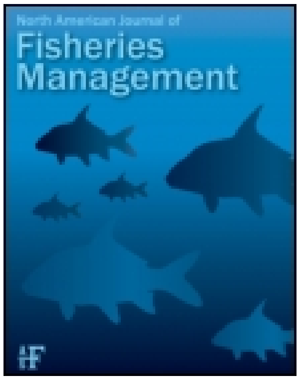

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ARTICLE

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Abstract
Circle hooks are becoming commonplace in recreational fisheries because they often reduce deep hooking, but there has been little evaluation of their effectiveness in trout fisheries. To compare the occurrence of deep hooking and angling success rates for stream-dwelling trout, we used three baited hook types (i.e., inline circle hooks, inline J hooks, and 4°-offset J hooks) fished with two angling methods (i.e., active fishing, using a traditional bait fishing hook set; and passive fishing, with no sharp hook set). Of the 583 wild trout caught by anglers, 20% were deep hooked. The deep hooking rate varied by hook type and angling method, but the interaction term hook type × angling method was statistically significant, indicating that the effect of hook type could not be interpreted separately from fishing method. Accordingly, the occurrence of deep hooking was significantly greater for offset J hooks fished passively (28 ± 9% [95% CI about the mean]) and inline J hooks fished actively (27 ± 9%) than for offset J hooks fished actively (9 ± 6%) and inline circle hooks fished actively (10 ± 6%). Fish length affected deep-hooking rates, such that trout smaller than 250 mm were less likely to be deeply hooked than trout 250–350 mm in length. Hooking success (i.e., successful hook-ups divided by strikes) was greatest for actively fished inline J hooks (75 ± 7%), lowest for passively fished inline circle hooks (45 ± 6%) and passively fished offset J hooks (48 ± 8%), and always greater for actively fished hooks than for passively fished hooks of the same type. We found deep hooking was nearly twice as likely for inline circle hooks when fished according to manufacturers' recommendations (i.e., passively) than when fished actively. These results and those of others suggest that fishing circle hooks actively when bait fishing for stream-dwelling trout will result in less deep hooking than fishing circle hooks passively.

Catch-and-release angling has become more commonplace in the last several decades due to voluntary release of fish by anglers and special-regulation fisheries (Bartholomew and Bohnsack 2005). However, catch and release benefits the fishery only by the rate at which released fish survive to reproduce or are caught again by anglers (Wydoski 1977; Cooke and Suski 2005). Postrelease mortality of trout has been researched extensively, and the type of fishing gear and angling methods used can affect trout survival (Mongillo 1984; Jenkins 2003). Most research on trout has compared hooking mortality rates of fish caught when bait is used with those caught with artificial flies or lures; nearly all have concluded that the use of bait results in higher mortality (Shetter and Allison 1955; Hunsaker et al. 1970; Mongillo 1984; Meyer and High 2010). This increased mortality usually results from fish being hooked in critical locations, including the gills, esophagus, or other organs, after the bait is ingested (Mason and Hunt 1967; Schill 1996).

Because of high mortality rates associated with bait-caught fish, many special-regulation fisheries that restrict harvest also prohibit bait fishing to maximize survival of fish caught by anglers (Noble and Jones 1999). However, such restrictions can alienate bait anglers and lead to dissension among angling groups (Thurow and Schill 1994; Noble and Jones 1999). Alternative hook types have been developed that often reduce deep-hooking rates for bait anglers, thus reducing hooking-related mortality of bait-caught fish. For example, circle hooks, which are specifically designed with the hook point oriented perpendicular to the shank, have been shown to reduce deep-hooking

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rates in some species (Aalbers et al. 2004; Cooke and Suski 2004). Unlike conventional J hooks, which often penetrate surrounding tissue when pressure is applied by the angler, circle hooks are designed to slide past critical structures such as the esophagus and gills and pivot only when exiting the mouth, thus penetrating the jaw more frequently (Johannes 1981).

