North American Journal of Fisheries Management 24:1309–1321, 2004

The Influence of Hook Type, Angler Experience, and Fish Size on Injury Rates and the Duration of Capture in an Alaskan Catch-and-Release Rainbow Trout Fishery

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Abstract.—Owing to concerns about the high incidence of past hooking injuries in Alagnak River rainbow trout *Oncorhynchus mykiss*, fish were captured with spin- and fly-fishing gear with barbed and barbless circle and ''J'' hooks to determine gear types contributing to injury. Landing and hook removal times were measured for a portion of fish captured, and the anatomical hooking location, hooking scar locations, bleeding intensity, angler experience, and fish size were recorded for all captured fish. Approximately 62% of fish captured experienced at least one new hooking injury, and 29% of fish had at least one past hooking injury. Small fish sustained higher new injury and bleeding rates, but large fish had higher past injury rates. Injury rates were higher for barbed J hooks, barbed J hooks took longer to remove, and fish caught by spin-fishing were injured more frequently than fish caught by fly-fishing. Fewer fly-fishing-caught fish were injured using circle hooks, and circle hooks tended to hook fish in only one location, generally in the jaw. Barbed J hooks were more efficient at landing fish, and J hooks were more efficient at landing fish than circle hooks. Novice anglers injured proportionally more fish than experienced anglers, primarily during hook removal. Landing time was positively correlated with fish size, and experienced anglers took longer to land fish than novices because they captured larger fish. These results suggest that a reduction in hooking injuries may be achieved by using circle hooks as an alternative to J hooks and barbless J hooks to reduce injury and handling time, yet catch efficiency for both methods would be reduced. Although fish captured with barbless J hooks and circle hooks had fewer injuries, it is important to note that each hook type also caused significant injury, and angler education is recommended to promote proper hook removal techniques.

Recent studies have emphasized a holistic approach to evaluating the effects of catch-and-release angling on fish by evaluating both sublethal and lethal effects (Cooke et al. 2002; Stockwell et al. 2002). When fish are subjected to angling stress, they are affected by stressors that may not cause immediate mortality; in fact, some may influence ultimate survival. These stressors include physiological disruptions from landing time, handling time, and exposure to air during the hook removal process or when photographed, as well as the potentially confounding effects of nonlethal hooking injuries. Physiological stress disruptions have been demonstrated to be cumulative (Barton et al. 1986). Therefore, fish subjected to intense angling pressure that may be caught and released several times during a fishing season may be more vulnerable to disease, parasites, and predators (Snieszko 1974; Esch et al. 1975; Wydoski 1977), and incur a greater chance of being lethally injured. Fisheries managers and scientists face challenges when evaluating these effects on wild fish populations because of the logistics of conducting fieldwork in remote locations, associated effects of holding fish for observation after capture, possible unobserved delayed mortality, and uncertainty in relating the results from research conducted in hatcheries or laboratories to the equivalent response in wild fish. Further challenges lie in choosing appropriate measures of angling stress on fish in addition to immediate mortality, and interpreting study results to population-level effects.

A study of Alagnak River rainbow trout *Oncorhynchus mykiss* in 1997–1998 revealed over 40% of trout caught in the watershed to have at least one distinctive scar, most likely from a previous hooking (J. M. Meka, unpublished data). The Alagnak National Wild River, located within Katmai National Park and Preserve in southwest Alaska, supports natural, self-reproducing populations of rainbow trout and is one of the most heavily used trout sport fisheries in southwest Alaska. Sportfishing on the Alagnak River has increased greatly since the early 1980s, prompting the adoption of emergency catch-and-release fishing regulations for rainbow trout in 1996 that were permanently adopted in 1998 (Meka et al. 2003). Nu-

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Received June 11, 2003; accepted March 8, 2004

merous cases of angler dissatisfaction due to Alagnak River rainbow trout deformities or scars purportedly resulting from repeated hooking by anglers have been reported, as well as complaints that rainbow trout abundance and size have declined (Meka et al. 2003).

Injured fish may be at greater risk for secondary parasitic, bacterial, or fungal infections, and certain injuries may influence feeding habits or survival (Wright 1972; Chipeniuk 1997). Numerous studies of the effects of hooking injuries on mortality indicate the anatomical hooking location with associated bleeding to be the most important factor influencing initial mortality of angler-caught fish (e.g., Falk et al. 1974; Warner 1976; Loftus et al. 1988; Nuhfer and Alexander 1992). Studies evaluating the influence of barbed or barbless hooks on hooking injury and mortality have produced variable results (Falk et al. 1974; Dotson 1982; Mongillo 1984; Barnhart 1990; Muoneke and Childress 1994; Schill and Scarpella 1997). A few recent studies have focused on the impacts of angler experience on the duration of the angling process and associated hooking injuries (Dunmall et al. 2001), and whether the use of circle hooks in freshwater fisheries could serve as a conservation tool by reducing the severity of hooking injuries (Cooke et al. 2003b, 2003c; Jenkins 2003). To my knowledge, these effects have not been evaluated for wild rainbow trout in an Alaskan catch-and-release fishery. Research on the angling factors that influence hooking injuries and duration of capture (by recognizing methods that reduce the severity of injury and handling times) may provide information useful in evaluating ways to reduce angling mortality (Wright 1972) and sublethal effects.

