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Article

# Biologgers reveal unanticipated issues with descending angled walleye with barotrauma symptoms

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## Abstract

Without sufficient time to diffuse air from their swim bladders, physoclistous fish caught in deep water can exhibit symptoms of barotrauma. In this study, we tested the effectiveness of four barotrauma relief techniques on 76 walleye (*Sander vitreus*) and compared their 10 min post-release behaviour and depth selection with an untreated control group using a biologger containing a tri-axial accelerometer and depth sensor. Vented fish showed the best success rate of returning to depth, while no untreated controls were able to swim down. For fish that remained at depth, half were found to have lost orientation and were upside down during the entire monitoring period, with this orientation being strongly associated with the relief method. Vented fish had higher chances (80%) of remaining in the correct orientation at depth compared with the other methods (average of 38%). Our research shows that the best way to prevent negative outcomes of barotrauma is to avoid fishing at depths that yield barotrauma; however, if unavoidable, affected fish should be carefully vented by trained anglers to best reduce post-release impairments.

**Key words:** barotrauma, venting, descending, rapid recompression, orientation, *Sander vitreus*

## 1. Introduction

While there is always a risk of injury or death to fish during catch-and-release (C&R) angling events (Arlinghaus et al. 2007; Cooke and Schramm 2007), some situations and species have a higher risk of negative outcomes, such as a temperature-sensitive species on an exceptionally warm day (as in Boyd et al. 2010). It is prudent for anglers as well as managers to be aware of these "risky" situations and adapt their behaviour accordingly, whether that means abstaining from fishing, adjusting their behaviour, or using various mitigative measures. The use of best practices by anglers is instrumental in maintaining the welfare of fish and the overall health of recreational fisheries (Cooke and Suski 2005; Brownscombe et al. 2017). Thus, it is of great importance that both situation- and species-specific best practices in C&R fishing be scientifically validated, robust, and well communicated to angling communities (Brownscombe et al. 2017).

With often obvious symptoms, situations where angled fish show signs of barotrauma are perhaps those that most clearly demand action from the angler (Arlinghaus et al. 2007). Barotrauma occurs when fish are caught in deep water and quickly brought to the surface, where rapid decompression causes gases in their body to expand (D'Aoust and Smith 1974). This typically occurs in physoclistous fish since they lack a pneumatic duct and therefore cannot quickly empty gases from their swim bladder to avoid expansion and maintain neutral buoyancy (Strand et al. 2005; Hughes et al. 2016). However, barotrauma has also been documented in physostomes in cases of very rapid ascents or subsurface movement, such as angling deep-water residing lake trout (*Salvelinus namaycush*) or salmonids going through hydroturbine passages (McKinstry et al. 2007; Stephenson et al. 2010; Brown et al. 2012; Richmond et al. 2014; Ng et al. 2015; Sitar et al. 2017). While symptoms such as positive buoyancy, bloated abdomen, bulging eyes, organ protrusion, and loss of equilibrium can be obvious to anglers (Feathers and Knable 1983; Rummer and Bennett 2005; Carlson 2012), other, less obvious but potentially lethal physiological changes include red blood cell lysis, hemorrhaging, formation of gas bubbles in blood, gill emboli, and swim bladder rupture (Feathers and Knable 1983; Morrissey et al. 2005; Stephenson et al. 2010). Barotrauma has been recorded in depths as shallow as 3 m (Shasteen and Sheehan 1997), though most often occurring at depths of 6–7 m, with a sharp increase in occurrence and mortality found around 9–10 m (Schreer et al. 2009; Twardek et al. 2018; Lyon et al. 2022). Thus, in general, mortality following C&R increases with greater depths (St John and Syers 2005; Arlinghaus et al. 2007). In addition to depth, barotrauma has also been found to be exacerbated, and mortality increases with time retained at surface pressure (Jarvis and Lowe 2008).

Without mitigation by anglers, fish with moderate to severe barotrauma will be left floating on the surface, unable to swim back to depth (Brown et al. 2010). Even in ideal conditions, some species will only have a 50% chance of surviving in this state (without even considering vulnerability to predation during this time; Gravel and Cooke 2008; Eberts et al. 2018). For this reason, it is imperative that anglers practicing C&R recognize the symptoms of barotrauma and take action to relieve the symptoms of the fish and avoid high release mortality. Deep-water releases (using various descending devices) and venting (i.e., fizzing) are the main two strategies for barotrauma relief in both marine and freshwater recreational fisheries (Bartholomew and Bohnsack 2005; Wilde 2009; Drumhiller et al. 2014). Deep-water releases work by recompressing fish by returning them to deep water (usually with weights—termed rapid recompression) and can be performed with a variety of commercial and handmade recompression devices or tools (Bartholomew and Bohnsack 2005). These descenders vary in complexity from an easily fashioned weighted crate or hook to more complex pressure-release clamps that are set to release at specific depths (Gitschlag and Renaud 1994; Bellquist et al. 2019). Both in the laboratory and field setting, rapid recompression has been found to reverse visible barotrauma symptoms and reduce mortality in physoclistous species, such as some species of grouper, multiple rockfish species, and red snapper (*Lutjanus campechanus*), compared with controls (Parker et al. 2006; Jarvis and Lowe 2008; Drumhiller et al. 2014; Runde et al. 2020). Venting, on the other hand, has been the subject of controversy in its use for mitigating barotrauma (Wilde 2009). The practice involves using a hollow needle to puncture through the skin of the fish into the swim bladder to allow gases to escape. While some governing bodies discourage venting (e.g., Washington Department of Fish and Wildlife and the Ontario Ministry of Natural Resources; Kerr 2001), conclusions about its efficacy from research have been mixed and often species-specific (Bartholomew and Bohnsack 2005; Wilde 2009). In their review on C&R angling mortality, Bartholomew and Bohnsack (2005) concluded that venting fish was indeed successful in reducing post-release mortality in many species if performed correctly. Conversely, Wilde's (2009) review on venting found little evidence that venting fish improved survival and suggested the practice be banned altogether. Nevertheless, venting fish continues to be studied (with often positive results; Eberts and Somers 2017) and used by anglers as a quick and inexpensive way to return game fish impacted by barotrauma to depth (Scyphers et al. 2013).

