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ARTICLE

The Postrelease Survival of Walleyes Following Ice-Angling on Lake Nipissing, Ontario

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Abstract
Natural resource agencies have developed catch-and-release regulations for Walleyes *Sander vitreus* of prohibited size and number to reduce mortality in many recreational fisheries. The efficacy of such regulations is contingent upon the released fish surviving, but survival data on Walleyes captured by ice-angling are lacking. We estimated the survival of Lake Nipissing (Ontario, Canada) Walleyes that were captured by both active and passive ice-angling methods using a variety of hook types and lures baited with Emerald Shiners *Notropis atherinoides*. We also assessed the role of de-hooking methods on the survival of deeply hooked Walleyes. After the angling event, Walleyes (n = 260) were held for 24 h in a submerged holding pen to estimate postrelease survival. Average mortality after the 24-h holding period was 6.9%. Fewer Walleyes captured by active angling were deeply hooked (9.3%) than passively caught fish (50.4%), and deeply hooked Walleyes were observed to have more frequent postrelease mortality (14.8%) than shallow-hooked Walleyes (3.0%). There was no significant difference in mortality rates of Walleyes caught by passive angling (9.8%) or active angling (2.8%); mortality rates of fish caught on circle hooks (6.1%), J-hooks (8.2%), and treble hooks (5.6%) also did not differ. Neither air temperature nor the presence of barotrauma had a significant effect on mortality of captured Walleyes. Survival did not significantly differ between deeply hooked fish that had the line cut (11.1%) and those that had the hook removed (22.6%). Results from this study suggest a relatively high incidence of Walleye survival after catch-and-release angling through the ice.

Angling is a popular recreational activity worldwide that provides economic, social, and cultural benefits (Tufts et al. 2015; Barnett et al. 2016). Following capture by angling, a fish may be harvested or released by the angler. Catch-and-release (C&R) angling may be more prevalent where regulations include size-based harvest rules but may also occur as a voluntary conservation action on the part of the angler (Arlinghaus et al. 2007). Regardless of the motive, a substantial number of fish are released from recreational fisheries based on the premise that released fish will survive (Wydoski 1977; Cooke and Schramm 2007). Angling capture and handling can impose significant fitness costs to individuals, which may scale to the population level when a substantial number of fish are captured and released (Post et al. 2002).

Stressors related to the angling event, such as exercise and air exposure, can induce physiological alterations in captured fish (e.g., Wood 1991; Ferguson and Tufts 1992;

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Cook et al. 2015), while severe physical damage may occur in instances where fish are forced to rapidly ascend from deep water to the surface, causing gases to expand and rupture the swim bladder (i.e., barotrauma; Rummer and Bennett 2005; Parker et al. 2006). Furthermore, physical damage may arise when hooks penetrate buccal tissue and sensitive organs. Deep-hooking and the resulting bleeding and organ damage are often considered the primary source of mortality in recreationally caught fish (Muoneke and Childress 1994; Bartholomew and Bohnsack 2005). As a result, numerous studies have evaluated the importance of various hook specifications (e.g., type, size, presence of a barb, and presence of bait) on the hooking locations and mortality of captured fish (Arlinghaus et al. 2008; Rapp et al. 2008; Serafy et al. 2012; Stein et al. 2012). Other factors, such as the angling method, have also been shown to affect hooking location: passively angled Rainbow Trout *Oncorhynchus mykiss* were deeply hooked more often than those actively angled (Sell et al. 2016). Although numerous factors may contribute to angling-induced mortality, the extent to which each of these components influences the outcome of an angling event can be highly dependent on the species as well as the spatial and seasonal context of the fishery (Cooke and Suski 2005). Despite a growing number of interspecific evaluations, there is a further need for context-specific evaluations to establish whether there are sensitive periods for fish, such as during spawning (Lowerre-Barbieri et al. 2003) or during winter, when fish metabolism is considerably slower (Egginton 1997).

Fish are ectotherms and have thermal optimums and pessimums that vary across species and contexts (Pörtner and Farrell 2008). Although cooler temperatures are suggested to decrease mortality following C&R (reviewed by Gale et al. 2013), most studies have been conducted almost exclusively in spring, summer, and fall, with less attention paid to winter, when temperatures are extremely cold (Lavery 2016). Angling of fish through ice is a unique stressor given that ambient environmental temperatures can be very cold. For warmwater fish species, water temperatures near 0°C may impair the physiological capacity to cope with stress and may prolong recovery (reviewed by Egginton 1997; Wendelaar Bonga 1997). The stress responses (blood concentrations of glucose, lactate, and cortisol) of ice-angled Bluegills *Lepomis macrochirus*, Yellow Perch *Perca flavescens*, Eurasian Perch *Perca fluviatilis*, and Northern Pike *Esox lucius* are prolonged but diminished relative to those of summer-caught fish (Acerete et al. 2004; Cook et al. 2012; Cousineau et al. 2014; Louison et al. 2017a, 2017b; Pullen et al. 2017). A prolonged elevation of glucocorticoids such as cortisol can have adverse health consequences and can decrease overwinter survival (Pickering and Pottinger 1988; O'Connor et al. 2010; Midwood et al. 2017). Unlike summer fisheries for the Walleye *Sander vitreus*, ice-angled Walleyes are exposed to additional stressors, including freezing air temperatures upon removal from the water and more severe barotrauma resulting from short fight times and rapid ascension. In the former case, the cold air temperatures can result in extensive damage to epithelial tissue in the eyes, skin, and gills and can greatly impair physiological functioning (Tilney and Hocutt 1987). Ice-angling may also pose a greater threat to captured fish due to the extent of passive fishing (passively suspended hooks) that occurs, increasing the likelihood of hooking injury to critical organs, as is often the case with passive angling methods (Lennox et al. 2015; Sell et al. 2016). Together, stressors associated with a C&R winter fishery may pose a significant risk to the survival of targeted fish species, particularly in fisheries where angling pressure is high (Post et al. 2002).

