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Synergistic and interactive effects of angler behaviour, gear type, and fish behaviour on hooking depth in passively angled fish

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ABSTRACT

Despite a growing body of literature on the impacts of recreational fisheries on wild populations, surprisingly little is known regarding how individual differences in fish behaviour and their interaction with a baited hook influences hooking injury. We used an underwater video camera, fixed to the fishing line, to record the behaviour of wild sunfishes (*Lepomis* spp.) as they approached and attacked one of four treatments of baited hook used under a passive angling scenario. Angler reaction time was measured as the difference between the fish strike and hook set. Length-corrected hooking depth was evaluated as a function of multiple putative explanatory variables. Angler performance (hooksets/min) varied over the two day study, where hooksets/min decreased with small hooks and increased with large hooks. Model selection and model averaging revealed the top models included the terms: angler reaction time, approach to bait (cautious, deliberate, aggressive), hook size (small or large), and the interaction between approach to bait and hook size. The model-averaged fitted values indicated that length-corrected hooking depth increased most dramatically with angler reaction time when fish aggressively attacked a baited hook. A cautious approach to a large baited hook led to a deeper length-corrected hooking depth than a similar approach to a small baited hook. These results illustrate synergistic and interactive relationships among factors known to influence impairment, injury, and mortality in caught and released fish. Of particular novelty was our ability to assess the variation in how fish behaviour influences injury in a catch-and-release fishery using underwater cameras, which suggests that this approach holds promise in fisheries science.

1. Introduction

Across the globe, millions of fish are released annually by recreational anglers as a result of conservation ethics or to comply with fishing regulations—an activity called “catch-and-release” (herein termed C&R; Arlinghaus et al., 2007). The premise of C&R is that released fish survive with negligible injury and sublethal physiological and behavioural alterations (Cooke and Schramm, 2007; Wydoski, 1977). Despite the good intentions of anglers and managers, C&R exposes fish to injuries and stressors that potentially decrease their chances of survival (Arlinghaus et al., 2007; Cooke and Suski, 2005). C&R science has largely been directed toward understanding endpoints (e.g., injury, impairment and mortality) in an effort to minimize the negative consequences of C&R and maximize the likelihood that fish survive. The result has been a growing body of literature that forms the scientific basis for best angling practices (Arlinghaus et al., 2007; Bartholomew and Bohnsack, 2005; Muoneke and Childress, 1994).

For C&R angling studies that examine injury, statistical variance is often explained with controllable variables that originate from the angler and the environment (Arlinghaus et al., 2007). For instance, hooking depth, eye injury and the amount of bleeding varies according to multiple factors such as hook type, angler experience, and hook-set behaviour (Bacheler and Buckel, 2004; Cooke et al., 2003, 2001; Dunmall et al., 2001; Lennox et al., 2015). While C&R science often focuses on angler behaviour and the environment, fish behaviour is increasingly being considered as a largely uncontrollable, though nonetheless important, component of the C&R process (Brownscombe et al., 2014; Thorstad et al., 2003; Vainikka et al., 2016; Wilson et al., 2015). However, given that impairment, injury and mortality manifest from several sources in C&R fisheries (Cooke et al., 2013), understanding the contribution of fish behaviour to any potential endpoint requires the investiga-

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tion be inclusive and capable of decoupling the influence of fish behaviour from those well-known and independent factors.

Determining or manipulating angler behaviour is a relatively straightforward exercise. For instance, participation, knowledge and skill can be used to define angler experience while hook types can be easily incorporated as experimental treatments (Dunmall et al., 2001; Lennox et al., 2015; Rapp et al., 2008). Given that wild fish are cryptic by nature and often strike angling gear without warning, there are few appropriate techniques for evaluating fish behaviour prior to hooking. However, underwater action cameras (Struthers et al., 2015) provide the opportunity to study fish behaviour as they approach, inspect and interact with baited hooks (e.g., Alós et al., 2014; Alós et al., 2015). When examined in conjunction with angler behaviour, underwater videography techniques provide the ability to evaluate the potential influence of multiple factors on injury or mortality in C&R fish immediately prior to capture.

In this study, we use newly available underwater video cameras and an information theoretic analytical framework to better understand the influence of fish behaviour on hooking depth in wild-caught sunfishes (Lepomis spp.). The study was performed by novice anglers using four hook and bait configurations. Fish were captured from their natural environment using passive angling where the only indication of a strike was through the movement of a bobber (i.e., fishing float). This technique simulated real angling situations for these species while enabling us to simultaneously measure angler reaction time, record fish behaviour and control gear type. Using underwater cameras and model selection, our objectives were to reveal: 1) synergistic and interactive effects from multiple explanatory variables and; 2) the putative influence of fish behaviour on hooking depth in a C&R fishery.

