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# Effect of hook type and hook setting method on deep-hooking rates when bait fishing for trout in lentic waters

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## Abstract

Fishing with circle hooks along with prescribed hook-setting methods can reduce deep-hooking rates in some fisheries, but baited circle hooks have not been evaluated in stillwater trout fisheries. Deep-hooking rates and catch probabilities were compared for cutthroat trout *Oncorhynchus clarkii* (Richardson), rainbow trout *Oncorhyncus mykiss* (Walbaum), cutthroat × rainbow trout hybrids, and brook trout *Salvelinus fontinalis* (MItchill) caught using three types of baited hooks (circle, intermediate circle and traditional J) and two hook-setting methods (active and passive) in several lakes containing naturally reared trout. Hook type had a negligible effect on deep-hooking rates, which averaged 20%. Actively setting the hook and fishing with a bobber both reduced deep-hooking rates, regardless of hook type. Larger fish were deeply hooked more frequently regardless of hook type. Catch probabilities were higher when active rather than passive hook-setting was used, particularly in combination with intermediate circle hooks. The present results, which indicate that circle hook use did not reduce deep hooking in lentic settings, contrast earlier studies done in lotic waters. Therefore, before proposing hook-type regulations intended to reduce deep hooking, fisheries managers should consider waterbody type in addition to fishing methods, fish size and species.

KEYWORDS
active hook-setting, catch probability, circle hooks, j hooks, passive hook-setting, salmonids

## 1 | INTRODUCTION

Catch-and-release is a widespread practice among recreational anglers worldwide, even when not required by regulations (Arlinghaus et al., 2007; Bartholomew & Bohnsack, 2005). Its purpose can serve fisheries managers seeking to reduce fishing-related mortality, or recreational anglers driven by a variety of individual preferences resulting in catch-and-release (Arlinghaus et al., 2007). The effectiveness of catch-and-release angling as a management tool and as an individual ethic depends on the survival of released fish. One of the most important factors affecting post-release survival of caught-and-released fish in recreational fisheries is deep-hooking, wherein an angler hooks a fish and the hook point penetrates the gill arches, oesophagus or stomach, potentially causing critical injury (reviewed in Bartholomew & Bohnsack, 2005; Huhn & Arlinghaus, 2011; Muoneke & Childress, 1994; Wydoski, 1977). These reviews highlight that deep-hooking rate (and by extension hooking mortality) is affected by numerous factors such as angling method, angler experience, terminal tackle, environmental conditions and species and size of fish caught. One generalisation accepted by fisheries managers and anglers is that fishing with bait often results in higher deep-hooking and hooking mortality rates compared with artificial flies and lures. One taxon for which this generalisation appears to apply more consistently is salmonids (e.g. High & Meyer, 2014; Hunsaker et al., 1970; Schisler & Bergersen, 1996; Shetter & Allison, 1955; Stringer, 1967). Thus, when fisheries managers partially or completely restrict harvest in trout fisheries to increase abundance or improve population size structure (commonly referred to as special regulations), they often preclude the use of bait as well (Thurow & Schill, 1994; Noble & Jones, 1999; but see Carline et al., 1991). However, empirical evidence to support this generalised managerial decision is equivocal. In a review by Bartholomew and Bohnsack (2005), they found six studies demonstrating higher mortality with bait and five demonstrating no significant difference.

Although the restriction of bait use in trout fisheries is a common management strategy, it may not be necessary if other gear restrictions can reduce deep hooking without precluding bait. For example, in recent decades, circle hooks have been shown to reduce deep hooking under a variety of marine and freshwater recreational fishing scenarios (reviewed in Cooke & Suski, 2004; Serafy et al., 2012). Circle hooks are designed with the hook point facing at a 90° angle back towards the shank, whereas the hook point on conventional J-style bait fishing hooks is parallel to the hook shank (Figure 1). This design is intended to improve the ability of the circle hook to pull free from vital areas (such as the gills or oesophagus) as the fish tries to swallow the bait (and hook). As the angler tightens the line, the circle hook is designed to rotate at the edge of the mouth and lodge in the jaw. For proper circle-hook function, in terms of both reduced deep hooking and effective hookup, manufacturers recommend against the traditional deliberate hook set (herein termed active hook set) in favour of applying gentle, steady pressure when a fish strike is detected (herein termed passive hook set). However, a series of studies on bait fishing for stream-dwelling trout in Idaho (U.S.A.) demonstrated that circle hooks reduced deep hooking relative to conventional J hooks regardless of whether the hooks were set actively or passively, and also that active setting of the hook increased angling success and reduced deep hooking regardless of hook type (High & Meyer, 2014; High et al., 2014; Sullivan et al., 2013). These findings have been corroborated for bluegill *Lepomis macrochirus* Rafinesque (Lennox et al., 2015), but there is a need to evaluate active and passive fishing with circle hooks and more conventional bait hooks in additional angling settings (Cooke et al., 2012). For example, anglers experienced with using circle hooks indicated that, when used in a vertical jigging fashion, circle hooks were ineffective for fish capture whilst reducing deep hooking (Cooke et al., 2012), but this has not been evaluated for a stillwater trout fishery. Lakes differ from rivers in abiotic factors such as temperature, flow, turbidity, turbulence, depth and light, all of which can affect the mechanics of fish feeding behaviour, and thus recreational fishing outcomes (Higham et al., 2015).

