FISHERY RESEARCH

WILD TROUT EVALUATIONS: DEEP HOOKING STUDIES ON WILD TROUT USING CIRCLE HOOKS AND SHORT-TERM PERSISTENCE OF HATCHERY RAINBOW TROUT STOCKED IN STREAMS

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CHAPTER 1: DEEP HOOKING AND ANGLING SUCCESS WHEN PASSIVELY AND ACTIVELY FISHING FOR STREAM-DWELLING TROUT WITH BAITED J AND CIRCLE HOOKS

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. We compared deep hooking occurrence and angling success rates for stream-dwelling trout using 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). A total of 583 wild trout were caught by anglers, 20% of which were deep hooked. Deep hooking rate varied between hook types and angling method, but the interaction term hook type*angling method was also statistically significant, indicating the effect of hook type could not be interpreted separately from fishing method. Accordingly, deep hooking occurrence 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%). Fish length affected deep hooking rates, with trout <250 mm less likely to be deeply hooked than trout 250-350 mm. 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 was always greater for actively fished hooks than passively fished hooks of the same type. We found deep hooking was nearly twice as likely for inline circle hooks when fished according to manufacturer recommendations (i.e., passively) than when fished actively. These results and those of others suggest that circle hooks fished actively when bait fishing for stream-dwelling trout may minimize deep hooking more than fishing circle hooks passively.

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INTRODUCTION

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 at the rate that released fish survive to reproduce or are caught again by anglers (Wydoski 1977; Cooke and Suski 2005) (2004 in Lit Cited). Post-release 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 using bait with those caught using artificial flies or lures, and 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 exacerbate 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 are specifically designed with the hook point oriented perpendicular to the shank, and have been shown to reduce deep hooking 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 intensely studied 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 circle hooks for rainbow trout *Oncorhynchus mykiss* caught in a southern Idaho stream. However, because their study involved inline circle (i.e., non-offset, 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 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 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 may 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 >200 millimeters (mm), a size desirable to anglers. Rivers were fished from late June to early October 2010, after spring high flows had receded and angling could be effectively conducted. Streams ranged from 10-50 m wide, 800-2,100 m in elevation, and 0.5-2.8% in stream gradient. Trout present included rainbow trout, bull trout *Salvelinus confluentus*, brook trout *S. fontinalis*, cutthroat trout *O. clarkii*, and rainbow x cutthroat hybrids. Few brook trout and bull trout were caught and they were therefore not included in 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-pound 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 nightcrawlers. 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 seconds) by the number of strikes. Landing success rate was determined by dividing the number 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. 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 multi-way analysis of variance (ANOVA) rather than logistic regression because all independent variables were categorical. Accordingly, we 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 x 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 be as likely to be parabolic in shape as linear. We also tested for first-order interactions among all combinations of independent variables. Non-significant variables were removed from the model in a backwards stepwise manner. We used Tukey's 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 x cutthroat hybrids (6%) were also caught. The average size (± standard error) of landed fish was 309 ± 3.3 mm and ranged from 155-500 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.

Analysis of variance indicated that a number of factors influenced deep hooking rates (global model $F_{12} = 5.33$, $P < 0.001$). For example, 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 with passive fishing (24 ± 5%) than active fishing (15 ± 4%). However, the interaction term hook*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%) (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 were less likely to be deeply hooked compared to trout 250-350 mm, 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 only differed 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 prior to reporting the global model F-value. There were no other statistically significant first-order interaction terms.

Due to data recording errors by one angler, 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 ($X^2_{0.05,\ 5}$ = 13.0, P = 0.02; Table 3). Hooking success was greatest for actively fished inline J hooks (75 ± 7%) and lowest for 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 ($X^2_{0.05,\ 5}$ = 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 ($X^2_{0.05,\ 5}$ = 12.2, P = 0.03; Table 3). Capture efficiency was highest for actively 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 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 post-release 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), that showed an increase in deep hooking of rainbow trout with circle hooks fished passively rather than actively, but 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 to 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 to the other hooks may have made it inherently 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 the smallest gap width (4.1 mm) compared to 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 if 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%) compared to inline circle hooks (6%) for striped bass *Morone saxatilis*, whereas Graves and Horodysky (2008), studying white marlin *Kajikia 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. 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 bait-fishing deep hooking rates 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, thus resulting in less deep hooking.

Six anglers collected data during the study, and deep hooking rates differed among anglers with the lowest deep hooking rate and the three anglers with the highest deep hooking rates. This may be explained in part by size of fish caught by those anglers. Angler 1, whose overall deep hooking rate was 4%, caught trout that averaged 213 mm, whereas the other anglers with higher deep hooking rates caught trout that averaged 291 mm, 323 mm, and 349 mm. Because smaller trout were less likely to be hooked deeply in our study, this likely explained 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 reduced capture efficiency compared to conventional hooks. We found that capture efficiency for inline circle hooks was lower than 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, thus 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 found 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 similar or lower deep hooking rates compared to 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 evaluating 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, 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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TABLES

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

Hook type and angling method	**n**	**Mean Fish Length (mm)**		**Deep Hooking Rate**	
		Estimate	**SE**	**Estimate**	**95% CI**
Inline circle (active)	97	282	6.8	0.10	0.06
Inline circle (passive)	100	294	6.4	0.19	0.08
Inline J hook (active)	92	316	7.8	0.27	0.09
Inline J hook (passive)	99	325	7.1	0.24	0.08
Offset J hook (active)	94	313	9.1	0.09	0.06
Offset J hook (passive)	101	326	8.9	0.28	0.09

Table 2. Deep hooking rates (± 95% confidence intervals) for different length groups of trout caught with baited inline circle hooks and inline and offset J hooks.

