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ARTICLE

Ultralight or Heavyweight? The Interactive Effects of Gear Strength and Air Exposure on Reflex Impairment in Largemouth Bass

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Abstract
Although much is known about the factors that influence the effects of catch-and-release angling on fish condition and survival, relatively little is known about the effects of fishing gear strength on fight time and, hence, fish condition. Moreover, little is known about how gear strength and fight time interact with air exposure duration to ultimately influence the level of exhaustion experienced by fish at time of release. Here we systematically varied fishing gear strength (ultralight versus medium-heavy) and air exposure duration (0 versus 120 s) when targeting Largemouth Bass *Micropterus salmoides*. We relied on reflex impairment (using five different reflexes) as a real-time indicator of fish condition. Largemouth Bass fight durations were highly variable between fishing gear types and across fish sizes. Largemouth Bass captured on ultralight fishing gear experienced longer fight times, and there was a stronger positive relationship between fish length and fight time than for those captured on heavier fishing gear. However, fish captured using ultralight gear were easier to handle upon landing and thus experienced shorter hook removal times, which may result in less air exposure in actual angling scenarios. Fish captured with ultralight gear had significantly higher reflex impairment than those captured with heavy gear with no air exposure, while fish captured with both gear types had similarly high reflex impairment when exposed to the air. These results indicate that gear strength does influence the level of exhaustion experienced by Largemouth Bass. However, fish that are landed quickly are so vigorous that handling and hook removal are challenging. We submit that there is likely a compromise where neither ultralight nor ultraheavy gear (always relative to the size and species targeted) is appropriate. Moreover, our findings emphasize the importance of minimizing air exposure, particularly for fish that are exhausted already from a protracted fight.

Recreational angling is a popular activity around the globe and leads to the capture of billions of fish annually (Cooke and Cowx 2006). Although some fish are harvested, even more are released in a practice known as catch and release (Brownscombe et al. 2014a). Release rates are highly variable among species and fisheries. The motivation for releasing fish also varies and can include compliance with regulations or the conservation ethic of the angler (Arlinghaus et al. 2007). An inherent premise of catch and release is that the fish survives with negligible impacts to its fitness or health (Wydoski 1977; Cooke and Schramm 2007). Yet a large body of research has demonstrated that not all fish survive, and there are a variety of injuries, physiological disturbances, and behavioral alterations that can arise from recreational fisheries interactions (reviewed in Muoneke and Childress 1994; Bartholomew and Bohnsack 2005; Arlinghaus et al. 2007). Catch-and-release science has emerged as a practical research area focused on identifying strategies for minimizing the negative consequences of fishing practices on the welfare of released fish (Cooke and Schramm 2007).

The body of research on catch-and-release fishing has been synthesized in an effort to identify general patterns or guidelines that should apply to most species or fisheries scenarios (see Cooke and Suski 2005; Pelletier et al. 2007; Brownscombe et al., in press). For example, it is well established that the anatomical location of hooking has a strong influence on the outcome of an angling event; hooks embedded in regions such

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as the esophagus can cause lethal damage to vital tissues (Arlinghaus et al. 2007). As such, any efforts to reduce deep-hooking injury through selection of hook types and baits and/or lures can be beneficial. Also, the process of angling and handling a fish induces a stress response, which is mediated by intrinsic biotic factors (e.g., interspecific variation, body size, fish health), environmental factors (e.g., water temperature), and factors that are largely under the control of the angler (e.g., fight duration, air exposure duration). To that end, it is generally recommended that anglers minimize fight time and air exposure duration and recognize that this is even more important at higher water temperatures. The science supporting the notion that air exposure should be minimized is extensive (reviewed in Cook et al. 2015) and is epitomized by the popular #KeepemWet campaign (http://www.keepemwet.org/#home). While it is intuitive that longer fight times lead to greater exhaustion and poorer outcomes for fish, it is unclear whether fight duration is an important factor in real angling scenarios. For example, Gustaveson et al. (1991) found that longer simulated angling fight times cause greater physiological stress in Largemouth Bass *Micropterus salmoides*; however, Brownscombe et al. (2014b) found no correlation between fight time or intensity and physiological stress or reflex impairment in real angling scenarios with typical Largemouth Bass angling gear. This lack of relationship between fight time and fish condition is common in the catch-and-release literature (Thorstad et al. 2003; Danylchuk et al. 2007, 2014; Landsman et al. 2011). It is also challenging to assess this relationship because fight time is nearly always confounded by body size; larger fish take longer to land (Meka and McCormick 2005; Cooke et al. 2008). Moreover, because fish that have been fought longer experience longer periods for a physiological stress response to be manifested in tissues such as blood (which can be easily collected for analysis), relationships between fight duration and blood physiology are not overly informative unless blood sampling time is standardized from hooking time (Cooke et al. 2013). In addition, in the few studies that have evaluated fight time, it is often done by using the same gear and simply instructing anglers to bring in fish slowly or quickly, which is different than evaluating the role of gear strength on fish condition. To our knowledge, no one has systematically manipulated gear strength to assess its role in mediating fight duration. While ideally anglers use fishing gear designed to capture a target species based on its size and fighting abilities, bycatch is common in many fisheries. Further, gear-strength-specific records are still common, where anglers aim to catch the largest fish on light fishing gear (Shiffman et al. 2014).