Therefore, the objectives or the present study were to: (1) determine whether use of circle hooks when bait fishing for trout in lentic waters reduces deep-hooking rates relative to traditional J hooks; (2) determine whether actively or passively setting the hook affects deep hooking rates in lentic waters; and (3) compare hooking, landing and catch probabilities among the three hook types and two hook-setting methods.

## 2 | METHODS

### 2.1 | Study areas, fish species and capture methods

Angling was conducted at 11 stillwater fisheries in Idaho (U.S.A.) during the months of June-August 2019. These lakes are known to have trout species that were either spawned in the wild or stocked as fry by Idaho Department of Fish and Game (IDFG). These lakes are all situated in coniferous montane geography and are either natural lakes or reservoirs impounded by small earthen dams. They vary in elevation from 1913 to 2526 m and in size from 0.2 to 139 ha. Temperatures during sample period varied from 13–20°C. Target species included cutthroat trout *Oncorhynchus clarkii* (Richardson), rainbow trout *Oncorhynchus mykiss* (Walbaum), cutthroat ×rainbow hybrids and brook trout *Salvelinus fontinalis* (Mitchill). Hereafter, these species and their hybrids are referred to collectively as 'trout'.

In this study, anglers consisted of 21 IDFG employees with various levels of angling experience. Anglers fished with one of three

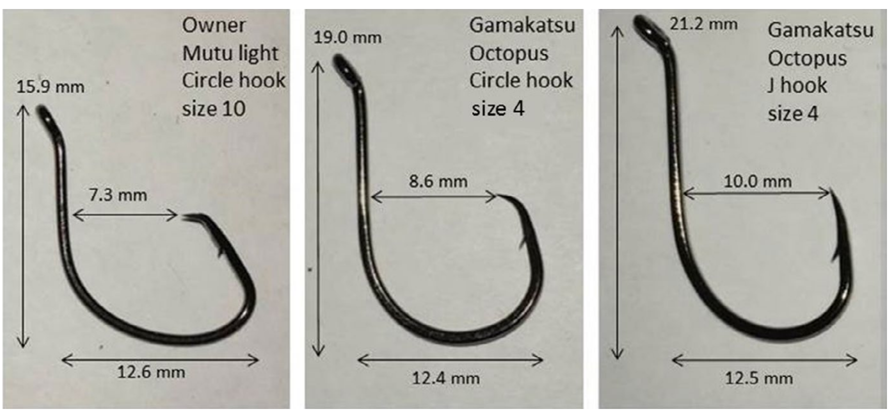


FIGURE 1 Hook manufacturers, styles and dimensions used to determine deep-hooking rates, hooking efficiency and landing efficiency for trout in stillwater fisheries of Idaho (U.S.A.). The Owner Mutu light hook (hereafter termed "circle" hook), Gamakatsu Octopus circle hook (hereafter termed "intermediate" circle hook) and Gamakatsu Octopus J hook (hereafter termed "traditional J" hook) were sized accordingly to achieve equal swallow widths

hook types (Figure 1), hereafter referred to as: circle hook (size 10 Owner Mutu Light, Owner American Corporation, Costa Mesa, CA): intermediate circle hook (size 4 Gamakatsu Octopus circle, Gamakatsu® USA Inc., Tacoma, WA); and J hook (traditional type: size 4 Gamakatsu Octopus, Gamakatsu® USA Inc., Tacoma, WA; Figure 1). These hook sizes (Figure 1) were selected to ensure equivalent swallow widths for each hook type (Shetter & Allison, 1955; Hulbert & Engstrom-Heg, 1980). For both the circle and intermediate circle hooks, the hook point was perpendicular to the shank. However, the circle hook had a more pronounced bend than the intermediate circle hook, resulting in a shorter gap between the point and the shank. These two different circle hook designs were evaluated because previous results suggested that circle hooks with a more severe bend and shorter gap reduced deep hooking to a greater degree (from High et al., 2014). To reduce confounding effects of the differing hook eye angles, the circle hook eyes were bent to match the other two hooks.

Fishing rods used were 1.98-m, medium strength graphite spinning rods (Berkeley Fishing, Spirit Lake, Iowa). The overwhelming majority (97%) of fish were caught using night crawlers, consisting of an approximately 2–4 cm piece of worm covering the hook. The remainder were caught using salmon eggs (Pautzke Bait Co., Ellensburg, Washington) or power bait-artificial scented trout bait (Berkeley Fishing, Spirit Lake, Iowa, U.S.A.), also in amounts that covered the hook. A 28 g removable split-shot was pinched onto the line ≈ 25 cm above the baited hook to help sink the hook to the depth of the fish. Ball bobbers were used in some situations when they appeared to improve catch rates. Anglers fished from a boat or from the bank using a common technique in which the angler lightly jigged and retrieved the bait to keep a tight line, a method used with or without a bobber. Although the hook was usually suspended in the water column, in situations where angling occurred close to shore, hooks sometimes may have been bouncing on the bottom during retrieval. Anglers were instructed to fish with either a passive or active hook set and to alternate between the two methods for each fish hooked. For active hook sets, when a strike was detected, the angler used the standard bait fishing hook set method of abruptly lifting the rod tip and quickly reeling in slack line to set the hook in the fish. For passive hook sets, the angler instead lifted slowly and steadily on the rod and gently reeled in slack line until the fish was discernibly hooked. Anglers then continued to retrieve line until the fish could be landed with a net or by hand.