The primary objective of this study was to determine whether fish size, fishing method (fly or spin), terminal gear (barbed and barbless circle and conventional J hooks), and angler experience influence hooking injury rates and the duration of capture (landing and hook removal times) in angled Alagnak River rainbow trout. For fly-fishing, circle hooks were chosen for comparison purposes to J hooks because it has been suggested they provide lower injury and mortality rates than other conventional hook types (Montrey 1999; Strange 1999; Cooke et al. 2002; Cooke et al. 2003a). Circle hooks also have been gaining popularity for use with artificial flies when fishing for salmonid species. A secondary objective was to compare hooking efficiency between J and circle hooks and between barbed and barbless hooks. When assessing hooking injuries in this study, no fish were held after capture for observation, as holding fish can bias hooking mortality estimates by confounding stress effects from confinement and associated handling, which may decrease the survival potential and condition of the confined fish after release (Wright 1972; Cooke and Hogle 2000).

Methods

Field study.—Rainbow trout were captured by hook and line at Nonvianuk Lake outlet and the main-stem Alagnak River between June and August 2000 and 2001 and at the outlets of Nonvianuk and Kukaklek lakes in June 2002 (Figure 1). Most of the fishing effort took place at the lake outlets and in braided reaches of the Alagnak River main stem, where the trout sport fishery is concentrated. The daily decision of where to fish mainly depended on where the fishing was most successful the previous day, reflecting common strategies used by area anglers and guides. Anglers consisted of fishery biologists and technicians with the U.S. Geological Survey and National Park Service, Student Conservation Association volunteers, as well as other governmental and nongovernmental volunteers. Angler experience varied greatly, from novice (first time fishing) to experienced anglers (typically fish over 100 d/year). Each angler completed a survey designed to categorize anglers into a specific level of expertise. Categories included novice (fished fewer than 10 times over their lifetime) and experienced (fished more than 10 d/year). Novice anglers were given informal fishing lessons and were guided on proper handling and hook removal techniques prior to fishing.

Both spin- and fly-fishing methods were used to capture fish so as to reflect true angling conditions for rainbow trout on the Alagnak River. Artificial flies and lures were used as terminal gear. Barbed and barbless J hooks were tested for both spin- and fly-fishing, but barbed and barbless circle hooks were used for fly-fishing only. Circle hooks were not used for spin-fishing because the rainbow trout sport fishery only allows artificial flies and lures; circle hooks are typically used with bait when spin-fishing (e.g., Cooke et al. 2003a). Hooks were made barbless by crimping the barb down with pliers on circle and J hooks. Size 8 J hooks were used for spin- and fly-fishing, size 8 circle hooks (Eagle Claw; Model NT2050) were used in 2000 and 2001, and size 6 circle hooks (Gamakatsu Octopus Circle; Model 20841) were used in 2002. Hook sizes were determined by measuring the hook against a hook gap-measuring

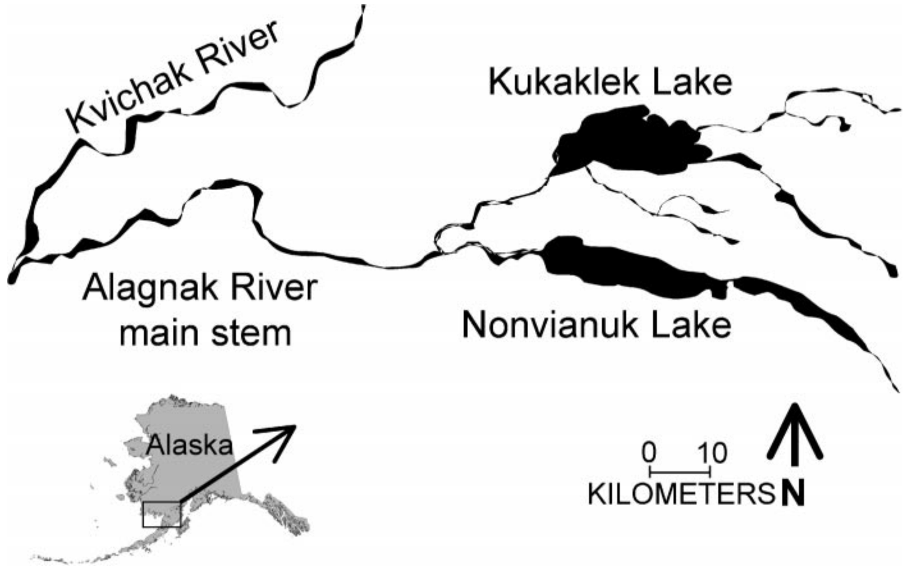

FIGURE 1.—Map of the Alagnak River watershed in southwest Alaska. Rainbow trout were captured by hook and line in 2000–2002 on the Alagnak River main stem and at the outlets of Kukaklek and Nonvianuk lakes.

gauge, because gap size can vary slightly among hook manufacturers. Six methods of fishing were categorized: (1) spin barbed J hook; (2) spin barbless J hook; (3) fly barbed J hook; (4) fly barbless J hook; (5) fly barbed circle hook; and (6) fly barbless circle hook. Anglers were randomly assigned a fishing method twice daily; the fishing method was either the same or different. Anglers chose their own lures and flies each day according to fishing method assigned and based on the advice of local guides and anglers. The number of anglers participating in the study varied each sampling trip; in general, three to seven anglers fished simultaneously at each fishing location each day. Anglers ceased fishing once a fish was hooked and until the sampling procedure was completed, therefore maintaining similar fishing effort.

