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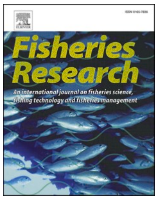

Do angler experience and fishing lure characteristics influence welfare outcomes for largemouth bass?

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ABSTRACT

Catch-and-release (C&R) angling is common with anglers releasing a portion of their catch to comply with harvest regulations or because of their conservation ethic. The basis of C&R lies in the assumption that a large proportion of the fish survive and experience limited fitness consequences – that is, the welfare status of individual fish is maintained. However, the level of experience of an angler, as well as use of different gear and lure types, can greatly influence the rate of hooking injury and mortality. These relationships have been documented for a variety of fish species, but few studies have considered the influence of both angler experience and gear or lure type simultaneously. The aim of this study was to evaluate the relationships between angler experience, lure characteristics, landing time, hooking injury, and handling time in the Largemouth Bass (*Micropterus salmoides*). Largemouth Bass were captured by hook and line between July and September 2018 by anglers with a wide range of experience (novice to professional). During and after these events, measurements were taken on fish characteristics, angler experience, lure characteristics, and welfare outcomes. Generalized linear models indicated that lure characteristics (lure type, size, and number of hooks) had a significant influence on fish injury and handling time, whereas angler experience did not. Specifically, lures with more hook points resulted in shallower hooking depths but longer dehooking times. These results indicate that lure choice is an important aspect of managing C&R fisheries. When choosing a lure, there may be a tradeoff between minimizing the physiological stress associated with handling and air exposure, and reducing the chances of injury and deep hooking. Additional research is needed to better understand such trade-offs across a range of environmental conditions and species.

1. Introduction

Recreational fisheries are often the primary use of freshwater fish stocks in industrialized countries, and are increasingly being recognized for their economic, ecological, and social importance in both industrialised and developing countries (Arlinghaus et al., 2016, 2012). Although a component of the catch is harvested, many fish are captured and subsequently released (called catch-and-release – herein C&R). The reasons for C&R vary and include compliance with fisheries management regulations (Anderson and Nehring, 1984; Johnston et al., 2011; Murray et al., 1999) and the voluntary, conservation driven behavior of anglers (Myers et al., 2008). Recent data from Canada suggests that 70 % of angled fish are released, with release rates in some provinces being even higher (e.g. > 80 % in Ontario; Fisheries and Oceans Canada, 2019). In the U.S. in 2017, 42.8 % of Americans who participated in recreational fishing released all of their catch, and an additional 17.0 % released at least some of their catch (Recreational Boating and Fishing Foundation, 2018). Additionally, C&R is becoming increasingly popular in other developed and developing nations worldwide (e.g. Gagne et al., 2017; Gupta et al., 2015; Jellyman et al., 2016). C&R as a conservation

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and management strategy assumes that a large proportion of fish survive post-release and experience limited fitness consequences– that is, their welfare status is maintained (Wydoski, 1977; Cooke and Schramm, 2007). However, fish may experience negative effects from stressors related to C&R angling such as hooking injury, air exposure, and exhaustive exercise (Brownscombe et al., 2017).

There are many different aspects of C&R angling events that can reduce welfare status (Cooke and Sneddon, 2007) and contribute to potential mortality of angled fish (Arlinghaus et al., 2007). These factors have been documented in many fish species and relate largely to the equipment used by anglers or the behaviour of the anglers themselves, and can include injuries or physiological stress that can have fitness consequences post-release (Brownscombe et al., 2017).Hooking injuries are considered the primary cause of mortality in released fish, because mortality is often associated with bleeding or tissue damage after hooking in sensitive tissues such as the gills and eyes, or from 'deep hooking' in the stomach, esophagus or gills (Bartholomew and Bohnsack, 2005; Brownscombe et al., 2017; Cooke and Suski, 2005; Muoneke and Childress, 1994). In general, shallower hooking (i.e. in the jaw or lip) is less harmful because it often results in only a small puncture wound and the hook is easier to remove (Brownscombe et al., 2017)..

Physiological stress during landing or handling (including air exposure) can have significant consequences for fish post-release because it can cause behavioural impairment(Raby et al., 2014), hinder their ability to avoid predators or forage for food (Siepker et al., 2007), or alter reproductive success (Richard et al., 2013). These stressors can be cumulative, and in highly exploited populations where fish can be caught and released several times a year, the compounded stress can leave fish more vulnerable to disease or infections (Skaggs et al., 2017; Snieszko, 1974; Wright, 1970). All of the above factors can increase the chance of post-release mortality and therefore reduce the effectiveness of C&R as a conservation strategy. With such high rates of release in recreational fisheries, particularly among black bass (Quinn, 1996), minimizing these effects is a key component to establishing sustainable fisheries.

When used properly, certain equipment has been shown to reduce injury rates and physiological stress of fish during capture (Brownscombe et al., 2017). Using hard lures such as crankbaits or spinnerbaits could reduce the chance of hooking injury compared to soft plastics or live baits (Arlinghaus et al., 2008; Reeves and Staples, 2011; Stålhammar et al., 2014). It is unclear if this is because of the nature of the bait type or differences in fishing style (e.g., if fished actively or passively). The type and number of hooks used is also an important factor. It is believed that using fewer hooks (i.e. fewer number of hooks or using single instead of treble) reduces injury and dehooking times but findings seem to be context specific (Muoneke and Childress, 1994). The size of hooks and baits used can also influence capture and injury rates, and it has been suggested that smaller lures and hooks increase the likelihood of deep hooking and potential physical injury (Arlinghaus et al., 2008; Brownscombe et al., 2017).

The knowledge and behaviour of the angler can also influence the level of stress and injury imposed on fish that are caught and released. Prolonged durations of capture (also referred to as landing time) can increase physiological stress (Meka and McCormick, 2005; Suski et al., 2007) or further injure the fish if it comes in contact with the fishing line or additional hooks on the lure (Colotelo and Cooke, 2011). Once reeled in to the boat, improper handling of fish can lead to air exposure (reviewed in Cook et al., 2015), slime loss, or physical injury to internal organs (reviewed in Brownscombe et al., 2017). Other factors related to handling that have been suggested to influence injury rates are the material and mesh size of landing nets (Lizée et al., 2018) and the use of mechanical lip-gripping devices (Danylchuk et al., 2008; Skaggs et al., 2017). More experienced anglers may have greater knowledge of proper handling techniques or of how to use appropriate equipment to minimize stress and injury. In recent years, angler education has become an increasingly important part of management of C&R fisheries (e.g. the Keepemwet program; Danylchuk et al., 2018), and at least in the short term, can help to encourage responsible angling practices (Delle Palme et al., 2016).