## 2.2 | Data collection and analyses

All anglers fished all hook types, periodically switching from one hook to another to accumulate evenly the desired sample size of at least 100 landed fish for each hook type and hook set combination. In general, anglers knew which hook type they were fishing. Landed fish were identified to species, measured to the nearest mm and assigned a hook location of oesophagus, gills, upper jaw or mouth, lower jaw or mouth, tongue or foul hooked (i.e. head, back, fin).

For data analysis, hooking locations were grouped into a binary category of either deeply hooked or not. Fish hooked in the oesophagus or gills were considered to be deeply hooked and assigned an indicator variable of "1". Fish hooked in all other locations were assigned a "0". Deep-hooking rate was calculated by dividing the number of landed fish that were deeply hooked by the total number of fish landed. A logistic regression analysis was performed to model the probability of deep hooking. A mixed-effects model approach was used, with specific fishery included as a random effect, and hook type, fish species, hook-setting method, bobber use, fishing mode (boat or shore) and fish length included as fixed effects. Potential interactions between some variables were included based on visual inspection of the data. Candidate models were built in R (R Core Team, 2020) to assess the fixed effects and were compared using an Akaike's information criterion (AIC; Akaike, 1973; Burnham & Anderson, 1998). Akaike's weights ($\omega_i$) were used to rank the relative plausibility of candidate models (Burnham & Anderson, 2004). Model coefficient estimates and 95% CIs were exponentiated, thus allowing the coefficient effect to be expressed in odds relative to the reference condition (Odds ratios). Coefficient confidence intervals that overlapped a value of '1' were statistically different from the reference value for that variable. The lme4 package in R was used for model building (Bates et al., 2015) and the MuMIn package was used for AIC multi-model inference (Barton, 2019).

For each hook type and hooking method, the number of strikes, hook-ups and landed fish were recorded. Hooking probability was calculated by dividing the number of successful hook-ups (i.e. the fish was hooked and fought for at least 1–2 sec) by the number of strikes. Landing probability was calculated by dividing the number of fish landed by the number of successfully hooked fish. Capture probability was calculated by dividing the number of fish landed by the number of strikes. Variance of proportions and 95% confidence intervals (CIs) for each of these rates were calculated following the methods of Thompson (2012). Hooking, landing and catch probabilities were compared among hook types and hook-setting methods using Pearson's Chi-squared contingency table tests with an $\alpha = 0.05$ level of significance.

# 3 | RESULTS

A total of 641 trout were caught at 11 lentic waters in Idaho, consisting of brook trout ($n$ = 397), cutthroat trout ($n$ = 76), rainbow trout ($n$ = 84) and cutthroat × rainbow hybrids ($n$ = 84). Mean total length (TL) was 251 mm (minimum–maximum = 116–410). Deep-hooking rates for circle, intermediate circle and J hooks were 26%, 18% and 17%, respectively, with an overall deep-hooking rate of 20% (Table 1). Deep-hooking rates for each species were 18% (brook trout), 11% (cutthroat trout), 12% (rainbow trout) and 48% (cutthroat × rainbow hybrids). Trout caught using active hook sets were deep hooked 16% of the time compared with 24% for passive hook sets, and for all three hooks used, deep hooking was reduced by actively setting the hook (Figure 2). Although not the objective of

**TABLE 1** Proportions and (numbers) of trout caught by hooking location using bait in 11 stillwater fisheries of Idaho with three hook types (traditional J, intermediate circle (I-circle) or circle) and two hook-setting methods (active or passive)

| | Hooking location | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oesophagus | Gill | Tongue | Lower jaw | Upper jaw | Foul | Total |
| Active | | | | | | | |
| J | 0.14 (15) | 0.01 (1) | 0.01 (1) | 0.09 (10) | 0.73 (81) | 0.03 (3) | 111 |
| I-circle | 0.12 (13) | 0.04 (4) | | 0.11 (12) | 0.73 (79) | | 108 |
| Circle | 0.15 (16) | 0.03 (3) | | 0.14 (15) | 0.67 (70) | 0.01 (1) | 105 |
| Total | 0.14 (44) | 0.02 (8) | 0.01 (1) | 0.11 (37) | 0.71 (230) | 0.01 (4) | 324 |
| Passive | | | | | | | |
| J | 0.17 (17) | 0.02 (2) | | 0.15 (15) | 0.65 (66) | 0.01 (1) | 101 |
| I-circle | 0.18 (19) | 0.02 (2) | 0.02 (2) | 0.10 (10) | 0.66 (69) | 0.03 (3) | 105 |
| Circle | 0.30 (33) | 0.04 (4) | | 0.16 (18) | 0.50 (55) | 0.01 (1) | 111 |
| Total | 0.22 (69) | 0.03 (8) | 0.01 (2) | 0.14 (43) | 0.60 (190) | 0.02 (5) | 317 |
| Grand Total | 0.18 (133) | 0.02 (16) | 0.00 (3) | 0.12 (80) | 0.66 (420) | 0.01 (9) | 641 |

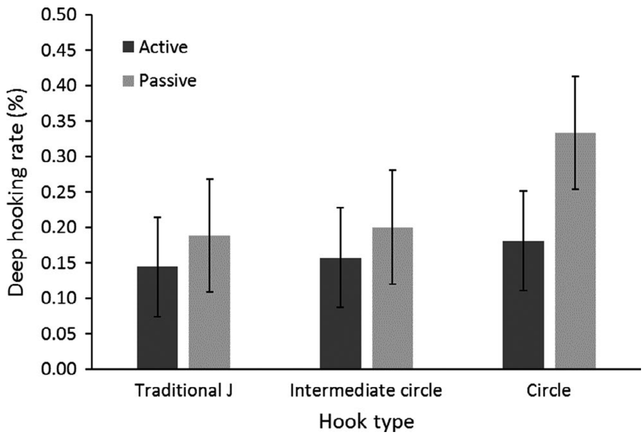


**FIGURE 2** Deep-hooking rates for trout caught on traditional J, intermediate circle and circle hooks using active and passive hook-setting methods. Bars indicate 95% confidence intervals

this assessment, deep-hooking rates were observed to be 17% when using a bobber compared with 29% without a bobber.

