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Hooking Mortality and Landing Success Using Baited Circle Hooks Compared to Conventional Hook Types for Stream-dwelling Trout

Abstract

We estimated hooking and landing success and relative hooking mortality for stream-dwelling trout caught with baited circle and J hooks, J hook dry flies, and treble hook spinners (all hooks barbed). Trout were caught, individually marked, and released for 69 days. Deep-hooking rate was higher for trout captured with baited J hooks (21%) than for spinners (5%), baited circle hooks (4%), and dry flies (1%). Relative mortality rate was higher for trout captured with baited J hooks (25%) and spinners (29%) than for trout captured with baited circle hooks (7%) and dry flies (4%). Deep-hooking was two and six times higher for baited J hooks than baited circle hooks for fish caught actively and passively, respectively. For baited circle hooks, deep-hooking was over three times greater when using an active fishing method (i.e., an active hookset) compared to passive fishing method (no hookset), which conflicts with manufacturer's recommendations on how circle hooks should be fished. Hooking success (ratio of hook-ups to number of fish strikes) was about one-third lower for baited circle hooks fished both passively and actively compared to other hook types and fishing methods, except for passively-fished baited J hooks. Once hooked, landing success (ratio of fish landed to number of hook-ups) was relatively high for all hook types and fishing methods (range 68-87%). Our results suggest that when bait fishing for trout in streams, circle hook use may reduce deep-hooking and hooking mortality (but also catch rate) regardless of whether anglers fish passively or actively.

Keywords: bait, angling, hooking mortality, circle hook, trout

Introduction

Increasing angler effort on popular wild trout fisheries has often led to implementation of "special regulations" such as creel limits, slot limits, size limits, and gear restrictions, which are designed to reduce mortality rates. Such management strategies assume negligible post-release or hooking mortality (Wydoski 1977). However, for trout species, most of the previous studies comparing bait hooking mortality to that for artificial flies and spinners have concluded that the use of bait results in mortality rates 3-6 times higher than other gear types (e.g., Shetter and Allison 1955, Hunsaker et al. 1970, Mongillo 1984). For this reason, it is often assumed that bait fishing conflicts with special regulations because the elevated hooking mortality rates are presumed to prevent sufficient increases in fish size or abundance that could result from creel, slot, or size limits. Although several studies have demonstrated that bait fishing can be compatible with special regulations for salmonids (e.g., Turner 1986, Orciari and Leonard 1990, Thurow 1990, Carline et al. 1991), fishery managers nevertheless often restrict the use of bait in an effort to obtain maximum trout yield, size, density, or survival (Noble and Jones 1999). In doing so, they must weigh the social risk of alienating bait fishermen against the potential for higher hooking mortality rates for fish caught and released with bait (Thurow and Schill 1994, Noble and Jones 1999).

Hooking mortality using conventional bait fishing gear is significantly higher than for other gear types because mortality of caught-and-released fish is strongly dependent on the anatomical site of hooking and resultant injury to vital organs due to deep-hooking and bleeding (Mason and Hunt 1967, Schill 1996). While artificial flies and spinners are also susceptible to hooking fish in critical areas such as the esophagus, stomach, or gills, they generally penetrate these critical areas less than 10% of the time, compared to a much higher rate (up to 50%) when bait is used with conventional J hooks (Mongillo 1984). Although circle hook styles have been around for centuries and major

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hook manufacturers have been producing circle hooks for decades (Bowerman 1984), they have only recently gained a reputation as a potentially more benign bait hook that often reduces hooking mortality relative to conventional J hooks (Cooke and Suski 2004). On a circle hook, the point of the hook is oriented perpendicular to the shank, rather than parallel as on a J hook. Because of this, once it is swallowed, the baited hook ostensibly can pull free from a fish's esophagus or stomach, until the hook's path of travel is changed at the edge of the mouth, where the hook is supposed to rotate and become embedded.

Numerous studies on a variety of species have shown that, in general, deep-hooking rates are reduced with circle hooks compared to conventional bait hooks, especially in marine settings (reviewed in Cooke and Suski 2004). This has fostered wide acceptance for circle hook use in commercial and recreational marine fisheries, but use in freshwater sport fisheries is also growing in popularity (Kaimmer and Trumble 1997, Trumble et al. 2000, Meka 2004, Cooke and Suski 2004), despite the fact that freshwater research has not demonstrated the benefits of circle hooks as consistently as marine studies (Cooke et al. 2003). Because hooking mortality rates for circle hooks relative to J hooks have been inconsistent across species and settings, Cooke and Suski (2004) suggest that management agencies should not universally adopt the use of circle hooks as a means of reducing deep-hooking in bait fisheries unless compelling comparative species-specific data exist.