Typically residing in 1–15 m of water (Hartman 2009), walleye (*Sander vitreus*) are a freshwater physoclistous fish that are highly sought-after in C&R fishing, angling tournaments, and for harvest (Quinn 1992; Hartman 2009). Walleye are also a species that is known to have issues with barotrauma (Schreer et al. 2009; Eberts et al. 2018; Twardek et al. 2018), yet, to date, there is only one study that has examined the effectiveness of decompression techniques. For tournament-caught walleye that were vented, Eberts et al. (2018) found that they used shallower and smaller areas of the site compared with descended and control fish, though there were no significant differences in displacement between groups. Given the need for science that can guide mitigation measures and best practices, our objective in this study was to compare the effectiveness of four different barotrauma relief techniques for walleye caught in relatively shallow (<12 m) water and determine the short-term (10 min) behaviour of these fish once released. This was facilitated by using biologgers equipped with acceleration, temperature, and pressure sensors to determine the orientation of fish once descended, their post-release depth use, and locomotor activity, and comparing these metrics against an untreated control group that exhibited signs of barotrauma.

## 2. Methods

### 2.1. Study site

This study was conducted in 2022 between 3 August and 22 August on Lake St. Joseph in Northwestern Ontario, Canada (51°05.154′N, 90°36.361′W). Known for its walleye recreational fishery, Lake St. Joseph is a large lake (surface area of 493 square kilometers) with a maximum depth of approximately 29 m, regulated by a controlled outflow that allows the depth to fluctuate over short periods of time. All research was conducted under the auspices of a Scientific Collection Permit from the Ontario Ministry of Natural Resources and Forestry and Animal Care Protocols approved by Carleton University in accordance with the guidelines of the Canadian Council on Animal Care.

### 2.2. Barotrauma assessments

Walleye were angled from depths greater or equal to 7.5 m. Preliminary assessments indicated 7.5 m as the lowest reasonable threshold at which fish would consistently exhibit barotrauma symptoms. Walleye were captured using medium-action spinning rods (213 cm) with 4.5 kg of braided line. Fish were caught by jigging close to the bottom with soft plastic artificial lures on jig heads and a single barbless hook. Once hooked, fish were brought to the boat, and fight time was recorded using a stopwatch. Each walleye was netted, unhooked, measured in a water-filled trough, and immediately placed in one of two ~100 L recirculating (3028 L $h^{-1}$) live wells. Total air exposure was less than 15 s. Once in the live well, fish were assessed for presence of barotrauma symptoms, including positive buoyancy, a bloated abdomen, bulging eyes, organ protrusion through the mouth or anus, and flared gills. Barotrauma scores were then determined by the number of external symptoms present in the walleye. Fish were then held for 30 min in the live wells, simulating a delay in release that may be observed in selective harvest or high grading. After the holding period and prior to release, fish were re-assessed for both barotrauma symptoms and further assessed on five reflex action mortality predictors (RAMP). These reflex tests included body flex when restrained, dorsal fin flare when restrained, operculum closure when manually opened, vestibular-ocular test when rotated, and orientation—all of which are widely used as mortality predictors (Davis 2007; Davis 2010). Reflexes were scored in binary with either a presence (scored 0) or absence (scored 1) of the reflex.

**Fig. 1.** Walleye (*Sander vitreus)* with the Axy-Depth tri-axial accelerometer positioned ventrally between the pelvic fins and attached around its body. The Velcro strap had a quick release clip positioned dorsally (not pictured), which would release the strap with a sharp tug from the attached line. The arrow points toward the approximate venting location.



## 2.3. Treatments

Fish were randomly assigned one of five treatments to compare four barotrauma relief techniques: (1) swim bladder venting using a needle, (2) *Fishsaverpro* weighted hook descender (Sustainable Recreation, Pachedu (Pty) Ltd.), (3) *SeaQualizer* lip clamp descender (SeaQualizer, LLC), (4) weighted crate descender, and (5) control—no barotrauma mitigation. All fish in this study were equipped with a biologger (Axy-Depth tri-axial accelerometer, TechnoSmart, equipped with depth and acceleration sensors; 7.5 g in air) attached to a Velcro strap, which was positioned ventrally between the pelvic fins and strapped around the body (LaRochelle et al. 2021; Chhor et al. 2022; LaRochelle et al. 2022; Fig. 1). The strap was then affixed to a line on a fishing rod, and the fish was released at the surface with the bail open and the line being fed out, allowing the fish to swim freely. After the 10 min post-release monitoring period, the bail of the reel was closed, and the strap and biologger were removed from the fish by a firm tug on the line and subsequently returned to the boat. Overall dynamic body acceleration (ODBA), a reliable measurement for overall locomotor activity (Gleiss et al. 2011), was calculated from the biologger using the absolute sum of dynamic acceleration from 3 axes (Halsey et al. 2011), with static acceleration due to gravity removed using a 2 s box smoother (Shepard et al. 2008). Surface temperature was also extracted from the biologgers and recorded for each fish.

