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Assessing the Technical and Economic Viability of Galvanizing Snow Crab (*Chionoecetes opilio*) Traps

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Abstract: Commercial harvesting of snow crabs (*Chionoecetes opilio*) began in Newfoundland and Labrador, Canada, in 1967. Today, the fishery consists of 2188 active fishing licenses and has grown into the province's most economically valuable fishery. Snow crabs are captured using conical traps consisting of a mild carbon steel frame, hard plastic entry funnel and a jacket of polyethylene netting. The frames of these traps corrode over time, which is expedited by being deployed in marine environments and stored on land near the ocean when not in use. As a result, there is interest within the community to increase the longevity of crab traps. One solution is to galvanize the steel frames prior to installing the funnel and netting. However, before harvesters transition to galvanized traps, two questions must be answered. Will the use of galvanized steel negatively impact catch rates? Will the life cycle of a crab trap be extended sufficiently to justify the additional cost of galvanizing? This study employed a generalized linear mixed model to evaluate the catch of legal-sized male crabs (CPUE) during the commercial fishery as a function of three trap frame treatments (old traditional, new traditional and new galvanized). We also assessed the economic viability of galvanizing trap frames by evaluating the life cycle cost (LCC) of traditional and galvanized traps to the harvester. The LCC was calculated over a range of inflation (0–6%) and discount (3–20%) rates. Our results found no significant difference in CPUE between new traps (traditional vs. galvanized) and concluded that except during instances of very high discount rates (12.9–19.9%), it is economically favourable to galvanize crab trap frames.

Keywords: snow crab fisheries; crab traps; crab pots; capture per unit effort; galvanizing; net present value; life cycle cost; sustainability

Key Contribution: Catch per unit effort for galvanized traps was not statistically significantly from new, traditional traps. The life cycle cost for galvanized traps is lower than that of traditional, ungalvanized traps except during periods of high discount rates. We believe this is the first scientific comparison between galvanized and traditional snow crab traps.

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1. Introduction

The fishery is a primary economic driver for Canada's most easterly province, Newfoundland and Labrador. In 2022, the Newfoundland and Labrador Department of Fisheries, Forestry and Agriculture [1] reported that provincial fisheries activities employed 17,000 people in 400 communities and 89 processing plants, and valued fisheries exports from the province to be CAD 1.4B. Snow crabs (*Chionoecetes opilio*) have been commercially harvested since 1967 in Newfoundland and Labrador [2]. This fishery represents a significant economic contributor to the province, with landings reaching 49,971 t in 2022, generating exports of CAD 761M or 54% of Newfoundland and Labrador's total fisheries exports [1] for that year. Recent figures from Fisheries and Oceans Canada (DFO) for 2023 report increases in snow crab landings (51,632 t) [3], confirming that the crab fishery remains significant to the economy of Newfoundland and Labrador.

The snow crab fishery commonly employs conical traps to harvest crab. These traps consist of a mild carbon steel frame, a hard plastic entry funnel and a jacket of polyethylene diamond-mesh netting (Figure 1) [4]. Mild carbon steel is defined as steel that contains iron and 0.05–0.25% carbon [5]. Mild carbon steel is widely used for its excellent formability and weldability characteristics, and its relatively low cost.

Figure 1. Traditional crab trap commonly used in Newfoundland and Labrador, Canada.

Galvanic corrosion of mild carbon steel in seawater is a well-known phenomenon [6,7] and the degradation it causes to traps deployed in and stored near marine environments and its associated costs have been reported for several decades [8–10]. DFO reported 2188 active, licensed, crab fishing enterprises in Newfoundland and Labrador in 2018 [11] and it is reported that approximately 2.5 million traps were in use in 2022 [12]. The typical lifespan for these traps is approximately seven years according to Bernard Chafe, Petty Harbour, NL, Canada, Personal Communication [13]. Therefore, the replacement costs of crab traps due to the steel frame corroding are of significant interest.

Previous attempts to develop longer lasting crustacean traps have been reported. Common construction materials include the use of plastic, fiberglass, stainless steel, painted steel, galvanic attachments and polyvinyl chloride (PVC)-coated wire and frames as materials for construction [10,14–16]. Hot-dip galvanization (HDG) is also a promising possibility for some fisheries [17,18]. HDG is a multistage process (Figure 2) which includes the following: (1) degreasing the frame to remove any organic solvents, oil and grease; (2) rinsing away the degreasing solution; (3) pickling the frame in a diluted solution of heated sulfuric acid (H_2SO_4) or ambient hydrochloric acid (HCl) to remove mill scale or iron oxide; (4) rinsing the pickling solution from the frame; (5) applying a flux solution of zinc ammonium chloride $(NH_4)_2ZnCl_4$ to remove any remaining iron oxide and to prevent further oxidizing prior to galvanizing; (6) allowing the flux solution to dry; (7) coating the surface of the frame with molten zinc at high temperatures to protect the frame; and (8) inspecting to ensure the coating thickness is correct and that it adhered to the frame [19]. Once removed and exposed to air, the zinc (Zn) reacts with oxygen (O_2) in the air to form the initial corrosion product zinc oxide (ZnO); ZnO then reacts with carbon dioxide (CO_2) to form an insoluble corrosion product, zinc carbonate ($ZnCO_3$) [20,21]. This produces a relatively strong, matte grey coating which can substantially decrease the rate of corrosion by more than 300% [22] and increase a component's lifespan.