In trout fisheries, studies comparing baited circle hooks to conventional bait hooks have been limited to hatchery settings, and methods and results have been inconsistent. Parmenter (2000) found hooking mortality was twice as high for conventional baited J hooks (19%) compared to baited circle hooks (10%) for rainbow trout *Oncorhynchus mykiss* caught in hatchery raceways, but, unexpectedly, deep-hooking rates were similar. The author reported volunteer anglers fishing baited circle hooks 'incorrectly' (i.e., setting the hook with a traditional hook set), which he believed may have confounded the results. In aquaculture pens, deep-hooking of hatchery rainbow trout was 2.4 times higher for baited J hooks than baited circle hooks (Jenkins 2003); however, mortality rates were higher for baited circle hooks (9%) than for J hooks (0%), perhaps because all circle hooks were removed from the fish regardless of hooking location (including several hooked in the esophagus), whereas for J hooks, lines were cut for deep-hooked fish. The applicability of these studies to wild trout fisheries is questionable considering their artificial setting, and because wild trout may experience higher hooking mortality rates than their hatchery counterparts (Warner 1979, Mongillo 1984).

For circle hooks to perform as designed in recreational bait fishing, it is generally recommended (e.g., Montrey 1999, ASMFC 2003, Cooke and Suski 2004) that anglers must not use the traditional hook set when a fish strikes the hook, which typically involves a rapid and forceful sweeping motion of the rod intended to sink the hook into the mouth of a fish (defined herein as an active hook set). Rather, a circle hook arguably performs properly only when the angler, once a fish strike is detected, applies gentle pressure to the hook with their rod to retrieve the fish (defined herein as passive fishing). Cooke and Suski (2004) assume this recommendation is sound but point out that virtually no studies have tested whether circle hook performance is affected by whether the angler actively or passively sets the hook. It has been suggested that the design of the circle hook may deter the hook from backing out on its own and may hold a fish even under slack line conditions (Johannes 1981). Such performance would help circle hooks gain acceptance among bait anglers and fish managers, since circle hooks would ideally perform at least similar to that of conventional J hooks in terms of hooking and landing success. Past studies comparing baited J hooks and baited circle hooks have produced somewhat equivocal results, but a literature summary by Cooke and Suski (2004) suggests that capture efficiency is generally lower for circle hooks than J hooks, although none of the 18 studies in their review of circle hook capture efficiency included bait fishing for freshwater salmonids in lotic systems. Meka (2004) found that using fly-tied circle hooks resulted in similar loss rates of hooked rainbow trout as fly-tied J hooks, with confidence bounds around the differences (using the formulas in Fleiss 1981) overlapping, but the applicability of fly-tied circle hook performance to bait fishing is tenuous.

The purpose of this study was to assess the utility of using of baited circle hooks in trout stream fisheries where management goals are aimed at minimizing total annual mortality. Thus, we assessed relative hooking mortality rates and rates of hooking and landing success for baited circle hooks and more conventional hook types (i.e., baited J hook, J hook dry fly, and treble hook spinner). We also assessed whether hooking and landing success were lower when bait fishing with circle hooks, and whether deep-hooking rates for baited circle hooks varied according to whether or not the hook was actively set by the angler (i.e., active and passive fishing methods).

Methods

We conducted our study in the lower portion of Badger Creek, a tributary of the Teton River in eastern Idaho (43°55’35” N, 111°14’53” E). Mean wetted width and stream depth in the study reach was 13.6 m and 0.20 m, respectively, and water temperatures during the warmest months of the summer (July and August) in 2006 averaged 10.9°C and fluctuated between 8.8 and 14.5°C. The study reach was in a deep, narrow canyon surrounded by private land and access was quite limited, thus fishing pressure and harvest was extremely low despite the fact that general fishing regulations (excluding the harvest of cutthroat trout *O. clarkii*) are in force (6 fish limit, no size restrictions).

A 1-km reach of Badger Creek was isolated with hardware cloth wire mesh (1.3 cm) weirs to prevent fish from entering or leaving the study reach during the study. The weirs were checked and cleaned frequently (at least every 2 days) to ensure proper function. Trout composition in the study reach consisted primarily of rainbow trout, with some cutthroat trout and rainbow trout x cutthroat trout hybrids present. We did not analyze cutthroat trout and rainbow trout separately for our analyses because of behavioral and ecological similarities between the two species (Behnke 2002). Mottled sculpin *Cottus bairdi* were also present.

