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Research Article

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# Gravel washing as a lacustrine spawning habitat restoration method for smallmouth bass

Daniel M. Glassman, Benjamin L. Hlina, Lisa A. Donaldson, Alice E.I. Abrams, Jordanna N. Bergman, Auston Chhor, Lauren J. Stoot and Steven J. Cooke*

Fish Ecology and Conservation Physiology Laboratory, Department of Biology and Institute of Environmental and Interdisciplinary Science, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada

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**Abstract –** Smallmouth bass (*Micropterus dolomieu*) spawn on gravel and cobble in the littoral zone of lakes that may become degraded by the presence of fine sediments and decomposing organic matter. Substrate size and composition have been identified as important variables for nest site selection by male smallmouth bass. We tested whether ‘cleaning’ substrate by removing sediment with a pressure washer would increase the number of bass nests or the average total length (mm) of nesting smallmouth bass in selected areas of Big Rideau Lake, Ontario, Canada the following year using a before-after control-impact design. Treatment was not a significant predictor of nest abundance or average male length. Considering the strength of the experimental design it is reasonable to conclude that this intervention failed to enhance spawning substrate for smallmouth bass. Understanding the factors that maintain productive spawning sites for smallmouth bass is important to restoration effectiveness and determining where habitat enhancement will provide the greatest benefits.

**Keywords:** Habitat / restoration / substrate / spawning / enhancement

## 1 Introduction

Globally, freshwater ecosystems are under continued and increasing threats from habitat loss and degradation, climate change, pollution, invasive species, and exploitation of species (Reid et al., 2019). The current state of freshwater biodiversity is so dire, and the acknowledgement of it so lacking, it has been termed a “hidden” crisis (Harrison et al., 2018). A recent emergency action plan was constructed to address the freshwater biodiversity crisis by halting future declines in species abundance through the development of novel recovery plans (Tickner et al., 2020). Central to that plan is the need to restore degraded habitats (i.e., ecological restoration; Suding et al., 2015; Piczak et al., in press), especially critical habitats needed to support reproduction (e.g., spawning habitat) for freshwater fishes. The information available to guide spawning habitat enhancement, however, is currently limited, with many studies having flawed designs, and little replication of methodology (e.g., lack of proper experimental controls, pseudoreplication, lack of before-after control-impact (BACI) design, and poor matching of control and experimental sites (reviewed in Rytwinski et al., 2019)). A recent review identified there is limited knowledge centered on the effectiveness of substrate cleaning as a potential tool to adequately create and enhance spawning habitat for substrate-spawning freshwater fishes (Taylor et al., 2019).

A common threat to substrate-spawning freshwater fishes is the accumulation of fine sediments over their preferred substrate, as this causes oxygen depletion resulting in increased egg mortality and abandonment of spawning habitats (Baetz et al., 2020). Furthermore, presence of specific substrate conditions are required for egg and fry development of many species (salmonid fry; Sternecker and Geist, 2010; Sternecker et al., 2013, 2014). For example, European nase (*Chondrostoma nasus* L.) have increased hatching and recruitment success in habitats with more interstitial spaces and more porous stream beds (Duerregger et al., 2018; Nagel et al., 2020a, 2020b). Previous studies have found that jetting or washing substrates can successfully improve conditions for substrate-spawning fish by reducing fine sediment content near the substrate surface (Meyer et al., 2008; Mueller et al., 2014; Bašić et al., 2017). In lotic environments, disturbed sediment is moved away from the area, increasing the effectiveness of cleaning. In lentic lacustrine environments, there might be little to no current to move sediment away from the treated area, but there is potentially less transport of sediment into the habitat; thus, although cleaning might be less effective, the

*Corresponding author: steven_cooke@carleton.ca

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results may persist longer. Studies of spawning-substrate cleaning effectiveness are heavily biased towards salmonid species that spawn in rivers (Taylor et al., 2019), so although the method could be beneficial for other fishes in lacustrine environments, there are no current studies to evaluate that possibility.