Times (minutes and seconds) to land fish and handle fish while removing the hook were recorded for a portion of the fish captured. Every angler participating in the study was given a timer to record landing and handling times. The angler or biologist with the first recorded time as soon as a fish was hooked continued to take timed data for the duration of the sampling procedure. In general, fish were landed when they could be netted without difficulty and were never played to exhaustion. Anglers were advised to land fish as they normally would while fishing recreationally, thus landing times varied for each angler. Landing time started when a fish was initially hooked. Once a fish was netted (by another angler), landing time stopped and handling time for hook removal began. Handling time stopped when the angler removed the hook. Anglers were advised to keep fish under water during the entire hook removal process to avoid confounding effects of air exposure (Bouck and Ball 1966; Ferguson and Tufts 1992).

Fishing method (fly or spin), hook shape (J or circle), hook type (barbed or barbless), and lure or fly type were recorded for all captured fish. The initial location of hook penetration (i.e., hook location) was recorded and the angler who caught the fish removed the hook. Once the hook was removed, fish length (mm) and weight (g) were measured either in the net while submerged in water or in a sampling tub. Fish were examined for bleeding from the hook wound or flowing from the gills and recorded as either present or absent (Cooke et al. 2003c). Each fish's mouth was thoroughly examined for any past or present injuries thought to be due to capture by angling, and injury locations were recorded. Past hooking scars were defined as healed wounds obviously due to previous capture by angling and present wounds were defined as those that occurred during this study's angling or hook removal. New hooking injuries included those beyond simple puncture wounds that caused significant tissue damage that would result in scarring, may interfere with anatomical function, or have punctured or caused damage to the eye, esophagus, gills, or tongue were all noted.

All injuries were grouped into one of two categories for a portion of the data analysis, since fish with injuries to certain locations, such as the eye, esophagus, gills, and tongue, suffer the highest mortality rates (Stringer 1967; Hunsacker et al. 1970; Falk et al. 1974; Warner 1979; Siewert and Cave 1990). These categories were defined as sensitive (eye, esophagus, gills, tongue) and nonsensitive (foul, operculum, gular region, upper and lower jaw, snout, roof of mouth; modified from Loftus et al. 1988). Although the initial hooking location was recorded, data analyses focused on new hooking injuries noted after hook removal because new injuries can be missed if only recording the initial hooking location. For example, rainbow trout typically jump out of the water multiple times when hooked or become tangled in the net once landed. These conditions may cause hook points to penetrate more than one location during capture, and anglers may overlook injuries that occurred during this process if only recording the initial hooking location. If fish were caught with more than one hook-point penetration, or injured in more than one location, injury locations were recorded for data analysis as (1) sensitive if fish were injured in both nonsensitive and sensitive areas and (2) nonsensitive if fish sustained more than one injury in nonsensitive areas. All fish were released near the area of capture. Fish hooked but not landed were described as lost, and fishing method, hook shape, and hook type were recorded.

The Nonvianuk Lake outlet was seined prior to the fishing season in June 2001 to estimate past hooking injuries on rainbow trout not angled in this study. After capture, fish were placed into sampling tubs filled with freshwater and measured for fish length (mm) and weight (g) and examined for past hooking injuries. These data were used to compare past injuries with those fish caught by hook and line at the lake outlet in 2001.

Statistics and data analysis.—Logistic regression analysis using SAS software (SAS Institute 1999) determined which main-effects variables significantly influenced injury location (i.e., sensitive or nonsensitive), the number of hook-point penetrations per capture, frequency of new hooking injuries, and frequency of bleeding. Independent variables included the effect of fish size (independent logistic regressions) and fishing method, hook shape, and hook type (multiple logistic regressions with stepwise selection). The influence of angler experience on the frequency of new hooking injuries, the influence of fish size on prevalence of past hooking injuries, and the influence of injury location on the frequency of bleeding were evaluated using independent logistic regression models. The influences of angler experience and fish length on landing time were evaluated independently using linear regression (length) or a two-sample *t*-test (experience) and then combined using the analysis of variance (ANOVA) general linear model (GLM) procedure (Minitab 2000). Differences in hook removal time among fishing methods, hook shape, hook type, angler experience, initial hook location, and fish length were compared using the GLM procedure. Hook removal time, landing time, and length were transformed to logarithmic values to correct for nonnormality of the data. Fish length was used as a continuous variable in the linear regression or ANOVA, and was divided into two categories (small, $<$440 mm; large, $>$440 mm FL) for interpretation purposes in logistic regressions; the division was based on large fish being the most sought after in the sport fishery. Catch efficiency, or the catch–loss rate, was estimated as the ratio of fish lost to the total number of fish hooked (landed and lost combined; Barnhart 1990). Catch efficiency was evaluated using logistic regressions to determine whether the numbers of fish caught and lost were independent of fishing method, hook shape, and hook type. All statistical tests were considered significant at $P \leq 0.05$. Significance levels reported in Results are for logistic regression tests, unless stated otherwise. All three years of data were combined for analysis because methods remained constant throughout the study.

Results

A total of 666 rainbow trout (length = 352.25 ± 7.60 mm [mean ± SE]) were captured by angling. Of these, 306 fish were caught fly-fishing with J hooks, 293 were caught spin-fishing with J hooks, and 67 were caught fly-fishing with circle hooks (Table 1). The majority of fish captured using J hooks were hooked in the upper or lower jaw (73.5%), followed by sensitive areas (10.5% eye; 7% esophagus, tongue, gills) and other nonsensitive areas (9%). Fish captured using circle hooks were hooked primarily in the upper or lower jaw (86%), followed by other nonsensitive areas (9%). The absolute location of hook penetration was undetectable in approximately 3% (n = 22/666) of the fish and these fish were not included in any data analysis.