The fishing industry has generated countless products that enable anglers to select gear (e.g., fishing line, reel size, rod strength) that ranges from ultralight to heavy. Some anglers intentionally target fish with ultralight gear so that they can better appreciate the fight or give the fish a fighting chance. Other anglers use heavy gear to bring in fish as rapidly as possible to reduce loss (e.g., in a tournament) or to pull fish from heavy cover. Obviously the size of fish plays an important role. Although intuitively one could recommend selecting gear type to appropriately match the size of the target species, anglers rarely can be certain of what they will catch, so a massive fish could be inadvertently hooked on ultralight gear leading to fights that in extreme cases can take many hours. There is also some thought that landing a fish too quickly could make it more difficult or dangerous (for fish and anglers) to land or handle a fish for hook removal or admiration. However, to our knowledge, no one has assessed how gear strength mediates handling time or how the level of exhaustion from the fight interacts with the duration of air exposure.

Here, we present the results of a study where we systematically varied gear strength (ultralight and medium-heavy) and air exposure duration (0 versus 120 s). Research focused on Largemouth Bass given their popularity as a sport fish (Quinn and Paukert 2009) as well because they can be easily targeted using both ultralight and heavy gear. Release rates of Largemouth Bass are also exceptionally high (Quinn 1989; Brownscombe et al. 2014a). Because of the aforementioned problems with using blood-based biomarkers for assessing physiological disturbance relative to fight duration (see Cooke et al. 2013), we relied on reflex impairment as a real-time indicator of fish condition. Reflex impairment has become a valuable tool for assessing the overall condition of the fish, and when done in a consistent manner using multiple indices, it can be predictive of release mortality and behavioral impairment in a variety of species (Davis 2010; Raby et al. 2012; Brownscombe et al. 2013, 2014c). Given the manifold effects of water temperature on fish (Brett 1969), including in the context of catch and release (Gale et al. 2013), we controlled for temperature by collecting data only during the midsummer when surface waters were stable and high. This also coincides with a season where there is much angling effort for Largemouth Bass (Quinn and Paukert 2009). Fishing occurred in a lentic water body that contained submerged macrophytes but no woody debris and relatively little emergent macrophyte cover. Thus, we did not test whether ultralight gear could be used to pull fish out of the complex cover where bass are sometimes targeted (e.g., stump field with floating lily pads). Anglers were instructed to bring in the fish as fast as reasonably possible reflecting the inherent limitations of the different gear. Fish captured by ultralight gear were not intentionally fought longer, but fight durations were an inherent outcome of gear selection.