It is apparent that both the use of certain equipment, and the behaviour or knowledge of anglers can greatly affect injury rates in fish and therefore influence effectiveness of C&R angling as a management strategy. While this has been documented extensively in the literature, few studies have considered both the influence of angler experience and gear type or compared a wide range of equipment. The aim of this study was to evaluate the relationships between angler experience, lure characteristics, duration of capture and handling, and rates of hooking injury (i.e. welfare outcomes) in a socio-economically important fish, largemouth bass (*Micropterus salmoides*). Largemouth bass were chosen as a study species because they are one of the most sought-after sportfish in North America (Quinn and Paukert, 2009), and can readily be captured by both novice and experienced anglers.

It was hypothesized that lure characteristics (lure type, size, and number of hooks) would influence the dehooking time (Fig. 1a) as well as welfare outcomes (occurrence of blood, hooking depth and location, and reflex impairment; Fig. 1b). Specifically, lures with more hooks were expected to lead to prolonged dehooking time (because of the higher chance for entanglement with the net or line and higher number of hooks to remove; Lizée et al., 2018) and higher occurrence of blood, while larger lures were expected to result in shallower hooking depths because the fish would not be able to ingest it as far (Arlinghaus et al., 2008). Angler experience was hypothesized to influence the landing time, as well as welfare outcomes in largemouth bass (Fig. 1), with more experienced anglers having shorter landing times, and fewer instances of injury. Dehooking time was also expected to be influenced by hooking depth and hooking location, with deeper hooks taking longer to remove as well as hooks in sensitive locations (e.g. gills, eye, esophagus).

2. Materials and methods

2.1. Field methods

All research was conducted under an animal use permit issued by the Carleton University Animal Care Committee (Protocol 110558) as well as scientific collection permits issued by the Ontario and Quebec governments. Largemouth Bass were captured by hook and line between July and early September 2018, after water temperatures had stabilized to between 24 and 26 °C. Angling occurred at two main locations: the Rideau Canal Waterway between Kingston and Ottawa, Ontario, Canada; and on Papineau Lake located in the Kenauk Nature Reserve near Montebello, Quebec, Canada. These waterways were chosen because they both support popular sport fisheries where largemouth bass are targeted and have similar thermal regimes. The sites are separated by less than 200 km of linear distance and less than 50 km of latitudinal difference.

Anglers consisted of fishery biologists and undergraduate students from Carleton University, as well as volunteer anglers (including professional anglers and children – all of whom completed volunteer forms). Anglers were scored based on their fishing experience on a scale from one to three. A score of one was given to novices with little to no fishing experience (who had been fishing on less than 10 occasions); a score of two was given to intermediates with moderate fishing experience (between novice and expert); and a score of three was given to experts who had extensive experience fishing bass (~5 years of experience with 50+ days per year – often fishing guides or professional anglers) (adapted from Meka, 2004). For all of our research activities involving fish we record the research team members (and volunteers) who caught individual fish as part of our biological sampling strategy. We consulted the Carleton University Ethics Committee and for this study it was deemed that no ethics approval was required given that accounting for variation in sampling is an inherent aspect of science.

