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MANAGEMENT BRIEF

Influence of Hook Size and Style on Short-Term Survival of Deeply Hooked Bluegills

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Abstract
Catch and release is a common practice among recreational anglers. In instances when fish are deeply hooked, the proper techniques for promoting survival are poorly understood, although evidence suggests that the fishing line should be cut rather than attempting to remove the hook. Bluegills *Lepomis macrochirus* were used as a model to identify the role of hook size (sizes 8 and 12), style (Aberdeen, baitholder, single egg), and the presence of barbs (only for baitholder hooks in size 10) on survival and hook retention for fish deeply hooked and the line cut. Eight hook style and size variants were manually embedded in the dorsal esophagus of fish, monitored over 10 d, and compared with unhooked controls. There was some evidence that Aberdeen style and larger hooks (size 8) incurred greater mortality over the 10-d monitoring period, while barbless hooks did not improve survival. Hook retention was high (>90%) for all deeply hooked fish. "J" style hooks, such as Aberdeen, and larger hooks may not be warranted for bluegills; however, we suggest that anglers use an adaptive approach when they select for a gear type appropriate to their target catch and simply adjust for alternate gear and techniques if deep hooking persists.

The foundations of catch-and-release angling stem from the belief that released fish will survive, enabling potential recapture on another occasion (Arlinghaus et al. 2007). Although many fish appear healthy upon release, a growing body of work suggests that the mortality associated with catch-and-release practices commonly occur after release (termed delayed mortality; reviewed in Arlinghaus et al. 2007). The hooking location of an angled fish is typically regarded as the most important initial factor when assessing the probability of survival. The odds of a fish's survival is severely reduced when subjected to deep hooking (Bartholomew and Bohnsack 2005; Cooke and Suski 2005). Deep hooking typically refers to fish that are hooked in the esophagus, stomach, gills, or roof of the mouth. Given the proximity of these areas to the heart, liver, and associated vasculature, deep hooking can result in severe bleeding leading to either immediate or delayed mortality. Hook design (Cooke and Suski 2004), hook size (Alós et al. 2008), bait and lure type (Arlinghaus et al. 2008; Hoxmeier and Wahl 2009), and angler experience (Diodati and Richards 1996) influence the likelihood of deep hooking.

Despite the best efforts to reduce deep-hooking events (e.g., use of circle hooks; Cooke and Suski 2004; Cooke et al. 2012), it is unlikely that changes in gear type or angler behavior will ever completely eliminate deep hooking. When releasing a deeply hooked fish, the angler must decide whether to cut the fishing line and leave the hook in place, or attempt to remove the hook. Removing a hook under deeply hooked conditions will often lead to the fish's death as a result of severe injury to vital

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tissues (Aalbers et al. 2004; Fobert et al. 2009; Wilde and Sawynok 2009). Yet leaving a deep hook in place can also have undesirable consequences. For example, fish with retained hooks can have long-term pathological consequences (Borucinska et al. 2002), potentially reducing the fish's capacity to feed and subsequently grow. However, there is evidence to suggest that fish are eventually able to shed their hooks even when deeply hooked (DuBois and Pleski 2007; DeBoom et al. 2010; Stein et al. 2012).

To date, studies that have examined deep hooking have tended to simply compare deep hooking with shallow hooking, and the consequences of leaving the hook in place or removing it (or attempting to do so). Presumably a number of factors can potentially influence hook shedding such as hook type, size, and configuration (i.e., barbed versus barbless). To our knowledge, very few studies have systematically varied the size of hook or the type of hook to determine how those factors influence survival and hook retention (but see DuBois and Pleski 2007; Stein et al. 2012). The size and style of the hook may influence food intake, potentially damage vital organs, and affect the ability of a retained hook to be expelled (either orally or through the digestive tract). Similarly, whether a hook is barbed or barbless may also influence retention.

The objective of the present study was to identify the role of hook size, style, and the presence of barbs, on survival and hook retention of deeply hooked fish. The bluegill *Lepomis macrochirus*, often a subject of deep hooking (Cooke et al. 2003), was selected as a model species for its regional availability and its common association with angler catch and release. Previous research by Fobert et al. (2009) revealed that cutting the fishing line and leaving the hook in place for deeply hooked bluegills resulted in fewer sublethal physiological consequences, less injury, and lower mortality than removing the hook. However, Fobert et al. (2009) used only a single hook size and style. By comparing multiple hook styles and sizes in the present study, it was possible to determine the extent to which the recommendations from Fobert et al. (2009) (i.e., cutting the line and leaving deep hooks in place) vary with gear configuration. For the purpose of this study we focused only on leaving hooks in place and comparing the fate of those fish to controls.

