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Subtle fisheries gear model differences substantially influence catch rates of an invasive fish

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ABSTRACT

When sampling wild animals, the collection methods used can impact the number, sex, size, and behaviour of individuals captured and it is important to understand these impacts when making inferences about populations. While biases between different types of sampling gear are well recognized, biases that arise from using different models of the same gear type are often not considered. To test if different models of the same gear type influence the number and type of individuals collected, we first used two different models of the same gear type (silver and black minnow traps) to collect an invasive fish species, the round goby (*Neogobius melanostomus*). Next, we tested if any observed differences in capture rates between the different trap models could be explained by differences in: (a) colour, by painting silver traps black and deploying them in the field; and/or (b) retention, by quantifying fish exit rates from the different trap models in the laboratory. We found that silver traps captured approximately twice as many fish as black traps, and that the fish captured in silver traps were smaller on average. Next, we found when silver traps were painted black these now black traps still had catch rates comparable to regular silver traps. Lastly, we found that fish were 13 times more likely to exit from black traps compared to silver traps. Our results suggest that different models of the same gear type can differ substantially in terms of the number and type of individuals they capture. Being aware of these slight dimensional differences between models within a gear type and understanding how even small shape differences can impact the samples collected is important when assessing populations of wild animals and when comparing results and data across studies. To explore this issue further, we conducted a literature survey and identified that of the 275 studies identified that employed minnow traps, 37% provided no description of the traps employed. We advocate that researchers provide detailed information related to the sampling gear used when collecting wild animals to inform appropriate inferences and improve comparative analyses across studies.

1. Introduction

Fisheries scientists and resource managers use an assortment of gear types to estimate fish population size, status, and demographics. However, each gear type can select for particular fish species, sizes, sexes, and even behavioural types (Huse et al., 2000; Härkönen et al., 2014; Diaz Pauli et al., 2015; Jůza et al., 2018; Mehdi et al., 2021). It is generally well understood how various fisheries gear types differ from one another in terms of the types of species and size classes they most effectively target (Diana et al., 2006; Ruetz et al., 2007). Additionally, passive gear (e.g., trap nets and gill nets) generally select for individuals or species that are more active, bold, or exploratory as these gear types require fish to encounter the gear to be captured (Härkönen et al., 2014; Diaz Pauli et al., 2015). In contrast, active gear, which requires active human manipulation for capture (e.g., seine netting or electrofishing), is less likely to create such biases for a particular sex (especially in species where males and females differ in size), size range, or behavioural temperament. Consequently, the gear type used for sampling and assessment may limit and/or bias the population inferences that can be made from the data collected (Huse et al., 2000; Stergiou and Erzini, 2002; Ruetz et al., 2007; Brandner et al., 2013; Jůza et al., 2018). While scientists are generally aware of the biases induced *among* gear types, biases *within* a gear type—when there are various makes or models—are not as commonly considered or studied.

In this study, we tested if two models of the same gear type, minnow traps, differed in the number and type of individuals they captured,

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using the invasive round goby (*Neogobius melanostomus*) as a case study. We used the round goby as our study species because it is a highly prolific invasive fish in North America and Western Europe (Corkum et al., 2004; Kornis et al., 2012; Masson et al., 2018). Additionally, the round goby's rapid spread and detrimental ecological impacts have made monitoring and managing round goby populations increasingly important (Steinhart et al., 2004; Kwon et al., 2006; Yule et al., 2006; Bergman et al., 2022). We chose to test two different models of minnow traps as minnow traps are a popular gear used to capture small-bodied fishes, including round goby (Diana et al., 2006; Marentette et al., 2009; Young et al., 2010; Bose et al., 2018). These traps are widely available from a variety of companies and typically consist of fine mesh cylinders with funnels at each end (Fig. 1). The mesh can be made of fabric or metal and metal traps may or may not have vinyl coating. Two common minnow trap models in North America are galvanized silver metal traps and black vinyl coated metal traps, hereafter referred to as silver and black traps, respectively (Fig. 1). Despite being superficially similar in construction, these traps differ subtly in measures such as entry hole diameter and mesh thickness (see Table 1 for a full list of differences).

Previous research suggests that silver minnow traps catch more fish than black minnow traps when targeting three-spined stickleback, *Gasterosteus aculeatus* (Merilä et al., 2013), nine-spined stickleback, *Pungitius pungitius*, (Budria et al., 2015), pumpkinseed sunfish, *Lepomis gibbosus*, creek chub, *Semotilus atromaculatus*, and white sucker, *Catostomus commersonii* (Paradis et al., 2012), however this catch bias has yet to be tested for the round goby. The mechanisms explaining the observation of higher catch rates reported in silver traps compared to black traps are largely unclear, however there are a few potential explanations. One hypothesis is related to the visual property differences between the black vinyl coating versus the exposed galvanized steel. Fish may be less likely to approach objects that have greater contrast with the background environment, where black traps could have greater contrast

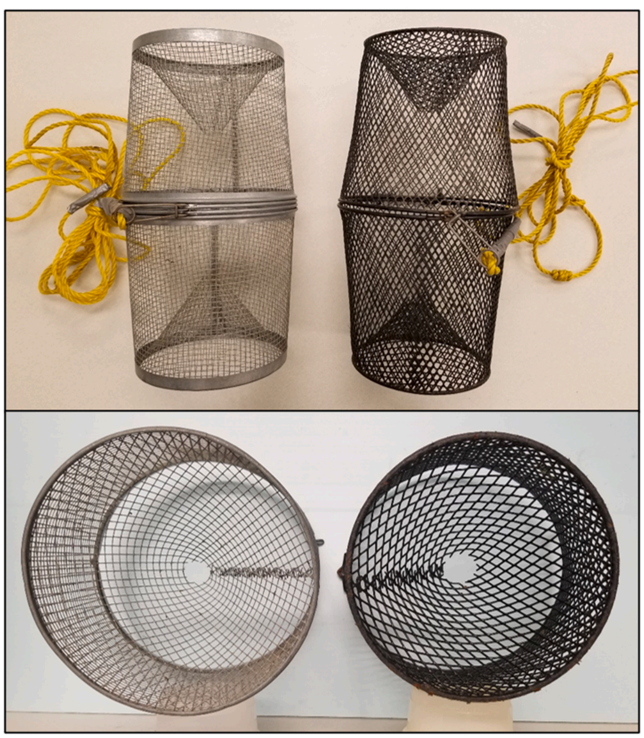

Fig. 1. Two popular minnow trap models, Gee's Galvenized (silver, left) and Eagle Claw (black, right) commonly sold in retail shops in North America. These were the trap types that were used in our study. Aside from colour differences, silver traps have a smaller entry hole and longer funnel length. Black Eagle Claw traps have a thicker mesh lining and a smaller base diameter.