Hooking Mortality

After the weirs were built, anglers fished from July 5 to 8, 2007, using J hook dry flies (size 4 to 14), treble hook spinners (Panther Martin® 3.5 g), in-line style circle hooks baited with nightcrawlers (Eagle Claw® size 8, model L2050-12), and minor off-set (4°) J hooks baited with nightcrawlers (Renegade snelled size 8). Hooks are shown in Figure 1. All hooks were barbed, but the baited J hook had two additional “microbarbs” on the shank designed to help hold bait on the shank; we assumed the microbarbs were too small to influence deep hooking. All anglers fished on average at least 10 days/year, and were therefore considered “experienced” as defined in Meka (2004). Baited circle hooks were fished according to manufacturer’s recommendations (Montrey 1999, ASMFC 2003, and Cooke and Suski 2004), which we earlier defined as passive hook setting. For baited J hooks, dry flies, and spinners, the hook was actively set once a fish strike was detected. All anglers fished all hook types, and periodically switched from one hook type to another until the desired sample size (about 75 fish for each hook type) was achieved.

Anglers fished all hook types throughout the study reach and captured fish in all habitat types, although fish densities and catch rates were highest in pools and runs. Because fish were more abundant in pools and runs, and bait fishing was especially ineffective in riffle habitat and required more effort (in terms of time) to land fish, our efforts when bait fishing were inherently more focused on pools and runs. We assumed this did not bias our results because pool sizes were small in the study stream, and fish caught while bait fishing included fish from riffle habitat as well as pool and run habitat.

Captured trout were landed by hand or by net generally in less than 1 minute, placed in a bucket of water without using a net, and anesthetized using MS-222. The angler removed the hook unless fish were hooked in the esophagus or deeper, during which cases the line was cut leaving the hook in the fish. Fish were measured for total length and categorized into 25-mm size groups, marked with an adipose fin clip, and passive integrated

