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Postrelease Hooking Mortality of Rainbow Trout Caught on Scented Artificial Baits

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Abstract.—The postrelease mortality of rainbow trout *Oncorhynchus mykiss* caught on scented artificial baits was compared with postrelease mortalities of rainbow trout caught on traditional artificial flies. In all, 457 fish were captured on flies, 505 on artificial baits fished actively (ABA), and 511 on artificial baits fished passively (ABP) in five replicate experiments. Water temperature, fish length, time played, time out of water, hook location, leader treatment, and bleeding intensity were recorded for each fish captured. Mortalities were recorded daily over a 3-week holding period. Overall mortalities were 3.9% for fly-caught fish, 21.6% for fish caught on ABA, and 32.1% for fish caught on ABP. Differential mortality among gear types resulted largely from differences in the number of fish hooked in the gill arches or deep in the esophagus (critically hooked) in each group. Overall, critical hookings were 3.9% for the fly-caught group, 45.7% for the ABA group, and 78.3% for the ABP group. The Akaike Information Criterion, a model selection procedure, was used to develop a logistical regression model that best fit the mortality data. Parameters that reduced mortality probability include using flies rather than synthetic baits, hooking the fish in a noncritical location, and cutting the leader on critically hooked fish. In addition, as fish length increased, mortality probability decreased. Length of time played and length of time out of water contributed to mortality, as did increasing water temperatures and bleeding intensity.

Special regulations such as catch and release and artificial-fly-and-lure-only regulations in trout waters are becoming more important as angling pressure increases and the number of quality trout fishing waters decreases due to habitat loss (Behnke 1980). Many fish stocks no longer can support excessive fishing pressure because of the high demand for quality trout fishing. A high percentage of fish must be returned unharmed by anglers for future recapture to keep the size and numbers of fish sufficient in quality waters to maintain angler satisfaction. Special regulations are useful in providing for increased demand on trout stocks. Colorado currently has special regulations such as catch and release on 6% of its fishable waters (Powell 1994). Special regulations are useful only if they can be enforced such that the original intent or purpose of the regulations is met. More specifically, special regulations on catch-and-release waters are used to ensure that a single fish can be caught by more than one angler. Fly-and-lure-only fishing in certain waters originally was adopted to reduce mortality of released fish. This regulation was based on overwhelming evidence in studies of hooking mortality that salmonids caught on bait sustain a higher percentage (30–50%) of mortalities when released than those caught on flies and lures (5–10%) (Mongillo 1984).

Recently, artificial scented baits that fit the Colorado Division of Wildlife's definition of "artificial fly or lure" have been developed. They are made of a combination of cellulose ether, a polyalkylene glycol, plasticizers, and other chemicals and are impregnated with amino acids that stimulate active feeding behavior. Fish attack these artificial scented baits ravenously because they are easily detected and are greatly preferred over other substances (Jones 1991). Because fish are strongly attracted to these artificial baits, they may be effectively fished passively, unlike the case with traditional artificial flies and lures. We hypothesized that these scented artificial baits would be swallowed like natural baits, causing fish to be frequently hooked in critical areas such as the gill arches or deep in the esophagus. The relation between deep hooking and mortality of released fish is well documented. In fact, it is the single most important factor in contributing to initial hooking mortality (Wydoski 1977). To test our hypothesis, we initiated a study to quantify mortalities of rainbow trout *Oncorhynchus mykiss* caught on artificial scented baits and to isolate the causes of mortality. The specific objectives of this study were to determine if active or passive angling with premolded, artificial scented baits resulted in the same mortalities as observed for traditional artificial flies

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and lures. In addition, the study was designed to quantify how bleeding, fish length, time played, time out of water, water temperature, and cutting the leader influenced survival of caught and released rainbow trout.

Methods

We conducted a series of five replicate experiments to meet our objectives. The first two were performed in late summer and fall 1993, and the remaining three in spring and early summer 1994. The study area chosen was Gates Pond, a 0.1-ha stream-fed pond in Rist Canyon near Fort Collins, Colorado. The site was chosen because of its limited public access and suitable water temperatures and forage for rainbow trout.

