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Effect of catch-and-release angling on growth and survival of rainbow trout, *Oncorhynchus mykiss*

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Abstract Catch-and-release angling is popular in many parts of the world and plays an increasingly important role in fish conservation efforts. Although survival rates associated with catch-and-release angling are well documented for many species, sublethal effects have been less studied. An experiment was conducted to directly assess the effects of catch-and-release angling on growth and survival of rainbow trout, *Oncorhynchus mykiss* (Walbaum). Catch-and-release events were simulated in laboratory tanks maintained at 15–16 °C with hooks manually placed in pre-designated locations in the mouths of the fish. There were no differences in standard length ($P = 0.59$) or wet weight ($P = 0.81$) gained between caught and uncaught fish over a 1-month angling and recovery period. Survival was 96.99 ± 0.06% for rainbow trout caught and released, and did not vary with number (one, two or four) of captures. Thus, catch-and-release angling appears to have little effect on growth and mortality of rainbow trout hooked in the mouth.

KEYWORDS: angling effects, growth, *Oncorhynchus mykiss*, weight.

Introduction

Energy obtained by fish is allocated among competing physiological processes, including metabolism, somatic growth and reproductive development (Calow 1985). Physical stress from handling can increase a fish's metabolic and maintenance demands for energy (Pankhurst & Van Der Kraak 1997). Stress also can disrupt feeding behaviour of fish (Beitinger 1990; Schreck, Olla & Davis 1997; Gregory & Wood 1999). Consequently, physical injuries (Fulmer & Ridenhour 1967; Meka 2004) and disturbance associated with catch-and-release angling (Stockwell, Diodati & Armstrong 2002; Siepker 2005) may inhibit short-term feeding by released fish. In combination, these varied responses by fish to stressors associated with catch-and-release angling might divert energy that otherwise could have been used for somatic or gonadal growth. The ultimate effects of stress on fish from catch-and-release angling are likely to vary with the severity and duration of the stressor(s), as well as with species, size, age and condition of fish.

Catch-and-release angling has increased in popularity in many places, including the USA (Barnhart 1989; Muoneke & Childress 1994), Australia (McLeay, Jones & Ward 2002) and Europe (Aas, Thaling & Ditton 2002) and plays an increasingly important role in fishery management (Hickley, Marsh & North 1995; Maitland 1995; Quinn 1996). Many salmonid anglers voluntarily practice catch-and-release as a conservation measure intended to maintain fishery quality. However, the success of catch-and-release angling to meet various angler and management goals requires that a substantial proportion of fish not only survive (Muoneke & Childress 1994) but continue to thrive after release.

The survival rates associated with catch-and-release angling are well documented for many species and are influenced by a number of factors, primarily temperature and hooking location (Muoneke & Childress 1994). However, potential sublethal effects of catch-and-release angling are less studied. The physiological responses of fish to stresses associated with capture, handling, air exposure and release were described by Wydoski (1977), Gustaveson, Wydoski & Wedemeyer (1991) and Cooke, Schreer, Wahl & Philipp (2002). Direct examinations of the effects of catch-and-release angling on growth were completed by Raat, Klein Breteler & Jansen (1997) and Pope & Wilde (2004) for five cyprinids and one centrarchid, fishes generally considered insensitive to handling stress. The effects of catch-and-release angling on growth and survival of

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salmonids, a group of fishes generally considered more sensitive to handling stress, have not been thoroughly evaluated. This paper reports results of an experiment designed to assess the effects of multiple catch-and-release angling events on growth and survival of rainbow trout, *Oncorhynchus mykiss* (Walbaum).

Materials and methods

Rainbow trout 167- to 263-mm standard length (SL) were obtained on 19 March 2005 from the Colorado Division of Wildlife Mt Shavano Fish Hatchery and transported in an aerated hauling tank to an indoor laboratory. Fish were allowed 2 weeks to acclimate to the laboratory, which had a 14 h:10 h light–dark photoperiod. Fish were then anaesthetised with 100 mg L^{-1} MS-222, implanted with a passive integrated transponder (PIT) tag following the methods of Prentice, Hernandez, Shaw & Wienecke (1991), measured (mm SL), weighed (g) and randomly placed into one of four aquaria at a density of approximately one fish per 15 L. Water temperature was maintained at 15–16 °C with the aid of two heater–chiller units placed in a 1995-L reservoir. A recirculating system connected all experimental aquaria to the reservoir and provided water flow in each aquarium. A pump distributed water from the reservoir into each of the experimental aquaria; return flow was established with a siphon in each aquarium. Additional aeration was supplied through airstones in each of the experimental aquaria. A biofilter, consisting of lava rocks placed within a bucket with an airstone to aid water flow through the filter, was placed in each experimental aquarium to maintain water quality. In addition, 23–39% of the total volume of water in the system was replaced twice daily. Rainbow trout were fed floating pellets daily, with a goal of providing fish all they could consume in 5 min.

