Articles

Is Barotrauma an Important Factor in the Discard Mortality of Yellow Perch?

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Abstract

In physoclistous fishes, barotrauma caused by rapid decompression during capture may be an important source of fishing mortality that is unquantified for some fisheries. We developed a predictive logistic model for barotrauma incidence in Yellow Perch (*Perca flavescens*) and applied this model to Ohio’s recreational and commercial fisheries in Lake Erie where fisheries managers implicitly consider discard mortality to be negligible in current stock assessment. As expected, capture depth explained most of the variation in incidence, with comparatively small effects of season, sex, and size categories. Measurements of whole body and gonad density provided limited explanation for the categorical effects. Both fisheries spanned a range of depths (7.6 to 16.8 m) that corresponded to a broad range of barotrauma incidence (13 to 74%). Using a recent example, we estimated that additional fishing mortality due to barotrauma in discards was approximately six-fold higher in the commercial than recreational fishery. Overall, this additional mortality was <1% of lake-wide population size estimates. Thus, the assumption that all discarded Yellow Perch survive is unlikely to result in a detectable bias in population estimates. One caveat is that we still do not understand how strong year-classes might influence discard mortality via increased discard rate and barotrauma incidence for small fish.

Keywords: barotrauma; Lake Erie; fishing mortality; discard

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Introduction

An important but sometimes overlooked component of total fishing mortality is discard mortality caused by barotrauma from rapid decompression of fish caught in deep water. Barotrauma manifests in a variety of sublethal and lethal symptoms and is a greater problem for physoclistous than physostomous fishes because of a lack of direct connection from the swim bladder to the gut in the former (Jones and Marshall 1933; Alexander 1966). Externally apparent consequences of barotrauma include esophageal eversion, cloacal prolapse, exophthalmia (eye protrusion), and an inability to regulate buoyancy—or simply, floating (Feathers and Knable 1983; St John and Syers 2005; Parker et al. 2006; Gravel and Cooke 2008; Hannah et al. 2008; Jarvis and Lowe 2008; Schreer et al. 2009). Internal symptoms include emphysema (gas bubbles) in various tissues, membranes, and organs; embolism; organ torsion; hemorrhaging; and overexpansion or rupture of the swim bladder (Beyer et al. 1976; Wilson and Burns 1996; Morrissey et al. 2005; Rummie and Bennett 2005; Gravel and Cooke 2008; Hannah et al. 2008; Rogers et al. 2008). Overexpansion of the swim bladder causes positive buoyancy and can render the fish incapable of returning to a neutral buoyancy compensation depth. Fish unable to descend are subject to exhaustion, thermal shock, and predation by other fish, mammals, or birds. Depending upon the length of time at the surface and whether decompression methods are applied, mortality due to barotrauma is positively associated with depth of capture (Gotshall 1964; Feathers and Knable 1983; Bruesewitz et al. 1993; Gitschlag and Renaud 1994; Wilson and Burns 1996; Collins et al. 1999; Burns and Restrepo 2002; Jarvis and Lowe 2008; Wilde 2009; Brown et al. 2010; Hannah et al. 2012; Scyphers et al. 2013; Drumhiller et al. 2014).