Fish Length	Inline circle hook				Inline J hook				Offset J hook			
	Active		Passive		Active		Passive		Active		Passive	
(mm)	n	Deep hooking	n	Deep hooking	n	Deep hooking	n	Deep hooking	n	Deep hooking	n	Deep hooking
< 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

Table 3. Hooking and landing success and capture efficiency rates (± 95% confidence intervals) 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	1054	610	487	0.58 ± 0.03	0.80 ± 0.03	0.46 ± 0.08

CHAPTER 2: DEEP HOOKING AND ANGLING SUCCESS RATES WHEN BAIT FISHING FOR STREAM-DWELLING TROUT USING CIRCLE AND J HOOKS WITH AND WITHOUT TRADITIONAL HOOK SETS

ABSTRACT

We fished actively and passively using baited inline and offset circle and J hooks to evaluate deep hooking and angling success rates for stream-dwelling trout. Active fishing resulted in less deep hooking than passive fishing for each hook type (J and circle). However, deep hooking rate was not influenced by hook type, fish length, species, or hook configuration (inline vs. offset). All hooks and fishing methods had similar hooking success rates, landing success rates, and overall capture efficiencies. The hooks we tested were different from those used in previous studies on stream-dwelling trout, and unlike previous studies that have documented reduced deep hooking rates when bait angling with circle hooks for trout, these results suggests that not all circle hooks are equally effective at minimizing deep hooking rates. However, our results concur with previous studies suggesting that deep hooking is reduced for circle hooks fished actively compared to passively.

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INTRODUCTION

The use of circle hooks when bait fishing has increased in the last decade because circle hooks have usually been shown to decrease deep hooking rates compared to more conventional terminal tackle such as J hooks (reviewed in Cooke and Suski 2004). Circle hooks are designed with the point oriented perpendicular to the hook shank, which may allow the hook to slide past critical structures such as the esophagus and gills before pivoting when exiting the mouth, where it often becomes embedded in the jaw. While most studies show a benefit when using circle hooks, their effectiveness may be dependent on a number of factors, including hook set method (i.e., active vs. passive), hook configuration (e.g., hook size, inline vs. offset shanks), and the species and size of fish being caught (Cooke *et al*. 2003a, 2003b, 2005; Prince et al. 2002; Sullivan et al. in press).

To date, most research on circle hooks has been conducted in marine environments, with few studies focusing on circle hook use when bait fishing for trout in lotic freshwater systems. Recently, Meyer and High (2010) documented that circle hook use resulted in significantly less deep hooking and angling related mortality compared to J hooks when bait fishing for trout in an Idaho stream. In a follow-up study, Sullivan et al. (in press) tested similar hooks and found angling method also influenced deep hooking rates, with active fishing resulting in less deep hooking than passive fishing, especially with circle hooks. Those studies suggest circle hooks can be beneficial, but their conclusions should be considered preliminary until further research can be conducted. One aspect these studies have failed to address is the influence of inline and offset hook shanks on deep hooking rates, as offset hooks have been shown to affect catch, injury, and mortality rates in other species (Swimmer et al. 2010; Epperly et al. 2012; Rice et al. 2012). Additionally, the same circle hook was tested by Meyer and High (2010) and Sullivan et al. (in press), and testing other circle hook designs is necessary to better understand their function. In an attempt to determine whether other circle hooks would perform as well as the hooks used in earlier studies, we chose a circle hook design that more closely matched a J hook (relative to overall size and dimensions), except the circle hook point was still oriented nearly perpendicular to the shank. Our primary objective was to test a circle hook design that had not been previously studied to gain a better understanding of the characteristics of circle hooks that make them effective at minimizing deep hooking.

For most bait anglers, the traditional hook set technique involves a sharp, quick lifting of the rod when a strike is detected (hereafter called “active fishing”). In contrast, it is assumed that when a strike is detected when fishing with circle hooks, anglers should lift the rod gently while slowly reeling line and applying constant pressure (hereafter called “passive fishing”); otherwise the hook will not capture the fish, or will be more likely to deep hook fish (Montrey 1999; ASMFC 2003; Cooke and Suski 2004). However, comparisons of these two different fishing styles have rarely been evaluated with circle hooks in freshwater. Preliminary evidence for circle hooks used to catch stream-dwelling trout suggests that active fishing (i.e., setting the hook) actually results in less deep hooking (Meyer and High 2010; Sullivan et al. in press). If this is indeed true for stream-dwelling trout fisheries, anglers are being misled by manufacturers and conservation advocacy groups about the most effective way to fish circle hooks to minimize deep hooking rates. Therefore, our secondary objective was to determine if deep hooking rates differed when actively or passively fishing circle hooks.