Smallmouth bass (*Micropterus dolomieu*) are valuable to recreational fishing in North America by annually contributing billions of dollars to the economy and improving social and mental wellbeing (Tufts et al., 2015). Smallmouth bass (hereafter "bass") spawn once a year in spring (13–20 °C) and exhibit paternal parental care. Males create nests and then after spawning they aerate and defend the eggs until hatching and then continue to defend the developing offspring for 4–6 weeks post-fertilization (Ridgway, 1989; Barthel et al., 2008). Males often show nest site fidelity, nesting in the same area (within 10 m) in successive years (Ridgway et al., 1991b; Ridgway et al., 2002; Barthel et al., 2008). Abandonment of nests by nest guarding males can occur and is more common in younger individuals and through anthropogenic pressures (e.g. capture by anglers; Philipp et al., 1997; Suski et al., 2003; Hanson et al., 2007). Due to their need to spawn in littoral regions, they are subject to habitat alterations associated with shoreline development (Jennings et al., 2002). Work has revealed that littoral habitats are extensively altered in most lakes and reservoirs, with shoreline development correlated with reduced habitat structure and suitability for nesting bass (Kaufmann et al., 2014; Lawson et al., 2011). To ensure sustainable recreational fisheries and maintain ecosystem stability, continued efforts on improving the quantity and quality of spawning habitats that are available to wild fish populations is necessary (Lapointe et al., 2014). In areas with fine, easily-suspended substrates (e.g., sand and silt), water movement may deposit fine sediments onto fish nests (Rytwinski et al., 2019). Male bass swim constantly above and around their nests to guard against brood predators and to remove fine sediment from the nest, preventing the eggs from being eaten or smothered. During the parental care period, the male drastically reduces feeding, relying primarily on energy reserves (Mackereth et al., 1999), so choosing a nest site with less fine sediments may be more favourable to reduce energy expenditures and improve both present and future reproductive success.

We conducted substrate cleaning, focussing on gravel and cobble areas, to reduce fine sediment and organic debris in several areas in Big Rideau Lake, Ontario, Canada. We hypothesized that substrate cleaning could result in increased numbers and/or larger individuals of bass nesting in an area. Nesting smallmouth bass, however, are territorial and will drive other individuals away from their nest, so there maybe a limit to the number of nests an area can support regardless of its quality. Improvements in habitat quality could lead to better habitat being selected by larger (older) bass that tend to have higher reproductive success and are able to secure better territories than smaller conspecifics (Raffetto et al., 1990; Wiegmann and Baylis, 1995; Gingerich and Suski, 2011). Larger bass are known to spawn earlier in the season, possibly due to having larger energy stores that allow them to spend a longer time preparing a nest and providing parental care (Ridgway et al., 1991a; Wiegmann and Baylis, 1995). Therefore, if a change in nest abundance is not seen in restored areas, an increase in the size of fish using those sites could indicate an improvement in substrate quality. We employed a replicated BACI design because it measures the impact of an event while controlling for the effects of unrelated changes or processes over the same period. By including a control that is similar to the treated area and influenced by the same factors, the true effect of the treatment can be measured as the relative difference in change within the treatment areas compared to the control areas (Smith, 2014). Using only a single treatment or control area runs the risk of mistaking natural variability in the system for an effect, though sometimes this is unavoidable due to the nature of the event being measured (e.g., construction of a dam on a river), in which case careful statistical analysis and replicate measurements in time should be used to minimize the effect of sampling error (Smokorowski and Randall, 2017).

## 2 Methods

### 2.1 Study site

The study took place in Big Rideau Lake (44.728819° N, −76.216208° W), a 4700 ha meso-oligotrophic lake in southeastern Ontario, Canada (Fig. 1). Big Rideau Lake is the largest lake on the Rideau Canal Waterway, a 202 km historic waterway used for recreation and travel and maintained by the federal agency "Parks Canada" (Bergman et al., 2022). The shoreline is a mixture of land uses and includes numerous cottages and houses, a public recreation area, provincial campground, and Crown land. Most development on the lake is related to cottage ownership and includes shoreline hardening and landscape modifications which can impact water quality and limit ecosystem services and biodiversity (Gittman et al., 2016). Big Rideau Lake is a popular destination for anglers with multiple bass fishing tournaments hosted on the lake every year. Using knowledge from researchers who had previously studied nesting bass on the lake, we identified several shorelines that contained suitable nesting habitat, were close in proximity and similar in habitat quality and had been used for spawning in the past. We also identified shorelines that could support spawning but were not known to be used previously. Habitat was considered suitable for spawning if: 1) the predominant grain size of the substrate ranged from sand to cobble, 2) had a low slope, and 3) negligible macrophyte growth in the 0–3 m depth range (Bozek et al., 2002). We chose shoreline habitat on mid-lake islands to test this method because the limited catchment area relative to the habitat area should minimize terrestrial sediment inputs.