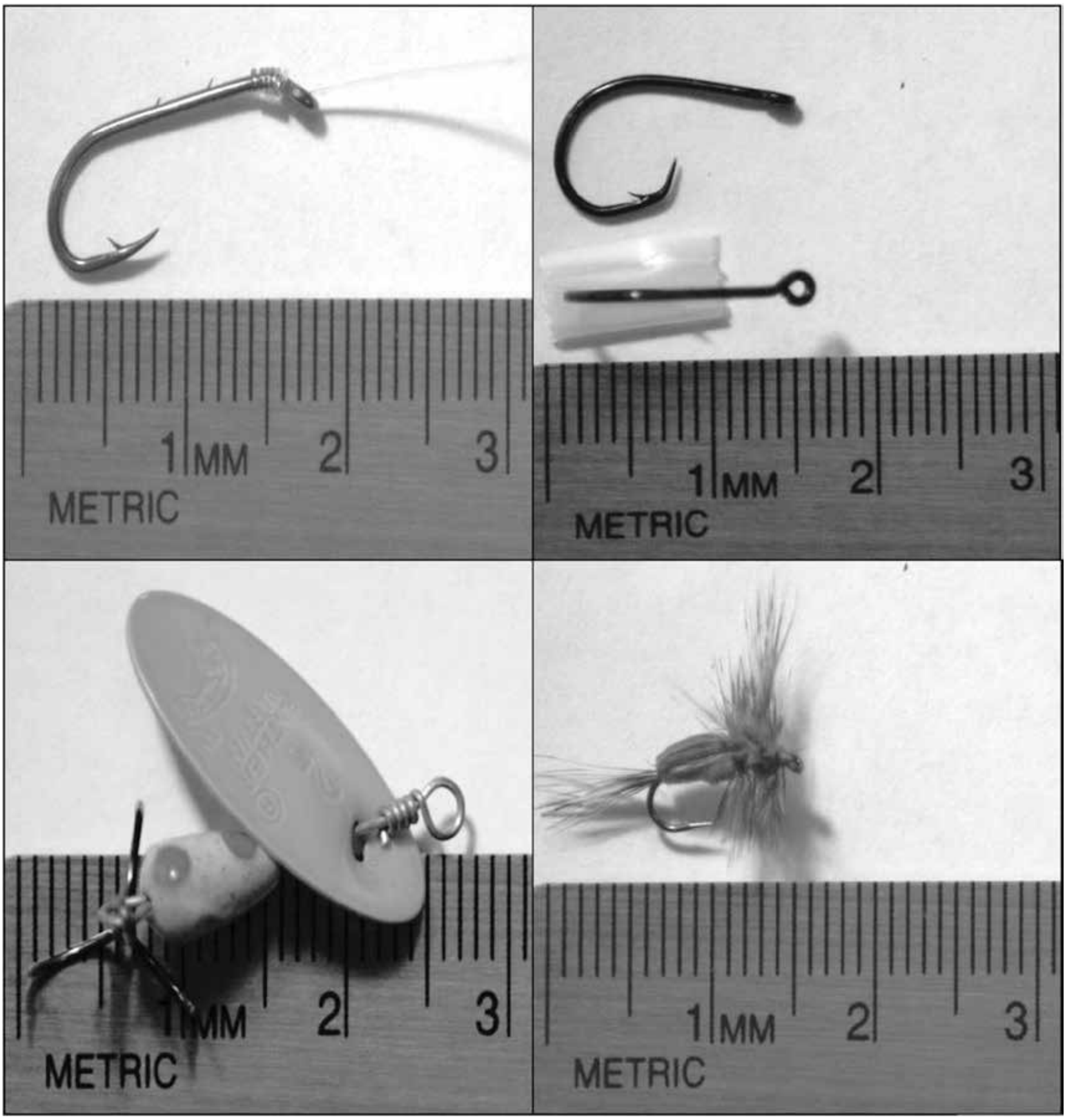

Figure 1. The four hook types used in the present study (clockwise from upper left): Renegade snelled size 8, Eagle Claw ® size 8 model L2050-12 circle hooks, J hook dry flies sizes 4 to 14, and Panther Martin ® #2 3.5 g treble hook spinners.

transponder (PIT) tags were placed intraperitoneally using a rinsed, 12 gauge hypodermic needle; the insertion point was ventral and posterior to the pectoral fin, offset slightly to the right or left side depending on the individual tagger. The anatomical location of hooking was noted as well as other observations including relative amount of bleeding (two categories: light or heavy), whether the hook was removed or the line was cut, and the presence of disease or existing health problems. Fish were then placed in a bucket of freshwater where they recovered in 2 to 5 min. Upon recovery, fish were released where they were captured. No fish were caught twice during this angling effort.

After the 4-day angling event, the weirs were operated as long as possible (resulting in a 69-day holding period) before heavy debris inputs from leaf fall in autumn rendered weir maintenance impractical. Due to debris building up against the hardware cloth, the lower weir partially failed three times for no more than one full day before repairs could be made. A small tear in the upper screen was also repaired once. At the conclusion of the observation period, electrofishing passes were made approximately 100 m above and below the weirs to assess the level of fish escapement that may have occurred during weir failures.

A mark-recapture electrofishing survey was conducted within the study reach at the end of the study using backpack electrofishing units. Electrofishing units produced pulsed DC at settings of about 60 Hz, 2 ms pulse width, and 400 volts. Captured fish were measured to the nearest mm. During the marking run, the caudal fin was partially clipped to mark fish, and captured fish with adipose-clips were scanned for PIT tags. We conducted the recapture run the following day. We used the Fisheries Analysis Plus program (Montana Fish, Wildlife, and Parks 2004) to calculate abundance estimates and 95% confidence intervals (CIs) using the Lincoln-Petersen M-R model as modified by Chapman (1951). Abundance estimates were made for all trout in the study reach as well as the remaining abundance of test fish (i.e., fish originally caught and PIT tagged by anglers) for each hook type. To control for size selectivity bias, estimates were separated into the smallest size-groups possible (usually 100 mm) which met the criteria that (1) the number of fish marked in the marking run multiplied by the catch in the recapture run was at least four times the estimated population size and (2) at least three recaptures occurred per size group; meeting these criteria creates modified Petersen estimates that are less than 2% biased (Robson and Regier 1964).

Some test fish shed PIT tags during the holding period and thus could not be traced back to hook type. We estimated how many fish shed PIT tags by calculating a M-R population estimate based on the number of fish in the mark and recapture runs with adipose clips but without PIT tags. We assumed no differences in PIT tag shedding rates between hook types, and distributed the estimate of test fish that lost PIT tags and the corresponding variance back into the four hook types. We weighted this adjustment based on the proportion of the total sample size estimated to remain after the holding period for each hook type. We calculated a relative mortality rate over the test period for each hook type as follows:

$$M_n = (A_n - B_n)/A_n$$

where M_n is the relative mortality rate for fish of hook type *n,* A_n is the number of fish of hook type *n* initially tagged while angling, and B_n is the estimate of the abundance of fish of hook type *n* at the end of the study. Confidence intervals for the relative mortality rates were derived by using lower and upper bound values of the B_n estimate in the above formula for each hook type, respectively. Differences in relative mortality rates were noted by non-overlapping 95% CIs around the estimates.

We tested whether fish size, hook type, or angler affected deep-hooking rates using multiple logistic regression with a binary response variable (0 = not deep-hooked; 1 = deep-hooked); hook type and angler were included as class variables in the model. Deep-hooking was defined as captured fish having the hook embedded in the gill arches or esophagus (or deeper). We tested whether hook type influenced the size of fish captured using analysis of variance (ANOVA), and used Duncan's multiple range test to assess differences between hook types. Statistical analyses were performed with SAS statistical software (SAS 1999).

