Performance of Circle Hooks When Bait Fishing for Stream-Dwelling Trout

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Abstract—Although the use of circle hooks in some settings demonstrably reduces deep hooking of fish, little information exists for circle hooks when bait-fishing for stream-dwelling trout. We used a series of studies to compare hooking mortality and deep hooking with circle hooks to more conventional hook types (baited J hooks, J hook dry flies, and treble hook spinners), and assessed the attributes of circle hooks that produced the largest reductions in deep hooking. We landed over 2,000 trout using a variety of baited circle hooks and J hooks noting hooking location, number of strikes, hook-ups, and landings. Deep hooking with circle hooks was much lower than for J hooks, and for both hooks, active fishing nearly always reduced deep hooking compared to passive fishing (i.e., no traditional hook set); a combined estimate of deep hooking for circle hooks was 11% and 17% for active and passive fishing, respectively, compared to 20% and 26% for actively and passively fished J hooks. Capture efficiencies (the number of landings per number of strikes) for circle hooks were 43% and 36% for actively and passively fished baited circle hooks, respectively, compared to 54% and 42% for actively and passively fished baited J hooks. We found no difference in deep hooking or capture efficiency by anglers between in-line and 4° offset circle hooks. In a another study, we caught and released trout in a 1-km enclosed section of stream, and estimated relative hooking mortality 69 days later. Relative mortality was higher for trout caught with spinners (29%) and baited J hooks fished actively (25%) than for trout caught with baited circle hooks fished passively (7%) and dry flies (4%). We conclude that circle hooks successfully reduced deep hooking and hooking mortality when bait fishing for stream-dwelling trout compared to more conventional bait hooks.

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 tackle restrictions designed to reduce mortality rates. Thus, post-release hooking mortality must be negligible for restrictive regulations to be effective (Wydoski 1977). Numerous studies have shown that bait fishing for trout results in mortality rates 3 to 6 times higher than other gear types such as flies or spinners (e.g., Shetter and Allison 1955; Hunsaker et al. 1970; Mongillo 1984). Hooking mortality for trout 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 not immune to hooking fish in critical areas such as the esophagus, stomach, or gills (areas generally referred to as "deep hooking"), 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). Therefore, it is often assumed that bait fishing is incompatible with special regulation fisheries, even though several studies have demonstrated that bait fishing can be compatible with special regulations for salmonids in some situations (e.g., Carline et al. 1991).

Although circle hooks have been used for centuries, and major 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 (reviewed in Cooke and Suski 2004). On a circle hook, the point of the hook is oriented perpendicular to the shank, rather than being more parallel as on a J hook (Figure 1). It is generally assumed that for circle hooks to perform properly, anglers must not set the hook, but rather should lift lightly on the rod and slowly retrieve the fish (Montrey 1999; ASMFC 2003; Cooke and Suski 2004). This has been termed "passive fishing" (Prince et al. 2002; Alós 2009). Because of the paucity of information on the use of baited circle hooks for trout in riverine settings, we undertook a series of studies to compare deep hooking and hooking mortality with circle hooks to more conventional hook types and fishing methods (i.e., baited J hook, J hook dry fly, and treble hook spinner), and evaluated what hook designs and angling methods influenced deep hooking rates for stream-dwelling trout.

Methods

Hooking Location and Capture Efficiency

To assess deep hooking with baited hooks, angling was conducted on a number of streams in southern Idaho using a variety of barbed hooks (Table 1; Figure 1). Anglers fished from late June to early October between 2006 and 2011 where wild Rainbow Trout *Oncorhynchus mykiss*, Cutthroat Trout *O. clarkii*, and Rainbow x Cutthroat hybrids dominated species compositions.