METHODS

Angling experiments.—This study was conducted in two interconnected private lakes in Greely, Ontario, at water temperatures ranging from 25°C to 27°C during daylight hours from July 15 to August 30, 2015. Largemouth Bass were angled using either medium-heavy (MH) fishing gear (standard-size spinning reel with 30-lb test line and 6-ft-length medium-heavy rod; $n = 54$) or ultralight (UL) fishing gear (small ultralight fishing reel with 4-lb test line and 6-ft-length ultralight rod; $n = 53$) and retrieved as quickly as reasonably possible given the limitations on gear strength. The drag was adjusted to be tighter on the MH gear than the UL gear to prevent the line from breaking. We did so based on the premise that anglers will adjust the drag to match their gear in an effort to reduce the likelihood of line breakage. Once fish were reeled near to the angler, fish were landed with a rubberized mesh net and either held in water without any air exposure (MH, n = 30; UL, n = 27) or exposed to the air for 120 s (MH, n = 24; UL, n = 26) to simulate a hook removal and admiration period. Upon landing, the angler attempted to "lip" the fish (secure by the lower jaw using thumb and forefinger), and the total time taken to do so and subsequently remove the hook from the fish using bare hands or pliers was recorded to the nearest second (termed "hook removal time"). Hook removal time was included in the air exposure period for fish in the 120-s air exposure treatment. When fish were hooked in sensitive tissues (e.g., esophagus or gills), hooks were not removed and the line was cut, and fish were immediately released and excluded from the study. Fish were also measured for TL (mm).

Reflex impairment, as evaluated by reflex action mortality predictors (RAMP), was measured after hook removal (in the 0-s air exposure treatment) or air exposure period (in the 120-s air exposure treatment) in the following order: jaw twitch, body flex, head complex, equilibrium, and tail grab. Jaw twitch was assessed by attempting to pick up the fish using the lower jaw (i.e., lipping) and holding the fish vertically for 3 s; if the fish twitched during attempts to lip and hold, that indicated a positive response. Body flex was assessed by lifting the fish into the air by the center of the body; body flexing as an attempt to escape indicated a positive response. Head complex was tested by observing the fish's operculum; consistent, rhythmic opercular beats indicated a positive response. Equilibrium was assessed by flipping the fish upside down; the fish righting itself within 3 s indicated a positive response. Tail grab involved grabbing the fish's tail while in water; the fish trying to escape the handler indicated a positive response. The tail grab was conducted last so that the fish could swim away at that point. Each test was scored as either 1 for impaired or 0 for unimpaired, which was converted into a proportional value from 0 to 1. Greater RAMP scores indicated greater impairment (as per Davis 2010). Reflex tests took less than 15 s to complete. RAMP has been established as an effective measure of vitality in a variety of freshwater and marine fish species (Raby et al. 2012; Brownscombe et al. 2013, 2014a; Cooke et al. 2013).

Data analysis.—Fish lengths were compared between gear types using a Student's t-test, and there was no significant difference between gear types (t = 0.29, df = 100, P = 0.77). To examine which factors contributed to fish fight times, unhooking times, and reflex impairment, a series of linear models were used. Fish fight time and RAMP score were predicted by gear type, fish length, and their interaction. Hook removal time was predicted by gear type alone. Models were validated by examining graphical plots of the residuals versus fitted values, as well as all predictors for visible patterns indicative of poor model fit, or serial autocorrelation (per Zuur et al. 2009). Data analysis was conducted using R Studio version 0.99.447 (R Studio Team 2015). Data are reported as mean ± SE, and the level of significance was set at α = 0.05.

RESULTS

Largemouth Bass (n = 107, mean TL ± SE = 300 ± 44 mm) fight durations were highly variable between fishing gear types and across fish sizes (Figure 1). There was a significant interaction between gear type and fish length in predicting fight durations (Table 1). Largemouth Bass captured on UL fishing gear experienced longer fight times, and there was a stronger positive relationship between fish length and fight time than those captured on MH fishing gear. However, once landed, fish captured on UL gear experienced shorter hook removal times (Figure 2; Table 1). Fish that were exposed to the air for 120 s had higher reflex impairment than those held entirely in water (Figure 3). Similarly, fish captured using UL gear had greater levels of reflex impairment than those captured on MH gear (Figure 3). There was a significant interaction between air exposure and gear type in predicting reflex impairment (Table 1). Largemouth Bass captured on UL gear had significantly higher reflex impairment than those captured with MH gear with no air exposure, while fish captured with both gear types had similarly high reflex impairment when air exposed.

