Walleye Responses to Barotrauma Relief Treatments for Catch-and-Release Angling: Short-Term Changes to Condition and Behavior

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Abstract

Barotrauma causes stress and impairment in fish and can cause mortality after catch and release. Relief of barotrauma symptoms is necessary to reduce mortality, but we currently know little about sublethal effects associated with relief methods. Here, we assess the condition and behavior of tournament-caught Walleye *Sander vitreus* with barotrauma by using three popular relief methods: 1) swim bladder venting, 2) deep-water release (descending), and 3) livewell reorientation with fin weights. In a short-term ex situ experiment, 50% of untreated fish with barotrauma did not recover sufficiently to be released after 20 h. Fin weighing immediately improved condition by enabling fish to regain correct orientation; however, only 53% of fin-weighted fish recovered sufficiently to be released. All vented fish were negatively buoyant, but 73% were releasable after the holding period. In a concurrent in situ study, acoustic telemetry showed that Walleye without barotrauma (controls) made variable postrelease movements (total distance: 5.1–27.6 km), descended fish behaved similarly to controls (4.7–28.6 km), and vented fish made the shortest movements (2.6–16.7 km). However, there were no statistically significant differences in distance metrics among groups. Control and descended fish used larger areas and volumes of the lake than vented fish. Descended fish also used significantly deeper depths than vented fish, and control fish were intermediate in the depth used. Telemetry did not indicate mortality of any fish in the in situ study. Our data suggest that without treatment, mortality of Walleye with barotrauma could be as high as 50%. Fin weighting is not an effective catch-and-release aid for Walleye with moderate-to-severe barotrauma, and swim bladder venting may alter short-term, postrelease movements and habitat use. The consequences of these short-term changes to Walleye behavior from a fisheries management perspective are unclear. Eliminating catch-and-release angling in deep water is the best means of managing barotrauma in Walleye. If deep-water angling cannot be avoided, we recommend noninvasive descending over venting.

Keywords: barotrauma; venting; descending; fin weights; condition; behavior; telemetry

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Introduction

Barotrauma is a widespread issue for recreational catch-and-release (CAR) fisheries. The rapid pressure reduction that occurs when a fish is angled in deep water and brought to the surface can result in a suite of physiological impacts, including swim bladder overexpansion, organ eversion, hemorrhaging, and eye bulging (Bartholomew and Bohnsack 2005; Pribyl et al. 2009; Schreer et al. 2009; Rogers et al. 2011). The severity of injuries ranges from mild decompression (e.g., Nguyen et al. 2009) to catastrophic decompression wherein the swim bladder ruptures (Rummer and Bennett 2005). The positive buoyancy and loss of equilibrium associated
with barotrauma are immediate issues for CAR because fish are unable to submerge; consequently, they are vulnerable to delayed mortality from exposure, stress, and predation (Bruesewitz et al. 1993; Keniry et al. 1996; Gravel and Cooke 2008; Schreer et al. 2009; Rudershausen et al. 2014; Curtis et al. 2015). Fish with barotrauma are often unsuitable for release without intervention; however, whether they are released or harvested depends on regulations combined with angler discretion. In addition, anglers in competitive fishing events (CFEs) may release fish with barotrauma during culling (Nguyen et al. 2009), or because of weight penalties for nonreleasable fish. Regardless of the circumstances, anglers and CFE staff often require specific instructions on how to handle fish with barotrauma (e.g., harvest, release unaided, or release with aid).

Relieving major symptoms before release, or releasing with aid, is the prevailing strategy for releasing fish affected by barotrauma. Two of the most common methods of barotrauma symptom relief are swim bladder venting and deep-water release. Venting, often called fizzing, is puncture of the swim bladder with a needle to expel gases. The deflated swim bladder eliminates positive buoyancy and equilibrium issues for affected fish, enabling them to submerge upon release (Collins et al. 1999; St. John and Syers 2005; Sumpton et al. 2010). Deep-water release (hereafter descending) involves rapidly returning fish to a depth of neutral buoyancy via temporary attachment of a weighted device. The return to depth recompresses gases in the swim bladder and other tissues, eliminating buoyancy and equilibrium issues (Bartholomew and Bohnsack 2005; Roach et al. 2011; Ferter et al. 2015). In addition, at CFEs in North America, anglers often practice fin weighting, in which they attach weighted metal clamps to the pectoral and pelvic fins of fish held in livewells. The weights counteract positive buoyancy and equilibrium loss by turning the fish upright (e.g., http://www.flipclipfishing.com/). All three barotrauma relief methods provide attractive alternatives to simply harvesting fish or releasing them without aid. However, the effectiveness of venting, descending, and fin weighting is unclear, especially in freshwater species (Eberts and Somers 2017).

To date, the majority of barotrauma relief studies have assessed the effectiveness of venting and descending on survival outcomes. Based largely on marine studies, previous reviews show that some sort of barotrauma relief is likely beneficial, but clear evidence supporting a specific method is lacking (Wild 2009; Eberts and Somers 2017). This lack of evidence may be partly because of challenges with using short-term survival as a comparative endpoint (see Pollock and Pine 2007; Eberts and Somers 2017). Venting is an invasive technique that creates an additional wound at the puncture site, perforates the swim bladder, and potentially damages other organs or causes infection (Kerr 2001; Nguyen et al. 2009; Scyphers et al. 2013). In addition, venting requires species-specific landmarking for needle insertion and only relieves the swim bladder; it does not address gas expansion in other areas of the body. In contrast, descending is broadly applicable across many species by using an almost identical protocol, and it is a noninvasive method addressing whole-body symptoms (Bartholomew and Bohnsack 2005; Drumhiller et al. 2014; Curtis et al. 2015). Descending is therefore an attractive alternative to venting, but few studies have adequately assessed the two approaches in parallel (see Eberts and Somers 2017). In addition, no studies that we are aware of have tested the value of fin weighting, also a noninvasive technique, for relieving barotrauma.

Examining changes to sublethal endpoints (e.g., condition, behavior) that generate a range of responses following barotrauma relief may be a more sensitive approach than studying mortality. To be considered effective, relief methods should quickly reduce or eliminate barotrauma symptoms and enable fish to resume species-typical behavior as soon as possible. Immediate postrelief assessments of condition (e.g., reflex response, orientation) show improved likelihood for fish treated for barotrauma to avoid harmful exposure after release (e.g., Bruesewitz et al. 1993; Sumpton et al. 2010; Hochhalter and Reed 2011; Butcher et al. 2012; Kerwath et al. 2013; Drumhiller et al. 2014; Curtis et al. 2015). Biotelemetry assessments of postrelease movement and habitat use in situ would inform immediate and delayed behavioral changes (reviewed in Donaldson et al. 2008), but this approach has been underused for understanding barotrauma relief. Only a few studies have assessed postrelease behavior of treated fish (e.g., Nguyen et al. 2009; Butcher et al. 2013; Curtis et al. 2015; Rankin et al. 2017), and the findings vary. For example, Nguyen et al. (2009) found that ventil Smallmouth Bass Micropterus dolomieu moved farther than unvented fish after release, which suggested that venting facilitates movement. In contrast, Butcher et al. (2013) found no difference in the postrelease movements of vented, descended, or control Mulloway Argyrosomus japonicus, but fish treated for barotrauma used much shallower depths than fish not treated for barotrauma, regardless of method. Overall, insights into sublethal changes caused by barotrauma relief are limited, especially for freshwater species.

