Survival of Walleye released following ice-angling on Lake Nipissing

FECPL Report 03-2017

A report submitted to the Ontario Ministry of Natural Resources and Forestry

March 16, 2017

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Executive Summary

Ice-fishing for Walleye is a popular recreational activity on Lake Nipissing, Ontario. To increase escapement of Walleye in the fishery, the Ontario Ministry of Natural Resources and Forestry has mandated catch-and-release (CnR) regulations for Walleye of prohibited size (i.e. slot limit) or number (i.e. quota or bag limit). Since the implementation of a minimum size limit of 46 cm in the recreational fishery, there has been an increase in the number of Walleye being released. The efficacy of such a regulation depends on the survival of Walleye that are released, but data on Walleye survival following ice angling is lacking. We evaluated the post-release survival of Lake Nipissing Walleye captured by both active (i.e. jigging lures) and passive (i.e. passively suspended hooks) ice angling methods using a variety of hook types and lures (buckshot jigging spoons, Octopus J-hooks, and Octopus circle hooks) tipped with minnows. After being assessed for total length and anatomical hooking location, captured Walleye (N = 260) were held for 24 hours in a submerged net pen to determine survival. Walleye mortality following the 24 hours holding period was 6.9 ± 3.1% (mean ± 95% CI). Fewer Walleye captured by active angling were deeply-hooked (9.3 ± 2.8%) than passively caught fish (50.4 ± 4.2%). More deeply-hooked Walleye died than shallowly-hooked Walleye. Hook type, air temperature, and the presence of barotrauma had no significant effect on mortality of captured Walleye. Post-release mortality of deeply-hooked Walleye that had the line cut (11.1 ± 4.7% mortality) was not statistically different than those that had the hook removed (22.6 ± 7.6% mortality). A separate group of Walleye was either kept completely wet, air exposed for 2 minutes, or snow exposed for 2 minutes and then blood sampled. Blood samples were immediately measured for indicators of physiological stress (glucose and lactate). Circulating metabolite values suggested that winter CnR triggers stress in Walleye as also occurs during the ice-free period, although exposure to snow or air did not exacerbate the stress response relative to handling in water (pending further blood analyses on cortisol). Results from this study indicate relatively high survival for Lake Nipissing Walleye under the minimum size limit following CnR angling.

INTRODUCTION

Lake Nipissing is an 87,325 hectare mesotrophic lake in Fisheries Management Zone 11 that maintains a diverse fish community comprising 42 species. The lake is surrounded by a human population of approximately 75,000 spread 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 7th most fished lake in the province of Ontario, supporting traditional, commercial, and recreational fisheries (OMNRF, 2013). Walleye (*Sander vitreus*, Mitchill, 1818) is a popular species caught in both recreational and commercial fisheries year-round and, consequently, is the most exploited fish species in the lake (OMNRF, 2013). Recreational fishing effort for Walleye often reaches 500,000 hours per year (OMNRF, 2013). This represents a potential source of anthropogenic-induced stress with possible population-scale impacts. Walleye are also the main species targeted by Nipissing First Nation (OMNRF, 2013). Together, these influences have resulted in an exploited population that is currently suffering from population declines that have corresponded to changes in harvest regulations for the species in recent years, particularly a change from a protected 40 to 60 cm slot size limit to a 46 cm minimum size limit (Morgan, 2013; OMNRF, 2013).

Fishing regulations for the recreational Walleye fishery on Lake Nipissing have changed markedly over the past 20 years. From 1960 to 1998, six Walleye of any size could be caught and possessed each day. The increasing trends in total mortality and decreasing mean age of catch in the local Walleye population (OMNRF, 1998) were issues to be targeted in the Lake Nipissing Fisheries Management Plan (1999-2003). This plan attempted to reduce the harvest of Walleye females at reproductive size, by protecting individuals between 40 and 60 cm total length during the open water fishing season. Catch and possession limits were also set at four Walleye per angler. In 2000, the Walleye population was designated as “stressed” resulting from a catch and keep fishery that promoted overharvest (Rowe and Seyler, 2000). To bolster the protection of the Lake Nipissing Walleye population, slot size regulations to protect Walleye (40-60 cm) were extended to encompass the winter angling season in 2005 (Morgan, 2013). Despite these changes, the abundance and size structure of the Walleye population was still considered to be impacted by over-harvest of adult Walleye in the recreational and commercial fisheries (Morgan, 2013). A year-round protected slot limit for Walleye 40-60 cm was implemented for the recreational fishery and continued from 2007 until 2014 (OMNRF, 2006). In 2013, daily catch-and-possession limits were reduced (2 Walleye for sport, and 1 Walleye for conservation license), and in 2014, a new minimum size limit was put in place that allowed anglers to harvest Walleye only greater than 46 cm (OMNRF, 2013). This new and current regulation was instituted to protect the remaining juveniles of the strong year classes (2009-2012) and support their survival to reproductive maturity (i.e. Fall Walleye Index Netting; OMNRF, 2013).

The success of the current recreational fishing regulations is contingent on a high proportion of these released Walleye surviving. However, CnR can impose a significant physiological burden resulting from a multitude of stressors under which the animal is exposed. Exercise and air exposure both induce physiological alterations (e.g., Wood, 1991; Ferguson and Tufts, 1992;

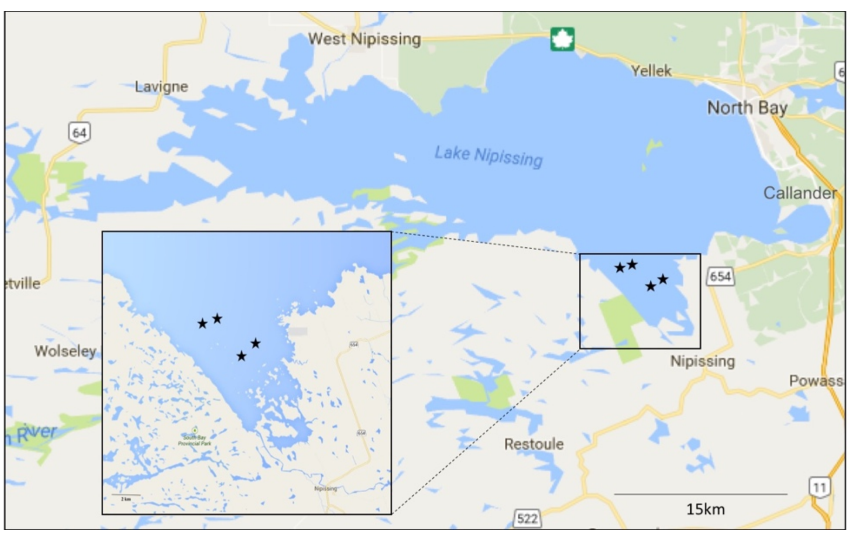
Cook et al., 2015). Prolonged elevations in glucocorticoids associated with the fish's stress response (i.e., cortisol) can have adverse health consequences (reviewed in Wendelaar Bonga, 1997) and decrease overwintering survival (Pickering and Pottinger, 1988; O'Connor et al., 2010; Midwood et al., 2017). In addition, physical damage associated with hooking and handling can occur (Hühn and Arlinghaus, 2011). The relative importance of each of these stressors (e.g., air exposure, hooking injury, exercise, etc.) varies by species and can be highly dependent on the spatial and seasonal context (Cooke and Suski, 2005). For example, CnR survival estimates have been conducted several times for summer Walleye and ranged from 0.8% to 31% depending on the fishery (i.e., environmental characteristics, intrinsic biological factors, gear choice; Fletcher, 1987; Payer et al., 1989; Schaefer, 1989; Bruesewitz et al., 1993; Reeves and Bruesewitz, 2007; Talmage and Staples, 2011). Comparatively little research has evaluated the survival of Walleye in the winter following an angling CnR event. Unlike summer Walleye fisheries, ice-angled Walleye are exposed to additional stressors including freezing air temperatures upon removal from the water and more severe barotrauma (expended swim bladder in buccal cavity) 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). Furthermore, barotrauma in Walleye, which results from a rapid decompression of gasses as the fish is brought from depth to the surface (Rummer and Bennett, 2005), often manifests as an over-expanded swim bladder that impairs buoyancy regulation thereby preventing the fish from descending (Parker et al., 2006). Barotrauma-related injuries were suggested as the primary source of the 19% mortality rate of Walleye released by Nipissing ice anglers by Rowe and Esseltine (2001). Together, stressors associated with a CnR ice fishery could pose a significant risk to the survival and overall physiological health of the Walleye.