The most plausible of the candidate set of models for deep-hooking probability included hook type, hook-setting method, bobber use and fish TL (Table 2), with the probability of deep hooking increasing with fish TL, no bobber and passive hook setting (Figure 3). The odds of deep hooking were 2.725× higher when not using a bobber, 1.823× higher when passively setting hooks and 1.464× higher for every standard deviation (60 mm) increase in fish TL. In the top-ranked model accounting for hook-setting method, fish TL, and bobber use, the odds of deep hooking did not differ between hook type, as indicated by 95% CIs overlapping a value of 1 (Table 3). The second and third most plausible candidate models indicated that an interaction between hook-setting method and bobber use or between hook type and bobber use accounted for some of the variation in the data (Table 2), but the exponentiated CIs overlapped 1 (Table 3), indicating no difference from the reference condition. Because specific fishery was modelled as a random effect, species and fishing mode (boat or shore) could not be included in the multiple logisitic regressions because all of the possible values for each category were not represented in each water body. Therefore, the model could not separate random variation of deep hooking due to each fishery from variation due to species or fishing mode.

Overall hooking probability was 53% and was higher for active hook setting (59%) than for passive hook setting (48%; $\chi^2 = 15.825$, $df = 1$, $p < 0.001$; Table 4). For passive hook setting, there was little difference among hook types in the probabilities of successfully hooking a fish (47%–49%; $\chi^2 = 0.225$, $df = 2$, $p = 0.894$) or landing a fish (89%–92%; $\chi^2 = 0.665$, $df = 2$, $p = 0.717$). However, when actively setting the hook, hooking and landing probabilities differed among hook types. For example, hooking probability was significantly higher for circle hooks (68%; $\chi^2 = 11.747$, $df = 1$, $p = 0.001$) and intermediate circle hooks (61%; $\chi^2 = 3.891$, $df = 1$, $p = 0.049$) than for J hooks (51%), whereas landing probability was highest for intermediate circle hooks (97%), lowest for circle hooks (82%) and intermediate for J hooks (89%). Catch probability, which is contingent upon both hooking and landing the fish, was higher overall for actively set hooks (53%; $\chi^2 = 11.192$, $df = 1$, $p < 0.001$) than for passively set hooks (44%). Catch probability was higher for actively set intermediate circle hooks (60%; $\chi^2 = 7.804$, $df = 1$, $p = 0.005$) than for actively set J hooks (45%). Catch probability did not differ among hook types for passively set hooks ($\chi^2 = 0.210$, $df = 2$, $p = 0.900$).

## 4 | DISCUSSION

The results of the present study indicate that, when compared with J hooks, neither of the circle hook variations tested led to reduced deep hooking of bait-caught trout in lentic settings (Table 3). This contradicts the findings of several studies in running waters where the use of circle hooks consistently reduced deep hooking of bait-caught trout compared with J hooks (e.g. High & Meyer, 2014; High

**TABLE 2** Comparison of mixed-effects logistic regression models that estimated deep-hooking rates of trout caught from 11 stillwater fisheries in Idaho

| Model | df | $AIC_c$ | $\Delta AIC_c$ | $\omega_i$ |
|---|---|---|---|---|
| Hook + method + bobber + TL | 7 | 590.4 | 0.00 | 0.33 |
| Hook + method + bobber (method × bobber) + TL | 8 | 590.5 | 0.16 | 0.31 |
| Hook + method + bobber + (hook × bobber) + TL | 9 | 591.0 | 0.63 | 0.24 |
| Hook + method + (hook × method) + bobber +TL | 9 | 594.2 | 3.85 | 0.05 |
| Hook + method + bobber | 6 | 595.2 | 4.85 | 0.03 |
| Hook + method + bobber + (method × bobber) | 7 | 595.3 | 4.99 | 0.03 |
| Hook + method + (hook × method) + bobber + (method × bobber) + TL | 14 | 599.3 | 8.99 | <0.01 |
| Bobber | 3 | 600.7 | 10.34 | <0.01 |
| Hook + method + (hook × method) + bobber + (method × bobber) | 13 | 604.1 | 13.70 | <0.01 |
| Hook + method + TL | 6 | 604.3 | 13.91 | <0.01 |
| TL | 3 | 608.0 | 17.67 | <0.01 |
| Hook + TL | 5 | 608.2 | 17.84 | <0.01 |
| Method | 3 | 611.2 | 20.89 | <0.01 |
| Hook + method | 5 | 611.6 | 21.22 | <0.01 |
| Species | 5 | 611.7 | 21.36 | <0.01 |
| Mode | 3 | 612.6 | 22.24 | <0.01 |
| Hook + method + (hook × method) | 7 | 614.9 | 24.52 | <0.01 |
| Intercept | 2 | 615.0 | 24.62 | <0.01 |
| Hook | 4 | 615.0 | 24.63 | <0.01 |

*Note:* Degrees of freedom (*df*), Akaike's information criteria corrected for small sample size ($AIC_c$), change in $AIC_c$ ($\Delta AIC_c$) and $AIC_c$ weights ($\omega_i$) were used to assess the most plausible of all candidate models. The variables hook type, hook-setting method, bobber use, fish total length (TL), fishing mode were considered as fixed effects. Specific fishery was included as a random effect in each model. Total length was scaled to a standard normal distribution.