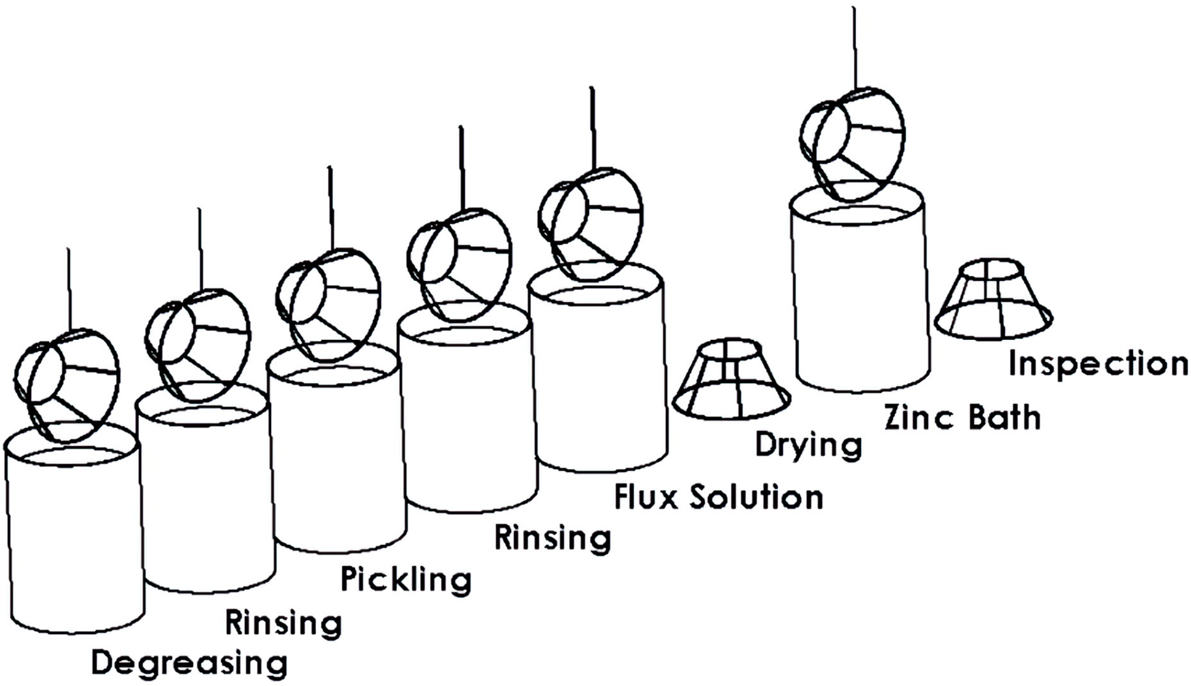

Figure 2. Schematic diagram identifying the steel galvanizing process used for the crab trap frames. Steps include degreasing, rinsing, pickling, rinsing, applying flux solution, drying, dipping in a molten zinc bath and inspecting.

In this paper, we assess the technical and economic viability of galvanizing snow crab traps for the snow crab fishery in Newfoundland and Labrador, Canada. We compared traditional and galvanized traps in terms of the number of legal-sized male crabs caught per trap (CPUE) and performed an economic analysis based on the life cycle cost (LCC) of both traps.

2. Materials and Methods

Our hypothesis at the onset of this study was that galvanizing trap frames does not affect snow crab CPUE; however, no scientific studies could be found to support or refute this. A comparative fishing experiment was undertaken between 23 April and 19 May 2015 to determine whether galvanizing the steel frames before the funnel and jacket were installed would impact the trap's CPUE. Testing took place in Northwest Atlantic Fisheries Organization (NAFO) division 3L approximately 20 nautical miles (37 km) southeast of Petty Harbour, NL (Figure 3), on the *F.V. Phoenix* during the commercial fishing season.

Traditional snow crab traps were constructed using a mild carbon steel frame, a hard plastic entry funnel and a jacket of polyethylene diamond-mesh netting with a minimum, nominal mesh size of 133 mm (Figure 1) [4]. The mild steel frame (Figure 4) was fabricated from ø12 mm and ø14 mm bar stock and weighed approximately 12.5 kg.

