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Free Falling: Fizzing Wild-Caught Smallmouth Bass Results in the Inability to Control Buoyancy in Deep Water

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ABSTRACT

Fizzing, a somewhat controversial technique for mitigating barotrauma, uses hollow hypodermic needles to release gas from the swim bladder of fish. To isolate effects of fizzing, 106 smallmouth bass (*Micropterus dolomieu*) were caught from shallow water without barotrauma and tested to determine if they could effectively control their buoyancy after having their swim bladder fizzed or punctured by releasing them over shallow (10 m) or unsuitably deep (55 m) habitat. Depth and behavior were monitored with biologgers. Most fizzed (57%) and punctured (61%) fish were unable to regulate their buoyancy in deepwater, sinking to the bottom and appearing moribund. In shallow water, punctured smallmouth bass stayed higher in the water column (like controls), while many fizzed fish stayed on the bottom. Our results suggest that if smallmouth bass are fizzed and immediately released, precautions should be taken to ensure they are released in areas of appropriate water depths (< 10 m).

1 | Introduction

Recreational fisheries provide social and economic benefits to society, while also providing a source of food (Cooke et al. 2018; Lynch et al. 2024). Some of the recreational catch is released (i.e., catch-and-release) under an assumption that most survive (Wydoski, 1977; Arlinghaus, Mehner, and Cowx 2002). Actions of individual anglers can impact the wellbeing of released fish (Brownscombe et al. 2017). For example, water temperature (Gale, Hinch, and Donaldson 2013; Havn et al. 2015), gear choice (Muoneke and Childress 1994; Alós 2008), and air exposure (Arlinghaus and Hallermann 2007; Gingerich et al. 2007) can all affect survival following release. Water depth is an especially important variable in predicting post-release survival of physoclistous fish, because fish caught in deepwater can have lethal barotrauma symptoms (St John and Syers 2005; Ferter et al. 2015).

Barotrauma occurs in fish when they experience rapid changes in pressure, such as being angled from depth (Carlson 2012). The decrease in pressure causes the gas in their body—most notably in their swim bladder—to expand, which in turn causes a wide array of internal injuries, including hemorrhaging, hematomas, exophthalmia (bulging eyes), and organ protrusion through the mouth or anus (Feathers and Knable 1983; Morrissey et al. 2005; Rummer and Bennett 2005; Carlson 2012). For anglers releasing barotrauma-affected fish, the most immediately problematic symptom is positive buoyancy due to swim bladder overinflation, which can prevent affected fish from returning to depth on their own (Hannah, Parker, and Matteson 2008), while also impeding their ability to maintain their equilibrium (Schreer et al. 2009). While other barotrauma symptoms may not always be lethal, an inability to resubmerge leaves fish incapable of returning to their capture depth, and makes them vulnerable to predation (e.g., Gravel and Cooke 2008; Kerwath, Wilke, and Götz 2013; Madden et al. 2024), surface exposure (Keniry et al. 1996), swimming impairments (Louison et al. 2023), and physiological exhaustion as they struggle to right themselves (Keniry et al. 1996; Ferter et al. 2015; Madden et al. 2024). Mitigation is required in these situations to relieve fish of their positive buoyancy. Like other catch-and-release topics, barotrauma mitigation measures have been well-studied, albeit with a bias toward marine environments (Wilde 2009).

Fizzing (also called venting) is a barotrauma mitigation technique in which a hollow hypodermic needle or similar device is inserted into the swim bladder of a fish to manually release gas until the fish returns to an upright position and neutral buoyancy (Kerr 2001). Compared to the other recognized mitigation technique of rapid recompression (i.e., using weighted descending devices to return fish to depth; hereafter termed "descending"), fizzing is more invasive and requires a high level of precision and competence by the angler (Kerr 2001; Scyphers et al. 2013). Consequently, fizzing has been controversial, with doubt about its efficacy and appropriateness (Wilde 2009; Scyphers et al. 2013; Demirci and Bayraktar 2019). A meta-analysis of 17 studies found fizzing to be ineffective at improving survival of fish with barotrauma (Wilde 2009), but a more recent review indicated that fizzing and descending resulted in similarly high survival (Eberts and Somers 2017). More recently, both fizzing and descending increased post-release survival of black sea bass (*Centropristis striata*) (Rudershausen et al. 2023), whereas fizzing was more effective at keeping walleye (*Sander vitreus*) at depth and correctly oriented than descending devices (Madden et al. 2024).

