4 for the light fishing method, and Income = 83.167 x (crab price) - 171.45 for the traditional fishing method. The results indicate that the higher crab price, the less time that is required to reach the break-even point (when D=0), and suggest that the use of LED lights would start producing the profit when the crab price is $2.5 CND per kg. Finally, the financial gain realized using LED lights is also proportional with an enterprise's quota allocation over the fourteen year period (see Figure 11). With each ton of increased quota, the gain increases $21.985 CND. The results suggest that the use of LED lights would be profitable ($D > 0$) when the vessel is allocated greater than 2.3 mt of quota based on the relationship shown in Figure 11.

4. Discussion

The results from this experiment demonstrated no significant differences in CPUE among the experimental treatments using different locations and orientations of lights. These results suggest that 'how' the trap is illuminated (see Figure 2) is immaterial to snow crab. We speculate then, that whatever the light illuminates (e.g., the trap, the seafloor, or even conspecifics), is less important than the light itself. These findings lend support for the hypothesis that snow crab simply find white LED light to be a novel stimulus in a dark and barren landscape. In other words, simply the presence of the light, and not what the light illuminates, appears to be important.

Compared to control traps (without light) in this study, the addition of LED lights inside the traps produced a significant increase in CPUE. The catch rate of legal-sized crab increased on average 53% (60% for high upright treatment, 52% for high upside down treatment, 57% for low upright treatment, and 44% for low upside down treatment) in traps equipped with white LED lights. These findings are consistent with previous studies using artificial light in stationary fishing gears. For example, the CPUE of large scale fish-traps, cod traps, and snow crab traps were shown to increase up to 200%, 80%, and 77%, respectively with the addition of underwater lights inside the fishing gear (Masuda et al., 2013; Bryhn et al., 2014; Nguyen et al., 2017). However performance is known to vary across different fishing gears and species. For example, lightsticks played a primary role in attracting target species (i.e., swordfish, tuna) to pelagic longlines, but were also the main cause of increasing bycatch (e.g., sea turtles) (Witzell, 1999; Bartram & Kaneko, 2004; Lohmann et al., 2006; Wang et al., 2007; Gless et al., 2008). Yet the use of LED lights were found to help these same species of turtles easily avoid gillnets and set-nets (Wang et al., 2010; Darquea et al., 2016; Ortiz et al., 2016, Virgili et al., 2018).

However, our results showed that traps equipped with LED lights also harvested a higher CPUE of sublegal-sized crab compared to control traps, yielding on average 53% higher CPUE of sublegal crab than control traps (41% for upright treatment, 53% upside down treatment, 52% for low upright treatment, and 62% for low upside down treatment). This suggests that white LED lights increase the vulnerability of both legal and sublegal size crab to capture. While this suggests a potential conservation issue associated with the unnecessary handling of pre-recruit crab (Grant, 2003), this impact must be considered in the context that a fishing enterprise is concurrently catching its allocated quota of legal size snow crab faster, thus reducing the overall number of trips and trap hauls over the fishing season.

Our results revealed several positive benefits of longer soak times when using LED lights in crab traps. Increasing the soak time from four to six days, and from four to fifteen days, increased the catch of legal crab by 9.2% and 26% on average, respectively. These findings are consistent with Nguyen et al. (2017) who reported that snow crab traps with lights performed better as soak time increased. The authors speculated that bait plays a pivotal role in the first few days of soaking, but as the odor depletes, illuminated traps begin to perform better as they continue to attract crab irrespective of bait. The findings from this study support this hypothesis. We also found that increasing soak time significantly reduced the capture of sublegal crab. While increased soak times are known to generally promote sorting and improve trap selectivity (Winger & Walsh, 2011), the effect appears to be enhanced when traps are equipped with lights. Functional explanations for this finding are unclear, but it may be related to small crab finding and escaping through the exterior walls of the traps with greater efficiency due to enhanced visual capability (i.e., small crab are able to see and feel their way through the meshes).

Assuming an average 60% increase in CPUE and an average CND $11,780 decrease in annual variable costs when using LED lights is representative for commercial fishing enterprises in the province of Newfoundland and Labrador, the wide spread use of LED lights is predicted to substantially increase the profitability of the fishery. For example, we estimated that the gain of using LED lights per one ton of quota per year was approximately CND $1,180. If this result is representative for the entire snow crab fishery (35,419 tonnes of quota allocated in the year of 2017), the financial gain to the snow crab fishery would be CND $41,794,420 annually.

Our economic analysis shows that an investment of LED lights produces high variable costs in the short term, but that fishing enterprises require only a short period of approximately two years to recover the investment, at which point they begin earning profit due to increased catch rates and reduced operating time (i.e., trips). Our review of the scientific literature in which the economic benefits of making adjustments to fishing gears resulted in surprisingly few examples (see O’Neill et al., 2014; SEAFISH, 2017). By comparison, several studies have investigated the benefits of above-water use of LED lights in different fishing applications. An et al. (2017) showed that replacing traditional metal halide lights with LED lights on vessels targeting hairtail (*Trichiurus lepturus)* around the Korean Peninsula, increased their initial investment cost, but fishing enterprises would achieve a “break-even” point relatively quickly depending on the fuel price and number of fishing trips per year. Similar economic benefits have been documented for squid jigging fisheries in Japan (e.g., Matsushita et al., 2012), purse seine fisheries in Vietnam (e.g., Nguyen & Tran, 2015), and lift-net fisheries in Indonesia (e.g., Susanto et al., 2017).