Table 1
A comparison of various measurements between Gee's Galvanized (silver) and Eagle Claw (black) minnow traps used in our study.

Measurement	Black Traps	Silver Traps
Total mass	614 g	609 g
Mesh wire thickness	1.7 mm	0.8 mm
Mesh hole diameter	7.6 mm	5.8 mm
Funnel length	85 mm	115 mm
Entry hole diameter	21 mm	17 mm
Base diameter	167 mm	183 mm
Middle diameter	212 mm	212 mm
Total Length	419 mm	419 mm

with a background (Diana et al., 2006). Colour of a trap has also been found to be an important factor in attracting and influencing the number and type of individuals captured. For example, more male velvet bean caterpillar moths, *Anticarsia gemmatalism,* and fall armyworm moths, *Spodoptera frugiperda*, were captured in multicoloured traps compared to traps that were monocoloured (just green) (Mitchell et al., 1989). In another study, green and blue glow-sticks captured the most Centrarchid fish larvae while red and pink glow-sticks captured the least (Marchetti et al., 2004). Additionally, fish may be attracted to the reflective "sheen" properties of galvanized steel. One or a combination of these visual factors may result in the observed higher catch rates of silver traps.

Another explanation for the observed differences in catch between silver and black traps is that fish may be less likely to exit from silver traps due to differences in trap dimensions. Indeed, three-spined stickleback were less likely to exit silver traps compared to black traps over a 24-hour period (Budria et al., 2015). It is possible that the slightly smaller entry hole and longer funnel of silver traps makes it harder to exit from compared to the larger diameter entry hole and short funnel of black traps. Alternatively, exit rates from traps may be influenced by fish density, cover, or individual motivation (Marsden and Marcy-Quay 2021). It is currently unknown whether silver traps capture a higher number of round goby and also whether visual differences, shape differences, or a combination are responsible for any possible catch rate differences.

To inform if gear bias exists when using different models of the same gear type, we first tested if the number and type (size, sex, reproductive status) of round goby captured differed between black and silver traps deployed in the field. As some of our traps were baited and others were not, we also analyzed the above between baited and unbaited traps, however this was not the main focus of our study. Second, we tested if contrast/colour could explain the differences in catch observed by painting silver traps black, deploying them in the field, and quantifying the catch compared to unaltered silver traps or to silver traps painted with a clear transparent paint. Third, we tested if there are differences in trap retention between the two minnow trap models by comparing if more round goby exited black traps or silver traps in the laboratory. Lastly, we conducted a literature review to evaluate how often the model/ and colour of trap is reported in the primary literature.

2. Methods

2.1. Study 1: Minnow trap catch differences

2.1.1. Fish collection

To test if black and silver traps (Fig. 1) differ in the number and type of round goby captured, we set minnow traps at six locations around Hamilton Harbour, Ontario, Canada, an area of concern under the Great Lakes Water Quality Agreement. Locations sampled were Desjardins Canal (DC; 43.277984, −79.888725), Grindstone Creek (GC; 43.286629, −79.886802), LaSalle Marina (LS; 43.300212, −79.846016), Fisherman's Pier (FP; 43.296320, −79.796384), Pier 27 (P27; 43.284453, −79.791594), and Pier 15 (Sherman's Inlet, SI; 43.270107, −79.833852). These sites were chosen because they are part of a long-term round goby monitoring project in Hamilton Harbour that has been ongoing since 2002. Additional detailed information on site characteristics and sampling regime can be found in Young et al. (2010) and McCallum et al. (2014). Briefly, at each site, a set of four silver traps (Gee's galvanized G40 brand) and six black traps (Eagle Claw brand) were set simultaneously roughly every two weeks between August–November 2018 and between April–November 2019, for a total of 18 set dates. At each collection site, two silver traps and two black traps were left unbaited, and two silver traps and four black traps were baited with ~25 g of corn. Both black and silver traps were used at each location. Traps were attached to ropes and thrown ~5 m from the shore where they were left at ~1 m depth for approximately 24 h before they were collected. Black traps have been historically used at our long-term monitoring project sites, however due to space limitations at some sites we could not deploy as many silver traps as black traps. After collection, round goby from each trap were counted and sexed by examining their external urogenital papilla; female papillae are short and broad while male papillae are thin and triangular (Marentette et al., 2009). Round goby were then euthanized by overdosing using a benzocaine-water mixture and transported to McMaster University on ice in labelled bags associated with collection date, site, and which trap they were collected from. Native species captured were recorded and released at the point of capture.

2.1.2. Sex, status, and morphological measurements

To test if fish captured in silver traps differ in morphology compared to those captured by black traps, we measured the following for each fish caught: standard length, total length, papilla length, head width, body width, total mass, liver mass, total gonad mass, and seminal vesicle mass (males only). Morphological body measures were taken with calipers accurate to the nearest millimeter. Body and organ masses were taken in grams using an Ohaus Adventurer Pro digital scale, accurate to 0.001 g. To assess the degree of investment in gonads and confirm reproductive status, we calculated the gonadosomatic index (GSI) (total gonad mass (g)) / (total mass (g) – total gonad mass (g) x 100). Additionally, we tested if silver and black traps differed in the ratio of males to females and guarder males to sneaker males captured. In round goby, males have alternative reproductive tactics (ARTs) where some males defend territory and guard a nest, termed guarder males, and some males are not territorial and parasitize reproduction from guarding males, termed sneaker males (Marentette et al., 2009; Bleeker et al., 2017; Bose et al., 2018). The seminal vesicles (accessory glands) differ between round goby ARTs; sneaker males commonly have small accessory glands relative to their gonads while and guarder males usually have larger accessory glands (Marentette et al., 2009; Bose et al., 2018). For more detailed methods of how round goby reproductive status is determined see Synyshyn et al. (2021). Briefly, males were classified as sneaker males if they had a combination of the following traits: light body colour, large papillae relative to their body size, narrow cheek pads (small head width), small seminal vesicles compared to their gonad size, and a GSI of greater than 2% (Marentette et al., 2009; Young et al., 2010). Males were classified as guarder males if they were very dark or black in colour, had a large seminal vesical mass compared to gonad mass, had enlarged cheek pads, and had a GSI of greater than 1%. The > 1% GSI threshold is used to assign reproductive status to male round goby while sneaker males typically have a higher > 2% GSI cut-off. Note that not all male round goby with > 2% GSI are considered sneaker males, other traits are also considered to make that tactic determination. Females were classified as reproductive if they had a GSI greater than 8% (Marentette and Corkum, 2008).