Rather than comparing specific lures or baits, this study aimed to

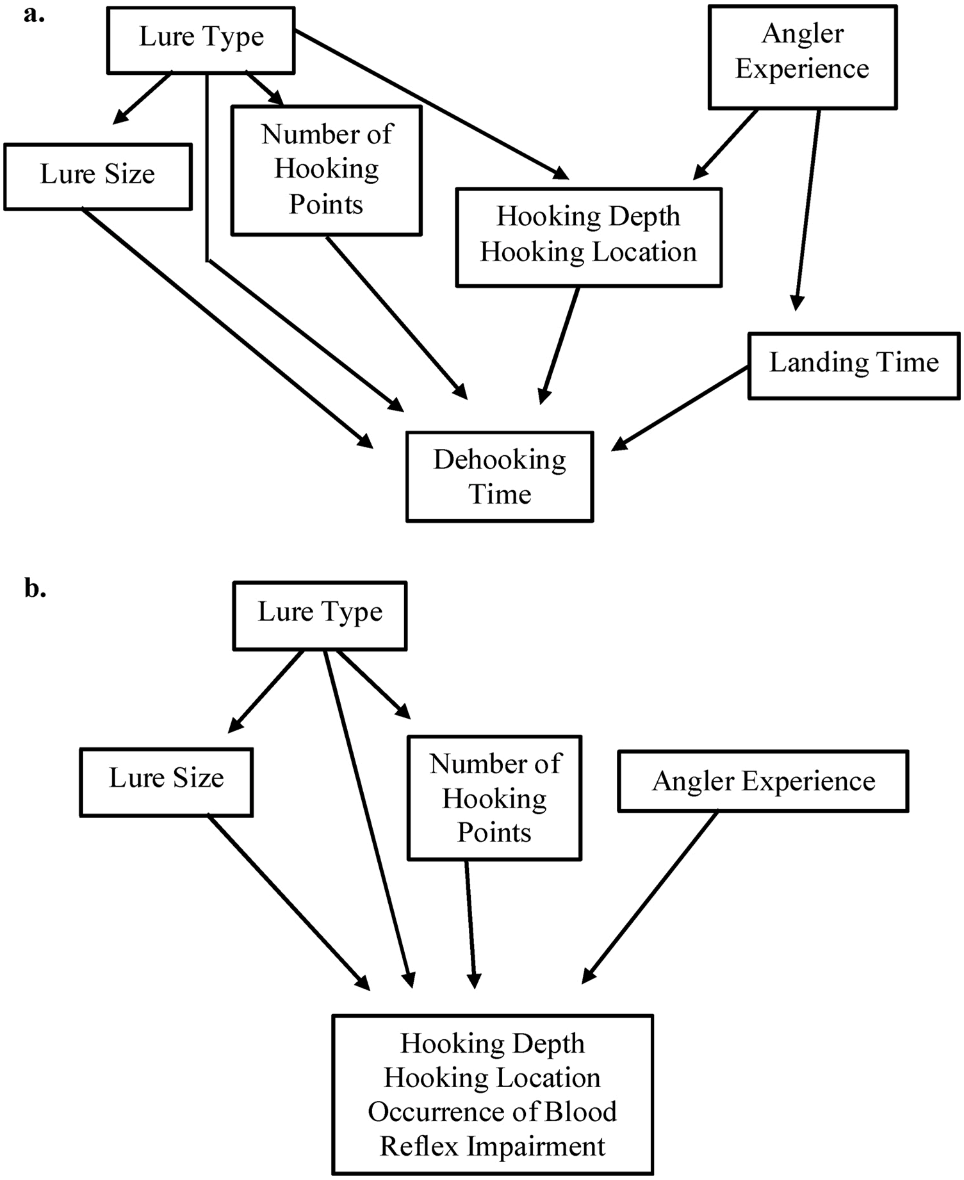

Fig. 1. Hypothesized Influence of Angler Experience and Lure Characteristics on **a.** Duration of Capture and **b.** Rates of Injury in Largemouth Bass. Arrows indicate predicted influences of independent variables on welfare outcomes.

Fig. 2. Lure types used during study, shown in increasing order of size; average size is listed below each lure type.

simulate authentic recreational fishing conditions where the choice of tackle was dependent on the habitat and conditions, as well as the discretion and knowledge of the anglers. Therefore, very little direction was given to the anglers and they were advised to fish as they regularly would during recreational angling based on their experience and knowledge. A variety of bait types and sizes were used, with the anglers deciding what was most appropriate based on the location, time of day, etc. Five different types of lures were used: chatterbait, crankbait, soft plastic, spinner, and topwater (Fig. 2); most of these lures included barbed hooks, but this was not measured during the study. The chatterbaits used were bladed swim jigs with a single hook and an average size of 154.6 ± 30.7 mm which included the soft plastic trailer. Crankbaits (including some that were short and stubby and others that were more elongate) were hard-bodied diving lures, with two treble hooks, and the average size used was 72.6 ± 16.3 mm. Soft plastic was used to describe any bait exclusively made of flexible rubber or plastisol (e.g. Senko, fluke, tube jig, crawfish), placed onto a single hook; the average size was 116.3 ± 34.0 mm. Spinners had an average size of 65.0 ± 23.9 mm, and included both spinnerbaits (with a single hook) and inline spinners (with a treble hook). Finally, topwater lures were any lure that was fished on the surface of the water (e.g. plastic frogs, surface popper, buzzbait) with one or two single hooks or treble hooks, and had an average length of 95.3 ± 47.9 mm.

The number of anglers varied between fishing trips, with between two and five anglers fishing simultaneously. Times (in s) to land fish and handle fish while removing the hook were recorded for each fish captured. In general, fish were netted as soon as possible and were rarely played to exhaustion (i.e., fish were still swimming to resist capture upon landing). Landing time was measured as the time from when a fish was initially hooked to the time the fish was landed in the net. Some anglers naturally heaved in the fish while others fought the fish until it was in a condition that it could be easily landed. Handling time began once the fish was removed from the water and stopped when the hook was removed from the fish.

Once the hook(s) was removed, the fish was placed in a non-aerated sampling tub or trough a minimum or 0.5 m in length (with enough room to submerge the fish), and the fish's reflexes were tested immediately before the fish was exposed to handling stress during the rest of the measurements. Two reflexes, adapted from the Reflex Action Mortality Predictor (RAMP) method (Raby et al., 2012), were measured on a binary scale (0 = unimpaired, 1 = impaired). The fish's ability to right itself was measured by testing whether the fish regained orientation within 3 s of being flipped upside down. The tail grab reflex was measured by determining whether the fish attempted to burst swim away during pinching of the caudal fin. These two reflexes were chosen because they could be assessed while the fish remained in the water, reducing additional air exposure for the fish.

Following RAMP assessment, the total length and gape of the fish were both measured (in mm, using a tape measure). For each fish hooking location(s) were noted and hooking depth was measured (in mm) for each hook point that was in the fish. The hooking depth was measured as the depth of the hook from the front of the mouth to the hook location (therefore hooks in the esophagus or gills would be deeper than those in the lip, etc.). Finally, the presence or absence of blood was noted (0 = absent, 1 = present). Once the fish was released back to the water near the area of capture, the name of the angler and the lure type were noted, the number of hooking points on the lure were noted (e.g., a treble hook would have 3 hooking points so if a lure had two treble hooks the maximum number would be 6), and the lure size was measured (in mm). Water was changed for every fish and additional water was added if the handling period extended beyond 1 min.

2.2. Statistical analyses

The data were prepared in MS Excel and analyzed using R statistical software with the *stats* package (version 3.5.1; R Core Team, 2018). Length-corrected hooking depth was used throughout all the analyses and was calculated by dividing the hooking depth by the total length of the fish. For fish with multiple hooking points, the deepest hooking point was used during statistical analyses.

Generalized linear models (GLM) were used to asses which variables significantly influenced capture duration (i.e. landing time), and handling (i.e. dehooking) time. Prior to completing any of the following GLMs, the relationships between predictive variables were explored to ensure they were all independent. For landing time, angler experience and fish length were included as the only two predictors. The independent variables included in the dehooking time model were angler experience, landing time, hooking location, length-corrected hooking depth, lure size, number of hooks, and fish length. A second GLM was run for dehooking time that included angler experience, landing time, hooking location, length-corrected hooking depth, fish length, and lure type (instead of lure size and number of hooks). Lure type was analyzed separately from lure size and number of hooks because during exploratory analyses it was found to be correlated with both of these variables. Fish length and gape were found to be correlated, so only length was included in the models. Final model structure was determined using backward model selection based on Akaike Information Criterion (AIC). The results of these two separate GLMs were then compared to assess which was the better model to explain the data. For all of these models, a gaussian distribution was used in the GLM (i.e. a general linear model). Dunnett's T3 post hoc test was used to assess the differences in landing time between different angler experience levels, and dehooking times between different hooking locations, different lure types, and different numbers of hooks.