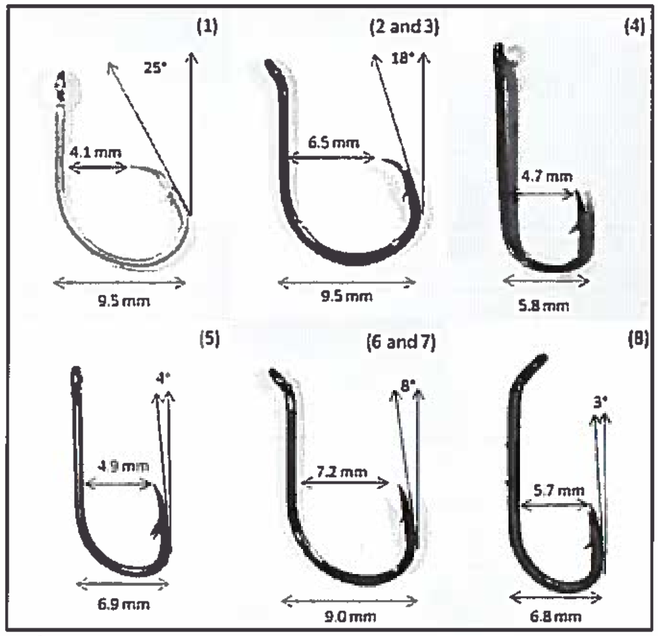

Figure 1. Hook gap, hook width, and front angle (°) for J and circle hooks used to bait fish for stream-dwelling trout in Idaho. Hook numbers (in parentheses) correspond to Table 1. Hook number 4 has a 0° front angle.

Table 1. Hook characteristics and rates of deep hooking and hooking and landing success for the various barbed hooks involved in our study.

Hook number	Hook	Offset	Fishing method	Brand	Hook size	Front angle (°)	Hook gap (mm)	Hook width (mm)	Number of landed fish	Deep hooking	Hooking success	Landing success	Capture efficiency
1	Circle	0	Active	Eagle Claw	8	25	4.1	9.5	97	0.10 ± 0.05	0.61 ± 0.07	0.78 ± 0.08	0.48 ± 0.07
1	Circle	0	Active	Eagle Claw	8	25	4.1	9.5	106	0.03 ± 0.06	0.40 ± 0.07	0.74 ± 0.07	0.30 ± 0.05
1	Circle	0	Passive	Eagle Claw	8	25	4.1	9.5	100	0.19 ± 0.08	0.45 ± 0.06	0.77 ± 0.08	0.35 ± 0.06
1	Circle	0	Passive	Eagle Claw	8	25	4.1	9.5	100	0.10 ± 0.06	0.37 ± 0.05	0.68 ± 0.08	0.25 ± 0.04
1	Circle	0	Passive	Eagle Claw	8	25	4.1	9.5	75	0.04 ± 0.04	-[a]	-[a]	-[a]
2	Circle	0	Active	Gamakatsu Octopus	8	18	6.5	9.5	45	0.13 ± 0.07	0.66 ± 0.10	0.80 ± 0.11	0.53 ± 0.11
2	Circle	0	Passive	Gamakatsu Octopus	8	18	6.5	9.5	65	0.25 ± 0.09	0.70 ± 0.08	0.77 ± 0.09	0.54 ± 0.09
3	Circle	4	Active	Gamakatsu Octopus	8	18	6.5	9.5	96	0.19 ± 0.06	0.69 ± 0.07	0.91 ± 0.06	0.63 ± 0.08
3	Circle	4	Passive	Gamakatsu Octopus	8	18	6.5	9.5	80	0.31 ± 0.08	0.69 ± 0.08	0.78 ± 0.08	0.54 ± 0.08
4	J	0	Active	Eagle Claw	8	0	4.7	5.8	92	0.28 ± 0.09	0.75 ± 0.07	0.84 ± 0.07	0.63 ± 0.08
4	J	0	Passive	Eagle Claw	8	0	4.7	5.8	99	0.24 ± 0.08	0.66 ± 0.08	0.76 ± 0.09	0.50 ± 0.07
5	J	4	Active	Eagle Claw	8	4	4.9	6.9	94	0.09 ± 0.05	0.61 ± 0.07	0.80 ± 0.07	0.49 ± 0.07
5	J	4	Passive	Eagle Claw	8	4	4.9	6.9	101	0.28 ± 0.08	0.48 ± 0.08	0.86 ± 0.07	0.41 ± 0.06
6	J	0	Active	Gamakatsu Octopus	6	8	7.2	9	87	0.23 ± 0.08	0.65 ± 0.08	0.84 ± 0.07	0.55 ± 0.08
6	J	0	Passive	Gamakatsu Octopus	6	8	7.2	9	87	0.29 ± 0.08	0.66 ± 0.08	0.85 ± 0.07	0.56 ± 0.08
7	J	4	Active	Gamakatsu Octopus	6	8	7.2	9	75	0.20 ± 0.07	0.64 ± 0.08	0.84 ± 0.08	0.54 ± 0.08
7	J	4	Passive	Gamakatsu Octopus	6	8	7.2	9	90	0.32 ± 0.08	0.68 ± 0.07	0.83 ± 0.07	0.56 ± 0.08
8	J	4	Active	Renegade	8	3	5.7	6.8	100	0.19 ± 0.08	0.63 ± 0.05	0.82 ± 0.08	0.52 ± 0.07
8	J	4	Active	Renegade	8	3	5.7	6.8	76	0.21 ± 0.09	-[a]	-[a]	-[a]
8	J	4	Passive	Renegade	8	3	5.7	6.8	100	0.20 ± 0.08	0.38 ± 0.05	0.69 ± 0.07	0.26 ± 0.04
9	Fly	-	Active	-	4-14	-	-	-	100	0 ± 0	0.56 ± 0.07	0.87 ± 0.06	0.49 ± 0.07
9	Fly	-	Active	-	4-14	-	-	-	74	0.01 ± 0.03	-[a]	-[a]	-[a]
10	Spinner	-	Active	Panther Martin	3.5 g	-	-	-	100	0.01 ± 0.05	0.65 ± 0.07	0.73 ± 0.08	0.47 ± 0.07
10	Spinner	-	Active	Panther Martin	3.5 g	-	-	-	75	0.05 ± 0.05	-[a]	-[a]	-[a]