Not all species that experience rapid decompression are subject to the same barotrauma effects, due to variations in how the swim bladder functions as a hydrostatic organ. Species without a swim bladder (e.g., many mesopelagic and bathypelagic fishes) may be negatively buoyant or may modify their depth behaviorally by swimming, or via sequestration of waxy esters or low-density lipids in fat bodies, gonads, or the liver (reviewed by Alexander 1990). When the swim bladder is present and functions as a hydrostatic organ, its expansion and attendant barotrauma effects vary dependent upon the magnitude of depth change, density of the soma, thickness and rigidity of surrounding tissue (to resist pressure changes with depth), and concentration of lipids and waxy esters that may provide supplementary buoyancy (Taylor 1922; Tester 1939; Jones and Marshall 1953). Blaxter and Battu (1990) and Davenport (1999) noted that simplistic models (e.g., Jones 1951, 1952) applying Boyle’s Law based solely on whole-body volume and density tended to overestimate swim bladder volume. Thus, rapid decompression effects on the swim bladder are not easily generalizable across species (Hannah et al. 2008). Still, closely related species with similar habitat preferences and body styles should share similar responses to rapid decompression. Early studies on swim bladder decompression evaluated Eurasian Perch Perca fluviatilis as a model physoclist and revealed that rapid changes in pressure >60% of the acclimation pressure (equivalent to bringing the fish to the surface from 13.7 m) resulted in swim bladder rupture (Jones 1951, 1952). Similar in size and appearance, congeneric Yellow Perch Perca flavescens are affected by decompression with high rates of floating and mortality in fish collected from depths >10 m (Keniry et al. 1996; Schreer et al. 2009). In addition, neutral buoyancy at depth via swim bladder inflation must compensate for the density of the body, including gonads, which may differ from the soma and between sexes. Roach et al. (2011) observed small but significant effects of sex-biased barotrauma in Australian Bass Macquaria novemaculeata; therefore, we hypothesized similar effects for Yellow Perch.

Here, we examined barotrauma in Yellow Perch as it pertained to both recreational and commercial fishery discards in Lake Erie. Lake Erie Yellow Perch are the focus of one of the most valuable (recreational and commercial) freshwater fisheries in the world (Hushak et al. 1988; Allen and Southwick 2007). In Lake Erie, recreational fishing for Yellow Perch is via angling, whereas the commercial fishery uses primarily trap nets and gill nets, respectively, in U.S. and Canadian waters. The fishery is managed with individual quotas and minimum length requirements for commercial license holders, and daily bag limits per recreational angler with no minimum size requirement (YPTG 2018). From 2002 to 2006, the recreational fishery was estimated to release between 25 and 60% of the total lake-wide catch of Yellow Perch, but latent mortality (from hooking injuries or barotrauma) from these discards has not been estimated (STC 2007). Independent technical reviews of both fisheries stressed the need to estimate discard mortality and highlighted barotrauma and hooking injuries as primary mechanisms to be investigated and quantified (Lester et al. 2005; STC 2007). Further, recent anecdotal evidence suggests that discard mortality may be linked to barotrauma.

We focused on Ohio waters where recent data on discarding practices were available from the Ohio Department of Natural Resources for commercial trap net and recreational angling fisheries. In Ohio waters, the commercial trap net fishery is restricted to areas >4 nautical miles from primary ports (Figure 1). The recreational fishery primarily utilizes shallow areas <4 nautical miles from shore but is also permitted in offshore areas. Based on previous studies of barotrauma in Yellow Perch, we postulated that discard mortality would be greater for the commercial than recreational fishery because it operated in deeper areas. Our objectives were three-fold: 1) quantify the relationship between depth and incidence of externally observable barotrauma, 2) determine how this relationship varied with sex and total length category (based upon minimum size limit), and 3) extrapolate the results to the fishery to understand potential consequences of barotrauma on discard mortality. Our results not only support a mechanistic understanding of Yellow Perch
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Methods

To understand how barotrauma varied with depth of capture, size (total length [TL]), and sex, we coordinated interagency data collection from bottom trawl surveys (n = 284) and a short-term trap net study (in May 2015) across a range of depths (3.3 to 27.2 m) in Lakes Erie and Huron (Tables S1 and S2, 2018 Supplemental Material; see also ODW 2018 for a description of trap net and bottom trawl methods). Bottom trawls target demersal habitats; therefore, fish could be accurately assigned to a depth. Data from 9665 individual Yellow Perch, ranging in size from 60 to 352 mm TL, were available for analysis. Samples were distributed unevenly across 6 y (2000, 2006, 2010, 2012, 2014, 2015), and unevenly across seasons within each year. Spring samples (collections in April and May) were only available from 2010 and 2015. Other months (June through October) were only available from 2010 and 2015. Samples from 2000 to 2015 were pooled and categorized for analysis by season (defined as spring: April through May; summer: June through October), commercial fishery size restrictions on total length (TL < 216 mm fish, which are illegal to keep, vs. TL ≥ 216 mm fish, which can be landed legally), and sex. Note: unequal sampling effort by depth and season and recruitment variability affected the availability in each length class; therefore, the patterns may not represent the abundance or distribution of fish in the ecosystem.