In temperate regions, Walleye fisheries receive considerable angling pressure during both the open-water and winter angling seasons (Deroba et al. 2007). Numerous studies have addressed the C&R mortality rates of Walleyes during the open-water season (Fletcher 1987; Payer et al. 1989; Schaefer 1989; Bruesewitz et al. 1993; Reeves and Bruesewitz 2007; Reeves and Staples 2011; Talmage and Staples 2011), though little research has been done on the C&R survival of Walleyes after an ice-angling event. Considering the high angling pressure faced by Walleyes in many winter fisheries and given the lack of assessments for postrelease survival of Walleyes after ice-fishing, we attempted to assess fishing-induced mortality over a 24-h period after an ice-angling event. The objectives of this work were to (1) assess the postrelease mortality and hooking locations of Walleyes captured during the Lake Nipissing winter fishery and (2) determine what factors contribute to postrelease mortality of released Walleyes. The goal of this research was to provide fisheries managers with recommendations for minimizing postrelease mortality of Walleyes during winter recreational fisheries.

METHODS

Study site.— Lake Nipissing (Ontario, Canada) is an 87,325-ha mesotrophic lake that maintains a diverse fish community comprising 42 fish species (Morgan 2013). The lake is surrounded by a human population of approximately 75,000 distributed across North Bay, Callander, West Nipissing, and nearby areas, as well as a substantial number of tourists that visit the lake on an annual basis. Lake Nipissing is the seventh most fished lake in Ontario, supporting indigenous, commercial, and recreational fisheries (OMNRF 2013). The Walleye is currently the most popular species in all of these fisheries and is the most targeted fish species in the lake. Recreational fishing effort for Walleyes averages 500,000 angler-hours/year (OMNRF 2013), representing a potential source of anthropogenic-induced stress with possible population-scale impacts. Additionally, the

Walleye is also the main species targeted by Nipissing First Nation for their commercial fishery (OMNRF 2013). Together, these influences have resulted in an exploited Walleye population that has undergone a population decline in recent decades. Consequently, the Ontario Ministry of Natural Resources and Forestry (OMNRF) has changed the harvest regulations for the species in recent years from a protected 40–60-cm TL slot size limit to a 46-cm TL minimum size limit (Morgan 2013; OMNRF 2013).

Collection method.— Ice-fishing for Walleyes was conducted in South Bay of Lake Nipissing from January 10 to February 26, 2017. Fishing sites were selected with guidance from local outfitters and operators and under the advisement of OMNRF personnel. Multiple gear types were used for targeting Walleyes, encompassing both passive and active fishing methods that are typical of the local fishery. Active fishing was conducted by an angler actively jigging off the bottom with medium- to light-action ice-fishing rods spooled with 2.72-kg test (6-lb test) monofilament line. Lures used included 7.09–10.63-g (0.25–0.375-oz), treble-hooked jigging spoons (Buckshot and Macho Minnow; Northland Fishing Tackle, Bemidji, Minnesota) and jigheads (Cabela's solid-color barbed jigheads; Cabela's, Inc., Sidney, Nebraska) baited with dead Emerald Shiners *Notropis atherinoides*. Passive angling included angling techniques that were not actively presented to the fish by an angler (e.g., flag tip-ups, doorstop tip-ups, and setlines). All passive lines were set between 15 and 30 cm off the bottom, with suspended hooks (Gamakatsu number 4 octopus J-hooks; Gamakatsu number 4 octopus circle hooks; and 7.09–10.63-g, treble-hooked jigging spoons) baited with a live Emerald Shiner and weighted with a 7.09-g lead sinker. Terminal tackle used for both active and passive fishing methods was barbed. All passive lines were set out each day, with most lines (~75%) suspending the octopus J-hooks that were most frequently used in the fishery. Passive lines were checked immediately when an indicator was triggered and were checked routinely throughout the soak time, typically ranging between 0.25 and 0.75 h. Passive and active lines were fished both inside heated ice huts and outside. Both angling methods were used in approximately the same ratio at various water depths (~1 active line per 10 passive lines). Water temperature remained at 4°C in the hypolimnion layer, whereas ambient air temperature varied from −19.4°C outside to 15.0°C inside. All air temperature data were retrieved from the IONTARIO1123 weather station located in Callander, Ontario (46.217°N, −79.370°E), approximately 16 km from the study area. The total number of rod hours was recorded each day for both passive and active angling across each hook type to the nearest full hour.