[a]Fish were part of hooking mortality study, and hooking and landing success data were not collected.

Anglers fished hooks baited with night crawlers both actively and passively. Spinners and flies were fished actively using standard angling techniques. All anglers fished all hook types, and periodically switched from one hook to another to collectively accumulate sample size for each hook. Landed fish were identified to species, measured to the nearest millimeter in 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.). The number of strikes, hook-ups, and landings were recorded to estimate hooking success and capture efficiency.

Hooking Mortality

We conducted a hooking mortality experiment in 2006 in Badger Creek, a tributary of the Teton River in eastern Idaho within a 1-km section isolated by weirs. Anglers fished within the enclosed section of stream using baited in-line circle hooks (hook number 1 in Table 1), baited 4° off-set J hooks (hook number 8), J hook dry flies (hook number 9), and treble hook spinners (hook number 10). All anglers fished all hook types, and periodically switched from one hook to another until the desired sample size (n = 75 fish for each hook type) was achieved. Hooking location was noted for captured trout, and all fish were measured and received a PIT tag and an adipose clip prior to release.

After a 69-d holding period, a mark-recapture (M-R) electrofishing survey was conducted within the study reach. The Lincoln-Petersen M-R model as modified by Chapman (1951) was used to estimate abundance for all trout in the study reach as well as the remaining abundance of test fish for each hook type as identified by PIT tags. Some test fish shed PIT tags during the holding period and could not be traced back to hook type. We estimated how many fish shed PIT tags by calculating a M-R population estimate for this group. We assumed no differences in PIT tag shedding rates among fish caught with different 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 captured with hook type n at the end of the study. Confidence intervals (CIs) for the relative mortality rates were derived by using the lower and upper bound values of the B_n estimate in the above formula for each hook type, respectively. In all deep hooking and hooking mortality analyses, we used α = 0.10 or non-overlapping 90% CIs to indicate statistical significance.