as angling and traps. Further, data from the trap net study were from a single depth (14.2 m); thus, due to lack of contrast in depth, we did not evaluate gear effects.

For purposes of this study, we defined binary presence of barotrauma simply by visible swim bladder distension into the buccal cavity. This aided field data collection efficiency but did not account for subtler internal effects of rapid decompression. For analysis of barotrauma incidence, the primary focus was depth, which we modeled as a covariate in binary logistic regression. In addition to a depth-only model, we evaluated models with depth and all possible combinations and interactions of season (spring and other months), sex (male and female), and size class (small: <216 mm TL; large: ≥216 mm TL) using an information theoretic approach with Akaike’s second-order information criteria (AICc), $\Delta$AICc (values <2 indicate high support for the model), and AICc weight of evidence, $\omega$ (Burnham and Anderson 2002). Thus, we based model selection upon a collection of 12 common slope models. We selected the highest ranked model as the final model. For the final model, we estimated the depths at 50 and 90% barotrauma incidence via bootstrapping for each level of the other factors (Ogle 2016). We also constructed an analysis of deviance table for the final model to compare depth with other factors.

Mechanistic effects of rapid depth-change decompression of the swim bladder in physoclistous fishes are primarily a function of the density of other tissues. As

Figure 1. Map of Lake Erie depicting Ohio’s spatial management districts for Yellow Perch Perca flavescens in Lake Erie (numbered, hashed areas; as defined in 1993 and updated in 2004). In management districts 2 and 3, nearshore zones near access points and along the shoreline are closed to commercial fishing (gray shaded areas). There are also some restrictions on commercial fishing in district 1, which vary seasonally and annually (e.g., Ohio Administrative Code 2015). Recreational fishing is allowed in these areas. Restricted fishing areas and management districts are compared with lake-wide areas of high barotrauma incidence (blue shaded areas represent depths >13 m and have >50% probability of barotrauma) as predicted from a logistic regression model based upon depth.

Figure 2. Depth distribution of Yellow Perch Perca flavescens samples used in logistic regression analyses of barotrauma incidence ($n = 9665$, Table 1; Tables S1 and S2, Supplemental Material). Samples from 2000 to 2015 were pooled and categorized for analysis by season (defined as spring: April through May; summer: June through October), commercial fishery size restrictions on total length (TL < 216 mm fish, which are illegal to keep, vs. TL ≥ 216 mm fish, which can be landed legally), and sex. Note: unequal sampling effort by depth and season and recruitment variability affected the availability in each length class; therefore, the patterns may not represent the abundance or distribution of fish in the ecosystem.
gonads often concentrate low-density lipid rich substances (such as vitellogenin in gravid ovaries), swim bladder volume for neutral buoyancy at depth may be smaller during reproductive periods (Tester 1939). Differences in mass and density between male and female gonads may also result in swim bladder volume differences at depth. To better understand density effects on barotrauma incidence, we measured whole body and gonad density on a small sample of Yellow Perch \( n = 44 \) females, \( n = 16 \) males; Tables S1 and S3, Supplemental Material), following methods in Harvey (1963). Fish were preserved frozen and then thawed later for laboratory processing. Briefly, we placed thawed fish in a graded series of salt baths ranging in specific gravity from 1.05 to 1.13 as measured with a hydrometer to the nearest 100th of specific gravity. For each fish, a ventral incision exposed the swim bladder, which we also incised to ensure that no gases were present during the measurement process. We recorded the density of the bath at which the fish was neutrally buoyant as the density of the fish. On a subset of these fish \( n = 16 \) females, \( n = 3 \) males), we removed whole gonads to determine gonad density via the same method (Table S3, Supplemental Material). Instead of contrasting reproductive with nonreproductive periods, we collected fish for density analysis during summer months when the Ohio commercial fishery is open (a closed period protects spawning fish from the commercial fishery in the spring). We compared mean density between sexes with analysis of variance (ANOVA).