Although there is currently no scientific literature demonstrating negative effects of underwater light on habitat and marine ecosystems, evidence has revealed that the nocturnal activities of marine animals (i.e. sea birds) have been affected by surface artificial lights such as oil and gas platforms, lighthouses, and costal lighting (Montevecchi, 2006). With approximately 1.2 million snow crab traps deployed in the province of Newfoundland and Labrador, Canada (DFO, 2009), it is conceivable that a significant area in the seafloor would be “illuminated” in the event LED lights were to be widely applied. We recommend future research investigate whether the wide-spread use low-powered underwater lights (such as those used in this study) could disturb or harm animal behaviour and ecosystem function.

5. Conclusions

This study demonstrated that installing low-powered LED lights in snow crab traps produced an average increase in CPUE of 53% and that the location and orientation of the light does not appear to be important. We also showed that fishing enterprises can improve their nearterm financial profitability if they were to install lights in all of their traps. For a typical inshore vessel, we estimated the initial increase in variable costs would reach a break-even point within approximately two years due to a noticeable reduction in operating costs. Changes in the landed and price for crab and total quota allocation have direct effects on the economic performance of this fishery.

Acknowledgements

Funding for this project was provided by the Fisheries and Marine Institute, Memorial University. We wish to acknowledge Bob Parsons for his in-kind contribution through the use of his vessel, as well as providing information for our economic analysis. We are also grateful crew of *F/V Flat Rock Byes* for their valuable assistance setting-up the experimental equipment. We also thank our colleagues Tomas Araya-Schmidt for assisting with data collection, David Mercer for assisting with the Figure 1.

References

An HC. 2013. Research on artificial light sources for light fishing, with a focus on squid jigging. Symposium on impacts of fishing on the environment: ICES-FAO Working Group on Fishing Technology and Fish Behaviour. May 6-10, Bangkok, Thailand.

An YI, He P, Arimoto T, Jang UJ. 2017. Catch performance and fuel consumption of LED fishing lamps in the Korea hairtail angling fishery. Fisheries Science 83: 343-352.

Bartram PK, Kaneko JJ. 2004. Catch to bycatch ratios: comparing Hawaii’s longline fisheries with others. SOEST 04-05. JIMAR Contribution 04-352. University of Hawaii-NOAA. 40p.

BCAN. 2017. Bank of Canada - Monthly Exchange Rates. http://www.bankofcanada.ca/rates/exchange/monthly-exchange-rates. Retrieved September 12, 2017.

Breen M, Lerner A. 2013. An introduction to light and its measurement when investigating fish behaviour. Symposium on Impacts of Fishing on the Environment: ICES-FAO Working Group on Fishing Technology and Fish Behaviour. May 6-10, 2013, Bangkok, Thailand.

Bryhn AC, Königson SJ, Lunneryd S, Bergenius MA J. 2014. Green lamps as visual stimuli affect the catch efficiency of floating cod *(Gadus morhua)* pots in the Baltic Sea. Fisheries Research 157: 187-192.

Bungay T, Winger PD, Walsh P. 2015. Development and Evaluation of Galvanized Crab Pots in the Newfoundland Snow Crab Fisher. Centre for Sustainable Aquatic Resources, Fisheries and Marine Institute, Memorial University, Technical Report P-485: 21p.

Darquea J, Medina R, Alfaro-Sigueto J, Mangel J. 2016. Assessing sea turtle bycatch in the Ecuadorian small-scale gillnet fishery and trialing net illumination as a mitigation measure. 4th International Marine Conservation Congress. 30 July - 3 August. St. John's, Newfounland, Canada.

Dawe EG, Mullowney DRJ. 2016. Baited traps used in the Newfoundland and Labrador fishery for snow crab *(Chionoecetes opilio)*. Journal of Ocean Technology 11: 13-23.

DFO. 2009. Snow Crab *(Chionoecetes opilio)* Newfoundland and Labrador Region 2009 – 2011. *http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/snow-crab-neige/snow-crab-neiges2009-eng.htm*. Retrieved September 12, 2017.

DFO. 2015. Seafisheries. Atlantic & Pacific coasts commercial landings. Retrieved September 12, 2017 from *http://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/sea-maritimes/s2015pq-eng.htm*

DFO. 2016. Assessment of Newfoundland and Labrador (Divisions 2HJ3KLNOP4R) Snow Crab. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2016/013.

DFO. 2017. Snow Crab Fishery, Newfoundland and Labrador *http://www.dfo-mpo.gc.ca/decisions/fm-2017-gp/atl-02-eng.htm.* Retrieved April 21, 2017.

Farnell. 2017. Specifications for nichia white LED, Model NSPW500DS. See page 3, available at: *http://www.farnell.com/datasheets/1830865.pdf?_ga=2.49248934.1090778724.1500500911-1014048545.1495819746.* The document was provided by Lindgren-Pitman Company via email in July 20, 2017.

FFAW. 2017. Crab Prices. *http://ffaw.nf.ca/en/crab-prices-2017#.Wb_btMZ4GUk* Retrieved August 1, 2017.

Gless JM, Salmon M, Wyneken J. 2008. Behavioral responses of juvenile leatherbacks Dermochelys coriacea to lights used in the longline fishery. Endangered Species Research 5: 239-247.

Grant SM. 2003. Mortality of snow crab discarded in Newfoundland and Labrador's trap fishery: At-sea experiments on the effect of drop height and airexposure duration. Can. Tech. Rep. Fish. Aquat Sci, No. 2481, vi+28 p.

Grant SM, Hiscock W. 2009. A bait comparison study in the Newfoundland and Labrador snow crab (*Chionoecetes opilio*) fishery: does Atlantic herring stand a chance against squid? Centre for Sustainable Aquatic Resources, Fisheries and Marine Institute, Memorial University, Technical Report P-317: 56p.