### 2.2 Before-After Control-Impact (BACI) design

To evaluate and compare the potential effects of substrate cleaning we used a BACI experimental design. We compared the change of measured variables before and after the treatment (cleaning) within the treated areas and control areas which were not treated by the cleaning. This provides two categorical predictor variables, each with two levels: year (2018 and 2019) and treatment (treatment and control). The reason for including control sites is to provide a reference to the treatment site that experiences similar environmental conditions such as weather

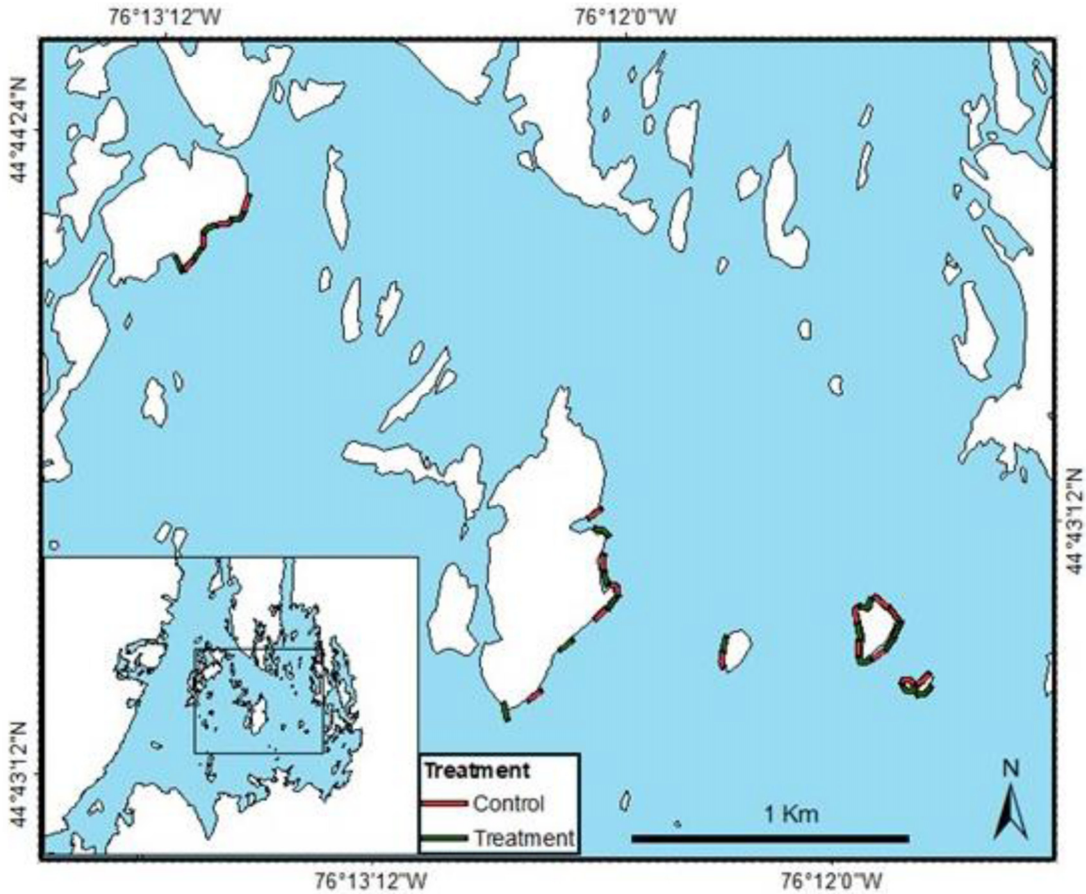


**Fig. 1.** Locations of treatment (green) and control (red) transects on Big Rideau Lake, Ontario.

during the spawning season or lake-wide water quality changes that could influence the number of spawning bass in a season.

Baseline monitoring of spawning occurred in late spring 2018 (May 28–June 4) after surface water temperatures near spawning sites reached 15 °C, the threshold for bass spawning to begin (Beeman, 1924). Each shoreline was surveyed twice, one week apart by a single snorkeler, to capture the use of the site over the course of the spawning period. Baseline monitoring involved surface visualization of nest formation and snorkel surveys to confirm the presence of bass on and/or near nests. After baseline monitoring and mapping of the nests using GPS coordinates, each identified shoreline was divided into a 50 m treatment and then 50 m control in a continuous line to evenly distribute the number of nests between the control and treatment groups. Prior to treatment in fall 2018 before ice-on, each treatment transect ($n = 17$) was snorkeled with the same snorkeler recording the transect using a GoPro to document the amount of the sedimentation. Treatment transects were cleaned with a pressure washer for a minimum of 10 mins to remove and clean sediment. A red rope was used to mark the transect and the diver worked along the rope facing away from shore so the sediment plume would travel away from the spawning habitat into deeper water. The cleaned substrate was measured visually, with the snorkeler swimming the transect with a GoPro to document the clean substrate. Improvement in substrate quality was measured through the reduction in biofilm, vegetation, and organic sediment which increased visibility of larger substrates in the treated section. In spring 2019 (June 4–13), treatment transects, and their paired control transects were snorkeled using the same method as spring 2018, to determine if treatment influenced the number of nests and spawning bass.