To understand the potential magnitude of additional mortality on Yellow Perch due to barotrauma effects on discarded fish, we applied the logistic barotrauma incidence model to recent fishery-dependent data from the commercial and recreational fisheries in Ohio. We limited our application to data from 2017, when contemporaneous data for both fisheries were available, and to illustrate how this approach can be applied to other fishery data sets. We obtained catch data from both fisheries from a recent status report (ODW 2018), but obtained more detailed information on depth of fishing from ancillary information in handwritten angler interview notes and unpublished investigations by the Ohio Division of Wildlife (ODW; Tables S1 and S4, Supplemental Material). Importantly, both fisheries lacked direct measurements of lake depth for catch; therefore, we approximated depth by two methods (one for each fishery) so that we could apply the barotrauma incidence model to discard data in each fishery. Because we could evaluate fishery discards by depth but not sex or size class, we applied a depth-only logistic regression to fishery data to estimate barotrauma incidence.

When interviewed, anglers inconsistently reported lake depths, but most participants (393 out of 491 interviews in 2017) provided either a specific depth or a geographic place name from which we could approximate lake depth from nautical charts. Once we determined depth, we calculated average fishing depth and estimated barotrauma incidence (from application of the logistic model to average fishing depth) for each Ohio management district. Barotrauma incidence was multiplied by reported numbers released (ODW 2018) to estimate discard mortality, assuming all discarded fish with barotrauma died. This assumption likely underestimates mortality from barotrauma due to the possible occurrence of internal injuries without externally visible barotrauma.

For the commercial fishery, Ohio’s annual report does not quantify released fish; therefore, we obtained data from an ODW special investigation in 2017 on discarding from commercial trap nets (Tables S1 and S5, Supplemental Material). The ODW investigators examined discards from a total of 878 trap net catches targeting Yellow Perch, but unfortunately neither was depth recorded nor were these observations indexed to trap net location. To estimate fishing depth for discards, we determined net location from vessel monitoring system data and indexed net depth from National Oceanic and Atmospheric Administration bathymetry data (Holcombe et al. 2005). Due to uncertainty in matching each catch to net and discard amount, we aggregated data and matched them by geographic grids (defined by DOW as 10 by 10 minutes of longitude by latitude; see ODW 2018), vessel, and day (total grid-vessel-days: \( n = 692 \)). Each day of fishing, vessels typically visited a cluster of nets in the same approximate location. Consequently, for most of the data (96.5%, \( n = 668 \)), the range of depth for each grid-vessel-day was \(< 2 \text{ m}\), which was within the expected range of uncertainty for depth due to changes in lake level and resolution of the bathymetry data. We did not use grid-vessel-days with a higher range of depth (3.5%, \( n = 24 \)) in the estimation of barotrauma. For each grid-vessel-day, we calculated discard rate as the quotient of discards divided by the sum of catch and discards, and estimated barotrauma incidence from average depth using the logistic regression model. To estimate total trap net discards in 2017, we multiplied mean discard rates by district by total reported catch—obtained from the most recent ODW report (ODW 2018). For each management district, we calculated discard mortality as the product of discards and mean barotrauma incidence, assuming all discarded fish with barotrauma died. Because trap net catch and derived quantities were in pounds, we converted estimated discards, catch, and discard mortality to numbers of fish by multiplying by three (average weight reported in the stock assessment is 0.141 kg), which is an accepted conversion used by Lake Erie fishery managers (YPTG 2018).