In this study, we examined the condition and behavior of CFE-angled Walleye Sander vitreus with barotrauma after different relief treatments. Walleye are the most important recreational freshwater fish species in Canada (DFO 2010) and are widely known to experience barotrauma (Schreer et al. 2009; this study); however, there has been no barotrauma relief research published on Walleye to date (Eberts and Somers 2017). Accordingly, we conducted two concurrent experiments at a CFE in Saskatchewan, Canada, where barotrauma is a common problem: 1) a short-term (~20-h) ex situ experiment in which we held Walleye in tanks and assessed their condition before and after being treated for barotrauma; and 2) an in situ telemetry study (7+ d) in which we assessed dispersal behavior and depth and space uses by Walleye after barotrauma relief treatment. Our overall objective was to compare Walleye condition and behavior after barotrauma relief and provide an
evaluation of sublethal effects to help determine the best technique to use.

**Methods**

**Study site**

This study took place in 2016 at the Last Mountain Fall Walleye Classic, CAR CFE on Last Mountain Lake, Saskatchewan, Canada (Figure 1; 51°5′32.522″N, −105°12′2.929″W). Last Mountain Lake is a large (surface area: 215 km²), moderately deep (mean: 7.5 m, maximum: 31 m), polymictic prairie lake located in southern Saskatchewan. It is regionally known for its fishing opportunities for Walleye and Northern Pike *Esox lucius* and hosts several CFEs annually. The event we studied is held out of Rowan’s Ravine Provincial Park on the second weekend in September each year (September 10 and 11; Figure 1). The CFE hosts ~150 teams of two anglers that fish for 2 d and weigh in their best five fish each day. Water temperature can be quite warm at this time of year (surface water temperature: 18.3°C in this study), and CFE boundaries span a large area 12 km north and 16 km south of the weigh station, encompassing the deepest portion of the lake. Walleye are likely seeking cooler water in deeper locations, so anglers at this CFE routinely weigh-in fish caught at depths from 10 to 15 m that have barotrauma. The location of the weigh station for the CFE was on land in a marina; however, after being weighed, CFE staff transported all fish in livewells to one of two offshore release sites (Figure 1). Fish without barotrauma and fish that have been vented can submerge on their own, so we released these fish at the surface at an area that was 5 m deep (surface release). We took fish that we descended to a spot ~200 m away that was 11 m deep (deep-water release). In 2016, tournament staff established a format for release as a systematic way to release fish with barotrauma and to release all fish outside of the busy, shallow marina (also too shallow for descending). The province of Saskatchewan requires for CFE licenses that >90% of fish be released unharmed (Government of Saskatchewan 2017a); thus, there is considerable interest from both anglers and CFE staff to successfully manage barotrauma.

**Study design**

Our study consisted of two separate experiments that addressed different objectives. The first experiment was an ex situ study in holding tanks that examined change in condition (stress, swimming behavior/buoyancy) of Walleye with barotrauma that were left untreated (*n* = 14), fin weighted (*n* = 15), or vented (*n* = 15). Our objective was to determine whether condition improved over time (20 h) and after treatment and to determine whether fish could be released. The second experiment was an in situ acoustic telemetry study that examined postrelease movement and depth use by Walleye in three groups: 1) control, with no barotrauma or relief treatment (*n* = 6); 2) descended to relieve barotrauma (*n* = 6); and 3) vented to relieve barotrauma (*n* = 6). Our objective was to determine whether barotrauma relief method affected postrelease behavior. We performed fin weighing in the ex situ study only and descending in the in situ study only.

**Fish selection**

We selected Walleye for experiments during weigh-in procedures. During the CFE, anglers transferred Walleye from livewells into dry tubs (without water) for weighing. We moved all fish temporarily from the scales to an oxygenated holding tank (~1,000 L of surface lake water) for observation by CFE staff. We intercepted both apparently normal fish and those with obvious barotrauma from the CFE observation tank. We selected individuals with barotrauma if they exhibited abdominal bloating and equilibrium loss. Importantly, the fish we selected with barotrauma were highly impaired and would have been unsuitable for live release without intervention. Individuals for the telemetry control group showed no signs of barotrauma and exhibited neutral buoyancy (i.e., they moved throughout the water column without obvious floating or sinking). Also, because our study aimed to examine relief of barotrauma-related impairment, rather than other stressors, we selected fish that appeared otherwise vigorous (i.e.,

**Figure 1.** Location of the Walleye *Sander vitreus* competitive fishing event studied in Rowan’s Ravine Provincial Park (inset) on Last Mountain Lake in September 2016. Last Mountain Lake is situated in the southern region of Saskatchewan, Canada. Inset: We selected Walleye for this study at the weigh station in a small marina. An ex situ barotrauma relief experiment took place on shore directly behind the weigh station. For the in situ telemetry study, we released Walleye at either the 5-m “normal” surface release site (control and vented treatment groups) or at the 11-m deep-water release site (descended treatment group).
ventilating, fin and body movement, no apparent loss of color). After selection, we placed fish in a holding tank (1 \( \times \) 0.5 \( \times \) 0.5 m, 120 L) with flowthrough lake surface water to be formally scored and processed for our experiments. We selected fish randomly for each experiment; however, we selected those with a minimum mass of 1.8 kg for the telemetry study to minimize the percentage of body mass (maximum: 0.7%) represented by the transmitter.

**Fish condition scoring**

We measured the total length and mass of each fish and then assigned the fish three different scores for condition based on barotrauma symptoms, reflexes, and swimming behavior. Summing the presence or absence (presence = 1, absence = 0) of each of the following symptoms provided a score of barotrauma severity: 1) bloated abdomen, 2) bulging eye(s), 3) oral organ eversion, 4) anal organ eversion, and 5) equilibrium loss. We scored fish stress using a set of reflex impairment tests modified from Davis (2010) and then summed the presence or absence (presence = 1, absence = 0) of the following reflexes and conditions: 1) body flex upon grasping, 2) dorsal fin flare upon grasping, 3) operculum clamp after manual opening, 4) ability to orientate in 3 s after being turned on side (orientation), and 5) vestibular-ocular response. Lastly, we scored swimming behavior on a scale of 0 to 5 according to methods used by Gingerich et al. (2007): 0, swimming normally; 1, swimming normally but with signs of fatigue; 2, swimming rapidly, randomly, or erratically; 3, resting on bottom; 4, partial equilibrium loss; or 5, complete equilibrium loss. Scoring provided initial (prerelief) measures of fish condition for comparison to after barotrauma relief in the ex situ study and enabled us to examine potential influences of fish condition on behavior in the in situ study.