2.2. Study 2. Visual attraction of Minnow traps

To test if silver traps attract more fish due to their colour or reflectivity, every two weeks from June 30th 2020 to August 26th, 2020 we set three baited traps at each site: one silver trap painted with black paint, one silver trap painted with transparent paint, and one unaltered silver trap (Fig. 5a; transparent painted trap not pictured). We used Plasti Dip® paint to coat the traps as this brand has been used for various applications in past aquatic studies with no harmful effects to fish (Herke and Moring, 1999; Cooke and Philipp, 2004).

2.3. Study 3: Laboratory trap retention comparisons

2.3.1. Fish collection

To test if round goby were more likely to exit from black traps compared to silver traps, we collected round goby from LaSalle Marina on September 12th, 2020 and October 30th, 2020. Fish were caught in September using five passes of a beach seine on a sandy beach area (total area seined = 163.5 m^2) over 1.5 h. Fish were caught in October using black (Eagle Claw brand) minnow traps set for a duration of 3, 6, or 24 h. After capture, fish were transported in opaque, aerated marine coolers back to the Aquatic Behavioural Ecology Lab at McMaster University in Hamilton, Ontario. A total of 134 goby (46 females: mean body mass ± SE = 4.74 ± 0.33 g; 42 males: mean mass = 12.53 ± 1.45 g; 46 juveniles: mean mass = 1.94 ± 0.10 g) were used, 70 from the September sampling and 64 from the October sampling.

2.3.2. Housing and tagging

In the lab, round goby were housed in 75 L tanks (61 ×46×30 cm) fitted with filters, air stones, a shallow layer of aquarium gravel, and black PVC tubes as shelters. Fish were kept in sex mixed groups of eight per tank in water ranging from 18° to 19°C and on a 13:11 h light:dark schedule. Fish were fed daily with Nutrafin Basix Staple Food flakes and all tanks were treated with Nox-Ich and aquarium salt on the day of capture. Approximately one week after capture and acclimation to the holding tanks, we tagged individuals by injecting a small amount of non-toxic acrylic paint just under the surface of the skin (Wolfe and Marsden, 1998) on either the head, the tail, or both with one of five colours. Use of the different colours and positions on the body ensured that every individual in each tank could be distinguished and had a unique tag. Before tagging, all fish were sexed (male, female, or juvenile) and weighed with an electronic scale accurate to 0.01 g.

2.3.3. Retention experimental procedure

To test if black and silver traps differ in retention after a 24 h period, we filled four 320 L plastic black tubs (Tuff Stuff Heavy Duty 85 Gallon Tub) with filtered water to a depth of 30 cm and equipped each tub with two foam filters. Water temperatures ranged from 18.4° to 19.5°C and we used a 13 h light:11 h dark cycle during the course of the experiment. One silver and one black trap were placed inside each of the four tubs and a single goby was placed in each trap type. The goby were then left undisturbed for approximately 24 h before the traps were checked to see whether the single goby had exited a trap. Trials began during the same period of the day so that the day:night cycle was consistent among all trials.

2.4. Study 4: Literature survey

Using the "Advanced Search" function in Google Scholar, we performed a literature survey and reviewed all articles that included the term "minnow trap" anywhere in the article. We used Google Scholar because it is possible to search for target terms throughout the entire text of a selected item while in contrast other databases (e.g. PubMed, Web of Science) are more limiting, restricting search terms to what might be found in titles, abstracts, and keywords only (Hemminger et al., 2007; Penning de Vries et al., 2020). As minnow traps are often described only in the methods section of an article, the use of Google Scholar to search the entire articles' text yielded more results/hits. We began our search on February 12th, 2021 and limited ourselves to articles published between 2005 and 2020, which initially yielded 1309 hits. Patents and citations were excluded from the list, as were any duplicate search