In light of the challenges that Lake Nipissing Walleye face during the winter fishery, we investigated the acute effects associated with CnR angling of the local Walleye population during the ice fishing season. More specifically, we attempted to address a short-term time course of fisheries-induced mortality over a 24 hour period and the acute physiological stress responses over the hour following an angling event. To ascertain potential predictors of survival and develop best practices (Brownscombe et al., 2017), we addressed the influences of angling method (active vs passive) and hook choice (octopus circle, octopus J, treble) on the survival of angled Walleye held in under-ice net pens.

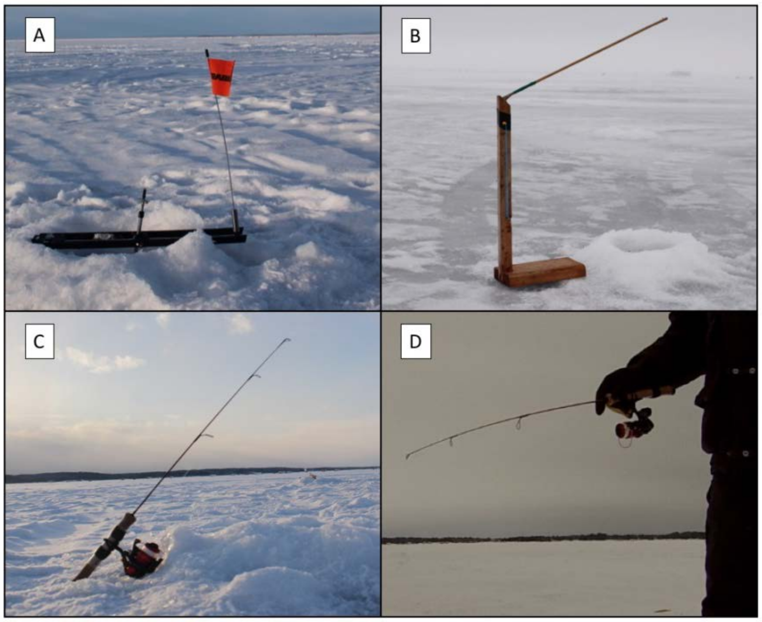
METHODS

Study Site and Collection Method

Ice fishing was conducted in South Bay of Lake Nipissing from January 10th to February 26th, 2017 (see Map 1). Fishing sites were selected with guidance from local outfitters and operators and under the advisement of Ontario Ministry of Natural Resources and Forestry personnel. Multiple gear types were used for targeting Walleye, encompassing both passive and active fishing methods that are typical of the local fishery (see Picture 1). Active fishing was conducted by an angler actively jigging off the bottom with medium-light action ice fishing rods spooled with 6 lb test monofilament line. Lures used included ¼ to ⅜ oz. treble hooked jigging spoons (Northland Fishing Tackle®, Bemidji, Minnesota, buckshot and macho minnow) and jigheads (Cabela's Inc., Sidney, New England, Cabela's Solid Color barbed Jigheads) baited with Emerald Shiner (*Notropis atherinoides*, Rafinesque 1818). Passive angling included angling techniques that were not actively presented to the fish by an angler (e.g., flag tipups, doorstop tipups, and set lines). All passive lines were set between 15-30 cm off the bottom, with suspended hooks (Gamakatsu Octopus #4, Gamakatsu Octopus circle #4, and ¼ to ⅜ oz. treble hooked jigging spoons) baited with shiner and weighted with a ¼ oz. lead sinker. All lines were set out each day with most lines (~75%) suspending the Octopus J-hooks. Passive lines were checked immediately when an indicator was triggered, and routinely throughout the soak time typically ranging between 0.25-0.75 h. Passive and active lines were fished both inside heated ice huts and outside. 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 was retrieved from the IONTARIO1123 weather station located in the local town of Callander (46.217, -79.37) 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.



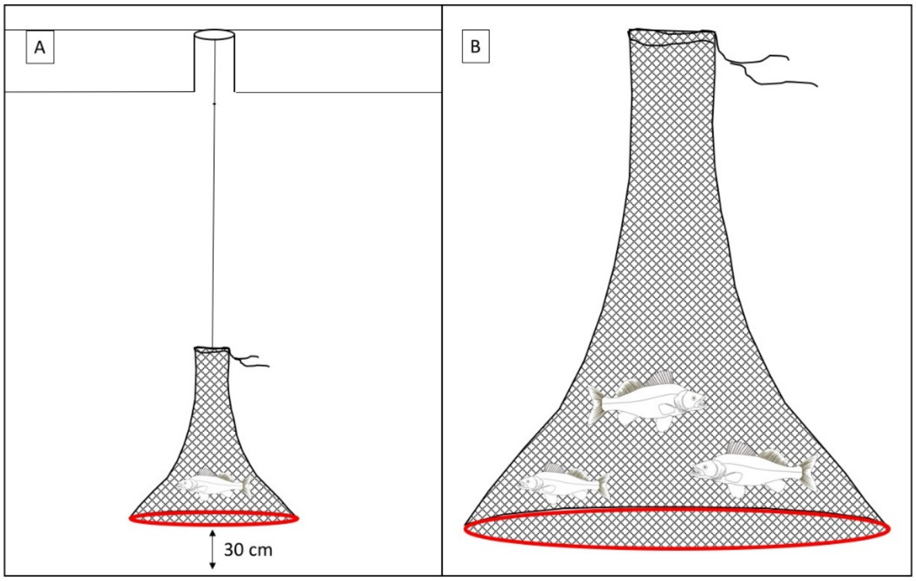
Map 1. A map of Lake Nipissing and surrounding communities. The study site in South Bay is highlighted by two black squares. Specific sampling locations are marked by black stars.



Picture 1: The fishing methods used to capture Walleye on Lake Nipissing. A) A tip-up set up that passively fishes for Walleye. The flag is raised when a fish has taken the bait. B) A homemade passive fishing setup commonly used by anglers on Lake Nipissing. C) A rod-and-reel set to fish passively. D) An angler using a rod-and-reel to actively fish (jig) for Walleye.

Mortality Assessment

Information on fishery specific handling practices was used to design handling treatments following capture based on personal observations and communications with local anglers, outfitters, and operators in South Bay. Fish were angled from depths ranging from 6.0-12.5 m to assess the proximal influences of barotrauma on post-release mortality. Upon hook set, each Walleye was retrieved to the surface where the hook was removed, hook location was noted, and total length was measured to the nearest 5 mm. During hook removal, physical signs of barotrauma were recorded if present (expended swim bladder in buccal cavity). A unique identifying combination of fin and/or dorsal spine clips was applied to each fish caught. For deeply-hooked Walleye (esophagus, gills, tongue), the line was either cut immediately or carefully removed using pliers. During fish processing, air exposure did not exceed 45 seconds. Fish were then assessed for the presence of the equilibrium reflex (a Reflex Action Mortality Predictor; RAMP) as described in Raby et al. (2012). Following exposures, fish were transferred into a water-filled holding tank and then into to a conical 0.5 m^3 sub-surface fish pen (0.5m diameter by 1.9m high conical net pen constructed of 25mm diameter nylon mesh from the H. Christiansen Company, MN, USA) within 90 seconds of landing. Nets were suspended in the water approximately 30 cm off bottom (see Pictures 2 and 3, respectively). Each successive Walleye captured was added to the same net pen until a maximum of 15 Walleye was reached. Walleye were held for variable periods and at changing densities throughout the holding period. The unique order that fish were put in the net was recorded to evaluate the potential influence of holding period and fish density on mortality.



Picture 2. Diagrams of the sub-surface holding pens used to monitor Walleye survival. A) The sub-surface holding pen suspended 30 cm off bottom by a rope connected from the sub-surface holding pen to the top of the ice fishing hole. B) A magnified view of the sub-surface holding pen featuring the drawstring used to quickly open and close the holding pen during fish transfers.

Picture 3. A photograph of the sub-surface holding pen for Walleye. The net presented here was recently removed from the lake and was frozen from cold air temperatures. The pen had approximate dimensions of 0.5 m radius, 1.9 m height, for a volume of 0.5 m^3.