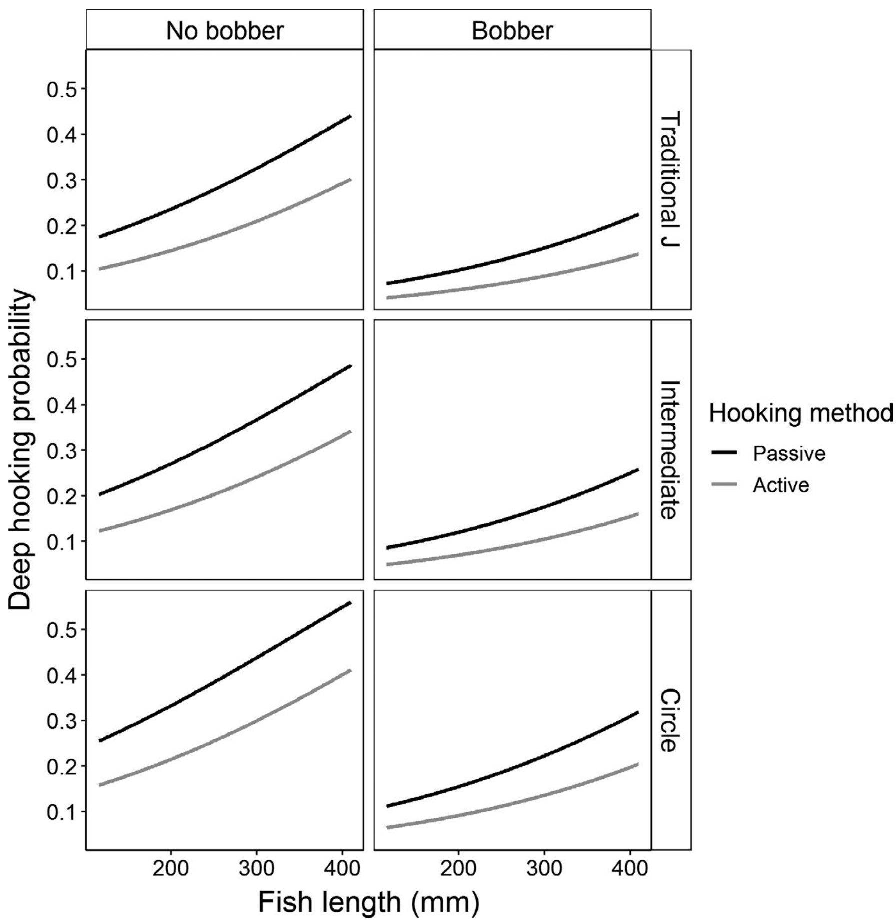


**FIGURE 3** Predicted probabilities from the top-ranked model that a trout of a given total length would be deeply hooked using three hook types (traditional J, intermediate and circle), two hook-setting methods (active [grey lines] and passive [black lines]) fished with and without a bobber

**TABLE 3** Variables, exponentiated coefficient estimates (odd ratios), and 95% confidence intervals (CI) for the top three mixed-effects, logistic regression models elaborated to predict deep-hooking rates

| Variable | Estimate | 95% CI |
|---|---|---|
| Model 1: Deep ~ Hook + Method + Bobber + TL | | |
| Intercept | 0.270 | 0.117–0.576 |
| Hook method (passive) | 1.823 | 1.199–2.795 |
| Hook type (J) | 0.833 | 0.485–1.423 |
| Hook type (circle) | 1.344 | 0.819–2.217 |
| Bobber (yes) | 0.367 | 0.224–0.598 |
| TL (scaled) | 1.464 | 1.103–1.937 |
| Model 2: Deep ~ Hook + Method + Bobber + (Method × Bobber) + TL | | |
| Intercept | 1.192 | 0.138–0.737 |
| Hook method (passive) | 1.192 | 0.567–2.499 |
| Bobber (yes) | 0.263 | 0.133–0.520 |
| Hook type (J) | 0.838 | 0.488–1.433 |
| Hook type (circle) | 1.379 | 0.838–2.279 |
| TL (scaled) | 1.466 | 1.103–1.942 |
| Hook method (passive) x Bobber (yes) | 1.884 | 0.765–4.694 |
| Model 3: Hook + Bobber + (Hook × Bobber) + Method + TL | | |
| Intercept | 0.235 | 0.089–0.568 |
| Hook method (passive) | 1.850 | 1.213–2.845 |
| Bobber (yes) | 0.442 | 0.196–1.029 |
| Hook type (J) | 1.417 | 0.568–3.602 |
| Hook type (circle) | 1.167 | 0.463–2.968 |
| TL (scaled) | 1.467 | 1.105–1.940 |
| Bobber (yes) × Hook type (J) | 0.442 | 0.140–1.372 |
| Bobber (yes) × Hook type (circle) | 1.215 | 0.403–3.644 |