METHODS

Angling was conducted on the Big Lost and East Fork Big Lost rivers, Big Elk Creek, and Palisades Creek. These locations were selected because bait angling was legal, trout densities were high, and there was an abundance of trout >200 mm. Anglers fished from late July through early September after spring high flows had receded and angling could be effectively conducted. Streams ranged from 5-20 meters (m) wide, 1,790 to 2,316 m in elevation, and 0.6-3.0% in stream gradient. Trout present included rainbow trout *Oncorhynchus mykiss*, brook trout *Salvelinus fontinalis*, cutthroat trout *O. clarkia*, and rainbow x cutthroat hybrids. Additionally, a large number of hatchery rainbow trout, stocked at catchable size (i.e., approximately 250 mm total length), were present in the East Fork Big Lost River.

Six anglers fished from shore or waded into the stream to cast to trout holding areas with standardized fishing rods, reels, and lines. Anglers used inline and offset circle hooks (Gamakatsu® octopus circle size 8) and inline and offset J hooks (Gamakatsu® octopus size 6), all barbed and baited with nightcrawlers. Size 8 circle hooks and size 6 J hooks were selected to best match hook gaps (6.5 mm for circle and 7.2 mm for J) and hook width (9.5 mm for circle and 9.0 mm for J) between the two hooks (Figure 1). All hooks purchased were manufactured with ~4° offset; therefore hooks were bent to an inline (i.e., zero offset) orientation prior to fishing inline hooks.

Anglers fished each hook actively and passively. Anglers alternated hook type and angling method to ensure they caught similar numbers of fish with each hook type/angling method combination. The number of strikes and number of successfully hooked and landed fish were recorded for each hook type and angling method to determine hooking and landing success rates and capture efficiency. Landed fish were identified to species, measured to the nearest millimeter (total length), and assigned a hook location of esophagus, gills, upper jaw or mouth, lower jaw or mouth, or foul hooked (any location outside the mouth). Deep hooking was characterized as hooks that were embedded in the esophagus or gill arches. Trout that were not landed due to line breakage were not included in these analyses.

Deep hooking rates were determined for each hook type and angling method by dividing the number of deeply hooked fish by the total number of landed fish. Hooking success rate was determined by dividing the number of hook-ups (i.e., the fish was on the line for at least 1-2 seconds) by the number of strikes. The landing success rate was calculated by dividing the number of fish landed by the number of successfully hooked fish. We calculated capture efficiency by multiplying the hooking percentage by the landing percentage.

We used analysis of variance (ANOVA) to test the relationship between deep hooking of wild trout and the following five variables: species (brook trout, rainbow trout, cutthroat trout, and rainbow x cutthroat hybrid trout), fish length (<250 mm, 250-350 mm, and >350 mm), hook type (inline circle hook, inline J hook, offset circle 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 of the likelihood that the relationship between fish length and deep hooking would be parabolic in shape. We also tested for first-order interactions between all variables, though none were significant. We used Duncan's post-hoc tests to assess differences within groups. The ANOVA was performed with SAS statistical software (SAS 2009) at $\alpha = 0.10$. We used contingency tables (at $\alpha = 0.10$, computed by hand) to test for differences in hooking and landing success rates and overall capture efficiency. For reporting purposes, we also calculated 90% confidence intervals (CIs) around all proportions.

RESULTS

A total of 747 trout were caught by anglers during the study. Nearly half of the trout landed were wild rainbow trout (45.0%), but cutthroat trout (24.6%), hatchery rainbow trout (16.3%), brook trout (9.8%), and rainbow x cutthroat trout hybrids (4.3%) were also caught. The average size (± standard error) of landed fish was 283.4 ± 2.4 mm and ranged from 130-520 mm. Landed fish were hooked in the mouth or jaw most frequently (72.7%), but deep hooking occurred 27.3% of the time. Foul hooking was infrequent and accounted for less than 1% of the landed fish. Mean deep hooking rates for all hook types combined were higher for hatchery rainbow trout (40.9 ± 7.1%) than wild trout (24.6 ± 3.0%); for this reason hatchery trout were not included in our analyses.

Wild trout deep hooking rates for individual hook type/angling method combinations ranged from 13.3% for inline circle hooks fished actively to 32.2% for offset J hooks fished passively (Table 4). Analysis of variance indicated that only two factors influenced deep hooking rates for wild trout (F_{14} = 2.20, P = 0.007). Deep hooking rates were influenced by fishing method (F_1 = 8.67, P = 0.003), with less deep hooking occurring when actively fishing (19.5% for all hooks combined) than when passively fishing (29.6% for all hooks combined). In fact, active fishing resulted in lower deep hooking rates than passive fishing for all four hook types. Individual anglers also influenced deep hooking rates (F_5 = 2.13, P = 0.060), and post-hoc analysis showed anglers 1 and 6 had significantly different deep hooking rates (16.4% vs. 31.9%). Species (F_3 = 2.07, P = 0.103), fish length (F_2 = 1.79, P = 0.168), and hook type (F_3 = 0.53, P = 0.659) did not influence deep hooking rates in this study.