**Ex situ condition study**

**Barotrauma relief treatment.** All fish in the ex situ study were affected by barotrauma; the control group in this case refers to fish affected by barotrauma that received no relief treatment. After pretreatment scoring, we tagged fish with a unique T-Bar anchor tag (Floy Tag Manufacturing Inc., Seattle, WA) behind the first dorsal fin. We divided fish into three groups: 1) untreated (control), 2) fin weighted, and 3) vented. For fin-weighted fish, we clamped one to three 1-oz (28-g) fin weights (FinClip LLC, Bulger, PA) to the pectoral and anal fin, depending on the size of the fish. We used the minimum number of clips necessary to enable fish to regain equilibrium and submerge. For vented fish, we capitalized on a protocol already in use at this CFE. An experienced venter inserted a sterile 16-gauge hypodermic needle through the ventral surface of the fish approximately 5 cm anterior and 2.5 cm lateral to the cloaca. The needle went through the abdominal wall into the swim bladder at a 45° angle, and the venter held the fish underwater while it vented so that we could see bubbles escaping from the needle. The venter released enough air to eliminate positive buoyancy and enable fish to regain equilibrium and vented several fish twice at the same location if they subsequently lost equilibrium after the first attempt.

**Condition analyses.** After treatment, fish were held overnight in 1,700-L tanks filled with approximately 1,000 L of lake water. The tanks were housed in an enclosed utility trailer located near the weigh station (Figure 1). Tank water was constantly circulated, and the temperature was held at 16°C. Aeration of the water was by a combination of air stones and disruption of the surface. A maximum of 13 fish was kept in each tank to prevent crowding, and treatment groups were spread between two identical tanks. The following morning (experiment repeated over 2 d, approximately 20 h posttreatment [minimum: 16 h, maximum: 23 h]), we rescored each fish for swimming behavior, collected each from the tank with a rubberized net, and then rescored the fish for stress in a smaller tub (150 L). We scored individuals in the fin-weighted group after we removed the fin weights. We still scored fish that appeared dead for reflex responses; however, we omitted these fish from the swimming behavior analysis. After completion of scoring, we attempted to live release all fish in the marina; we recorded fish as “released” if they appeared to hold orientation and stay submerged or as “failed release” if they subsequently floated to the surface after release and could not resubmerge.

We tested for differences in fish length and mass across the three treatment groups by using 1-way analysis of variance (ANOVA). We compared pretreatment barotrauma and stress scores across the three treatment groups by using a nonparametric Kruskal–Wallis test (K-W). We compared pre- and posttreatment swim and stress scores statistically within each treatment group by using a Wilcoxon signed-rank test to determine whether scores improved. We evaluated conformation to underlying assumptions for all tests and conducted all analyses in SPSS 20 (IBM Corporation 2010) using an \( \alpha \) value of 0.05.

**In situ telemetry study**

**Tag application, treatment, and tracking.** After pretreatment scoring, we outfitted fish with an external, pressure-sensitive acoustic transmitter with a battery life of either 6–11 d (7 tags) or 142 d (11 tags) (V13P-1x, Vemco, Bedford, Nova Scotia, Canada). We chose a rapid external attachment approach for transmitters to avoid the additional stress of anesthesia and surgery, and because swim bladder expansion caused by barotrauma makes abdominal insertion of transmitters difficult. We first tagged fish with a unique cinch-up tag (FT-4; Floy Tag Manufacturing Inc.) behind the first dorsal fin. We attached acoustic transmitters to the tag loop either directly through the transmitter cap (for 142-d transmitters) or with PDSII 2–0 violet monofilament dissolvable suture (Ethicon, San Lorenzo, Puerto Rico) for 6-d
transmitters such that transmitters would fall off after the monitoring period (modified from Kaintz and Bettoli 2010). The tagging and transmitter attachment procedure took approximately 2 min per fish, and we submerged fish in water the entire period. The smallest fish in our study was 1,810 g; thus, the mass of the transmitter (13 g) was at maximum 0.7% of body mass for that fish.

After tagging them, we released the fish without barotrauma in the control group at the surface release site (total depth: 5 m) along with other fish from the CFE (Figure 1). We randomly assigned fish with barotrauma to vented or descended treatment groups. Fish in the vented group had air released from the swim bladder with a hypodermic needle as described above and we then released them at the surface release site. We rapidly lowered fish in the descended group to a depth of ~11 m at the deep-water release site (Figure 1) via shot-line release. In brief, shot-line release devices consisted of a weighted (230-g) metal hook attached via 18 m of spooled line to a small marker buoy (Figure S1, Supplemental Material). We descended fish by placing the weighted hook on the upper lip through the membrane between the lip and the jaw, tossing the marker buoy overboard, and letting the fish sink passively as a result of the attached weight. When the weight reached the bottom, we released the fish by giving the line a sharp pull upward, thereby dislodging the hook (see schematic in Bartholomew and Bohnsack 2005). The marker buoy system allowed several fish to be released in rapid succession because the descender could move on to descending the next fish while the previous fish sank. The buoys also ensured that the line descended unencumbered (i.e., line unwinds from the buoy freely without snagging on the boat or equipment), thereby avoiding premature release of fish.

After release, we manually tracked fish and relocated them daily by boat using a VR100 receiver and both directional and omnidirectional hydrophones (Vemco). We identified and recorded fish locations and depth (depth of fish, not depth of water column) when acoustic signals had high and approximately equal signal strength (60–100 dB) in all four cardinal directions. We tracked all 18 fish for 7 d postrelease (September 11–17) and then attempted to relocate the subset of fish with longer lasting transmitters (n = 11: four descended, four vented, three control fish) at 17 d post-CFE (September 27) and 42 d post-CFE (October 21). We tested for differences in fish length and mass across the three treatment groups using 1-way ANOVA following testing for underlying assumptions. We compared pretreatment barotrauma, stress, and swim scores across the three treatment groups by using a K-W test, including Bonferroni-corrected pairwise comparisons. We conducted all tests in SPSS 20 (IBM Corporation 2010) using an α value of 0.05.