*Note:* Specific fishery was included in each model as a random effect. Total length (TL) was scaled to a standard normal distribution.

et al., 2014; Kazyak et al., 2016; Sullivan et al., 2013). This discrepancy suggests that the ability of circle hooks to reduce deep hooking of bait-caught trout differs between lentic and lotic environments. The speed at which the bait is moving may indeed affect the performance of circle hooks, shown to be less prone to deep hooking flounder *Paralichthys dentatus* (L.) when drift speed was highest (Zimmerman & Bochenek, 2002). In still waters, the bait and hook combination is more stationary than in running waters; this may allow trout to track the bait more readily and ingest it more quickly (and deeply) regardless of hook type. One study comparing hooking mortality of rainbow trout caught in a lake on different tackle types demonstrated reduced deep hooking by circle hooks compared with J hooks, contrary to the present results (Jenkins 2003). However, the aforementioned study involved trout caught from a floating aquaculture netpen, which may confound any conclusions that apply specifically to hooking mortality in lake settings. Although circle hooks are designed to pull free from deep-hooking locations and lodge more often in the jaw even when they are swallowed deeply, this did not happen in the present study for either circle hook variation. Considering the dearth of studies evaluating deep-hooking rates of bait-caught trout between circle and J hooks, additional research should be undertaken on circle-hook performance in trout bait-fisheries in lentic settings to support or refute the present findings.

The reduction in deep hooking demonstrated in the present study through use of an active, rather than passive, hook-setting method is consistent with most previous studies. This is especially the case with studies of trout anglers (e.g. High & Meyer, 2014; Kazyak et al., 2016; Schisler & Bergersen, 1996; Sell et al., 2016; Sullivan et al., 2013). Also, active hook sets more often resulted in successful hook-ups in the present study (Table 4), as has been commonly observed in prior studies (*ibid.*). Once trout were hooked, landing probability was high across all hook-type and hook-setting methods. Thus, it appears that for trout anglers bait

**TABLE 4** Hooking, landing and catch probabilities for three hook types (traditional J, intermediate circle (I-circle) and circle) and two hook-setting methods (active or passive), with 95% confidence intervals reported for each proportion

| Hook type and hooking method | Number of strikes | Number hooked | Number landed | Hooking probability | Landing probability | Catch probability |
|---|---|---|---|---|---|---|
| Active | | | | | | |
| J | 244 | 125 | 111 | 0.51 ± 0.03 | 0.89 ± 0.03 | 0.45 ± 0.06 |
| I-circle | 181 | 111 | 108 | 0.61 ± 0.04 | 0.97 ± 0.02 | 0.60 ± 0.07 |
| Circle | 188 | 128 | 105 | 0.68 ± 0.03 | 0.82 ± 0.03 | 0.56 ± 0.07 |
| Total | 613 | 364 | 324 | 0.59 ± 0.02 | 0.89 ± 0.02 | 0.53 ± 0.04 |
| Passive | | | | | | |
| J | 242 | 114 | 101 | 0.47 ± 0.03 | 0.89 ± 0.03 | 0.42 ± 0.06 |
| I-circle | 239 | 117 | 105 | 0.49 ± 0.03 | 0.90 ± 0.03 | 0.44 ± 0.06 |
| Circle | 247 | 121 | 111 | 0.49 ± 0.03 | 0.92 ± 0.02 | 0.45 ± 0.06 |
| Total | 728 | 352 | 317 | 0.48 ± 0.02 | 0.90 ± 0.02 | 0.44 ± 0.04 |
| Grand Total | 1341 | 716 | 641 | 0.53 ± 0.01 | 0.90 ± 0.01 | 0.48 ± 0.03 |

fishing in either lotic or lentic waters, actively setting circle hooks results in better hooking success and reduced deep hooking, both of which provides incentive to set the hook actively. The present results suggest that in stillwater trout fisheries, anglers may need to use active hook-setting methods when using circle hooks to maximise catch rates, contrary to recommendations from circle hook manufacturers.

In the present study, bobber use reduced deep hooking for trout regardless of hook-type and hook-setting method (Table 3, Figure 3). The only known study of deep hooking in a recreational fishery that included bobbers found that bobber use increased deep hooking for bluegill (Lennox et al., 2015), but that study included a passive hook set method only. The disparity in findings from these two aforementioned studies could be related to differences in the amount of mouth suction force generated by bluegill (Day et al., 2005) relative to salmonids (Van Leeuwen, 1984) during the food ingestion process, or perhaps to differences in feeding behaviour or aggressiveness. When using a bobber, the results of the present study suggest that anglers can react more quickly to the strike or that less line slack exists, either of which would reduce the amount of time for fish to swallow the bait before the strike was detected.