Gates Pond 1993.—During the summer experiments of 1993, Gates Pond was stocked with 1,200 hatchery-reared rainbow trout. These fish had been measured to the nearest millimeter and tagged with visible implant tags (Northwest Marine Technology, Shaw Island, Washington) in the adipose tissue posterior to the eye before stocking. Fish were captured with flies, artificial baits fished passively (ABP), and artificial baits fished actively (ABA). The flies were traditional wet or dry flies fished with either a fly rod or a spinning rod and casting bubble. The artificial bait consisted of a slip-rig with a number 10 hook and one or two artificial eggs attached. Passive fishing of artificial eggs is a common trout angling technique. After bait is cast, the fishing rod is set down, and the angler waits for a fish to take the bait. Active fishing of artificial eggs involves keeping the bait in constant motion, never setting the rod down, and setting the hook as soon as a strike is felt. The two methods of fishing with artificial eggs were used to test the hypothesis that active fishing would reduce mortalities to a level similar to that of traditional flies and lures, which usually are fished actively.

Fish were captured by anglers with a wide range of angling experience. Anglers were required to record the gear type and fishing method, tag number, time played, time out of water, hook location, and bleeding intensity for each fish. We recorded time played to the nearest second by timing the angler with a stopwatch from the instant the hook was set until the fish was removed from the water. Time out of water was recorded as the moment the fish was removed from the water until it was returned to the water. Surface water temperature at the time of capture was recorded in each replicate experiment as well.

Hook location was recorded as one of the following: upper jaw, lower jaw, corner of mouth, roof of mouth, tongue, gill arches, eye, deep hooked, or foul hooked. A fish was considered critically hooked if it was hooked in the gill arches or esophagus. Anglers were asked to alternate between cutting the leader and removing the hook from the fish that were critically hooked so that the number of both treatments would be relatively equal. This procedure was used to test the hypothesis that cutting the leader on a critically hooked fish improved its chances of survival. Bleeding intensity was described as none (no visible bleeding), light (small droplets of blood at location of hook penetration), medium (blood dripping from location of hook penetration), or heavy (blood actively flowing from location of hook penetration and running down the sides of the fish).

Anglers were asked to switch fishing method frequently to reduce bias caused by differential handling. If the fish had lost its tag, the tag was replaced and the fish was remeasured. After fish were captured and the data recorded, the fish were temporarily placed into 1.2 m × 1.2 m × 1.2-m live-cages and then moved to a large 9.1 m × 9.1 m × 1.8-m holding pen for the duration of the experiment. The fish were fed once daily with pelleted fish food, and pens were checked every 24 h for dead fish over a 3-week period. Date of death and tag number were recorded for each death observed.

Gates Pond 1994.—The experiments took place in spring and early summer 1994. During the experiment, 900 hatchery-reared rainbow trout were stocked. About 200 fish stocked for the 1993 experiment were still present in the pond. All aspects of the experimental design remained the same in 1994 with the following exceptions: (1) fish were tagged and measured upon capture instead of before stocking, (2) two 3.1 m × 3.1 m × 1.8-m holding pens were used for each replication instead of one 9.1 m × 9.1 m × 1.8-m holding pen, and (3) fish were given a series of coded fin punches to identify method of capture and treatment in case of tag loss.