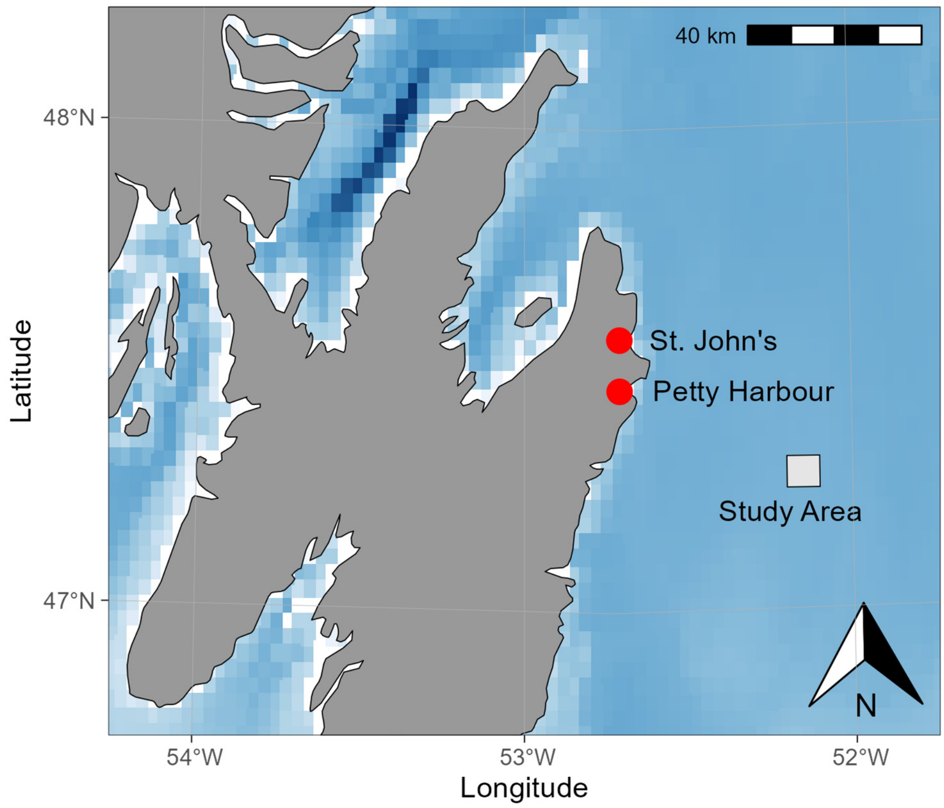

Figure 3. Map of the study area located in NAFO Division 3 L approximately 20 nautical miles (37 km) southeast of Petty Harbour, Newfoundland and Labrador, Canada. The map was created using the ggOceanMaps package (version 2.1.1) [23] in R. Arctic polar stereographic projection was used.

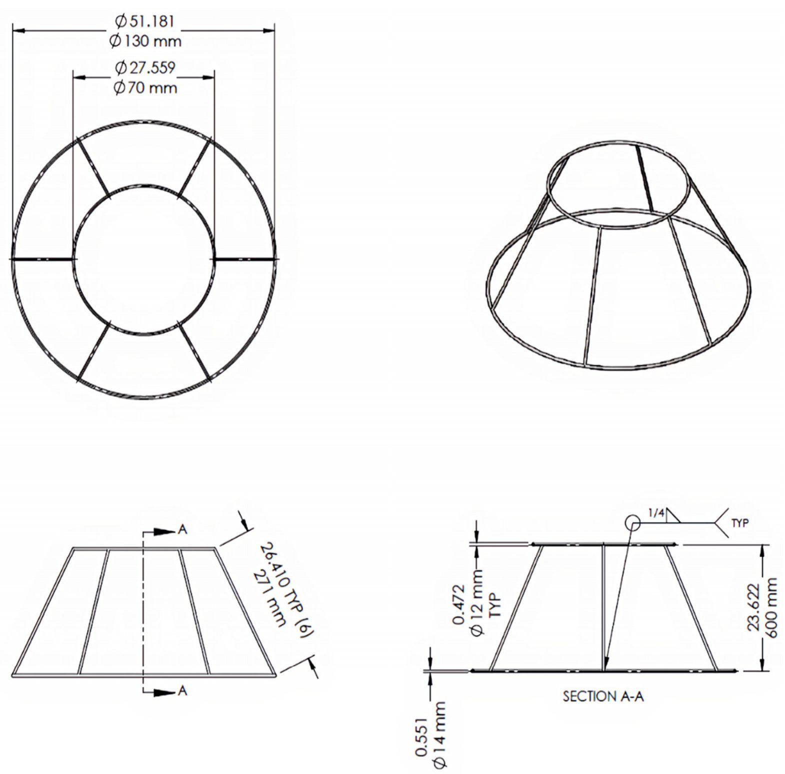

Figure 4. Mild steel frame construction for a traditional crab trap commonly used in Newfoundland and Labrador, Canada.