Hooking success rates did not differ between the eight hook type and angling method combinations ($X^2_{0.05,\ 7}$ = 1.49, P = 0.983), nor did landing success rates ($X^2_{0.05,\ 7}$ = 9.77, P = 0.202), or overall capture efficiency ($X^2_{0.05,\ 7}$ = 2.43, P = 0.932). Hooking success rates ranged from 64.0-70.0%, landing success rates ranged from 76.5-90.6%, and overall capture efficiency ranged from 53.0-62.3% (Table 4).

DISCUSSION

In this study, the use of inline and offset circle hooks to bait fish for stream-dwelling trout resulted on average in 9% and 23% less deep hooking than using J hooks, but these differences were not statistically significant. This lack of difference contrasts previous results on bait fishing for stream-dwelling trout. For example, Meyer and High (2010) found deep hooking rates for baited J hooks was 21%, compared to only 4% for baited circle hooks, and Sullivan et al. (in press) found actively fished inline circle hooks produced deep hooking rates of 10% compared to 27% for inline J hooks fished in the same manner. The discrepancy in our results compared to the earlier findings is likely due to differences in hook configurations between studies (Figure 1). Both hooks in our current study were octopus style, which were configured so that the point shank was angled back about 18° toward the hook shank. The only difference between our circle and J hooks was that the point of the circle hook turned back nearly perpendicular to the hook shank. In contrast, the circle hooks used by Meyer and High (2010) and Sullivan et al. (in press) were designed so that the point shank was angled about 25° back toward the hook shank, whereas the point shank and hook shank were parallel for the J hooks. It, therefore, appears that having the hook point turned back perpendicular to the hook shank is not enough by itself to cause a reduction in deep hooking for circle hooks. Rather, the turned-back hook point in combination with the additional turn-back of the entire point shank appears necessary for circle hooks to significantly reduce deep hooking. How much of an angle inward needed is unknown, but it appears that the optimal angle is at least 25° for stream-dwelling trout. In reality, it is probably not the angle of turn-back in the point shank, but rather the relationship between the resulting hook gap and width, and the size and species of fish being captured that determines how effective circle hooks are at reducing deep hooking.

Developing a definitive circle hook definition has been a topic of interest among many researchers, anglers, and regulatory agencies (Smith 2006), and new criteria was recently proposed by Geir Sivertzen to act as a guideline for defining circle hooks (Serafy 2012). When we measured the circle hooks in our study and compared them to Sivertzen's standards, we found our hooks did not satisfy any of the recommended criteria. He suggested a 90° minimum angle of the point to the shank (our hooks were about 85°), a 20° minimum angle of the front length of the hook bend back toward the shank (our hooks were about 18°), and the front length of the hook should be 70-80% of the hook's total length (our hooks were about 50%; Figure 1). In contrast, the circle hooks used by Meyer and High (2010) and Sullivan et al. (in press) conformed to two of the three guidelines proposed by Sivertzen (90° angle point to shank and 25° angle of front shank), and this could explain the lower deep hooking rates reported in those studies. However, both of the hooks used are advertised as "circle hooks" which makes it difficult for anglers and fishery managers to determine which hooks to use and promote to reduce deep hooking. Furthermore, the fact that circle hooks which do not conform to all of the criteria proposed by Sivertzen have been shown to reduce deep hooking for stream-dwelling trout (e.g., Meyer and High 2010; Sullivan et al. in press) suggests that these criteria may need to be modified at least for some species in some inland freshwater fisheries.

Our results suggest that fishing method can influence deep hooking rates when bait fishing for stream-dwelling trout. All of the hook types we tested produced the lowest deep hooking rates when they were actively fished, corroborating previous work (Meyer and High 2010; Sullivan et al. in press) but contradicting manufacturers' recommendations (see Montrey 1999; ASMFC 2003; Cooke and Suski 2004) and conventional wisdom regarding circle hooks. Cooke and Suski (2004) noted that "the use of circle hooks also apparently requires a change in angler hook-set behavior," meaning that anglers must avoid the conventional method of quickly setting the hook when a fish strikes. Our current and previous results suggest that, for stream-dwelling trout, the exact opposite is true. Instead of the current recommendations, manufacturers and fishery managers should encourage anglers to actively set the hook when bait fishing for stream-dwelling trout in order to reduce deep hooking, regardless of whether they are using J hooks or circle hooks.

That deep hooking rates varied among the six anglers that participated in the study is not surprising and could be attributed to subtle differences in angling methods and skill. From an experimental perspective, it would be more logical (though logistically less feasible) to have a single angler conduct all of the fishing to minimize variation in fishing methods and better test the effects of hooks and fishing methods on deep hooking rates. However, from a management perspective, to see these trends emerge from a pool of anglers provides a more thorough understanding of how these hooks would perform when used by the general public. The lack of significant interaction between angler and the other variables in our modeling results infers that our analyses were unhindered by the variation in deep hooking among anglers.