Results

Deep Hooking

A total of 2,114 fish were landed by anglers with all hooks combined to determine deep hooking rates and capture efficiency (Table 1). Fish averaged about 300 mm total length and ranged from 130 to 520 mm.

Use of baited circle hooks resulted in significantly less deep hooking compared to baited J hooks, and for both circle and J hooks, we found that active fishing nearly always resulted in less deep hooking compared to passive fishing (Table 1; Figure 2). For circle hooks (pooled across all hooks used), deep hooking rate was 11% ± 3% and 17% ± 4% for active and passive fishing, respectively, compared to 20% ± 3% and 26% ± 3% for actively and passively fished J hooks, respectively. In comparison, deep hooking averaged 1% when using dry flies and 3% when using spinners (Table 1).

Despite the fact that use of circle hooks generally resulted in less deep hooking, rates of deep hooking varied widely among hook designs for circle hooks (3-31%) and J hooks (9-32%; Table 1). Because we only used two different circle hooks in our study, deep hooking rate for circle hooks was correlated equally to (1) hook gap, (2) the front angle of the point shank, and (3) the proportion of the entire hook width that the hook gap comprised (r = 0.72). In contrast, none of these hook characteristics were correlated to deep hooking rates for J hooks (r varied from 0.17 to 0.28; Figure 3).

There were only four direct comparisons of in-line and offset hooks (i.e., hooks 2 vs. 3 and 6 vs. 7, each fished actively and passively; Table 1). In these four direct comparisons, there was no difference in deep hooking for in-line hooks (24% ± 5%) compared to offset hooks (26% ± 5%).

Capture efficiency (which combined hooking success and landing success) was generally lower for circle hooks than for J hooks, and passively fishing either hook type reduced capture efficiency compared to actively fishing the hook (Figure 2). Across all experiments, capture efficiency for circle hooks was 43% ± 3% and 36% ± 3% for active and passive fishing, respectively, compared to 54% ± 3% and 42% ± 2% for actively and passively fished J hooks. Thus, capture efficiency was reduced by about 17% when using circle hooks compared to J hooks, and by about 20% when passively fishing compared to actively fishing. For dry flies and spinners, capture efficiency was 49% and 47%, respectively (Table 1). Capture efficiency was virtually identical between directly comparable in-line hooks (55% ± 4%) and offset hooks (57% ± 4%).

For circle hooks, capture efficiency decreased as deep hooking decreased (correlation coefficient $r = 0.59$). For J hooks, the relationship between capture efficiency and deep hooking was much less pronounced ($r = 0.25$). Most of the reduction in capture efficiency for circle hooks compared to J hooks, and for passive fishing compared to active fishing, was in reduced hooking success (Table 1). Once fish were successfully hooked, there was little difference in landing success between hook types or angling methods.

Hooking Mortality

The majority (72%) of the 300 trout caught by anglers were hooked in the upper or lower jaw, followed by the roof and floor of the mouth (13%). Eight percent were deep-hooked, most (67%) of which