Data analysis.—An unexpected die-off of fish occurred at the beginning of the third week of the second replicate experiment. This die-off was due to suspension of anoxic sediments in the pond when the first holding cage was removed. As a result, data were truncated at 2 weeks for all five replicates to give comparable results for all replicates. From 67 to 83% of all mortalities occurred within the first week of each experiment, so results

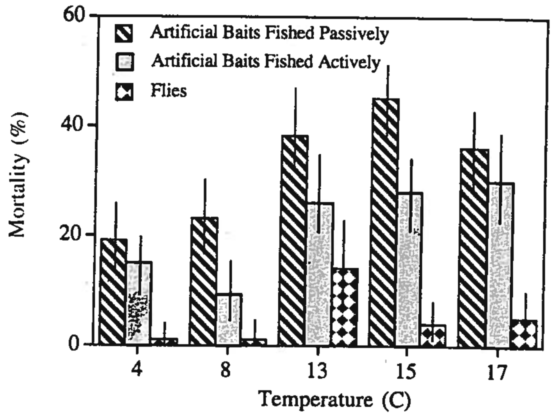

FIGURE 1.—Percent mortality (and 90% confidence intervals) of rainbow trout for each of the five replicate experiments at Gates Pond. Surface temperatures (°C) at time of capture are given as a substitute for replicate number.

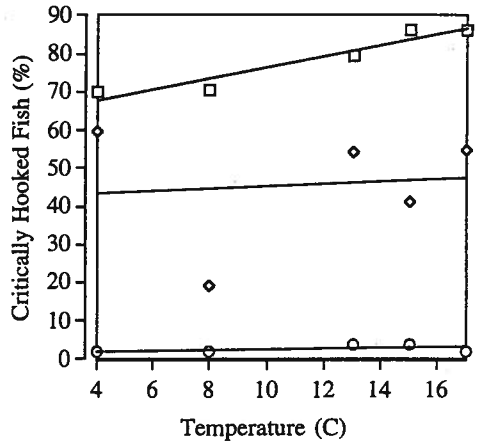

FIGURE 2.—Percentages of critically hooked rainbow trout by gear type for each replicate experiment at different surface temperatures (°C). Squares represent fish caught on artificial baits fished passively, diamonds represent fish caught on artificial baits fished actively, and circles represent fish caught on flies. Simple linear regression lines are drawn through the data points to emphasize trends.

were not greatly affected by this action. Mortality rates and proportions of critically hooked fish were calculated for each gear type and fishing method as

$$\hat{p} = \frac{y}{n}; \tag{1}$$

$\hat{p}$ = proportion dead or proportion critically hooked; y = number of fish dead at the end of the holding period or number of fish critically hooked; and n = total number of fish caught in a particular category.

Binomial confidence limits were calculated with SAS system software. An alpha level of 0.10 was chosen to determine 90% confidence intervals.

Logistic-regression analysis.—Logistic-regression analysis was used to identify a model that would best describe the relation between the variables recorded and mortality observed in this experiment. To avoid problems associated with model selection in multiple-regression analysis caused by traditional goodness-of-fit tests and likelihood-ratio tests, the Akaike Information Criterion (AIC) was used for model selection (Lebreton et al. 1992). The AIC is a method for selecting a model that most closely fits the theoretical distribution of the data without overparameterization. With this model selection procedure, one also can choose from many different alternative models at once. The AIC values were calculated as

$$\text{AIC} = -2 \log_e L + 2k; \tag{2}$$

L = likelihood value calculated for the model, and k = number of parameters used in the model. An AIC value was calculated for each candidate model. Models with AIC values within one or two of the minimum AIC value were considered to be valid candidate models. In this analysis, the GENMOD procedure in SAS system software was used to obtain log-likelihood values for the AIC formula. Incomplete records were eliminated from the data set to maintain homogeneity and to arrive at comparable AIC values.

Results

Mortality for fish caught with artificial baits fished passively averaged 32.1% and ranged from 19 to 45% between experiments (N = 511; Figure 1). Mortalities for fish caught on artificial baits fished actively averaged 21.6% and ranged from 9% to 29% (N = 505). Mortalities for fly-caught fish averaged 3.9% and ranged from 1% to 14% (N = 457). Water temperatures at the time of capture were at least 2°C different for each replicate experiment, providing a wide range of experimental temperatures. Experiments conducted at higher water temperatures resulted in higher mortalities in most cases (Figure 1).