Acute Physiological Responses to Angling Stressors

A separate group of Walleye were assessed for their physiological stress response to various handling treatments. Walleye were captured using passive angling gear only (tip-ups) and were assigned to one of four exposure groups: a 0 second air exposure, a 2 minute air exposure, a 2 minute snow exposure or a baseline group. 0 sec air exposed Walleye were transferred immediately to a water-filled holding tank. Air exposed Walleye were held in the angler's hands out of the water for 2 minutes. Snow exposed Walleye were placed on the snow for 2 minutes. All treatment fish (i.e., not baseline) were subsequently moved to the under-ice net pens and held for 1 hour. This number was selected as the stress response is typically upregulated by this point in time (reviewed in Barton and Iwama, 1991). After 1 hour of holding, blood was sampled via caudal venipuncture using a 21 gauge needle and a heparinized (Picture 4; Na^+ heparin, 10, 000 USP units·ml^{-1}; Sandoz Canada Inc., Boucherville, QC, Canada) 1 ml syringe. Fish in the baseline group had blood sampled immediately upon landing to ascertain baseline blood physiology values. A 3 minute cut-off time for the bleeding event was used to ensure no adverse effects associated with the sampling event (M. J. Lawrence and S.J. Cooke et al., unpublished data). Blood was then assessed for stress related metrics including concentrations of glucose and lactate using portable glucose (Accu-Chek Compact Plus, Hoffman-La Roche Limited, Mississauga, ON, Canada) and lactate (Lactate Plus, Nova Biomedical Corporation Canada Ltd, Mississauga, ON, Canada) portable point-of-care devices that have been validated for use with fish blood (reviewed in Stoot et al., 2014), respectively. Blood was then immediately centrifuged for 2 minutes to separate plasma from erythrocytes (2,000 ×g; Mandel Scientific, Guelph, ON, Canada). Plasma was decanted and stored at -80°C for later assessment of plasma [cortisol] and alanine amino transferase activities.

Picture 4. A non-lethal blood sample (~0.7 ml) being taken from the caudal vasculature of a Walleye using a 21 gauge heparinized needle.

Statistical Analysis

All statistical analyses were conducted in R Statistical Software (R Core Team, 2015). Statistical significance was assessed at $\alpha = 0.05$ and where appropriate data are presented as mean ± 95% confidence intervals. A logistic regression model was used to predict the factors contributing to mortality and anatomical hooking location. Both models included gear type, hook type, and total length 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, inner mouth) or deep (esophagus, gills, tongue) for statistical analysis to maintain sufficient sample size for each group. A separate logistic regression model was fitted with the order that fish were put into the net as a predictor variable for mortality. Differences in catch-per-unit effort (CPUE) across hook types (passive gear only) and gear were also evaluated using logistic regression models. CPUE was only evaluated for a subset of days (January 18^{th} to 27^{th}). During this period all three hook types were used on passive gear, and both active and passive fishing were used concurrently.

After modelling survival data by logistic regression we tested the applicability of the equilibrium reflex test (a RAMP indicator) to predict mortality using a chi-square test of proportions. We also subsampled data to only include deeply-hooked fish and compared cutting the line to removing the hook using a chi-square test.

Circulating metabolite concentrations (glucose and lactate) were modelled using analysis of variance (ANOVA), with handling treatment, fish length, and air temperature hypothesized as predictor variables.

Insufficient data existed for 20 of the Walleye captured and these fish were therefore only included for the mortality estimate and excluded from statistical models. All ANOVA 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 with the *hoslem_gof* function in the sjstats package (Lüdecke 2016). 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 assumption of logistic regression. In both the logistic regression and ANOVA, the intercept is the estimate for modeled factors with a level not explicitly shown in the output. A post-hoc Tukey test for general linear hypotheses was used when statistically significant differences existed for factors with greater than 2 levels. Where appropriate odds ratios (OR) are presented.

RESULTS

Size Classes

A total of 260 Walleye were angled by active (N = 113) and passive fishing methods (N = 147) with an average total length of 355 ± 5mm. Most Walleye caught were less than the 46 cm minimum size limit (only 2 of the 260 fish caught were larger than 46 cm; Figure 1). Mortality was not affected by the capture order in which fish were put into the net (z-value = -1.03, N = 240, p = 0.31).

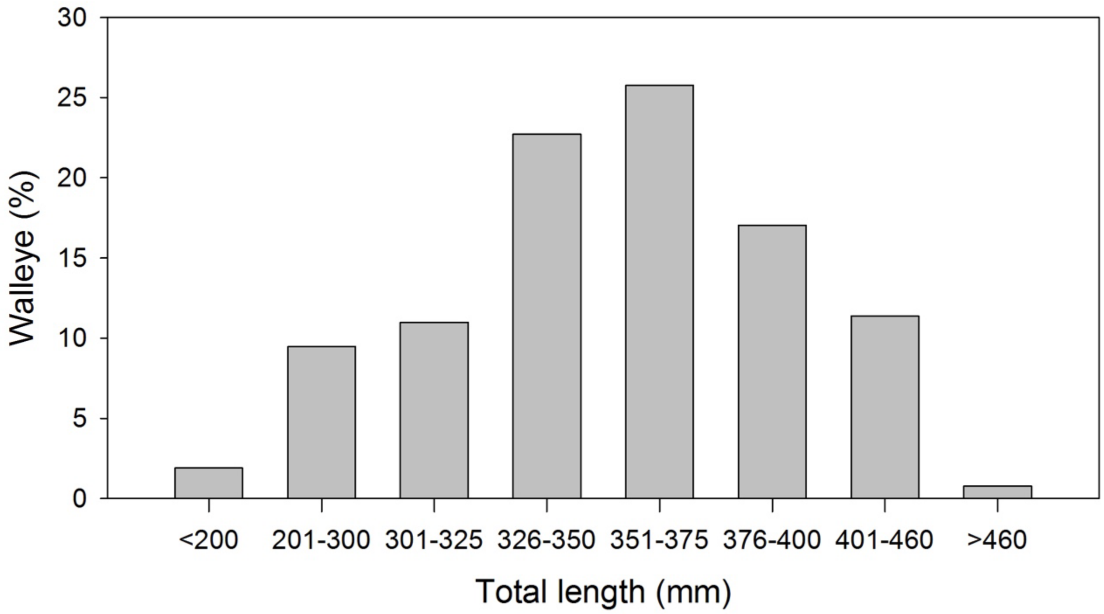


Figure 1. A relative frequency histogram depicting the size distribution of captured Walleye.

Catch Per Unit Effort (CPUE)

From January 10th to the 27th a total of 167 Walleye were caught during 3,655 hours of fishing. CPUE when passively fishing was significantly greater for circle (0.13 ± 0.02 fish·hour^{-1}) than both Octopus J (0.04 ± 0.01 fish·hour^{-1}; $p<0.01$), and treble hooks (0.05 ± 0.02 fish·hour^{-1}; $p<0.001$; Figure 2). CPUE when actively fishing (0.21 ± 0.06 fish·hour^{-1}) was significantly greater ($p<0.01$) than when passively fishing (0.04 ± 0.01 fish·hour^{-1}; Figure 3).

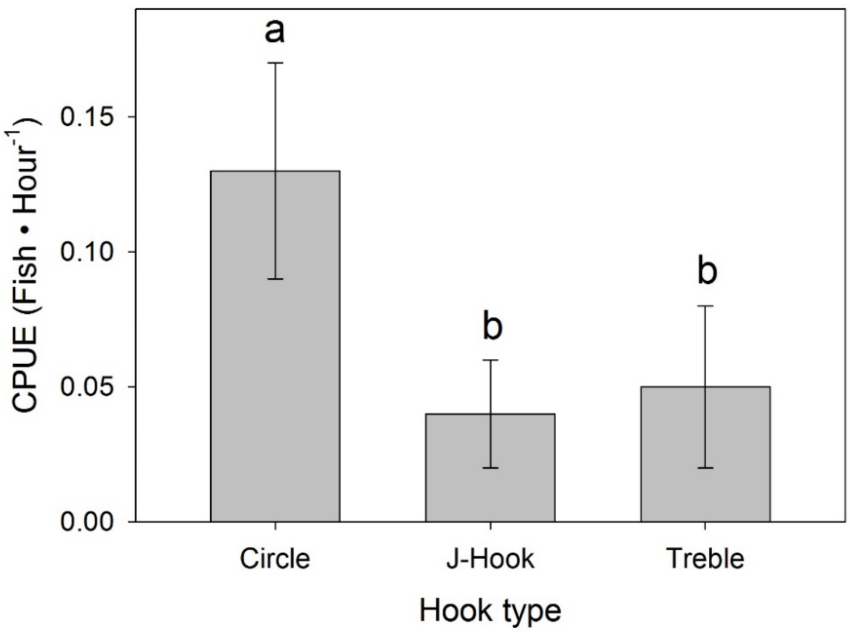


Figure 2. The CPUE (means ± CI fish·hour^{-1}) of Walleye using circle, J-hook, and treble hooks on passive fishing gear. Different letters denote a significant difference according to the Tukey HSD test ($p<0.05$).