Hazin HG, Hazin FHV, Travassos P, Erzini K. 2005. Effect of light-sticks and electralume attractors on surface-longline catches of swordfish *(Xiphias gladius, Linnaeus, 1959)* in the southwest equatorial Atlantic. Fisheries Research: 72: 271-277.

Hébert M, Miron G, Moriyasu M, Vienneau R, DeGrâce P. 2001. Efficiency and ghost fishing of snow crab *(Chionoecetes opilio)* traps in the Gulf of St. Lawrence. Fisheries Research 52: 143-153.

Holst R, Revill A. 2009. A simple statistical method for catch comparison studies. Fisheries Research 95: 254-259.

Ito RY, Dollar RA, Kawamoto KE. 1998. The Hawaii-based longline fishery for swordfish, *Xiphias gladius*. Biology and fisheries of swordfish, *Xiphias gladius*. NOAA Technical Report NMFS 142; 77-88.

Jørgensen T, Løkkeborg S, Furevik D, Humborstad OB. 2017. Floated cod pots with one entrance reduce probability of escape and increase catch rates compared with pots with two entrances. Fisheries Research 187: 41-46.

LINPIT. 2017. LP Electralume light - W/Lithium battery. *https://www.lindgren-pitman.com/23-lp-electralume-light-2-color-w-lithium-battery.html*. Retrieved August 1, 2017.

Lohmann KJ, Wang JH, Boles LC, McAlister J, Lohmann CMF, Higgins B. 2006. Development of turtle-safe light sticks for use in longline fisheries. Sea Turtle and Pelagic Fish Sensory Biology: Developing Techniques to Reduce Sea Turtle Bycatch in Longline Fisheries. NOAA Technical Memorandum NMFS-PIFSC-7, Pacific Islands Fisheries Science Center. National Marine Fisheries Service. National Oceanic and Atmospheric Administration. U.S. Department of Commerce. pp. 65 - 76.

Marchesan M, Spoto M, Verginella L, Ferrero EA. 2005. Behavioural effects of artificial light on fish species of commercial interest. Fisheries Research 73: 171-185.

Masuda D, Kai S, Kumazaw T, Matsushita Y. 2013. Application of the low-power underwater light to a large scale fish-trap fisher. Symposium on impacts of fishing on the environment: ICES-FAO Working Group on Fishing Technology and Fish Behaviour. May 6-10, Bangkok, Thailand.

Matsushita Y, Azuno T, Yamashita Y. 2012. Fuel reduction in coastal squid jigging boats equipped with various combinations of conventional metal halide lamps and low-energy LED panels. Fisheries Research 125: 14-19.

Montevecchi WA. 2006. Influences of artificial light on marine birds. Ecological consequences of artificial night lighting. Edited by Catherine Rich and Travis Longcore. Island Press/Washington. ISBN-10: 1559631295: pp 94-113.

NRCAN. 2017. Natural Resources Canada. Energy Sources. Average Retail Prices for Diesel in 2017 St. John's. *http://www2.nrcan.gc.ca/eneene/sources/pripri/prices_bycity_e.cfm?productID=5&locationID=44&frequency=M&priceYear=2017&Redisplay*. Retrieved September 21, 2017.

Nguyen KQ, Tran P D. 2015. Benefits of using LED light for purse seine fisheries: a case study in Ninh Thuan Province, Viet Nam. Fish for the People 13: 30 - 36.

Nguyen KQ, Winger PD, Morris C, Grant S. 2017. Artificial lights improve the catchability of snow crab *(Chionoecetes opilio)* traps. Aquaculture and Fisheries 2: 124-133.

O'Neill FG, Lines EK, Kynoch RJ, Fryer RJ, Maguire SA. 2014. Short-term economic assessment of incentivised selective gears. Fisheries Research 157: 13–23.

Ortiz N, Mangel JC, Wang J, Alfaro-Shigueto J, Pingo S, Jimenez A, Suarez T, Swimmer Y, Carvalho F, Godley BJ. 2016. Reducing green turtle bycatch in small-scale fisheries using illuminated gillnets: the cost of saving a sea turtle. Marine Ecology Progress Series 545: 251-259.

SEAFISH. 2017. Best Practice Guidance for Assessing the Financial Performance of Fishing Gear: Industry-led gear trials. Prepared for the UK Fisheries Economic Network (UKFEN) by Seafish. 12p.

Sokimi W, Beverly S. 2010. Small-scale fishing techniques using light: A manual for fishermen, Secretariat of the Pacific Community Noumea, New Caledonia. ISBN: 978-982-00-0449-8. 54p.

Solomon OO, Ahmed OO. 2016. Fishing with Light: Ecological Consequences for Coastal Habitats. International Journal of Fisheries and Aquatic Studies 4: 474-483.

Stone HH, Dixon LK. 2001. A comparison of catches of swordfish, Xiphias gladius, and other pelagic species from Canadian longline gear configured with alternating monofilament and multifilament nylon gangions. Fishery Bulletin-National Oceanic and Atmospheric Administration 99: 210-216.

Susanto A, Irnawati R, Syabana MA. 2017. Fishing Efficiency of LED Lamps for Fixed Lift Net Fisheries in Banten Bay Indonesia. Turkish Journal of Fisheries and Aquatic Sciences 17: 283-291.

Tüzen MT, Ceyhan T, Akyol O, Özkan CM. 2013. Light stick trials, being used for boosting catch efficiency, on pelagic longline for swordfish in Fethiye region (Mediterranean Sea). Ege Journal of Fisheries and Aquatic Sciences 30: 133-137.

Virgili M, Vasapollo C, Lucchetti A. 2018. Can ultraviolet illumination reduce sea turtle bycatch in Mediterranean setnet fisheries? Fisheries Research 199: 1-7.