The lack of scientific consensus also extends to regulatory bodies, with some agencies such as the Florida Fish and Wildlife Conservation Commission encouraging fizzing (FWC 2023), while others like the Minnesota Department of Natural Resources ban the same practice (MN DNR 2023). Other, non-regulatory but influential organizations such as the Bass Anglers Sportsman Society (BASS) promote fizzing in their Bassmaster tournaments, by offering fizzing kits and tutorials by experts on how to correctly fizz black bass (*Micropterus* spp.; Gilliland and Schramm 2002; Gilliland 2023). Fizzing is particularly advantageous for retention in tournaments. In most freshwater fishing tournaments, anglers fish for 6–8 h and hold their catch in live wells before end-of-day weigh-in and subsequent release (LaRochelle et al. 2022). However, fish with barotrauma that are held at surface pressure will rapidly deteriorate in condition and barotrauma symptoms will worsen if not mitigated (Parker et al. 2006; Jarvis and Lowe 2008). Unlike use of descending devices, fizzing allows anglers holding fish to manage barotrauma symptoms immediately, and for fish to recover in a live well before release (Elliott, Row, and Tufts 2021).

Though studies have investigated post-release behavior of tournament-fizzed fish (e.g., Nguyen et al. 2009), the extent to which fizzed fish can regulate buoyancy after release has not been studied. The effect of controlled swim bladder deflation on buoyancy has been explored in laboratory studies (Shasteen and Sheehan 1997; Humborstad and Mangor-Jensen 2013), but not in the wild where fish behavior may impact conclusions and create more realistic and applicable results for anglers. Such research is timely considering anglers and tournament organizations may not necessarily take precautions to release fish over suitable habitat. Herein, we sought to answer whether fizzed fish can regulate buoyancyusing smallmouth bass (*Micropterus dolomieu*), a popular physoclistous North American game species often targeted and fizzed in black bass fishing tournaments (Quinn and Paukert 2009; Elliott, Row, and Tufts 2021). Using angled fish without barotrauma, to isolate the effects of fizzing, we compared post-release behavior of fish after being fizzed and after a simple puncture to their swim bladder, by releasing fish over two sites with different depths. Use of biologgers with pressure and acceleration sensors allowed us to monitor depth, locomotor activity, and orientation of fish after fizzing, compared to controls.

2 | Methods

2.1 | Study Site and Fish Collection

The study was conducted in August and September, 2023 on Big Rideau Lake in Southeastern Ontario, in Fisheries Management Zone 18 (surface water temperatures 22.2°C–27.4°C). A shallow release site (N 44° 44.090, W 076° 12.789) and a deep release site (N 44° 43.972, W 076° 13.963) were used on the lake. Both sites were chosen for their bathymetry and depth, with the shallow release site representing a depth in which smallmouth bass would regularly be found (9–10 m) and the deep site representing depths where smallmouth bass would not likely be found (50–55 m). Shoreline and thus shallower water were within 75 m of the shallow site and 100 m of the deep site.

Smallmouth bass were caught with medium action spinning rods (213 cm) and 4.5 kg braided line. Fish were caught from depths of 0.5–6 m, and none had any observable barotrauma symptoms. Fight time was minimized (< 15 s) and all fish were landed with a net. Once landed, each fish was placed in a water-filled measuring trough, measured in total length (mm) and anchor-tagged (Floy Manufacturing) for individual identification. Fish were then moved to a ~100 L live well with recirculating water (3028 L h^{-1}), and time was recorded. Fish were held in a live well for variable amounts of time, to mimic tournament situations. Time in the live well was noted and never more than 110 min before being released.

2.2 | Treatments

Fish were assigned to one of three treatments, paired with one of two release locations: (1) fully fizzed and released over deepwater (FD); (2) fully fizzed and released over shallow water (FS); (3) punctured swim bladder and released over deepwater (PD); (4) punctured swim bladder and released over shallow water (PS); (5) control released over deepwater (CD); and (6) control released over shallow water (CS).

Fish that were fully fizzed (FD and FS) were placed in a live well and positioned onto their side with the pectoral fin laid flat. Fizzing location was determined by drawing a vertical line between the fourth dorsal spiny ray and the anus, and fizzing at the intersection with a horizontal line from the base of the pectoral fin. A 21-gauge hypodermic needle was inserted under a scale, into the body, at a 90° angle until bubbles escaped. Fish had no observable barotrauma, so we were unable to use typical methods for knowing when fizzing should be halted, such as when the fish reorients or when it is no longer positively buoyant. For this reason, and to determine a threshold that could be used for all fish, fizzing was continued until bubbles slowed or stopped. This treatment most accurately represented a situation where a fish was over fizzed (i.e., too much gas was removed from the swim bladder). Fizzing time was consistent, with 6–9 s for bubbles to stop in all fish. When fizzing required more than one attempt, the number of attempts was recorded.