Postrelease behavior analyses. We inferred movement paths for each fish from the daily location data, and we calculated several postrelease movement metrics: 1) maximum number of days to leave the release area, 2) total distance moved, 3) total displacement, 4) daily distance as distance per day, and 5) straightness index. The release area was a 500-m radius around the release site (adapted from Brown et al. 2015). We used the straightness index to describe the efficiency of reaching the final destination of the location 7 d postrelease (Benhamou 2004). We did not calculate metrics 2, 4, and 5 if fish had two or more consecutive days of missing data. We determined all values using path metrics in Google Earth 7.1.7.2602 (Google Inc. 2016). We reconstructed the paths using the shortest straight-line distance over water, and around land features (e.g., shoreline points) when necessary; thus, all distances are minima. We report movement metrics as means and standard deviations. We compared movement metrics statistically between groups by using 1-way ANOVA as described above. We constructed depth profiles for each fish over the 7-d tracking period to assess depth use patterns. We compared mean depth use across treatment groups and displayed the values with standard error.

We compared the space use (area and volume) of each treatment group (all fish combined in each group) using two-dimensional (2D) and three-dimensional (3D) kernel densities (Simpfendorfer et al. 2012; Tracey et al. 2014; Udyawer et al. 2015). We calculated kernel densities for each treatment in the R 1.10.6 package ‘ks’ (Duong 2017; R Core Development Team 2017) using the code and protocol provided in Simpfendorfer et al. (2012). From 2D kernel densities we calculated the surface area used at 50 and 95% confidence contours and visualized these contours as maps made in ArcGIS 10.4 (ESRI 2016). From 3D kernel densities we calculated the volume used at 50 and 95% confidence contours and visualized kernels in a 3D plot by using the R 0.98.1 package ‘rgl’ (Adler et al. 2017; R Core Development Team 2018). Lastly, we jackknifed the 2D and 3D kernel density estimates and 1) examined whether confidence intervals of jackknifed estimates overlapped and 2) calculated the probability that the area/volume estimates of one treatment group were larger or smaller than another. We based probability calculations on the frequency of values being larger or smaller across all 36 possible comparisons (e.g., six descended area estimates vs. six control area estimates). This permutation approach reduces the potential influence of individual fish on the observed outcome.

Results

Ex situ condition study

Preliminary condition. In total, we included 44 Walleye (14 untreated, 15 fin weighted, 15 vented) in the ex situ condition study (Table 1). There was no significant difference in the length (ANOVA: F2,43 = 0.524; P = 0.596) or mass (ANOVA: F2,43 = 0.380; P = 0.686) of fish among groups. There was little variation in barotrauma severity
in selected fish; all individuals had bloated abdomens and exhibited equilibrium loss, but no other external symptoms. As a result, fish in all treatment groups had identical barotrauma scores (Table 1). All initial swim scores were either 4 (partial equilibrium loss) or 5 (full equilibrium loss; Table 1) and did not vary significantly among groups (K-W: 0.436). Descriptive data for each fish in the ex situ study are provided in Table S1 (Supplemental Material).

Postrelief condition. Postrelief swim and stress scores generally improved compared to initial scores for all treatment groups (Table 1). Wilcoxon signed-rank tests indicated that swim scores improved significantly during the holding period for all groups of fish: untreated (z = –2.585, P = 0.010), fin weighted (z = –3.225, P = 0.001), and vented (z = –3.169, P = 0.002). These improvements remained significant following Bonferroni correction for multiple comparisons (α = 0.0167). At reassessment the fish in the untreated and fin-weighted groups had swim scores across the range of possible values (Figures 2a and 2b). In contrast, the majority (80%) of fish in the vented group exhibited a score of 3, or “resting on the bottom,” because of negative buoyancy (Figure 2c).

Reflex scores for fish in the untreated group tended to improve over time but showed wide variance and no significant change overall (z = 1.833, P = 0.067; Figure 3). For the two treatment groups that had barotrauma relief, reflex scores improved more consistently: fin-weighted (z = 2.295, P = 0.022) and vented (z = 2.052, P = 0.040; Figure 3). These differences, however, were not significant following Bonferroni correction (α = 0.0167). Interestingly, the individual test for the orientation reflex improved consistently; many fish in all treatment groups (including untreated) regained the capacity to right themselves during the holding period (Figure 4). Some fish in the fin-weighted and vented treatment groups also showed improvements in body flex and fin flare reflexes (Figure 4).

After the overnight holding period, we found 3 (20%) of 15 vented fish and 1 (7%) of 15 fin-weighted fish dead (Table 1). In addition, 3 (21%) of 14 untreated fish and 1 (7%) of 15 fin-weighted fish were moribund by the end of the experiment. Thus, we attempted to live release 11 of 14 untreated fish, 12 of 15 vented fish, and 13 of 15 fin-weighted fish in the marina area after our assessment period. All of the released fish appeared to swim away normally (maintained orientation, submerged) and would likely have been considered successful releases by anglers. However, after release, we found 4 (36%) of 11 untreated fish, 5 (38%) of 13 fin-weighted fish, and 1 (8%) of 12 vented fish floating on the lake surface; we had to retrieve and euthanize them (failed release; Table 1). Detailed scoring and fish fate details are available in Table S1. Ultimately, after our ex situ experiment, 7 (50%) of 14 untreated fish, 7 (47%) of 15 fin-weighted fish, and 4 (27%) of 15 vented fish were not in suitable condition for live release.

In situ telemetry study

Prerelief condition. We included 18 Walleye (six control, six descended, six vented) in the in situ telemetry study (Table 1). There was no significant difference in the length (ANOVA: F2,16 = 0.574; P = 0.575) or mass (ANOVA: F2,16 = 0.483; P = 0.626) of fish among groups (Table 1). Similar to the ex situ study, all fish in the vented and descended groups had distended abdomens and could not maintain equilibrium (control fish did not have barotrauma), so they all had the same barotrauma scores. One vented fish also had a bulging eye in addition to the other visible barotrauma symptoms (Table 1). Prerelase swim scores varied significantly among groups (K-W: H2,16 = 15.045; P = 0.001); swim

| Group          | n   | Length (cm) | Baro score | Swim score Before | After* | Stress score Before | After | M    | FR    | R    |
|----------------|-----|-------------|------------|-------------------|-------|---------------------|-------|------|-------|------|
| Ex situ study  |     |             |            |                   |       |                     |       |      |       |      |
| Untreated      | 14  | 53.6 ± 9.1  | 2 ± 0      | 4.7 ± 0.5         | 2.6 ± 2.1 | 3.0 ± 0.9        | 3.9 ± 1.2 | 3 | 4 | 7    |
| Fin weighted   | 15  | 55.3 ± 6.9  | 2 ± 0      | 4.9 ± 0.4         | 2.0 ± 1.9 | 3.1 ± 0.9        | 4.4 ± 1.3 | 2 | 5 | 8    |
| Vented         | 15  | 52.3 ± 9.9  | 2 ± 0      | 4.8 ± 0.4         | 3.3 ± 1.0 | 2.7 ± 0.8        | 3.8 ± 1.7 | 3 | 1 | 11   |
| In situ study  |     |             |            |                   |       |                     |       |      |       |      |
| Control        | 6   | 73.6 ± 8.8  | 0 ± 0      | 0.7 ± 1.2         |       | 5.0 ± 0             |       |      |       |      |
| Descended      | 6   | 77.4 ± 5.5  | 2 ± 0      | 4.8 ± 0.4         |       | 3.3 ± 0.8          |       |      |       |      |
| Vented         | 6   | 74.1 ± 5.1  | 2.1 ± 0.4  | 5.0 ± 0           |       | 3.0 ± 0.6          |       |      |       |      |