Sixty-two percent (n = 416/666) of the fish caught during this study were either given puncture wounds in sensitive areas, obtained a wound

TABLE 1.—Number of Alagnak River rainbow trout caught by angling or lost (hooked but not landed) during the reeling-in process and fish that received hook injuries during capture. Fish were captured using six types of gear: fly-fishing with barbed or barbless J hooks, spin-fishing with barbed or barbless J hooks, and fly-fishing with barbed or barbless circle hooks. The six types of gear were combined for the angler experience analysis. Novice anglers were defined as individuals who fished less than 10 d over their lifetime, experienced anglers as those who fished more than 10 d per year.

Fishing type and hook	Number of fish			Percent injured	Fish lost	
	Hooked	Caught	Injured		Number	Percent
Fly-fishing						
Barbed J hook	275	187	122	65	88	32
Barbless J hook	203	119	65	55	84	41
Total	478	306	187	61	172	36
Spin-fishing						
Barbed J hook	242	138	108	78	104	43
Barbless J hook	341	155	89	57	186	55
Total	583	293	197	67	290	50
Fly-fishing						
Barbed circle hook	62	37	17	46	25	40
Barbless circle hook	67	30	15	50	37	55
Total	129	67	32	48	62	48
Angler experience						
Novice		73	56	77		
Experienced		592	359	61		
Total		665	415	62		
Overall total	1,190	666	416	62	524	44

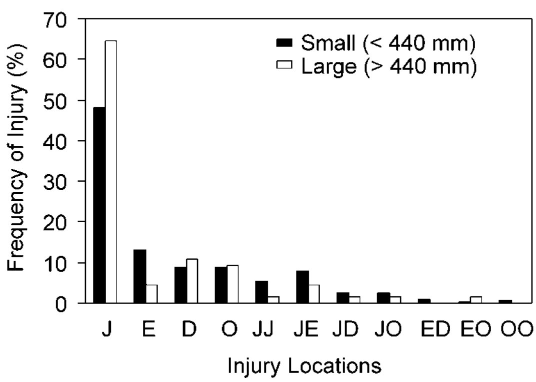

FIGURE 2.—Frequency of new hooking injuries in small and large rainbow trout captured by hook and line in the Alagnak River watershed. New injuries were defined as injuries beyond simple puncture wounds that caused tissue damage that would result in scarring or might interfere with anatomical function as well as any wound puncturing or causing damage to the eye, esophagus, gills, or tongue. The graph denotes sensitive injury locations as the eye (E) and deep (D; esophagus, gills, and tongue) categories and nonsensitive injuries as the jaw (J) and other (O; e.g., snout, gular, and operculum) categories. Injury locations with two letters refer to fish injured in more than one location from two hook-point penetrations during capture.

that would most likely result in scarring from torn tissue, obtained a wound that interfered with anatomical function, or obtained a combination of injuries (Figure 2). Of injured fish, 67% (n = 280/416) sustained nonsensitive injuries and 33% (n = 136/416) sustained injuries to sensitive areas. The majority of injuries in fish caught using J hooks were in the upper or lower jaw (61%), followed by injuries to sensitive areas (17% eye; 11% esophagus, gills, or tongue). Fishing method and whether J or circle hooks were barbed or barbless did not influence the location of new injuries (i.e., sensitive or nonsensitive areas; $P > 0.05$); however, some of these factors contributed to the frequency of new injuries. For example, fishing method and whether J hooks were barbed ($P = 0.0334$) or barbless ($P = 0.0002$) significantly influenced new overall injury rates (Table 1). Fish caught by spin-fishing had similar injury rates as those caught by fly-fishing (spin, 67% injured, n = 197/293; fly, 61% injured, n = 187/306); thus, significance was from higher injury rates with barbed hooks for both fishing methods as well as higher injury rates for barbed hooks between fishing methods (spin, 78% injured with barbed, n = 108/138; fly, 65% injured with barbed, n = 122/187; spin, 57% injured with barbless hooks, n = 89/155; fly, 55% injured with barbless hooks, n = 65/119).

Most injuries in fish caught fly-fishing with circle hooks were in the upper or lower jaw (74%), followed by injuries to other nonsensitive areas (14.5%) and sensitive areas (8.5% eye; 3% esophagus). Fly-fishing-caught fish with new injuries obtained injuries to sensitive areas with J hooks (37% in sensitive areas; n = 70/191) more frequently than with circle hooks (12% in sensitive areas; n = 4/32); however, the sample size for circle hooks was too low to test for statistical significance. Hook shape significantly influenced new injury rates (J hook, 61% injured, n = 187/306; circle hook 48% injured, n = 32/67; P = 0.0444). There was no significant difference in injury between barbed and barbless circle hooks or size 6 and 8 circle hooks ($P > 0.1086$). An additional factor contributing to new injuries was angler experience. Based on the number of fish caught spin- and fly-fishing with J and circle hooks by novice or experienced anglers, novice anglers injured proportionally more fish than experienced anglers (novice 77%, n = 56/73; experienced 61%, n = 359/592; P = 0.0059; Table 1).

The number of new injuries per capture was most significant in small fish. Hook points penetrated more than one anatomical location in 16% (n = 106/644) of rainbow trout, and most penetrations caused at least one injury (98%; n = 104/106). Hooks most commonly penetrated the jaw and eye (41%; n = 43/106) and the upper and lower jaw (26%; n = 28/106). Fish caught by fly-fishing with J hooks were hooked in more than one location more frequently compared with circle hooks (J hook, 17%, n = 47/247; circle hook, 6%, n = 4/64); however, the sample size for circle hooks was too low to test for significance between hook shapes. Small fish were hooked in more than one location more frequently than large fish (small fish <440 mm, 19% hooked in more than one location, n = 95/511; large fish >440 mm, 8%, n = 11/133; P = 0.0055), primarily through the jaw and eye, indicating hook size may be a factor influencing the number of hook penetrations per capture in small fish.