Mortality assessment.— Information on fishery-specific handling practices was used to design postcapture handling treatments based on personal observations and communications with local anglers, outfitters, and operators in South Bay. Walleyes were angled from depths ranging from 6.0 to 12.5 m to assess the proximal influences of barotrauma on postrelease mortality. This depth range corresponded to a 0.60–1.24-atm change in pressure. Upon hook set, each Walleye was retrieved to the surface, where the hook was removed, hook location was noted, and fish TL was measured to the nearest 5 mm. During hook removal, physical signs of barotrauma, such as a distended swim bladder in the buccal cavity, were recorded if present. A unique identifying combination of fin clips and/or dorsal spine clips was applied to each fish caught. For Walleyes that were hooked deeply in the esophagus, gills, or tongue, the line was either cut immediately or the hook was removed using pliers. Following this processing period, the surface temperature of the operculum was measured using an infrared digital thermometer with a laser pointer measuring tool (Bearings Canada, Concord, Ontario). Operculum temperature was measured to evaluate the influence of air temperature on body temperature. Air exposure did not exceed 45 s during fish processing. After exposures, fish were transferred into a water-filled holding tank and were then assessed for the presence of the equilibrium reflex using the reflex action mortality predictor (RAMP) as described by Raby et al. (2011). Fish were then transferred to a custom-made conical, 0.5-m^3, subsurface holding pen (0.5-m-diameter × 1.9-m-high conical holding pen constructed of 25-mm-diameter nylon mesh; H. Christiansen Company, Duluth, Minnesota) within 90 s of landing. Nets were suspended in the water approximately 30 cm off the bottom (Figure 1). Each successive Walleye captured was added to the same holding pen, with a maximum of 15 fish held in the pen at a given time. Walleyes were held for variable periods and at changing densities throughout the holding period. The unique order in which fish were put into the net was recorded to evaluate the potential influence of holding period and fish density on mortality.

Statistical analysis.— A logistic regression model (R function "glm," specifying "family = binomial"; R Core Team 2015) was used to predict the factors contributing to mortality and anatomical hook location. Both models included gear type, hook type, and Walleye TL as explanatory variables. Anatomical hooking location, presence of barotrauma, and air temperature (°C) were used as explanatory variables in the mortality model only. Anatomical hooking locations were classified as either superficial (lips or inner mouth) or deep (esophagus, gills, or tongue) for statistical analysis to maintain a sufficient sample size for each group. A separate logistic regression model was fitted with fish order (order of placement into the holding pen on a given fishing day) as a predictor variable for mortality. After modeling survival data by logistic regression, we evaluated the applicability of the equilibrium reflex test (a RAMP indicator) to predict mortality

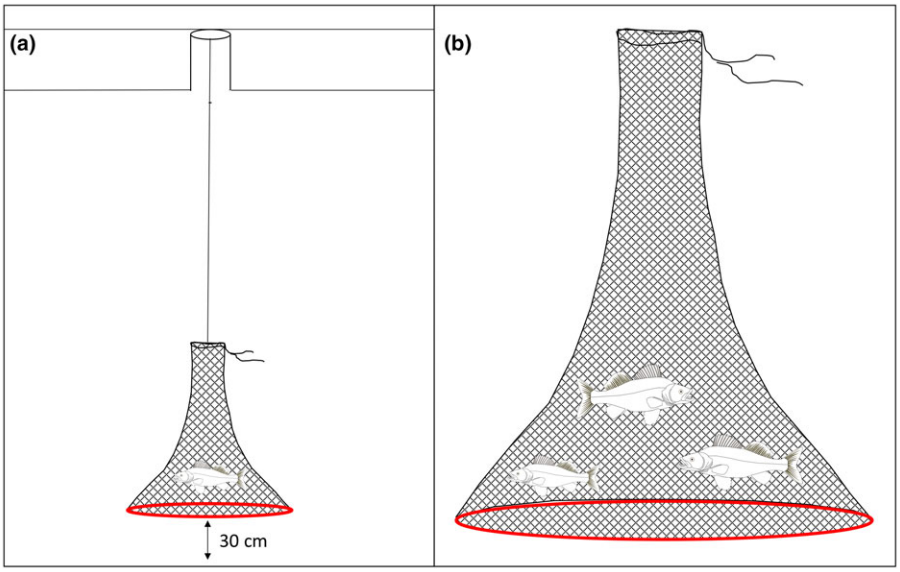

FIGURE 1. Diagrams of the subsurface holding pens used to monitor Walleye survival: **(A)** sub-surface holding pen suspended 30 cm off the bottom by a rope connected from the holding pen to the top of the ice-fishing hole; and **(B)** a magnified view of the holding pen, featuring the drawstring used to quickly open and close the holding pen during fish transfers. [Color figure can be viewed at afsjournals.org.]

by using a chi-square test of proportions with the R function "chisq.test" (R Core Team 2015). We also subsampled data to only include deeply hooked fish and used a chi-square test to compare mortality results from cutting the line to those obtained from removal of the hook. Differences in CPUE across hook types (passive gear only) and across gear were evaluated using ANOVA with the "aov" function in R (R Core Team 2015). The CPUE across hook types was only evaluated for the January 18–27 period, when all three hook types were used on passive gear. The influence of air temperature on operculum temperature was modeled using linear regression implemented with the R function "lm" (R Core Team 2015).