Hooking and Landing Success

Additional angling was conducted in July 2009 (within the same study reach) to evaluate how baited circle and J hooks performed when fished both actively and passively. In addition, rates of hooking success and landing success were compared by counting the number of fish strikes and the number of hook-ups it took to land 100 fish for each hook type and fishing method. Four experienced anglers each captured 25 fish for the following hook types and fishing methods: J hook dry fly fished actively, treble hook spinner fished actively, baited J hook fished actively, baited J hook fished passively, baited circle hook fished actively, and baited circle hook fished passively. All of the hooks were the same as described above, and landed fish were handled as described above. Hooking success rate was calculated as the number of successful hook-ups (i.e., the fish was "on" the line for at least a few seconds) divided by the number of fish strikes. Landing success rate was calculated as the number of fish successfully landed (i.e., reducing the fish to hand) divided by the number of successful hook-ups. Deep hooking rates were also calculated. We calculated 95% CIs around these percentages following Fleiss (1981), and used X^2 tests and non-overlapping CIs to assess differences between hook types and fishing methods.

Results

Hooking Mortality

During a 4-day period, anglers caught and PIT tagged 300 test fish using four different hook types. The majority (72%) of the trout caught were hooked in the upper or lower jaw (Table 1), followed by the roof and floor of the mouth (13%). Eight percent were deep-hooked, most of which (67%) occurred with baited J hooks. The deep-hooking rate was significantly higher for baited J hooks (21%) than for treble hook spinners (5%), baited circle hooks (4%), and J hook dry flies (1%) as indicated by logistic regression ($X^2_{0.05,\,3}$ = 10.47, P = 0.02). There was no effect on deep-hooking by angler ($X^2_{0.05,\,6}$ = 1.54, P = 0.96) or fish length ($X^2_{0.05,\,1}$ = 0.26, P = 0.61). Only one immediate mortality was observed, occurring after the release of a fish caught in the esophagus on a baited J hook.

After a 69-day holding period, a total of 1,738 trout were captured during the mark and recapture electrofishing survey, including 240 test fish (i.e., fish caught by anglers and monitored for hooking mortality). The average size of captured test fish was 252 mm TL (range 126-370 mm). The length of test fish caught was not significantly different between baited J hooks (mean ± SD = 276 ± 49 mm) and baited circle hooks (262 ± 55 mm) but was significantly larger for these baited hooks than for spinners (242 ± 60 mm) and dry flies (239 ± 112 mm) ($F_{6,\,292}$ = 6.73, P < 0.001).

We estimated 2,255 (± 66) trout ≥ 100 mm were present within the 1 km study reach. We captured 44 test fish that had lost their PIT tags, and estimated from the mark-recapture data that a total of 47 test fish had lost their tag. Population estimates (and 95% CIs), corrected for PIT tag loss, for each hook type ranged from 53 fish (54-62) for spinners, 57 fish (54-62) for baited J hooks, 70 fish (66-75) for baited circle hooks, and 71 (64-74) for dry flies (Table 2). Comparing the population estimates to the initial number of fish for each hook type yielded relative mortality rates (and 95% CIs) that were higher for fish caught with spinners at 29% (23-36%) and baited J hooks at 25% (19-29%) than for fish caught with baited circle hooks at 7% (1-13%), and dry flies at 4% (1-14%; Table 2). For baited J hooked fish, relative mortality was 54% (39-69%) for deep-

TABLE 1. Number and percent of trout caught by anatomical hooking locations using four different hook types.

Hook location	J hook (%)	Circle hook (%)	Spinner (%)	Dry fly (%)	Total (%)
Upper jaw	35 (46)	58 (77)	22 (29)	44 (59)	159 (53)
Lower jaw	9 (12)	4 (5)	23 (31)	20 (27)	56 (19)
Mouth roof	7 (9)	4 (5)	5 (7)	2 (3)	18 (6)
Mouth floor	5 (7)	3 (4)	6 (8)	6 (8)	20 (7)
Tongue	1 (1)		5 (7)	1 (1)	7 (2)
Gill	6 (8)		4 (5)	1 (1)	11 (4)
Esophagus	10 (13)	3 (4)			13 (4)
Belly (foul)			1 (1)		1 (0.3)
Eye	3 (4)	3 (4)	8 (11)		14 (5)
Unknown			1 (1)		1 (0.3)
Total	76	75	75	74	300

TABLE 2. Initial population; ending population estimates (with associated 95% confidence interval [CI] bounds); and relative hooking mortality rate estimates (with associated 95% CI bounds) for each of the four hook types.

		Ending population		Hooking mortality rate	
Hook type	Initial population	Estimate	95% CI	Estimate	95% CI
Spinner	75	53	48-58	29	23-36
J hook	76	57	54-62	25	19-29
Circle hook	75	70	66-75	7	1-13
Dry fly	74	71	64-74	4	1-14

hooked fish compared to only 14% (8-21%) for those that were not deep-hooked. For baited circle hooks, flies, and spinners, there were not enough deep-hooked fish to make similar comparisons.