In addition to fish size influencing the number of hook-point penetrations during capture, small fish were injured more frequently, and bleeding was most significant in fish hooked in sensitive areas and in small fish. The proportion of overall new injuries (sensitive and nonsensitive) was greatest in small fish (66% injured; n = 349/529) compared to large fish (47% injured; n = 65/137; $P < 0.0001$; Figure 2). Small fish were also injured in sensitive locations more frequently than large fish; however, the relationship was not significant (small fish, 35% in sensitive areas, n = 122/351; large fish, 23% in sensitive areas, n = 15/65; P = 0.0683). Bleeding from new hooking injuries occurred in 25% (n = 167) of the fish captured. There was no difference in the frequency of bleeding between barbed and barbless J hooks or fishing method ($P > 0.0905$). However, there was a significant relationship between injury location and fish size on the frequency of bleeding for fish caught using J hooks ($P < 0.0160$). These tests were not run for fish captured using circle hooks because of the small sample size of bleeding fish caught with circle hooks (n = 9). Fish injured in sensitive locations (55%) bled more frequently than fish injured in nonsensitive locations (27%), and small fish had higher bleeding rates (29%) than large fish (18%). Immediate mortality was observed for 8 fish (1.2%; n = 8/666) captured using J hooks (n = 3, fly-fishing; n = 5, spin-fishing), the majority of which were small (<440 mm), hooked in the tongue or gills (87%; n = 7/8), and experienced blood flow from the wounds. Although there was no significant difference in injury location between small and large fish, bleeding was more prevalent in small fish. This presumably was because they were injured in sensitive areas more often as well as injured more often.

Fish with past hooking scars tended to be larger, regardless of the capture method. At least one past hooking injury was present in 29% (n = 195/666) of fish captured during the study, 38% (n = 75/195) of which had more than one past hooking scar. The majority of past hooking scars were located on the upper or lower jaw (82%); scars in other nonsensitive areas (11%; e.g., snout, gular region) and in the eye (4%) were the next most common locations. Approximately 53% of large fish (n = 73/137) and 23% of small fish (n = 123/529) had at least one past hooking injury ($P <$ 0.0001; Figure 3). The frequency of past injuries in large fish was similar to new injury rates for large fish (47%; n = 65/137); however, past injury rates for small fish were much lower than new injury rates (66%; n = 349/529). The frequency of past injuries in seined fish caught at Nonvianuk Lake outlet (24%; n = 24/100) was not significantly different from angler-caught fish captured from the same location (28%; n = 20/72; P = 0.7362). Fish with past injuries were similar in length regardless of capture method; the average length of fish with past injuries was greater than the average length of fish without injuries (no past injury: seine = 323.9 ± 12.34 mm, angling = 348

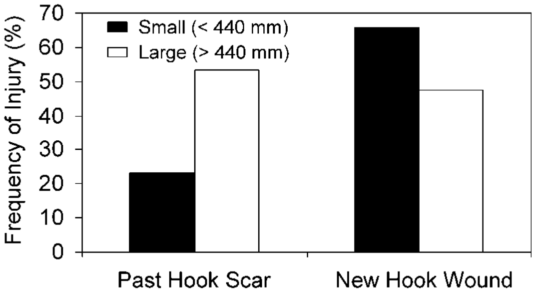

FIGURE 3.—Comparison of past and new hooking injuries by size category in rainbow trout captured by hook and line. Past injuries were defined as healed wounds obviously resulting from previous capture by angling. Logistic regression revealed significant differences between size-classes for both past and present hooking injuries ($P < 0.05$).

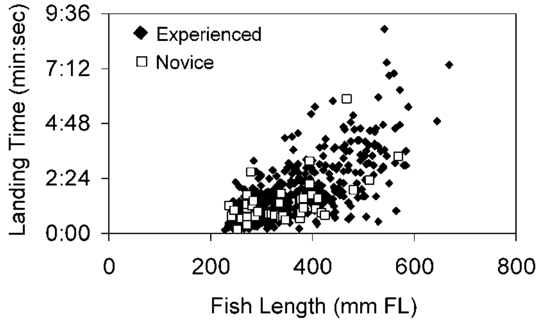

FIGURE 4.—The relationship between landing time and rainbow trout size ($P < 0.05$) by angler experience. Experienced anglers fished more than 10 d/year and novice anglers fished less than 10 d over their lifetime.

± 19.58 mm SE; past injury: seine = 415.7 ± 34.32 mm, angling = 416.4 ± 29.52 mm).

Fish size influenced landing time and hook type influenced hook removal time. There was a positive relationship between fish size and landing time ($P = 0.001$; linear regression). Experienced anglers took significantly longer to land fish than novice anglers (novice = 1:13 ± 0:17 min, experienced = 1:37 ± 0:07 min; $t = -2.01$, df = 44, $P = 0.05$) and tended to catch larger fish, although the relationship between fish size and experience was not significant (novice = 341 ± 22 mm, experienced = 361 ± 8 mm; $t = -1.96$; df = 46, $P = 0.056$). Analysis of covariance (ANCOVA) with the GLM procedure was used to observe any difference in landing time by angler experience and fish size, using fish length as a covariate to reduce error variance in the model because of the relationship between fish size and angler experience. Fish length was the only significant factor ($P = 0.0001$), indicating that longer landing times were primarily due to fish size and significance involving angler experience was most likely due to experienced anglers catching more large fish than novice anglers (Figure 4). Hook removal time was not related to fishing method, hook shape, initial hook location, angler experience, or fish size ($P > 0.505$). However, hook removal time was significantly longer when barbed J hooks were used compared to barbless J hooks ($P = 0.0001$; Figure 5). There were no time differences between barbed or barbless circle hooks ($t = -0.10$, df = 32, $P = 0.922$).