* We based postrelief swim scores in the ex situ study on 13 fin-weighted fish and 12 vented fish due to removal of mortalities.
scores were significantly higher (worse) for descended fish ($H_{2,16} = 8.500; P = 0.005$) and vented fish ($H_{2,16} = 9.500; P = 0.001$) than for controls, but not significantly different from each other ($H_{2,16} = 1.000; P = 1.000$; Table 1). Pretreatment stress scores varied significantly among groups ($H_{2,16} = 12.724; P = 0.002$); control fish were less stressed (passed more reflex tests) than vented fish ($H_{2,16} = -9.833; P = 0.003$) and descended fish ($H_{2,16} = -8.167; P = 0.017$); vented and descended fish did not differ from each other ($H_{2,16} = 1.667; P = 1.000$). Full scoring details for fish in the telemetry study are provided in Table S2.

Postrelease movement. The daily detection rate of fish during manual acoustic tracking was generally high at 86.5% (descended: 97.6%, control and vented: 81.0%). The lower detection rates in vented and control groups were due to one fish in each group that had more than 2 d of consecutive missing data, as opposed to lower detection rates across all fish in these groups (see Table S2). We did not use the fish with missing data in calculations of total distance, distance rate, or straightness index, but we did use them to calculate total displacement (found on last day) and maximum days to leave the release area (they were not within the 500-m release area on the first day of tracking). Detection rates at 17 and 42 d postrelease were similar across treatment groups. Out of the four control fish outfitted with long-term tags, we relocated two fish at 17 d and two at 42 d (all fish relocated in total). Out of the four descended fish with long-term tags, we found three fish at 17 d and two at 42 d (one fish not found). Similarly, out of the four vented fish with long-term tags, we found three fish at 17 d and two at 42 d (one fish not found).

Movement metrics varied considerably across fish in all treatment groups (see Figure S2). On average, vented fish left the release area at least a half day sooner than...
control or descended fish (Table 2; no statistical test possible because of lack of variance in vented group). On average, descended fish travelled the farthest and fastest and had the highest straightness, or orientation efficiency, followed generally by control and then vented fish (Table 2). In particular, the total distance moved by control fish (range: 5.05–27.6 km) and descended fish (4.7–28.6 km) was substantially larger than that observed in vented fish (2.6–16.8 km; Figure S2; Table S2). However, there were no significant differences in total distance (ANOVA: $F_{2,16} = 0.362; P = 0.703$), daily distance ($F_{2,16} = 0.362; P = 0.703$), total displacement ($F_{2,16} = 0.833; P = 0.454$), and straightness index ($F_{2,16} = 0.728; P = 0.501$) across the three treatment groups.

**Postrelease depth use.** After release at the surface, the majority of control fish moved to deeper water near the maximum depth at the release site (total depth: 5 m). These fish remained at similar depths (3.6–4.6 m) until day 3 or 4 when their depths became more variable (Figure 5). In contrast, the majority of vented fish, which we also released at the surface, did not move to deeper water; they remained shallower (0–3 m) for 3–7 d (Figure 5). Lastly, after their deep-water release at 11 m, the majority of descended fish moved to and remained at depths between 6–9 m until day 4 or 5 when their depths became more variable (Figure 5). Correspondingly, we found descended fish, on average, at the deepest depths (5.7 ± 1.0 m), followed by control (3.8 ± 0.8 m) and then vented fish (3.2 ± 0.5 m). Interestingly, we found vented fish were often occupying shallow depths in a deeper water column, rather than in generally shallower areas of the lake. Statistically, there was a significant difference in the average depth used across treatment groups (K-W: $H_{2,16} = 6.484; P = 0.039$), and pairwise tests showed this difference was the result of descended fish using deeper depths than vented fish. However, this pairwise difference was only borderline in a post hoc comparison (K-W: $H_{2,16} = 9.958; P = 0.062$). Comparisons of depth use were weakened to some degree by poor detection of two fish (one vented, one control) that were only detected on the first and last days of tracking. These two fish appeared to use very shallow depths near the surface, which may have affected acoustic signal transmission.

Depth of relocation at 17 and 42 d for fish with longer-term transmitters was highly variable (see Table S2). At 17 d, depths ranged from 1.1 to 2.3 m for control fish ($n = 2$), from 2.7 to 12.0 m for descended fish ($n = 3$), and from 2.7 to 9.7 m for vented fish ($n = 3$). At 42 d, depths ranged from 6.7 to 8.2 m for control fish, from 3.0 to 17.1 m ($n = 3$) for descended fish, and from 10.0 to 22.1 m for vented fish ($n = 2$). We did not conduct any statistical tests based on the very low sample sizes, but the limited observations available do not suggest consistent differences among treatment groups.

**Postrelease space use.** Control (area$_{95} = 6.0$ km$^2$) and descended fish (area$_{50} = 5.8$ km$^2$) used similar areas of water at the 50% confidence level, but over fivefold more than vented fish (area$_{95} = 1.1$ km$^2$; Figure 6). At the 95% confidence level, control fish (area$_{95} = 58.4$ km$^2$) used over twofold more surface area than descended fish (area$_{95} = 28.5$ km$^2$).

![Graph showing percentage of individual Walleye Sander vitreus in one of the three barotrauma relief treatment groups (untreated, fin weighted, vented) that showed an improvement, no change, or worsening in five reflex tests used to assess stress (legend; VOR = vestibular-ocular response).](Image)

**Figure 4.** Percentage of individual Walleye Sander vitreus in one of three barotrauma relief treatment groups (untreated, fin weighted, vented) that showed an improvement, no change, or worsening in five reflex tests used to assess stress (see legend; VOR = vestibular-ocular response). We sampled Walleye from the weigh station of a competitive fishing event on Last Mountain Lake, Saskatchewan, Canada, in September 2016 and then transferred fish to a holding tank for treatment and scoring. Reflex tests are scored as a pass or fail; thus, an improvement in a given reflex test indicates a fish that passed a previously failed test.