During the mark-recapture effort, no test fish were captured within 100 m below the lower weir, but three were captured within 100 m above the upper weir. An additional 500 m was surveyed above the upper weir, but no additional test fish were captured.

Hooking and Landing Success

Hooking success was significantly different between hook types ($X^2_{0.05,5} = 31.1, P < 0.001$) (Table 3), being highest for treble hook spinners at 65% (58-71%), actively-fished baited J hooks at 63% (58-68%), and J hook dry flies at 56% (49-63%), and lowest for passively-fished baited circle hooks at 37% (32-42%), actively-fished baited circle hooks at 40% (33-47%), and passively-fished baited J hooks at 38% (33-43%). Once fish were hooked, landing success was generally high for all hook types (range 68-87%)(Table 3) and not statistically different ($X^2_{0.05,5} = 2.8, P = 0.73$), although proportionally, landing success was highest for dry flies and lowest for both passively-fished baited hooks. Deep-hooking differed between hook types ($X^2_{0.05,5} = 42.0, P < 0.001$), being more common for baited J hooks (19% actively fished, 20% passively fished) than baited circle hooks, spinners, or dry flies (Table 3). Deep-hooking for baited circle hooks was 3% and 10% when actively and passively fished, respectively, but the 95% CIs overlapped for these proportions.

Discussion

Results of the present study indicate that passively-fished barbed circle hooks baited with nightcrawlers caused minimal hooking-related mortality for stream-dwelling trout, similar to J hook dry flies but much lower than for treble hook spinners and actively-fished baited J hooks. Relatively low mortality rates for stream-dwelling trout caught with baited circle hooks in our study corroborated results of previous studies using baited circle hooks on hatchery rainbow trout, which reported 9% mortality after 26 days in a net pen (Jenkins 2003) and 10% mortality after 28 days in a hatchery setting (Parmenter 2000). Moreover, we also observed less deep-hooking of

TABLE 3. Hooking success, landing success, and deep-hooking rates by hook type and fishing method with associated 95% confidence interval bounds.

	Hooking success		Landing success		Deep hooking	
Hook type	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Fly	56.1	49.2-63.0	87.0	80.8-93.2	0.0	0.0-0.0
Spinner	64.5	58.0-71.0	72.5	64.9-80.1	1.0	0-6.2
Baited J (active)	63.2	58.4-68.0	82.0	74.3-89.7	19.0	11.2-26.8
Baited J (passive)	37.9	32.7-43.1	68.5	61.2-75.8	20.0	12.0-28.0
Baited circle (active)	39.9	33.0-46.8	74.1	67.1-81.1	2.8	0.0-8.5
Baited circle (passive)	37.1	32.2-42.0	67.6	59.9-75.3	10.0	4.0-16.

stream-dwelling trout while fishing with baited circle hooks than with baited J hooks regardless of whether the hooks were actively or passively fished, indicating that circle hooks reduced deep-hooking no matter how they were fished. This contrasts with the findings of Parmenter (2000), who found a higher deep-hooking rate using baited circle hooks (identical to our hooks) in rainbow trout caught in a hatchery (55%), and he attributed this finding to his observation that some anglers actively set the hook (against instructions). Conventional wisdom says that when fishing with baited circle hooks, once a fish strike is detected, the angler cannot set the hook with the normal vigor used for conventional hooks, otherwise the hook either will not capture the fish at all or will be more likely to lodge deeply, in areas that are more injurious (Cooke and Suski 2004). Our results suggest that, for stream-dwelling trout, neither may be the case. We suspect that actively fishing the baited circle hook resulted in less deep-hooking than passive fishing because by setting the hook when a fish strike occurs, the hook was less likely to have already been deeply ingested by the fish, and subsequently was less likely to lodge there. Surprisingly, we did not see a similar reduction in deep-hooking by actively fishing baited J hooks, although others have (Schisler and Bergersen 1996). More research is clearly needed to test comparative deep-hooking rates under a variety of lentic and lotic conditions using various hook sizes and sizes of trout before strong conclusions regarding the use of circle hooks for freshwater salmonid fishing can be made.