Barbed hooks were more efficient at landing fish than barbless hooks, and J hooks were more efficient than circle hooks. For fly-fishing only, the proportion of fish lost using circle hooks (48%; $n = 62/129$) was higher than for fish lost using J hooks (36%; $n = 172/478$; $P = 0.0217$; Table 1), and efficiency was not related to the circle hook being barbed or barbless ($P = 0.0918$). Barbed J hooks were more efficient at landing fish than barbless hooks; the proportion of fish lost using barbed J hooks (37%; $n = 192/517$) was less than the proportion lost using barbless hooks (50%; $n = 270/544$; $P < 0.0001$; Table 1), regardless of fishing method. The use of two sizes of circle hooks during the study did not influence catch efficiency ($P = 0.7994$).

Discussion

Permanent scarring from hooking injuries is inevitable in fish that survive being hooked or released, especially in a fishery with high recapture rates. The most common new hooking injuries in Alagnak River rainbow trout were in the jaws (e.g., missing maxillary, inverted maxillary, scarring to

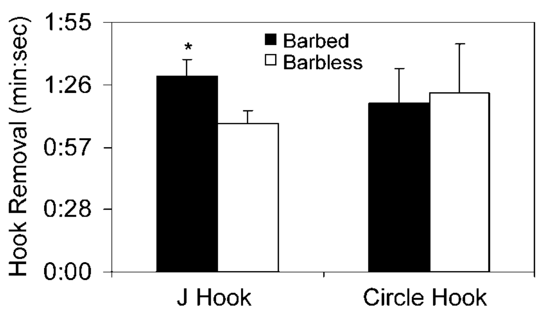

FIGURE 5.—Comparison of hook removal time by hook shape and type for rainbow trout captured by spin-fishing or fly-fishing. There was a significant ($P < 0.05$) difference between the handling times with barbed and barbless J hooks, which is noted by an asterisk.

the dentary) and eye; past injuries were primarily in the jaws and other nonsensitive areas. Bleeding incidence was relatively low in this study (25%), but this was related to the fact that 33% of new hooking injuries were in sensitive areas. Some studies have reported over 40% mortality in salmonids hooked in the eye and 25–71% mortality when hooked in the esophagus, gills, or tongue (Warner 1976; Mongillo 1984; Loftus et al. 1988; Nuhfer and Alexander 1992). Bleeding associated with being hooked internally can also contribute greatly to mortality, because injuries to critical internal areas bleed more than external locations (Falk et al. 1974; Nuhfer and Alexander 1992; Schisler and Bergersen 1996). I observed immediate mortality in only eight fish (1.2%), seven of which were hooked internally and experienced blood flow from the wound. Mortality from angling generally occurs within the first 24–48 h following capture, but fish with less severe hooking wounds may take up to 10 d to die (Mongillo 1984). Because fish were not held after capture to estimate mortality rates, it is possible that unobserved delayed mortality did occur.

It is not known whether new injury rates relative to past injury rates were indicative of mortality rates in recaptured rainbow trout. For example, over 60% of fish captured were given new injuries, yet only 29% of fish had evidence of past injury. These results imply that roughly half of newly injured fish are not recaptured in the sport fishery, indicating potential delayed mortality may be occurring at rates much higher than the results of most studies on hooking mortality. It was sometimes difficult to identify if fish had a previous puncture wound to the tongue or esophagus, which may have slightly reduced past injury estimates. Fish exhibiting avoidance behavior may also be a factor influencing the discrepancy in recaptured fish with past injuries (Lewynsky and Bjornn 1987), yet this is difficult to investigate in large rivers such as the Alagnak. Examination of injury and fish size revealed the frequency of new injuries (47%) and past injuries (53%) to be similar for large fish. However, smaller fish were given new injuries more frequently (66%), more of the injuries were to critical areas, and the frequency of past injuries (23%) in recaptured small fish was significantly less than for new injuries. Small fish also constituted the majority of the 16% of fish captured with hook points penetrating more than one location, most of the penetrations resulting in at least one new injury, and injuries to the jaw and eye. Other studies examining the relationship between fish size and hooking mortality have had variable results (Schisler and Bergersen 1996). Nuhfer and Alexander (1992) found hooking mortality in brook trout *Salvelinus fontinalis* to increase with fish size, most likely because large fish were hooked in critical locations more often and the fish were caught with treble hooks. Mortality was also higher for fish caught with treble hooks compared with single hooks, presumably because the increase in hook-point penetrations increased the probability of injury to critical locations and associated bleeding. Another study found the highest mortality rates in lake trout *S. namaycush* to be among smaller size-classes, but found no significant difference in mortality between hook types (treble and single; Loftus et al. 1988). Although estimating mortality rates from the relationship between new injury rates and the frequency of past injuries would require further investigation, my results indicate that smaller fish may be more vulnerable to mortality. It is also possible that hook size may have been an important factor influencing the number of hook points penetrating small Alagnak River rainbow trout which, in turn, caused increased injury to sensitive locations, associated bleeding, and subsequent mortality. Development of methods to evaluate mortality based on new injury and past injury rates is recommended to determine if delayed mortality is occurring beyond the typical holding period (e.g., 72 h) of most hooking mortality studies, particularly for fish with nonsensitive injuries that are generally considered nonlethal.