**Table 2.** Postrelease movement metrics (mean ± SD) for Walleye Sander vitreus in three barotrauma relief treatment groups (control, descended, vented) based on manual acoustic telemetry (7-d period) in Last Mountain Lake, Saskatchewan, Canada, in September 2016. Metrics are presented as mean ± SD. Days to exit is the number of days it took for a fish to vacate a predefined 500-m release area. Daily distance is the rate at which fish moved per day based on daily relocations and displacement is the total straight-line distance between the release site and the location of the fish on the seventh day. Straightness index is the ratio between the displacement and total path length (sum of daily distances) and is a value between 0 and 1 (least to most efficient movement to the final relocation).

| Group    | $n$ | Days to exit | Total distance (km) | Daily distance (km/d) | Displacement (km) | Straightness index |
|----------|-----|--------------|---------------------|-----------------------|-------------------|--------------------|
| Control  | 6   | 1.6 ± 0.9    | 11.7 ± 9.2          | 1.7 ± 1.3             | 8.2 ± 10.7        | 0.58 ± 0.31        |
| Descended| 6   | 1.5 ± 0.5    | 13.2 ± 9.5          | 1.9 ± 1.4             | 11.5 ± 10.2       | 0.76 ± 0.25        |
| Vented   | 6   | 1.0 ± 0      | 8.9 ± 5.9           | 1.3 ± 0.8             | 5.4 ± 4.1         | 0.61 ± 0.21        |
26.3 km²), and over fivefold more area than vented fish (area₉₅: 18.1 km²; Figure 6). Qualitatively, control and descended fish used a much larger area north of the release site and along the eastern shoreline; vented fish were more concentrated around the release area and used both eastern and western shorelines (Figures S2 and 6). Volume estimates based on 3D kernel densities (see Figure S3 for 3D models) include depth and area use and followed the same trends as those for surface area. Control fish used the most volume (volume₅₀: 0.05 km³, volume₉₅: 0.3 km³), followed by descended (volume₅₀: 0.03 km³, volume₉₅: 0.3 km³) and then vented fish at both confidence levels (volume₅₀: 0.01 km³, volume₉₅: 0.1 km³).

When we jackknifed kernel densities, the trends described above persisted for both area and volume use (Figure 7). Based on permutated area and volume estimates, there was high probability that vented fish used less area (50% confidence = 97.2% of outcomes) and volume (50% and 95% confidence = 88.9% of outcomes) than control fish. There was also high probability that vented fish used less area (50% confidence = 100% of outcomes, 95% confidence = 91.7% of outcomes) and volume (50% confidence = 83.3% of outcomes, 95% confidence = 97.2% of outcomes) than descended fish. There was a lower probability that control fish consistently used more area (50% confidence = 69.4% of outcomes, 95% confidence = 86.1% of outcomes) or volume (50% confidence = 63.9% of outcomes, 95% confidence = 52.8% of outcomes) than descended fish, suggesting the volume use of these two groups was similar (Figure 7).
Ex situ condition study

Walleye with moderate-to-severe barotrauma are typically unable to submerge and therefore require aid of some kind to improve their condition before release. In Saskatchewan, CFEs must ensure that at least 90% of the fish weighed in are alive and immediately released unharmed. The definition of unharmed includes fish that are able to hold themselves upright in the water and sound to the bottom and that are not visibly stressed (Government of Saskatchewan 2017a). In our study, 50% of untreated fish with barotrauma were ultimately not releasable based on these criteria (i.e., did not stay submerged), even when held under ideal conditions for more than 20 h. Importantly, there were no obvious cues useful for identifying fish capable of recovery or not based on reflexes or swimming behavior. Under normal recreational angling conditions in deep water, which are common on Last Mountain Lake, the 50% nonreleasable value is well above the assumed background mortality rate for CAR (10%; Government of Saskatchewan 2017b). Our finding of critical impairment for a high proportion of Walleye is similar to those for a wide variety of other species and contexts, further demonstrating the major influence that barotrauma can have on mortality after CAR (Keniry et al. 1996; Hochhalter and Reed 2011; Hall et al. 2013; Curtis et al. 2015). However, the population-level impact of deep-water angling and associated CAR mortality in the Last Mountain Lake recreational Walleye fishery (and other similar situations) is unknown and should be further investigated.

Interestingly, fish in all groups, including those that were untreated, improved their orientation reflex. This improvement is consistent with the idea that fish may recover from an acute pressure change over time, but it may take several days (Keniry et al. 1996; Parker et al. 2006). In many cases, the improvement in our fish was insufficient to enable them to maintain equilibrium after surface release, and under normal angling or CFE circumstances their risk of dying would be additionally elevated by harmful surface exposure and predators (Keniry et al. 1996; Shasteen and Sheehan 1997; Gravel and Cooke 2008). American white pelicans Pelecanus erythrorhynchos may pose a particular risk of depredation for fish floating moribund on the surface after CAR on prairie lakes (C.M. Somers, personal observations). The condition of fin-weighted fish did not improve any more than that of untreated fish, suggesting that fin weights alone are not the intervention needed to relieve moderate-to-severe barotrauma in Walleye and likely most physoclist. Fin weights may be useful for temporarily restoring equilibrium as a result of non-barotrauma issues such as stress and exhaustion, but these circumstances need to be formally assessed. In the meantime, we conclude that Walleye with barotrauma require symptom relief before release, but fin weights alone are not a suitable approach.

Venting to relieve barotrauma produced marked improvements in Walleye condition during our ex situ experiment and also changes to swimming behavior that may be cause for concern. Vented fish were immediately able to regain orientation and submerge, similar to other species in similar contexts in several studies (e.g., Keniry et al. 1996; Shasteen and Sheehan 1997; Hochhalter and

Figure 7. Estimations of postrelease (a) area and (b) volume used by Walleye Sander vitreus in three barotrauma relief treatment groups (control, descended, vented). We sampled Walleye from the weigh station of a competitive fishing event on Last Mountain Lake, Saskatchewan, Canada, in September 2016. We then scored, treated, fitted with an acoustic transmitter, released, and subsequently manually relocated fish for 7 d. We based estimations of area and volume on jackknifed two-dimensional kernel densities (area) and three-dimensional kernel densities (volume) with one of six individuals removed until we calculated all combinations (six permutations). We performed jackknifing at 50% confidence level (patterned boxes) and 95% confidence level (gray boxes). Bolded lines through the middle of the boxes represent the median, whereas the box represents 50% of the data, and the top and bottom whiskers represent the upper and lower quartiles, respectively. Data points beyond the 95% confidence intervals are shown.
Reed 2011; Butcher et al. 2012); however, the swimming behavior of vented fish was distinct. Vented Walleye became negatively buoyant, sank rapidly to the bottom of holding tanks, and rested there with almost no movement unless agitated. These observed behavioral changes persisted for >20 h posttreatment. Ideally, only enough gas should be released from the swim bladder during venting to allow the fish to regain neutral buoyancy (Kerr 2001). We attempted to accomplish this by having a highly experienced person vent our Walleye only until they rolled into an upright position. However, our data suggest that either we overvented our fish or that gas continued to escape the swim bladder after removal of the needle, causing the fish to sink. Similar observations were made by Shasteen and Sheehan (1997) in Largemouth Bass *Micropterus salmoides*, which remained negatively buoyant and resting on the bottom for up to 31 h after a 0.5-cm incision in the swim bladder. Ultimately, 73% of vented fish in our ex situ study were able to be released after 20 h, which is a substantial improvement over no treatment (50% released) or fin weighting (53% released). However, the changes to buoyancy and swimming behavior raise concerns about the behavioral competency of these fish.