METHODS

Study area and fish capture.—Our study was conducted at the Queen's University Biological Station (44°34′N, 76°19′W), located on Lake Opinicon, a centrarchid-dominated lake in southeastern Ontario. Additional details on Lake Opinicon and the bluegill fishery can be found in Cooke et al. (2003). Our experiment was conducted between August 21 and 30, 2010, in which all fish were collected and subjected to experimental treatment on the first day and posttreatment monitoring occurred over the following 10 d. Water temperature ranged between 23°C and 25°C during the capture and holding period.

Within a 6-h period, we collected 179 bluegills (mean total length ± SD, 130 ± 25 mm) by rod and reel using a small piece of earthworm on barbless circle hooks (size 10). All fish were landed within 10 s of being hooked. We retained all fish that were shallowly hooked (i.e., hooked in the jaw) and appeared healthy (i.e., showed no sign of bleeding, parasites or fungus; had regular ventilation rate). We did not select for a specific size of fish; however, by using a size 10 hook we excluded many of the highly abundant subadult fish (Cooke et al. 2005). Hooks were removed underwater in a water-filled trough and fish were temporarily (i.e., for no more than 10 min) transferred to a 50-L cooler and supplied with frequently replenished fresh lake water before processing.

Experimental treatments.—We had eight different deep hooking treatments and a control group in which fish were only subjected to the stressors of capture and captivity. The treatment hooks varied in the size, style, and presence of barbs. To evaluate survival and hook retention of fish deeply hooked with different hook styles and sizes we used three barbed hook types (Aberdeen, Mustad, model 3260b; baitholder, Mustad, model 92681; single egg, Gamakatsu, model GAM-0052) in two sizes (large, size 8; small, size 12) that are commonly used by anglers when targeting bluegill and other panfish. The hook styles chosen each have distinct design elements (see Figure 1). Baitholder style hooks possess a set of small barbs along the shank, and a point aligned in the direction of the eye. Aberdeen style hooks resembled a typical "J" style design and have an extended shank and parallel point. Single egg hooks have a relatively round bend, and a short shank compared with the alternate styles. In addition, to evaluate the extent to which a barb influenced hook

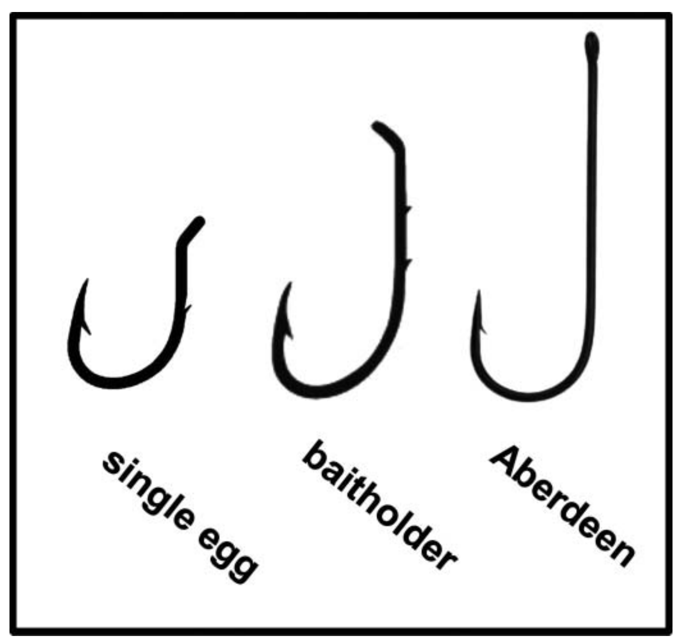

FIGURE 1. The different hook styles employed in experimentally deeply hooked bluegills.

retention and survival, we used and compared the performance of barbed and barbless hooks using a single hook type and size (size 10 baitholder, Mustad, model 92681).