Fish caught on artificial baits were more likely to be hooked in critical areas and thus more likely to die (Figure 2). In every replicate experiment, the number of critically hooked fish was less than 5% (average, 2.6%) for fish caught on flies, 19–59% (average, 45.7%) for fish caught on artificial baits fished actively, and 70–86% (average,

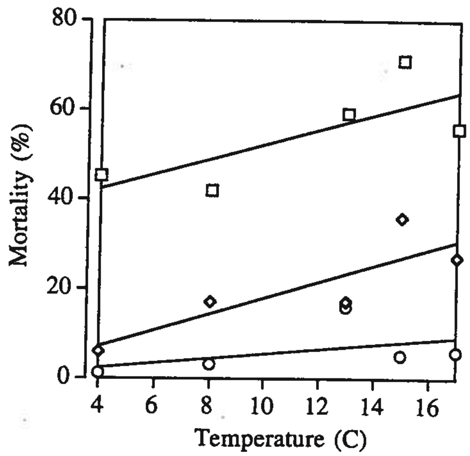

FIGURE 3.—Percent mortalities of rainbow trout by hook location and leader treatment for each replicate experiment at different surface temperatures (°C). Squares represent critically hooked fish with the leader not cut, diamonds represent critically hooked fish with the leader cut, and circles represent superficially hooked fish. Simple linear regression lines are drawn through the data points to emphasize trends.

78.3%) for fish caught on artificial baits fished passively. The number of fish critically hooked when caught on artificial baits fished passively also increased as water temperature increased.

Mortalities of fish superficially hooked were much lower than those of fish critically hooked, and critically hooked fish that had the leader cut had lower mortalities than those without the leader cut (Figure 3). Critically hooked fish experienced mortalities of 44.9–70.9% (average of 55.3%) when the hook was removed (N = 333), and of 5.7–36.2% (average of 20.6%) when the leader was cut (N = 310). Superficially hooked fish (N = 829) experienced mortalities of 1.1–15.5% (average of 5.2%). Some fish from the group of deeply hooked fish that had not had the hook removed and had died during our experiment were X-rayed and autopsied to identify where the hook had penetrated and to find out if the fish had shed the hook before death. Of the 22 fish sampled that were deeply hooked and had had the leader cut, 4 (18.1%) had shed the hook, 14 had the hook embedded in the esophagus, 3 had the hook lodged in the gill arches, and 1 had the hook in the stomach. Fish in a sample of 79 deeply hooked fish that had not had the hook removed and that lived to the end of the 3-week holding period were also X-rayed and autopsied. Of these fish, 20 had shed the hook (25.3%), 45 had the hook embedded in the esophagus, 2 had the hook lodged in the gill arches, and 12 had the hook in the stomach.

A high proportion of the fish hooked in the gills exhibited medium to heavy bleeding (Figure 4). Deeply hooked fish that had the hook removed exhibited bleeding intensities similar to those of fish hooked in the gills. Deeply hooked fish that had the leader cut bled about the same as fish hooked in noncritical locations. Heavy bleeding was rarely observed among superficially hooked fish.

Model Selection

Other variables that affected mortality, but were difficult to isolate because of the overwhelming effects of variables such as gear type, were identified by the model selection procedure. The AIC values were calculated with different combinations of potentially important parameters and potential

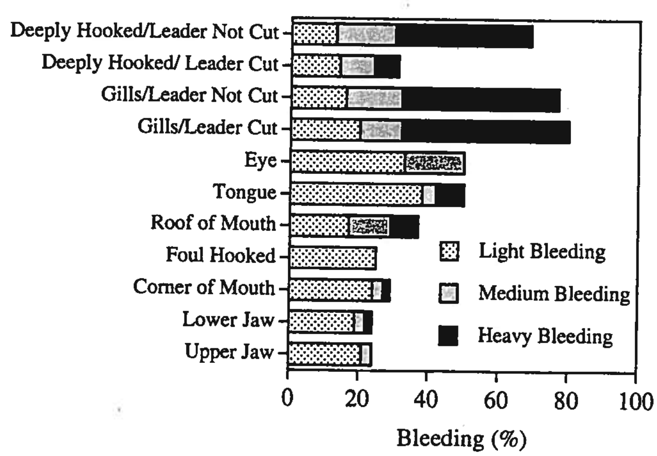

FIGURE 4.—Bleeding intensities of rainbow trout by hook penetration location and leader treatment.