The finding that deep hooking increased in larger trout, suggests a hook size to fish size relationship, largely driven by the diameter of the fish's oesophagus relative to the hook width. Such a relationship has been demonstrated for bluegill using various bait hooks but not for circle hooks (Cooke et al., 2003). The hook sizes used in the present study, whilst numbered differently according to the different manufacturers, were consistently all of swallow widths. Despite standardising swallow widths among hook types, the hooks varied in shank lengths, potentially confounding effects of circle or J shape on deep-hooking rates. Nevertheless, no significant difference in deep-hooking rate was due to hook type, but rather was due to fish length. Several studies have related hook size, fish size and hook performance, with mixed results. These studies tended to focus on hooking mortality as the outcome, whereas the present study measured deep-hooking rates, which ultimately affect hooking mortality (Muoneke & Childress, 1994). Trophy-sized brook trout (>38.1 cm), caught with artificial lures, were more often hooked in the gills or oesophagus than smaller fish (<39 cm; Nuhfer & Alexander, 1992). However, no relationship was found between fish length and hooking mortality of rainbow trout (Dotson, 1982; Schisler & Bergersen, 1996), cutthroat trout (Dotson, 1982; Marnell & Hunsaker, 1970; Pauley & Thomas, 1993; Titus & Vanicek, 1988). Trout on the lower end of the sampled TL range in the present study were likely unable to swallow these hooks as deeply as larger fish, thus resulting in lower deep-hooking rates. In hatchery rainbow trout of 235–326 mm TL, the smallest of four hook sizes had the highest deep-hooking rates when actively fishing for raceway-dwelling fish (Sell et al., 2016). Although anglers can choose their hook sizes, they cannot necessarily choose the size of fish they are catching, and therefore, anglers can do little to alleviate the effect of fish size on deep hooking. However, trout bait anglers participating in catch-and-release angling should be encouraged to monitor the occurrence of deep hooking when they are fishing, and to consider switching to larger-sized hooks if deep hooking frequently occurs.

In conclusion, although the post-release fates of deeply hooked fish in the present study are unknown, it is widely accepted that hooking location affects hooking mortality (Wydoski, 1977). Therefore, factors that affect deep-hooking rates are also likely to affect hooking mortality. For fisheries managers concerned about hooking mortality, the circle hooks used in the present study did not reduce deep hooking in lake-dwelling trout, contrary to similar research done in rivers. This suggests that circle hooks may not provide a consistent benefit of reduced deep hooking among different types of water body and thus may be of limited use in regulations aimed at reducing hooking mortality. Furthermore, anglers ought to consider using active hook-setting methods, regardless of which hook type they use, to maximise their catch rates and reduce deep-hooking rates.

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## REFERENCES

Akaike, H. (1973) Information theory as an extension of the maximum likelihood principle. In: Petrov, B.N. & Csaki, F. (Eds.) *Second international symposium on information theory*. Budapest: Akademiai Kiado, pp. 267–281.

Arlinghaus, R., Cooke, S.J., Lyman, J., Policansky, D., Schwab, A., Suski, C. et al. (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. & Bohnsack, J.A. (2005) A review of catch-and-release angling mortality with implications for no-take reserves. *Reviews in Fish Biology and Fisheries*, *15*, 129–154.

Barton, K.A. (2019) *MuMIn: Multi-model inference*. R package version 1.43.6. https://CRAN.R-project.org/package=MuMIn

Bates, D., Martin, M., Bolker, B. & Walker, S. (2015) Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*, 1–48.

Burnham, K.P. & Anderson, D.R. (1998) *Model selection and inference: a practical information-theoretic approach*. New York: Springer-Verlag.

Burnham, K.P. & Anderson, D.R. (2004) Multimodel inference: understanding AIC and BIC in model selection. *Sociological Methods and Research*, *33*, 261–304.

Carline, R.F., Beard, T. Jr & Hollender, B.A. (1991) Response of wild brown trout to elimination of stocking and no-harvest regulations. *North American Journal of Fisheries Management*, *11*, 253–266.

Cooke, S.J., Nguyen, V.M., Murchie, K.J., Danylchuk, A.J. & Suski, C.D. (2012) Scientific and stakeholder perspectives on the use of circle hooks in recreational fisheries. *Bulletin of Marine Science*, *88*, 395–410.

Cooke, S.J. & Suski, C.D. (2004) Are circle hooks an effective tool for conserving marine and freshwater recreational catch-and-release fisheries? *Aquatic Conservation: Marine and Freshwater Ecosystems*, *14*, 299–326.

Cooke, S.J., Suski, C.D., Barthel, B.L., Ostrand, K.G., Tufts, B.L. & Philipp, D.P. (2003) Injury and mortality induced by four hook types on bluegill and pumpkinseed. *North American Journal of Fisheries Management*, *23*, 883–893.

Day, S.W., Higham, T.E., Cheer, A.Y. & Wainwright, P.C. (2005) Spatial and temporal patterns of water flow generated by suction-feeding bluegill sunfish *Lepomis macrochirus* resolved by particle image velocimetry. *Journal of Experimental Biology*, *208*, 2661–2671.

Dotson, T. (1982) Mortalities in trout caused by gear type and angler-induced stress. *North American Journal of Fisheries Management*, *2*, 60–65.

High, B. & Meyer, K.A. (2014) Hooking mortality and landing success using baited circle hooks compared to conventional hook types for stream-dwelling trout. *Northwest Science*, *88*, 11–21.

High, B., Meyer, K.A. & Sullivan, C.L. (2014) Performance of circle hooks when bait fishing for stream-dwelling trout. In: Carline, R.F. & LoSapio, C. (Eds.) *Wild Trout Symposium XI: looking back and moving forward*. West Yellowstone, Montana: Wild Trout Symposium, pp. 247–253.Available at: www.wildtroutsymposium.com/proceedings-11.pdf [Accessed 19 Mar. 2021].

Higham, T.E., Stewart, W.J. & Wainwright, P.C. (2015) Turbulence, temperature, and turbidity: the ecomechanics of predator–prey interactions in fishes. *Integrative and Comparative Biology*, *55*, 6–20.