**Results**

Barotrauma incidence in Yellow Perch from bottom trawls was significantly associated with all four variables (depth, sex, size, season). Based on \( \text{AIC}_c - \omega \) and \( \Delta \text{AIC}_c \), the top-ranked model included depth as a covariate with a three-way interaction between sex, size, and season. This model had the overwhelming weight of evidence (\( \text{AIC}_c = 8302, \omega > 0.99, \text{for} \ K = 9 \text{ parameters} \)), and was selected as the final model. Other candidate models had negligible support from the weight of evidence metric (\( \omega < 1.0 \times 10^{-21} \)), and the next highest ranked model had \( \Delta \text{AIC}_c = 97.8 \); therefore, we do not present model
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Table 1. Logistic regression model results predicting external barotrauma incidence in Yellow Perch *Perca flavescens* (n = 9665; Tables S1 and S2, Supplemental Material) captured by bottom trawls and scientific trap nets from 2000 to 2015. We evaluated explanatory variables, depth (range: 3.3 to 27.2 m), size class (small: <216 mm; large: ≥216 mm total length), sex, and season (spring vs. summer), using Akaike’s second order information criterion (AIC,; Burnham and Anderson 2002). We selected the final model from a list of models with all possible combinations of categorical variables (each of which included depth as a covariate) based upon the lowest AICc and highest weight of evidence (ω). Parameter estimates for the final model are presented with standard error (SE) and deviance values for comparing the amount of variability in the data explained by each variable. Reference variable levels for the intercept were small, males, and in spring; the estimates are on a logit scale.

| Variable | Estimate | SE  | Deviance | P-value |
|----------|----------|-----|----------|---------|
| Intercept (small, male, spring) | -4.8 | 0.11 | — | — |
| Depth (m, covariate) | 0.35 | 0.0069 | 4.717 | <0.001 |
| Size (large) | 1.2 | 0.16 | 1.7 | 0.19 |
| Sex (female) | -0.48 | 0.081 | 200 | <0.001 |
| Season (summer) | 0.93 | 0.089 | 66 | <0.001 |
| Size × sex (large, female) | -0.7 | 0.21 | 29 | <0.001 |
| Size × season (large, summer) | -1.4 | 0.23 | 85 | <0.001 |
| Sex × season (female, summer) | -0.4 | 0.13 | 8.9 | 0.003 |
| Size × sex × season (large, female, summer) | 0.29 | 0.29 | 1.1 | 0.3 |

In the final model (Table 1), depth accounted for most of the explained deviance (4716.9), followed by sex (200.5) and then other single and interaction terms (combined deviance = 191.6). The magnitude of the categorical factor effects was small and best illustrated via bootstrap estimation of the depth of 50% barotrauma incidence confidence intervals (Figure 3). In spring, this depth was significantly greater in females than males, and was significantly greater for large (15.1 m) than small (13.6 m) females. In spring, depth of 50% barotrauma incidence averaged 11.3 m with overlapping confidence intervals between small and large males (Figure 3). In summer, depth of 50% barotrauma incidence was greater for small females (15.1 m) than small males (13.8 m), and while no sex difference for large fish in summer was evident, depths of 50% barotrauma incidence were shallower than for any other grouping (10.1 and 8.9 m, respectively for males and females; Figure 3). For all variable combinations above, the pattern was the same for 90% barotrauma incidence but deeper by 6.3 m.