interactions between variables. Several candidate models had quite large AIC values. Large AIC values were caused by use of too few parameters (underfitting the model) or too many parameters (overfitting the model). An example of underfitting would be exclusion of important parameters such as gear type or hook location. An example of overfitting would be inclusion of unnecessary variables such as an interaction term between length of fish and water temperature. The model chosen for the mortality data set was within one or two points of the minimum AIC and included all parameters deemed important to mortality (equation 3).

$$\begin{aligned}\text{Log}_e(M/1 - M) = &-3.1459 - 0.9141(G1)\\ &+ 0.0960(G2) + 0.1057(T)\\ &- 0.9418(S) + 0.9834(\text{NC})\\ &+ 0.0053(\text{PL}) + 0.0092(O)\\ &+ 0.4262(B) - 0.0031(L);\end{aligned} \quad (3)$$

M = probability of fish dying;
$G1$ = 1 if fish are caught on flies, or 0 if not;
$G2$ = 1 if fish are caught on ABA, or 0 if not, (only the intercept is used if the fish are caught on ABP);
T = surface temperature (°C) at time of capture;
S = 1 if fish are hooked superficially, or 0 if not;
NC = 1 if fish are critically hooked and the leader is not cut, or 0 if fish are critically hooked and the leader is cut;
PL = length of time the fish is played in seconds;
O = length of time the fish is out of water in seconds;
B = bleeding intensity (from 0 to 3 as described in methods);
L = length of fish in millimeters.

One could use the model not only to quantify how important each parameter is to mortality, but also to predict mortality probability of a fish in a given scenario by replacing numeric values for given variables in equation (3).

Model Results

The serious effect of critical hooking, especially when the leader is not cut, can be illustrated by the logistical-regression model (Figure 5). In this example, mortality is shown for a 380-mm trout

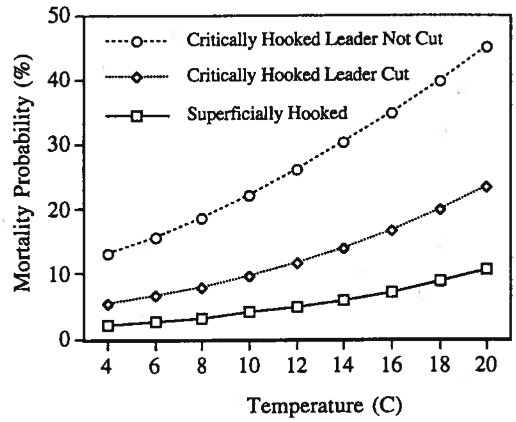

FIGURE 5.—Effect of temperature (°C), hooking severity, and leader treatment on mortality probability of a 380-mm rainbow trout as calculated by the logistical-regression model. The fish was caught on synthetic baits fished passively, played for 60 s, held out of water for 30 s, and showed light bleeding. Variables not shown are held constant.

caught on synthetic baits fished passively, played for 60 s, held out of water for 30 s, and showed light bleeding. If the fish was superficially hooked, mortalities would remain below 11%, whereas a critically hooked fish with the leader not cut could have a mortality probability approaching 45% at 20°C. Cutting the leader on a critically hooked fish in this case would reduce mortality probability by 5.3% at 4°C and 21.6% at 20°C. Note that this difference reflects only the effect of hook location and leader treatment. Bleeding intensity increases when a fish is critically hooked, especially if the leader is not cut, and contributes to mortality beyond the effect seen here. Relative differences in mortality by hook location and leader treatment are much higher when individual parameter effects are not isolated (Figure 3).