We compared inline and offset hooks to evaluate whether deep hooking rates would differ for each hook type, and our results suggest the average increase of 16% in deep hooking rate for offset compared to inline hooks for each hook type and angling method was not statistically different. Those studies that have documented higher deep hooking rates for offset hooks have typically used severely offset hooks of 10° or more (Hand 2001; Malchoff et al. 2002; Prince et al. 2002), whereas in our study the degree of offset was only 4°, and this could explain the lack of difference in deep hooking rates between inline and offset hooks. Sullivan et al. (in press) showed more deep hooking for inline J hooks compared to offset J hooks when fishing for trout in streams, but they attributed this effect to differences in hook gap widths and swallow diameters, not the inline or offset nature of the hooks. Cooke and Suski (2004) suggest minimally offset hooks (i.e., <5°) perform nearly the same as inline hooks, and the results from our study support this.

It was interesting that the hatchery rainbow trout (stocked at catchable size) caught during this study were deeply hooked nearly twice as often as wild trout. One explanation is there are differences in feeding behavior, and that hatchery trout may have been conditioned by pellet feeding in hatcheries to ingest food more quickly and deeply than wild trout, thus promoting more deep hooking. Indeed, hatchery trout have been shown to exhibit "scrambling behavior" (Marnell 1986), and act more aggressively than wild trout (Bachman 1984; Mesa 1991). There was little difference in the average length of hatchery (280.3 mm) and wild (283.4 mm) trout, so differences in fish length did not contribute to the observed differences in deep hooking rates. Because our results showed higher deep hooking rates for passive fishing than active fishing, one might assume that a higher percentage of hatchery rainbow trout were caught by passive fishing, thereby resulting in more deep hooking, but the opposite was actually true (55% caught actively vs. 45% caught passively). Although the high incidence of deep hooking for hatchery trout was an interesting result, it is worth noting that special regulation waters for trout such as catch-and-release fisheries usually attempt to increase survival of wild trout, not hatchery trout, so this difference may be less relevant.

We evaluated hooking and landing success rates and overall capture efficiency because little is known about the effectiveness of circle hooks compared to J hooks at capturing trout in lotic systems. Sullivan et al. (in press) found capture efficiency was lower for inline circle hooks (average of 53% for active and passive) compared to inline J hooks (average of 70% for active and passive) when bait fishing for stream-dwelling trout, but deep hooking rates were also lower for inline circle hooks than inline J hooks in their study. Studies conducted in marine environments to evaluate capture efficiency are more numerous, but it is not clear whether J hooks or circle hooks are superior at hooking and landing fish (Cooke and Suski 2004) and outcomes may be species dependent (Prince et al. 2002). We found that the four hook types we tested had similar hooking rates, landing rates, and capture efficiencies that did not change with active or passive fishing methods, and unlike the study by Sullivan et al. (in press), deep hooking rates were not different among the four hook types. It is possible that the similar performance of the hooks could be explained by the similarity in dimensions, but regardless of the explanation, it is encouraging that anglers could use these circle hooks in an active or passive manner and not suffer reduced catch rates. However, these results combined with those of Meyer and High (2010) and Sullivan et al. (in press) suggest that to achieve the lowest possible deep hooking rates, anglers may need to use circle hook designs that have lower capture efficiencies.

In summary, results from this study and previous work suggest that when bait fishing for stream-dwelling trout, actively setting the hook has consistently resulted in less deep hooking using circle hooks or J hooks, regardless of hook design. Management agencies and hook manufacturers must realize that these results conflict with conventional wisdom and current recommendations. These results should be confirmed in other settings with different species and using different circle hook designs with varying hook gaps and hook widths. Moreover, circle hooks that maximize the difference between hook gap and hook width are likely to maximize the reduction in deep hooking compared to J hooks, but this will also likely result in slightly less hooking success.

RECOMMENDATIONS

1. Work to inform hook manufacturers, outdoor media, and fisheries managers that circle hooks should be fished actively to reduce deep hooking when bait fishing for stream-dwelling trout.

2. Consider conducting similar research in lentic environments such as Henrys Lake or special regulation waters that currently restrict bait fishing (i.e., trophy waters) to evaluate if the same benefits can be attained in these habitats.

3. Consider the need for continued research using different circle hook designs that maximize the difference between hook gap and width in an effort to determine ideal circle hook characteristics for trout bait fishing in streams.

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TABLES

Table 4. Rates of deep hooking, hooking success, landing success (± 90% confidence intervals), and capture efficiency for each hook type/angling method combination from trout caught with bait during 2011.

Hook Type/Angling Method	# Landed	Deep Hooking Rate	Hooking Success Rate	Landing Success Rate	Capture Efficiency
Inline circle-active	45	0.13 ± 0.07	0.66 ± 0.10	0.80 ± 0.11	0.53
Inline circle-passive	65	0.25 ± 0.09	0.70 ± 0.08	0.77 ± 0.09	0.54
Offset circle hook-active	96	0.19 ± 0.06	0.69 ± 0.07	0.91 ± 0.06	0.62
Offset circle hook-passive	80	0.31 ± 0.08	0.69 ± 0.08	0.78 ± 0.08	0.54
Inline J hook-active	87	0.23 ± 0.08	0.65 ± 0.08	0.84 ± 0.07	0.54
Inline J hook-passive	87	0.29 ± 0.08	0.66 ± 0.08	0.85 ± 0.07	0.57
Offset J hook-active	75	0.20 ± 0.07	0.64 ± 0.08	0.84 ± 0.08	0.54
Offset J hook-passive	90	0.32 ± 0.08	0.68 ± 0.07	0.83 ± 0.07	0.56