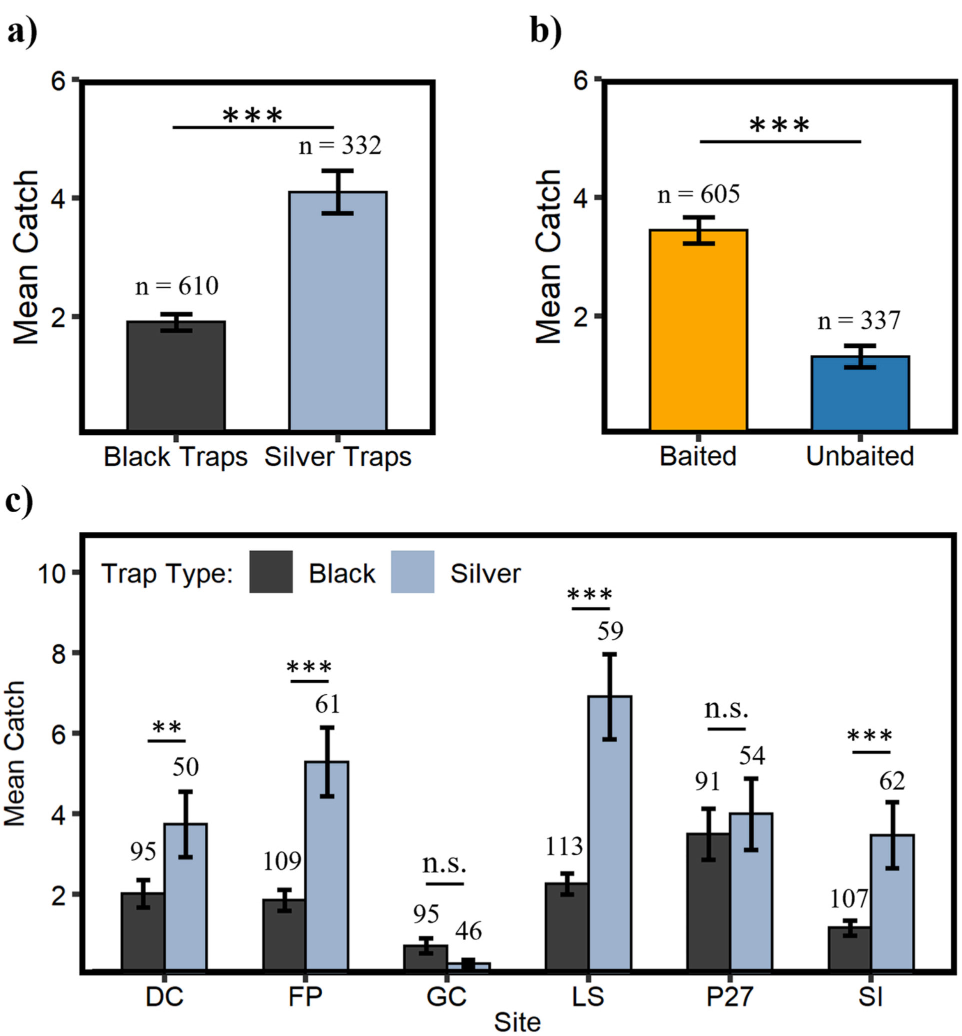

Fig. 2. a) Mean catch per trap ± SE of round goby caught in black and silver minnow traps, b) Mean Catch per trap ± SE of round goby caught in baited and unbaited minnow traps, and c) Mean catch per trap ± SE round goby caught in black and silver minnow traps by each sampling site within Hamilton Harbour, ON, Canada: Desjardin's Canal (DC), Fisherman's Pier (FP), Grindstone Creek (GC), LaSalle Marina (LS), Pier 27 (P27), and Sherman's Inlet/Pier 15 (SI). Error bars represent mean ± SE. *$p < 0.05$, * *$p < 0.01$, * **$p < 0.001$. Sample sizes indicate the total number of traps set.

results. Additionally, articles were excluded for any of the following reasons: 1) the article was not peer-reviewed, 2) the article was a review and not an empirical study, 3) minnow traps were not used to capture fish, or 4) the authors' description of their "minnow trap" was incongruent with typical minnow trap designs (fine mesh metal cylinders in two halves which latch together at the centre, with funnelled entrance holes at each end (Fig. 1)). For example, if the minnow trap had four openings rather than the typical two, such an article was excluded. After all exclusions, a total of 275 articles remained and were included in our literature survey. We then read over these remaining articles in their entirety, including any supplementary data or appendices, searching for information about minnow trap brand, dimensions, opening diameter, colour, or material. If the article listed a specific minnow trap brand (e.g., "Gee", "Frabill", or "Promar"), then this article was coded as providing a description of minnow trap brand. Similarly, if the article provided even one dimensional measurement of the minnow trap employed (e.g. mesh size, trap length, or opening diameter) this article was coded as providing a description of minnow trap dimensions. We paid particular attention to descriptions of opening diameter since this measurement was particularly relevant to our study. We were also particularly interested in descriptions of minnow trap colour. Articles were coded as including a description of minnow trap colour if they listed a specific colour (e.g. "silver" or "black"), or if they included a photograph of the minnow trap, or if the word "galvanized" was used. If an article used the word "galvanized", we additionally coded this as a description of minnow trap material. We also coded any mention of a specific material (e.g., "steel", "vinyl", "polyethylene-coated mesh") as a description of minnow trap material. We coded "bar mesh" and "wire mesh" as descriptions of minnow trap material, but "mesh" alone was not considered a sufficient description. Finally, if the article listed a specific minnow trap model (e.g. "G-40″, "Frabill#1279″, "Gee's Improved"), this was additionally coded as a descriptor of minnow trap brand, material, dimensions, opening diameter, and colour.

2.5. Statistical analysis

All statistical analyses were performed using R (Version. 3.6.1, R Core Team, 2019). A significance of $\alpha < 0.05$ was used for all tests. Linear models were visually assessed for fit by plotting simulated residuals using quantile-quantile and scale-location plots. Transformations were used when necessary and noted for each model. Binomial and negative binomial models were visually assessed by using the DHARMa package to plot simulated residuals. Sum-to-zero contrasts for all categorical predictors for each model were used for easier interpretation of effect sizes. Interactions were retained in all models regardless of significance. Interactions were assessed with the Anova function from the 'car' package using type three sums-of-squares (Fox and Weisberg, 2019). The comparisons for each interaction were assessed using the emmeans function in the 'emmeans' package (Lenth, 2020).

We compared black and silver trap catches with a generalized linear mixed model using maximum likelihood estimation via template model