The higher mortality rate we observed when actively fishing baited J hooks relative to other hook types was likely caused by the higher rate of deep-hooking with baited J hooks. The anatomical site of hooking is strongly related to hooking mortality because deep-hooked trout often die due to hooking damage to organs such as the heart and liver (Mason and Hunt 1967, Schill 1996). In our study, deep-hooking most commonly occurred when fishing with baited J hooks, but was low relative to other studies. For example, Jenkins (2003) reported over 60% of the hatchery rainbow trout he caught were hooked in the esophagus using J hooks with Powerbait® (a flavor-impregnated artificial bait) while fishing net pens in a pond. The stream setting may have influenced our deep-hooking rates, since slackwater habitat in our study reach was not extensive. Thus, stream flow within or adjacent to the pools may have affected our ability to allow trout to consistently swallow the bait, as observed by Jenkins (2003) for baited J hooks. Moreover, it is not surprising that deep hooking was substantially higher in Jenkins (2003), a study conducted in raceways on hatchery trout which typically display more aggressive behavior and feeding habits than wild trout (reviewed in Weber and Fausch 2003).

Our results suggest that bait anglers actively fishing with conventional J hooks to catch stream-dwelling trout may experience a 1/3 reduction in hooking success (but little change in landing success) if they switch to baited circle hooks, regardless of whether they fish the circle hooks actively or passively. Thus, fishery managers should expect lower catch rates for baited circle hooks compared to traditional baited J hooks if regulations are put in place that require the use of circle hooks when angling with bait. However, many anglers already fish baited J hooks passively, and for those anglers, it appears that hooking success would not change with a switch to circle hooks.

Our finding that deep-hooking rates for passively fished baited circle hooks (10%) were more than three times that for actively fished baited circle hooks (3%) was contrary to our expectations, because it is generally assumed that circle hooks should be passively fished in order to minimize deep-hooking (Montrey 1999, ASMFC 2003, Cooke and Suski 2004). Due perhaps to small sample size, this large difference was not statistically significant. Nevertheless, passive fishing of bait hooks may result in hooks residing in deeper, critical hooking areas for a longer period of time, and our results suggest this may increase the likelihood of deep-hooking for circle hooks. Zimmerman and Bochenek (2002) reported that circle hooks appeared to be more prone to deep-hooking flounder when drift speed was lowest. To our knowledge, the present study is the first to compare baited circle hook performance for trout angling using different types of hook set methods. Future research regarding differences in hooking locations when circle hooks are fished passively or actively would help determine if circle hooks could be used as a regulation tool, because not all anglers will fish circle hooks the same way.

Although deep-hooking with spinners was uncommon (5%), the relative mortality rate was high (29%) and not significantly different from that for fish caught with baited J hooks (25%). Most previous studies have indicated that spinners do not cause high hooking mortality rates within resident trout populations (Wydoski 1977, Dubois and Dubielzig 2004). The higher relative mortality rates we observed for spinners may have been related to eye hooking, which was 2.6 times higher for spinners than any other hook treatment in our study, and may directly increase post-release mortality rate (Siewert and Cave 1990). Alternatively, the small size of spinner used in our study relative to the size of caught fish may have resulted in higher mortality, as the size of fish relative to hook size is considered to be important in hooking related damage (Cooke and Suski 2004). We noticed a few of the fish landed with spinners were hooked in the jaw, but had sustained damage to the gill arches. In these situations, mortality may have been caused by initial deep-hooking in the gill arches with the spinner that damaged that area prior to lodging in the mouth or jaw.

Our study had a number of limitations that could have biased our estimates of deep-hooking and relative mortality. First, fishing effort in each habitat type was not equivalent between hook types because catch rates were especially low in riffles when bait fishing. Since fishing in pools may result in higher deep-hooking rates for trout (Schill 1996), our estimates of relative mortality rates may have been biased high for baited J and baited circle hooks compared to estimates for dry flies and spinners. However, the small sizes of pools in the study stream did not allow anglers to fish baited hooks sitting motionless on the bottom. Rather, the baited hooks drifted relatively swiftly through all habitat types, including pools. Moreover, the fact that rates of deep-hooking and relative mortality for baited circle hooks were low and similar to dry flies supports our conclusion that use of baited circle hooks resulted in less deep-hooking and less hooking mortality than baited J hooks. Our estimates of deep-hooking and hooking mortality for dry flies and spinners may likewise have been biased low relative to bait fishing because for these hook types we landed more fish in riffle habitat (relative to bait hook types). However, we assumed the visual nature of the strike and hook set for dry flies and the active retrieval for spinners probably minimized the effect this might have had on deep-hooking and hooking mortality relative to bait fishing.

Another limitation was that we assumed emigration out of our study reach was negligible and did not differ between fish caught with different hook types. Emigration likely had little effect on our relative mortality estimates because escapement was entirely blocked for about 94% of the study (except for short durations while weir failures were repaired) and we detected only 4 emigrated test fish (1%) while electrofishing above and below our study reach. In a study of northern pike *Esox lucius* released with a retained lure (simulating hooking damage followed by line breakage), test fish moved less than control fish in the first day, more in the second day, and similarly for the remainder of a 21-day study (Arlinghaus et al. 2008). None of our weir failures occurred in the first few days, so we believe it is unlikely that movement biased actual mortality rates substantially. Moreover, even if a more substantial amount of movement occurred that went undetected, it is unlikely that such movement would have differed between fish caught with different hook types.