Smallmouth bass in the punctured swim bladder treatments (PD and PS) were initially treated the same as fish in the FD and FS treatments, but the needle was quickly removed as soon as it was evident that the needle was in the swim bladder (one bubble escaping). This method sought to determine differences between fish being affected by an empty or near empty swim bladder (treatments FD and FS) and fish affected by a puncture wound in their swim bladder intended to emulate a fish that had been fizzed only until it could maintain equilibrium.

After treatment, reflex action mortality predictors (RAMP) were used to assess overall condition before release (Davis 2010). Control fish were also assessed. Five reflexes were tested to determine if each fish: (1) could reorient after being placed upside down; (2) showed a burst response after being pinched on their caudal peduncle; (3) would flex their body when held sideways by the abdomen out of water; (4) would bite down on a finger placed in their mouth; and (5) gilled when held out of water. All fish were given 3 seconds to react before responses were recorded as a binary response (0 or 1), with zero indicating no impairment (reflex was present) and 1 indicating impairment (reflex was absent).

2.3 | Post-Release Monitoring

Before release, fish were equipped with a biologger containing a pressure sensor (± 5 cm) and tri-axial accelerometer (AXY Depth biologger; 12 × 31 × 11 mm; 7.5 g in air. ~3.5 g in water; TechnoSmArt, Guidonia Montecelio, Italy). Data were internally archived on the biologger at an 8-bit resolution with a 25 Hz sampling frequency. Biologgers were attached to fish while submerged in a water-filled trough with fresh lake water. The biologger was placed ventrally on each fish between the pelvic fins, and affixed by a Velcro strap that was wrapped around the body of the fish. The strap of the biologger was attached to a line and fishing rod, which was left with the bail open to allow the fish to freely swim during the monitoring period (see LaRochelle et al. 2021; Chhor et al. 2022; Figure 1).

After free swimming for 10 min, a boat was slowly moved via electric trolling motor in the direction of the fish by following the line attached to the biologger. Coordinates and water depth were recorded when the line was directly vertical (indicating the fish was under the boat) or when the fish was visually located (if near the surface). This method was not exact but was intended to provide a general metric for whether a fish dispersed from the release location or stayed in the same relative location. The biologger was then retrieved using a sharp tug of the fishing rod, which removed the Velcro strap from the body of the fish. For some fish, before the biologger was retrieved, but after the 10-min monitoring period, a Gladius Mini underwater drone (Chasing, Beijing) was deployed to obtain imagery of fish at depth, and to visually assess the condition and location of fish.

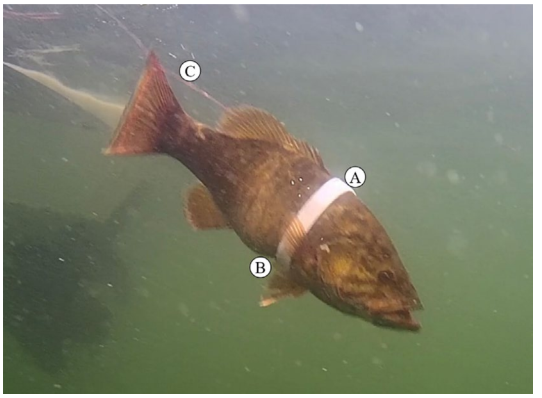

FIGURE 1 | Smallmouth bass (*Micropterus dolomieu*) being released with biologging setup including (A) Velcro strap, (B) biologger (positioned between pelvic fins), and (C) fishing line attached to strap via quick release clip (not pictured) in Big Rideau Lake, Southeastern Ontario, on September 7th, 2023. Picture taken with Gladius Mini underwater drone.

2.4 | Biologging Data

End depth of fish and sinking were determined by depth data collected from biologgers. At the deep site, fish that reached the maximum depth of the site or fish that were nearing that depth at the end of the 10-min period were categorized as sinking fish. To account for error in accuracy of coordinates from the chart plotter (Humminbird Helix 7 G3 GPS), any fish that failed to move more than 15 m away in the shallow depth were considered as not moving, which was noted visually in the field (i.e., the line attached to the fish went to the bottom and did not move for 10 min) and confirmed with biologging data. To provide an equivalent for sinking at the shallow site, fish released at the shallow site were classified as either "off bottom" or "on bottom" at the end of the monitoring period using depth data. Any depth greater than 9 m was considered "on bottom" for the shallow treatment.