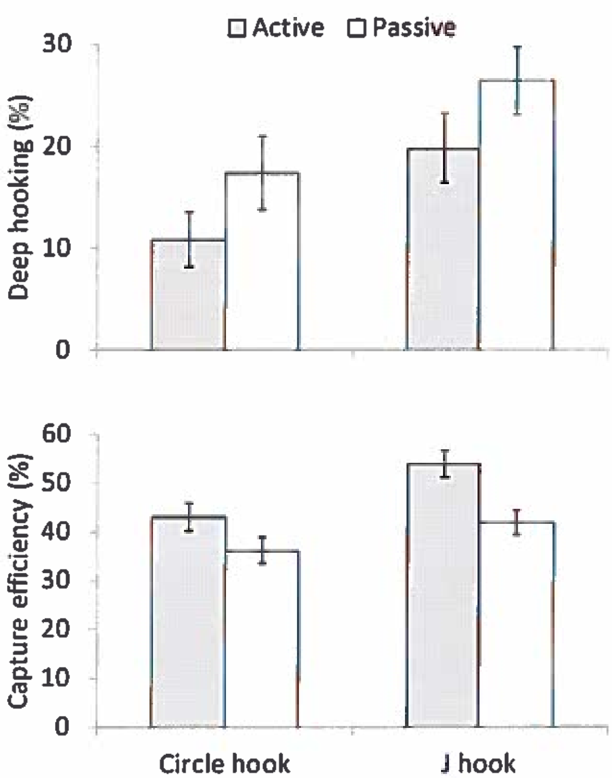

Figure 2. Rates of deep hooking and capture efficiency for circle and J hooks fish actively and passively, pooled across all hook designs. Error bars are 90% confidence intervals.

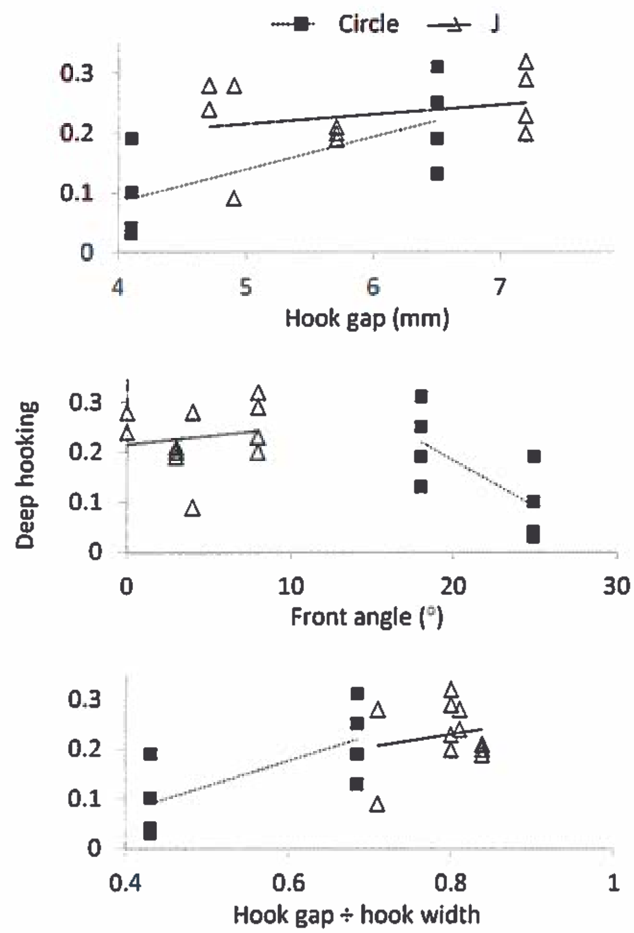

Figure 3. Relationship between deep hooking rates and three hook characteristics: (1) hook gap; (2) front angle; and (3) proportion of the entire hook width that the hook gap comprises. Lines represent trends through the data.

occurred with baited J hooks. Only one immediate mortality was observed, occurring after the release of a fish caught in the esophagus on a baited J hook. Deep-hooking was significantly higher for baited J hooks fished actively (21% ± 9%) than for treble hook spinners (5% ± 5), baited circle hooks fished passively (4% ± 4), and J hook dry flies (1% ± 3; Table 1).

Relative mortality over the 69-d holding period was significantly higher for fish caught with spinners (29%; 90% CI = 24-35) and baited J hooks fished actively (25%; 90% CI = 19-28) than for fish caught with baited circle hooks fished passively (7%; 90% CI = 1-11) and dry flies (4%; 90% CI = 1-12). For baited J hooked fish, relative mortality was 54% (90% CI = 41-67%) for deep-hooked fish compared to only 14% (9-20%) for those that were not deep-hooked. For circle hooks, flies, and spinners, there were not enough deep-hooked fish to make similar comparisons.