In this study, barbed J hooks caused significantly more new hooking injuries, took longer to remove, and were more efficient at catching fish than barbless hooks. It is important to note, however, that injury rates using barbless J hooks were also high and hook type did not influence the frequency of sensitive injuries. Higher injury rates and longer handling times for barbed hooks were most likely due to difficulty in hook removal and hooks becoming tangled in landing nets, both of which were observed to intensify injuries and bleeding. Barbless hooks have been found to cause a lower incidence of injury and bleeding than barbed hooks and decrease the amount of time fish are handled and exposed to air while removing hooks (Taylor and White 1992; Muoneke and Childress 1994; Cooke et al. 2001; Schaeffer and Hoffman 2002). Some of these results prompted barbed-hook restrictions in several freshwater fisheries in the United States (Barnhart 1990; Turek and Brett 1997), and some researchers disagree with regulation changes based on little evidence that barbed hooks contribute significantly to mortality, making the issue predominately social and lacking biological significance (Schill and Scarpella 1997). However, certain nonlethal injuries and recovery from injury or blood loss may interfere with the feeding, reproduction, physiology, behavior, or disease resistance of angled fish (Snieszko 1974; Lewynsky and Bjornn 1987; Campbell et al. 1992; Schreck et al. 1997; Cooke et al. 2000; Thorstad et al. 2003). Although my results indicate that barbed hooks did not contribute to sensitive injuries and likely mortality, the increase in handling time and overall injury is consistent with results from other studies and should be taken into consideration by fisheries managers assessing the sublethal effects of angling.

Circle hooks tended to hook fly-fishing-caught fish in the jaw with only one hook penetration per capture, and overall injury rates were significantly lower when circle hooks were used (circle, 48%; J hook, 61%). The high overall injury rate for circle hooks, although lower than J hooks, most likely occurred during the hook-removal process because circle hooks were often more difficult to remove than J hooks, regardless of the presence of a barb. A similar observation was noted by Cooke et al. (2003c), who reported more tissue damage resulted when removing circle hooks from largemouth bass *Micropterus salmoides*, even when the hook removal procedure was classified as ''easy.'' Anglers in this study were most successful landing fish using circle hooks if the hooks were fished passively (i.e., allowing fish to hook themselves as opposed to the angler setting the hook). Fish were commonly missed if anglers attempted to set the hook, which was the main reason for lower catch efficiency. At times, the difficulty in landing fish with circle hooks prompted poor angler motivation for novice anglers, which likely had some effect on catch success (Schaeffer and Hoffman 2002). Although my results suggest circle hooks used with artificial flies may be appropriate to reduce lethal and nonlethal injuries in rainbow trout, the low catch efficiency may make them less desirable to anglers than is being promoted in popular literature, particularly for novice anglers who lack experience in varying their hook-setting methods.

It is important to note that the circle hooks used in this study are typically used in bait fisheries, and the hook point is bent significantly inward toward the hook shank as with marine circle hooks. Recent new designs in the circle hook shape, purportedly more suitable for freshwater fly-fishing, will likely have different results than those observed in this study (Cooke and Suski, in press). The use of circle hooks in marine fisheries has been gaining credence as causing less hooking damage and mortality in both the scientific and popular literature (e.g., Prince et al. 2002; Schaeffer and Hoffman 2002; Skomal et al. 2002), along with suggestions that these hooks may provide similar benefits in freshwater fisheries (Strange 1999). Scientific studies have had variable results with the catch efficiency of circle hooks compared to conventional hook types for largemouth bass, rock bass *Ambloplites rupestris,* brown trout *Salmo trutta*, and rainbow trout, yet most found internal injury and bleeding frequencies were less with circle hooks, which was consistent with my results (Cooke et al. 2003a, 2003b; Jenkins 2003; D. Pecora, Connecticut Department of Environmental Protection, unpublished data). Variability may, in part, be due to differences in terminal tackle used (e.g., bait or artificial flies) and the particular hook shape, but the variability may also be due to the foraging behavior and mouth morphology of the specific species of study (Cooke et al. 2003b).

Novice anglers often had difficulty removing both J and circle hooks and consequently injured proportionally more fish than experienced anglers. Dunmall et al. (2001) reported that experienced anglers influenced hook placement and the severity of injuries in smallmouth bass *Micropterus dolomieu* compared to novices, but did not significantly influence release times. In this study, the most influential factor to landing time was fish size. Experienced anglers tended to catch larger fish and higher numbers of larger fish than novices, which was reflected in longer landing times. Landing and hook removal times may have been slightly reduced by the anglers because they were familiar with the study objectives and participated in the methods, likely producing some bias in timed events (Schaeffer and Hoffman 2002). Timed events also varied slightly with habitat in the area of capture. For example, it was often observed that a fish hooked while an angler was wading deep in a strong current took longer to land and handle than if the angler was fishing from shore. Although these factors may have also contributed to slight variations in landing and release times, the influence of fish size to landing time and barbed hooks to hook removal times were significantly strong. Landing time has been demonstrated to cause significant physiological disruptions in wild rainbow trout, yet has generally resulted in little to no observed mortality (Wydoski et al. 1976; Pankhurst and Dedual 1994), particularly if fish aren't angled to exhaustion and air exposure during handling is avoided (Ferguson and Tufts 1992; Schisler and Bergersen 1996). Because the average landing time was less than 2 min and anglers were instructed not to exhaust fish and to avoid air exposure during hook removal, mortality from these factors was likely minimal based on inference from similar studies. However, sublethal effects, such as changes in reproductive behavior (Carragher et al. 1989; Campbell et al. 1992; Cooke et al. 2000), disease resistance (Pickering and Pottinger 1989), growth suppression or decrease in appetite (Pickering 1990; Gregory and Wood 1999), and other behavioral effects (Lewynsky and Bjornn 1987; Heath 1990; Gregory and Wood 1999; Thorstad et al. 2003) could have resulted. In sport fisheries where fish may be caught several times within a fishing season, it is important to reduce the amount of time fish are landed, handled, and exposed to air during the angling process to avoid either mortality or sublethal effects.