Post-release locomotor activity of smallmouth bass was determined from overall dynamic body acceleration (ODBA) of fish during the 10-min monitoring period. To obtain the ODBA, the absolute sum of dynamic acceleration from three axes was calculated (Gleiss, Wilson, and Shepard 2011; Halsey et al. 2011) and then a 2 s box smoother was used to remove static acceleration due to gravity (Shepard et al. 2008). Finally, ODBA was taken as an average per minute over 10 min.

2.5 | Statistical Analyses

To determine the relationship between reflex impairment (RAMP score) and treatment (fully fizzed, punctured or control), chi-squared tests were used to compare treatments, followed by further chi-squared post hoc tests to determine pairwise differences. Analyses and figures were completed with RStudio statistical software version 12.0 (R Core Team 2023).

2.5.1 | Sinking and Site Dispersal

Generalized linear models (GLMs) with binomial distribution were used to test which variables affected sinking of deep-released fish. All models included sinking as the response variable (0 = did not sink to maximum depth or 1 = sank to maximum depth), and all combinations of predictor variables for treatment (fizz, puncture, control), total length (mm), time held in livewell (min), and reflex impairment. Models were ranked using AICc and chi-square tests were used to compare differences within variables that were present in the best ranking model. The number of fizzing attempts was not recorded for all treatments, so was not included in models. Instead, the number of fizzing attempts was tested only for the PD treatment using a chi-square test to determine if fizzing attempts was related to sinking. The number of fizzing attempts was mostly 1 or 2, with few incidences of more attempts, so was categorized as one or multiple.

Another model was used to determine which variables affected dispersal of fish released at the shallow location. GLMs with binomial distribution included treatment (fizz, puncture, control), time in the livewell, reflex impairment, and total length as predictor variables, and interactions where logical.

Depth of fish that dispersed from the release site at the end of the 10-min period was compared within release locations and between release locations using one-way ANOVA. One ANOVA included fish in the shallow treatment that were on or very near the bottom, and another ANOVA excluded these fish. Mean depth over the 10-min period was modeled using linear mixed effect models in the *lme4* package and lmer function (Bates et al. 2015) and ranked with AICc. Variables included treatment, minutes after release, total length, and time in the livewell, with individual fish as random effects.

The *aictab* function from the *AICcmodavg* package (Mazerolle 2020) was used to complete all Akaike Information Criterion (corrected for small sample size; AICc) model selections throughout the analysis. All model selections included a null model for comparison and only models within a ΔAICc of two of the highest-ranking model were retained. The *emmeans* package and function (Lenth 2023) was used for Tukey post hoc tests on the best ranking models. Analyses of variance (ANOVA) was used to test differences between total length and time in the livewell among treatments.

2.5.2 | Overall Dynamic Body Acceleration

ODBA over 10 min was modeled for all fish and only those fish that dispersed from the shallow release location or did not sink in the deep release location. For both models, linear mixed effect models included individual fish as a random effect, and predictor variables of treatment combination (FD, FS, PD, PS, CD, CS), treatment (fizz, puncture, control), release location (deep or shallow), minutes post-release, reflex impairment, fish length, and total time spent in the livewell before release. Interactions between treatment and size and treatment and minutes post release were included. Tukey post hoc tests were used for pairwise comparisons between groups for variables in the best ranking model.

3 | Results

3.1 | Pre-Release

The smallmouth bass used in the study ($n = 106$) averaged 360 mm (SD = 48 mm; range = 300–494 mm) in total length. Total length did not differ significantly among treatments ($F_{5,100} = 0.175$, $p = 0.971$). Average time held in the livewell before release (mean = 55 min; SD = 15 min; range = 29–108 min) did not differ significantly among treatments ($F_{5,100} = 1.55$, $p = 0.180$).

Reflex impairment was minimal during the study, with most ($n = 90$, 85%) fish not impaired and the rest showing only one reflex impaired, mostly the tail grab reflex ($n = 13$, 12%). Absence of the tail grab reflex was significantly associated with treatment ($X(2) = 6.17$, $p = 0.046$). Eight punctured fish had no tail grab reflex, while four fizzed fish and one control fish had no tail grab reflex. Punctured fish had significantly higher occurrence of the tail grab reflex than control fish ($X(1) = 6.03$, $p = 0.014$), with no other differences among treatments. Loss of body flex was the only other impairment observed, in only three fish, all of which were fizzed.

3.2 | Post-Release Activity

3.2.1 | Sinking and Site Dispersal

At the deepwater site, 11 fizzed (58%) and 11 punctured (61%) fish quickly sank down to the maximum depth of 55 m after release, while only one control fish sank (Figures 2 and 3). The model that best predicted sinking included only treatment as a predictor variable (AICc = 63.9, weight = 0.49). No other models were within a delta AICc of two. Fizz ($X(1) = 10.3$, $p = 0.001$) and puncture ($X(1) = 11.2$, $p < 0.001$) treatments had significantly higher sinking than control group, but did not differ significantly from each other ($X(1) = 0.040$, $p = 0.842$). The number of fizzing attempts did not influence the likelihood of a fish sinking in the puncture treatment ($X(1) = 0.234$, $p = 0.629$), and insufficient data were collected to test the fizzing treatment.