For all fish except the controls, treatments involved deep-hooking a fish using hemostats (as per Pope et al. 2007). Unlike Fobert et al. (2009), attempts were made to reduce the variation associated with the degree of deep hooking and specific anatomical location by adopting a more experimental and controlled approach where fish were hooked manually in the esophagus to enable for a more direct assessment of hook size and style and their influence on survival and hook retention. The hook was passed into the esophagus of the bluegill until the hook point was no longer visible and gently pulled anteriorly with the hook oriented upwards to hook the tissue and emulate a moderate hook set. Hooks were therefore uniformly positioned in all fish. The esophagus appears to be the most sensitive location to be hooked and incurs the greatest mortality compared with other hooking locations (Pelzman 1978; Pope et al. 2007), which is why we selected that location. Each hook had 15 cm of 2.72-kg (6 lb) test fishing line attached to determine hook retention based on line protrusion from the mouth or anus. All fish, including controls, were marked with individually numbered anchor tags (Floy Tag & Manufacturing, Seattle, Washington) posterior to the dorsal fin on the left side to distinguish fish among groups. After processing, fish were transferred to a round tank (1.4 m diameter, 1 m depth) containing a continuous flow of approximately 700 L/h of lake water and held for 10 d. Water temperatures were the same as lake temperatures (23–25°C) and dissolved oxygen was at ambient levels (80–100% saturation). The holding tank was outdoors with a mesh covering (to prevent predation), thus providing fish with natural light and weather conditions. During the holding period, fish were fed twice daily until satiation with frozen blood worms. The tank was siphoned and cleaned daily.

Data collection.—Fish were assessed over the following 10 d for mortality and hook retention. Initial (within 2 h of treatment processing) and daily (at the end of each day) mortality was determined when fish exhibited indicators of morbidity (e.g., substantial bleeding or blood loss from the fins, floating at the surface, inability to respond to stimuli, minimal to no respiratory activity, or any combination of those indicators) or death. Moribund fish were euthanized using cerebral percussion and dead fish were removed from the tank. All mortalities were recorded and fish were examined for the presence of the hook. If the line was not visible, a post mortem examination was performed to confirm the absence of the hook. In no cases during the experiment did we find fish for which the hook was still present in the fish but the line not visible. As such, at the end of the study period all survivors were identified, examined for hook retention, and released. It was not possible to determine the timing of hook passage for those fish that expelled hooks during the study period.

Statistical analysis.—We conducted two separate analyses: one focused on the role of different hook styles and sizes and one focused on the role of barbed versus barbless hooks. A Cox proportional-hazards regression was used to determine whether the survival of fish differed over time among the different hook style and size treatments (excluding controls owing to data redundancy). Fish size (total length) was included as a covariate to control for differences in survival due to size. Any surviving fish at the end of the study period were censored in the analysis. Cox regressions were performed, with a Bonferroni correction, to determine how hook type, size, or both differed from each other (e.g., similar to a posthoc test). Hook type and size treatments were also compared with controls using a log-rank test, which compares survival curves with censored data. Posthoc, log-rank pairwise tests, with a Bonferroni correction, determined which treatments varied from controls. For the barbed versus barbless analysis, Cox regressions were performed, with a Bonferroni correction, on the barbed, barbless, and control treatments that included fish size as a covariate to determine how treatments differed in survival. Regarding hook retention, a contingency analysis and Fisher's exact test were performed on whether fish retained the hook with different hook styles and sizes and with barbed or barbless hooks, respectively. A contingency analysis was used instead of a Fisher's exact test as the table was greater than 2×2. All analyses were conducted using SPSS version 20.0.0. For all statistical tests, significance was evaluated at $\alpha = 0.05$ unless a Bonferroni correction was applied.

RESULTS

Over the course of the 10-d study, 61% ($N = 179$) of the fish died. Many of the fish (i.e., 21%) died within the first 2 h of the treatment. No control fish died during the first 2 h emphasizing that the initial mortality was associated with the treatments rather than the effects of capture or captivity. The general trend was that the majority of fish (60% across all treatments) died within the first 4 d, with only an additional 1% of fish dying during the remainder of the study.