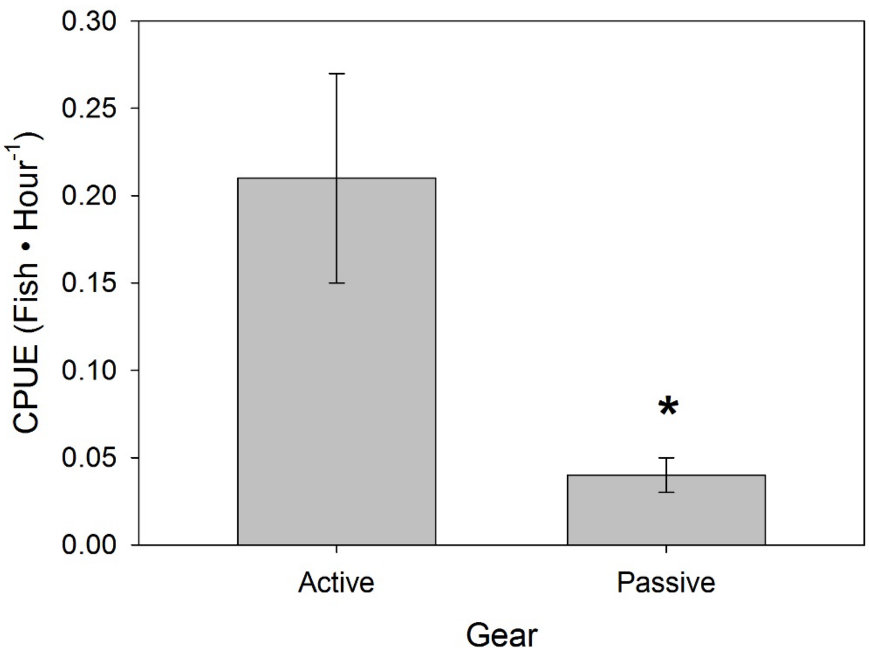


Figure 3. The CPUE (means ± CI fish·hour^{-1}) of Walleye using active (0.21 ± 0.06 fish·hour^{-1}) and passive (0.04 ± 0.01 fish·hour^{-1}) fishing gear. Asterisks denote a significant difference ($p<0.05$).

Mortality

A total of 18 Walleye died following ice-angling indicating a mortality rate of 6.9 ± 3.1% (N = 260). Mortality of Walleye caught by passive (9.8 ± 4.9%) and active angling (2.8 ± 3.2%) was not significantly different (z-value = 1.36, N = 240, p = 0.18; Figure 4). Mortality was not significantly different for Walleye caught by treble (N = 73) or octopus (N = 133) hooks relative to circle hooks (N = 34;, p = 0.12, p = 0.49; Figure 5). Deep-hooking increased odds of mortality by 5.19 (z-value = -2.40, N = 240, p = 0.02; Figure 6). Barotrauma was present in 22.2 ± 2.6% of captured Walleye, but did not significantly increase mortality relative to Walleye without barotrauma (z-value = -0.20, N = 240, p = 0.84; Figure 7). There was no significant effect of air temperature (z-value = -0.49, N = 240, p = 0.62), or length (z-value = -1.52, N = 240, p = 0.13; AIC = 122.58; Figure 8) on mortality rate. The same model for mortality was analyzed again with the inclusion of the interaction between hooking location and gear type (AIC = 124.30). Walleye that were caught on passive gear and deeply-hooked were not significantly more likely to succumb to mortality than Walleye caught actively and shallowly-hooked (z-value = -0.54, N = 240, p = 0.59). This model was not significantly different from the model excluding the interaction term (P=0.60). Statistical outputs are presented in Table 1.

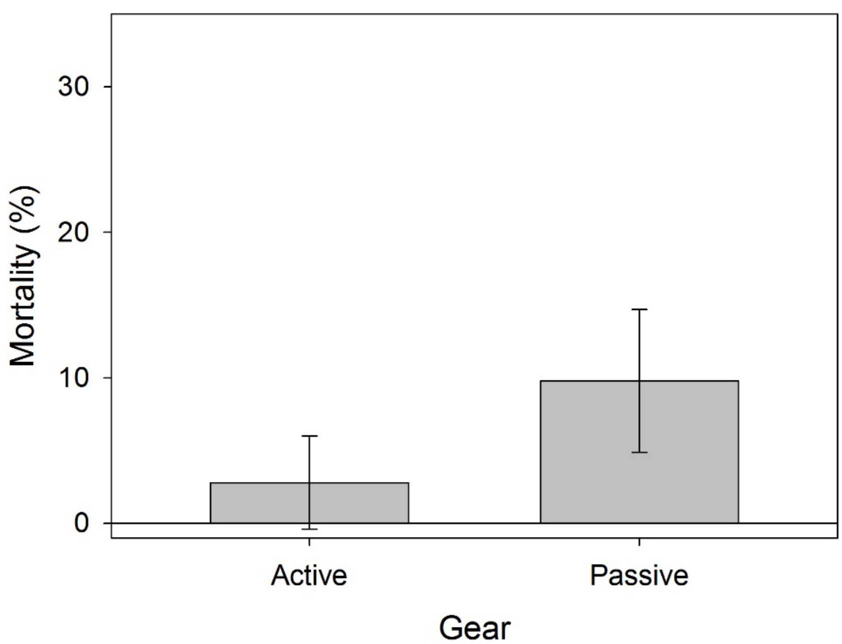


Figure 4. The 24 hour mortality (means ± CI%) of Walleye following ice-fishing CnR using active (2.8 ± 3.2%) and passive gear (9.8 ± 4.9%).

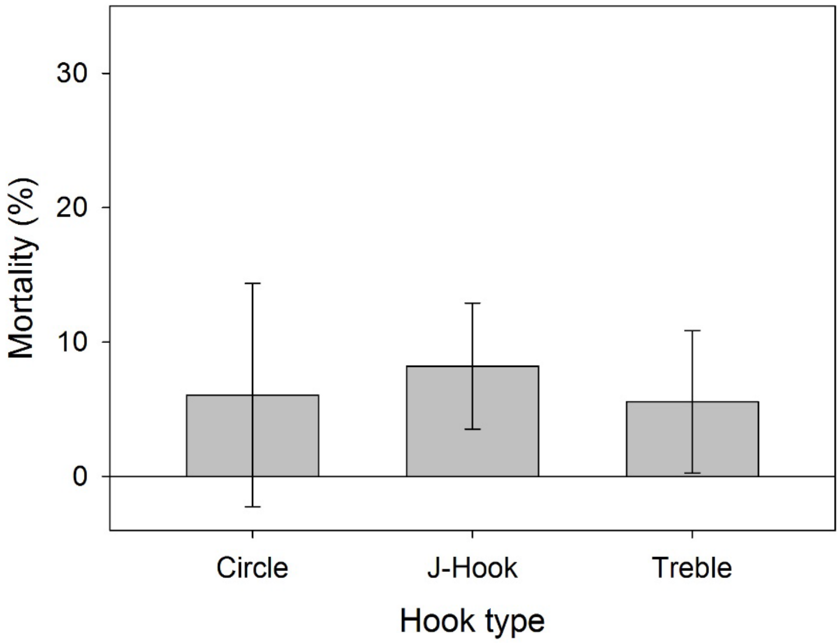


Figure 5. The 24 hour mortality (means ± CI%) of Walleye following ice-fishing CnR across circle (6.1 ± 8.3%), J-hook (8.2 ± 4.7%), and treble hooks (5.6 ± 4.6%).