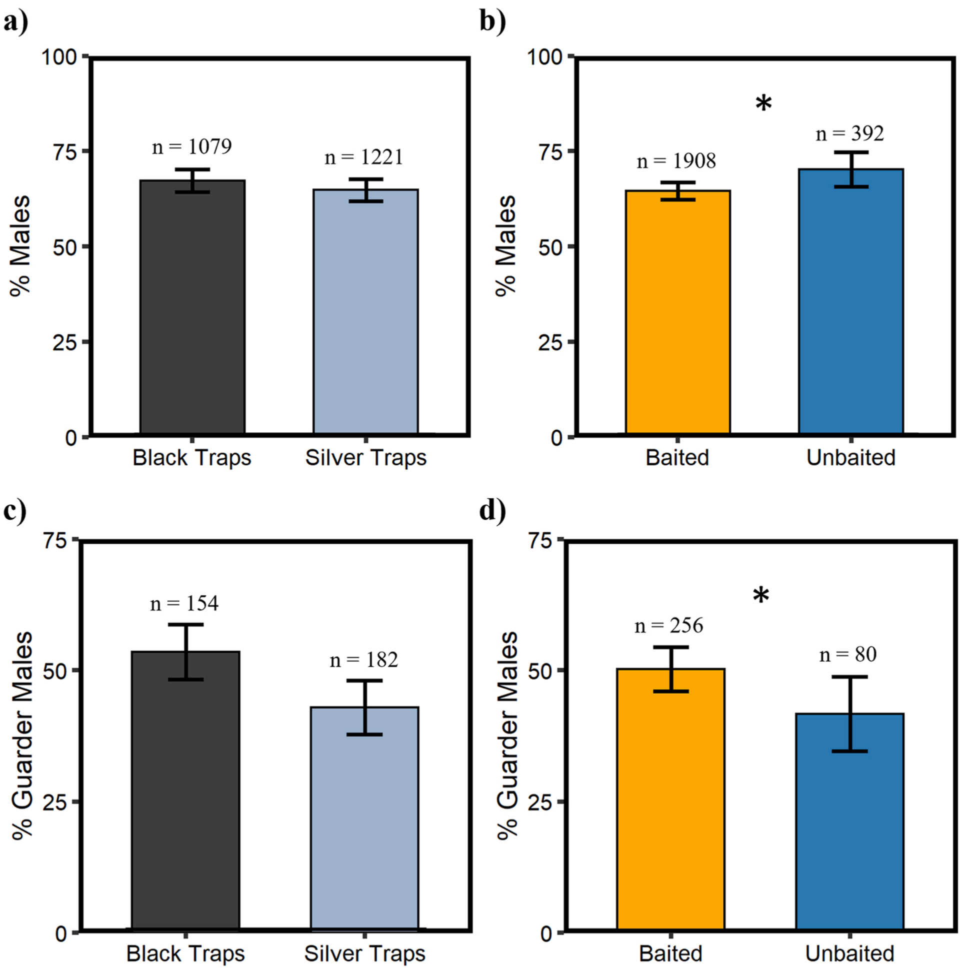

Fig. 3. a) The percentage of males captured in black and silver minnow traps and b) the percentage of males captured in minnow traps baited with corn and traps left unbaited. Of traps that captured reproductive round goby males, c) the percentage of guarder males captured in black and silver minnow traps and d) the percentage of guarder males captured in minnow traps baited with corn and traps left unbaited. Sample sizes represent a) & b) the total number of males and females captured for each trap or bait type, and c) & d) the total number of guarder males and sneaker males captured for each trap or bait type. $^{*}p < 0.05$.

builder in the 'glmmTMB' package assuming a negative binomial error distribution, hereafter referred to as 'NB-GLMM' (Brooks et al., 2017). This model included bait type (baited vs unbaited), trap type (black vs silver), site, and year as fixed predictor variables. We included a trap type by bait type interaction and a trap type by site interaction as the sites varied in physical and chemical characteristics (ex. substrate type, water quality) which may differently affect the performance of black and silver traps. Month and individual trap ID within each site, to account for the fact that trap A is different among sites, were included as random effects in each model. To determine if total catch between painted silver minnow traps and unaltered traps differed, we also used a NB-GLMM. Trap type (painted black, painted with clear paint, and unaltered silver), site, and year, with an interaction between trap type and bait type as well as trap type and site were included as fixed predictor variables. Date was included as a random effect.

The overall sex ratio and the male tactic ratio were analyzed using a one-way chi-squared test. We used two separate generalized linear mixed models using maximum likelihood estimation via template model builder assuming a binomial error distribution, hereafter referred to as 'Binomial-GLMM', to determine if the ratio of males to females captured and the ratio of guarder males to sneaker males captured differed between silver and black traps. We performed the same analysis as above to examine the differences between baited and unbaited traps. Both models included trap type and bait type as fixed predictor variables, as well as trap type by bait type interaction. Random effects for both models included month, site, and trap within site. A zero inflation parameter was included for the male to female ratio model only as many traps had only one sex.

We compared the standard length of fish using a univariate linear mixed effects model (LMER) from the 'lme4' package (Bates et al., 2015). Standard length was $\log_{10}$ transformed to meet the assumptions of linearity. Sex, trap type, and bait were included as fixed predictors variables. Year was included as a fixed covariate. Interactions included trap type by bait type, sex by trap type and sex by bait type. Random effects included month, site, and trap within each site.

We compared whether round goby were more likely to exit from black traps compared to silver traps using generalized linear models (GLMs) assuming binomial error distributions. Whether a fish exited a trap (yes vs no) was related to the trap type (black vs silver) the fish was placed in. Body mass was included as a fixed covariate as we predicted that smaller fish can more easily fit through the opening and therefore may be more likely/able to exit. Body mass was $\log_{10}$ transformed to meet assumptions of linearity and then centered. The sampling event of when fish were caught (September or October) was also included as a covariate since different sampling methods were used (seining vs. trapping, respectively). An additional GLM was run including the covariates described above with the addition of sex as a fixed covariate. This model was run separately to maximize the sample size as 34% (46/134) of the fish were juveniles and could not be sexed.

2.6. Ethical note

All protocols in this study were approved by the McMaster Animal Research Ethics Board (Animal Utilization Protocol 17–12–45). Protocols adhered to the guidelines of the Canadian Counsel on Animal Care (CCAC) and ASAB/ABS (2020) regarding the use of animals in research and teaching.