Circle hooks have been studied intensely in marine environments, but little research has been conducted in freshwater systems (Cooke and Suski 2004), especially for stream-dwelling trout. A recent study by Meyer and High (2010) found that deep hooking was, on average, almost five times higher and mortality was almost four times higher for J hooks than for circle hooks for Rainbow Trout *Oncorhynchus mykiss* caught in a southern Idaho stream. However, because their study involved inline circle hooks (i.e., nonoffset; point shank is parallel to main hook shank) and offset J hooks, differences in the effectiveness of each hook type may have been confounded by differences in the angle of offset rather than by the point configuration. We are not aware of any studies comparing inline (i.e., zero offset) and offset designs of the same hook type on stream-dwelling trout. The few studies conducted on other species have found that offset hooks may be more damaging than inline hooks, and in the case of circle hooks, may reduce or eliminate the benefits of using circle hooks over conventional J hooks (Hand 2001; Prince et al. 2002).

Because limited circle hook research has been conducted on trout in lotic systems, Meyer and High (2010) suggested that further research comparing circle hook and J hook performance for trout is needed in other streams before conclusions about their effectiveness can be reached. To add to this knowledge base, we angled for trout in several streams in southern Idaho to evaluate (1) deep-hooking rates for actively and passively fished inline circle and inline and offset J hooks, and (2) hooking and landing success rates and overall capture efficiency for each hook type and angling method combination. If circle hooks reduced deep-hooking rates, we hypothesized that it might occur at the cost of reduced catchability, in terms of lower hooking and landing success rates, and that larger fish might be more susceptible to deep hooking with all hook types.

METHODS

Rivers selected for this study were the Big Lost, Big Wood, Boise, Malad, and South Fork of the Boise rivers in southern Idaho. Bait fishing is legal on all of these rivers except the South Fork of the Boise and is the most popular angling method used by anglers statewide (IDFG 2007). These fisheries were selected because of their moderate to high trout densities and an abundance of fish larger than 200 mm, a size desirable to anglers. Rivers were fished from late June to early October 2010, after high spring flows had receded and angling could be effectively conducted. Streams ranged from 10 to 50 m wide, from 800 to 2,100 m in elevation, and from 0.5% to 2.8% in stream gradient. Trout present included Rainbow Trout, Bull Trout *Salvelinus confluentus*, Brook Trout *S. fontinalis*, Cutthroat Trout *O. clarkii*, and Rainbow × Cutthroat hybrids. Few Brook Trout and Bull Trout were caught and thus were not included in the analyses.

Six experienced trout anglers fished from shore or waded into the stream to cast into trout holding areas, focusing their efforts in pools and slower runs where trout densities were highest. Fishing rods, reels, and lines (Berkley Trilene 6-lb. monofilament) were standardized for all anglers. Anglers used inline circle hooks (Eagle Claw size 8, model L702G-8), inline J hooks (Eagle Claw size 8, model L214-8), and minor offset (~4°) J hooks (Eagle Claw size 8, model 084-8), all barbed and baited with night crawlers. Size 8 hooks were used because they are one of the most common sizes used by trout bait anglers in Idaho and elsewhere. Hooks were attached to the end of the line and a removable split shot weight (0.88–2.65 g), was attached to the line above the hook. These rigs were drifted through the holding water until a strike was detected.

Anglers fished each hook type both actively and passively. Active fishing used the traditional hook-setting technique of setting the hook with a sharp, quick lifting of the fishing rod when a strike was detected. In contrast, passive fishing, as defined by Prince et al. (2002), was characterized by lifting the rod slightly and gently while slowly reeling up slack line and applying constant pressure when a strike was detected. It is generally assumed that circle hooks must be fished passively to reduce deep hooking (Montrey 1999; ASMFC 2003; Cooke and Suski 2004). Anglers alternated hook type and fishing method (active or passive) periodically to ensure they caught similar numbers of fish with each combination of hook type and angling method. Landed fish were identified to species, measured to the nearest millimeter (mm, total length), and assigned a hook location of esophagus, gills, upper jaw or mouth, lower jaw or mouth, or foul hooked (i.e., head, back, fin, etc.). Deep hooking was characterized by hooks embedded in the esophagus (or deeper) or gill arches. Trout that were not landed due to line breakage were not included in these analyses.