FIGURES

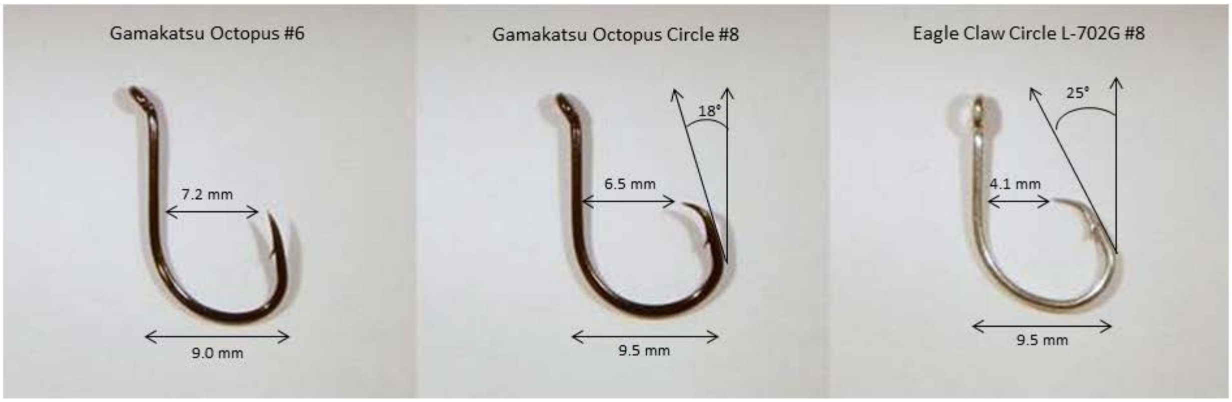

Figure 1. Gamakatsu J and circle hooks used in our current study and example of Eagle Claw circle hook used by Meyer and High (2010) and Sullivan *et al.* (in press).

CHAPTER 3: SHORT-TERM PERSISTENCE OF CATCHABLE-SIZED HATCHERY RAINBOW TROUT RELEASED IN STREAMS

ABSTRACT

Triploid hatchery rainbow trout of catchable-size (i.e., trout ≥200 mm total length (TL); hereafter catchables) were stocked in several streams in Idaho to assess the relationship between time passed and their persistence during the first month post-stocking. Catchable abundance within the reach where they were stocked declined over time in a statistically significant, negative-logarithmic manner (r^2 = 0.79), with abundance reduced to 50%, 25%, and 10% of their initial stocking abundance in 4.1, 15.6, and 34.9 days, respectively. Roughly 33% of all catchables that were captured in either the marking or recapture run had moved out of the stocking reach (but less than 200 meters) within the first 5 days after stocking, and 72% of the movement occurred in a downstream direction. That catchables incur a 50% reduction in abundance due to mortality and emigration after only 4 days post-stocking suggests stocking should occur within a few days of expected angler effort in order to maximize return-to-creel rates.

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INTRODUCTION

Hatchery trout are an important and expensive component of many states' fisheries management programs. For example, 1.8 million catchable-sized hatchery trout (i.e., trout ≥200 mm total length (TL); hereafter referred to as catchables) were stocked in 2009 into more than 300 Idaho waters to improve angling catch rates, at a cost of $1.2 million. Indeed, catchable stocking can provide an immediate increase in catch rates in lakes or rivers that cannot support a robust trout fishery or cannot sustain harvest rates desired by the angling public (Baer et al. 2007). However, because of the high cost associated with raising and stocking catchable trout, it is important to maximize return-to-creel rates for catchables.

It is well known that hatchery trout are not as resilient as wild trout and suffer high annual mortality, especially in lotic systems (e.g., Miller 1951; Heimer et al 1985; Dillon et al. 2000). For example, Bettinger and Bettoli (2002) found that catchable rainbow trout persistence was 17% in a Tennessee tailwater after 35 days, whereas High and Meyer (2009) estimated persistence of catchable rainbow trout was 15% after 30 days in an Idaho stream. Several factors have been associated with low post-release survival of hatchery trout, including poor adjustment to natural foraging behavior and predator avoidance (Suboski and Templeton 1989), stress from transport and stocking (Miller 1958), and habitat constraints such as high flows, low oxygen, high water temperatures, or dense vegetation (Wiley et al. 1993).

Unfortunately, the majority of studies conducted on the survival of catchables have focused on estimating survival after a particular interval of time had passed, such as several weeks, several months, or one year. To our knowledge, none have attempted to define the mathematical relationship between time passed and persistence of stocked catchables. Knowing the rate at which stocked catchables die in streams or leave the area where they are stocked is important for managers wishing to maximize return-to-creel rates. For instance, it does not benefit anglers in a put-and-take fishery if the fish that are stocked die or leave the area before anglers have a chance to catch them.

The objective of this study was to evaluate the relationship between the persistence of catchables and days post-stocking during the first month after stocking. Persistence was defined as the proportion of catchables stocked in a stream reach that remained in that reach some days later, and therefore included both mortality and dispersal. Thus, while this estimate of persistence directly addressed expected residence times for catchables, at some locations we attempted to assess how much of the residence time was associated with dispersal compared to mortality.