As would be expected, increasing bleeding intensity increased mortality probability. The example in Figure 6 depicts a 380-mm trout caught on synthetic baits fished passively, played for 60 s, held out of water for 30 s, and critically hooked with the leader not cut. As in Figure 5, mortality probability increases with temperature but even more dramatically with increasing bleeding intensity. In this case, a fish caught in 10°C water would have mortality probability increasing from 16% with no bleeding to 40% with heavy bleeding.

Length of time played and length of time out of water both increased mortality probability, with length of time out of water increasing mortality probability at about twice the rate as length of time

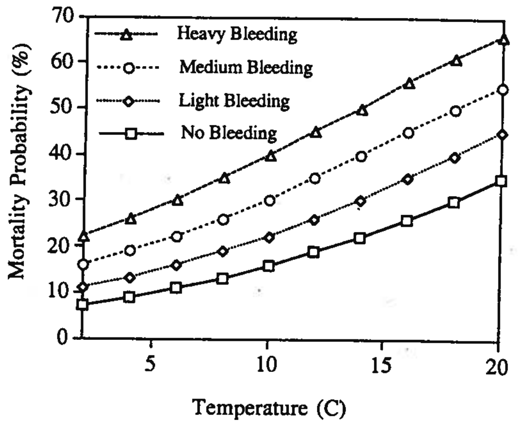

FIGURE 6.—Effect of water temperature (°C) and bleeding intensity on mortality probability of a 380-mm rainbow trout as calculated by the logistical-regression model. The fish was caught on synthetic baits fished passively, played for 60 s, held out of water for 30 s, and critically hooked with the leader not cut. Variables not shown are held constant.

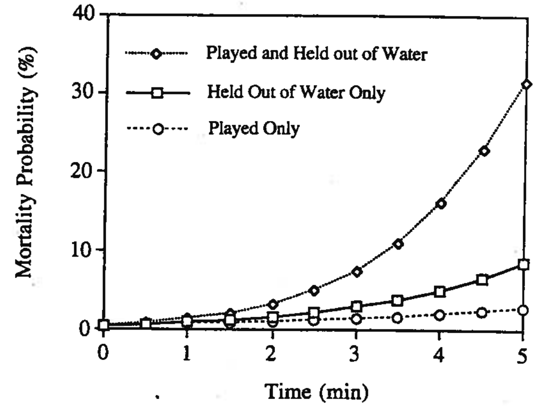

FIGURE 7.—Effect of time played and time out of water on mortality probability of a 380-mm rainbow trout as calculated by the logistical-regression model. The fish was caught on a fly in 10°C water and was superficially hooked and not bleeding. Variables not shown are held constant.

played. Figure 7 depicts a 380-mm trout that was caught on a fly in 10°C water and was superficially hooked and not bleeding. One can observe the effect of time out of water alone by following the increasing mortality function where time played is equal to 0 minutes. In this situation, mortality rises to 8.6% after the fish is out of water for 5 min if no bleeding occurs and the fish is not played. If playing time is increased from 0 to 5 min, mortality rises to 31.6%. Increasing bleeding intensity or water temperature would similarly raise the mortality probability.

Lengths of fish caught in the experiments ranged from 186 to 440 mm (mean, 300.1). Mortality probability decreased with increasing fish length, although the effect was not as dramatic as that of many of the other variables. Figure 8 depicts mortalities of rainbow trout that were caught on flies in 10°C water, superficially hooked, bleeding lightly, and held out of water for 30 s. A 400-mm fish played for 1 min would have a 1.5% mortality probability, whereas a 200-mm fish played for the same length of time would have a 2.8% mortality probability, a difference of only 1.3 percentage points. However, when playing time is increased to 5 min, the 200-mm fish would have a 9.3% mortality probability, and the 400-mm fish would have a 5.3% mortality probability, a difference of 4.0 percentage points.