Wang JH, Boles LC, Higgins B, Lohmann KJ. 2007. Behavioral responses of sea turtles to lightsticks used in longline fisheries. Animal Conservation 10: 176-182.

Wang JH, Fisler S, Swimmer Y. 2010. Developing visual deterrents to reduce sea turtle bycatch in gill net fisheries. Marine Ecology Progress Series 408: 241-250.

Wassmann P, Duarte CM, Agusti S, Sejr M. 2011. Footprints of climate change in the Arctic marine ecosystem. Global Change Biology 17: 1235–1249.

Winger PD, Walsh PJ. 2011. Selectivity, efficiency, and underwater observations of modified trap designs for the snow crab *(Chionoecetes opilio)* fishery in Newfoundland and Labrador. Fisheries Research 109: 107-113.

Winger P D, Løkkeborg S, Pol M. 2016. Fish capture by baited pots: A review of fish behaviour. Journal of Ocean Technology 11: 1-12.

Witzell W. 1999. Distribution and relative abundance of sea turtles caught incidentally by the US pelagic longline fleet in the western North Atlantic Ocean, 1992-1995. Fishery Bulletin 97: 200-211.

Yami B. 1976. Fishing with light. FAO fishing manuals. Published by arrangement with the Food and Agriculture and Organization of the United Nations by Fishing News Books Ltd. ISBN: 085238078X. 121p.

Zhou S, Shirley TC. 1997. Behavioural responses of red king crab to crab pots. Fisheries Research 30: 177-189.

Figure 1(on next page)

Location of the study area, along the northeast coast of the island of Newfoundland.

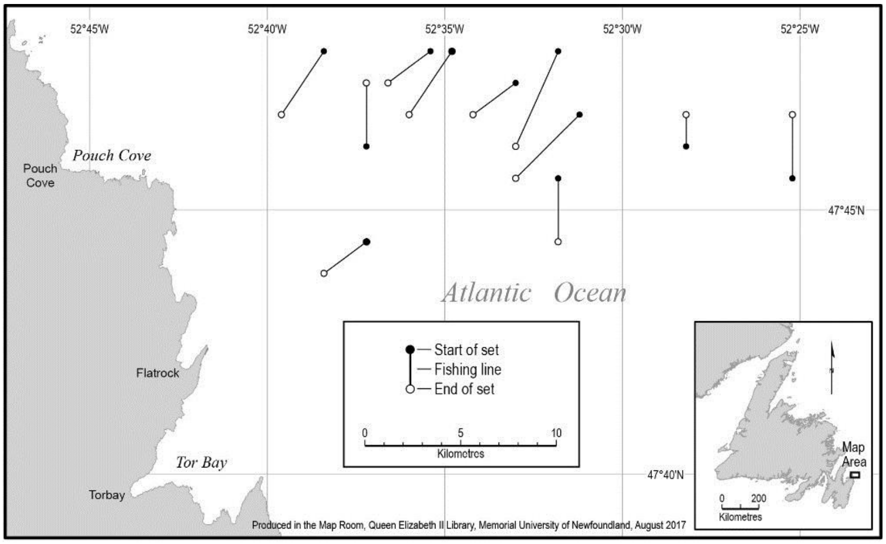
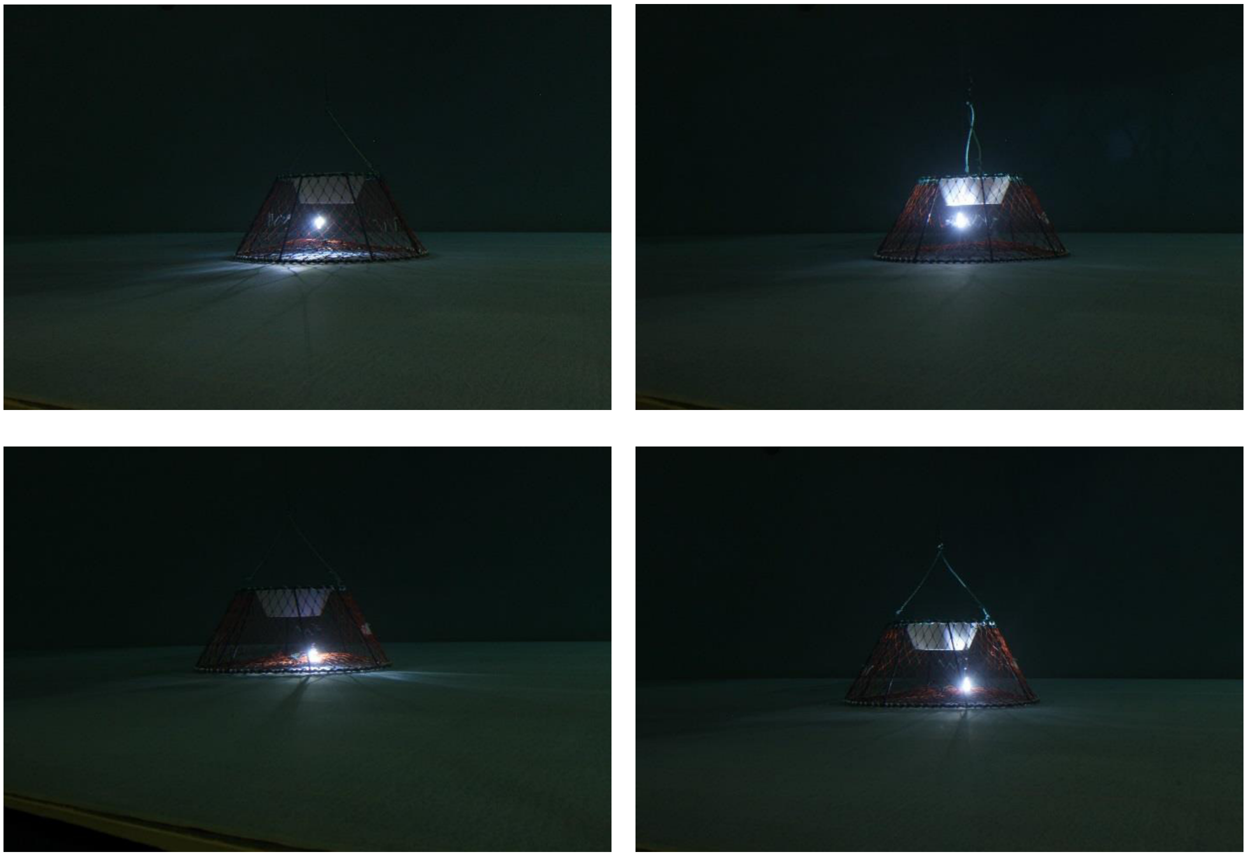