Fish assigned to the swim bladder venting technique were vented in the live well by inserting a 21-gauge hypodermic needle at a 45-degree angle approximately two-thirds of the way between the pelvic fins and anal fin, near the gradient of pigmentation (Fig. 1). This small-gauge needle was chosen to minimize the wound caused during venting. Venting continued until the fish was no longer positively buoyant.

Fish in the weighted hook descender treatment were attached to a *Fishsaverpro* hook descender fixed with a 170 g weight and hooked through their lower jaw. The fish were released on the surface and descended by weight to the same depth they were captured from. When there was slack in the line, indicating that the fish and weight were at the bottom, the line attached to the descender was reeled in. Similarly, fish in the *SeaQualizer* lip clamp descender treatment were clamped on their bottom jaw with the device and a 170 g weight, with a *SeaQualizer* shallow release model and descent setting set to release at 30 feet (9.1 m). Preliminary assessments showed that though the device was set to 9.1 m, the actual release depth varied greatly—always less deep than the intended setting. A second device was tested at this stage to rule out a defective unit, but showed the same result. For this reason, even when fish were being released into depths less than 9.1 m, this setting was used. There were no instances when the clamp did not release the fish. When the line attached to the fish stopped moving at the same speed as the descent device (indicating the clamp had released), the descender was reeled in, and the fish was left with the biologger strap attached for 10 min. Fish in the weighted crate descender treatment were placed in an inverted standard 15 L milk crate (33 cm L × 28 cm W × 33 cm H) fixed with approximately 7 kg of weight, and the crate was lowered with a rope until it reached the bottom, at which point it was pulled back to the surface and the fish was monitored for 10 min.

Lastly, after being held for 30 min, control fish were equipped with the accelerometer strap and released at the surface with no treatment for their symptoms. All fish were released into areas with the same depth (±0.5 m) that they were caught from. Successful descents were determined using depth data from the biologgers, with a successful descent characterized by the fish remaining at depth for the whole 10 min monitoring period, while fish that ascended to and floated at the surface at any point in the 10 min were labelled an unsuccessful descent. Orientation on the bottom was determined for each fish using the *z*-axis of the biologger data and characterized into three groups: correct orientation (ventral side down), incorrect orientation (fish was upside down—ventral side up), or flipping, which was defined as the fish actively flipping between correct and incorrect orientation throughout the monitoring period.

## 2.4. Statistical analyses

### 2.4.1. Barotrauma progression and RAMP scores

All analysis and figure creation were completed with R statistical software version 4.2.2 (R Core Team 2021). The *vglm* command from the *VGAM* package (Yee 2022) was utilized to create generalized ordinal regression models to test ordinal response variables such as initial, final, and delta barotrauma scores and RAMP scores. Predictor variables in each model included depth angled (m), total length (mm), fight time (s), and rate of ascent (m $s^{-1}$). To test the same predictor variables with the occurrence of any particular barotrauma symptom, a generalized linear model (GLM) with a binomial distribution representing the presence or absence of the symptom was used. Barotrauma progression over 30 min was tested with a chi-squared test.

### 2.4.2. Descent and post-release monitoring

To test differences in successful descents between treatments, a chi-squared test was used, followed by Tukey's post-hoc tests to find pairwise differences. Model selection was completed by comparing six binomial GLMs with successful descent as the response variable and with different combinations of predictor variables of barotrauma score, treatment, RAMP score, depth angled, and size of fish.

A chi-squared test was done to test for associations between treatment and orientation at depth, followed by post-hoc tests for pairwise comparisons (including only fish that were successfully descended). Model selection was performed to determine which factors influenced orientation at depth using analysis of variance (ANOVA) models. Models included predictor variables of treatment, equilibrium (RAMP) score, barotrauma score, and total size of fish.

Analysis of ODBA began when the fish was free-swimming, either at the point of release from the device or at the surface for vented fish. ODBA was taken as an average calculated every 30 s and split into two groups for analysis: the first 60 s post-release, and the remaining 9 min. Data was split this way to evaluate both differences between treatments in ODBA immediately when the fish was positioning itself at depth as well as general differences in ODBA once positioned at depth. A model selection was conducted for each time group to determine which factors influenced ODBA. Five linear mixed-effect models were created to model ODBA for the first 60 s, with treatment, fish length, orientation at depth, and fight time as predictor variables. ODBA from minute 2 to 10 was similarly modelled with six linear mixed effect models with treatment, fish length, fight time, orientation at depth, and minutes post-release as predictor variables. All models for both time groups included individual fish as a random effect. The *lmerTest* package (Kunzetsova et al. 2017) was used to extract *p*-values, and Tukey's post-hoc tests were performed for pairwise comparisons between treatments with the *emmeans* package (Lenth 2023) for the highest ranked models.

All model selection was completed using the Aikaike Information Criterion corrected for small sample size (AICc) using the *AICcmodavg* package (Mazerolle 2020). Each model selection included one null model to compare with the other models. Only models with $<2\Delta$ AICc were considered.