METHODS

Between 2006 and 2011, catchable-sized rainbow trout raised at Nampa and Hagerman fish hatcheries were stocked 10 times in four different streams in southern Idaho (Table 5). Catchables were raised from all-female triploid (and therefore sterile) rainbow trout eggs purchased from Troutlodge Inc. and reared to catchable size. Study streams that were selected to receive catchables were chosen such that catchable stocking was not ongoing in the stream, and wild trout were prevalent in the study reaches (see Meyer et al. 2012 for details on wild trout). Stocking occurred from late June to late August, after peak spring streamflow had largely dissipated, except for one stocking event in 2011 (see results).

A subsample of hatchery fish throughout the study period was measured for mean length, which averaged 249 mm TL (SD = 31; range 195-300 mm); based on hatchery records, year-to-year variation in fish length at stocking was minimal. Hatchery trout were stocked at a density of about 4.2 fish/100 m^2 (range 3.2 to 5.2 fish/100 m^2), which is a common (but somewhat high) catchable stocking density used by the Idaho Department of Fish and Game (IDFG). In each stream, equal numbers of catchables were stocked at the top, middle, and bottom of each stocking reach, which on average was 614 meters in length.

Between 2 and 38 days post-stocking, catchables were sampled within the stocking reach using backpack electrofishing gear to conduct mark-recapture (M-R) population sampling. For each reach, one recapture run was made 1 day after the marking run. During the marking run, all netted catchables were marked using an adipose fin clip, and returned to their general area of capture, and during the recapture run, catchables were examined for the presence of an adipose clip. Population estimates for catchables were calculated with the Fisheries Analysis Plus program (Montana Fish, Wildlife, and Parks 2004) using the Lincoln-Petersen M-R model as modified by Chapman (1951). Persistence of catchables was determined by dividing the abundance estimates by the total number of catchables stocked in each stocking reach. Data were plotted to assess linearity, and linear and non-linear regressions were developed to ascertain what relationship best fit the data. Outliers were examined using standardized residuals, and residuals from the best model were examined for normality.

At a subsample of sites (n = 3), additional shocking was conducted several hundred meters above and below the stocking reach boundaries to estimate the proportion of catchables that had moved out of the reach. Population estimates were calculated to include the catchables that had moved out of the reach and were compared to estimates from within the stocking reach to assess how much of the reduction in abundance was likely due to dispersal.

RESULTS

Catchables declined in abundance immediately after being stocked. The best fit to the data was a negative-logarithmic relationship between days post-stocking and the proportion of stocked catchables remaining within the stocking reach (Figure 2); this relationship was statistically significant ($F_{0.05(1),\ 1,\ 8}$ = 28.7; P = 0.0007). Based on the observed relationship, catchables within the stocking reach were reduced to 50%, 25%, and 10% of their initial abundance in 4.1, 15.6, and 34.9 days, respectively. The stocking event that occurred during high flow resulted in much lower persistence of catchables post-stocking (only 14% after four days; Figure 2); this event was judged to be an outlier (standardized residual = 2.2) and was removed from the final model.

For the subsample of stocking events for which movement was monitored, an average of 56% of the reduction from the initial abundance was due to dispersal out of the reach. Of those catchables that moved out of the reach, 72% moved downstream.

DISCUSSION

The results of this study suggest that catchable-sized trout stocked in streams decline exponentially over time within the reach where they were stocked, with a 90% reduction in less than 35 days. More than one-half of this reduction was apparently the result of movement after stocking, mostly in a downstream manner, and we believe that most of the remaining reduction was probably caused by direct mortality, although observed mortalities only accounted for about 1% of all stocked fish. These conclusions concur with previous work conducted on catchable-sized trout stocked in streams. For example, in a series of studies in the 1950s, R. B. Miller reported that catchables tended to move downstream after stocking, but perished quickly due to rapid build-up of lactic acid post-stocking (see Miller 1951, 1953, 1958). He concluded that catchables died of exhaustion, partly from harassment by wild trout but largely due to naivety in holding favorable stream feeding positions. Later studies repeatedly confirmed these findings, and in general suggest that catchables disperse no more than about 1 km after being stocked in streams (Trembley 1945; Helfrich and Kendall 1982; Heimer et al. 1985; High and Meyer 2009; but see Bettinger and Bettoli 2002), and only a small portion survive more than about 30 days (Miller 1951, 1953; Walters et al. 1997; Bettinger and Bettoli 2002; High and Meyer 2009).

Despite the rapid decline of catchables in streams, return-to-creel rates for catchables stocked in Idaho streams are not negligible. In fact, in a statewide study of angler harvest of catchables stocked in Idaho streams, average harvest was 34%, with most of the harvest occurring in the first 21 days post-stocking (Dillon et al. 2000). At that point, our results suggest that only about 20% of the catchables stocked in a particular stream reach remain in that reach. While High and Meyer (2009) concluded that catchables should be stocked within 3 weeks of expected needs and within 1 km of the stream locations most heavily used by anglers, our results suggest that by then, only a fraction of the catchables initially stocked will still be available to anglers. Based on our results, we suggest that catchables should be stocked within a few days of expected angler effort in order to maximize return-to-creel rates.