52°45'W
52°40'W
52°35'W
52°30'W
52°25'W
47°45'N
47°40'N
Pouch Cove
Pouch Cove
Flatrock
Tor Bay
Torbay
Atlantic Ocean
Start of set
Fishing line
End of set
0
5
10
Kilometres
Map Area
0
200
Kilometres
Produced in the Map Room, Queen Elizabeth II Library, Memorial University of Newfoundland, August 2017

Figure 2(on next page)

Four light treatments photographed in an underwater tank.

Top left panel is High Upright treatment; Top right panel is High Upside Down treatment; Bottom left panel is Low Upright treatment; Bottom right panel is Low Upside Down treatment.



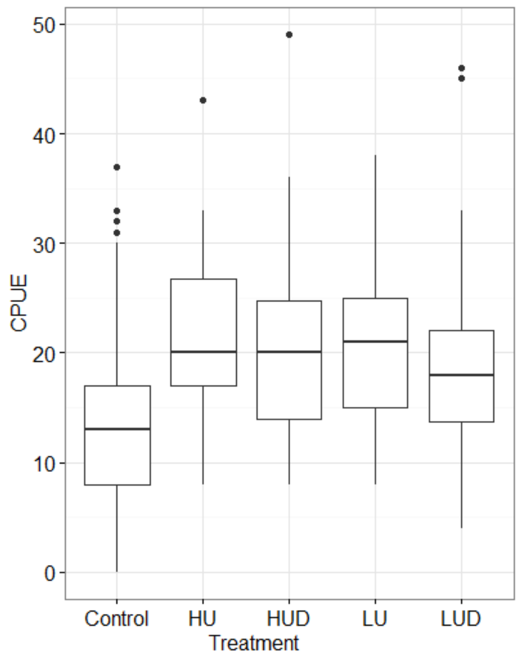
PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Figure 3(on next page)

Boxplots of CPUE of snow crab captured by different experimental treatments.

Left panel: legal-sized crab. Right panel: sublegal-sized crab. HU is high upright. HUD is high upside down. LU is low upright, and LUD is low upside down.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018


50
40
30
20
10
0
CPUE
Control
HU
HUD
LU
LUD
Treatment

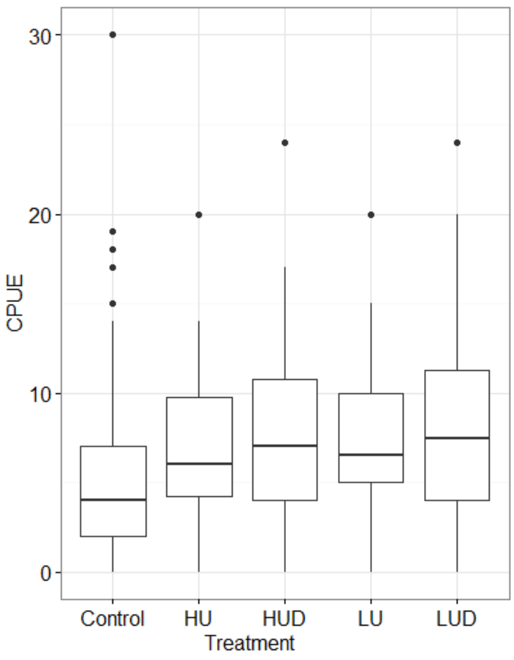
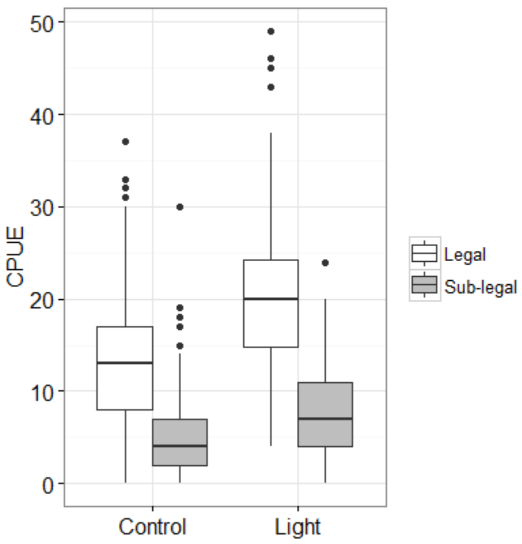

30
20
10
0
CPUE
Control
HU
HUD
LU
LUD
Treatment

Figure 4(on next page)

Boxplots of CPUE of crab classified by legal and sublegal size for the control treatment and light treatments (combined).



PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Figure 5(on next page)

Boxplots of CPUE of crab classified by legal and sublegal size for the different light locations (high combined and low combined).