Three different trap treatments were evaluated: (1) new galvanized crab traps, (2) new traditional crab traps and (3) older traditional crab traps (Table 1). Fifty new traps were purchased (Vónin Canada Ltd., Port de Grave, NL, Canada) for this evaluation and the steel frames for the 25 galvanized traps were hot-dip galvanized (Island Manufacturing and Galvanizing Inc., Wabana, Bell Island, NL, Canada) prior to installing the funnel and netting jacket. The new traps were compared with the harvester's existing traps and were found to be consistent in size and mesh size. The harvester's existing traps were assessed for damage (broken frames, damaged funnels and torn, fouled netting) prior to use to confirm whether they were in good condition. Galvanizing increased the weight of each frame by approximately 0.34 kg on average and increased the diameter of the steel bars by approximately 0.29 mm on average. This was obtained by measurements taken of 25 crab trap frames before and after galvanizing. All traps were randomly placed in a single fleet spaced at intervals of 36.6 m between traps and baited with chopped squid (*Illex illecebrosus*) in bait jars.

Table 1. Comparison of snow crab traps.

Treatment	Frame	Netting Jacket	Notes
1	New Galvanized	New	
2	New Ungalvanized	New	
3	Older Ungalvanized	Existing	Existing traps were assessed for fitness prior to use

The fleet of traps was hauled four times: (1) 3 May 2015, (2) 12 May 2015, (3) 16 May 2015 and (4) 19 May 2015. A fleet of 50 traps (16 old, 16 new and 18 galvanized) was used for the first haul and a fleet of 77 traps (27 old, 25 new and 25 galvanized) was used for the remaining hauls. Soak time was ten days for "Haul 1", nine days for "Haul 2", four days for "Haul 3" and three days for "Haul 4". Soak time was categorized into two levels: (1) short ($\leq$5 days) and (2) long (>5 days). The total number of legal-sized male snow crabs was counted for each trap and recorded. No female snow crabs were captured as part of this experiment because this is prohibited by management regulations [4].

An exploration of the data was completed to help minimize common analysis issues [24] and statistical analysis of the CPUE data was performed using R statistical software (version 4.3.2) [25]. CPUE was treated as count data and not transformed to model a normal distribution [26]. A generalized linear mixed-effects model (GLMM) was fitted using the glmmTMB package (version 1.1.8) [27]. We fit the model as follows:

$$\log(y) = \alpha + \beta_1 \text{ TrapType} + \beta_2 \text{ Soak} + b + \varepsilon_1 + \varepsilon_2, \quad (1)$$

where y is CPUE, α is the intercept, β_1 TrapType is the trap treatment, β_2 Soak is the soak treatment, b~N (0, σ^2) is the random nested variable, ε_1 is the error term for the model and ε_2 is the error term for the random variable. One dependent variable, the number of crabs per trap (CPUE) and independent variables "Trap_Type" (old, new or galvanized frame treatment) and "Soak" (short or long soak times) were used for the model. Nested, random effects included "Haul" (haul number, 1–4) and "Trap_Number" (location of the trap within the fleet, 1–77). A Second Order Akaike Information Criterion (AICc) score was used to identify the model that better fit the data. The DHARMa package (version 0.4.6) [28] was used to evaluate model fit using a residual investigation, quantile–quantile plot and dispersion test. Pairwise comparisons and estimated marginal means (EMM, i.e., least-squares mean) for CPUE with its 95% confidence intervals (CIs) were calculated using the function pairs and emmeans, respectively, from the emmeans package (version 1.9.0) [29].

To estimate the lowest overall trap cost for harvesters, a life cycle cost (LCC) analysis was completed similar to other LCC analyses [30–34]. A crab trap is a simple device; therefore, for this analysis, the LCC was defined as the total cost of owning and maintaining it over its expected life discounted into current Canadian dollars [32]. For this analysis, a new ungalvanized trap was purchased in year 0 and replaced in years 7 and 14; replacement jackets were purchased in years 4, 11 and 18. A new galvanized trap was purchased at year 0 and replacement jackets purchased in years 4, 8, 12 and 16. The discounting rate is defined as the interest rate which reflects the harvester's time value of money [32]; this means the interest rate where the harvester becomes indifferent to extending the life of his traps because borrowing costs are too high, or a better rate of return can be achieved by an alternate investment or gear purchase. A harvester might also require a higher discount rate to offset any potential risks associated with this additional cost (e.g., loss of gear, reduced quotas, or lower prices), but aversion to risk will differ for each harvester. LCC was calculated using Equation (2) which incorporates net present value (NPV) and future cost (C_f) in the equation. NPV discounts future expenditures into current Canadian dollars (Equation (3)). Future costs (C_f) were estimated using Equation (4) based on expected inflation rates. The NPV was calculated for both new galvanized and new traditional crab traps. The lifespan of a traditional steel crab trap was estimated to be seven years based on local harvester experience [13], while a galvanized frame is expected to last three times as long [22]; therefore, a least common denominator lifespan of 21 years was selected. Crab trap and jacket costs were provided by Dean Bartlett of Vónin Canada Ltd., Port de Grave, NL, Canada, Personal Communication [35] and jackets are expected to require replacement after approximately 4 years. The cost of galvanizing was supplied by Nadia Faccin of Island Manufacturing and Galvanizing Inc., Wabana, Bell Island, NL, Canada, Personal Communication [36]. Models were constructed for a 21-year period, the discount rate was evaluated between 3% and 20% for each model and inflation rates between 0% and 6% were evaluated.