RECOMMENDATIONS

1. For catchable trout stocked in streams, angler harvest may be improved by stocking within a few days of expected angler effort.

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TABLES

Table 5. Stream and stocking characteristics and mark-recapture data for streams stocked with catchable-sized hatchery rainbow trout. For mark-recapture data, M is number of fish caught and marked in marking run, C is number caught in recapture run, and R is number of marked fish caught in recapture run.

Stream	Stream width (m)	Reach length (m)	Stocking dates: Stocked	Surveyed	Days at large	Number stocked	Stocking density (fish/ $100m^2$)	Mark-recapture data M	C	R	Est	SD	Abundance remaining
Rock Creek	3.6	812	6/2/06	6/13/06	11	153	5.2	23	19	9	48.0	10.2	0.31
Rock Creek	3.6	812	6/6/07	6/19/07	13	153	5.2	31	32	25	40.6	3.6	0.27
Rock Creek	3.6	812	6/10/08	6/24/08	14	153	5.2	39	34	24	56.0	5.9	0.37
Willow Creek	4.7	461	6/12/06	6/26/06	14	69	3.2	8	9	6	12.9	2.5	0.19
Willow Creek	4.7	461	6/10/08	7/1/08	21	69	3.2	15	12	10	18.9	2.1	0.27
Second Fork of Squaw Creek	9.9	684	6/16/06	7/7/06	21	264	3.9	27	31	15	56.0	9.6	0.21
Second Fork of Squaw Creek	9.9	684	6/8/07	7/10/07	32	264	3.9	3	6	2	9.3	3.5	0.04
Second Fork of Squaw Creek	9.9	684	6/11/08	7/9/08	28	264	3.9	19	12	4	52.0	16.7	0.20
Pikes Fork of Crooked River	2.6	500	7/14/11	7/18/11	4	57	4.4	5	3	2	8.0	2.0	0.14[a]
Pikes Fork of Crooked River	2.6	500	8/9/11	8/11/11	2	57	4.4	33	33	27	41.0	3.2	0.72
Pikes Fork of Crooked River	2.6	500	9/22/11	9/27/11	5	57	4.4	17	15	15	18.0	0.0	0.32

[a]Removed from regression model as an outlier due to high flows (see text).

FIGURES

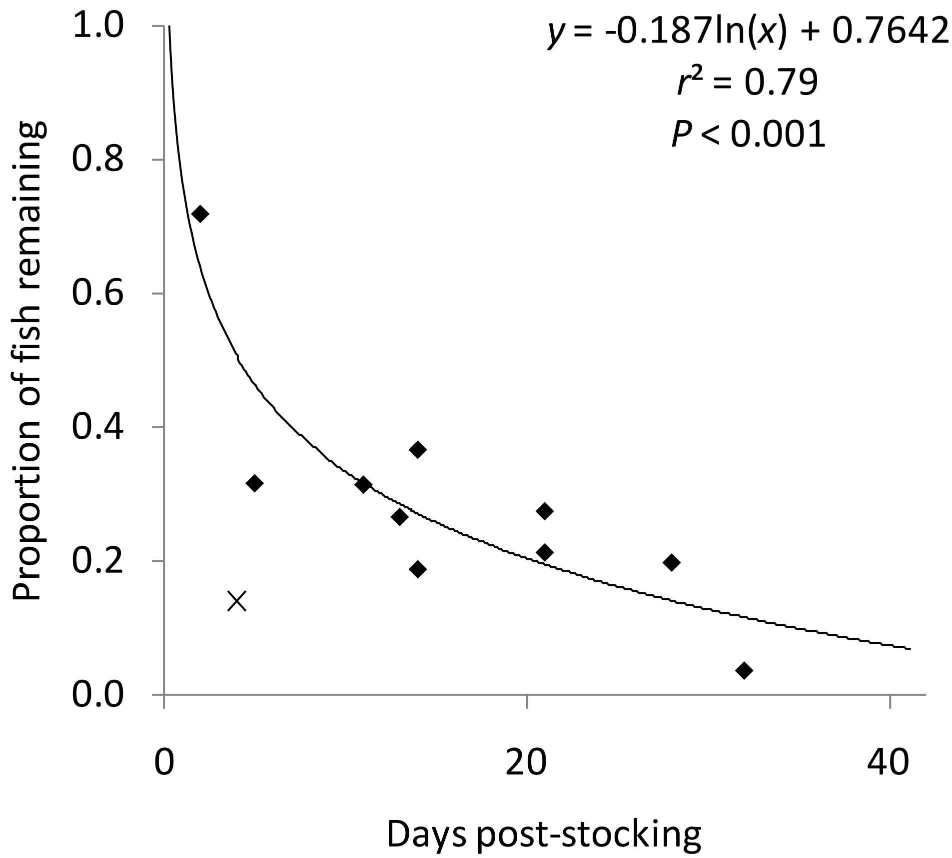

Figure 2. Relationship between days post-stocking and estimated persistence in stream reaches stocked with catchable-sized hatchery rainbow trout. The data point represented by an "x" was judged to be an outlier and was removed from the model.

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