Discussion

The results of the experiments in this study give a good general overview of the effects of using synthetic baits versus traditional artificial flies in a catch-and-release rainbow trout fishery (Figure 1). We observed much higher mortalities when fish were caught on synthetic baits, especially when fished passively, than when fish were caught on traditional artificial flies. Actively fishing synthetic baits reduced mortalities of fish caught, but not to the level observed with flies. Numbers of critically hooked fish varied widely, especially in the ABA group. This variation could be due to a number of factors, including individual angler ex-

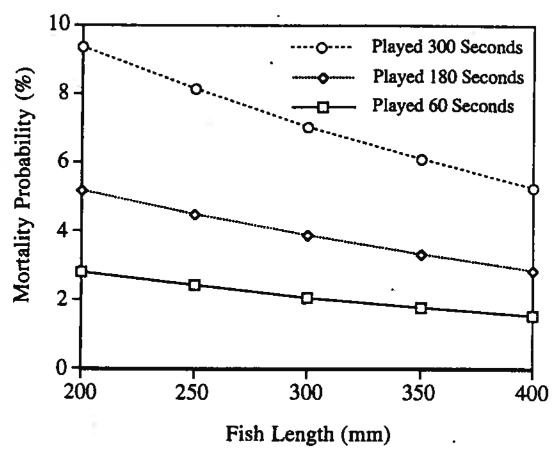

FIGURE 8.—Mortality probability of rainbow trout as a function of fish length and time played, as calculated by the logistical-regression model. Fish were caught on flies in 10°C water, were superficially hooked and bleeding lightly, and were held out of water for 30 s. Variables not shown are held constant.

perience and attentiveness or fish behavior. We believe that mortality varied among replicate experiments because of the many factors contributing to mortality. For example, mortalities for fly-caught fish were unexpectedly high at 13°C. High mortalities in this case were not necessarily a function of temperature but could be attributed to long playing times, holding the fish out of water for long periods, or simply poor handling of the fish by a few individual anglers.

The logistical regression model identified variables such as gear type, fishing method, hook location, leader treatment, water temperature, bleeding intensity, and length of time out of water as major contributors to hooking mortality probability. Fish size and length of time the fish was played were minor contributors and would have been eliminated from the model with traditional goodness-of-fit or likelihood-ratio tests of significance.

Critical hooking is the single most important factor in catch-and-release mortality because of the potential for serious tissue and organ damage (Wydoski 1977). The proportion of fish that are critically hooked when organic baits are used is roughly 50%, whereas critical hooking with traditional flies and lures is typically less than 10% (Mongillo 1984). Our results showed a very high incidence of critical hooking when artificial baits were passively fished. Actively fishing the baits reduced critical hooking, but fish were still hooked in critical anatomical areas much more frequently than fish caught with traditional flies and lures.

Our findings support the long-held belief that cutting the leader on a deeply hooked fish improves its chance of survival. Mason and Hunt (1967) observed mortalities of 34.5% in rainbow trout when the line was cut ($N = 200$), 82% when the hook was pulled out with an extractor ($N = 100$), and 95% when the hook was pulled out without an extractor ($N = 100$). Hulbert and Engstron-Heg (1980) observed mortalities of 59.04% in sublegal-sized brown trout *Salmo trutta* when the hook was removed ($N = 83$), and 18.75% when the leader was cut ($N = 80$). Many other catch-and-release studies have either not indicated how deeply hooked fish were treated, or hooks were pulled out of all fish. Our results are consistent with the results of studies in which the subject was addressed. In typical fishing situations, anglers rarely cut the leader when a sublegal fish is captured, so overall mortalities in our experiments for both active and passive fishing with scented, premolded artificial baits are probably lower than would be expected under field conditions with the average angler.

Mason and Hunt (1967) found that 76 of 131 (58.1%) fish had lost their hooks after 4 weeks. Our results also support the hypothesis that when a fish is critically hooked and the hook is left in, the fish is likely to shed the hook on its own. Even if the hook is not shed, fish surviving for 3 weeks appear to be able to move the hook farther down the digestive tract, away from vital organs such as the heart and liver.