# 3. Results

In total, 76 walleye were angled from depths ranging from 7.5–12 m for this study (mean + standard deviation: 9.01 m $\pm$ 0.94 SD), with depth being similar across treatments ($F_{4,71} = 0.331$, $p = 0.856$). The total length of walleye did not significantly differ across treatments ($F_{4,71} = 0.255$, $p = 0.916$), with the average length being 432 $\pm$ 6 mm (315–553 mm).

## 3.1. Barotrauma progression and RAMP scores

Almost all fish in this study were observed with a bloated abdomen (97%), and all were observed with positive buoyancy (100%), while flared gills (10%) and bulging eyes (1%) were less common. Organ protrusion was somewhat in between these extremes—observed in 17% of fish. Of the 13 instances where this symptom was observed, 7 were observed both before and after the 30 min holding period (average depth = 10 $\pm$ 1.4 m), 6 were observed only before the holding period (average depth = 8.8 $\pm$ 0.6 m), and 5 were observed only after the 30 min (average depth = 9.2 $\pm$ 1.4 m).

Capture depth was significantly associated with initial barotrauma symptoms, with greater depth of capture resulting in higher reflex impairment ($z = 2.21$, $p = 0.027$), more barotrauma symptoms ($z = -2.39$, $p = 0.017$), and particularly, higher occurrence of organ protrusion ($p = 0.003$; Fig. 2). Conversely, the final barotrauma score (number of symptoms; $z = -1.44$, $p = 0.151$) and change in barotrauma score over the 30 min ($z = 1.02$, $p = 0.308$) were not associated with depth angled. However, in general, the number of barotrauma symptoms was found to be significantly higher after the 30 min holding period ($X^2(9) = 32.1$, $p < 0.001$). The number of barotrauma symptoms observed initially (reported here or at any time) or RAMP score were not related to fight time ($z = 0.491$, $p = 0.623$), rate of ascent ($z = -0.45$, $p = 0.964$), surface temperature ($z = 0.227$, $p = 0.820$), and fish length ($z = -0.425$, $p = 0.671$).

## 3.2. Descent and post-release monitoring

The proportion of successful descents and orientation of fish at depth is described for each treatment in Table 1. The AICc ranking revealed that the best model predicting whether a fish stayed down or floated up contained solely treatment as a predictor variable (AICc = 59.37, cumulative weight = 0.92) and did not include fish size, RAMP score, barotrauma score, or depth angled (Supplementary Table S1). For this reason, treatments were tested further against the success of descent to determine specific differences between treatments. The control treatment, with no successful descents, had significantly lower success than every other treatment (Crate: $X^2(1) = 21.0$, $p < 0.001$, Hook:

**Fig. 2.** Relationship between depth angled and (A) barotrauma scores initially and after the 30 min retention period and (B) RAMP scores. Barotrauma scores were determined by the number of external symptoms observed in the walleye, with five total possible symptoms evaluated. RAMP scores were determined using six reflex tests and presented as a proportion where 1 is 100% impairment (no reflexes present) and 0 is zero impairment (all reflexes present). The data were slightly jittered to allow for clearer representation of all data points on the graph.

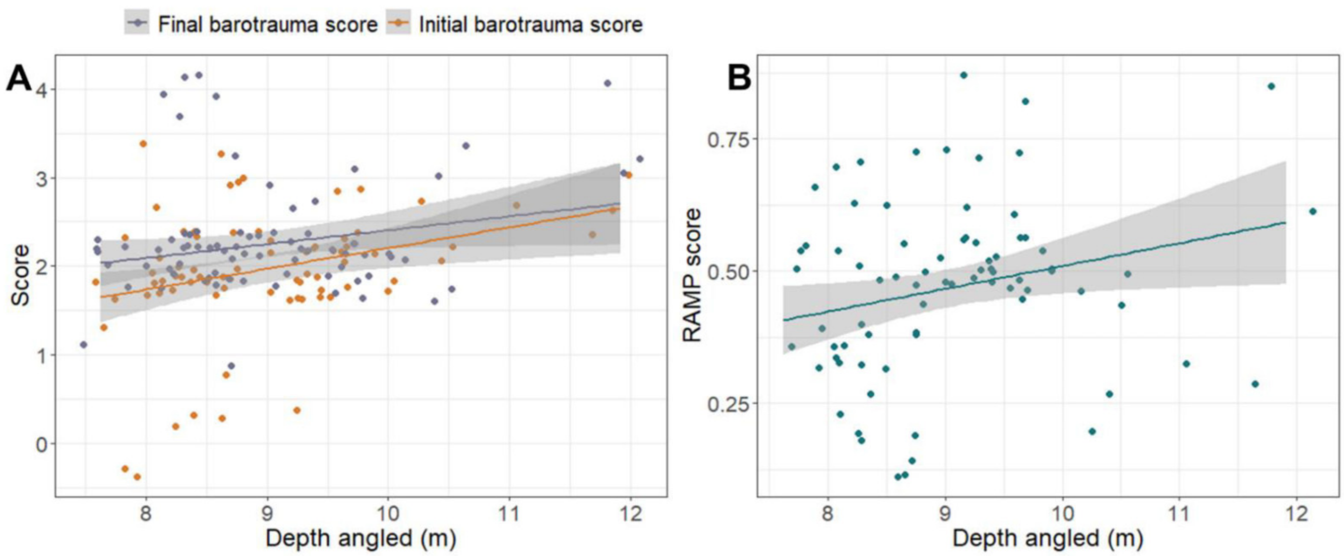



**Table 1.** Sample size, body length, and descent and post-release status of walleye in each barotrauma mitigation treatment and the control.