Generalized linear modeling was also used to assess which variables significantly influenced fish welfare outcomes: hooking depth (length-corrected), hooking location, and presence or absence of blood. Because very few fish (only 2.2 %) experienced loss of reflexes following angling events, this was not used as an outcome in the models. The independent variables included in these models were angler experience, lure size, number of hooks (on the lure), and fish length. For hooking depth, a gaussian distribution was used, for hooking location and presence/absence of blood, a binomial distribution was used, and for hooking location, a multinomial distribution was used. A Dunnett's T3 post hoc test was used to assess the differences in length-corrected hooking depth between different lure types and different numbers of hooks. Again, a second GLM was ran with lure type instead of lure size and number of hooking points, and the two GLMs were compared. In addition, a chi-squared test was used to compare the differences between two categorical variables (i.e. hooking location and lure type; hooking location and number of hooks). For all of the models, residuals were generated to assess the overall fit of the model. In addition, because of the wide range of equipment used, there were not enough data between groups, so interaction terms were not assessed.

3. Results

A total of 323 fish were captured from the Rideau Canal Waterway (n = 240) and Papineau Lake (n = 83) by 27 different anglers; nine of these anglers were novices, eleven were intermediates, and seven were experts. Soft plastics were the most frequently used lure in the study (41.1 %, n = 134), followed by spinners (32.2 %, n = 105), topwater lures (15.3 %, n = 50), crankbaits (5.8 %, n = 19), chatterbaits (4.3 %, n = 14), and jerkbaits and spoons (both with <1%). Novice anglers primarily used soft plastics (85.2 % of baits used), intermediate anglers used spinnerbaits and soft plastics most frequently (48.9 % and 28.6 %, respectively), and expert anglers primarily used soft plastics and topwater lures (53.8 % and 20.2 %, respectively). The lures used had one, two, three, or six hooking points (79.3 %, 12.4 %, 1.5 %, and 6.8 %, respectively). Of the lures with a single hooking point, only 1.6 % of fish caught were hooked twice (i.e. the single hook punctured tissue twice). Lures with two hooking points resulted in 32.5 % of fish being hooked twice. Similarly, lures with three hooking points resulted in 40 % of fish being hooked twice; and lures with six hooking points resulted in 40.9 % of fish being hooked twice, 9.1 % of fish being hooked three times, and 4.5 % of fish being hooked four times.

Captured fish ranged in total length from 107 mm to 491 mm TL ($\mu = 334.5 \pm 61.9$ mm), with mouth gapes of 11 mm–111 mm ($\mu = 56.8 \pm 15.0$ mm). Of these fish, 7.8 % were hooked in a critical location (i.e., eye, gills, tongue; Table 1), 8.7 % were punctured by more than one hook point (this included lures with a single hook that punctured tissue twice), and 15.2 % experienced bleeding. The majority of the fish were hooked in the jaw (62.2 %), roof of mouth (13.9 %), or cheek (11.4 %) (Table 1). No fish were hooked in the gullet or otherwise required that the line be cut and the hook left in place, and no fish were foul hooked (external hooking of the abdomen or tail). Landing times ranged from 2 s to 50 s ($\mu = 11.5 \pm 6.9$ s), and dehooking time ranged from 1 s (i.e. the fish shook the hook out during netting) to 79 s ($\mu = 10.0 \pm 10.6$ s). Only 2.2 % of the fish had reflex impairment, and only one instance of mortality was recorded after hooking in the gills and excessive blood loss (total length of the fish was 180 mm).

3.1. Relationship between angler experience, fish length, and duration of capture

Duration of capture was significantly related to the total length of the fish, with larger fish resulting in longer durations of capture (Table 2; Fig. 3; $p < 0.001$). Level of angler experience, however, had no significant effect on duration of landing time during this study (Dunnett's T3 test; $p > 0.09$). Additionally, fish length did not differ between different levels of angler experience (ANOVA; $p = 0.108$).

3.2. Models for dehooking time

Fish dehooking time was significantly related to hook location, length-corrected hooking depth, fish length, and the number of hooking points on the lure (Table 2). Results were similar when including lure type as a predictor instead of lure size and number of hooking points, with dehooking time being significantly related to hook location, length-corrected hooking depth, fish length, and lure type (Table 2). Dehooking time varied for different lure types, with crankbaits resulting in the longest hooking times (18.0 ± 19.3 s). Crankbaits had a significantly longer dehooking time (Dunnett's T3 test; $p < 0.04$) than all other lure types (Fig. 4a). Dehooking time was significantly longer for lures with six hooking points than lures with only one hooking point (Dunnett's T3 test; $p = 0.0022$; Fig. 4b). When comparing the two final models, the model with lure type better explained the differences in dehooking time than the model with the number of hooking points.

Hooking location, fish length and length-corrected hooking depth were significant terms in the final models from both of the GLMs. Fish that were hooked in the gills had significantly longer dehooking times ($\mu = 36.8$, $N = 6$) than fish that were hooked in other locations (Dunnett's T3 test; $p < 0.01$; Fig. 4c), and deeper hooking depths resulted in longer dehooking times (Fig. 4d). Larger fish also resulted in longer dehooking times (Fig. 4e). Landing time and lure size did not have any effect on the dehooking time.

3.3. Models for hooking location

Hooking location was significantly affected by both the lure type used and the lure size(Table 2). Hooking location was significantly different between different lure types (Chi-squared; $X = 72.59$; $p < 0.001$), with crankbaits resulting in higher hooking in the gills than the other lure types (Table 1). Hooking in the nose only resulted when using soft plastics, and topwater lures resulted in higher hooking in the roof of the mouth than with other lures. Hooking location was also significantly different depending on the size of the lure, however only between the nose and jaw; larger lures resulted in hooks in the nose, while smaller lures resulted in hooks in the jaw (Dunnet's T3 test; $p = 0.044$). Angler experience and lure size did not have any effect on the hooking location.