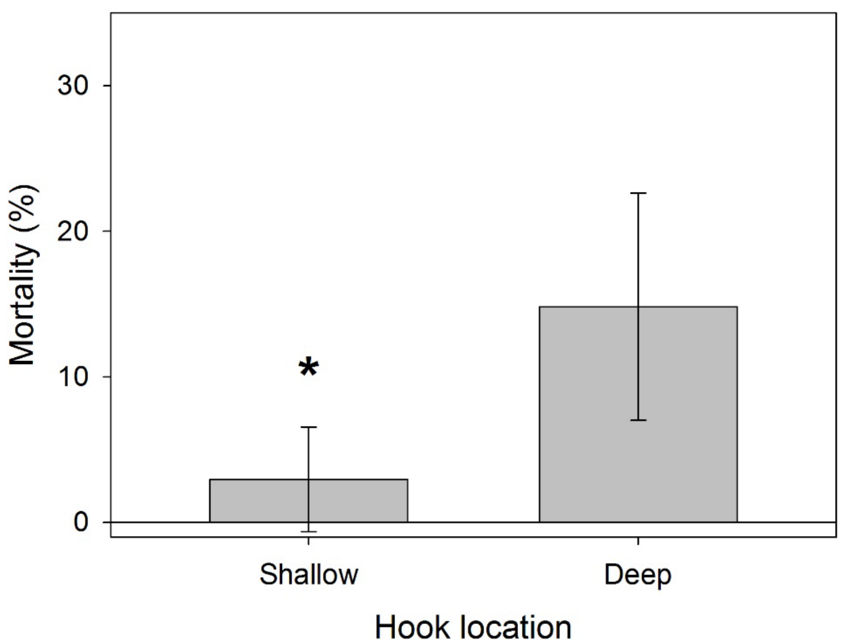


Figure 6. The 24 hour mortality (means ± CI%) of Walleye that were shallow (3.0 ± 2.6%), and deeply-hooked (14.8 ± 7.8%) following ice-fishing CnR. Asterisks denote a significant difference ($p<0.05$).

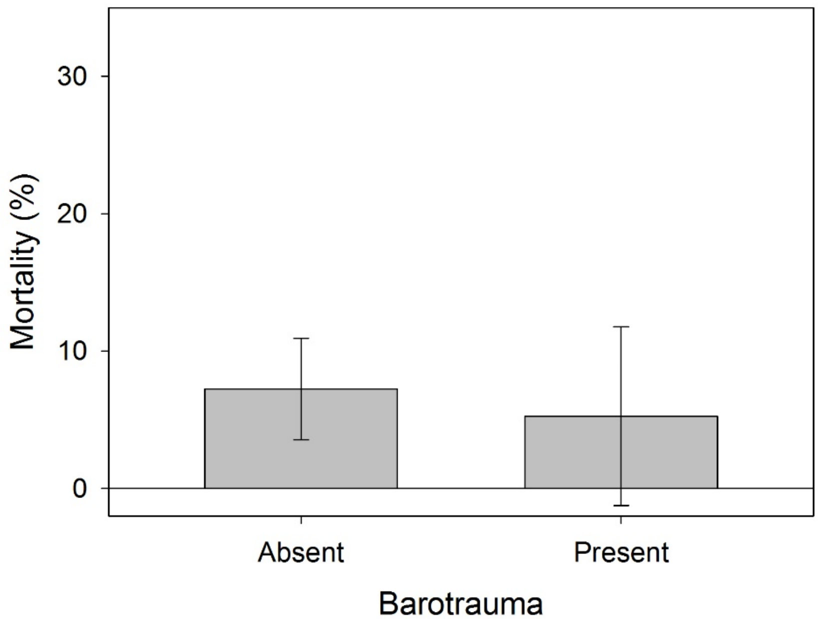


Figure 7. The 24 hour mortality (means ± CI%) of Walleye that had signs of barotrauma absent (7.3 ± 3.7%) and present (5.3 ± 6.1%) following ice-fishing CnR.

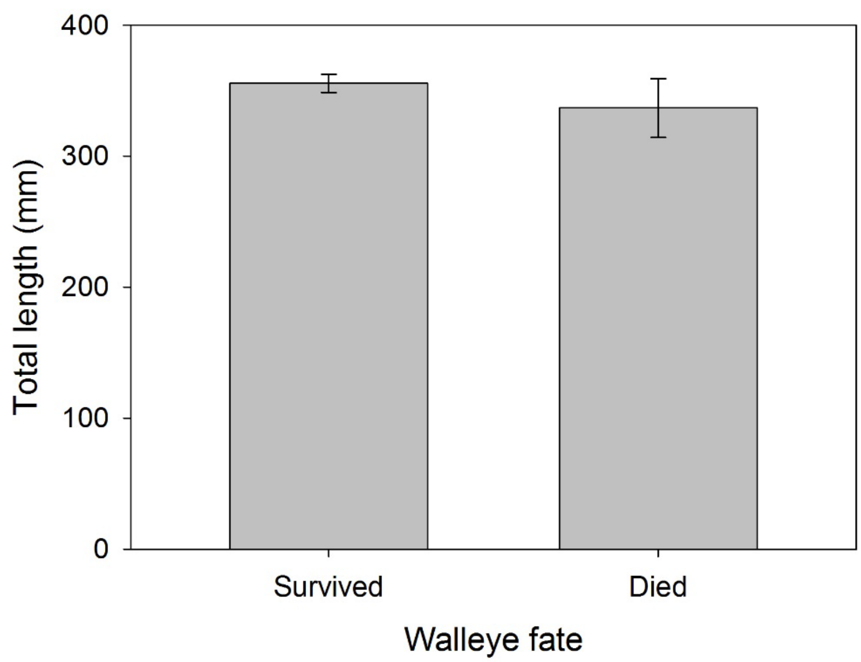


Figure 8. The average total length (means ± CI) of Walleye that survived (355.6 ± 6.9mm) and died (336.7 ± 22.4mm) ice-fishing CnR.

Table 1. Logistic regression model output predicting mortality of Walleye (*Sander vitreus*) captured by ice fishing. The model incorporated two continuous variables, total length and air temperature, and four factors. Inferences for factors are presented relative to reference levels, which were active for gear type, circle hook for hook type, deeply hooked for hooking location, and for the absence of barotrauma. Significant effects are highlighted by boldface font.

Model variable	Estimate ± SE	z-value	p-value
Intercept	-2.73 ± 1.84	-1.48	0.14
Total length (cm)	-0.01 ± 0.01	-1.52	0.13
Gear type: Passive	1.23 ± 0.91	1.36	0.18
Hook type: Octopus J	0.59 ± 0.84	0.69	0.49
Hook type: Treble	1.79 ± 1.14	1.56	0.12
Hooking location: Deep	**1.65 ± 0.70**	**-2.34**	**0.02**
Barotrauma: yes	-0.14 ± 0.70	-0.20	0.84
Air temperature (°C)	-0.02 ± 0.04	-0.49	0.62

Deep-hooking

Deep-hooking occurred in 32.5% of fish. Deep-hooking was significantly more frequent for passive (50.4 ± 8.2%) than active (9.3 ± 5.5%) fishing methods (z-value = 4.56, N = 240, p<0.01; Figure 9). Deep-hooking was not significantly more common for fish captured by treble (z-value = -1.63, N = 240, p = 0.10) or octopus J (z-value = 0.76, N = 240, p = 0.45) hooks relative to circle hooks (Figure 10). The total length of Walleye was also not a significant predictor of deep-hooking (z-value = -1.04, N = 240, p = 0.30). All statistical outputs are presented in Table 2.

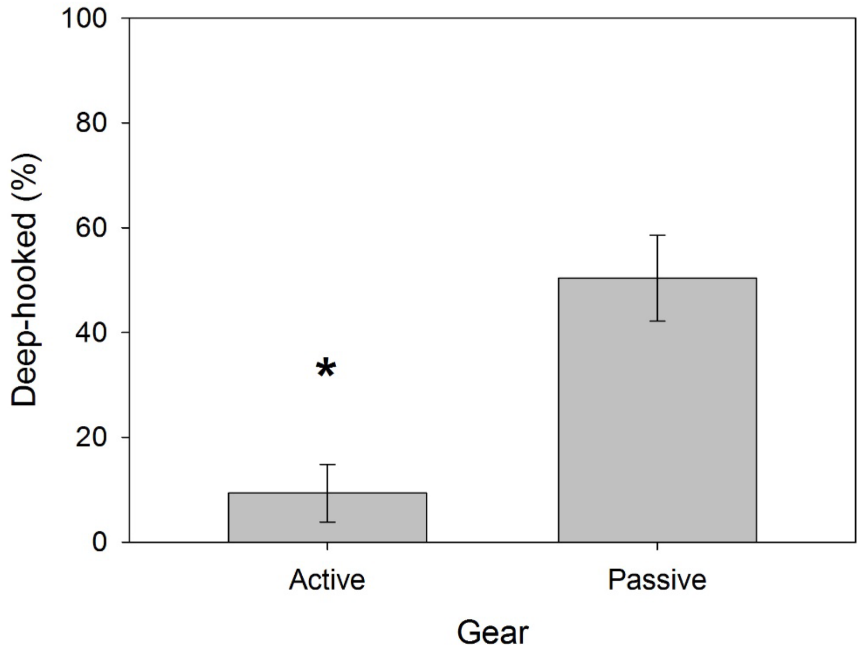


Figure 9. The extent of deep-hooking (means ± CI%) for Walleye captured by active (9.3 ± 5.5%) and passive ice-fishing gear (50.4 ± 8.2%). Asterisks denote a significant difference ($p<0.05$).