Sex and size differences in the barotrauma incidence model could not be explained by density of either the whole fish or variation in gonad density. Whole-body specific gravity averaged 1.082 (SE = 0.001) with no significant differences by sex, size, or their interaction (ANOVA: P > 0.1). Due to low sample size for gonad measurements, only three fish were present in the small size category; therefore, we evaluated size separately from sex. Gonad specific gravity (mean = 1.0699, SE = 0.014) was lower than for whole body, but we detected no difference between ovaries and testes (P = 0.82). Small fish gonads had higher specific gravity than large fish by 0.034 units (SE = 0.01, P = 0.004).

Application of the depth-only barotrauma incidence model to Ohio fishery data in 2017 illustrated higher discard mortality rates in the commercial than in the recreational fishery. As expected, commercial fishing depths were greater than for the recreational fishery and this led to higher barotrauma incidence predictions for all districts (Table 2). Increased fishing depths and greater discards in the commercial than recreational fishery resulted in approximately sixfold higher discard mortality (Table 2). Thus, for this scenario in 2017, our analysis indicated the potential for additional unaccounted total annual mortality of 193,965 fish due to...
Table 2. Estimated Yellow Perch *Perca flavescens* discard mortality due to barotrauma by fishery (recreational angling vs. commercial trap net) in each Ohio management district (district 1, 2, or 3; delineated in Figure 1) during 2017. We predicted barotrauma incidence from a logistic regression model of depth (range: 3.3 to 27.2 m; \( n = 9665 \); Tables S1 and S2, *Supplemental Material*) that was applied to the mean lake depth for each fishery in each district. The parameter estimates for the logistic model of depth were the same as in the more complex barotrauma model that additionally evaluated size, sex, and season (Table 1). Catch and discard data were supplied by the Ohio Division of Wildlife (Tables S1, S4, and S5, *Supplemental Material*). We calculated discard mortality as the product of discards and mean barotrauma incidence, assuming all discarded fish with barotrauma died. For the commercial fishery, we performed calculations on the original data, which were reported in pounds (U.S. units), and resulting values were converted into numbers of fish.

| District | Lake depth (m) | Barotrauma incidence | Discards | Catch | Discard mortality |
|----------|----------------|-----------------------|----------|-------|-------------------|
| **Recreational fishery** | | | | | |
| 1 | 7.2 | 0.10 | 125,390 | 2,792,000 | 12,689 |
| 2 | 11.4 | 0.33 | 17,505 | 113,000 | 5,778 |
| 3 | 16.0 | 0.71 | 9,117 | 94,000 | 6,451 |
| **Total** | | | | | 24,918 |
| **Commercial trap nets** | | | | | |
| 1 | 12.9 | 0.45 | 202,312 | 1,341,789 | 91,773 |
| 2 | 14.5 | 0.58 | 102,338 | 1,771,341 | 59,780 |
| 3 | 16.8 | 0.74 | 23,559 | 1,349,937 | 17,493 |
| **Total** | | | | | 160,047 |

Barotrauma in Ohio waters (Table 2). This value is potentially overestimated by an unknown amount because the depth of capture in the recreational fishery may have been shallower (albeit unreported) if fish were suspended in the middle of the water column to avoid hypoxic areas that commonly develop in the central basin (districts 2 and 3) during summer (Roberts et al. 2012; Kraus et al. 2015). By comparison, trap nets were placed on the bottom, and additional unaccounted total mortality due to barotrauma does not have the same overestimation bias as the recreational fishery.