3.4. Models for hooking depth

Length-corrected hooking depth was significantly related to lure type, size, and number of hooking points (Table 2). The hooking depth between different lure types varied (Fig. 5a), with crankbaits having the smallest length-corrected hooking depths (0.06 ± 0.05). Hooking depths for crankbaits were significantly different from all other lure types except for chatterbaits (Dunnett's T3 test; $p < 0.04$). Larger lures resulted in deeper hooking depths (Fig. 5b), and lures with six hooking points resulted in significantly shallower hooking depths (Dunnett's T3 test; $p < 0.02$) than all other numbers points (except for lures with three hooking points; Fig. 5c). Lures with two hooking points resulted in significantly deeper hooking depths than other types (Dunnett's T3 test; $p < 0.02$), and lures with one hook point resulted in the second deepest hooking depths (Fig. 5c).

3.5. Other relationships and fit of models

Occurrence of blood was not related to any of the independent variables tested (the strongest model was blood ~ 1; and $p > 0.05$ for all variables). The residuals were tested for all of the models (using a plot of the dependent variable against the residuals) however none of them were randomly distributed, indicating that there could be other independent variables influencing the occurrence of the dependent variables tested.

4. Discussion

During this study, 27 anglers caught 323 largemouth bass on lakes in Ontario and Quebec. Overall mortality was likely low due to the majority of the fish experiencing no bleeding, and there was only one observed instance of mortality following severe bleeding from being hooked in the gill. Although only 2.2 % of largemouth bass in our study exhibited impaired reflexes and 15.2 % has signs of bleeding, other trends provide important insights into the role of angler experience and

Table 1
Percentage of largemouth bass hooked in different locations using different lure types during catch-and-release angling in Papineau Lake, QC, and the Rideau Canal Waterway, ON. Values in parentheses are the numbers of fish.

	Non-sensitive Hooking Locations					Sensitive Hooking Locations		
Bait Type	Cheek	Floor	Jaw	Nose	Roof	Eye*	Gills	Tongue
Chatterbait	0 (0)	0 (0)	71.4 (10)	0 (0)	7.1 (1)	14.3 (2)	0 (0)	7.1 (1)
Crankbait	0 (0)	0 (0)	76.2 (16)	0 (0)	9.5 (2)	0 (0)	14.3 (3)	0 (0)
Soft Plastic	14.9 (20)	2.2 (3)	59.0 (79)	6.7 (9)	9.7 (13)	3.7 (5)	0.7 (1)	3.0 (4)
Spinner	15.2 (16)	1.9 (2)	64.8 (68)	0 (0)	14.3 (15)	3.8 (4)	0 (0)	0 (0)
Topwater	2.0 (1)	2.0 (1)	57.1 (28)	0 (0)	28.6 (14)	2.0 (1)	4.1 (2)	4.1 (2)
Total	11.4 (37)	1.9 (6)	62.2 (201)	2.8 (9)	13.9 (45)	3.7 (12)	1.9 (6)	2.2 (7)

* Hooking in the eye occurred both externally and internally, but was grouped into one category here.

Table 2
Generalized linear models fitted to length-corrected hooking depth, hooking location, dehooking time, and landing time from catch-and-release angling in Papineau Lake, QC, and the Rideau Canal Waterway, ON.

Response Variable	Final Model Terms	Scaled Deviance	*p*	*Estimate ($\beta_1, \beta_{,2}$, etc)*[*]	*β_0 (intercept of final model)*	Comparing GLM Rank	 *p* (of final model)
Landing Time (s)	Fish Length	46.85	*< 0.001*	0.04	−2.20	–	
	Hook Location	36.27	*< 0.001*	–			
	Hooking Depth	10.33	*0.001*	45.59			
	Number of Hooking Points	12.69	*0.005*	–	1.70	2	< *0.001*
Dehooking Time (s)	Fish Length	4.196	*0.041*	0.02			
	Hook Location	35.82	*< 0.001*	–			
	Lure Type	22.11	*< 0.001*	–	−5.19	1	< *0.001*
	Hooking Depth	10.22	*0.002*	44.72			
Hooking Location[‡]	Fish Length	6.38	*0.012*	0.02			
	Lure Size[†]	803.5	*< 0.001*	–	–	1	< *0.001*
	Lure Type	752.3	*0.001*	–	–	2	< *0.001*
	Lure Size[†]	6.58	*0.08*	<0.001			
Length-Corrected Hooking Depth	Number of Hooking Points	13.45	*0.07*	–	0.08	2	< *0.001*
	Lure Type	12.75	*0.01*	–	0.11	1	< *0.001*

[*] The estimates for categorical variables (Lure Type, Hook Location, and Number of Hooking Points) are found in Table S1.

[†] This refers to the actual size of the lure used to capture each fish (not an average across lure type).

[‡] The scaled deviance values for hooking location are not scaled; they are residual deviance from the multinomial GLM model. The coefficients for the multinomial GLMs are found in Tables S2 and S3.

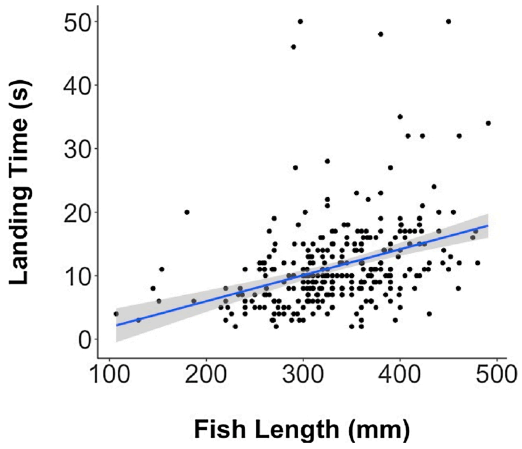

Fig. 3. Fish landing time (i.e. duration of capture, in s) as a function of the total length of the fish (in mm). The shading indicates the 95 % confidence interval of the fitted values.

lure characteristics other fish welfare. For instance, hooking location and depth can be used as a measure of hooking injury, and landing and dehooking time can be used to assess the physiological stress that fish undergo during angling and handling.