DISCUSSION

Despite the wide range of fishing gear available to recreational anglers, few experiments have addressed the effects of fishing gear strength on fish vitality. Using ultralight and heavyweight

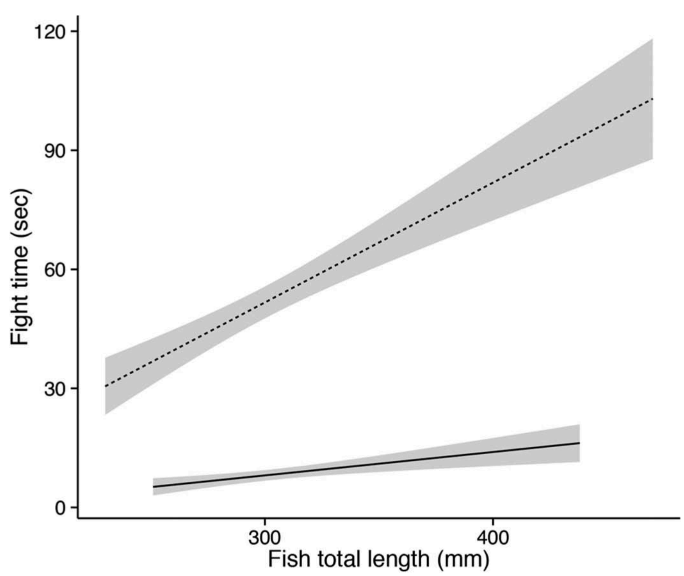

FIGURE 1. Fitted linear models (±95% CI) of Largemouth Bass fight time (s) by fish TL (mm) captured on medium-heavy (solid line) and ultralight (dotted line) fishing gear.

TABLE 1. Linear model estimates for Largemouth Bass fight time and reflex impairment score (RAMP), with gear type (medium-heavy or ultralight gear strength), fish TL, and their interaction as predictors, as well as hook removal time with gear type as a predictor. *P*-values in bold italics indicate significant effects.

Response predictor	Estimate	SE	*t*-value	*P*-value
Fight time				
Gear	29.33	14.70	2.00	***0.048***
TL	0.06	0.04	1.62	0.11
Gear : TL	0.24	0.05	5.04	***<0.001***
Hook removal time				
Gear	4.70	0.86	5.44	***<0.001***
RAMP score				
Gear	0.26	0.04	5.88	***<0.001***
TL	0.28	0.04	6.25	***<0.001***
Gear : TL	0.18	0.06	2.89	***0.005***

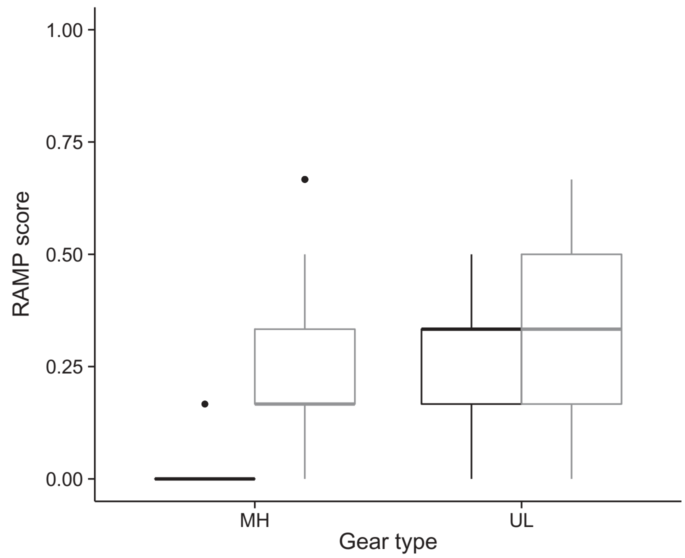

FIGURE 3. Reflex impairment, determined by the RAMP score (i.e., reflex action mortality predictors) of Largemouth Bass captured on different gear types (gear strength: MH = medium-heavy, UL = ultralight) and subjected to 0 s (black outline) or 120 s (gray outline) of air exposure. 0 = low impairment, 1 = high impairment.

rods, reels, and fishing line, we contrasted the role of gear strength on aspects of fish injury and condition. We also considered how gear strength mediates handling time and how the level of exhaustion from the fight interacts with air exposure duration. Although fight time is often considered in catch-and-release studies as potential drivers of physiological disturbance, reflex impairment, and mortality, fight time is almost always confounded with fish size (Meka and McCormick 2005; Cooke et al. 2008). Previous studies that have explicitly studied the role of fight time have done so by using a single gear type, or simulated angling stressors, and have either expedited or extended the fight to generate variation in fish duration (J.W.B., unpublished results).