At the shallow release location, nine fizzed fish (50%), two punctured fish (12%), and three control fish (17%) did not move away from the release location during the 10-min observation period, and all other fish moved > 15 m. The model that best predicted movement away from the release site included treatment and time in livewell as predictor variables (no interaction; AICc = 58.3, weight = 0.51), and the second-best model included only treatment (AICc = 59.7, weight = 0.25). The fizz treatment differed from controls (Tukey post hoc test, $z = 2.31$, $p = 0.055$) and fizz and puncture treatments differed ($z = -2.29$, $p = 0.057$), whereas the puncture treatment did not differ from controls ($z = 0.069$, $p = 0.997$).

Average depth of fish that moved from the release location at the end of the 10-min period was 12.9 ± 10.4 m for fish released in the deep location and 23.9 ± 11.9 m for fish released at the shallow location. End depth did not differ significantly among treatments at each release site (deep: $F_{2,26} = 0.321$, $p = 0.728$; shallow: $F_{2,41} = 0.516$, $p = 0.601$), but differed significantly between release locations ($F_{1,71} = 15.4$, $p < 0.001$). Excluding 55% of CS fish, 78% of FS fish, and 47% of PS fish that were on or near the bottom at the end of the post-release observation period (Figure 4), the average end depth of fish in the shallow treatments (12.2 ± 6.66 m) not differ significantly between release locations ($F_{1,49} = 0.009$, $p = 0.924$) or between shallow treatments ($F_{2,18} = 0.697$, $p = 0.511$). The model that best predicted mean depth for all fish included treatment, the interaction, and minutes post-release as predictor variables (AICc = 7272, weight = 1). Treatment ($F_{5,104} = 9.47$, $p < 0.001$), minutes post release ($F_{9,936} = 32.9$, $p < 0.001$), and the interaction ($F_{45,936} = 9.95$, $p < 0.001$) were all significant predictors of mean depth. Excluding fish that sank (deep) or remained at the release location (shallow), the best model also included treatment ($F_{5,74} = 2.54$, $p = 0.035$), minutes post release ($F_{9,666} = 10.6$, $p < 0.001$), and the interaction ($F_{45,666} = 2.83$, $p < 0.001$; Figure 5).

3.2.2 | Overall Dynamic Body Acceleration

The model that best described average ODBA of all fish included mean depth and the interaction between treatment and minutes post release as predictor variables (AICc = 3832, weight = 1.00). Overall, treatment was significantly related to ODBA ($F_{5,95} = 7.63$, $p < 0.001$). Average ODBA differed between FD and all other treatments except PD (CD: $t = 3.12$; $p = 0.027$; CS: $t = 4.69$, $p < 0.001$; FS: $p = 4.81$, $p < 0.001$; PS: $t = 4.18$, $p < 0.001$). Average ODBA of the PD treatment differed from the CS ($t = 3.68$, $p = 0.005$), FS ($t = 3.77$, $p = 0.004$) and PS ($t = 3.28$, $p = 0.022$) treatments. Average ODBA did not differ significantly between other treatment groups. Average ODBA was negatively related to mean depth ($F_{1,503} = 28.1$, $p < 0.001$) and minutes post release ($F_{9,935} = 19.9$, $p < 0.001$). A significant interaction between treatment and minutes post release ($F_{45,926} = 3.03$, $p < 0.001$) was caused by the FD treatment having significantly