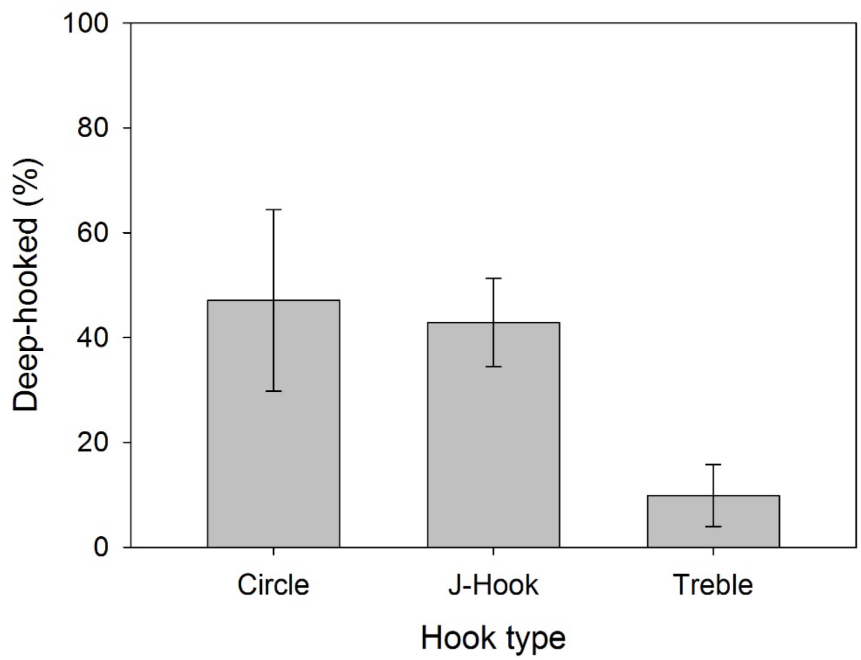


Figure 10. The extent of deep-hooking (means ± CI%) for Walleye captured by circle (47.1 ± 17.3%), J-hook (42.9 ± 8.4%), and treble hooks (9.9 ± 5.9%) during ice-fishing.

Table 2. Logistic regression model output predicting deep-hooking of Walleye (*Sander vitreus*) captured by ice fishing. The model incorporated total length as a continuous variable, and gear type and hook type as factors. Inferences for factors are presented relative to reference levels, which were active for gear type, and circle hook for hook type. Significant effects are highlighted by boldface font.

Model variable	Estimate ± SE	z-value	p-value
Intercept	-1.14 ± 1.14	-0.99	0.32
Total length (cm)	-0.01 ± 0.01	-1.04	0.30
Gear type: Passive	**2.12 ± 0.47**	**4.56**	**<0.01**
Hook type: Octopus J	0.31 ± 0.40	0.76	0.45
Hook type: Treble	-1.04 ± 0.64	-1.63	0.10

Cutting the Line vs Hook Removal

Deeply-hooked Walleye that had the hook removed (N = 31, 22.6 ± 15.0% mortality) had no significant difference in mortality compared to deeply-hooked fish that had the line cut (N = 45, 11.1 ± 9.3% mortality; χ^2 = 1.06, N = 76, p = 0.30; Figure 11).

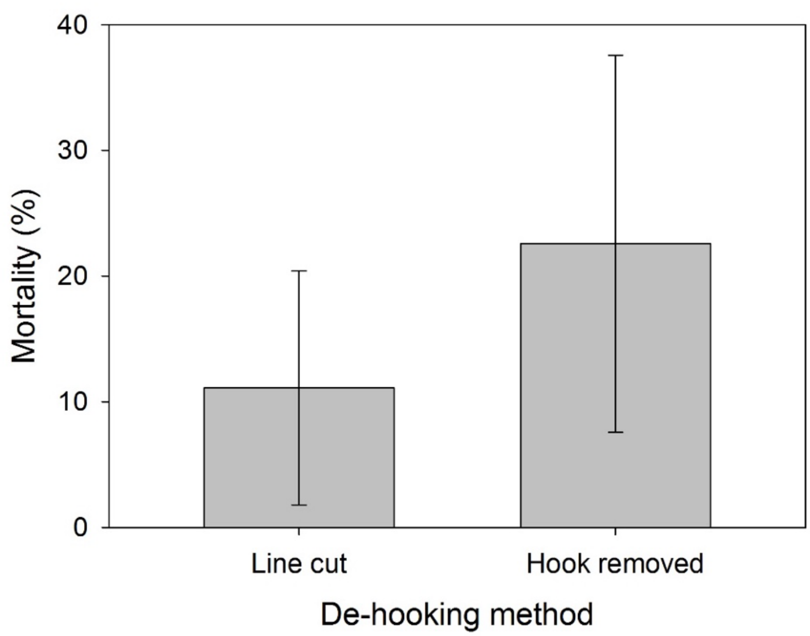


Figure 11. Mean 24 h mortality (means ± CI%) of deeply-hooked Walleye that had the line cut (11.1 ± 9.3%) or hook removed (22.6 ± 15.0%) following ice-fishing CnR.

Reflex Impairment Test

Impairment of the equilibrium reflex was not a significant predictor of Walleye mortality ($\chi^2 <$ 0.0001, DF = 1, p = 1.0).

Blood Metabolite Responses

Walleye angled and snow exposed for 2 minutes (t-value = 2.19, N = 11, p = 0.04), and Walleye angled with a 0 s exposure (t-value = 2.63, N = 10, p = 0.01) had significantly higher blood glucose levels than baseline blood glucose levels (N = 9), although no difference existed for Walleye that were air exposed for 2 minutes (t-value = 1.43, N = 11, p = 0.16; Figure 12). Blood lactate levels were significantly greater for Walleye angled with a 0 s exposure (t-value = 3.47, N = 9, $p<0.01$), angled with 2 minutes air exposure (t-value = 3.90, N = 12, $p<0.01$), and angled with 2 minutes snow exposure (t-value = 4.07, N = 11, $p<0.01$) compared to baseline lactate levels (N = 8). There were no significant differences in glucose or lactate levels between the 0 second, 2 minutes air, or 2 minutes snow exposure groups (all $p>0.05$). Neither of these blood physiology values were significantly affected by the ambient air temperature nor the length of the fish. All statistical outputs are presented in Tables 3 and 4.

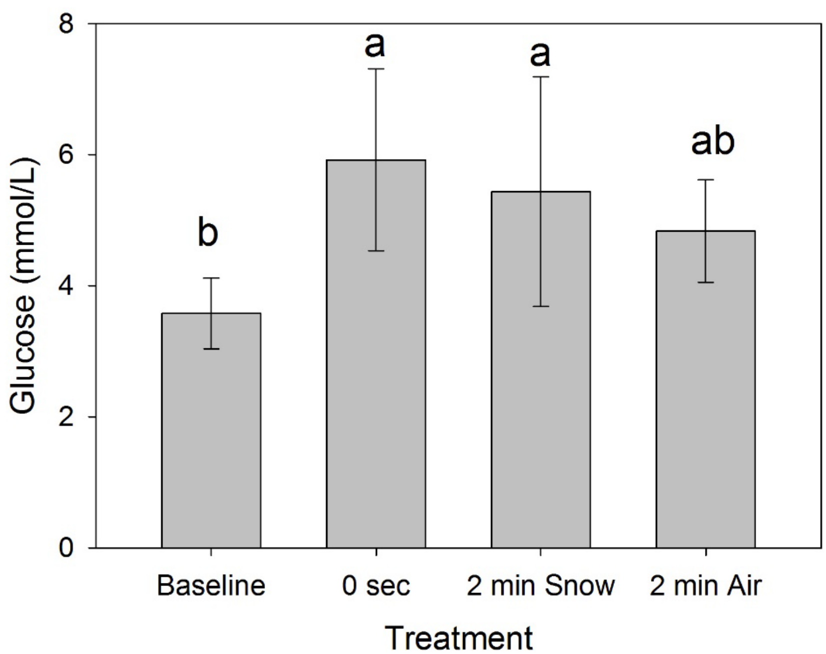


Figure 12. Blood glucose levels (means ± CI mmol·L^{-1}) of Walleye captured and blood sampled immediately (3.58 ± 0.54 mmol·L^{-1}), or after a 0 second exposure (5.92 ± 1.39 mmol·L^{-1}), 2 minutes snow exposure (5.44 ± 1.75 mmol·L^{-1}), or 2 minute air exposure (4.83 ± 0.40 mmol·L^{-1}) and one hour of holding. Different letters denote a significant difference ($p<0.05$).