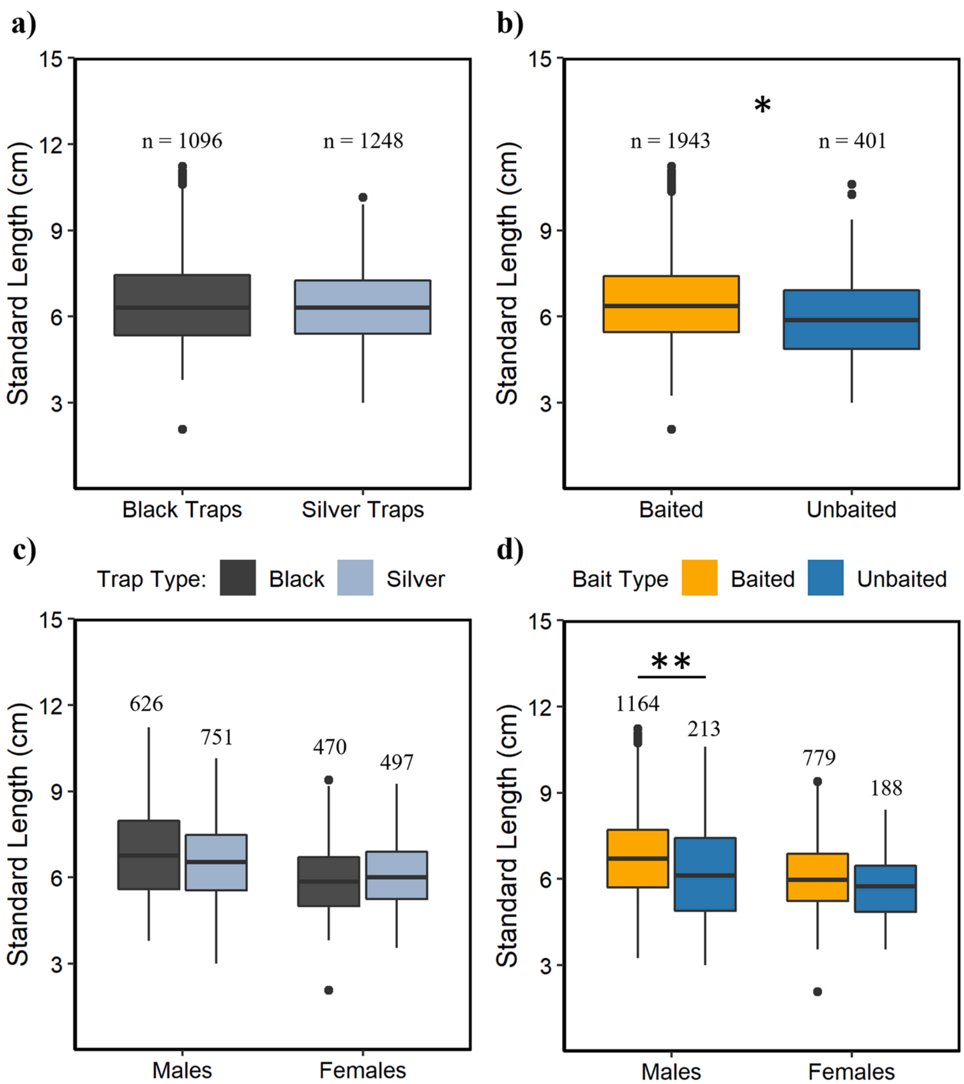

Fig. 4. a) Overall standard length (cm) of round goby captured in black and silver minnow traps and b) in baited and unbaited minnow traps. b) Standard length (cm) for males and females captured in black and silver minnow traps and d) in baited and unbaited minnow traps. Boxplots indicate median and whiskers extend to the furthest datapoint within 1.5x the interquartile range. Individual points indicate values falling outside this range. *p < 0.05, * *p < 0.01, * **p < 0.001. Sample sizes indicate the total number of round goby sampled.

3. Results

3.1. Study 1: Minnow trap catch differences

3.1.1. Trap type and bait type comparisons

Silver traps captured 1.7 times more round goby than black traps (NB GLMM TMB, $\beta = 0.53$, SE = 0.12, $z = 4.50$, $p < 0.001$, Fig. 2a) and baited traps captured 3.2 times more round goby than unbaited traps (NB GLMM, $\beta = 1.16$, SE = 0.11, $t = 10.5$, $p < 0.001$, Fig. 2b). There was a significant trap type by site interaction ($\chi^2 = 28.6$, $p < 0.001$, Fig. 2c). Silver traps outperformed black traps at four of the six sites: DC (NB GLMM, $\beta = 0.60$, SE = 0.25, $z = 2.39$, $p = 0.02$), FP ($\beta = 1.21$, SE = 0.23, $z = 5.37$, $p < 0.001$), LS ($\beta = 1.02$, SE = 0.22, $z = 4.74$, $p < 0.001$), and SI ($\beta = 0.95$, SE = 0.24, $z = 3.96$, $p < 0.001$). However, we observed no difference in the catch rates of black and silver traps at P27 ($\beta = 0.16$, SE = 0.24, $z = 0.70$, $p = 0.48$). At GC, black traps tended to outperform silver traps, but this comparison did not reach significance ($\beta = -0.77$, SE = 0.40, $z = -1.94$, $p = 0.053$, Fig. 2c). Black traps ($n = 610$) captured a total of 95 native fish while silver traps ($n = 332$) captured 144 native fish. Species captured were yellow perch (*Perca flavescens*), spottail shiners (*Notropis hudsonius*), rock bass (*Ambloplites rupestris*), pumpkinseed (*Lepomis gibbosus*), bluegill (*Lepomis macrochirus*), green sunfish (*Lepomis cyanellus*), logperch (*Percina caprodes*), largemouth bass (*Micropterus salmoides*), and fathead minnows (*Pimephales promelas*).

3.1.2. Sex, status, and morphological measurements

3.1.2.1. Sex and reproductive ratios. A total of 1017 female round goby were captured, 666 were non-reproductive (65.5%) and 351 were reproductive (34.5%). An additional 73 females could not be categorized as reproductive or non-reproductive due to a freezer failure event and were excluded from analysis. A total of 1382 male round goby were captured, 1024 were non-reproductive (74.1%), 205 were guarder males (14.8%), and 153 were sneaker males (11.1%). An additional 19 males could not be distinguished because of the same freezer failure and were excluded from analysis.

Our overall catch was biased towards males, with 1.3 males caught for every 1 female (1382 males and 1017 females captured; $\chi^2 = 55.5$, $p < 0.001$). The ratio of males to females captured did not differ between black and silver traps (binomial-GLMM, $\beta = -0.23$, SE = 0.14, $z = -1.58$, $p = 0.11$; Fig. 3a). Unbaited traps captured more males versus females compared to baited traps (binomial-GLMM, $\beta = 0.30$, SE = 0.14, $z = 2.07$, $p = 0.039$; Fig. 3b). The operational sex ratio was close to 1:1 (358 reproductive males to 351 reproductive females; $\chi^2 = 0.07$, $p = 0.79$).