$$LCC = \Sigma \left((C_p\ (1 + i)^t) / (1 + r)^t \right) + C_0, \tag{2}$$

where LCC is the life cycle cost [$], C_p is the present cost [$], i is the inflation rate [decimal], r is the discount rate [decimal], t is the time [years, 1–20] and C_0 is the initial cost [$] in year zero.

$$NPV = C_f / (1 + r)^t, \tag{3}$$

where NPV is the net present value [$], C_f is the future cost [$], r is the discount rate [decimal] and t is the time [years, 1–20].

$$C_f = C_p\ (1 + i)^t, \tag{4}$$

where C_f is the future cost [$], C_p is the present cost [$], i is the inflation rate [decimal] and t is the time [years, 1–20].

3. Results

In total, 281 trap hauls were completed during the experiment. Data exploration identified the following: (1) "Trap 5" was empty after all four hauls, assumed suspect and removed from the data set; (2) "Haul 2, Traps 19 and 69" were also inexplicably empty and suspected to have tipped over or lost bait and were removed from the data set; (3) for the longer fleets "Hauls 2, 3 and 4", the first and last two traps consistently fished poorly and were suspected to be unstable and removed; (4) data exploration also identified one trap in Haul 1 (Trap 15) and five traps in Haul 2 (Traps 49, 56, 61, 71 and 75) which fished poorly (CPUE $\leq$ 3 while the surrounding traps fished consistently better). In total, 24 trap hauls were identified as outliers and removed from the analysis (eight old traps, eight new traps and eight galvanized traps), leaving 257 trap hauls included in the final model.

The observed mean CPUE based on the raw data was 34.4 ($\pm$15.8 standard error of the mean (SEM)) crabs per trap for old traps compared with 39.5 ($\pm$14.5 SEM) crabs per trap for new traps and 39.4 ($\pm$13.9 SEM) crabs per trap for galvanized traps (Figure 5). It was also observed that CPUE appeared to decrease as the season progressed. A Poisson GLMM was fitted to CPUE (count data). However, the model was underdispersed and did not fit the data well. It has been reported in the literature that Generalized Poisson distributions [37] and Conway–Maxwell–Poisson (CMP) distributions [38] are better suited to underdispersed count data. A CMP GLMM which included "Trap_Type" and "Soak" as independent variables and "Haul/Trap_Number" as nested random effects was selected based on its AICc score. The resulting model showed that using old traps significantly decreased CPUE (*p*-value = 0.0126) compared with using galvanized traps and that there was no statistically significant difference in CPUE (*p*-value = 0.8924) between new and galvanized traps (Table 2). Old traps decreased CPUE by 12.08% (Confidence Interval (CI): 20.53–2.72) compared to galvanized traps. Furthermore, the model indicated that there was no statistically significant difference in CPUE between short and long soak times (*p*-value = 0.0565).