Hook Type and Size

Overall, 10-d group survival ranked from highest to lowest was: control (87.0%, $N = 23$); baitholder size 12 (55.6%, $N = 18$); single egg size 12 (52.9%, $N = 17$); single egg size 8 (29.4%, $N = 17$); Aberdeen size 12 (29.4%, $N = 17$); baitholder size 8 (22.2%, $N = 18$); and Aberdeen size 8 (11.8%, $N = 17$). Cox regressions (where $\alpha = 0.025$) indicated that bluegills with Aberdeen hooks had a 2.61 times greater risk of mortality than fish with single egg hooks, when controlling for hook and fish size (Wald = 9.433, df = 1, $P = 0.002$; Figure 2). There was no difference in the risk of mortality between fish with Aberdeen and baitholder hooks (Wald = 3.561, df = 1, $P = 0.059$) or between fish with baitholder and single egg hooks when controlling for hook and fish size (Wald = 1.663, df = 1, $P = 0.197$; Figure 2). Bluegills deeply hooked with large size 8 hooks had 1.99 times the risk of mortality than those hooked with smaller size 12 hooks when controlling for hook type and fish size (Wald = 7.552, df = 1, $P = 0.006$; Figure 2). Increasing fish

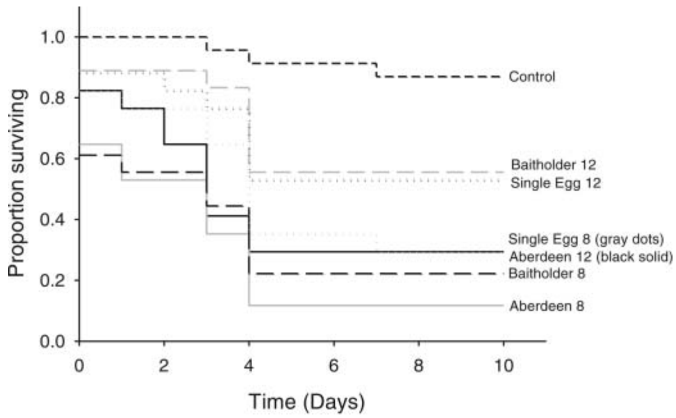

FIGURE 2. Proportion of surviving bluegills over a 10-d period that were experimentally deeply hooked in the esophagus with different hook styles and sizes. Treatments include a mixture of three hook styles (Aberdeen, baitholder, and single egg) and two sizes (8 and 12), as well as control fish that were not deeply hooked.

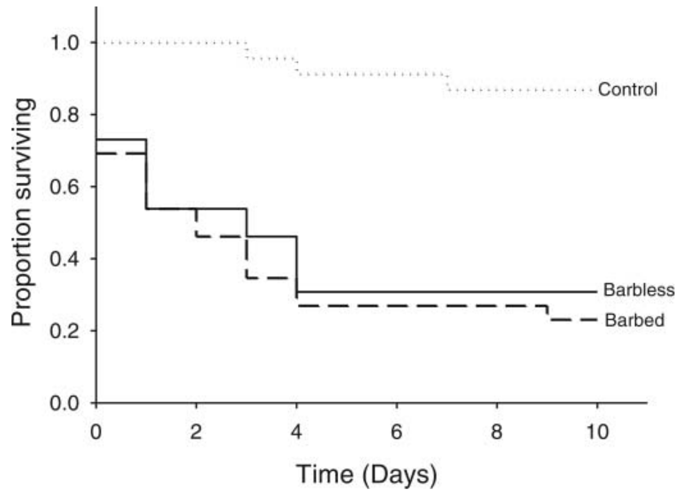

FIGURE 3. Proportion of surviving bluegills over a 10-d period that were experimentally deeply hooked in the esophagus with barbed and barbless baitholder size 10 hooks. Control fish were not deeply hooked.

size reduced the risk of mortality when controlling for hook type and size (Wald = 13.136, df = 1, $P < 0.001$), where every 1-mm increase in total length reduced the risk of mortality by 0.977 times. Fish mortality rates differed among the various hook types and sizes and the control ($\chi^2 = 36.211$, df = 6, $P < 0.001$; Figure 2). Log-rank pairwise comparisons with a Bonferroni correction (where $\alpha = 0.008$) revealed that fish with larger size 8 hooks (of all types) and small Aberdeen 12 hooks died sooner than control fish (Figure 2; Table 1).

There was no difference in hook retention among fish that were deeply hooked with different hook styles and sizes ($\chi^2 = 7.410$, df = 5, $P = 0.1919$). The majority of fish with different hook styles and sizes retained their hooks (98%, $N = 104$). Only 1 of 17 fish hooked with Aberdeen size 12 (5.9%) and 2 of 17 fish hooked with single egg size 12 (11.8%) hooks were able to expel the hook within the 10-d retention period.