The overall ART ratio was biased towards guarder males (57.3%; $\chi^2 = 7.55$, $p = 0.006$). The ratio of guarder males to sneaker males did not differ between black traps and silver traps (binomial-GLMM, $\beta = -0.28$, SE = 0.32, $z = -0.90$, $p = 0.37$; Fig. 3c). The ratio of guarder males to

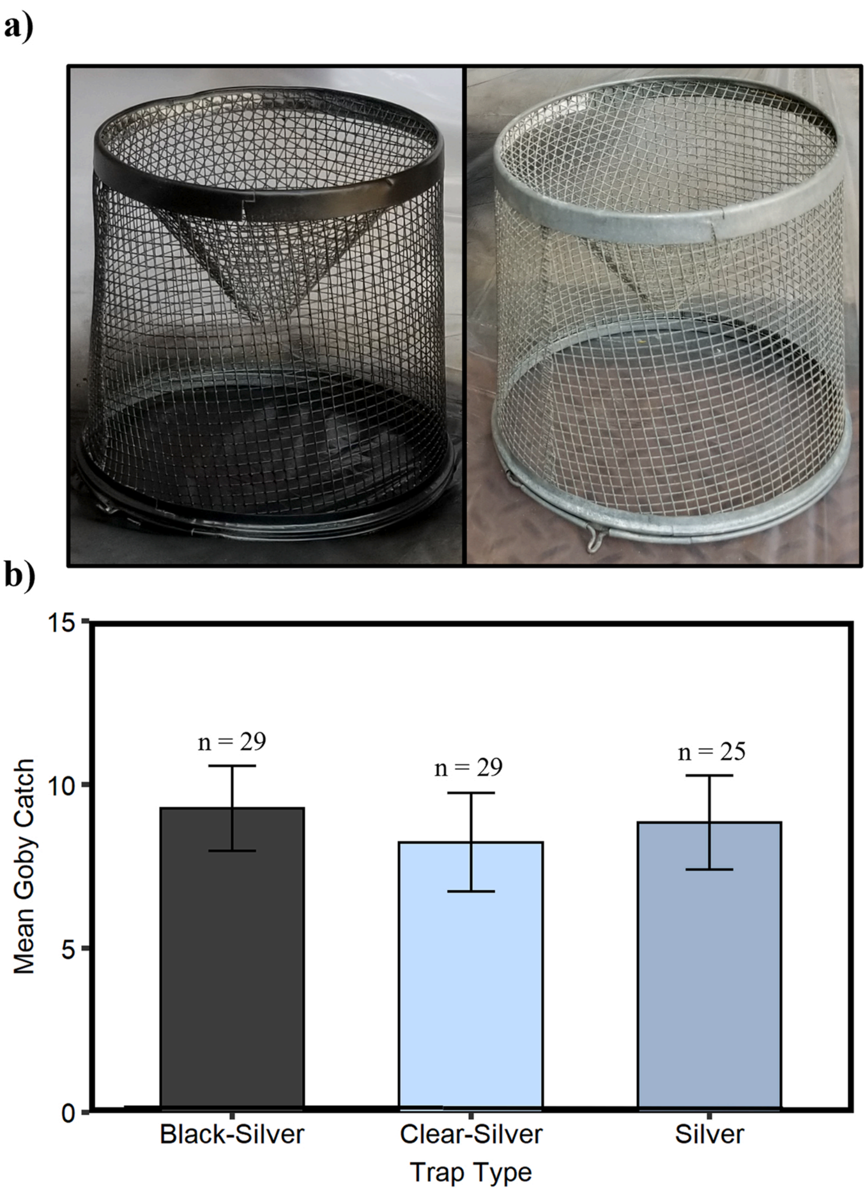

Fig. 5. a) Manipulation of trap colour for the silver Gee's galvanized minnow traps. The picture on the left is a black spray-painted (previously) silver trap and the picture on the right is an unaltered silver trap. A third of the silver traps were also painted with clear spray-paint that did not alter the appearance of the trap (not pictured). b) There was no statistical difference in round goby catch between black spray-painted silver traps (black), clear spray-painted silver traps (light blue), and unaltered silver traps (grey). Sample sizes indicate the total number of traps set.

sneaker males differed between baited and unbaited traps with unbaited traps capturing a lower ratio of guarder males to sneaker males (binomal-GLMM, $\beta = -0.60$, SE = 0.30, z = −1.98, p = 0.047; Fig. 3d).

3.1.2.2. Size differences. Black and silver traps captured round goby of similar standard lengths (log_{10}-LMER, $\beta = -0.002$, SE = 0.011, t = −0.16, p = 0.87, Fig. 4a). Baited traps captured round goby that were 1.1 cm larger on average than those captured in unbaited traps (log_{10}-LMER, $\beta = 0.027$, SE = 0.011, t = 2.52, p = 0.01, Fig. 4b). There was a significant trap type by sex interaction on the size of round goby captured ($\chi^2 = 7.68$, p = 0.006). Silver traps captured smaller males and larger females compared to black traps, however neither of these comparisons were significant (log_{10}-LMER; $\beta_{Males} = -0.008$, $SE_{Males} = 0.011$, $t_{Males} = -0.74$, $p_{Males} = 0.46$; $\beta_{Females} = 0.012$, $SE_{Females} = 0.012$, $t_{Females} = 1.03$, $p_{Females} = 0.31$; Fig. 4c). Baited traps captured larger males compared to unbaited traps (log_{10}-LMER, $\beta = 0.033$, SE = 0.012, t = 2.84, p = 0.006). Baited traps also appeared to capture larger females, but this comparison did not reach significance (log_{10}-LMER, $\beta = 0.021$, SE = 0.012, t = 1.78, p = 0.08, Fig. 4d).

3.2. Study 2. Spray painted and unaltered silver traps

Black painted, clear painted, and unaltered silver traps did not differ in their overall catch (GLMM TMB NB, $z_{(Black\text{-}Silver)} = 0.27$, p = 0.96; $z_{(Clear\text{-}Silver)} = -1.86$, p = 0.16; $z_{(Black\text{-}Clear)} = 2.14$, p = 0.09; Fig. 5b). Across the four sampling dates, there was no trap type by site interaction ($\chi^2 = 8.92$, p = 0.54).

3.3. Study 3: Laboratory trap retention differences

After accounting for body mass and sampling month, we found that fish were 13 times more likely to exit black traps compared to silver traps (binomial-GLMM, $\beta = 1.66$, SE = 0.32, z = −5.19, p < 0.001), with 51% (34/67) of the fish placed in black traps exiting but only 6% (4/67) of the fish placed in silver traps exiting. Fish that exited were smaller on average (3.4 ± 0.50 g) than fish that did not exit (7.3 ± 0.8 g; binomial-GLMM, $\beta = -4.25$, SE = 1.19, z = −3.56, p < 0.001). Exit likelihood was unrelated to sex and sampling month (binomial-GLMM, $\beta = 0.09$, SE = 0.36, z = 0.25, p = 0.80 and $\beta = -0.54$, SE = 0.35, z = −1.56, p = 0.12, respectively).