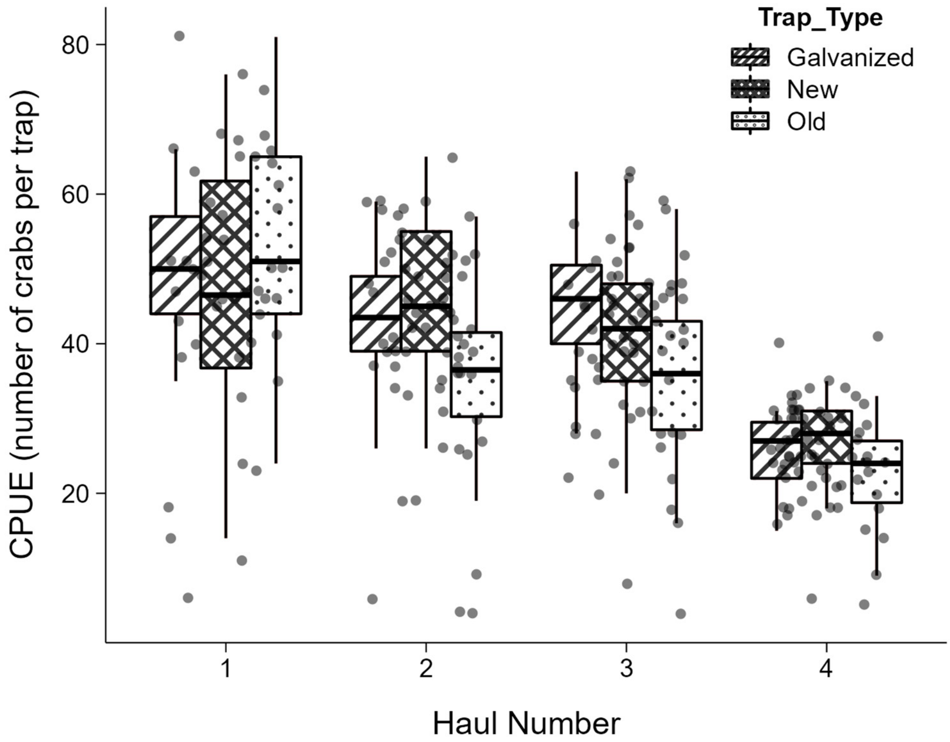

Figure 5. Boxplot showing number of legal-sized male crabs per trap (CPUE) as a function of haul number and trap type. The horizontal line in the middle of each box represents the median CPUE. The lower and upper limits of each box represent the first and third quartile, respectively. Lower and upper whiskers represent CPUE values outside the interquartile range. Dots show the observed values. This figure was created using ggplot2 (version 3.4.4) [39] in R.

Table 2. Generalized linear mixed model (GLMM) estimates for the total number of crabs per trap (CPUE) including standard error, *z*-value and *p*-value. Comparison of new and old traps to galvanized traps and a long soak (>5 days) to a short soak (≤5 days).

CPUE Model	Estimate	Standard Error	*z*-Value	*p*-Value
Intercept	3.50041	0.12703	27.555	$<2 \times 10^{-16}$
Trap_Type (New)	0.00685	0.05062	0.135	0.8924
Trap_Type (Old)	−0.12871	0.05158	−2.496	0.0126
Soak (Long)	0.33294	0.17456	1.907	0.0565

When examining the EMM pairwise comparisons [29] using the Tukey method for comparison and averaged over both levels of soak, the observations were as follows: (1) galvanized traps increased CPUE 13.7% (CI: 0.8–28.0) compared with old traps; (2) new traps increased CPUE 14.5% (CI: 1.4–29.0) compared to old traps; and (3) galvanized and new traps were not significantly different (*p*-value = 0.9900). This results in an increase in CPUE of 5.0 (CI: 0.5–10.0) crabs per trap for new traps and 4.7 (CI: 0.3–9.6) crabs per trap for galvanized traps when compared to old traps (Figure 6). Figure 6 also confirmed there was no significant difference in CPUE for new and galvanized treatments.

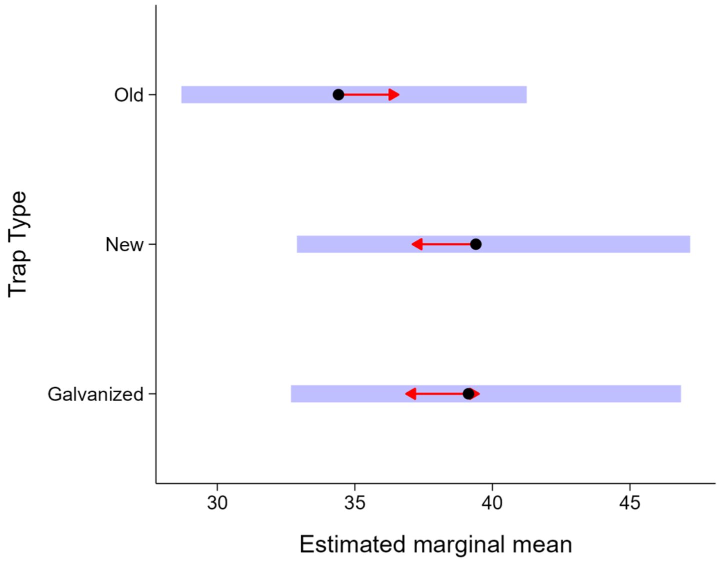

Figure 6. Estimated marginal means (EMMs) comparing the mean number of legal-sized male crabs per trap (CPUE) and confidence interval (CI; expected range: 2.5–97.5%) for each trap treatment predicted by the model. The black dots represent the mean estimate, the blue bars represent the CI and the red arrows are comparisons between each treatment. The overlap between the red arrows for new and galvanized traps confirms that the difference between these two treatments is not statistically significant. There is no overlap between the red arrow for old traps and the red arrows for galvanized or new traps, confirming that these increases in CPUE are statistically significant. This figure was created using ggplot2 (version 3.4.4) [39] in R.