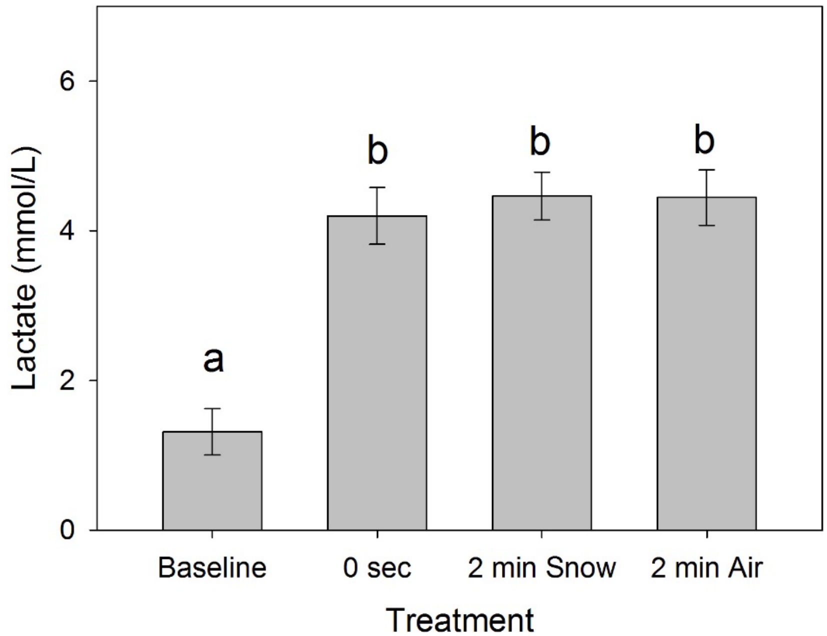


Figure 13. Blood lactate levels (means ± CI mmol·L^{-1}) of Walleye captured and blood sampled immediately (1.31 ± 0.31 mmol·L^{-1}), or after a 0 second exposure (4.20 ± 0.38 mmol·L^{-1}), 2 minutes snow exposure (4.46 ± 0.32 mmol·L^{-1}), or 2 minutes air exposure (4.44 ± 0.37 mmol·L^{-1}) and one hour of holding. Different letters denote a significant difference ($p<0.05$).

Table 3. Linear regression model output predicting blood glucose levels of Walleye (*Sander vitreus*) following capture by ice fishing. The model incorporated total length and air temperature as continuous variables and air exposure duration as a factor. Inferences for the factor are presented relative to a reference level, which is the baseline air exposure group. Significant effects are highlighted by boldface font.

Model variable	Estimate ± SE	t-value	p-value
Intercept	2.78 ± 1.98	1.41	0.17
Total length (cm)	0.01 ± 0.01	0.13	0.89
Exposure: 2 min air	1.27 ± 0.89	1.43	0.16
Exposure: 0 s air	**2.58 ± 0.98**	**2.63**	**0.01**
Exposure: 2 min snow	**2.00 ± 0.91**	**2.19**	**0.04**
Air temperature (°C)	-0.08 ± 0.05	-1.50	0.14

Table 4. Linear regression model output predicting blood lactate levels of Walleye (*Sander vitreus*) following capture by ice fishing. The model incorporated total length and air temperature as continuous variables and air exposure duration as a factor. Inferences for the factor are presented relative to a reference level, which is the baseline air exposure group. Significant effects are highlighted by boldface font

Model variable	Estimate ± SE	t-value	p-value
Intercept	1.70 ± 1.61	0.30	0.30
Total length (cm)	0.01 ± 0.01	0.86	0.86
Exposure: 2 min air	**2.91 ± 0.75**	**3.90**	**0.01**
Exposure: 0 s air	**2.85 ± 0.82**	**-3.47**	**0.01**
Exposure: 2 min snow	**3.12 ± 0.77**	**4.07**	**0.01**
Air temperature (°C)	0.02 ± 0.04	0.41	0.68

DISCUSSION

Overview

Recreational ice fishing for Walleye is a popular activity in north temperate regions. In many winter Walleye fisheries a substantial number of fish are released to comply with Provincial or State fishing regulations. The present study evaluated the survival of Walleye following ice-angling on Lake Nipissing, Ontario and investigated which factors may contribute to Walleye mortality. On Lake Nipissing it is estimated that ~99% of Walleye are under the legal minimum size (personal comm. OMNRF staff and consistent with data presented in this study). Winter Walleye mortality following CnR was estimated to be 6.9 ± 3.1% after 24 h. Deep-hooking occurred in 32.5% of captured Walleye and was significantly more common for fish caught using passive fishing gear and represented a modestly elevated rate of mortality when compared to shallowly-hooked fish. Other environmental variables such as capture depth (barotrauma) and air temperature had little influence on Walleye survival. Walleye captured by angling had significantly higher blood glucose and lactate levels compared to baseline levels (as expected), although no differences existed across different air exposure groups.

Walleye Mortality

Walleye mortality following ice-angling was 6.9 ± 3.1%. Previous CnR research on Walleye caught in the summer (non-tournament only) have reported hooking mortality rates 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). Water temperature in particular is associated with release mortality in many species (i.e., higher temperatures correspond with higher levels of mortality; Cooke and Suski, 2005). These Walleye mortality estimates are particularly wide-ranging, and could be partly explained by differences in study design (e.g., holding pen style, holding duration, and fish handling) but are a likely reflection of differences across Walleye fisheries and the water bodies where the studies occurred. Abiotic and intrinsic biological factors related to the fishery can explain context-specific differences in CnR outcomes (Cooke and Suski, 2005). Differences in weather conditions, fish physiology, and angler behaviour during the winter months could play an important role in the mortality of ice-angled Walleye.

Mortality and Angling Method

Fisheries-related differences in angler behaviour (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 Walleye had a particularly high rate of deep-hooking (32.5% overall), which may in part be explained by the considerable use of passive gear. Fish caught passively had a significantly higher incidence of deep-hooking (50.4 ± 4.2% deep-hooking) in contrast to fish caught actively (9.3 ± 2.8% deep-hooking). 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 (Lennox et al., 2015). Deep-hooking is also typically more common in fish captured by live bait (Arlinghaus et al., 2008), which is used almost exclusively when ice-angling Walleye on Lake Nipissing. The 32.5% deep-hooking rate for Walleye captured in the present study is considerably higher than in many other CnR fisheries (Sell et al., 2016), a likely result of using live bait and passive angling on Lake Nipissing. Although previous research suggests deeply-hooked fish are at risk of death due to critical damage to vital organs and blood loss (Hall et al., 2015), the deeply-hooked Walleye in our study had a remarkably high 24 hour survival rate (85%) and low incidences of bleeding (10%). Minimal blood loss may be explained in part by the lowered metabolism of fish during cold temperatures and correspondingly slower blood flow (Egginton, 1997), and ultimately explains the observed high survival rates. Nonetheless, deeply-hooked Walleye were significantly more likely to die than shallow-hooked Walleye highlighting the importance of hooking location in fish survival. As such any efforts to reduce deep hooking would be of benefit to released fish.

Anglers that choose to release a deeply-hooked fish can 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 tearing of vital organs (e.g., gills, esophagus). 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 Bluegill (*Lepomis macrochirus*, Rafinesque 1818) has indicated a relatively high ability to shed the hook over a short-term period (within 48 hours), and higher survival compared to Bluegill that had the hook removed (Fobert et al., 2009). To evaluate the potential role anglers have on the survival of deeply-hooked Walleye fish in our study either had the line cut or had the hook removed using pliers. Consistent with the findings of Reeves and Bruesewitz (2007) there was no statistically significant difference in survival for Lake Nipissing Walleye.