Contrary to our predictions, there was no significant relationship between angler experience and landing time. This could partly be due to the fact that retrieval gear (fishing rods, reels, and lines) was not measured or controlled during this study and could have impacted landing times. Gear that is too light for a species may result in prolonged landing times if the angler is not able to reel it in as easily, and could potentially result in higher physiological stress (Brownscombe et al., 2017). In general, however, there is no consensus in the literature about the relationship between landing time and stress. While longer landing times have been shown to result in higher stress during simulated experiments with largemouth bass (e.g. Gustaveson et al., 1991), recent data from real angling scenarios show no association between landing time and condition of the fish (both reflex impairment and physiological stress levels) (Brownscombe et al., 2014). Therefore, landing time may not be the best measure of stress in largemouth bass, especially compared to dehooking time which involves handling and air exposure, both of which are highly correlated to stress and behavioural impairment (Arlinghaus et al., 2007; Cooke et al., 2002; Thompson et al., 2008; Wedemeyer and Wydoski, 2008).

Dehooking time was significantly related to the lure type, number of hooking points, fish length, and both hooking depth and location. Hooking in the gills required significantly longer to dehook than hooks in other locations. These findings are similar to those of Arlinghaus et al. (2008) who found that in Northern Pike (*Esox lucius*), hooking in the gills increased the handling time required to remove the hook. Deeper hooks also required longer dehooking times, mainly due to the increased difficulty in removing a hook from further in the fish's mouth. Because largemouth bass do not have sharp teeth, most of the hooks in this study were removed by hand, especially those hooked in the lip. However, when the hook was too deep to remove by hand, some anglers used pliers or other dehooking devices that were more useful in removing deeply embedded lures. The use of readily accessible pliers may aid in reducing the time spent dehooking or reduce the damage at the hooking location. Unfortunately, we did not collect data on the use of pliers during dehooking, nor did we ensure that pliers were made available to all participants of the study. Because pliers may have aided in the removal of lures, especially in fish that were hooked deeply or in sensitive locations, this may have influenced our results.

Crankbaits had significantly longer dehooking times than other lure types, likely due to the fact that a high proportion (50 %) of fish that were caught with a crankbait were hooked by more than one hook point (e.g. on a treble hook). Lures with six hook points also had a high proportion of fish hooked multiple times, which may be why they required longer dehooking times than lures with only one hooking point. Being hooked multiple times likely resulted in prolonged dehooking times because it was more difficult to remove the hook from the fish (Bartholomew and Bohnsack, 2005). Crankbaits and other lures with six hooking points may also resulted in prolonged dehooking times because extra hooks not embedded in the fish may have tangled in the landing net or pierced the hand of the person performing the dehooking (similar to what was found by Lizée et al., 2018). In other studies, prolonged air exposure associated with longer dehooking times often resulted in loss of equilibrium, behavioural impairments (e.g. staying at the release site), and longer recovery times (Cooke et al., 2001; Danylchuk et al., 2007; Thompson et al., 2008). In this study, while we did not observe many instances of equilibrium loss (and only 2.2 % of fish experienced any

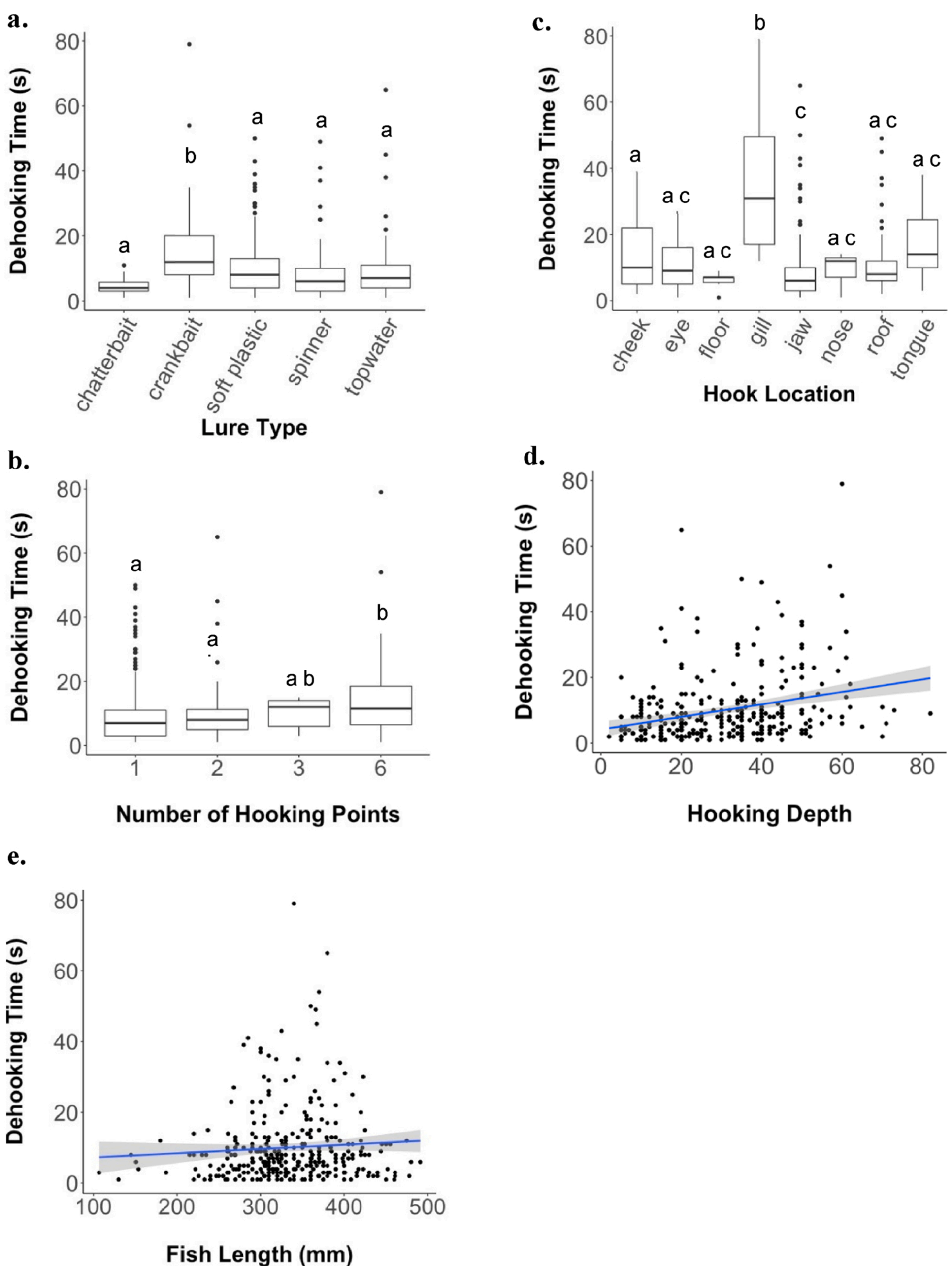

Fig. 4. Fish handling time (i.e. dehooking time, in s) plotted against final model terms from generalized linear model analysis; different letters indicate significance. **a.** Dehooking time as a function of the lure type used. **b.** Dehooking time as a function of the number of hooks on the lure. **c.** Dehooking time as a function of the hook location. **d.** Dehooking time as a function of length-corrected hooking depth. **e.** Dehooking time as a function of fish total length (in mm). The shading in d and e indicates the 95 % confidence interval of the fitted values.