## 2.3 Smallmouth bass nest monitoring

The shorelines snorkeled by each person were selected randomly therefore the same shoreline was surveyed by different people on different days/years. Due to the layout of the transects, each person surveyed an equal number of control and treatment transects with 4 snorkelers participating in 2018 and 2 snorkelers in 2019. Snorkelers began at a set location and swam along shore visually inspecting the area for bass nests. The snorkeler moved in and out from shore, covering the littoral zone from 0–3 m depth to standardize the habitat observed. Nests were rarely observed deeper than 3 m. When a nest was located, the snorkeler confirmed the presence of eggs and/or fry and that it was guarded by a male bass, recorded the depth of the nest from the surface of the water to the nearest 0.5 m, and a visual estimate of size of the male to the nearest 5 cm. The location of each nest was recorded on a map (drawn on a dive slate) and assigned a unique ID corresponding to a white PVC nest tag (Fig. 2a), placed near the nest, to avoid

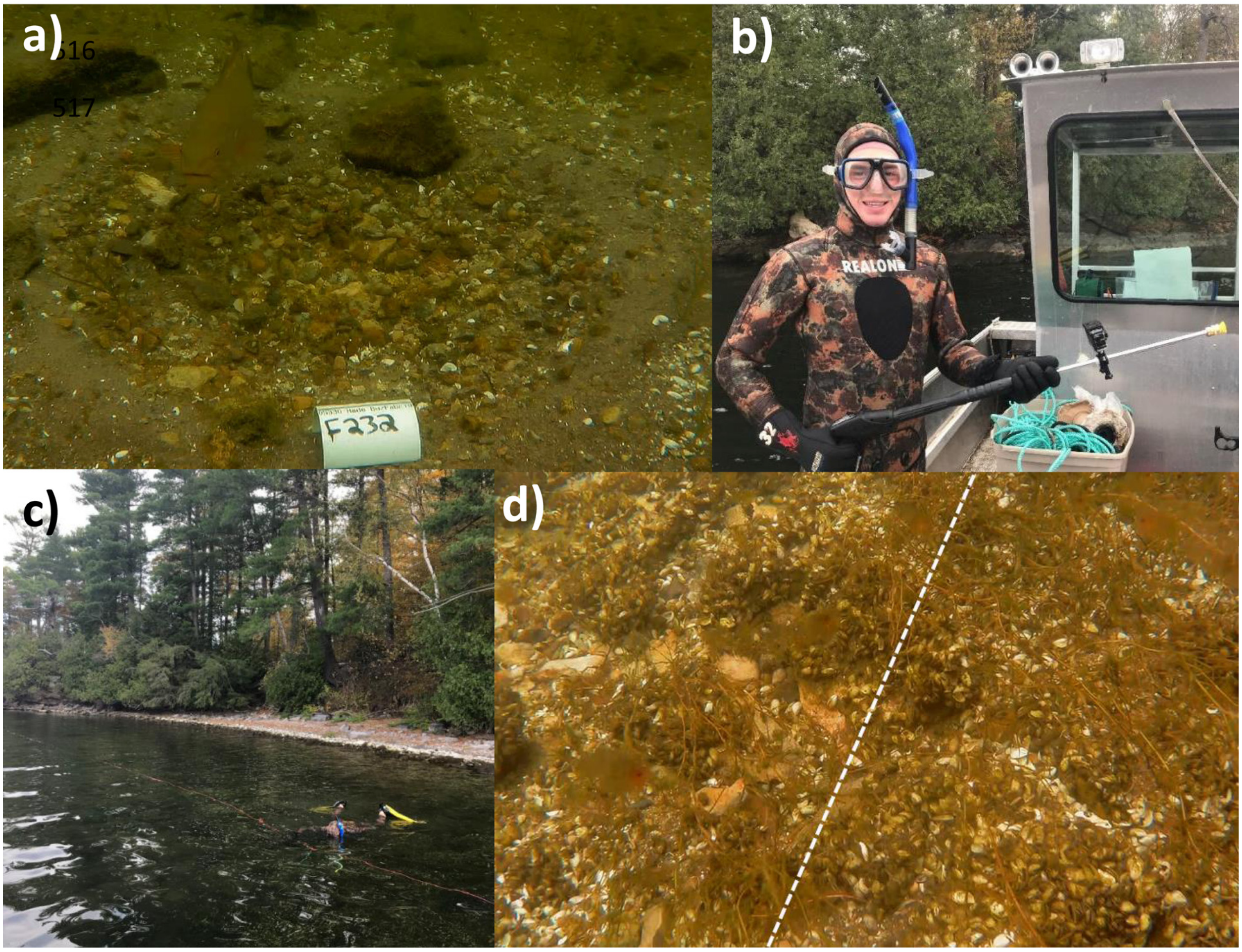


**Fig. 2.** a) Photo of a smallmouth bass nest with a male guarding and a white PVC nest tag used to avoid double-counting nests. The larger gravel and cobble substrate in the nest can be clearly distinguished from the surrounding fine substrate. b) A snorkeler wearing a 7-mm neoprene wetsuit and gloves, holding the pressure washer wand used for substrate cleaning. c) A red rope was used to mark the transect and the diver worked along the rope facing away from shore so the sediment plume would travel away from the spawning habitat into deeper water. d) Picture taken following substrate cleaning. The white dashed line was added to show the edge of the treated area on the left side of the image, while the area to the right is untreated. Improvement in substrate quality can be seen through the reduction in biofilm, vegetation, and organic sediment which make the untreated side darker, and increased visibility of larger substrates in the treated section.