A final limitation was that some of the mortality we observed which we ascribed to hooking mortality may have been caused by other factors, such as fish handling (including PIT-tagging), short-term (i.e., 24 hours in our study) electrofishing mortality, angler harvest, and natural mortality. With virtually no public access to the study reach, and a reasonably short summer holding period, angler harvest and natural mortality were probably negligible, and not different between our test groups. Indeed, no anglers were observed while walking between the upper and lower weirs during routine (almost daily) weir maintenance. While electrofishing is known to cause spinal injury and muscular hemorrhaging in fish, short-term mortality for trout is typically negligible at the electrofishing settings we used (e.g., McMichael 1993, Dalbey et al. 1996, Meismer 1999). In fact, since relative mortality for fish caught with dry-flies in our study was very low (4%) over the 69-day holding period, and was in general agreement with other hooking mortality estimates involving trout caught with artificial flies (Shetter and Allison 1955, Hunsaker et al. 1970, Mongillo 1984, Schisler and Bergerson 1996), it appears that all other potential sources of mortality were (at best) negligible for this hook type. This suggests our estimate of mortality were not substantially biased by a lack of control fish in our study. Inclusion of control fish (i.e., those not captured by angling) to compare to our test fish would not have eliminated all potential sources of bias because we still would have had to capture and handle the control fish, which may have caused some mortality once released. If dry-fly fishing truly caused zero mortality in our study, then all other potential sources of mortality (PIT-tagging, fish handling, angler harvest, natural mortality, and 24 hour electrofishing mortality from the marking run of the population estimate) would have totaled 4%; under this scenario, adjusted hooking mortality estimates for the remaining hook types would have been 3% for baited circle hooks, 21% for baited J hooks, and 25% for spinners. Regardless of whether all our estimates of hooking mortality were biased high by a few percentage points, hooking mortality was still significantly higher for spinners and baited J hooks than for dry-flies and baited circle hooks.

Fishery managers often must balance social preferences for fishing regulations with the biological constraints of individual fish populations. Special regulations are typically put in place to limit annual mortality rates of fish populations by reducing angling mortality. Unfortunately, special regulations restricting bait have a tendency to alienate those constituents, sometimes with legal consequences (Gigliotti and Peyton 1993, Thurow and Schill 1994). Conventional bait-fishing gear has been shown to cause high rates of hooking mortality (Shetter and Allison 1955, Stringer 1967, Mongillo 1984), and thus are often considered incompatible with regulation schemes aimed at keeping hooking mortality as low as possible. However, the current study demonstrates that circle hooks may be fished with bait for stream-dwelling trout with resultant hooking mortality rates not unlike dry flies. Thus, allowing bait fishing in the development of future restrictive special regulation waters may be possible if additional studies confirm the present findings and subsequent use of properly designed circle hooks is mandated.

Although our results suggest the baited circle hooks we used reduced deep-hooking compared to conventional baited J hooks regardless of the fishing technique used, we tested the design and size of only one circle hook and one J hook. Not only do the shapes and sizes of circle and J hooks vary by manufacturer, but the profile differs as well. We used an in-line style of circle hook but a minor offset (4°) style of J hook. Had we compared minor offset baited circle hooks to minor offset baited J hooks, the difference in deep-hooking we found between baited circle and baited J hooks may have been diminished. Hand (2001) found in-line circle hooks had slightly lower deep-hooking rates (6%) compared to minor offset circle hooks (13%) for striped bass *Morone saxatilis*. Similar deep-hooking rates were seen for sailfish *Istiophorus* spp. using in-line (6%) and minor offset (14%) circle hooks, but deep-hooking rates for severe offset circle hooks (44%) were so high as to be comparable to rates for minor offset J hooks (46%) (Prince et al. 2002). Clearly, more research is needed from trout streams on a variety of hook designs and sizes before strong conclusions can be drawn regarding circle hook performance relative to conventional bait hooks.

In conclusion, our results suggest circle hooks may have the potential to reduce bait-hooking mortality for stream-dwelling trout compared to conventional bait hooks such as J hooks, regardless of whether the hook is actively set or not. However, angling success (i.e., catch rates for anglers) may also be reduced. Considering the scarcity of studies on stream-dwelling trout hooking mortality with baited circle hooks, our results should be viewed as preliminary, and additional studies with different species, stream conditions, and circle hook designs and sizes are warranted. The potential of other bait hook designs to reduce the incidence of deep-hooking should also be investigated.

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