Few studies have examined the biological significance of scarring, such as growth effects and tissue loss or the esthetic importance of scars to the angling public. There are several factors to consider on the issue of scarring after hooking. Injuries may expose fish to parasites, disease, or fungal infections. It has been suggested that eye injuries from hooking or confinement in largemouth bass puts the cornea at risk of infection (McLaughlin et al. 1997), and injuries to smallmouth bass from retention gear used for confinement led to delayed fungal infections and sometimes death (Cooke and Hogle 2000). Anecdotally, I observed rainbow trout with past hooking injuries to have higher incidences of the parasitic copepod *Salmincola* than fish without injuries. In fish subjected to different types of stress, such as capture by angling or recovery from injury, the natural resistance to parasites may be reduced, which can increase parasite loads (Esch et al. 1975).

Nonlethal hooking injuries may influence the feeding or survival of fish (Wright 1972). For example, Wright (1972) estimated a 4–36% mortality rate in Chinook *Oncorhynchus tshawytscha* and coho (*O. kisutch*) salmon injured by sportfishing gear to the extent where vision or feeding ability were compromised. Fish with eye injuries may lose the ability to forage competitively and avoid predators (Cooke et al. 2003b). Feeding cessation in response to stress has been reported to last from hours to days in the literature (Pickering et al. 1982; Schreck et al. 1997; D. Beyers, Colorado State University, unpublished data), sometimes resulting in growth reduction (Clapp and Clark 1989). Fish subjected to multiple captures per season may be even more vulnerable to reduced growth (Clapp and Clark 1989), particularly if the effects of each capture are cumulative (Barton et al. 1986) and in areas where food is limited (Stockwell et al. 2002). Presence of hook scars greatly diminishes the esthetic value of wild fish, yet subsequent biological or social consequences from these injuries have been given little to no attention by fisheries scientists, managers, and the general public.

Conclusions and Recommendations

The results of this study indicate that the use of barbless J hooks may minimize injury and reduce the amount of time fish are handled during hook removal and that angler experience can contribute to hooking injury. Because injury rates were high, regardless of hook type, and may be influenced by angler experience, it is difficult to estimate if a barbed-hook restriction would reduce overall injury rates in angled fish. However, a slight reduction in hooking injuries and less handling time are two important benefits to consider in support of a regulation change or promotion of angler education programs for catch-and-release trout fisheries with heavy angling pressure and high injury rates. These benefits may be particularly important for smaller fish that may be more vulnerable to injury and mortality. The use of circle hooks as an alternative to J hooks in a fly fishery could help reduce lethal hooking injuries and make the actual hooking and landing of fish more challenging and, possibly, self-limiting. However, as circle hooks continue to increase in popularity for use on freshwater fish and new and more efficient hooks become available, an increase in catch efficiency may result in increased injuries and necessitate further research with different circle hook types. This study demonstrated that information on factors influencing severity of hooking injuries in wild rainbow trout can be obtained without holding fish after capture.

Although these results apply most specifically to the Alagnak River rainbow trout fishery, they are representative of other popular, nonconsumptive rainbow trout fisheries in Alaska. As the popularity of angling for wild rainbow trout continues to rise in Alaska, resulting in heavier angling pressure, voluntary and mandated catch-and-release angling practices will inevitably continue to increase. Managers will need to carefully consider the impacts of multiple recaptures on the esthetic value of wild fish to visiting anglers, focus future research on the prolonged sublethal effects of hooking injury on trout populations, and develop angler education programs and gear restrictions to minimize injury.

Acknowledgments

This project was a combined logistical, technical, and financial effort between the U.S. Geological Survey—Alaska Science Center (USGS ASC), Natural Resource Preservation Project (NRPP) funds, and National Park Service (NPS)—Katmai National Park. I thank J. Nielsen (USGS ASC) and T. Hamon (NPS) who were responsible for the original study proposal, thorough reviews of this manuscript, and guidance during the study. I thank J. Margraf and N. Hughes of the University of Alaska–Fairbanks (UAF), School of Fisheries and Oceanic Sciences, for their consistent support, guidance, and critical reviews of this manuscript and my graduate research. Thank you to J. Finn and M. Udevitz for providing their generous assistance with the statistical analysis and conceptual development. Thank you to K. Burke-Brand, E. Knudsen, P. Richards, and T. Tingey for their complete reviews of this manuscript. I especially thank the many individuals who dedicated all or portions of their summers participating in this study to fish, learn, and aid in its development, including E. Aguilor, J. Bacchieri, R. Beatty, A. Birch, J. Boyd, B. Bundy, K. Bunny, B. Byrne, B. Cook, M. Crow, G. Cubit, R. D'Ambruoso, P. Fedor, J. Fountain, B. Frampton, R. Gray, B. Hanson, K. Johnson, C. Lagoudakis, J. Lyman, S. McCormick, D. Parker, J. Pikul, D. Oswald, P. Richards, J. Stubbs, D. Wilson, and C. Wall.

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