recounting the same nest. Nest tags were left on the nest until spawning concluded.

### 2.4 Treatment

In October 2018, treatment transects ($n = 17$) were cleaned with a power washer from a boat. A weighted line was used to mark the 50 m transect approximately following the 1 m depth contour. Surface water levels in Big Rideau Lake are regulated and drawn down in the fall to prepare for spring flooding (see https://www.pc.gc.ca/en/docs/r/on/rideau/pd-mp/page_11), corresponding roughly to the 1.5 m depth contour in the spring (the middle area surveyed, and the depth with the greatest number of nests). A 21 MPa gas-powered power washer was run on the deck of the boat with a 15 m hose connected to the spray wand with a 15° nozzle that was operated by the snorkeler (Fig. 2b). The snorkeler sprayed the nozzle at an angle of approximately 30° below horizon, from 30 cm away from the substrate to remove fine sediments from a strip 1 m wide, while travelling along the transect (Fig. 2c). The effectiveness of the substrate washing was impaired in some areas due to residual macrophyte growth from the summer; regardless, an improvement in substrate quality was visually observed. The boat remained idling nearby and moved with the snorkeler. To ensure the cleaning did not negatively impact aquatic organisms in the area, the turbidity of the water was measured by collecting water before and immediately after the cleaning and analyzing the sample in a Lamotte 2020e turbidity meter.

### 2.5 Data analysis

All statistical analyses were performed, and all figures were created, in R v4.0.3 (R Core Development Team, 2020).