| | | | | Descent | | Post-release | |
|---|---|---|---|---|---|---|---|
| Treatment | $n$ | Mean length (mm) | Mean depth angled (m) | Returned to depth angled (±0.5 m) | Stayed at depth for monitoring period | Correct equilibrium at depth (of those descended) | Mean ODBA (of those descended) |
| Vent | 15 | 442 ± 55.5 | 8.96 ± 0.98 | 15 (100%) | 15 (100%) | 12 (80%, $n$ = 15) | 0.728 ± 0.47 |
| *Fishsaver pro* hook | 15 | 434 ± 55.8 | 8.86 ± 0.79 | 15 (100%) | 13 (87%) | 5 (38%, $n$ = 13) | 0.589 ± 0.45 |
| Crate | 15 | 429 ± 69.9 | 9.20 ± 1.05 | 15 (100%) | 13 (87%) | 1 (8%, $n$ = 13) | 0.722 ± 0.46 |
| *SeaQualizer* | 18 | 423 ± 49.0 | 8.94 ± 0.77 | 5 (28%) | 9 (50%) | 6 (67%, $n$ = 9) | 0.569 ± 0.36 |
| No treatment | 14 | 434 ± 59.7 | 9.12 ± 1.03 | 0 (0%) | – | – | – |

**Note:** The standard deviation is presented alongside the mean length and depth.

$X^2(1) = 21.03$, $p < 0.001$, *SeaQualizer*: $X^2(1) = 9.16$, $p < 0.001$, Vent: $X^2(1) = 28.0$, $p < 0.001$). The crate, hook, and vent treatment had similar success compared with each other, but all significantly higher than the *SeaQualizer* (Crate: $X^2(1) = 4.95$, $p = 0.026$, Hook: $X^2(1) = 4.95$, $p = 0.026$, Vent: $X^2(1) = 10.3$, $p = 0.001$). While the *SeaQualizer* was set to release fish at 9.1 m, the mean release depth of the 18 fish in this treatment was 6.8 ± 1.7 m (2.4–9.1 m; Fig. 3). This treatment was successful at returning fish to depth and relieving positive buoyancy (keeping fish at depth) only 50% of the time (Table 1).

The orientation of each fish was also assessed with the acceleration data from the biologger. Within all fish that successfully returned to and remained at depth, acceleration data showed that 48% were found to have lost orientation and were upside down during the entire 10 min post-release period. This was distributed among treatments, with 80% of vented fish having the correct orientation, hooks having 38% correct orientation, crates with 8%, and *SeaQualizer* with 67% of fish correctly orientated (Table 1 and Fig. 4). These different treatments were significantly associated with orientation at depth ($X^2(6) = 18.467$, $p = 0.005$). Pairwise comparisons show that the crate treatment had significantly more fish that lost orientation than all other treatments (*SeaQualizer*: $X^2(1) = 7.87$, $p = 0.005$, Vent: $X^2(1) = 15.4$, $p < 0.001$, Hook: $X^2(1) = 4.10$, $p = 0.043$), and venting additionally had higher proportions of correct orientation compared with the hook treatment ($X^2(1) = 4.58$, $p = 0.032$). All other comparisons were not significant. It is important to note that the *SeaQualizer* had a much smaller sample size ($n = 9$) at this stage compared with the other treatments due to failed descents.

Results from the AICc model selection revealed that in addition to treatment affecting the at-depth orientation of fish, the equilibrium score from the RAMP test was also a predictor (best model included both treatment and equilibrium, AICc = 67.8, cumulative weight = 0.97; Supplementary Table S2). No other models were within a ΔAICc of two.

Treatment was the only predictor variable in the highest ranking AICc model predicting ODBA during the first 60 s post-release (AICc = 375.10, cumulative weight = 0.50; Supplementary Table S3), with no other models scoring within a

**Fig. 3.** Post-release depth selection of walleye in each barotrauma relief treatment over 10 min following release. Each individual line represents the movement of one fish. Fish that returned to the surface were categorized as an unsuccessful descent for that technique.