Hühn, D. & Arlinghaus, R. (2011) Determinants of hooking mortality in freshwater recreational fisheries: a quantitative meta-analysis. *American Fisheries Society Symposium*, *75*, 141–170.

Hulbert, P.J. & Engstrom–Heg, R. (1980) Hooking mortality of worm-caught hatchery brown trout. *NY Fish and Game Journal*, *27*, 1–10.

Hunsaker, D. II, Marnell, L.F. & Sharpe, F.P. (1970) Hooking mortality of Yellowstone cutthroat trout. *The Progressive Fish-Culturist*, *32*, 231–235.

Jenkins, T.M. (2003) Evaluating recent innovations in bait fishing tackle and technique for catch and release of rainbow trout. *North American Journal of Fisheries Management*, *23*, 1098–1107.

Kazyak, D.C., Sell, M.T., Hilderbrand, R.H., Heft, A.A. & Cooper, R.M. (2016) A comparison of catchability and mortality with circle and J hooks for stream-dwelling brook trout. *North American Journal of Fisheries Management*, *36*, 259–266.

Lennox, R., Whoriskey, K., Crossin, G.T. & Cooke, S.J. (2015) Influence of angler hook-set behavior relative to hook type on capture success and incidences of deep hooking and injury in a teleost fish. *Fisheries Research*, *164*, 201–205.

Marnell, L.F. & Hunsaker, D. II (1970) Hooking mortality of lure-caught Cutthroat Trout (Salmo clarki) in relation to water temperature, fatigue, and reproductive maturity of released fish. *Transactions of the American Fisheries Society*, *99*, 684–688.

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

Noble, R.L. & Jones, T.W. (1999) Managing fisheries with regulations. In: Kohler, C.C. & Hubert, W.A. (Eds.) *Inland fisheries management in North America*, 2nd edition. Bethesda: American Fisheries Society, pp. 455–477.

Nuhfer, A.J. & Alexander, G.R. (1992) Hooking mortality of trophy-sized wild brook trout caught on artificial lures. *North American Journal of Fisheries Management*, *12*, 634–644.

Pauley, G.B. & Thomas, G.L. (1993) Mortality of anadromous coastal cutthroat trout caught with artificial lures and natural bait. *North American Journal of Fisheries Management*, *13*, 337–345.

R Core Team. (2020) *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Available at: www.R-project.org/

Schisler, G.J. & Bergersen, E.P. (1996) Postrelease hooking mortality of rainbow trout caught on scented artificial baits. *North American Journal of Fisheries Management*, *3*, 570–578.

Sell, M.T., Kazyak, D.C., Hilderbrand, R.H., Heft, A.A. & Cooper, R.M. (2016) A comparison of circle hook size on hooking success, deep hooking rate, and postrelease mortality of hatchery-reared rainbow trout. *North American Journal of Fisheries Management*, *36*, 254–258.

Serafy, J.E., Cooke, S.J., Diaz, G.A., Graves, J.E., Hall, M., Shivji, M. et al. (2012) Circle hooks in commercial, recreational, and artisanal fisheries: research status and needs for improved conservation and management. *Bulletin of Marine Science*, *88*, 371–391.

Shetter, D.S. & Allison, L.N. (1955) *Comparison of mortality between fly-hooked and worm-hooked trout in Michigan streams*. Ann Arbor, MI: Michigan Department of Conservation, Institute of Fisheries Resources, Miscellaneous Publication 9.

Stringer, G.E. (1967) Comparative hooking mortality using three types of terminal gear on rainbow trout from Pennask Lake, British Columbia. *Canadian Fish-Culturist*, *39*, 17–21.

Sullivan, C.L., Meyer, K.A. & Schill, D.J. (2013) Deep hooking and angling success when passively and actively fishing for stream-dwelling trout with baited J and circle hooks. *North American Journal of Fisheries Management*, *33*, 1–6.

Thompson, S.K. (2012) *Sampling*, 3rd edition. Hoboken, NJ: Wiley.

Thurow, R.F. & Schill, D.J. (1994) Conflicts in allocation of wild trout resources: an Idaho case history. In: Barnhart, R., Shake, B. & Hamre, R.H. (Eds.) *Wild trout V: Wild Trout in the 21st Century*. Yellowstone National Park, Montana: Wild Trout Symposium, pp. 132–140. Available at: www.wildtroutsymposium.com/proceedings-5.pdf [Accessed 19 Mar. 2021].

Titus, R.G. & Vanicek, C.D. (1988) Comparative hooking mortality of lure-caught Lahontan cutthroat trout at Heenan Lake, California. *California Department of Fish and Game*, *74*, 218–225.

Van Leeuwen, J.L. (1984) A quantitative study of flow in prey capture by rainbow trout, *Salmo gairdneri*, with general consideration of the actinopterygian feeding mechanism. *Transactions of the Zoological Society of London*, *37*, 171–227.

Wydoski, R.S. (1977) Relation of hooking mortality and sublethal hooking stress to quality fishery management. In: Barnhart, R.A. & Roelofs, T.D. (Eds.) *Catch and release fishing: a decade of experience*. Arcata, CA: Humboldt State University, pp. 43–87.

Zimmerman, S.R. & Bochenek, E.A. (2002) Evaluation of the effectiveness of circle hooks in New Jersey's recreational Summer Flounder fishery. In: Lucy, J.A. & Studholme, A.L. (Eds.) *Catch and release in marine recreational fisheries*. Bethesda, MD: American Fisheries Society, pp. 106–109.

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