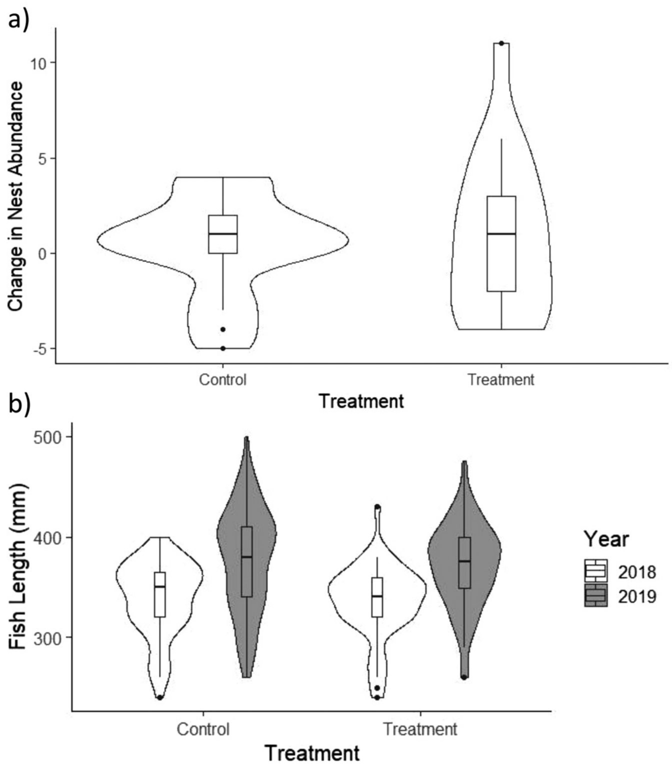


**Fig. 3.** Violin plots of the change in nest abundance in control and cleaned spawning habitat transects (a) and the distribution of nesting male smallmouth bass lengths in control and treatment transects before (white) and after (grey) restoration (b). The bold horizontal line shows the median change, the upper and lower box hinges show the 75th and 25th percentile, and the whiskers show 1.5 times the interquartile range. Points beyond 1.5 times the interquartile range are shown with black dots.

Data were assessed for normality and homoscedasticity using a Levene's test for equality of variance and a Shapiro–Wilk test for normal distribution. For a single before and after sampling period with multiple replicate sites, a two-tailed t-test was used to compare the means in nest abundance between control and treatment groups. The change in nest abundance on each transect was calculated by subtracting the spring 2018 abundance from the spring 2019 abundance. To test if substrate cleaning and the survey year influenced the size of bass, a two-way ANOVA was used with bass size as the response variable and treatment (i.e., control versus treatment) and year as interacting predictors.

## 3 Results

In 2018, the locations of 92 smallmouth bass nests were mapped across 34 transects. The mean (± standard error) baseline number of nests per transect was 2.5 (± 0.5) in the control ($n = 17$), and 2.9 (± 0.5) in the treatment groups ($n = 17$). The total number of nests documented in 2019 was 111, with an increase in total number of nests in both the control and treatment transects. The mean number of nests per transect in 2019 was 2.8 (± 0.7) in the control, and 3.7 (± 1.0) in the treatment groups. Although the cleaning did appear to reduce fine sediments and degree of embeddedness in the areas treated immediately after (Fig. 2d), the cleaned areas were indistinguishable from their immediate surroundings during follow-up monitoring seven months later (pers. observation). The mean change in nest abundance from 2018 to 2019 was 0.3 (± 0.6) in the control, and 0.8 (± 1.0) in the treatment group. Nest abundance between control and treatment groups were not statistically significant (*t*-test; $t = -0.440$, df = 32, $p = 0.663$; Fig. 3a). The mean length (cm) of fish was similar in the control and treatment transects in 2018 at 33.8 (± 5) cm and 33.5 (± 5) cm, respectively. The mean bass length in 2019 in the control transects was 37.8 (± 5) cm and 37.1 (± 5) mm in the treatment transects (Fig. 3b). There was a significant increase in average size from 2018 to 2019 overall (Two-way ANOVA; $F_{1,\ 266} = 47.51$, $P < 0.001$), however the change was similar between the control and treatment groups, so the interaction of treatment and year was not significant (Two-way ANOVA, $F_{1,\ 266} = 0.09$, $P = 0.76$). While monitoring the turbidity of the water in the transects, background turbidity ranged from 0.00 to 3.31 NTU. Samples taken after cleaning indicated a slight increase in turbidity, ranging from 0.05 to 1.41 NTU, with absolute values ranging from 0.17 to 4.72 NTU.

## 4 Discussion

Pressure washing of bass spawning substrate did not increase the abundance of nests the following year relative to the control. Similarly, other studies have found that substrate cleaning with pressurized water leads only to short-lived improvements in sediment size composition and substrate permeability (Sepulveda et al., 2015; Bašić et al., 2017). Over the time between cleaning and the next spawning period (~8 months), three periods of disturbance occurred which could be cause of resedimentation in the cleaned area and reduced treatment impact: fall turnover, ice breakup, and spring turnover. During fall and spring turnover, some fine sediment is resuspended and evenly dispersed throughout the lake. During ice breakup, ice sheets can be moved by wind or currents that disturb littoral sediment or thrust against shorelines and result in shoreline erosion and sediment runoff into the lake (Rosa, 1985). We chose shoreline habitat on mid-lake islands to test this method because the limited catchment area relative to the habitat area should minimize terrestrial sediment inputs. Shortening the interval between cleaning and spawning could result in a stronger treatment effect. However, due to winter ice cover and frigid spring water temperatures (near 0 °C), it was not possible to perform cleaning closer to the bass spawning period. Other sources for resedimentation of the study area could be a result of traditional high agricultural used surrounding the lake and the large input from several other waterbodies (e.g. Rideau Lake, Round Lake, Loon Lake) with only a single outflow (Chapman and Putnam, 1984; Forrest, 2002).