The number of strikes and number of successfully hooked and landed fish were recorded for each hook type and angling method to determine hooking success, landing success, and capture efficiency. Hooking success rate was determined by dividing the number of successful hook-ups (i.e., the fish was hooked and fought for at least 1–2 s) by the number of strikes. Landing success rate was determined by dividing the number of fish landed by the number of successfully hooked fish. Capture efficiency for each hook type and angling method combination was determined by multiplying hooking success by landing success. The deep hooking rate was determined by dividing the number of landed fish that were hooked in the gill arches or esophagus by the total number of fish landed.

Despite the binary nature of our response variable (i.e., fish were either deeply hooked or not), we used multiway analysis of variance (ANOVA) rather than logistic regression because all independent variables were categorical. Accordingly, we

TABLE 1. Mean fish length and deep-hooking rates for each hook type and angling method.

		Mean fish length (mm)		Deep-hooking rate	
Hook type and angling method	n	Estimate	SE	Estimate	95% CI
Inline circle (active)	97	282	6.8	0.10	0.05
Inline circle (passive)	100	294	6.4	0.19	0.08
Inline J hook (active)	92	316	7.8	0.28	0.09
Inline J hook (passive)	99	325	7.1	0.24	0.08
Offset J hook (active)	94	313	9.1	0.09	0.05
Offset J hook (passive)	101	326	8.9	0.28	0.08

constructed one global model to test the relationship between deep hooking and the following five categorical variables: species (Rainbow Trout, Cutthroat Trout, and Rainbow Trout × Cutthroat Trout hybrids), fish length (binned into sizes of <250 mm, 250–350 mm, and >350 mm), hook type (inline circle hook, inline J hook, and offset J hook), hook-set method (active or passive), and angler (angler 1–6). Fish length was binned rather than considered a continuous variable because we anticipated the relationship between fish length and deep hooking might just as likely be parabolic in shape as linear. We also tested for first-order interactions among all combinations of independent variables. Nonsignificant variables were removed from the model in a backwards stepwise manner. We used Tukey post hoc tests to assess differences within groups. The ANOVA was performed with SAS statistical software (SAS 2009) at $\alpha = 0.05$.

We used contingency tables and chi-square analyses (at $\alpha = 0.05$, computed by hand) to test for differences in hooking and landing success rates. For reporting purposes, we also calculated 95% confidence intervals (CIs) around all hooking and landing proportions.

RESULTS

From June to October 2010, six anglers landed 583 trout. The majority of trout landed were Rainbow Trout (76%), but Cutthroat Trout (18%) and Rainbow × Cutthroat hybrids (6%) were also caught. The size (average ± SE) of landed fish was 309 ± 3.3 mm and ranged from 155 to 500 mm. Landed fish were hooked in the jaw or mouth most frequently (80%), but deep hooking occurred 20% of the time. Foul hooking was infrequent and accounted for <1% of the landed fish.

Use of ANOVA indicated that a number of factors influenced deep-hooking rates (global model $F_{12} = 5.33$, $P < 0.001$). For example, the deep-hooking rate varied between hook types ($F_2 = 4.13$, $P = 0.017$), with mean deep-hooking rates (active and passive) being greatest for inline J hooks (26 ± 6%), lowest for inline circle hooks (15 ± 5%), and intermediate for offset J hooks (18 ± 5%). Also influencing deep-hooking rate was angling method ($F_1 = 7.23$, $P = 0.007$), with deep-hooking rates being greater when passive fishing (24 ± 5%) than active fishing (15 ± 4%). However, the interaction term hook type × angling method was also significant ($F_2 = 4.03$, $P = 0.018$), indicating that the effect of hook type could not be interpreted separately from how the hook was fished. Consequently, with hook type and angling method combined, post hoc analysis revealed that deep hooking was significantly greater for offset J hooks fished passively (28 ± 9%) and inline J hooks fished actively (27 ± 9%), than for offset J hooks fished actively (9 ± 6%) and inline circle hooks fished actively (10 ± 6%). These results are summarized in Table 1.