3.4. Study 4: Literature survey results

Of the 275 articles analyzed in our literature survey, 63% (n = 172) contained at least one descriptor (brand, material, dimensions, opening diameter, or colour) about the minnow traps used. Of the 172 articles that contained at least one descriptor, 27% (n = 47) included colour, 85% (n = 147) mentioned minnow trap dimensions, 56% (n = 96) included entry hole diameter, 49% (n = 84) included material of the trap, and 41% (n = 70) included brand information. When assessing how many minnow trap descriptors were given, we found 38% (n = 65) articles only provided one descriptor, 16% (n = 27) provided two, 24% (n = 42) provided three, 9% (n = 15) provided four, and 13% (n = 23) provided all five descriptors.

4. Discussion

Despite only subtle shape differences, silver traps captured almost twice as many round goby compared to black traps. Our findings align with three studies where silver traps were also found to capture more fish than black traps (Paradis et al., 2012; Merilä et al., 2013; Budria et al., 2015). Previously, it was hypothesized that the exposed galvanized steel or silver may have more visual saliency and the reflectivity may be more attractive to fish (Merilä et al., 2013). In our study, by spray-painting originally silver traps a matte black colour, we removed the reflective/colour properties of the silver traps. Under these conditions, the previously silver but now spray-painted black traps, performed equally well to silver traps, suggesting that the higher round goby catch efficiency of silver traps is not explained by the silver colour or reflectivity being more attractive.

A second finding of our study is that more round goby exited from black traps compared to silver traps after a 24 h period. This finding combined with black-painted (previously) silver traps performing just as well as unaltered silver traps suggests that trap dimensions may have a stronger influence than colour on the number and type of fish retained during sampling. Our results corroborate similar findings for three-spined stickleback (*Gasterosteus aculeatus*), where silver traps were significantly more likely to retain fish after three hours when compared to black and canvas traps (Budria et al., 2015). One possible explanation for the difference in retention observed between silver and black traps is the smaller entry hole and longer funnel of the silver trap, which may make exit once captured more challenging. Silver traps also have thinner mesh wire, which could make the entry hole more difficult to perceive due to lower contrast with the surrounding environment (see Figure1). It is important to note that the retention performance of black and silver traps may be heavily influenced by environmental factors such as density of fish or factors such as individual motivation or condition (Marsden and Marcy-Quay 2021). Future studies should be conducted to understand how these traps perform under more ecologically relevant conditions.

We also found that smaller fish were more likely to exit compared to larger fish. Larger fish may find it possible to enter a trap as they are ‘funneled’ in, however, but exiting without injury is more challenging because of the exposed sharp ends of the funnel wire mesh on the inside of the trap. We found no difference in the ratio of males to females captured between black and silver traps. We observed that males and females were equally likely to exit, regardless of whether the trap was black or silver. It is worth noting that our trap retention study was conducted during the non-reproductive season; so it remains possible that our results would differ in the reproductive season as reproductive guarding males often have enlarged cheek pads, a secondary sexual characters that increased the diameter of their head and likely limits their ability to enter and exit through the holes in a minnow trap (MacInnis and Corkum, 2000).

On average silver traps to outperform black traps in the field, however two of our study sites did not follow this trend. In Grindstone Creek (GC), which is characterized by high turbidity and a muddy substrate (with an average secchi depth of 37 cm ± 32 cm compared to the other field sites where the average secchi depth is 124 cm ± 41 cm), the black traps appeared to outperformed silver traps, however this result did not reach significance. It is possible turbidity might make it challenging for fish to locate the minnow trap holes to exit, leading to higher retention for both the black and silver traps. At a second site, Pier 27 (P27), silver and black traps had similar catch rates. P27 has fairly low turbidity but it is adjacent to a large, dense, nesting site for herring gulls, *Larus argentatus*, ring-billed gulls *Larus delawarensis*, and double-crested cormorants, *Phalacrocorax auritus* (Quinn et al., 1996), all of which predate on round goby (Somers et al., 2003; Corkum et al., 2004; Johnson et al., 2010). It is possible that under such conditions of high predation, traps are perceived as a refuge and fish are less likely to leave them. We recommend future studies to test this idea.

We observed no difference in the ratio of guarder males to sneaker males caught between the trap types. We had expected that black traps, with larger entry hole diameters, would capture a higher ratio of guarder males compared to silver traps as guarder males are larger and have wider heads than sneaker males (Marentette et al., 2010; Synyshyn et al., 2021). The average body size of round goby captured did not differ between the black and silver traps for males, females, and for all fish overall (males and females combined). We had expected that body size of males would differ between black and silver traps because male round goby are larger on average (Mean SL = 7.8 cm, Young et al., 2010), and the larger entry hole size in the black (see Table 1) should have selected for larger male size in black traps. Given the average small body size of female round goby in Hamilton Harbour (Mean SL = 6.5 cm, Young et al., 2010), most female round goby were likely able to easily fit through the holes of both trap types.

Finally, our literature survey demonstrated that many studies do not report on trap colour or give any information about the type of minnow trap(s) employed. This oversight might be because researchers are simply not aware of the large variety of minnow trap types available or because they assume that the different trap models are interchangeable and perform similarly. Of the articles that do provide a description of minnow traps used, the majority only reported on one parameter.

Overall, our study suggests that subtle differences between black and silver minnow traps can result in profound catch differences. This finding is particularly concerning as many previous studies using minnow traps do not provide adequate description of the trap type used. A growing body of evidence suggests that silver and black traps perform differently, hampering comparison among studies and potentially compromising the replicability across sampling sites, dates, and years. For example, researchers working in areas experiencing round goby invasions often wish to compare their sampling and calculations of population size on research that occurred in areas where round goby invaded in the past. Our results reinforce the need for researchers and conservation organizations to take caution when comparing data across studies as these different studies may have used different minnow trap models. We urge researchers and resource managers to be more explicit when describing the type of gear, minnow trap, and bait used to allow for consistent comparison of results across studies and/or years.

CRediT authorship contribution statement

Caitlyn Synyshyn: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Megan Cyr:** Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Lucas Eckert:** Methodology, Formal analysis, Investigation, Data curation, Writing – original draft. **Adrienne McLean:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Sigal Balshine:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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.

Data Availability

Data will be made available on request.

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