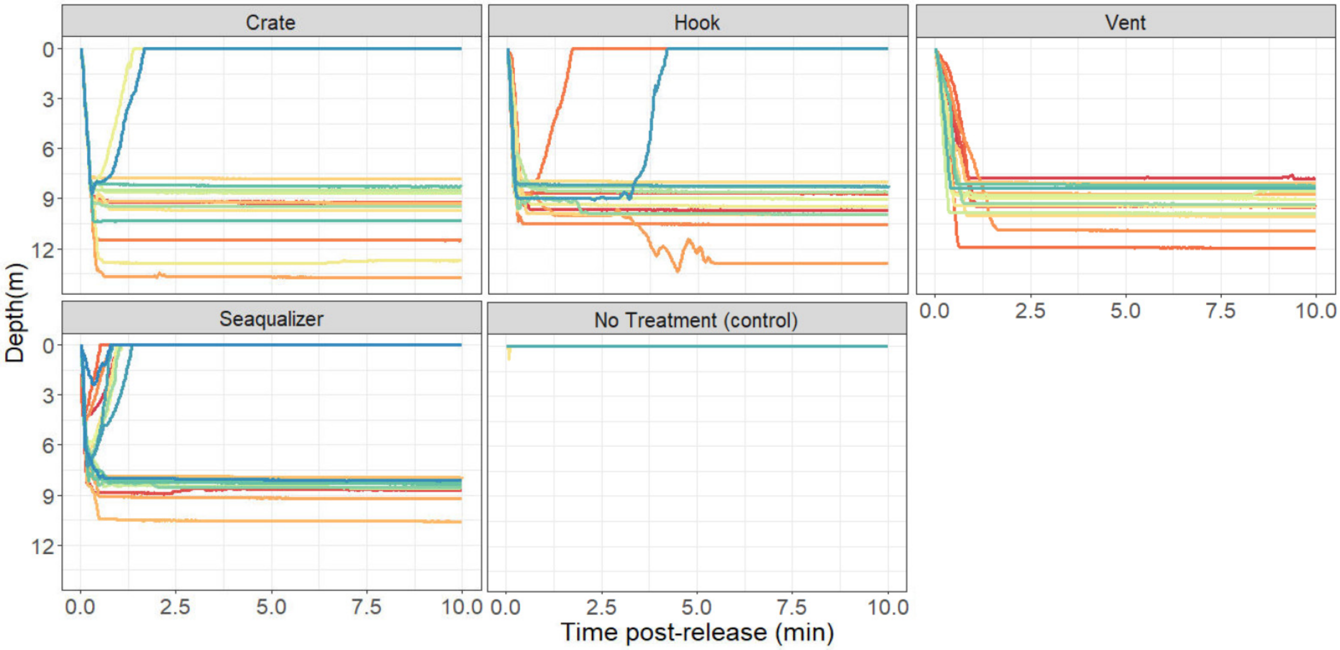
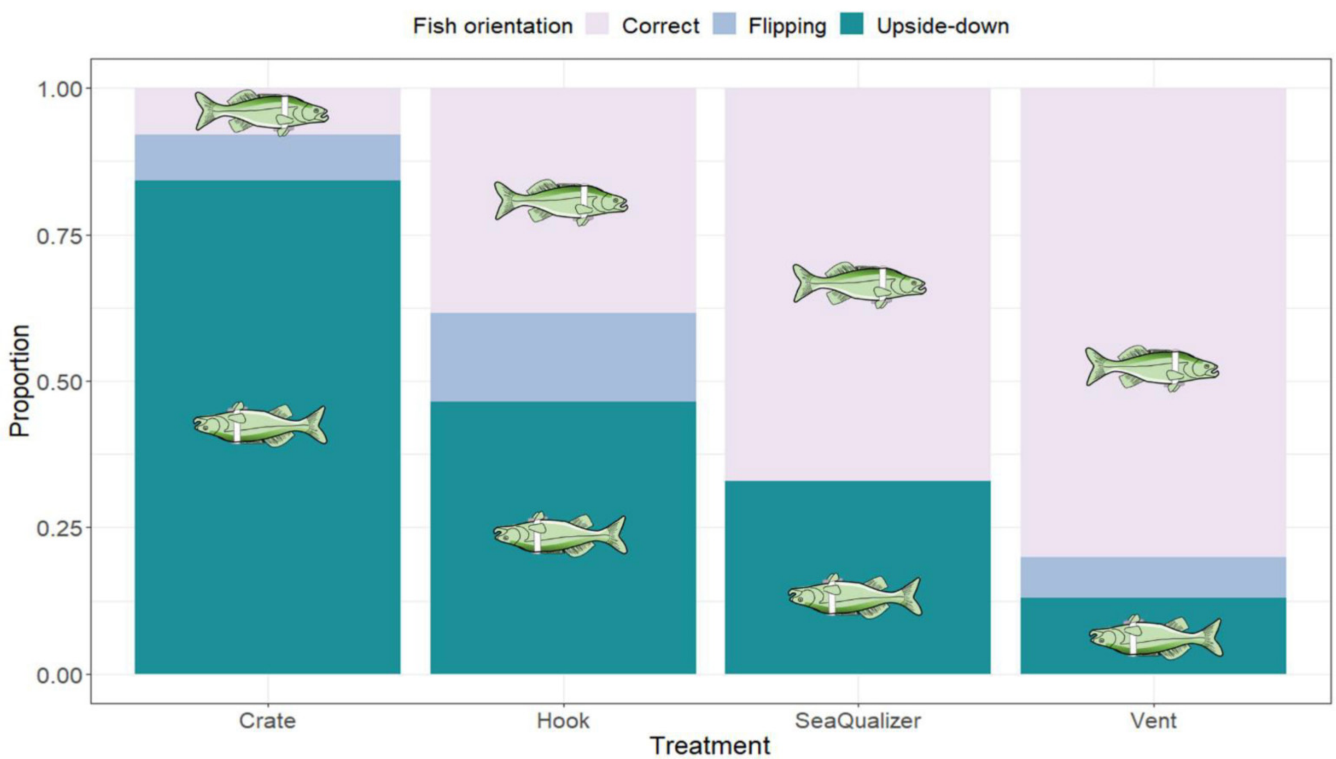
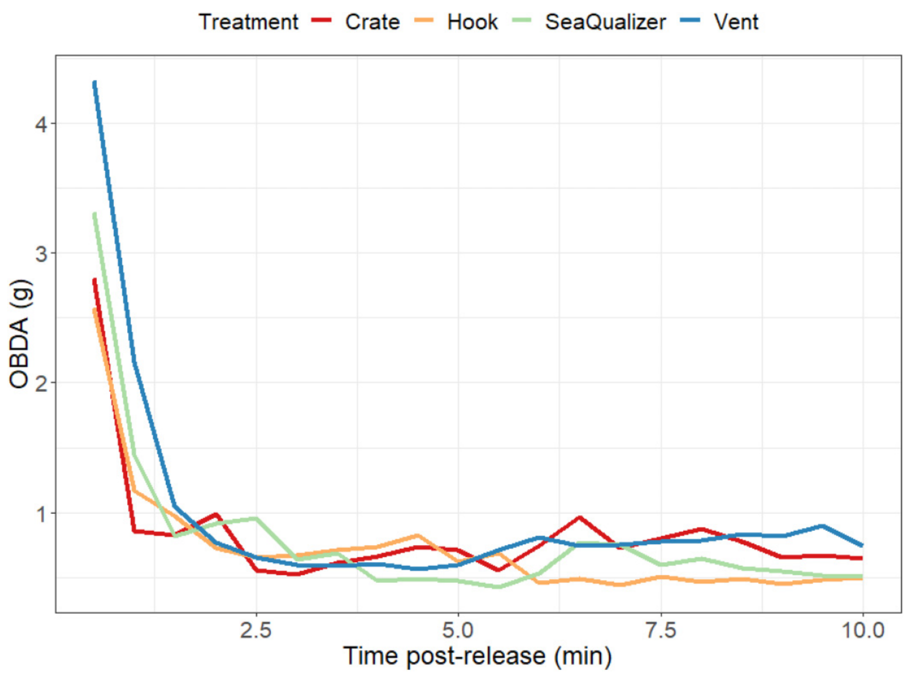