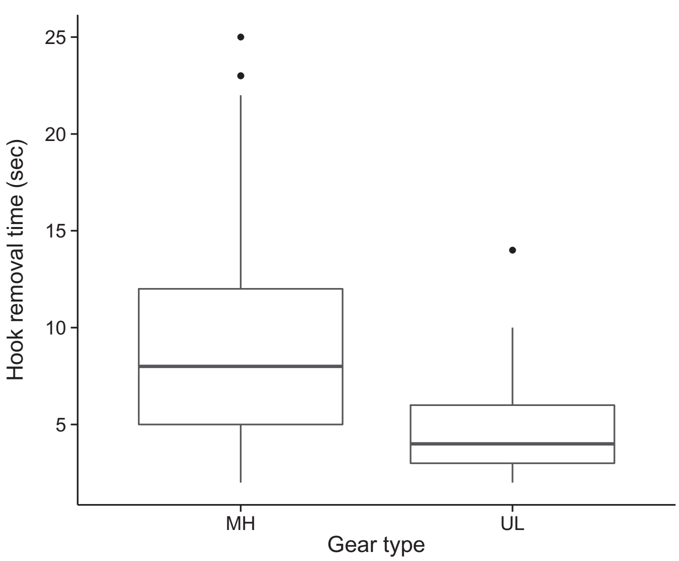

FIGURE 2. Hook removal time (amount of time taken to remove the hook from the fish using pliers) in Largemouth Bass captured with medium-heavy (MH) or ultralight (UL) fishing gear.

Our study revealed that use of ultralight gear led to prolonged fight times and greater levels of reflex impairment relative to fish landed using heavyweight gear. Although we did not measure biochemical indices of exhaustion in this study, it is well known that tissue energy stores (e.g., phosphocreatine, ATP, glycogen) become depleted, metabolites (e.g., lactate) accumulate, and both acid–base balance (i.e., typically acidosis) and ionic status are altered due to angling stressors (reviewed in Kieffer 2000; Cooke and Suski 2005). Moreover, oxygen debt associated with anaerobiosis occurs (Kieffer 2000). In our study, reflex indicators (especially loss of equilibrium and bursting) were consistently impaired in fish that were exhausted, which represents a manifestation of the combined aforementioned physiological disturbances. Upon release, problems with maintaining equilibrium or bursting to escape predators could impede predator avoidance (Brownscombe et al. 2013) and lead to postrelease predation (Cooke and Philipp 2004; Raby et al. 2014). Ultimately, reflex impairment tests are considered the best predictors of fitness impairments and mortality (Davis 2010; Raby et al. 2012).

One of the more interesting observations from this study was that fish that were landed rapidly and thus in better condition were more difficult to handle, which led to longer air exposure. We are aware of anglers and scientists that have mused about the trade-offs between fight time and ease of handling, but to our knowledge this is the first study to formally assess this idea. Upon landing, we observed anecdotally that fish captured on the heavy gear with shorter fight durations were more difficult to lip and thrashed more during hook removal (authors' personal observation; note landing and handling all occurred in a rubber landing net), leading to longer hook removal periods. Fish that were captured on ultralight gear were clearly more exhausted such that they were generally quite easy to handle to remove the hook (authors' personal observations). In this study we used two extremes in gear type and suggest that moderate strength gear likely represents the best compromise in terms of achieving an appropriate level of exhaustion that would facilitate handling and hook removal without leading to complete exhaustion. It is important to consider the totality of the fishing gear when determining appropriate gear strength. For example, an ultralight rod with heavy line or a heavy rod with an ultralight reel and line with low break strength would both be equivalent to using lighter strength gear. Similarly, knot type and drag settings may also influence fight duration and the relative performance of a given gear type. For example, drag settings could be reduced on heavy gear to make it perform more like ultralight gear. For this study we worked within the inherent limitations of the gear assuming anglers wish to land fish as rapidly as possible. As such, fish on UL gear were landed as quickly as feasible, which took much longer than for fish that were hooked using MH gear, which would be reeled in more rapidly. Although angler behavior will vary, we submit that the type of gear used will be the primary driver of fight duration (beyond fish size and the depth and distance of hooking relative to position of the angler).