Fish length also affected deep-hooking rates ($F_2 = 7.76$, $P < 0.001$). Post hoc analysis revealed that, in general, trout <250 mm long were less likely to be deeply hooked than trout 250–350 mm long, but this relationship varied greatly between hook types and angling method (Table 2). Angler also influenced deep hooking ($F_5 = 4.98$, $P < 0.001$), with deep-hooking rates ranging from 4% to 28% for individual anglers. Deep-hooking rates for anglers differed only between the angler with the lowest deep-hooking rate and those three with the highest deep-hooking rates. Species was the only factor in our analysis that did not influence deep hooking ($F_2 = 0.39$, $P = 0.676$); this variable was subsequently dropped from the model before the F-value for the global model was reported. There were no other statistically significant first-order interaction terms.

Because of data recording errors by one angler, data for only 487 of the 583 landed trout were used in analysis of hooking and landing success and capture efficiency. Hooking and landing success rates and capture efficiency varied depending on hook type and angling method. Hooking success differed significantly among different combinations of hook types and angling methods ($\chi^2_{0.05,\,5} = 13.0$, $P = 0.02$; Table 3). Hooking success was greatest for actively fished inline J hooks (75 ± 7%) and lowest for both passively fished inline circle hooks (45 ± 6%) and passively fished offset J hooks (48 ± 8%). Once hooked, landing success on average was high (80 ± 3%), varied little between combinations of hook types and angling methods (range 76–86%), and did not differ statistically ($\chi^2_{0.05,\,5} = 0.5$, $P = 0.99$; Table 3). However, the significant difference in hooking success carried through to capture efficiency, which differed between hook types and angling methods ($\chi^2_{0.05,\,5} = 12.2$, $P = 0.03$; Table 3). Capture efficiency was highest for actively

TABLE 2. Deep-hooking rates (95% CIs about the mean) for different length groups of trout caught with baited inline circle hooks and inline and offset J hooks.

	Inline circle hook				Inline J hook				Offset J hook			
	Active		Passive		Active		Passive		Active		Passive	
Fish length (mm)	*n*	Rate	*n*	Rate	*n*	Rate	*n*	Rate	*n*	Rate	*n*	Rate
<250	37	0.05 ± 0.07	28	0.03 ± 0.07	23	0.35 ± 0.20	20	0.35 ± 0.21	34	0.06 ± 0.08	23	0.09 ± 0.12
250—350	48	0.04 ± 0.06	51	0.33 ± 0.13	48	0.31 ± 0.13	44	0.25 ± 0.13	27	0.19 ± 0.15	37	0.43 ± 0.16
>350	15	0.40 ± 0.25	21	0.05 ± 0.09	30	0.20 ± 0.15	38	0.18 ± 0.13	38	0.05 ± 0.07	41	0.24 ± 0.13

fished inline J hooks (63 ± 8%), lowest for passively fished inline circle hooks (35 ± 8%), and intermediate (41–50%) for the remaining combinations. Hooking success and capture efficiency was always greater for actively fished hooks than for passively fished hooks of the same hook type.

DISCUSSION

Results of the present study indicate that the incidence of deep hooking when bait fishing for stream-dwelling trout may be reduced when fishing with inline circle hooks, especially if they are fished actively. Considering that angling related mortality is predominantly caused by injuries related to deep hooking (Wydoski 1977; Mongillo 1984), we conclude that actively fishing with inline circle hooks should result in lower postrelease mortality when anglers bait fish for stream-dwelling trout. Indeed, these results suggest that the benefit of using inline circle hooks may be greatly reduced if they are fished passively rather than actively. This concurs with the findings of Meyer and High (2010), which showed an increase in deep hooking of Rainbow Trout with circle hooks fished passively rather than actively, although these results contradict conventional wisdom. According to circle hook manufacturers (see Montrey 1999; ASMFC 2003; Cooke and Suski 2004), passively fishing circle hooks should result in lower deep-hooking rates than active fishing because any deeply ingested hooks can slowly slide past the esophagus and gills before penetrating the corner of the jaw upon exiting the mouth. Our results and those of Meyer and High (2010) suggest that fishing passively provides no benefit when bait fishing for stream-dwelling trout with circle hooks and actually results in more deep hooking. One explanation for this may be that these studies were conducted in flowing water, and baited circle hooks drifting laterally through flowing water may perform differently than in lentic environments, where bait is usually fished vertically (e.g., longline marine fisheries). Zimmerman and Bochenek (2002) reported that circle hooks appeared to be less prone to deep-hooking flounder when drift speed was highest. Bait (and hook) retention time inside the fish (before a strike is detected) may be different between lentic and lotic environments, and actively setting the hook should minimize hook retention time compared with not setting the hook. This may influence deep-hooking rates as much as the type of hook set. It is also important to consider that anglers may not have always detected the intake of the bait prior to the hook set when active fishing, thus making those “active” hook sets more “passive” in nature. This could have biased the deep-hooking rates for active fishing and actually made them slightly higher.