Our economic analysis showed that galvanizing crab traps may be a cost-effective option in certain cases. Using 2023 Canadian dollars, our analysis assumes the cost of a new crab trap is $76.00 and the replacement jacket cost is $12.95 [35]. Galvanizing costs are $1.50/lb. ($3.31/kg) [36], and based on a weight of 12.5 kg (27.6 lbs.) for each frame [40], they would add $41.40 (54.5%) to the purchase price of each new trap. Therefore, the upfront cost for one trap will be $76.00 for a traditional trap and $117.40 for a galvanized trap. Based on local industry estimates [13], the typical lifespan of a crab trap is seven years, and the lifespan of a jacket is approximately four years [35]. Galvanizing is expected to increase the lifespan of the frame to 21 years [22].

Figure 7 shows the resulting LCC for traditional and galvanized traps under four different scenarios (0 to 6% inflation). The solid line shows the cost, in today's Canadian dollars, of purchasing ungalvanized traps and the dashed line shows the cost, in today's Canadian dollars, of purchasing a galvanized trap. For discount rates to the left of the intersection of the curves, the galvanized traps will have the lowest LCC. For discount rates to the right of the intersection of the curves, the traditional traps will have the lowest LCC. At the point of intersection, both traps will have the same LCC. At 0% inflation, a 12.9% discount rate would be required before a traditional trap became the low-cost solution (Figure 7A). The discount rate increases to 15.2% at 2% inflation (Figure 7B), 17.4% at 4% inflation (Figure 7C) and 19.9% at 6% inflation (Figure 7D).