**Fig. 4.** Post-release orientation of Walleye in each barotrauma relief treatment. "Flipping" refers to fish that were alternating between correct and incorrect orientation over the 10 min post-release period.




ΔAICc of two of this model. Tukey's post-hoc tests revealed that vented fish had significantly higher ODBA for the first minute post-release compared to the crate ($p = 0.005$) and hook ($p = 0.0071$) treatments. Model selection for the second time group—2–10 min post-release—showed no models ranking higher than the null model. There was thus no

**Fig. 5.** Average overall dynamic body acceleration (ODBA; calculated as an average every 30 s) of walleye during the 10 min post-release monitoring period in each barotrauma relief treatment. Post-release time for ODBA analysis began when the fish was free swimming, either when the fish was released from a device (crate, hook, and SeaQualizer) or at the time of surface release (vent).






difference after 1 min in the ODBA of descended fish between treatments (Supplementary Table S4 and Fig. 5).

## 4. Discussion

With so many options available for methods of barotrauma relief, it is necessary to determine the effectiveness of different tools and strategies, as well as their effect on the behaviour, movement, and depth-selection of the fish post-release. Using biologgers to monitor post-release behaviour, we were able to assess the orientation of the fish as a metric of barotrauma relief success in free-swimming walleye after four popular barotrauma relief techniques and non-treated fish. We revealed that venting fish was the most effective means of keeping the fish at depth and retaining correct orientation, while the *SeaQualizer* was the least effective at descending. The crate treatment yielded the greatest levels of orientation loss at depth. This study adds to the growing research on species and depth-specific barotrauma relief best practices, especially for freshwater species.

The number and extent of barotrauma symptoms, paired with reflex tests, can be used to determine the severity of barotrauma in a fish (Gravel and Cooke 2008). In this study, we utilized both to assess how depth angled, water temperature, and rate of ascent affected the occurrence and gravity of barotrauma in relatively shallow freshwater. We found no association between surface temperature, fight time, or fish length with the number of barotrauma symptoms observed, though the fish used in this study were of relatively small size, and it is possible there could be a correlation found with a larger size range. We found that depth was the only variable associated with the initial number of barotrauma symptoms, though it was not associated with the number of symptoms after the 30 min retention nor the change in the number of symptoms after this period. This information, paired with the fact that we generally observed significantly more symptoms after retention, suggests that external barotrauma progression is similar across all severity levels. Therefore, regardless of the initial number of symptoms, which does vary with depth, new barotrauma symptoms will appear and worsen at the same rate when held at surface pressure. Jarvis and Lowe (2008) similarly examined the effect of retention on the short-term mortality of nearshore and shelf rockfish (Scorpaenida, *Sebastes* spp.) with barotrauma after rapid recompression. They found that retention at the surface was the most significant predictor of short-term survival (not depth or fish size), with survival peaking at 83% if released within 2 min (Jarvis and Lowe 2008). At 30 min, the same amount of time that fish were held in this study, they observed about 50% mortality after 2 days. And while mortality was not included in this study, we found a similar proportion (48%) of fish were observed within 10 min post-release to lose orientation at depth, a widely used predictor of mortality (Davis 2007; Davis 2010). Though it is likely that there are species-specific and depth-specific differences in reactions to surface retention with barotrauma, it is possible that there is a general positive relationship between barotrauma mortality and retention time at the surface, as found by Jarvis and Lowe (2008) in rockfish. Additionally, this study and others found that this behaviour impairment was only associated with higher external barotrauma symptoms in some fish species and not in others (Jarvis and Lowe 2008; Louison et al. 2023). This adds to the growing sentiment in barotrauma research that reactions are highly species-specific, as we also did not observe any association between post-release orientation at depth and the number of barotrauma symptoms observed. In contrast, we found an association with relief technique.