The high deep-hooking rate for inline J hooks, regardless of whether they were fished actively or passively, may have been due in part to hook configuration and dimensions. The swallow diameter of the hooks (i.e., outside diameter) was 5.8 mm for inline J hooks, 6.9 mm for offset J hooks, and 9.5 mm for inline circle hooks. Thus, the streamlined shape of the inline J hook compared with the other hooks may have made it inherently

TABLE 3. Hooking and landing success and capture efficiency rates (95% CIs about the mean) for each hook type and angling method.

Hook type and angling method	Number of strikes	Number hooked	Number landed	Hooking success	Landing success	Capture efficiency
Inline circle (active)	168	103	80	0.61 ± 0.07	0.78 ± 0.08	0.48 ± 0.08
Inline circle (passive)	248	111	86	0.45 ± 0.06	0.77 ± 0.08	0.35 ± 0.08
Inline J hook (active)	149	112	94	0.75 ± 0.07	0.84 ± 0.07	0.63 ± 0.08
Inline J hook (passive)	143	95	72	0.66 ± 0.08	0.76 ± 0.09	0.50 ± 0.08
Offset J hook (active)	186	113	90	0.61 ± 0.07	0.80 ± 0.07	0.49 ± 0.08
Offset J hook (passive)	160	76	65	0.48 ± 0.08	0.86 ± 0.07	0.41 ± 0.08
All hooks combined	1,054	610	487	0.58 ± 0.03	0.80 ± 0.03	0.46 ± 0.08

easier for trout to swallow the hook once it was ingested. Similar results have been found for Bluegill *Lepomis macrochirus* and Pumpkinseed *L. gibbosus*, where deep-hooking rates increased with decreasing hook size (Cooke et al. 2005). Both hook size and gap width can affect deep hooking (reviewed in Cooke and Suski 2004), and it is not possible to standardize both with the same hooks. For example, because the hook point bends back toward the shank, the inline circle hook in our study had the largest swallow diameter but also a smaller gap width (4.1 mm) than the inline J (4.7 mm) and offset J (4.9 mm) hooks. Larger hooks may be harder to swallow than smaller hooks, but they may also cause greater damage when they puncture tissue (Pauley and Thomas 1993; DuBois et al. 1994). The relationship between hook size, fish size, and hook performance has varied widely among studies (Muoneke and Childress 1994), and further research comparing circle and J hooks with varying gap widths and swallow diameters would be useful to better assess how hook dimensions affect deep-hooking rates. Additionally, comparing circle and J hooks with identical dimensions (i.e., swallow diameter, gap width, or hook configuration) would be useful for evaluating circle and J hook performance.

Inline and offset J hooks were used to determine whether this characteristic would affect deep-hooking rates. Other studies have attempted to assess the impacts of inline and offset hook designs, and have produced equivocal results. Hand (2001) showed that circle hooks with a minor offset (~4°) had slightly higher deep-hooking rates (13%) than inline circle hooks (6%) for Striped Bass *Morone saxatilis*, whereas Graves and Horodysky (2008), studying White Marlin *Kajika albida,* showed no difference in deep hooking or survival between 5° offset and inline circle hooks. Intuitively, the exposed point on an offset hook should be more likely to lodge deeply in the fish. However, we found just the opposite in this study, with offset J hooks resulting in less deep hooking than inline J hooks. As mentioned above, this may have been related to swallow diameter, but the offset angle may also have further reduced the streamlined nature of the offset J hook relative to the inline J hook (beyond swallow diameter alone), making it more difficult to quickly swallow the hook deeply. Further research using offset and inline circle and J hooks would help elucidate the effect that hook alignment may have on deep-hooking rates for bait anglers.