Temperature has been identified as a key factor in mortalities of trout in many previous studies (Klein 1965; Hunsaker et al. 1970; Dotson 1982; Titus and Vanicek 1988; Nuhfer and Alexander 1992). Taylor and White (1992) in a metaanalysis of trout mortality found no relationship between temperature and mortality. However, they were limited to five studies in which temperature was used as a variable, and in three of them, mortality and water temperature were correlated. Our results clearly indicate a positive correlation between water temperature and mortality. This is especially true among critically hooked fish. Fish captured passively have extremely high mortalities because they tend to be critically hooked more often at high water temperatures. At colder water temperatures, the fish may feed less voraciously, which would explain fewer critical hookings.

Several studies have linked bleeding intensity with mortality (Clark 1991; Nuhfer and Alexander 1992; Pauley and Thomas 1993). In our experiments, increasing bleeding intensity contributed substantially to mortality. Fish hooked in critical areas (gills or esophagus) usually bled more heavily than those hooked in noncritical areas so the cause of death could be attributed largely to blood loss.

A recent study (Ferguson and Tufts 1992) demonstrated that mortalities can reach 80% when rainbow trout are played to exhaustion and held out of water. The modeling procedure we used to analyze our data allowed us to isolate the effect of holding a fish out of water. We found that such treatment increased mortalities but caused very high mortalities only when other factors such as long playing times contributed as well. Marnell and Hunsaker (1970) found no significant difference in mortality of lure-caught cutthroat trout *Oncorhynchus clarki* played 0, 5, and 10 min. Reported mortalities were 4% ($N = 100$), 6% ($N = 100$), and 5% ($N = 100$). Our modeling results indicate that length of time played does indeed contribute to mortality, although it is not as important as how long the fish is held out of water.

Previous investigators studying hooking mortality have reached different conclusions about the role of fish size as a contributor to mortality. Nuhfer and Alexander (1992) found that large brook trout *Salvelinus fontinalis* (particularly those >350 mm), swallowed artificial lures more often than smaller fish, which led to higher mortalities. Smaller fish in that study were unable to engulf the lures because of relatively small mouth size. Dotson (1982) found no significant correlation between length and mortality in rainbow and cutthroat trout; however, fish sizes ranged from only about 170 to 250 mm, which could explain the lack of size-related differences. Titus and Vanicek (1988) found no significant differences between three sizes of Lohontan cutthroat trout *O. c. henshawi.* Loftus (1986) found that smaller lake trout *Salvelinus namayacush* caught on lures had higher mortalities than larger fish. A decrease in mortality with increasing length of fish caught was also observed in our study when other variables were held constant.

Hooking mortality is caused by a variety of factors, which alone may not seriously affect the probability of mortality for a fish that is released. When faced with the challenge of recycling as many fish as possible in special regulation waters, managers should make every effort to inform and educate anglers on how to reduce mortalities of released fish. Our research has led us to several suggestions fishery managers may make to anglers.

(1) Use artificial flies and lures rather than artificial baits in fly-and-lure-only waters because baits, even if artificial, cause much higher incidence of critical hooking and lead to higher mortalities.

(2) Fish actively with all types of bait and set the hook immediately when a fish strikes the bait, thereby reducing the numbers of critically hooked fish.

(3) Cut the leader on all critically hooked fish. Removal of a hook embedded in the gills or deep in the esophagus will almost always do more damage than leaving it in place.

(4) Use extra care when water temperatures are high. Higher water temperatures increase mortality.

(5) Avoid touching the gill arches, and avoid tissue damage when removing a hook, even if the fish is hooked only in the lip or jaw. Bleeding intensity increases mortality.

(6) Leave the fish in the water. Length of time out of water is about twice as deadly to a fish as length of time played.

(7) Play the fish as quickly as possible. Exhaustive exercise can sometimes be lethal to a fish.

(8) Handle smaller fish very gently. Damage to internal organs is much more likely with small fish, and they have less ability to recover from such injuries.

Acknowledgments

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