All models were tested for instances of collinearity prior to further analyses, and plots of the residuals were examined for any deviance from heteroscedasticity. Logistic regression models were evaluated using Hosmer–Lemeshow goodness-of-fit tests via the "hoslem_gof" function in the R package sjstats (Lüdecke 2017). Neither the mortality model ($P = 0.43$) nor the hooking location model ($P = 0.69$) had observed values that were significantly different from expected values, meeting the assumptions of logistic regression. A post hoc Tukey test for general linear hypotheses was used when statistically significant differences existed for factors with greater than two levels. Ecologically relevant interactions were included in statistical models and compared with models that excluded the interaction term by using Akaike's information criterion (AIC; R Core Team 2015). When there was little to no difference in AIC values, only the model with fewer predictor variables is presented. Odds ratios are presented where appropriate. As sample sizes for mortalities were low and therefore lacked statistical power, we report mean values. Statistical significance was assessed at $\alpha = 0.05$.

RESULTS

Size-Classes

In total, 260 Walleyes were angled by active ($n = 113$) and passive ($n = 147$) fishing methods using octopus J-hooks ($n = 133$), treble hooks ($n = 73$), and circle hooks ($n = 34$). The average TL (±SE) of captured fish was 355 ± 5 mm, and less than 1% of the fish ($n = 2$) captured as part of this study were of legal size to harvest. The average holding period was 22 h, and the order in which fish were placed into the holding pen had no significant influence on mortality ($z = -1.03$, df = 239, $P = 0.31$). Data were incomplete for 20 of the Walleyes captured; therefore, those individuals were only included for the mortality estimate and were excluded from statistical models.

Catch per Unit Effort

From January 10 to January 27, a total of 167 Walleyes were caught during 3,655 h of fishing. The CPUE observed when actively fishing (0.21 fish/h) was significantly greater than that obtained when passively fishing (0.04 fish/h; $F = 7.61$, df = 1,463, $P < 0.01$; Figure 2;

Table 1). The CPUE when passively fishing was significantly greater for circle hooks (0.13 fish/h) than for both octopus J-hooks (0.03 fish/h; $F = 134.70$, df = 3,653, $P < 0.01$; Figure 2) and treble hooks (0.05 fish/h; $P < 0.01$).

Mortality

Eighteen Walleyes died after capture by ice-angling; the observed rate of postrelease mortality was therefore 6.9% ($n = 260$). Mortality of Walleyes caught by passive (9.8%) and active (2.8%) angling was not significantly different ($z = 1.36$, df = 232, $P = 0.18$; Figure 3; Table 2). Mortality was not significantly different for Walleyes caught by treble hooks (5.6%; $z = 1.56$, df = 232, $P = 0.12$) or octopus J-hooks (8.2%; $z = 0.69$, df = 232, $P = 0.49$) relative to circle hooks (6.1%; Figure 3; Table 2). Deep-hooking increased the odds of mortality by 5.19 ($z = 2.34$, df = 232, $P = 0.02$; Figure 3; Table 2). Barotrauma was observed in 22.2% of captured Walleyes but did not significantly increase mortality relative to Walleyes without barotrauma ($z = -0.20$, df = 232, $P = 0.84$; Figure 3; Table 2). There was no significant effect of fish TL ($z = -1.52$, df = 232, $P = 0.13$) or air temperature ($z = -0.49$, df = 232, $P = 0.62$) on mortality rate, although air temperature was a significant predictor of Walleye opercular temperature ($t = 4.57$, df = 65, $P < 0.01$). The same model for mortality was analyzed again with the inclusion of the interaction between hooking location and gear type. This model indicated that passively caught, deeply hooked Walleyes were not significantly more likely to succumb to mortality than actively caught, shallowly hooked fish ($z = -0.54$, df = 232, $P = 0.59$; Table 2). The model was not significantly different from the model that excluded the interaction term ($\chi^2 = 0.60$, df = 232, $P = 0.60$). Impairment of the equilibrium reflex was not a significant predictor of Walleye mortality ($\chi^2 < 0.01$, df = 1, $n = 246$, $P = 1.00$; Table 2).

TABLE 1. Logistic regression model outputs predicting Walleye CPUE during ice-fishing. The models evaluate the difference in CPUE across gear types and hook types. Significant effects are highlighted by bold italic font.

Model	*N*	df	*F*	*P*
Gear type	***1,466***	***1,463***	***7.61***	***<0.01***
Hook type	***3,655***	***3,653***	***134.70***	***<0.01***

Deep-Hooking

Deep-hooking occurred in 32.5% of fish ($n = 76$). Deep-hooking was significantly more frequent for passive (50.4%) than active (9.3%) fishing methods ($z = -0.99$, df = 235, $P < 0.01$; Figure 4; Table 3). Deep-hooking was significantly more common for fish captured by octopus J-hooks (42.9%) than for those captured by treble hooks (9.9%; $z = 2.48$, df = 235, $P = 0.01$), but there was no difference between circle hooks (47.1%) and treble hooks ($z = -1.63$, df = 235, $P = 0.43$) or between circle hooks and octopus J-hooks ($z = 0.76$, df = 235, $P = 0.45$; Figure 4; Table 3). The TL of Walleyes was also not a significant predictor of deep-hooking ($z = -0.99$, df = 235, $P = 0.30$; Table 3).