Barbed versus Barbless Hooks

Overall the groups with the highest survival were controls (87.0%), then barbless baitholder size 10 hooks (30.8%, $N = 26$), and finally barbed baitholder size 10 hooks (23.1%, $N = 26$). Cox regressions (where $\alpha = 0.025$) indicated that bluegills with barbed hooks had a similar risk of mortality to fish with barbless hooks when controlling for fish size (Wald = 0.023, df = 1, $P = 0.879$; Figure 3). While bluegills deeply hooked with both barbed and barbless hooks had a 13.841 and 13.169 times greater risk of mortality than controls when controlling for fish size, respectively (Wald = 17.242, df = 1, $P < 0.001$; Wald = 16.195, df = 1, $P < 0.001$, respectively; Figure 3). Every 1-mm increase in fish size reduced the risk of mortality by 0.964 times when controlling for treatment type (Wald = 16.826, df = 1, $P < 0.001$).

TABLE 1. Pairwise log-rank comparisons of the proportion of surviving bluegills over a 10-d period that were experimentally deeply hooked in the esophagus with different hook styles and sizes with fish that were not deeply hooked (controls). Significance values ($P < 0.008$) after a Bonferroni correction are indicated by an asterisk.

Hook types and sizes	χ^2	df	P
Aberdeen 8	28.06	2	<0.001*
Aberdeen 12	16.72	2	<0.001*
Baitholder 8	20.66	2	<0.001*
Baitholder 12	5.21	2	0.022
Single egg 8	15.29	2	<0.001*
Single egg 12	6.12	2	0.013

We did not observe a difference in hook retention between fish that were deeply hooked with barbed or barbless hooks (Fisher's exact test: $P = 0.490$). The majority of fish with barbed or barbless baitholder size 10 hooks retained their hooks (96%, $N = 52$). Only 2 of 26 fish with barbless hooks (7.7%) expelled the hook during the retention period, while no fish expelled the size 10 barbed baitholder hooks within 10 d.

DISCUSSION

The hook designs used in this study varied in a variety of ways including the configuration, size, and shape of the shank, bend, and point. There is some evidence that fish with Aberdeen hooks incurred higher levels of mortality. Fish with Aberdeen hooks had generally greater mortality rates than those with other hook styles, although this was only significantly with single egg hooks (Figure 2). Both sizes of Aberdeen hooks had greater mortality rates compared with controls (Table 1). Conversely, only larger size 8 baitholder and single egg hooks resulted in greater mortality than controls. We can only speculate that the long shank in Aberdeen hooks (compared with other hook types used here) may have contributed to the mortality in that it protruded deeper into the buccal cavity than the other hook types. If the end of the hook was in the buccal cavity it could be subject to more movement, which could macerate tissue near the hook point. Another possibility may be the fact that the other hook types (single egg and baitholder) have more rounded bends such that the hook point is oriented more towards the shank of the hook (like a circle hook but not to that extent) than the Aberdeen style, which is the quintessential "J" style hook. Without studies that incorporate radiographs or other imaging technology it will not be possible to identify the exact mechanisms associated with the apparent differences in mortality among hook types.

Hook size affected mortality rates in that bluegills treated with smaller size 12 hooks had lower mortality rates. This may reflect the fact that smaller hooks may be expected to cause less severe injury by not penetrating the esophagus to the same extent as the larger hooks. It is also worth noting that only fish with smaller hooks were capable of expelling them (although only three fish did so) within the 10-d study period. However, the use of smaller hooks may promote the occurrence of deep hooking (Cooke et al. 2005) as smaller hooks can more readily pass into the gullet compared with larger hooks (Beckwith and Rand 2005; Alós et al. 2008).

The presence of the barb on size 10 baitholder hooks had no effect on bluegill survival. However, mortality from both barbed and barbless hooks was significantly higher than in controls. Our results were similar to DuBois and Pleski (2007) who also found no difference in hooking mortality between barbed and barbless hooks on brook trout *Salvelinus fontinalis*. The presence of barbs on hooks may present more of an problem for anglers removing the hook. The use of barbed hooks typically results in greater handling times and consequently a higher probability of mortality (Cooke and Suski 2005; reviewed in Arlinghaus et al. 2007). Despite the lack of evidence to support the use of barbed or barbless hooks under these circumstances, two fish from the barbless treatment were able to expel their hooks. Additional studies that examine hook retention over longer periods (e.g., months) are needed to identify if there are any benefits of barbless hooks over barbed hooks relative to the ability of deeply hooked fish to expel hooks.