**Discussion**

In fisheries that subject physoclistous fishes to rapid decompression, barotrauma can be an important source of discard mortality, which is, as we demonstrated, easily calculated from depth-based predictions of barotrauma incidence. We refined logistic models of barotrauma incidence, bolstering previous analyses of barotrauma in Yellow Perch, which were limited in sample size as well as depth range (Keniry et al. 1996; Schreer et al. 2009). We also provided additional new insights for minor effects of sex, size, and season, which were associated with buoyancy mechanisms that were ancillary to the swim bladder (i.e., gonads). During spawning, when spawning happens, barotrauma in female fish occurred deeper than in males, suggesting that ovaries contributed more to buoyancy than testes. We anticipated this result because ovaries in Yellow Perch take up a greater volume than testes and because they concentrate vitellogenin and other low-density lipids. Thus, we would expect a smaller relative swim bladder volume in females compared to males, but researchers should examine this directly via comparison of body and gonad density in spawning fish. During the summer nonreproductive period, size was a more important factor than sex, with small Yellow Perch exhibiting barotrauma at deeper depths than large fish. Although this conflicts with the gonad density results (i.e., small fish gonad density was 3% higher than for large fish; thus, small fish swim bladders would take up a greater proportion of the body volume at neutral buoyancy), a larger sample size of small fish gonads is needed to refine our density estimates. Additionally, it would be worthwhile to explore physiological differences to understand how size affects a fish’s capacity to deal with barotrauma.

It was unclear how size-mediated barotrauma incidence may affect discard mortality in the Lake Erie Yellow Perch fishery, which primarily operates during summer and culls small fish (either voluntarily or via a minimum-size requirement). The size distribution of commercial discards was unquantified, and consequently, the weight conversion may underestimate numeric discard mortality in the commercial fishery. Engineering controls on trap net mesh size designed to permit escapement of small fish limit the catch size distribution to large fish, and some of the discards may have also been large fish that were undesirable due to poor quality. By comparison, anecdotes suggest the recreational practice of releasing small fish is common in Lake Erie, but size distribution of recreational discards was also unavailable. Because small fish experienced lower barotrauma incidence than large fish at the same depth during summer, accounting for fish size effects could improve discard mortality estimation.

In Lake Erie, fishing occurred across a range of depths (7.2 to 16.8 m), spanning most of the potential variability in barotrauma incidence (0.10 to 0.71) and emphasizing the need to partition discard mortality spatially by depth for an accurate account of total fishing mortality. For Yellow Perch fisheries in other ecosystems, spatial partitioning by depth of fishing would also be the primary consideration. At depths >18 m, 95% mortality of discarded fish could be assumed from the barotrauma incidence model. This situation would be common where Yellow Perch occupy deep habitats such as southern Lake Michigan, or eastern Lake Erie (Wells 1968; YPTG 2018). In shallow ecosystems, <6 m, typical of many small North American lakes, negligible barotrauma incidence (<5%) could be assumed.

The predominance of depth for predicting barotrauma incidence, while unsurprising, highlights the need for species- and fishery-specific understanding of barotrauma mortality. Although sympatric species may exhibit qualitatively similar responses to rapid decompression, patterns may vary by several meters across species (Feathers and Knable 1983; Keniry et al. 1996; Schreer et al. 2009); thus, fisheries managers should not apply the Yellow Perch barotrauma model presented here to other
species, except perhaps to the closely related Eurasian Perch. Managers should also take care if our model is applied in other systems with sharp gradients in bathymetry, which may increase uncertainty in depth of capture and contribute greater uncertainty to barotrauma incidence estimates.

While ultimately predicting discard mortality due to barotrauma may reduce uncertainty in stock assessments, it is initially important to understand how latent discard mortality is likely to bias current population estimates. Since 2000, annual lake-wide population estimates of Yellow Perch have been >100 million age-2+ fish (YPTG 2018). Our 2017 total discard mortality estimate from the combined recreational and commercial fisheries in Ohio was <1% of recent adult population estimates. This quantity is unlikely to be augmented in a significant way by fishing in other jurisdictions outside of Ohio. In Michigan waters of Lake Erie, lake depths are <10 m; therefore, barotrauma incidence would be low. In Ontario, most landings are from commercial gill nets, which are set overnight and retrieved into bins where they await onboard processing. Due to the length of time that fish in gill nets are out of the water, discarded Yellow Perch from the gill net fishery are already accounted as dead in stock assessment models. Finally, fisheries in New York and Pennsylvania are comparatively small: typically, <5% of lake-wide landings (YPTG 2018). Thus, the potential latent discard mortality due to barotrauma from all Lake Erie fisheries is far less than one standard error of recent estimates of adult abundance from any spatial management unit in Lake Erie (YPTG 2018). Further, in a previous analysis of the recreational fishery from 2003 to 2006 (STC 2007), Yellow Perch releases averaged 1.235, 0.564, and 0.043 million fish in management units 1, 2, and 3, respectively (note that Ohio management districts are the subareas of Ohio jurisdiction within in each management unit). Assuming similar fishing depths and associated barotrauma incidence as this study, we would estimate annual average discard mortality of 46,711 Yellow Perch for the recreational fishery from 2003 to 2006. Although the depths at which anglers fished in the previous study were unreported, this comparison illustrated how the magnitude of discards may influence latent mortality of released fish. We consider these benchmarks minimum estimates of discard mortality because additional internal barotrauma effects on the survival of released fish are unknown.