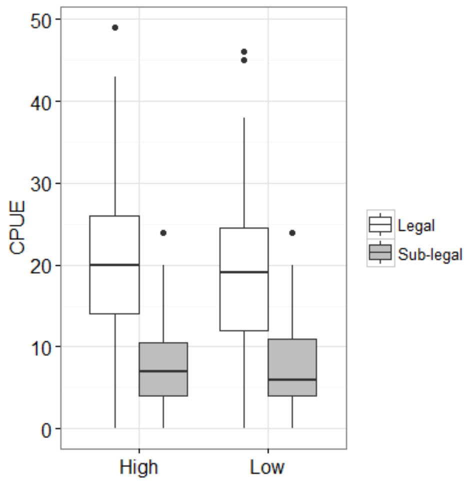
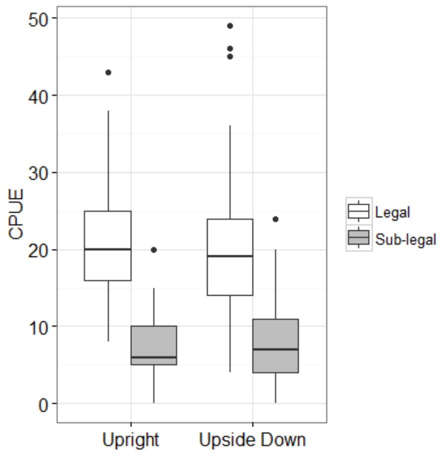

50
40
30
20
10
0
CPUE
High
Low
Legal
Sub-legal

Figure 6(on next page)

Boxplots of CPUE of crab classified by legal and sublegal size for the different light orientations (upright combined and upside down combined).



PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Figure 7(on next page)

Boxplots of CPUE of snow crab classified by different soak time.

The left panel represents legal-sized crab and the right panel represents sublegal-sized crab caught. Figures denoted as Light include all 4 light treatments combined.

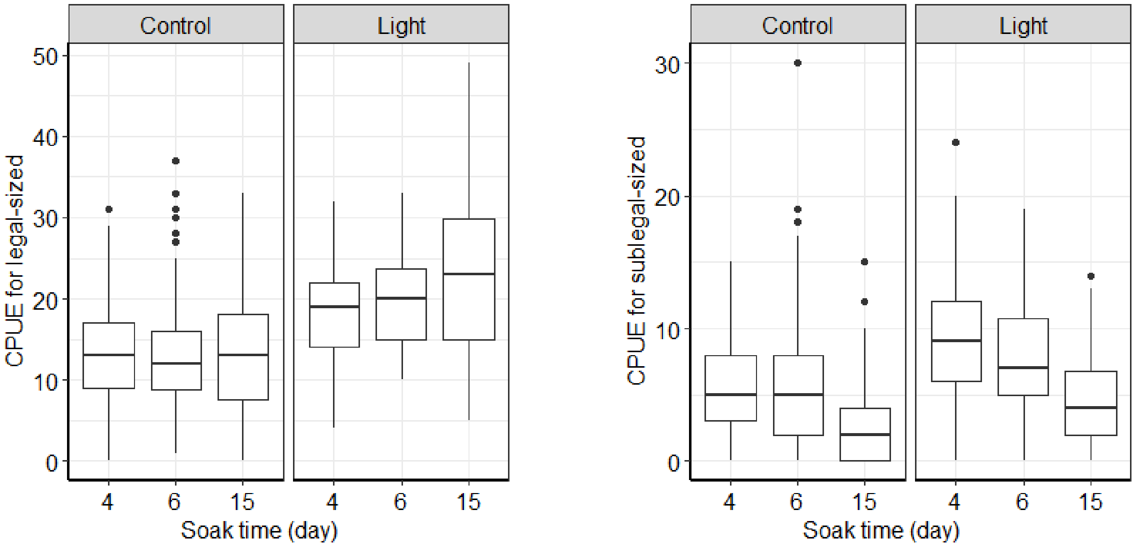
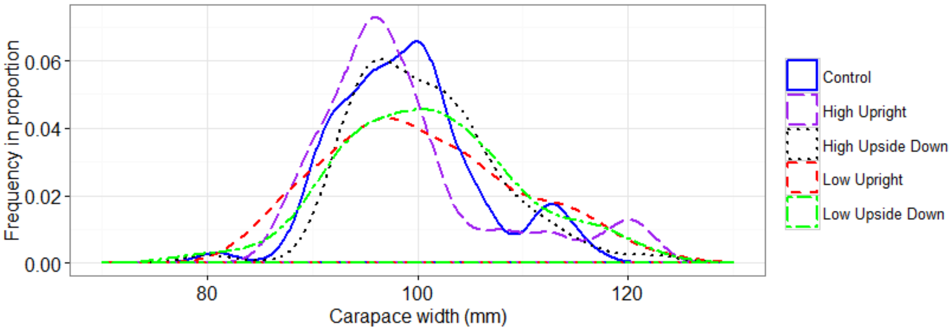

Control
Light
CPUE for legal-sized
0
10
20
30
40
50
4
6
15
Soak time (day)
Control
Light
CPUE for sublegal-sized
0
10
20
30
Soak time (day)

Figure 8(on next page)

Length distribution of snow crab recorded in the different experimental treatments.