We observed a negligible hook expulsion of 3% from all of our treatments. This is in contrast to the study by Fobert et al. (2009) where hook expulsion was 71.4% over 10 d when they used size 10 baitholder hooks. Fobert et al. (2009) considered deep hooking to be hook placement anywhere in the esophageal region including the anterior region of the roof of the mouth and the tongue, while in our study all fish were consistently hooked in the esophagus. Therefore, it appears that fish that are deeply hooked in the esophagus in the manner used in this study are unable to expel the hooks during at least a 10-d period. It is unknown whether these fish would have expelled the hooks over a longer period, especially as fish may retain hooks for months (e.g., whitespotted char *S. leucomaenis* takes 53.3 ± 36.3 d to expel hooks, Tsuboi et al. 2006). After 4 d, mortality rates decreased to near zero even with the hooks still retained suggesting that the effects of deep hooking may be more detrimental as a result of immediate injury, rather than the potential for long-term consequences such as restrictions to feeding and the potential for decreased resistance to pathogens associated with hook retention. That is speculative, however, given that a variety of authors (e.g., Borucinska et al. 2001, 2002; Van der Walt et al. 2005; Broadhurst et al. 2007; DuBois and Pleski 2007) have suggested that the long-term consequences of hook retention could result in delayed mortality.

The present study built on a previous study conducted on bluegills in the same lake by Fobert et al. (2009) where fish were deeply hooked by rod and reel as opposed to manually and consistently deep-hooking the fish in the same location. The differences in the manner in which fish were deeply hooked may not only affect hook retention but the extent of injury (e.g., hook penetration, severity of bleeding). In Fobert et al. (2009), deep-hooking injury would have been much less uniform. Indeed, Fobert et al. (2009) noted 12.5% mortality after 10 d in fish for which hooks were not removed, whereas we observed over 60% mortality during the same period, suggesting the esophageal region is sensitive to being deeply hooked. By controlling for hook location, this study sought to determine the extent to which variation in hook type and size and the presence of the barb influenced the outcome for the fish. We acknowledge that the actual level of mortality observed in this study is probably high compared with scenarios where fish deeply hook themselves during a fishing event. However, we feel that the relative differences (or lack thereof) among groups are informative for considering potential gear regulations. Also noteworthy is the relationship between fish size and mortality for deeply hooked fish. Indeed, when controlling for hook size and type, every 1-mm increase in total length of the fish reduced the risk of mortality by 0.977 times. Hence, the role of fish size seems to be an important but poorly understood component of mortality from deep hooking.

From an angling or management perspective, several strategies can be drawn from these results. First, we suggest that the primary goal should be to minimize deep hooking, and there is a growing body of literature on how to do so. When fish are deeply hooked, there is also growing evidence that it is better to cut the line and leave the hook in place rather than remove it. In this study we attempted to determine if, over a 10-d period, it was evident whether a specific hook type or size or the presence of the barb influenced survival and retention. It appears that Aberdeen hooks increase mortality in bluegills, which may be due to the "J" style of the hook. Smaller hooks reduced mortality; however, smaller hooks could also lead to more incidences of deep hooking. Thus, avoiding the use of "J" style hooks may be warranted. Interestingly, the baitholder hooks, which are also somewhat "J"-like in configuration, did not increase mortality suggesting that the long shank or other attributes of the Aberdeen hook may contribute to the heightened mortality. We also suggest that although management agencies can impose regulations to reduce deep hooking, their role with respect to dealing with deeply hooked fish should probably be more educational, at least for abundant species like bluegill. Of course, educational initiatives need to be based on credible science and our study provides some direction in that respect. However, we suggest that the onus is largely on the angler to modify their behavior or gear while fishing when they identify that many of their fish are being deeply hooked. By using an adaptive approach, an angler can select for a gear type appropriate to their target catch and simply adjust for alternate gear or techniques if deep hooking persists. In the event of deep hooking, it may prove useful to cut the line if the intent is to release the fish. Most of the mortality observed in this study occurred in the short term, and so anglers may be able to evaluate their practices in the field and adjust them accordingly as previously suggested by Wilde and Sawynok (2009). The challenge will be for management agencies to effectively communicate these messages to the angling community.

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