We found a relationship between deep-hooking rate and fish length, in that smaller trout (i.e., <250 mm) were less likely to be deeply hooked than intermediate-sized trout (i.e., 250–350 mm). The few previous studies investigating the relationship between fish length and deep-hooking rates when bait fishing have produced conflicting results. Grixti et al. (2007) showed a positive correlation between fish length and deep-hooking rates for Black Bream *Acanthopagrus butcheri* bait fished with longshank hooks, but Schill (1996) showed no relationship between Rainbow Trout length and deep-hooking rates when bait fishing with size 8 offset J hooks. Relationships between fish size and deep hooking are probably not causative, but rather may simply be a function of hook size (or bait size) relative to fish length (Cooke et al. 2005). The smallest trout captured in this study were probably not as capable of deeply ingesting bait (and hook) due to smaller mouth and esophagus openings, and thus had less deep hooking.

Six anglers collected data during the study, and deep-hooking rates differed between the angler with the lowest deep-hooking rate and the three anglers with the highest deep-hooking rates. This may be explained in part by the size of fish caught by those anglers. Angler 1, whose overall deep-hooking rate was 4%, caught trout that averaged 213 mm in length, whereas the other anglers with higher deep-hooking rates caught trout that averaged 291, 323, and 349 mm. Because smaller trout were less likely to be hooked deeply in our study, this probably explains some of the difference in deep hooking between these anglers. Thus, the fish size difference between anglers was the result of differences in fish length frequency between streams and the number of days these anglers spent fishing different streams, not differences in angling skill.

Circle hooks must perform at least nearly as well as conventional hook types to gain acceptance among anglers (Jordan 1999). Cooke and Suski (2004) reported that the use of circle hooks generally resulted in less capture efficiency than conventional hooks. We found that capture efficiency for inline circle hooks was lower than for inline and offset J hooks. However, these differences were inversely related to swallow diameter, which for inline circle hooks was larger than for inline and offset J hooks. When fished actively, capture efficiency for inline circle hooks was similar to capture efficiency for offset J hooks. Our study was not designed to control for differences in swallow diameter, so it is difficult to speculate whether hook size may have influenced capture efficiency. However, we believe our results suggest that anglers could transition to using circle hooks without suffering drastically reduced catch rates, regardless of fishing method. Nevertheless, our results are based on only three common hook types, all of similar size. More research is clearly needed on a variety of hook shapes and sizes before definitive conclusions can be drawn relative to capture efficiency with circle hooks on stream-dwelling trout.

We acknowledge it is nearly impossible for managers to stipulate angling methods with regulation changes, especially in stream trout fisheries. However, it is important for fishery managers to understand that active fishing with circle hooks does not appear to affect their ability to reduce deep hooking, as has been reported in a number of marine fisheries studies. Therefore, managers can institute the use of circle hooks in trout fisheries without concern as to whether anglers fish them actively or passively, and still gain the benefit of reduced deep-hooking rates.

In summary, circle hooks produced deep-hooking rates similar to or lower than both J hook styles, regardless of fishing method and therefore appear to be a viable option for fisheries managers attempting to reduce bait angling deep hooking (and subsequent related mortality) on stream-dwelling trout. This reduction in deep hooking will likely be accompanied by slightly lower capture efficiency. However, further research is needed on circle hook performance in which a variety of trout bait-angling scenarios, such as lentic and lotic environments, the effect of hook size, the inclusion of other circle hook designs (i.e., offset circle hooks), gap width compared to swallow diameter, and the degree of offset in the hook, are evaluated before definitive conclusions can be made about the performance of circle hooks when bait fishing for stream-dwelling trout. If future researchers continue to find that stream trout caught with actively fished circle hooks have lower deep-hooking rates than trout caught with passively fished circle hooks, then hook manufacturers, management agencies, and outdoor media will need to modify their hook set recommendations for circle hooks used to bait fish for stream-dwelling trout.

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