It is possible that an extraordinarily large year-class of Yellow Perch could augment discard mortality via small fish recruiting to the fishery. Small fish are less desirable to the recreational fishery; thus, discard rates could fluctuate substantially with recruitment. This situation would be more important for interjurisdictional quotas than for lake-wide population accounting. For example, in deep areas of Lake Erie such as New York, mortality from barotrauma combined with an increase in discard rates (due to a strong year-class) has the potential to represent a significant fraction of the quota and may warrant consideration in the allocation of total allowable catch. On the other hand, it is difficult to predict whether increased discard mortality would happen, because the recreational fishery may switch to other species as the frequency of less-desirable fish sizes increases in the catch. Although discard mortality due to barotrauma appears to be minor for the lake-wide population, future data collection efforts could include demographic information on released fish to evaluate the potential for disproportional discard mortality of young fish.

We equated visible barotrauma with mortality, which appeared reasonable given the inability of fish in this condition to swim back to their buoyancy compensation depth. Other mechanisms of discard mortality such as hooking injuries, handling trauma, internal barotrauma, and abiotic factors (Muoneke and Childress 1994; Davis 2002) that would increase discard mortality were beyond

### Supplemental Material

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**Table S1.** Description of field headings in Tables S2, S3, S4, and S5.

Found at DOI: https://doi.org/10.3996/062018-JFWM-056.S1 (4 KB TXT).

**Table S2.** Incidence of externally visible barotrauma of Yellow Perch *Perca flavescens* from bottom trawls and trap nets in Lakes Erie and Huron from 2000 to 2015.

Found at DOI: https://doi.org/10.3996/062018-JFWM-056.S2 (352 KB CSV).

**Table S3.** Measurements mass and specific gravity of whole bodies and excised gonads of male and female Yellow Perch *Perca flavescens* from Lake Erie in 2017.

Found at DOI: https://doi.org/10.3996/062018-JFWM-056.S3 (2 KB CSV).

**Table S4.** Recreational angling catches and releases of Yellow Perch *Perca flavescens* from Ohio waters of Lake Erie, reported by Ohio Division of Wildlife for 2017.

Found at DOI: https://doi.org/10.3996/062018-JFWM-056.S4 (16 KB CSV).

**Table S5.** Commercial trap net catches and releases of Yellow Perch *Perca flavescens* from Ohio waters of Lake Erie, reported by Ohio Division of Wildlife for 2017.

Found at DOI: https://doi.org/10.3996/062018-JFWM-056.S5 (19 KB CSV).

**Table S6.** Logistic regression model selection results to predict barotrauma incidence in Yellow Perch *Perca flavescens*.
flavescens from Ohio waters. Models with different combinations of explanatory variables, sex, size, season, and depth, are compared using Akaike’s second order Information Criterion (AICc), delta-AICc, and Akaike weights (\(\hat{w}\)).

Found at DOI: https://doi.org/10.3996/062018-JFWM-056.56 (1 KB CSV).

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