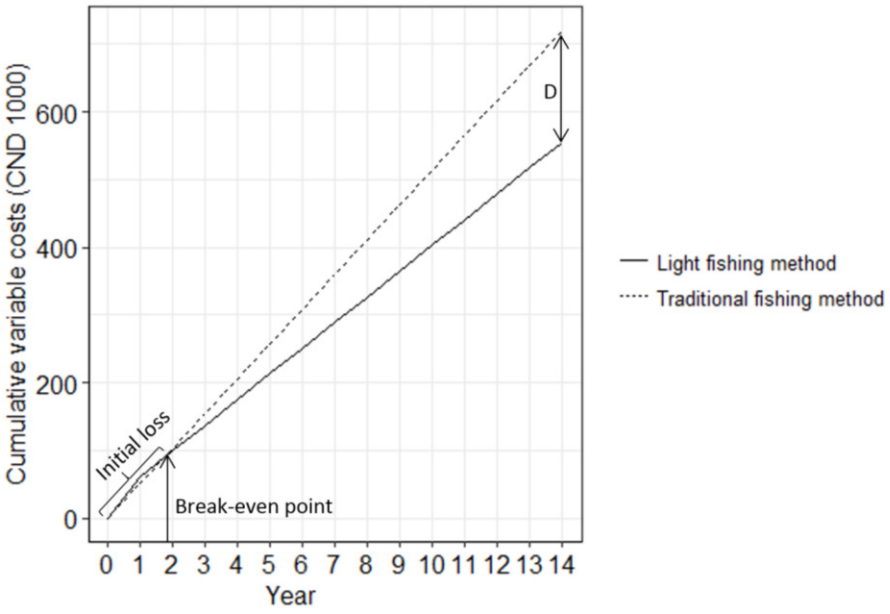


PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Figure 9(on next page)

Cumulative variable costs for the traditional and light fishing methods.

Fourteen year period is estimated based on steady state operating time of the LED light with 10,000 hours. The intersection of the curves designates the break-even point (D) that corresponds with the time until Return on Investment (ROI). The zone to the right of the break-even point and between the fishing methods indicates the financial gain realized when using LED lights, meanwhile the zone in the left side of break-even point indicates the initial loss when investing LED lights. Note: the cumulative variable costs of light fishing method is not a straight line in the first period because the investment of LED lights in the first year is usually higher than the years after. D is calculated by equation (9) for the fourteen year period.



PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Figure 10(on next page)

Cumulative income using the traditional and light fishing methods for different crab prices.

Cumulative income was obtained by equation (3) and (4) over a fourteen year period.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

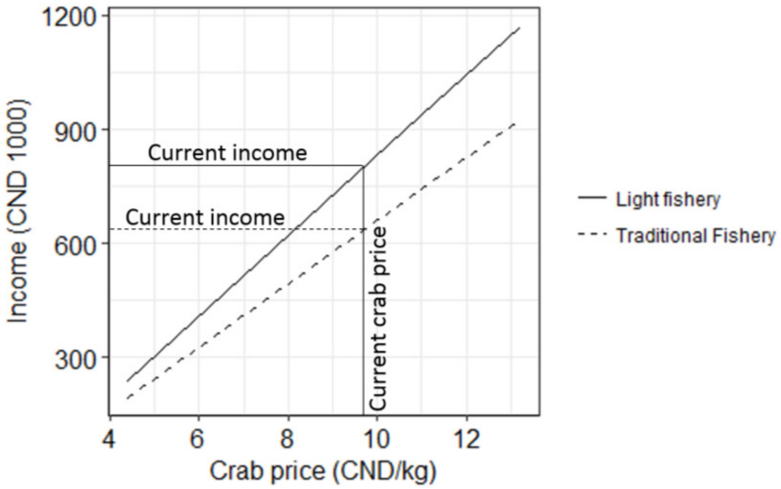

1200
900
600
300
Income (CND 1000)
Current income
Current income
Current crab price
4
6
8
10
12
Crab price (CND/kg)
Light fishery
Traditional Fishery

Figure 11(on next page)

Financial gain ($ CND) using LED lights under different quota allocations over a fourteen year period, compared to the traditional fishing method.

D is obtained by equation (9) at different quota levels. This relationship is expressed by the equation $D = 21.985Q - 50.562$ (Q is quota allocated, measured by metric tonnes).

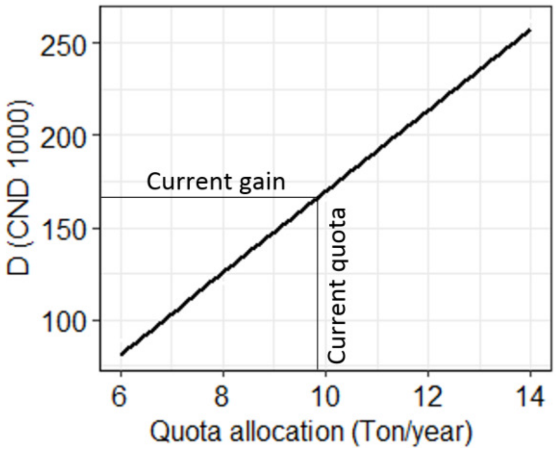

250
200
150
100
D (CND 1000)
Current gain
Current quota
6
8
10
12
14
Quota allocation (Ton/year)

Table 1(on next page)

Mean CPUE of legal and sublegal size crab captured by the different experimental treatments and their comparisons using Non-parametric Wilcoxon Rank-Sum Test.

As mean ± standard error. HU is High Upright; HUD is High Upside Down; LU is Low Upright; and LUD is Low Upside Down. (NS) indicates no significant difference. (S) indicates significant difference detected.