Discussion

Deep Hooking

All of the hook types we tested produced the lowest deep hooking rates when they were actively fished, which for circle hooks contradicts manufacturers' recommendations and conventional wisdom (Montrey 1999; ASMFC 2003; Cooke and Suski 2004). Our results suggest that, for stream-dwelling trout, fishery managers should encourage anglers to actively set the hook when bait fishing, regardless of whether they are using J hooks or circle hooks.

Actively setting the hook in our study may have resulted in less deep hooking (for both circle and J hooks), because our studies were conducted in flowing water, and 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).

For some hook comparisons in our study, the only difference between hooks was whether they were in-line or slightly offset (by 4°), but in-line and offset angles did not influence deep hooking rates in our study. Previous studies that have documented higher deep hooking rates for offset hooks have typically used severely offset hooks of 10° or more (Malchoff et al. 2002; Prince et al. 2002), whereas studies using minor offset hooks (~4°) have generally demonstrated no difference in deep hooking compared to in-line hooks (Hand 2001; Graves and Horodysky 2008). Our results concur with these latter findings.

We found that the better a circle hook was at reducing deep hooking, the worse it was at effectively catching fish, which may limit circle hook acceptance among anglers (Jordan 1999). Interestingly, anglers actively fishing circle hooks had capture efficiencies similar to anglers fishing J hooks passively in our study. Thus, for those anglers who fish passively, transitioning to circle hook use would result in virtually no change in angling success, if the angler also switched to active hook setting.

Hooking Mortality

Our results indicate that passively-fished baited circle hooks caused minimal hooking-related mortality, similar to J hook dry flies but much lower than for treble hook spinners and actively-fished baited J hooks. These results corroborate results of previous studies using baited circle hooks on hatchery Rainbow Trout, which reported 9% mortality after 26 d in a net pen (Jenkins 2003) and 10% mortality after 28 d in a hatchery setting (Parmenter 2000). 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 and associated tissue and organ damage (Mason and Hunt 1967; Schill 1996).

Our hooking mortality study used only one circle hook and one J hook, that were fished differently (passive for circle, active for J), thus our hooking mortality results should be considered preliminary. However, as high rates of hooking mortality for hooks with high rates of deep hooking were correlated, as were lower rates of mortality for hooks with lower rates of deep hooking, it is likely that any hook that reduces deep hooking reduces hooking mortality.

A limitation of our hooking mortality study was that fish handling (including PIT-tagging), angler harvest, and natural mortality may have caused some mortality during the study period which we could not account for, resulting in an overestimation of actual hooking mortality rates. However, the fact that relative mortality for fish caught with dry flies in our study was very low (4%) over the 69-d experiment, and 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), suggests that our estimate of mortality for fish caught with dry flies was not substantially biased by a lack of control fish.

Conclusion

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). The current study demonstrates that circle hooks may be fished with bait for wild trout in streams with resultant deep hooking and hooking mortality rates much lower than baited J hooks and in some cases not appreciably different than 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.

Our results highlight the conclusion by Serafy et al. (2012) that not all circle hooks are alike (also see Smith 2006), and some designs do not appear to reduce deep hooking as much as others. The relationship between deep hooking and hook configuration, such as hook size, the degree of offset, the front angle, the gap width compared to hook width, and other features of circle hooks are only beginning to be understood, and clearly require further research before definitive conclusions can be drawn regarding the use of circle hooks in freshwater fisheries. Nevertheless, the consistency with which active fishing results in less deep hooking than passive fishing suggests that hook manufacturers, management agencies, and outdoor media need to modify their hook set recommendations for circle hooks used to bait fish for stream-dwelling trout.

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