Cutting the Line Versus Hook Removal

Deeply hooked Walleyes that had the hook removed ($n = 31$; 22.6% mortality) exhibited no significant difference in mortality compared to deeply hooked fish for which the line was cut ($n = 45$; 11.1% mortality; $\chi^2 = 1.06$, df = 1, $P = 0.30$).

DISCUSSION

Walleye mortality after ice-angling was 6.9%. Previous C&R research on Walleyes caught in the summer (non-tournament only) have reported hooking mortality rates

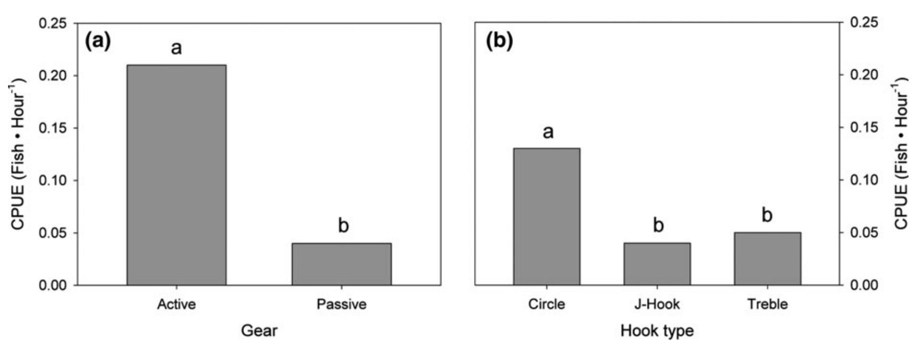

FIGURE 2. Walleye CPUE obtained when using **(A)** active (0.21 fish/h; $n = 201$) and passive (0.04 fish/h; $n = 3,454$) ice-fishing gear; and **(B)** circle hooks (0.13 fish/h; $n = 264$), octopus J-hooks (0.04 fish/h; $n = 987$), and treble hooks (0.05 fish/h; $n = 215$) on passive fishing gear. Different lowercase letters denote a significant difference (Tukey's honestly significant difference test: $P < 0.05$).

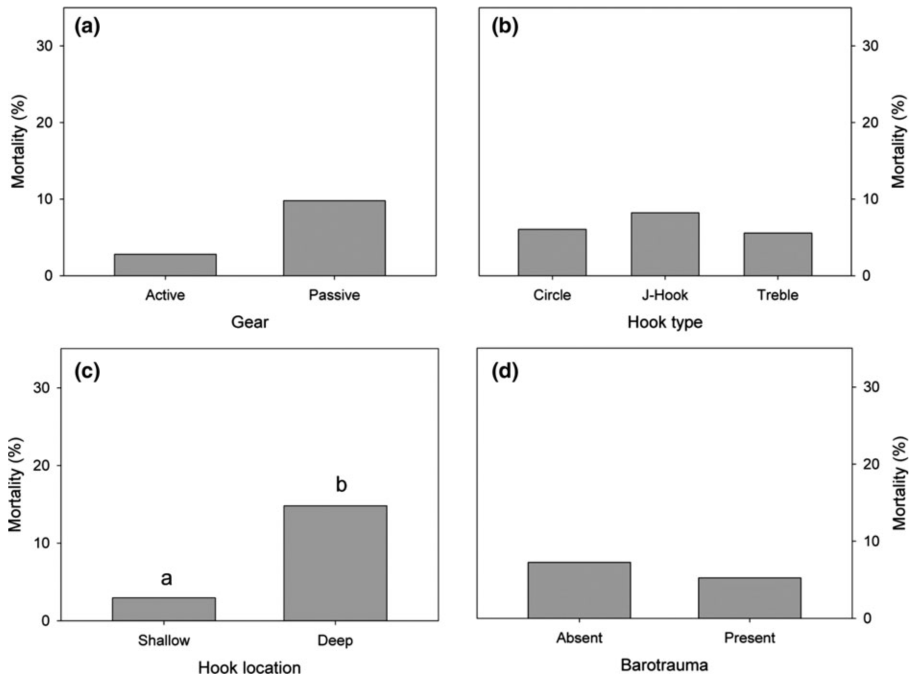

FIGURE 3. Mean 24-h mortality of Walleyes after catch-and-release ice-fishing using **(A)** active (2.8%; n = 99) and passive (9.8%; n = 141) gear; and **(B)** circle hooks (6.1%; n = 34), octopus J-hooks (8.2%; n = 133), and treble hooks (5.6%; n = 73). The 24-h mortality is also shown for **(C)** Walleyes that were shallow-hooked (3.0%; n = 162) or deeply hooked (14.8%; n = 78) and **(D)** Walleyes that had signs of barotrauma absent (7.3%; n = 184) or present (5.3%; n = 56). Different lowercase letters denote a significant difference (P < 0.05).