The negative consequences of air exposure for fish are well established (reviewed in Cook et al. 2015). In the context of recreational fishing, air exposure occurs during the handing phase where the fish are landed, the hook is removed, and the catch admired. When we systematically varied air exposure duration (i.e., 0 versus 120 s) for Largemouth Bass, we noted that the longer period was associated with greater levels of reflex impairment. However, most notable was that there was an interaction with gear strength such that fish that were generally more exhausted from the use of ultralight gear were more greatly influenced by air exposure than those fish that were landed rapidly by means of heavy gear. This result is not surprising given that we are increasingly recognizing that different fisheries stressors interact (e.g., water temperature and air exposure duration: Gingerich et al. 2007) often in an additive or multiplicative manner (see Cooke et al. 2013; Raby et al. 2015). Air exposure induces hypoxia in fish that are already exhausted (Ferguson and Tufts 1992) and affects both the magnitude of the physiological disturbance and the time required for the fish to recover. Using reflex indicators, we showed clearly that there was a gradient in reflex impairment with Largemouth Bass; fish captured on UL gear had significantly higher reflex impairment than those captured with MH gear with no air exposure, while fish captured with both gear types had similarly high reflex impairment when exposed to the air.

The findings from this study yield a number of conclusions relevant to catch-and-release science and the development of best practices for anglers (Cooke and Schramm 2007). Given that exhausted fish are easier to handle and remove from the hook, minimizing or even eliminating air exposure is more feasible for fish landed with ultralight gear, while with heavier gear and shorter fight times, increased difficulty in hook removal may lead to longer air exposure durations as well as a greater potential for injury due to contact with abrasive surfaces such as landing nets, boats, or land (e.g., Colotelo and Cooke 2011). In reality, there is likely an optimal fight time that enables a fish to be landed safely (without harming the fish or the angler) without causing the fish to become fully exhausted yet not landing the fish so rapidly that the "fight" continues during the handling phase, thus extending air exposure. In situations where environmental conditions (e.g., water temperature, predator burdens) are more extreme than what we studied here, using ultralight gear that requires fighting the fish to exhaustion could be more deleterious. As such, we recommend additional research on this topic focused in areas approaching thermal tolerance limits of the fish and in areas where predators are more abundant. This is particularly salient for competitive events that focus on rewarding individuals for capturing fish using different gear strength (e.g., line class awards; see Shiffman et al. 2014). Although it would be somewhat difficult to regulate gear strength, this knowledge is useful in the context of developing best practices for angler education and outreach programs. It is conceivable for some intensively managed fisheries for vulnerable species (e.g., endangered species, species sensitive to long fights such as some salmonids) that aspects of gear type (e.g., minimum of *x* line strength) or angler behavior (e.g., setting a maximum fight time, which would presumably require adjustments in gear type) could be regulated, but we are unaware of any such examples to date. The lack of previous catch-and-release research projects that have systematically varied gear strength is remarkable given the range of gear types available. Although our work focused on a single species, we expect that the general trends revealed here will apply to most other recreational fishing scenarios (e.g., species, bait and lure types).

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REFERENCES

Arlinghaus, R., S. J. Cooke, J. Lyman, D. Policansky, A. Schwab, C. Suski, S. G. Sutton, and E. B. Thorstad. 2007. Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from historical, ethical, social, and biological perspectives. Reviews in Fisheries Science 15:75–167.

Bartholomew, A., and J. A. Bohnsack. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Reviews in Fish Biology and Fisheries 15:129–154.

Brett, J. 1969. Temperature and fish. Chesapeake Science 10:275–276.

Brownscombe, J. W., S. D. Bower, W. Bowden, L. Nowell, J. D. Midwood, N. Johnson, and S. J. Cooke. 2014a. Canadian recreational fisheries: 35 years of social, biological, and economic dynamics from a national survey. Fisheries 39:251–260.