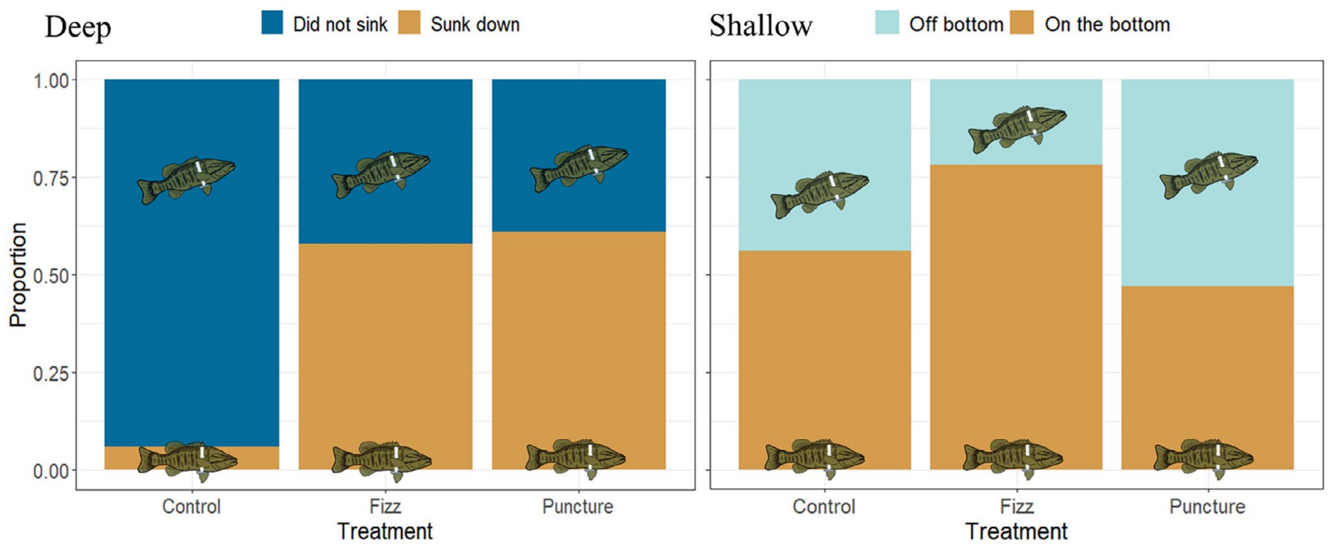

FIGURE 2 | Proportion of smallmouth bass (*Micropterus dolomieu*) not treated (control), fizzed (fizz), or punctured (puncture) that sunk down to the bottom of their respective sites (deep: ~ 55 m, shallow: ~ 10 m) at 10 min post-release in Big Rideau Lake, Southeastern Ontario, during August–September, 2023. All fish that sank in the deep release site did so immediately and remained on the bottom during the whole monitoring period, whereas fish on the bottom in the shallow treatment were only there at the 10-min mark.

FIGURE 3 | Fizzed smallmouth bass (*Micropterus dolomieu*) pictured on bottom of deep (~ 55 m) and shallow site (~ 10 m) *in* Big Rideau Lake, Southeastern Ontario, August 23rd, 2023. Pictures taken with Gladius Mini underwater drone.

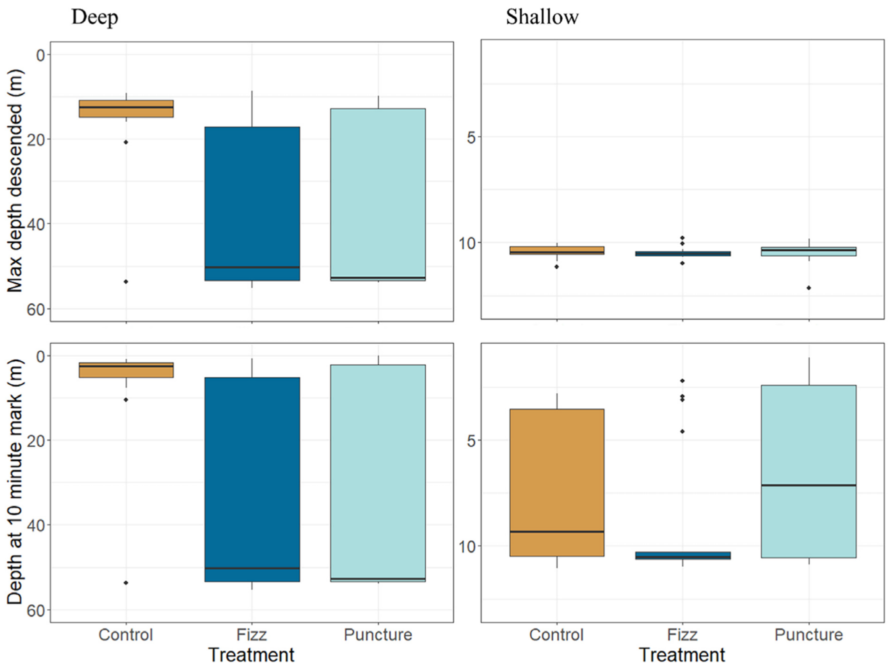

FIGURE 4 | Maximum depth descended and depth after 10-min of all smallmouth bass (*Micropterus dolomieu*) in each treatment not treated (control), fizzed (fizz), or punctured (Puncture) in Big Rideau Lake, Southeastern Ontario, during August–September, 2023. Boxes indicate median, first and third quartile, as well as minimum and maximum values. Dots represent outliers.