reflex impairment), we did not monitor the fish after release, so it is unclear whether they experienced behavioural impairment. In addition, because physiological stress in fish is cumulative (Barton et al., 1986; Cooke et al., 2002), the effects could be greater in fish that were captured multiple times in the same season.

One aspect that was overlooked during this study was the influence of the individual performing the dehooking. Less experienced anglers who are unfamiliar with the dehooking process may take longer to remove the hook or may injure the fish more during the process. Meka (2004) found that less experienced anglers had more difficulty removing hooks from rainbow trout than experienced anglers, and injured more fish during the dehooking process. In addition, Newman and Storck (1986) observed that novice anglers took longer to dehook muskellunge than more experienced anglers. We did not control who dehooked the fish, therefore we could not assess whether angler experience influenced dehooking time, and it could be a reason why there was no relationship between angler experience and occurrence of blood. Controlling for who performs the dehooking is an important aspect to consider in future study designs.

Lure type and lure size both had a significant impact on the hooking location. Hooking in the gills was more likely with crankbaits, and smaller lures resulted in hooking in the jaw rather than the nose. This differs from previous findings that soft plastic lures, rather than hard bodied lures like crankbaits, increase the chance of hooking in sensitive locations such as the esophagus or gills (Arlinghaus et al., 2008; Myers and Poarch, 2000). However, there were very few fish hooked in sensitive locations (7.8 %), and only five fish in this study were hooked in the gills, therefore we should be hesitant when making conclusions on this data. Hooking depth can provide more robust conclusions because there is data across all lure types and characteristics.

Hooking depth was significantly related to the lure type, size, and number of hooking points. Crankbaits and other lures with six hooking points had the shallowest hooking depths and this is likely due to the presence of treble hooks on these lures. Treble hooks are often not ingested as far as single hooks because they are more difficult to swallow (Muoneke and Childress, 1994). However, treble hooks can cause more

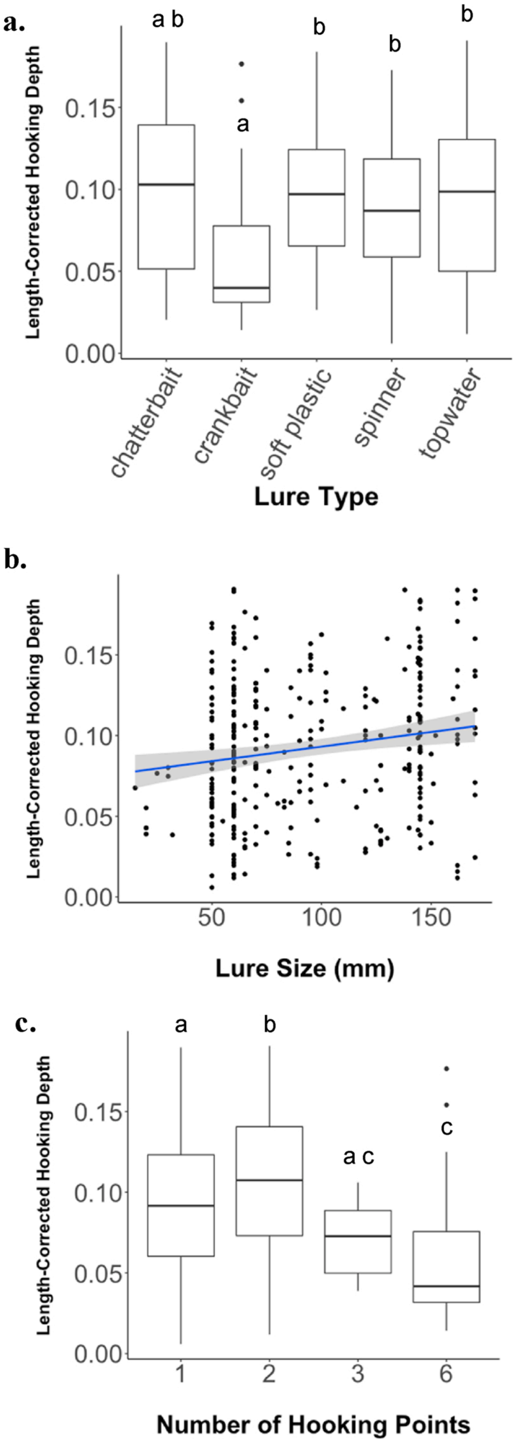

Fig. 5. Fish welfare outcomes, handling time, and duration of capture plotted against final model terms from generalized linear model analysis; different letters indicate significance. **a.** Length-corrected hooking depth as a function of lure type. **b.** Length-corrected hooking depth as a function of the number of hooking points on the lure; the shading indicates the 95 % confidence interval of the fitted values. **c.** Length-corrected hooking depth as a function of lure size (mm).

tissue damage once they are embedded, and more damage can be done specifically during the dehooking process. We found that larger lures resulted in deeper hooking depths, which contradicts most other studies that observed the opposite (Arlinghaus et al., 2008; Brownscombe et al., 2017). We propose that this is due to the fact that lure type was more important in determining hooking depth than lure size; crankbaits, which had the shallowest hooking depth, were also on average one of the smallest lures (72.6 ± 16.3 mm compared to an overall average of 95.3 ± 41.5 mm).