Treatment	Mean CPUE legal size	Mean CPUE sublegal size
Control	13.29 ± 0.37	4.91 ± 0.23
HU	21.22 ± 1.01	6.94 ± 0.57
HUD	20.17 ± 1.18	7.52 ± 0.78
LU	20.80 ± 0.85	7.45 ± 0.54
LUD	19.10 ± 1.09	7.98 ± 0.71
Treatment comparison		
Control vs. HU	S	S
Control vs. HUD	S	S
Control vs. LU	S	S
Control vs. LUD	S	S
HU vs. HUD	NS	NS
HU vs. LU	NS	NS
HU vs. LUD	NS	NS
HUD vs. LU	NS	NS
HUD vs. LUD	NS	NS
LU vs. LUD	NS	NS

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Table 2(on next page)

Mean CPUE of legal and sublegal size crab captured by the different soak times and their comparisons using Non-parametric Wilcoxon Rank-Sum Test.

As mean ± standard error. (NS) indicates no significant difference. (S) indicates significant difference detected.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Soak time	Mean CPUE legal-sized crab		Mean CPUE sublegal-sized crab	
	Control	Light pot	Control	Light pot
4 days	13.0 ± 0.53	18.4 ± 0.62	5.9 ± 0.34	9.1 ± 0.52
6 days	13.1 ± 0.60	20.1 ± 0.74	5.7 ± 0.45	7.9 ± 0.54
15 days	13.9 ± 0.81	23.2 ± 1.28	2.8 ± 0.3	4.8 ± 0.46
Soak time comparison				
4 days vs. 6 days	NS	NS	NS	NS
4 days vs. 15 days	NS	S	S	S
6 days vs. 15 days	NS	NS	S	S

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Table 3(on next page)

Parameter estimates and fit statistics of the Poisson model, with negative binomial distribution of catches of legal-sized crab.

HU is High Upright; HUD is High Upside Down; LU is Low Upright; and LUD is Low Upside Down.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Predictor	Estimate	SE	z value	P
Intercept	2.50	0.04	59.03	< 0.001
Soak time	0.01	0.00	2.73	0.006
HU	0.46	0.07	6.62	< 0.001
HUD	0.41	0.07	5.66	< 0.001
LU	0.45	0.06	6.89	< 0.001
LUD	0.37	0.07	5.61	< 0.001

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Table 4(on next page)

Parameter estimates and fit statistics of the Poisson model with negative binomial distribution of catches of sublegal-sized crab.

HU is High Upright; HUD is High Upside Down; LU is Low Upright; and LUD is Low Upside Down.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Predictor	Estimate	SE	z value	P
Intercept	2.06	0.07	31.41	< 0.001
Soak time	-0.06	0.01	-9.21	< 0.001
HU	0.36	0.11	3.23	< 0.001
HUD	0.43	0.11	3.75	< 0.001
LU	0.42	0.10	4.11	< 0.001
LUD	0.47	0.10	4.65	< 0.001

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Table 5(on next page)

Mean CW recorded for the different treatments and their pairwise post hoc comparison using Tukey’s HSD.

CW is carapace width. SE is standard error. CI is confidence interval. HU is High Upright; HUD is High Upside Down; LU is Low Upright; and LUD is Low Upside Down. (NS) indicates no significant difference. (S) indicates significant difference detected.

Treatment	Number of crab measured	Mean CW	SE
Control	70	99.01	0.81
HU	48	98.83	1.23
HUD	68	100.5	0.82
LU	59	100.38	1.16
LUD	51	100.95	1.17
Treatment comparison	**t-value**	**95% CI**	**p-value**
Control vs. HU	-0.19	-4.21 to 3.84	0.999
Control vs. HUD	1.49	-2.17 to 5.14	0.798
Control vs. LU	1.37	-2.43 to 5.17	0.859
Control vs. LUD	1.93	-2.02 to 5.89	0.665
HU vs. HUD	1.68	-2.37 to 5.72	0.787
HU vs. LU	1.56	-2.62 to 5.73	0.844
HU vs. LUD	2.12	-2.20 to 6.44	0.662
HUD vs. LU	-0.12	-3.94 to 3.70	0.999
HUD vs. LUD	0.45	-3.53 to 4.42	0.998
LU vs. LUD	0.56	-3.54 to 4.67	0.996

Table 6(on next page)

GLMM parameters of crab length class comparison.

HU is High Upright; HUD is High Upside Down; LU is Low Upright; and LUD is Low Upside Down.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Fixed effects	Estimate	Standard error	t-value	p
Intercept	4.60	0.01	486.55	0.000
HU	-0.01	0.01	-0.13	0.898
HUD	0.01	0.01	1.12	0.265
LU	0.01	0.01	0.99	0.322
LUD	0.02	0.01	1.34	0.180

1

Table 7(on next page)

Variable costs for each trip using the traditional fishing method.

Average catch of *F.V Flat Rock Byes* was estimated to be 1.467 mt per trip based on the average observed catch of the control treatment (see Table 1). Approximately 7 trips were needed to fully harvest the vessel's allocated quota of 9.979 mt in the year of 2017. Diesel price was calculated from NRCAN (2017).

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Item	Unit	Quantity	Price (CND)	Total Cost (CND)
Bait	kg	326	$2	$652
Fuel	l	500	$1.195	$598
Labour	% of revenue	40	$1,400	$5,600
Ice	Bag	10	$50	500
Sum				$7,350

1

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26833v1 | CC BY 4.0 Open Access | rec: 7 Apr 2018, publ: 7 Apr 2018

Table 8(on next page)

LED light investment in 14 years.

Price of LED light and batteries were received from LINPIT (2017)

Item	Quantity	Price (CND)	Cost (CND)
Year 1			
Initial LED Lights	240	$58	$13,993
Batteries (couple)	240	$17	$3,975
Total			$17,968
Year 2			
Replacement Lights	12	$58	$700
Batteries (couple)	480	$17	$7,951
Total			$8,650
Year 3 to year 14 is similar to year 2 ($8,650 CND for each subsequent year)			
Total LED light costs of 14 years			$130,423