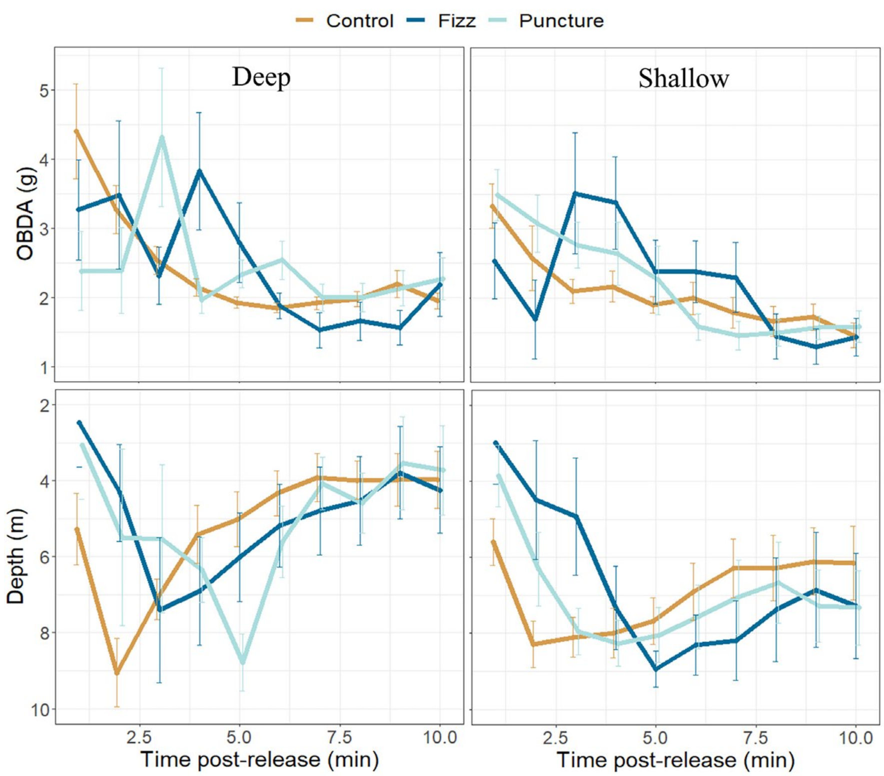

FIGURE 5 | Mean (±SE) overall dynamic body acceleration (ODBA) and depth of smallmouth bass *(Micropterus dolomieu)* that did not sink or stayed at the release location (n: FD = 8, CD = 15, PD = 6, FS = 10, CS = 18, PS = 17) over 10 min after release in Big Rideau Lake, Southeastern Ontario, during August–September, 2023.

higher ODBA half way through the monitoring period (minute 5) than all other treatments except PD (CS: $t = 5.10$, $p < 0.001$; FS: $t = 2.51$, $p < 0.001$; CD: $t = 4.41$, $p = 0.015$; PS: $t = 4.32$, $p = 0.021$).

Excluding fish that sunk or did not move away from the release position, the model that best predicted average ODBA included minutes post-release and release location as predictor variables

(AICc = 2503, weight = 0.61; Figure 5). Fish released at the deep location had higher average ODBA than fish at the shallow location ($F_{1,74}$ = 4.30 p = 0.042). Average ODBA was negatively related to minutes post release ($F_{1,666}$ = 128, p < 0.001).

4 | Discussion

Fizzing is a barotrauma relief technique that lacks scientific consensus on its appropriateness and effectiveness. Nevertheless, the practice remains convenient for use for retention of fish held in livewells during tournaments and is widely practiced by anglers. For this reason, effects of fizzing on swim bladder function of fish must be understood to develop best practices. Using biologgers to track post-release depth of smallmouth bass, we found that puncturing the swim bladder inhibited the ability to regulate buoyancy and sometimes resulted in sinking to depths outside of their preference over a short-term (10 min) period. The 23 smallmouth bass that sunk to 55 m in our study probably did not do so by choice, because smallmouth bass are typically found in water shallower than 14 m (Suski and Ridgway 2009). Further, the poor condition (appearing moribund) of fish observed with the underwater drone on the bottom at the deep site 10 min after release (Figure 3) may have been caused by pressure encountered at that depth (~6.5 bar), which was much higher than their typical habitat, and dissolved oxygen concentrations that may have been limited (Schwefel et al. 2018).