Barotrauma relief techniques are necessary to employ in C&R fishing when releasing fish with visible barotrauma that are unable to return to depth by themselves. Our study found that venting was the only technique that returned fish to depth 100% of the time, with the other techniques sometimes resulting in the fish floating back up to the surface. Further, we found that though vented fish generally had higher locomotor activity in the first-minute post-release (swimming down to depth), movements over the rest of the monitoring period were similar between treatments. While our study only monitored fish 10 min post-release, we can refer to other studies that have examined released fish with barotrauma over the long term. Nguyen et al. (2009) monitored the movements of vented smallmouth bass over four days to determine differences in behaviour from controls without barotrauma. They found no significant differences between the movements of vented fish and controls, but vented fish moved more than fish with untreated barotrauma (Nguyen et al. 2009). Conversely, Curtis et al. (2015) reported that descended red snapper were one and a half times more likely to survive compared with a vented treatment. The confusion around the effectiveness of venting is further muddled by the technique and experience of the individual venting the fish. While many anglers employing this technique are ill-informed about the correct venting location (Scyphers et al. 2013), the exact location can also vary between species. Venting fish incorrectly can result in extensive damage to internal organs, infection, and mortality (Haggarty 2019). It is for this reason that many authorities promote the use of descending devices, such as the pressure-release *SeaQualizer* clamp, over the practice of venting.

Always set at 9.1 m (30 ft setting), it is unclear why the *SeaQualizer* was so variable in its release depths here when it has shown positive results in other studies (e.g., Drumhiller et al. 2014; Runde and Buckel 2018; Bellquist et al. 2019; Wegner et al. 2021), albeit all in deeper marine environments. It is possible that the device simply does not work as reliably in shallower and fresh waters, where there is a smaller margin for error in release depth. In fact, every rapid recompression device in this study failed to keep fish at depth at least 13% of the time, resulting in fish floating at the surface. While these fish can be redescended, floating fish can easily be missed by an angler who has assumed the fish was successfully descended. Further, we witnessed frequent predation attempts on floating fish by various birds, including herring gulls (*Larus argentatus*), American white pelicans (*Pelecanus erythrorhynchos*), and bald eagles (*Haliaeetus leucocephalus*). These attempts would have been lethal without the intervention of the researchers. Thus, there is a trade-off where venting may be superior at keeping fish at depth but difficult to perform correctly without training, and descending (rapid recompression) is simpler to perform but less dependable at the release.

An additional important metric used in this study to examine behavioural differences after different relief techniques was post-release orientation at depth. Orientation, along with other reflexes, is used as a mortality predictor in RAMP assessments to determine the effect of stressors in fisheries research (Davis 2010). To our knowledge, this study is the first to examine post-release orientation in the field using acceleration sensors. Using video-equipped cages, both Hannah and Matteson (2007) and Rankin et al. (2017) observed behaviour after rapid recompression in Pacific rockfish (*Sebastes* spp.) and yelloweye rockfish (*Sebastes ruberrimus*), respectively. Both studies found approximately half of the fish were unable to vertically orient, observed in depths of 40–99 m and up to 200 m. Our study is the first to observe this in freshwater and in depths as shallow as 7.8 m. Additionally, this study is the first to observe a significant effect of the relief technique on orientation at depth. Venting in this study showed the highest proportion of correctly oriented fish, with the crate treatment showing significantly lower proportions than every other treatment. It is unclear exactly why these treatments differed in this respect. However, it is possible that the use of a crate or cage to descend a fish could aggravate existing disorientation, as the fish is forced to move laterally down in the water column (pushed down from above). To that end, both other studies witnessing this loss of orientation used a cage to descend fish (Hannah and Matteson 2007; Rankin et al. 2017). On the other hand, descending devices such as the *SeaQualizer* and *Fishsaverpro* hook return fish to depth head-first with water flowing through their gills (Runde and Buckel 2018), which could jump-start recovery (Ferguson and Tufts 1992). Some fish descended with these devices showed loss of equilibrium regardless, albeit in lower proportions than observed with the create. While we did not track fish over long periods and are unsure of the ultimate fate of fish that were left on the lake floor without equilibrium, there are concerns for those fish. Notably, trying to recover while lying on silt-covered bottoms could impede ventilation and potentially smother sensitive gill tissue with fine sediment. Smaller bodied fish may also be subject to predation depending on the predator community (e.g., diving birds, fish, turtles, and crayfish).

Our study adds to the small but growing research on barotrauma relief in relatively shallow and freshwater-residing game species (Eberts and Somers 2017; Louison et al. 2023). While the best way to avoid mortality and sublethal effects from barotrauma is to abstain from deep-water fishing, there must be guidelines on best practices when it inevitably occurs. Anglers should also keep in mind the possibility of barotrauma in shallower depths than perhaps expected (as shallow as 7.5 m) and be prepared for mitigation at these depths. From our results, we suggest venting walleye is the best technique to (1) ensure positively buoyancy will be eliminated and the fish do not float back to the surface, and (2) minimize the amount of immediate behavioural impairments to fish post-release. However, venting should only be attempted by individuals informed of the correct needle placement and technique. We suggest anglers without this experience descend fish using a device and not a crate or cage as an alternative to venting. Doing nothing for walleye exhibiting signs of barotrauma (i.e., releasing fish at the surface) seems to be a poor choice given the high levels of predation by birds. It is important to emphasize that this study only measured very short-term behavioural differences between different barotrauma relief techniques and requires further research to make any longer term conclusions about the fate of these fish. Additionally, future research is needed to further investigate the link between orientation loss and relief techniques in other species, as well as species-specific guidelines for weight choices in descending tools.

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### Data availability

Data generated during this study are available from the corresponding author upon reasonable request.

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## Supplementary material

Supplementary data are available with the article at https://doi.org/10.1139/cjfas-2023-0141.

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