Brownscombe, J. W., A. J. Danylchuk, J. M. Chapman, L. F. G. Gutowsky, and S. J. Cooke. In press. Best angling practices for catch-and-release fisheries – angling tools and tactics. Fisheries Research. DOI: 10.1016/j.fishres.2016.04.018.

Brownscombe, J. W., K. Marchand, K. Tisshaw, V. Fewster, O. Groff, M. Pichette, M. Seed, L. F. G. Gutowsky, A. D. M. Wilson, and S. J. Cooke. 2014b. The influence of water temperature and accelerometer-determined fight intensity on physiological stress and reflex impairment of angled Largemouth Bass. Conservation Physiology [online serial] 2:cou057.

Brownscombe, J. W., L. Nowell, E. Samson, A. J. Danylchuk, and S. J. Cooke. 2014c. Fishing-related stressors inhibit refuge-seeking behavior in released subadult Great Barracuda. Transactions of the American Fisheries Society 143:613–617.

Brownscombe, J. W., J. D. Thiem, C. Hatry, F. Cull, C. R. Haak, A. J. Danylchuk, and S. J. Cooke. 2013. Recovery bags reduce post-release impairments in locomotory activity and behavior of bonefish (*Albula* spp.) following exposure to angling-related stressors. Journal of Experimental Marine Biology and Ecology 440:207–215.

Colotelo, A. C., and S. J. Cooke. 2011. Evaluation of common angling-induced sources of epithelial for popular freshwater sport fish using fluorescein. Fisheries Research 109:217–224.

Cook, K. V., R. J. Lennox, S. G. Hinch, and S. J. Cooke. 2015. Fish out of water: how much air is too much? Fisheries 40:452–461.

Cooke, S., and H. Schramm. 2007. Catch-and-release science and its application to conservation and management of recreational fisheries. Fisheries Management and Ecology 14:73–79.

Cooke, S. J., and I. G. Cowx. 2006. Contrasting recreational and commercial fishing: searching for common issues to promote unified conservation of fisheries resources and aquatic environments. Biological Conservation 128:93–108.

Cooke, S. J., M. R. Donaldson, C. M. O'Connor, G. D. Raby, R. Arlinghaus, A. J. Danylchuk, K. C. Hanson, S. G. Hinch, T. D. Clark, D. A. Patterson, and C. D. Suski. 2013. The physiological consequences of catch-and-release angling: perspectives on experimental design, interpretation, extrapolation, and relevance to stakeholders. Fisheries Management and Ecology 20:268–287.

Cooke, S. J., and D. P. Philipp. 2004. Behavior and mortality of caught-and-released bonefish (*Albula* spp.) in Bahamian waters with implications for a sustainable recreational fishery. Biological Conservation 118:599–607.

Cooke, S. J., and C. D. Suski. 2005. Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? Biodiversity and Conservation 14:1195–1209.

Cooke, S. J., C. D. Suski, S. E. Danylchuk, A. J. Danylchuk, M. R. Donaldson, C. Pullen, G. Bulte, A. O'Toole, K. J. Murchie, and T. L. Goldberg. 2008. Effects of capture techniques on the physiological condition of Bonefish (*Albula vulpes*) evaluated using field physiology diagnostic tools. Journal of Fish Biology 73:1351–1375.

Danylchuk, A. J., C. D. Suski, J. W. Mandelman, K. J. Murchie, C. R. Haak, A. M. Brooks, and S. J. Cooke. 2014. Hooking injury, physiological status and short-term mortality of juvenile Lemon Sharks (*Negaprion bevirostris*) following catch-and-release recreational angling. Conservation Physiology [online serial] 2:cot036.

Danylchuk, S. E., A. J. Danylchuk, S. J. Cooke, T. L. Goldberg, J. Koppelman, and D. P. Philipp. 2007. Effects of recreational angling on the post-release behavior and predation of Bonefish (*Albula vulpes*): the role of equilibrium status at the time of release. Journal of Experimental Marine Biology and Ecology 346:127–133.

Davis, M. W. 2010. Fish stress and mortality can be predicted using reflex impairment. Fish and Fisheries 11:1–11.