Restoration of habitats is a common conservation approach, yet rarely is it done in a coordinated manner with systematic monitoring to determine effort effectiveness (Wortley et al., 2013; Geist and Hawkins, 2016). Understanding whether spawning habitat restoration efforts for fishes are successful is lacking, with many studies suffering from low levels of replication and proper BACI design, rather opting for either a before-after or control-impact only (Rytwinski et al., 2019). Additionally, one must also look at studies to understand which aspect restoration is targeting. For example, in the context of bass it is possible to improve spawning substrate such that more/bigger fish spawn and/or improvements in the success of eggs/fry. Both outcomes are important when assessing restoration activities as improving spawning habitat does not necessarily equate to recruitment (Knott et al., 2021). For example, Knott et al. (2021) found a high density of eggs from native species in an engineered spawning ground in the River Schwarzach in Germany but cautioned against using this metric to assess recruitment.

We included a high level of replication in our study by performing the treatment in many discrete patches and measuring the change in abundance at each site to evaluate the average effect of the treatment across multiple units, rather than the average change within a larger site. By performing true replication, we established results robust against chance variation in our control and impact sites that can significantly confound the results at low sample sizes and is identified as a fatal flaw in BACI studies with limited replication (Underwood, 1992; Conquest, 2000). We also had the benefit of being able to randomly assign control and impact sites that were carefully selected for physical proximity and similarity regarding habitat quality, as well as number of nests in the 'before' period (Smith, 2014). Ideally, a BACI experiment uses multiple years of before-and-after monitoring to ensure a better understanding of interannual variability and observe if the effect of intervention is delayed or short-lived (Smokorowski and Randall, 2017). Due to the time constraints of this study, only one year of 'before' data was collected. Treatment effect was expected to be immediate due to selection of superior nesting habitat by bass and short-lived due to potential for continued sediment accumulation at the site. A sudden and short-lived effect can be viewed as a "pulse" in which case testing only the sampling period immediately after the impact to the before period is preferable to avoid diluting the effect by including time after the effect has passed (Underwood, 1992). Therefore, we chose to conduct follow-up monitoring for one year, with the possibility of subsequent monitoring to determine the longevity of the benefit (if an effect was indeed detected the first year).

There is a strong bias in published studies of spawning habitat restoration, in particular gravel and cobble washing in lotic systems and towards salmonid species (Taylor et al., 2019). Observational studies have established a correlation between spawning habitat variables such as substrate size, hydraulic conductivity, and/or porewater dissolved oxygen, and egg survival (Lapointe et al., 2004), to indicate a change in reproductive potential of a site. Several studies have shown that gravel washing with specialized tools (e.g., benthic sled cleaning devices) as well as basic pumps and power washers, can improve the conditions of spawning gravel in terms of sediment composition, hydraulic conductivity, and dissolved oxygen for salmonids (Meyer et al., 2008; Pander et al., 2015; Gatch et al., 2021). Fewer studies have measured if these improvements were accompanied by improvements in biological variables (Mueller et al., 2014; Sternecker et al., 2014). For example, a study conducted on cutthroat trout (*Oncorhynchus clarkii*) used a gravel-washing tool and found significant reduction of fine sediment in the surface and subsurface of the spawning site but failed to document any change in egg biomass (Sepulveda et al., 2015). However, substrate excavation and redeposition (a more invasive method) was found to reduce fine sediment, increase survival of eggs, and increase young-of-the-year (YOY) brown trout (*Salmo trutta*) for two years post-restoration until the substrate became clogged with fine sediments again (Pulg et al., 2014). As such, any restoration efforts to clean spawning substrate must consider the need for long-term efforts that periodically re-apply treatments. Additionally, understanding the catchment use, intensity and how fine sediment is introduced into the waterbody is important when understanding success of substrate restoration measures. For example, Geist et al. (2023) found long-term effects (~2 years) of gravel washing in pristine Swedish streams compared to other studies (e.g. Sternecker et al., 2013; Mueller et al., 2014; Pander et al., 2015) only found short-term effects (~6 months) which was likely attributed to differences in land use and lower input of fine sediment in Swedish streams.