**In situ telemetry study**

The results of postrelease tracking suggest that vented Walleye may be movement impaired, as predicted based on our ex situ experiment. On average, vented fish showed a trend to move shorter distances and at slower rates than control or descended fish; they also used much less of the lake (surface area and volume) than the other treatment groups. The comparison between vented and descended fish is particularly important, as both sets of fish had barotrauma, and both groups had essentially identical stress and swim scores before treatment. Thus, vented and descended fish should show identical postrelease behavior if barotrauma relief method is not an important influence. In contrast, our data suggest that vented fish may not be capable of swimming as far as some descended fish. Descended fish, on average, moved similar distances to the control group, and the farthest traveling fish in the study (28.6 km) was a descended individual. Stockpiling of fish following CFES, defined as delayed or failed evacuation from the release site, is a concern for fisheries management and has been the subject of many other tracking studies (e.g., Richardson-Heft et al. 2000; Young and Isely 2006; Kaintz and Bettoli 2010; Brown et al. 2015). Our findings suggest that descending Walleye may be a better approach than venting for encouraging longer and faster movements away from CFES weigh stations after barotrauma relief. In fact, descended Walleye moved very similarly to control fish without barotrauma. However, vented Walleye left the pre-defined release area (500-m radius) quickly and were still moving fairly long distances (kilometers) over the 7-d tracking period. Consequently, the impaired movement may only be relevant as a comparison among treatments, and stockpiling may not be an issue for Walleye even with the tendency for reduced movement by vented fish. Given the lack of strong statistical support for our findings, we are unable to make a firm conclusion about the influence of barotrauma relief method on postrelease movement by Walleye. The sample sizes in our study were similar to those of previous publications using telemetry on other species (e.g., Danylchuk et al. 2007; Karam et al. 2008; Butcher et al. 2013), but high individual variance in behavior among Walleye reduced our ability to detect differences among treatment groups. We recommend additional studies in a variety of contexts (lake size, depth range, time of year and day) to further assess how barotrauma relief method affects postrelease movements by Walleye.

In general, Walleye exhibited much more variable postrelease movements than we were expecting. In the control and descended groups, we had individuals that differed over fivefold in the magnitude of their total path lengths, from those making minimal movements (e.g., ~5 km total distance) to large, potentially directed movements (e.g., >25 km total distance). Vented fish path lengths were shorter than fish in the other groups but also variable (~2.5 km to maximum = 16.8 km). Maximum displacement showed the same trend for high levels of interindividual variability. This variation indicates that other variables unrelated to barotrauma also influence postrelease movement and space use. Fish condition and stress are known to influence recovery time and movement postrelease (e.g., Gingerich et al. 2007; Davis 2010). Barotrauma severity is also known to affect postrelease survival and behavior in various species (St. John and Syers 2005; Alós 2008; Jarvis and Lowe 2008; Sumpton et al. 2010; Hall et al. 2013; Curtis et al. 2015; Ferter et al. 2015; Ng et al. 2015; Humборстад et al. 2016). However, there was generally very little variation in reflex performance or swim score and no variation in barotrauma severity across individuals within groups in our telemetry experiment. All Walleye with the exception of one, in both in situ and ex situ experiments, were characterized as having bloated abdomens and showing equilibrium loss, with no other injuries visible. Other factors such as capture circumstances (e.g., Thorstad et al. 2003) and habitat preferences of individual fish (Klefoth et al. 2008) may influence the postrelease behavior of Walleye and should be considered for future research.

Barotrauma relief treatment clearly affected the depth strata used by Walleye, especially in the first 3 to 4 days after release. The comparison between vented and descended fish is again most important. Enabling fish to submerge and return to capture depth is the fundamental goal of both venting and descending (Bartholomew and Bohnsack 2005; St. John and Syers 2005; Sumpton et al. 2010). Contrary to our prediction, vented Walleye used significantly shallower positions in the water column than those that we descended and...
even tended to use shallower strata than control fish. In addition, in many locations vented fish were not on the bottom of the lake in shallower areas but instead were occupying shallow positions in a deeper water column. This observation was somewhat puzzling given the sinking behavior of vented Walleye in our ex situ study and at surface release in the lake, which suggested that we would find vented fish associated with the lake bottom. Butcher et al. (2013) observed shallow-water use during postrelease tracking of both descended and vented Mulloway *Argyrosomus japonicus* up to 10 d after treatment. These authors suggested that damage to the swim bladder from catastrophic decompression compromised buoyancy regulation in both treatment groups, thereby causing altered habitat use regardless of the barotrauma relief method. In our case, the disruption appeared to affect only vented Walleye; thus, we conclude that swim bladder function was compromised by the venting itself (not angling). Importantly, because of their shallower depth strata, vented Walleye would not benefit as much as descended fish from relief of additional barotrauma symptoms outside of swim bladder overinflation.

The effects of venting on movement and habitat use by Walleye were short term. Vented fish returned to movements and water depth use similar to those in the control group after 3 to 4 days. Our limited tracking at 17 and 42 d postrelease also revealed no obvious indication that fish were behaving differently in any of the three treatment groups. The rapid return to more species-typical behavior by vented fish suggests that their compromised swim bladders heal rapidly, with effects beginning to dissipate around 72 h after treatment. This elapsed time is reasonable for healing of minor perforations of the swim bladder (e.g., Bruesewitz et al. 1993; Shasteen and Sheehan 1997; Nichol and Chilton 2006; Parker et al. 2006; Bellgraph et al. 2008; Midling et al. 2012; Humborstad and Mangor-Jensen 2013). However, the capacity for swim bladder healing likely varies based on a variety of factors, such as species, body condition, water temperature, and depth of capture, as well as the choice of venting tool. The skill of the venter is also an important consideration; there will be much more variance in the location and magnitude of injuries to the abdomen and swim bladder of fish if many different anglers do the venting instead of a single expert. In addition, in situations of catastrophic decompression during angling, choosing descending over venting will not affect changes to behavior and fish may experience longer periods of disruption. Ultimately, in our study none of the tracked vented fish died, and behavioral differences resolved after a few days, suggesting that venting may be more of a fish welfare concern rather than a fisheries management issue (sensu Humborstad and Mangor-Jensen 2013). However, we caution against making any firm conclusions in the absence of longer-term data on fish fate and reproductive success (fitness).