Ferguson, R. A., and B. L. Tufts. 1992. Physiological effects of brief air exposure in exhaustively exercised Rainbow Trout (*Oncorhynchus mykiss*): implications for "catch and release" fisheries. Canadian Journal of Fisheries and Aquatic Sciences 49:1157–1162.

Gale, M. K., S. G. Hinch, and M. R. Donaldson. 2013. The role of temperature in the capture and release of fish. Fish and Fisheries 14:1–33.

Gingerich, A. J., S. J. Cooke, K. C. Hanson, M. R. Donaldson, C. T. Hasler, C. D. Suski, and R. Arlinghaus. 2007. Evaluation of the interactive effects of air exposure duration and water temperature on the condition and survival of angled and released fish. Fisheries Research 86:169–178.

Gustaveson, A. W., R. S. Wydoski, and G. A. Wedemeyer. 1991. Physiological response of Largemouth Bass to angling stress. Transactions of the American Fisheries Society 120:629–636.

Kieffer, J. D. 2000. Limits to exhaustive exercise in fish. Comparative Biochemistry and Physiology A 126:161–179.

Landsman, S. J., H. J. Wachelka, C. D. Suski, and S. J. Cooke. 2011. Evaluation of the physiology, behaviour, and survival of adult Muskellunge (*Esox masquinongy*) captured and released by specialized anglers. Fisheries Research 110:377–386.

Meka, J. M., and S. D. McCormick. 2005. Physiological response of wild Rainbow Trout to angling: impact of angling duration, fish size, body condition, and temperature. Fisheries Research 72:311–322.

Muoneke, M. I., and W. M. Childress. 1994. Hooking mortality: a review for recreational fisheries. Reviews in Fisheries Science 2:123–156.

Pelletier, C., K. C. Hanson, and S. J. Cooke. 2007. Do catch-and-release guidelines from state and provincial fisheries agencies in North America conform to scientifically based best practices? Environmental Management 39:760–773.

Quinn, S., and C. Paukert. 2009. Centrarchid fisheries. Pages 312–339 *in* S. J. Cooke and D. P. Philipp, editors. Centrarchid fishes: diversity, biology and conservation. Blackwell Publishing, West Sussex, UK.

Quinn, S. P. 1989. Recapture rates of voluntarily released Largemouth Bass. North American Journal of Fisheries Management 9:86–91.

Raby, G. D., M. R. Donaldson, S. G. Hinch, T. D. Clark, E. J. Eliason, K. M. Jeffries, K. V. Cook, A. Teffer, A. L. Bass, and K. M. Miller. 2015. Fishing for effective conservation: context and biotic variation are keys to understanding the survival of Pacific salmon after catch-and-release. Integrative and Comparative Biology 55:554–576.

Raby, G. D., M. R. Donaldson, S. G. Hinch, D. A. Patterson, A. G. Lotto, D. Robichaud, K. K. English, W. G. Willmore, A. P. Farrell, and M. W. Davis. 2012. Validation of reflex indicators for measuring vitality and predicting the delayed mortality of wild Coho Salmon bycatch released from fishing gears. Journal of Applied Ecology 49:90–98.

Raby, G. D., J. R. Packer, A. J. Danylchuk, and S. J. Cooke. 2014. The understudied and underappreciated role of predation in the mortality of fish released from fishing gears. Fish and Fisheries 15:489–505.

RStudio Team. 2015. RStudio: integrated development for R. RStudio, Boston.

Shiffman, D., A. Gallagher, J. Wester, C. Macdonald, A. Thaler, S. J. Cooke, and N. Hammerschlag. 2014. Trophy fishing for species threatened with extinction: a way forward building on a history of conservation. Marine Policy 50:318–322.

Thorstad, E. B., T. F. Næsje, P. Fiske, and B. Finstad. 2003. Effects of hook and release on Atlantic Salmon in the River Alta, northern Norway. Fisheries Research 60:293–307.

Wydoski, R. S. 1977. Relation of hooking mortality and sublethal hooking stress to quality fishery management. Pages 43–87 *in* R. A. Barnhart and T. D. Roelofs, editors. Catch-and-release fishing as a management tool. Humboldt State University, Arcata, California.

Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R. Spring Science and Business Media, New York.