Although there has been evidence of increased reproductive success (e.g., egg survival rates, YOY abundance) from gravel washing, little information exists that details the relationship between gravel washing and spawning habitat selection by fishes. Salmonids have strong fidelity to their natal stream when selecting spawning habitat, and since many salmonids are semelparous and spend their non-reproductive life stages in a habitat different from their spawning habitat, it is difficult to know if they would find and use improved habitat over degraded habitat. A study found that after cleaning gravel, the number of trout and grayling (*Thymallus arcticus*) spawning in a degraded chalk stream increased (Pulg et al., 2014). Salmonids are generally less tolerant of low dissolved oxygen than bass, and their eggs are particularly susceptible to fine sediment accumulation in their spawning habitat (Tang et al., 2020), so their spawning habitat requirements are more specific, and they may not attempt to spawn without high-quality habitat. Bass have broad oxygen tolerances (Tang et al., 2020), so they have wider habitat requirements than salmonids and are more likely to be able to spawn in lower quality habitat. As a result, while our cleaning treatment may have improved habitat quality, the lack of significant findings between the treatment and control groups may simply have been because we did not increase the amount of 'suitable' bass spawning habitat.

Prior to bass spawning (early May 2019), we noticed bass nests from previous years were still visible. These previously-used, bowl-shaped depressions had larger substrate covered in a thin layer of fine sediment buildup and periphyton or biofilm accumulation. Smallmouth bass often show nest site fidelity, nesting in the same area in successive years (Ridgway et al., 1991b; Barthel et al., 2008). We observed many of these existing depressions being reused by bass, which would reduce energy required for nest preparation. Our substate cleaning methodology, which was to clean a $50\,m \times 1\,m$ strip of substrate, could have failed to attract bass because it varied slightly from typical spawning sites. Due to the amount of area that was treated, only the top layer of substrate was cleaned potentially having a limited influence on attracting bass to spawn. Restoration efforts could be more targeted by scouting for existing depressions (nests) and cleaning those, saving bass from having to expend energy creating and clearing a new depression and allowing him to devote energy towards parental care. Additionally, efforts could be considered to create nest formations by excavating a bowl-shaped depression 0.5 m in diameter and 5 cm deep; it may be that depression-shaped, cleaned formations are most attractive to male bass looking for a spawning site rather than a large (cleaned) area, however, this has yet to be tested.

Further research on spawning substrate cleaning, in addition to the physicochemical characteristics of spawning sites is needed to determine if cleaning could be used as an effective habitat restoration tool. Our study found no statistical evidence that substrate cleaning increased the number of bass nests or the size of nesting males in an area, however, other indicators of reproductive success could reveal potential effects. Although many males may reach the stage of making a nest and courting a female to deposit eggs, a large-scale 20-year study on Lake Opeongo, Ontario, Canada, centred on bass reproduction found that on average, approximately 50% of males abandoned their brood before fry reach independence (Suski and Ridgway, 2007). Nest abandonment is believed to be a cost-benefit analysis by male bass where they assess current and future fitness, with increasing likelihood of abandonment if brood viability decreases due to mortality (e.g., nest predation, weather events, climate, pathogens, hypoxia; Lukas and Orth, 1995; Dauwalter and Fisher, 2007; Suski and Ridgway, 2007; Kaemingk et al., 2011). If substrate cleaning leads to increased nest success and increased brood survival, restoration efforts could be considered successful, similar to how some salmonid habitat restoration studies measure egg development success (Shackle et al., 1999; Pulg et al., 2014). Measuring how restoration influences the physiochemical conditions (e.g., oxygen levels) within nests may also enable a better understanding of the mechanisms behind the resultant effects, or lack thereof, on reproductive success in bass potentially allowing better refinement of spawning habitat restoration methods (Geist and Hawkins, 2016).

To live up to the ambitions of the UN Decade on Ecosystem Restoration, we must drastically improve our understanding of ecosystem restoration (Geist and Hawkins, 2016; Cooke et al., 2019). This initiative requires strong monitoring of restoration effects to improve our methods, provide evidence of value for effort, and guide evidence-based environmental management particularly by sharing with such studies with practitioners who are often unaware of such studies (Barouillet et al., 2024). Without measuring progress in a scientifically robust fashion, we cannot know when restoration efforts are being wasted or if conservation goals have been achieved (Mahlum et al., 2018). Here, we found that substrate cleaning with pressurized water did not increase the abundance of bass nests in sedimented spawning habitat or the size of nest-guarding male bass in a lentic lacustrine environment.

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## Data availability statement

The data supporting this research is available upon request.

## Author contributions

DMG and SJC constructed the study design, with DMG analyzing, writing, and creating figures for the initial drafts. BLH, LAD, AEIA, JNB, AC, and SJC supported field work and provided edits and suggestions on drafts of this manuscript. LJS dealt with revisions and added further input which greatly improved this manuscript.

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