2. Methods

2.1. Study site and sample collection

The study was performed at the Queen's University Biological Station on Lake Opinicon in the Rideau Lakes area of Eastern Ontario (44° 34′N, 76° 19′W). Angling took place between approximately 14:00 to 16:00 h on 7 May and 8 May 2015. Lake Opinicon is shallow (<10 m deep), mesotrophic, and contains a diverse fish community including but not limited to largemouth bass (*Micropterus salmoides*), northern pike (*Esox lucius*) and two species of sunfish [Pumpkinseed, *Lepomis gibbosus* (Ps) and Bluegill, *Lepomis macrochirus* (Bg)]. Two novice participants (i.e., no previous angling experience) were employed to angle over the brief span of days. Participants were selected based on their similar lack of angling experience whereas the brief span of days helped reduce confounding influences of increasing water temperatures during the spring sampling period. Each of the two participants were outfitted with a medium action rod (198 cm) and reel, light-weight monofilament line (3.5 kg), and a Water Wolf underwater camera (Svendsen Sport, Gadstrup, Denmark). Cameras were tied between the main line and a leader that was approximately 60 cm long from the camera lens to the baited hook. A weight near the lens of the camera ensured it was oriented vertically and faced toward the baited hooks below (Fig. 1A, B). A small bobber was attached above the camera to provide additional buoyancy (Fig. 1B). Cameras were optimized for low-light conditions and able to internally record a series of 20-min videos for up to four hours (12 video files × 20 min/video file; resolution: 720 p).

From the camera it was possible to assess fish behaviour such as the approach and post-strike movement. Fish approach and attack was categorized as cautious (no clear forward motion with only buccal cavity suction to engulf the bait), deliberate (slow forward motion [approx. ≤1 body length s^{-1}] and buccal cavity suction), and aggressive (rapid forward motion [approx. >1 body length s^{-1}] to engulf the bait). During passive angling of sunfish, post-strike behaviour prior to hook setting usually involved rapid pivoting (e.g., a unidirectional head shake and 45° turn) with little lateral movement. As this was a common behaviour among angled sunfishes, post-strike and pre-hook set fish behaviour was assessed as the number of these movements. All research activities were conducted in accordance with guidelines from the Canadian Council on Animal Care at Carleton University, and under a scientific collection permit obtained from the Ontario Ministry of Natural Resources and Forestry (License no. 1079391).

Gear treatments included: a large baitholder hook (6/0) and large bait (3 cm piece of cut dew worm); a small baitholder hook (8/0) and small bait (1 cm piece of cut dew worm); a large hook and small bait; a small hook and small bait. Each angler used one hook size per day and changed bait sizes after capturing 10 fish for a total of 20 fish/day/angler. Anglers were instructed on how to set the hook by sharply pulling the bait away from a detected strike (Fig. 1C). Anglers were not permitted to sight fish their bait (i.e., the ability to observe fish while handling the bait), thus hook setting was only influenced by observing bobber movement. Once captured, fish body size (TL to the nearest mm) and hooking depth (mm) were measured. If the hook was not visible (i.e., lodged in the esophagus or stomach), the fishing line was cut and a new line retied. The depth to the eye of the hook plus the total length of the hook was used to estimate deep-set hooking depth. Length-corrected hooking depth was calculated as the ratio of hooking depth to fish total length (Dunmall et al., 2001). Anatomical hooking location was recorded prior to hook removal. From the recorded videos, angler reaction time was measured as the difference in time (to the nearest millisecond) between the hook set and fish strike.

3. Analyses

3.1. Angler performance and deeply hooked fish

We first explored the data for outliers, collinearity, and two-way relationships using various plotting functions in the R statistical environment (R Core Development Team, 2012). For this study we were interested in three possible response variables: angler performance, the number of deeply hooked fish, and length-corrected hooking depth. Although hooking depth may differ with hook type for Ps and Bg (Cooke et al., 2003), initial data exploration indicated no species-related differences in length-corrected hooking depth for the two baitholder hook sizes. Thus Ps and Bg catches were pooled for analysis. Angler performance was assessed by calculating the number of attempted hook sets per minute while the bait was submerged. This metric was calculated for each video file which was approximately 20 min in length. Hook sets/min served to illustrate trends related to angler behaviour. In addition, variation in performance (e.g., improvements by the novice anglers) would suggest that statistical models may be further explained using fixed or random effects for individual angler over time. The number of deeply hooked fish was plotted as a function of angler reaction time and length-corrected hooking depth. This plot was further used to illustrate the apparent minimum angler reaction time and length-corrected hooking depth to observe a deeply hooked sunfish.

3.2. Length-corrected hooking depth

Akaike information criterion was used to determine how angler behaviour, gear type, and fish behaviour may explain length-corrected hooking depth (Akaike, 1974). Models (n = 23) were *a priori* specified and compared using second-order AIC where mod-