TABLE 2. Logistic regression model output predicting mortality of Walleyes captured by ice-fishing (n = 240). The model incorporated two continuous variables (Walleye TL and air temperature) and four factors. Inferences for factors are presented relative to reference levels ("active" for gear type, "circle hook" for hook type, "shallow-hooked" for hooking location, and "absent" for barotrauma). Significant effects are highlighted by bold italic font.

Model variable	Estimate ± SE	z	df	P
Intercept	−2.73 ± 1.84	−1.48	232	0.14
TL (cm)	−0.01 ± 0.01	−1.52	232	0.13
Gear type: passive	1.23 ± 0.91	1.36	232	0.18
Hook type: octopus J	0.59 ± 0.84	0.69	232	0.49
Hook type: treble	1.79 ± 1.14	1.56	232	0.12
Hooking location: deep	***1.65 ± 0.70***	***−2.34***	***232***	***0.02***
Barotrauma: yes	−0.14 ± 0.70	−0.20	232	0.84
Air temperature (°C)	−0.02 ± 0.04	−0.49	232	0.62

from 0.8% to 31% (Fletcher 1987; Payer et al. 1989; Schaefer 1989; Bruesewitz et al. 1993; Reeves and Bruesewitz 2007; Talmage and Staples 2011). Most studies used holding periods longer than 5 d but found mortality rates typically less than 5% (Fletcher 1987; Payer et al. 1989; Reeves and Bruesewitz 2007), though this was not the case for the study by Talmage and Staples (2011), in which 31% mortality was observed. These extended holding periods account for a longer time-course after release, with the tradeoff of additional confinement stress and mortality (Portz et al. 2006). Perhaps the most comparable estimate is that of Meerbeek and Hoxmeier (2011), who estimated winter C&R mortality at 12% for congeneric Saugers *Sander canadensis* caught at the same depth range (6–12 m) and similar water temperatures as the Walleyes in our study. These mortality estimates are particularly wide ranging and may be partly explained by differences in study design (e.g., holding pen style, holding duration, and fish handling) as well as by differences across Walleye fisheries and the water bodies where the studies occurred. In two of the studies, water temperatures were shown to be positively correlated with 5-d mortality (Reeves and Bruesewitz 2007; Reeves and Staples 2011), while another two studies identified capture depth as significant sources of mortality (Bruesewitz et al. 1993; Talmage and Staples 2011). In most cases, mortality was driven by deep-hooking (Fletcher 1987; Payer et al. 1989; Schaefer 1989; Bruesewitz et al. 1993; Reeves and Bruesewitz 2007; Reeves and Staples 2011). Similarly, ice-fishing mortality estimates for Lake Trout *Salvelinus namaycush* (10% mortality) and Northern Pike (1–33% mortality depending on the hook type) were also driven by hooking location (Dextrase and Ball 1991; Dubois et al. 1994). Furthermore, percids

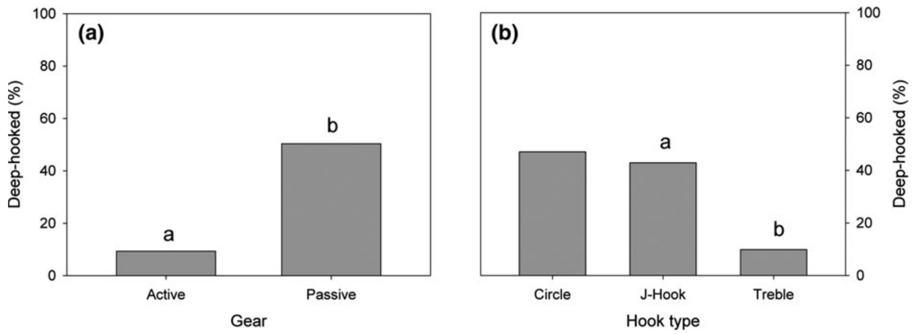

FIGURE 4. Mean deep-hooking rates for Walleyes captured by **(A)** active (9.3%; n = 99) and passive (50.4%; n = 141) ice-fishing gear; and **(B)** circle hooks (47.1%; n = 34), octopus J-hooks (42.9%; n = 133), and treble hooks (9.9%; n = 73) during ice-fishing. Different lowercase letters denote a significant difference (P < 0.05).

TABLE 3. Logistic regression model output predicting deep-hooking of Walleyes captured by ice-fishing (n = 240). The model incorporated Walleye TL as a continuous variable and included gear type and hook type as factors. Inferences for factors are presented relative to reference levels ("active" for gear type and "circle hook" for hook type). Significant effects are highlighted by bold italic font.

Model variable	Estimate ± SE	z	df	P
Intercept	−1.14 ± 1.14	−0.99	235	0.32
TL (cm)	−0.01 ± 0.01	−1.04	235	0.30
Gear type: passive	***2.12 ± 0.47***	***4.56***	***235***	***<0.01***
Hook type: octopus J	0.31 ± 0.40	0.76	235	0.45
Hook type: treble	−1.04 ± 0.64	−1.63	235	0.10

appear to suffer higher hooking mortality rates (mean = 19.9%) than any other family of fish (Hühn and Arlinghaus 2011). Abiotic and intrinsic biological factors have also been shown to explain context-specific differences in C&R outcomes across a range of recreational fisheries (Cooke and Suski 2005). In our study, these factors included differences in weather conditions (cold air temperatures reaching −19.4°C), fish physiology (J. M. Logan, M. J. Lawrence, W. M. Twardek, R. J. Lennox, and S. J. Cooke, unpublished data), and angler behavior (increased use of passive angling) during the winter months. As only a small number of mortalities existed, we often lacked the statistical power to detect significant relationships amongst the variables.