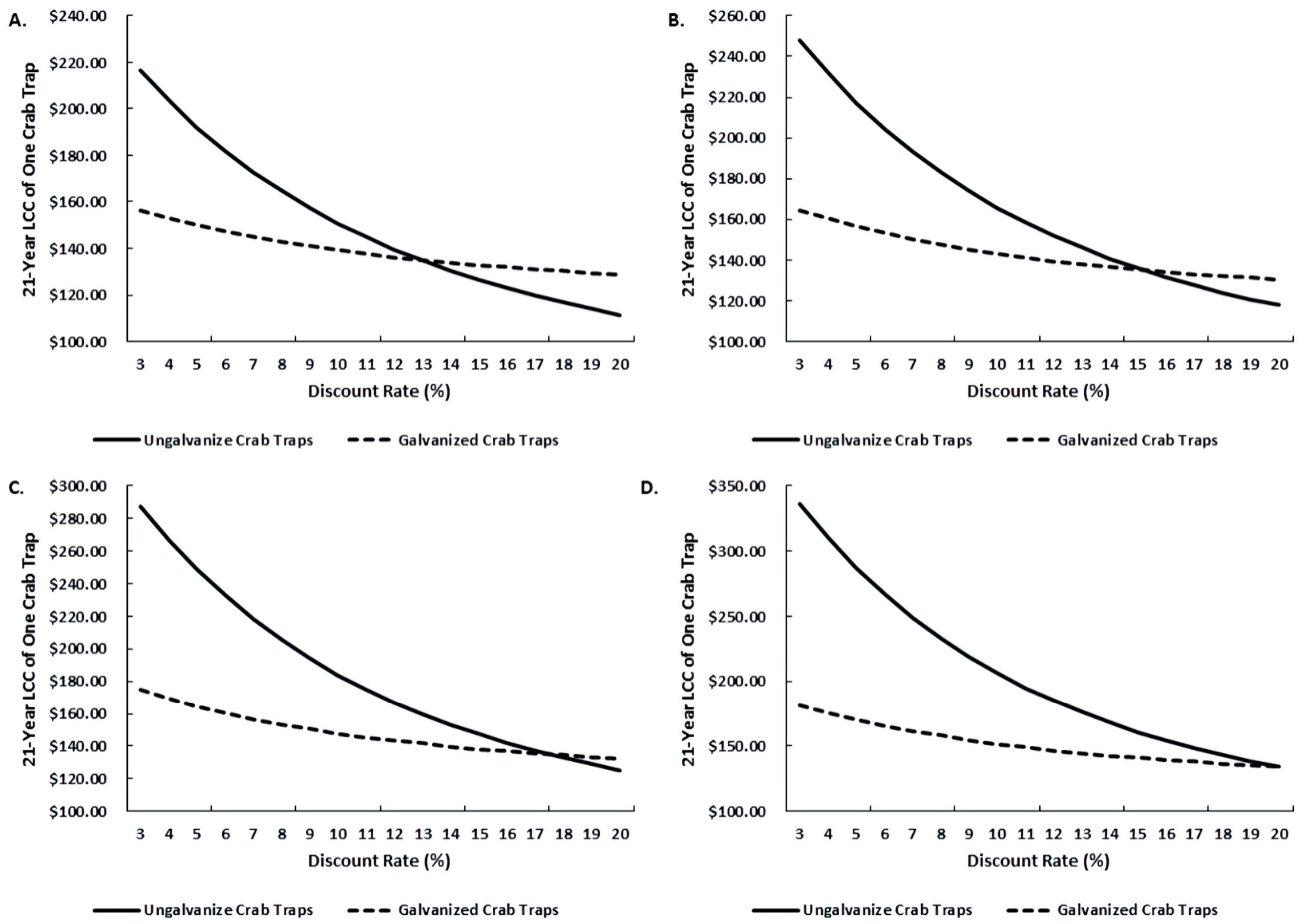

Figure 7. Comparison of the life cycle cost (LCC) for a traditional, mild steel crab trap and a galvanized, mild steel crab trap over a range of discounting rates between 3% and 20%. (**A**) LCC relationship at 0% inflation. (**B**) LCC relationship at 2% inflation. (**C**) LCC relationship at 4% inflation. (**D**) LCC relationship at 6% inflation. For each case, galvanizing the trap is more cost effective for discount rates to the left of the intersection between the two curves.

4. Discussion

Results showed no significant difference in CPUE between new traditional traps and new galvanized traps. While this is not entirely surprising, it does provide the first documented scientific comparison between galvanized and traditional snow crab traps, to our knowledge. These results demonstrate that a harvester's decision to purchase galvanized traps should not be based on any anticipated change in catch rates, but rather solely on the added lifespan of the trap.

It is worth noting that our results revealed a statistical difference between new and old traps. The model showed that using new traps increased CPUE by 14.5% (CI: 1.4–29.0) compared to old traps and galvanized traps increased CPUE by 13.7% (CI: 0.8–28.0). This result was unexpected and requires further consideration. One explanation, depending on water depth and the amount of light present, is that these traps were shinier than the old traps which had begun to rust. Therefore, shinier traps would potentially reflect more of the available light than rusty traps and attract more crabs. Several recent studies report that snow crab are attracted to artificial light and luminescent objects [41–43] and these results potentially help confirm this finding. This finding is also consistent with Paradis et al. and Merilä et al. [17,44] who reported that galvanized minnow traps produced better catch efficiencies of small-bodied fish than black ones. Looking at the data, another explanation is that in real numbers, this result may not be as substantive as it appears, as CPUE's CIs for the treatments were large and overlapped. The results from the EMM analysis showed that the mean increase in CPUE was 5.0 and 4.7 crabs per trap for new and galvanized traps, respectively, compared to old traps, which is substantial given that the means for all treatments were <40 crabs per trap. It is recommended that this result warrants further study to identify the mechanism or whether this result was anomalous. A comparison between the CPUEs for older and newer galvanized traps is also recommended for future study.

Galvanizing crab trap frames will result in an increased initial cost to the harvester. Based on reported costs, it will add $41.40 (54.5%) to the purchase price of each new trap. However, this extra cost is expected to increase each trap's lifespan from 7 years to 21 years with only some minor maintenance. This analysis showed that in current Canadian dollars, a 12.9% discount rate at 0% inflation and a 19.9% discount rate at 6% inflation would be the minimum needed before the traditional traps become the low-cost solution over a 21-year life span. These findings were consistent with Meenakumari and Mohan-Rajan [15] who also reported that using corrosion-resistant materials was in the long term financial interest of harvesters. Based on these high discount rates, at the current range of inflation rates, galvanized traps would be the low-cost option and provide harvesters with a reasonable buffer against potential risks.

The benefits of galvanizing trap frames include the following: (1) a longer lifespan so less effort is required by the harvester to replace damaged traps; (2) less cost to the harvester over the trap's lifespan; and (3) fewer steel frames being sent to landfill or recyclers prematurely.

5. Conclusions

In summary, this study evaluated the technical and economic viability of galvanizing snow crab traps. We measured the CPUE during the commercial fishery and found no significant difference between new traps (traditional vs. galvanized). We assessed the economic viability by evaluating the life cycle cost (LCC) over a range of inflation and discount rates. Our results show that except during instances of very high discount rates (>12.9–19.9%), it is economically favourable to galvanize crab trap frames.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/fishes9030109/s1, Data.csv: CPUE Data.

Author Contributions: Conceptualization, T.B. and P.D.W.; methodology, P.B., T.A.-S., T.B. and P.D.W.; validation, P.B., T.A.-S. and P.D.W.; formal analysis, P.B. and T.A.-S.; data curation, P.B., T.A.-S., T.B. and P.D.W.; writing—original draft preparation, P.B.; writing—review and editing, P.B., T.A.-S., T.B. and P.D.W.; visualization, P.B. and T.A.-S.; supervision, P.D.W.; project administration, P.D.W.; funding acquisition, P.D.W. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The animal study protocol was approved by the Animal Care Committee of Memorial University of Newfoundland, approval code 15-03-BF, Category A, and was dated 1 April 2015.

Data Availability Statement: Data are contained within the article and Supplementary Materials.

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