Management Implications

The findings from our study have both fish welfare and fisheries management implications. Although based on a CFE, these concepts extend to general recreational angling for Walleye as well. The only way to fully prevent damage from barotrauma in Walleye or similar species (e.g., Sauger *Sander canadensis*) is to restrict deep-water fishing. In the absence of such restrictions, our study yields several important summary points. First, without treatment, a high proportion of Walleye with moderate-to-severe barotrauma will not be able to maintain orientation or stay submerged after release and are highly likely to die without aid. From both welfare and management perspectives, Walleye barotrauma symptoms need to be relieved somehow to enhance survival after CAR. Second, although fin weights are popular at CFEs in Canada, our results indicate they are not an effective means of treating barotrauma. Keeping fish upright in livewells while they wait for additional barotrauma aid may be desirable (fin weights plus descending or venting), but this remains to be specifically tested. Third, venting Walleye causes short-term behavioral changes that are likely related to the purposeful perforation of the swim bladder, which compromises buoyancy regulation. If venting is done properly, these effects may be short term and limited to negative impacts on fish welfare rather than survival. Fish welfare concerns are becoming more prominent for CAR angling and are an important consideration when evaluating techniques (Cooke and Schramm 2007; Muir et al. 2013; Yang et al. 2017). Finally, recompression of fish via descending does not appear to affect fish behavior or habitat use compared to controls, and it does not require an additional wound that compromises buoyancy regulation. Thus, descending achieves the dual goals of enhancing CAR success for fisheries management, and minimizing negative impacts on fish welfare.

Our study is the first that we are aware of to examine multiple barotrauma relief approaches in Walleye, and one of few to do so for a recreational freshwater species (Eberts and Somers 2017). Based on the current state of knowledge, we recommend 1) deep-water fishing for Walleye is avoided at CFEs or under any other circumstances where large numbers of fish may experience barotrauma and 2) the use of descending over venting for Walleye barotrauma relief when deep-water fishing cannot be regulated. However, we strongly encourage additional research in this area to ensure that the best possible approaches are used to promote long-term survival.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.
Table S2. Size, condition scores, detection, and postrelease movement data for Walleye Sander vitreus in three barotrauma relief treatment groups (control, descended, vented). We sampled Walleye from the weigh station of a competitive fishing event on Last Mountain Lake, Saskatchewan, Canada, in September 2016. We then scored, treated, fitted with an acoustic transmitter, released, and subsequently tracked the fish daily. Control Walleye did not have barotrauma (as indicated by barotrauma scores of 0), and we released them untreated. Descended and vented fish had barotrauma (barotrauma scores 2 or 3), and we deep-water released them or vented them, respectively. We recorded fish size (length and mass), stress (0–5: least to most stress), and swim scores (0–5: best swimming ability to least) before release (vestibular-ocular response [VOR], maintained eye pitch when flipped on side). We tracked fish for 7 d (September 11–17). We only used fish with detection on appropriate days to calculate total distance moved, total displacement, distance rate, and straightness index (i.e., orientation efficiency, scale 0–1). We determined the maximum number of days it took a fish to leave a defined release area (500-m radius around release site) for all fish. We tracked fish with pressure sensitive acoustic transmitters and recorded depth (meters) for every relocation.

Table S3. Postrelease water volume use by Walleye Sander vitreus in (A) control, (B) descended, or (C) vented barotrauma relief treatment groups. We determined volume based on 7 d of acoustic telemetry with depth-sensitive transmitters. We sampled Walleye from the weigh station of a competitive fishing event on Last Mountain Lake, Saskatchewan, Canada, in September 2016. Fish were scored, treated, fitted with an acoustic transmitter, released, and subsequently manually tracked. We calculated the probability distribution of relocation at a longitude (Eastings Universal Transverse Mercator [UTM] units), latitude (Northings UTM units), and depth (meters) with three-dimensional kernel densities at 50% (dark blue) and 95% (light blue) confidence levels. We constructed kernel densities from the data for all fish in each treatment group combined. Depth is based on the depth of the fish (recorded by transmitters), not the depth of the water column.

Figure S1. The descending device (shot-line) used to release Walleye Sander vitreus with barotrauma in the descended treatment group in this study. We weighted the rig with 340 g of drop weights (four 85-g drop weights) and attached them to 18 m of rope with a 22-kg test fluorocarbon leader and swivel. We placed the hook in the upper jaw of the fish and allowed the weight to sink passively while unspooling line from the buoy as it floated on the surface.

Figure S2. Postrelease movement paths (connected black lines) based on acoustic telemetry for (A) control (no. 1–6), (B) descended (no. 7–12), and (C) vented (no. 13–18) Walleye Sander vitreus in Last Mountain Lake, Saskatchewan, Canada. Only the relevant portion of Last Mountain is shown. We sampled Walleye from the weigh station of a competitive fishing event in September 2016. We then scored, treated, fitted with an acoustic transmitter, released, and subsequently tracked these fish. We released all fish at Rowan’s Ravine Provincial Park (yellow arrow in panel A) and relocated them for 7 d (September 11–17). Control fish had no barotrauma, and we released them untreated. Descended fish had barotrauma, and we deep-water released them with a descending device. Vented fish had barotrauma and were vented with a hypodermic needle before release.

Figure S3. Postrelease water volume use by Walleye Sander vitreus in (A) control, (B) descended, or (C) vented barotrauma relief treatment groups. In each of three barotrauma relief treatment groups (untreated, fin weighted, vented) in our ex situ condition study. We sampled Walleye from the weigh station of a competitive fishing event on Last Mountain Lake, Saskatchewan, Canada, in September 2016 and then transferred them to a holding tank for treatment and scoring. All Walleye had barotrauma as indicated by barotrauma scores of 2 (i.e., two barotrauma symptoms identified). We recorded stress (0–5: least to most stress) and swim scores (0–5; best swimming ability to least) before and after (~20 h) treatment (vestibular-ocular response [VOR], maintained eye pitch when flipped on side). We housed fish in one of two 1,700-L drums between reassessments. After posttreatment assessments, we recorded mortalities or moribund fish. We did not record swim scores for dead fish. We released the remaining fish and recorded fish found floating within 30 min after release.

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