Hook Selection

Hook selection can have a considerable role in the severity of anatomical hooking damage following capture (Cooke et al. 2003). In the present study, we compared the hooking locations of treble hooks and octopus J-hooks as well as circle hooks, which have been suggested as a better alternative to conventional hooks (Serafy et al. 2012). Hooking location (shallow versus deep) in ice-angled Walleyes was partially related to the type of hook used. Treble hooks deeply hooked a significantly smaller proportion of fish (9.9%) compared to octopus J-hooks (42.9%); treble hooks also deeply hooked a smaller proportion of fish than circle hooks (47.1%), although not significantly so. This lower percentage of deep-hooking by treble hooks could be partly explained by the greater use of treble hooks when actively fishing, which tended to have lower deep-hooking rates. Treble hooks may also have reduced deep-hooking because they are larger in size (being three-dimensional) than a single hook, making them more difficult for fish to ingest deeply. A comprehensive review on hooking mortality across 32 taxa suggested that single hooks generally result in higher mortality rates than treble hooks (Muoneke and Childress 1994). However, mortality rates were similar for treble hooks in our study, suggesting that the additional stress associated with multiple hooking locations and the additional handling due to increased difficulty in hook removal may obscure the potential benefit of reduced deep-hooking. In some instances, circle hooks have shown promise as a better alternative to conventional hooks (Cooke and Suski 2005), but similar to the results reported for Rainbow Trout by Sell et al. (2016), we found no evidence of this (6.1% mortality). Circle hooks did, however, have a substantially higher CPUE, a finding that is contrary to most studies comparing catch rates of circle hooks and conventional hook types (Sell et al. 2016; but see Willey et al. 2016). A previous C&R study on Walleyes conducted in the summer found that circle hooks had significantly lower hooking efficiencies and lower injuries per strike than octopus J-hooks (Jones 2005). However, the Walleyes captured during the Jones (2005) study were actively angled, whereas the fish in our study were caught primarily by passive fishing. The higher CPUE for circle hooks observed in the current study may be related to their greater retention of live minnows compared to both treble hooks and octopus J-hooks, which were often observed to lose their minnows. A previous C&R evaluation of Walleyes used the exact same hook type (Gamakatsu size-4 octopus J-hooks) but had considerably different mortality estimates than those generated here (6.9% [present study] versus 25% [Reeves and Staples 2011]). However, the Reeves and Staples (2011) study occurred during the open-water season, when temperatures are considerably warmer. This large discrepancy between mortality estimates despite use of the same hook type suggests that other factors related to the fishery, such as capture depth, water temperature, and fishing method, may have greater roles in influencing mortality.

Gear Selection

Fisheries-related differences in angler behavior (gear, tackle, handling, etc.) can play an important role in the outcome of a capture event (Cooke et al. 2017). In our study, we found that ice-angled Walleyes had a particularly high rate of deep-hooking (32.5% overall), which may in part be explained by the considerable use of passive gear (57% of all fish captured). Passively caught fish had a significantly higher incidence of deep-hooking (50.4%) than actively caught fish (9.3%). However, active fishing caught 0.21 fish/h, while passive fishing caught just 0.04 fish/h, suggesting that total deep-hooking levels could be relatively even (1.95% versus 2.01% fish/h) for the same fishing effort. Nonetheless, greater deep-hooking rates for passively angled fish are potentially important, as Walleye angling during the winter months often employs a greater use of passive angling gear relative to the open-water season, when anglers may often only have one line in the water (OMNRF 2017). This increased deep-hooking rate of passively angled fish could be a consequence of diminished line monitoring by anglers, thus allowing the fish to swallow hooks and bait as well as greater opportunity for fish to ambush a stationary prey item (Lennox et al. 2015). Deep-hooking is also typically more common in fish that are captured using live bait (Arlinghaus et al. 2008), which is almost exclusively the case in ice-angling for Walleyes on Lake Nipissing. The 32.5% deep-hooking rate for Walleyes captured in the present study is considerably higher than that reported in many other C&R fisheries (Sell et al. 2016), probably due in part to our use of live bait on J-hooks (Bartholomew and Bohnsack 2005) while passive angling. Although previous research suggests that deeply hooked fish are at risk of death caused by critical damage to vital organs and blood loss (Alós 2008; Hall et al. 2015), the deeply hooked Walleyes in our study had a remarkably high survival rate (85%) and a low incidence of bleeding (10%). Minimal blood loss may be explained in part by the lowered metabolism of fish during cold temperatures and the correspondingly slower blood flow (Egginton 1997), and this could ultimately explain the observed high survival rates. Nonetheless, deeply hooked Walleyes were indeed significantly more likely to die than shallow-hooked Walleyes, highlighting the importance of hooking location in fish survival. As such, any efforts to reduce damage associated with deep-hooking would be of benefit to released fish.