The occurrence of bleeding was not related to any of the independent variables tested, which may be partly due to the overall low occurrence of bleeding in this study (15.2 %). Bleeding is often assumed to be the best predictor of mortality following capture during C&R, which also may help explain the very low mortality rate of the fish. Many studies have observed that bleeding is primarily related to the location of hooking, rather than the lure itself and hooking in the gills most often results in bleeding (Arlinghaus et al., 2008; Burkholder, 1992; Stålhammar et al., 2014). However, the amount of bleeding is also strongly dependent on the degree to which the tissue is damaged (Arlinghaus et al., 2007).

Fish length was significantly related to both landing time and handling time, with larger fish resulting in longer times for both. Larger fish are able to fight harder than smaller fish, which may prolong the time taken to reel it in to the boat and cause more difficulty while removing the hook. The relationship between fish size and duration of landing has also been found in several other species, both marine and freshwater (Brownscombe et al., 2014; Cooke and Philipp, 2004; Meka and McCormick, 2005). Therefore, larger fish may be at risk of experiencing prolonged angling events, which may result in higher levels of stress. On the other hand, we found that fish length was not related to either hooking depth, or hooking location, and therefore may not impact injury rates during C&R of largemouth bass. In other species, fish size has had varied effects on injury and mortality rates. Meka (2004) found that fish size influenced the level of injury in rainbow trout, however studies on both northern pike and striped bass have shown no relationship between fish size and short-term mortality rates during C&R (Arlinghaus et al., 2008; Millard et al., 2003). It remains unclear whether fish size has an effect on injury or overall mortality rates, and these relationships may be species dependent.

During this study, angler experience was measured as a proxy of the amount of time an individual had spent fishing (e.g. novice had fished less than 10 times, and an expert had been fishing for over 5 years). However, the amount of time spent fishing may not relate directly to the skills that individual has as a fisherman, or to their knowledge of proper fish handling. It was also very difficult to standardize behaviours between the different levels of experience (e.g. whether or not they set the hook, how long it took them to react once a fish bit the lure, etc.). These factors, along with the use of only three levels of experience, may have contributed to the lack of significance of angler experience during this study. Future research should focus more on quantifying specific angler behaviours or measure the anglers' knowledge of proper fishing and handling practices.

Our research provides evidence that in largemouth bass, lure choice is an important aspect in determining level of injury or stress. Both the lure type and lure characteristics (size and number of hooking points) significantly affected hooking depth, location, and dehooking time. Specifically, we found that lures with six hooking points (e.g. crankbaits) had the shallowest hooking depths, but the longest dehooking times; therefore, there may be a trade-off when choosing a lure between reducing injury and minimizing stress (air exposure). Though angler experience was not significant in any of the models, angler behaviour and knowledge are still important aspects of C&R fisheries and may be more relevant in a more sensitive species (i.e., largemouth bass are relatively robust). The behaviour and knowledge of an angler can inform lure choice and determine how they handle their fish (e.g. prolonged air exposure to take pictures, etc.). Angler education programs have been shown to improve outcomes for fish (Delle Palme et al., 2016), and therefore can contribute to more sustainable C&R angling (Danylchuk et al., 2018). Incorporating advice on lure choice into angler education programs can help generate more informed anglers who are more aware of the impacts of their choices.

This study was conducted during late summer, after water temperatures had stabilized between 24–26 °C, and therefore did not consider the effect of water temperature on fish injury or stress. The relationship between fish condition and water temperature has been well studied, and in general, extreme water temperatures (and especially high temperatures) result in increased physiological stress and higher chance of mortality (reviewed in Arlinghaus et al., 2007; Cooke and Suski, 2005; Hühn and Arlinghaus, 2011). A study by Wilde and Pope (2008) showed that largemouth bass survival was not related to water temperatures between 7–27 °C indicating that water temperature may not have played a role in fish survival during this study. Water temperature could still have had an effect on the relationships explored here. Recent research by Stalhåmmar et al. (2014) showed that water temperature influenced hooking location in northern pike; lower water temperatures actually resulted in deeper hooking. It would be interesting to re-conduct this study at different water temperatures to see if the relationships between hooking depth and lure type remain the same.

Another limitation of this study is that novice anglers used a much smaller variety of baits when compared to the expert anglers. This is because little direction was given to anglers in order to simulate real fishing conditions. However, it led to significant gaps in the data that limited the ability to analyze interactions and could have also limited the strength of the model prediction (hence why the residuals may be skewed). If a similar study were conducted again, there should be a focus on encouraging anglers of all experience levels to use a variety of baits, and also on collecting a larger sample size that may reduce gaps in the data.

5. Conclusions

In summary, this study found that lure characteristics, but not angler experience, had an influence on welfare outcomes in largemouth bass, therefore lure choice is an important consideration in managing C&R fisheries. Specifically, lures with six hooking points had the shallowest hooking depths but the longest dehooking times. Choosing a lure with fewer hooks or replacing a treble hook with a single hook may help to reduce dehooking time and minimize air exposure. In addition, hooking location and depth both influenced the time taken to dehook fish, with hooks in deeper and sensitive (i.e. gills) locations taking the longest to dehook. Therefore, reducing deep hooking and hooking in sensitive locations can not only reduce injury rates but can also minimize the physiological stress associated with prolonged air exposure during dehooking; pliers may be used to help minimize air exposure in the event that deep or sensitive hooking does occur. Though angler experience was not significant during this study, angler behaviour and knowledge are still key factors in the welfare outcomes of fish, because they may influence lure choice or affect fish handling (especially when the fish is deeply hooked). Angler education programs can help anglers make more informed choices about which lures to use to reduce injury and stress in angled fish. When choosing a lure, there may be a trade-off between minimizing the physiological stress associated with handling and air exposure and reducing the chances of injury and deep hooking. Additional research is needed to better understand such trade-offs across a range of environmental conditions and species.

CRediT authorship contribution statement

Shannon H. Clarke: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization. **Jacob W. Brownscombe:** Conceptualization, Methodology, Formal analysis, Writing – review & editing. **Liane Nowell:** Investigation, Resources, Writing – review & editing. **Aaron J. Zolderdo:** Conceptualization, Methodology, Investigation. **Andy J. Danylchuk:** Writing – review & editing. **Steven J. Cooke:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fishres.2020.105756.

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