While perhaps unsurprising to find that more than half of fizzed fish sank down to maximum depth when released, almost the exact same proportion of bass with punctured (but not emptied) swim bladders sank over deep habitat (Figure 2). By including fizzing and puncturing in our study, we conclude that the puncture wound, not fizzing or over-fizzing, was a primary cause of buoyancy issues in these fish. Similarly, in a laboratory study where swim bladders of Atlantic cod (*Gadus morhua*) were punctured and pressure was released by vacuum, fish were able to reinflate their swim bladder shortly after puncture (although "shortly" was not defined by the authors) and behaved similar to controls (Humborstad and Mangor-Jensen 2013). Similarly, largemouth bass (*Micropterus nigricans*) that had their swim bladders punctured with a needle in a laboratory were able to maintain neutral buoyancy immediately after surgery, because the swim bladder sealed and was immediately functional after being pierced with a hypodermic needle (Shasteen and Sheehan 1997). Results of these two studies may have differed from ours because of behavioral differences that arose when releasing fish back into the wild rather than a laboratory tank. For example, when released after angling, fish instinctively rest and recover on the bottom (Brownscombe et al. 2013; Chhor et al. 2022), similar to the fish released in shallow water in our study. Fish released over deepwater in our study likely, therefore, attempted to reach the bottom. We speculate that the high pressure encountered while swimming down may have affected the swim bladder of fizzed and punctured fish, perhaps by compressing the swim bladder and causing gas to escape from the puncture wound. This high pressure and possibly emptying swim bladder may have prevented fish from returning to shallower water when the bottom was out of reach. If these fish had been in a laboratory, however, these fish would have no reason or ability to dive to deeper depths. Indeed, fish released into shallower water in our study were more similar to a laboratory. Without the ability or need to descend, we conclude that punctured fish in shallow water were not as affected or constrained to the bottom as fizzed fish in shallow water, because their swim bladder functioned similar to laboratory studies.

The reason why some fish sank and others did not sink after fizzing or puncturing is not clear, but ODBA data can provide insight about the condition of fish that were treated but did not sink. For fish that did not sink or stayed at the release location, acceleration patterns differed between treatments and release locations (Figure 5). Control fish at both release sites decreased in acceleration over 10 min, while fizzed and punctured fish increased in acceleration during the first half of the release period. Consequently, even fish that were not obviously impaired by sinking were evidently still impaired by their treatment, and swam harder than controls to maintain the same depth (Figure 5). Fish from the same treatment groups (FD, FS, and PD) were impaired similarly as those found on the bottom (vs. fish that were found higher in the water column). Fish that were punctured and released in the shallow depth, on the other hand, maintained similar ODBA patterns to shallow controls. These results, in addition to off-bottom proportions, suggest that punctured fish did not experience similar buoyancy issues or behavioral changes when released over shallow water, and that diving to the bottom may have contributed to sinking.

Past studies suggests that fizzing to mitigate barotrauma, when done properly, can result in similar survival to other mitigation techniques (Eberts and Somers 2017; Munday et al. 2015). While two previous studies found that swim bladders were functional immediately or "soon" (although "soon" was not defined by authors) after being punctured (Shasteen and Sheehan 1997; Humborstad and Mangor-Jensen 2013), our study results suggest that fish behavior (i.e., seeking out the bottom) will affect this capability by immediately subjecting their injured swim bladder to higher pressure. Free-swimming smallmouth bass, tracked over 4 days with radio telemetry after swim bladder puncture by fizzing, and released over suitable depths and habitats where smallmouth bass were routinely captured, suffered no mortality over the monitoring period (Nguyen et al. 2009). Based on our results, releasing smallmouth bass over typical habitat after fizzing does not seem to negatively impact survival or behavior, whereas releasing fish over unsuitably deep habitat does, at least in the short-term. Our study was limited to a 10-min monitoring duration, but our results suggested that the depth over which fish were released has a considerable influence on the wellbeing of fizzed fish. Further field-based research is needed to better understand how long a swim bladder puncture needs to heal to withstand high pressure associated with depth.

Our results showed that after being fizzed, smallmouth bass were vulnerable to buoyancy issues. With the punctured treatment being the closest to a properly fizzed fish, foundbehavioural and physiological benefits to being released at appropriate depth for the species. We urge anglers who chooses to fizz their fish to release them at an appropriate depth to minimize physiological and physical consequences of extreme pressure and low oxygen levels—whether sublethal or lethal. Fishing tournaments that release large numbers of fizzed fish (e.g., with a live release boat) may also take precautions to choose appropriate release locations. For smallmouth bass, we suggest that fizzed fish should not be released over depths that exceed ~10 m.

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Ethics Statement

All research detailed here was conducted in accordance with the Canadian Council on Animal Care (approved by Carleton University) and under a scientific collection permit issued by the Ontario Ministry of Natural Resources and Forestry.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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