De-Hooking Method

Anglers that deeply hook a fish are confronted with the choice to either remove the deeply lodged hook or cut the line and release the fish with the hook still embedded. Hook removal is often considered more damaging to captured fish due to extra handling and the tearing of vital organs. Cutting the line has therefore been proposed as an alternative to removing the hook, with the caveat that the fish will now have the burden of a hook in its oral cavity. Previous research on Bluegills indicated a relatively high ability to shed the hook over the short term (Fobert et al. 2009). However, cutting the line was not an effective means to reduce mortality in deeply hooked Golden Perch *Macquaria ambigua*, which had just 24% survival (Hall et al. 2015). Consistent with the findings of Reeves and Bruesewitz (2007), there was no statistically significant difference in postrelease survival over 24 h for Lake Nipissing Walleyes, although cutting the line (11.1% mortality) resulted in a lower average mortality than hook removal (22.6%). Across species, cutting the line appears to decrease mortality in most C&R scenarios (Bartholomew and Bohnsack 2005) and is likely beneficial for deeply hooked, ice-angled Walleyes.

Abiotic Factors

Abiotic factors such as capture depth can have an important influence on fish physiology and mortality. Fish captured at depth experience a rapid decrease in ambient pressure when brought rapidly to the surface. The resulting pressure change leads to the expansion of air in the swim bladder, rendering the fish unable to swim away from the surface or unable to maintain normal orientation (equilibrium; Raby et al. 2011). Barotrauma may also rupture the swim bladder and tunica externa (the outer layer of the swim bladder), which are slow healing (Pribyl et al. 2012), and may cause prolapse of the cloaca, hemorrhages, and gastric herniation (Butcher et al. 2013). In our study, approximately 23% of Walleyes had physical symptoms of barotrauma, although fish with barotrauma were not more likely to die. This result is contrary to an earlier ice-fishing C&R study completed on Lake Nipissing Walleyes, which highlighted the importance of capture depth for influencing the presence of barotrauma and mortality (Rowe and Esseltine 2001). Winter-caught Saugers also appeared to have mortality increase proportionally with capture depth: from 2% (at <9 m) to 67% (at 21–24 m). Our results are consistent with those of Bettoli et al. (2000) and Reeves and Bruesewitz (2007), who observed little influence of capture depth and barotrauma on mortality. The high survival of fish with barotrauma in our study could be related to the submerged holding pens that forced Walleyes back to their capture depth, allowing swim bladder gases to recompress (Drumhiller et al. 2014). However, the pens may also have increased stress and barotrauma, as Walleyes could be brought to and from the surface several times during fish transfers. Regardless of the mechanism, several Walleyes in our study remained at the top of the ice-fishing hole upon release and were clearly unable to swim as a result of barotrauma.

Water temperature has been previously identified as an important factor contributing to C&R mortality, with warmer temperatures being positively correlated with mortality (Gale et al. 2013) and increased hooking stress (Wydoski et al. 1976). The peak stress response of ice-angled fish is typically lower and the corresponding recovery period is longer than those of fish angled in the summer (Louison et al. 2017a, 2017b). Water temperatures in Lake Nipissing were constant at 4°C in the hypolimnion layer where Walleyes were captured, although air temperatures varied greatly from −19.4°C outside to 15.0°C inside the heated ice huts. Indeed, air temperatures were positively correlated with operculum temperatures of captured Walleyes, indicating that fish surface temperatures can be influenced by air exposure in less than 45 s. Similar to observations by Rowe and Esseltine (2001), the Walleyes in our study showed signs of freezing damage to the eyes and gills, which could result in long-term structural damage due to the formation of both intracellular and extracellular ice crystals (Pegg 1987; Fletcher et al. 1988). These observations suggest that air exposure should be minimized during cold winter conditions to reduce physical damage to released Walleyes.

Management Implications

In many winter Walleye fisheries, a substantial number of fish are released after capture to comply with provincial or state fishing regulations. Ice-angling for Walleyes in Lake Nipissing resulted in relatively low mortality rates (6.9%) that were in line with other estimates of summer C&R mortality and lower than the previous estimate of ice-angling mortality on Lake Nipissing (19%) as reported by Rowe and Esseltine (2001). In our study, a high proportion of Walleyes were caught using small baited hooks set on passive lines, resulting in frequent deep-hooking. Although circle hooks were ineffective for reducing deep-hooking, larger hooks should be tested to determine whether they reduce the frequency of deep-hooking, as this is generally believed to be the most common cause of mortality among fish captured in recreational fisheries. However, mortality from deep-hooking in this study was also modest. Overall, Walleyes were resilient to capture and handling in the winter recreational fishery, including handling in air and on ice prior to release. Even fish that exhibited symptoms of barotrauma had high survival, despite a previous suggestion that barotrauma is an important factor causing mortality of Walleyes in the fishery (Rowe and Esseltine 2001). Fisheries managers should account for differences in catch rates and mortality rates across gear types, and it may be prudent to suggest that anglers cut the line for deeply hooked fish.

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