Mortality and Hook Selection

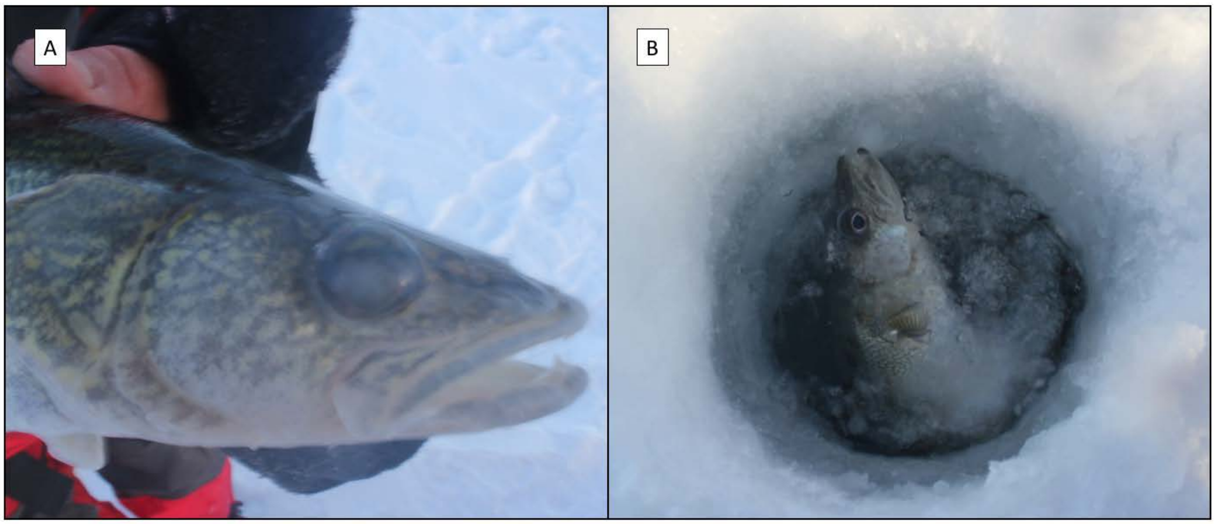
Hook selection can have a considerable role on the severity of anatomical hooking damage following capture (Cooke et al., 2003). In the present study, we compared the hooking locations of treble, Octopus J-hooks, as well as circle hooks that have been posited as a better alternative to conventional hooks (Serafy et al., 2012). Hooking location (shallow vs deep) in ice-angled Walleye was not related to the type of hook (circle, octopus J, or treble hooks), although treble hooks appeared to have deeply-hooked a lower proportion of fish compared to J-hooks. This lower percentage of treble hook deep-hooking 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 as they are larger in size than a single hook, thus making them more difficult to ingest. Mortality rates were not appreciably lower for treble hooks suggesting that the additional stress associated with multiple hooking locations and additional handling due to increased hook removal difficulty may obscure the potential benefit of reduced deep-hooking.

A previous CnR evaluation on Walleye used the exact hook type (Gamakatsu size 4 Octopus J-hooks) but had considerably different mortality estimates than those generated in this report (this studies estimate of ~7% vs 25% in Reeves and Staples, 2011). However the Reeves and Staples (2011) study occurred during the open water season when temperatures are warmer. This large discrepancy between mortality estimates despite using the same hook type suggests that other factors related to the fishery (e.g., water temperatures, fishing method, and capture depth) may have a greater role in influencing mortality.

Mortality and Abiotic Factors

Abiotic factors such as the water temperature of a lake can have an important influence on fish physiology and the resulting stress of capture particularly when temperatures are extreme. The corresponding recovery period of ice-angled fish is typically longer in duration but less intense than that of fish angled in the summer (Louison et al., In Press). In addition to metabolic constraints imposed by ice-angling, capture events can also result in epithelial damage from exposure to cold air temperatures. Similar to Rowe and Esseltine (2001), the Walleye in our study showed signs of freezing damage to the eyes and gills (see Picture 5). Air temperature was not a significant predictor of Walleye stress parameters (glucose and lactate), although we recommend that the exposure of Walleye to these extreme temperatures should still be avoided or minimized to reduce the potential for long-lasting physical damage.

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. This expansion can render fish unable to swim away from the surface or maintain normal orientation (equilibrium). Approximately 23% of Walleye had signs of barotrauma although fish with barotrauma were not significantly more likely to die. This result is contrary to the previous CnR study completed on Lake Nipissing Walleye that highlighted the importance of capture depth on the presence of barotrauma and mortality (Rowe and Esseltine, 2001). Our result is consistent with Reeves and Bruesewitz (2007) and Bettoli et al. (2000) who found little influence of capture depth and barotrauma on mortality. Further research could assess the efficacy of venting as a conservation tool for Walleye with severe signs of barotrauma.



Picture 5: Two common examples of physiological damage incurred following an ice angling event. A) A Walleye with frozen ocular tissue after exposure to cold air temperatures. B) A Walleye with a distended swim bladder (barotrauma) unable to swim down from the surface.

Blood Metabolite Response

The Walleye exposed to the fisheries related stressors (air or snow exposures) demonstrated elevated concentrations of lactate and glucose in the blood. This likely stems from a combination of the burst swimming during the angling event as well as the reduced gas exchange across the gills during the air or snow exposures (i.e., hypoxia; Wood, 1991) which is a common occurrence during an angling event (Perrier et al., 1978; Furimsky et al., 2003; Kieffer and Cooke, 2009; Brownscombe et al., 2014). Capture by anglers initiates the endocrine stress response, specifically stimulating glucorticoid release (cortisol) and glucose mobilization into the bloodstream, likely explaining the elevation in blood glucose concentrations observed here (Wendelaar Bonga, 1997). The metabolic acid load in the form of lactate represents a large fraction of the animal's oxygen debt that must be repaid over the hours following release. During this time, oxygen consumption is markedly elevated (excess post exercise oxygen consumption in order to repay the oxygen debt and generally includes the restoration of hydromineral balance and the re-synthesis of energetic substrates (e.g., PCr, ATP, glucose, etc.; reviewed in Wood, 1991). However, the amount of oxygen that can be devoted to such activities is limited by its metabolic scope which represents a budgeting of oxygen that can be devoted to non-essential functions (Fry, 1947). In instances where this scope is exceeded for extended durations, mortality can result which may explain some of the deaths occurring in the study (Sokolova, 2013). Furthermore metabolic scope is generally believed to be reduced under decreasing environmental temperatures which may act to further constrain energetic budgeting and enhance mortality in these conditions (Pörtner and Farrell, 2008). In more acute instances the diversion of the metabolic scope to repaying an oxygen debt may also impair other functions in the fish including swimming performance, predator evasion, and even reproduction (Guderley and Pörtner, 2008). Together the air and snow exposures represent a considerable threat to the physiological homeostasis of these fish and our general recommendations are to minimize air or snow durations to reduce the severity of the impact on these fish.

CONCLUSIONS

Ice angling for Walleye in Lake Nipissing resulted in relatively infrequent mortality (~7%) which is in line with other estimates of summer CnR mortality but lower than the previous estimate of ice-angling mortality on Lake Nipissing. The incidence of deep hooking was frequent, a probable outcome when angling with small baited hooks set on passive lines. Although circle hooks were ineffective for reducing deep hooking, larger hooks may be tested to determine whether they may reduce the frequency of deep hooking as this is generally believed to be the most common cause of mortality for fish captured in recreational fisheries. Mortality from deep hooking in this study was rather low at 14.8%. Overall, Walleye were resilient to capture and handling in the recreational winter fishery including handling in air and on ice prior to release. Even fish that exhibited symptoms of barotrauma had high survival which had previously been determined to be an important factor causing mortality of Walleye in the fishery (Rowe and Esseltine, 2001). We held Walleye at their capture depth which may have allowed fish with barotrauma to compensate. Results from this study suggest relatively high survival for Lake Nipissing Walleye following CnR angling in the winter.

ACKNOWLEDGEMENTS

We extend our gratitude to Mike Young of Lake Nipissing Ice Fishing Charters for providing valuable information on fishing locations and techniques specific to Walleye on Lake Nipissing. We thank Aaron Zolderdo, Dirk Algera, Tanya Prystay, Sindre Håvarstein Eldøy, Garrett Normoyle, Colin Raymond Davis, Emily J. Way-Nee, and the many research technicians from The Ontario Ministry of Natural Resources and Forestry (OMNRF) that donated their time to help make this project possible. We thank George Morgan and Kim Tremblay of OMNRF for their helpful comments and suggestions to the report. Funding was provided by OMNRF. All research was conducted in accordance with the guidelines of the Canadian Council on Animal Care as administered by Carleton University.

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