Fish were not handled in one of the four aquaria (negative control). Fish in the other three aquaria were randomly assigned a handling treatment of one (1×), two (2×) or four (4×) times; and rainbow trout within these aquaria were randomly assigned to receive a hooking or sham hooking (positive control) for each handling event. For each handling event, all rainbow trout in an aquarium were netted and placed into an aerated 190-L round aquarium separate from the recirculating system. Rainbow trout were then netted one at a time, scanned with a PIT-tag reader to identify the individual and designate the hooking location and hooked by hand with a size 4 barbed octopus hook in the predetermined site. Location for hooking within the mouth was randomly determined using a diagram of the fish mouth that was slightly modified from Pelzman (1978) (Fig. 1). No fish was hooked in the oesophagus or gills because these areas often result in high mortality rates for trout (Mason & Hunt 1967; Taylor & White 1992; Schisler & Bergersen 1996; Lindsay, Schroeder, Kenaston, Toman & Buckman 2004). Handling time, including hooking, ranged from 9 to 108 s. Rainbow trout were then returned to their experimental aquarium and played using a 1.2-m, medium-action rod with a 3.6-kg test monofilament line (playing time ranged from 0 to 295 s). Each rainbow trout was played until it could easily be handled by gently grasping the trout around the midsection or until the fish threw the hook. Captured rainbow trout were removed from the water, the hook was removed from the fish using needle-nose pliers and the fish was released back into the aquarium (de-hooking time ranged from 0 to 87 s). Positive control rainbow trout received the exact same handling until hooking; these fish were then given a sham hooking and released back into the aquarium. The

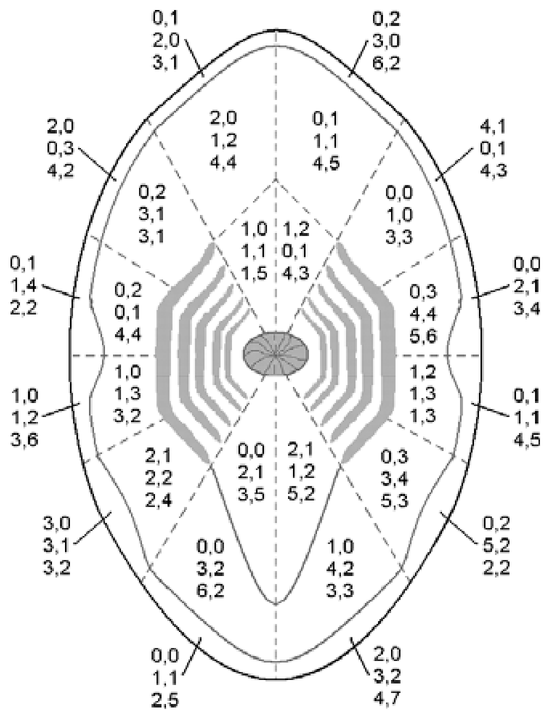

Figure 1. Schematic of fish mouth (modified slightly from Pelzman, 1978) identifying locations in which fish were hooked. Individual hook location was randomly determined for the 28 areas in the mouth that included roof and floor of mouth, tongue, mandible and maxilla. Numbers for each mouth area represent number of times a hooking event occurred for the respective location; the left column is the number of hookings and the right column is the number of sham hookings with one (1×), two (2×) and four (4×) handling and hooking events provided in the top, middle and bottom rows, respectively, for each location.

sham hooking consisted of touching the fish's mouth in a randomly selected site with a hook on which the point was bent in a circle back toward the shaft.

Handling events occurred twice a week for 2 weeks. After the final handling event, rainbow trout were maintained for an additional 2 weeks. Then, all rainbow trout were killed in 1 g L^{-1} MS-222, scanned with a PIT-tag reader to identify the individual, measured and weighed. For a statistical analysis, aquaria were treated as blocks and individual fish as the experimental unit. An analysis of variance was used to assess differences in growth between caught and uncaught fish within blocks (compare treatment with positive control) and among blocks (compare positive control with negative control). Data were normally distributed and, therefore, did not require transformation. Because sample sizes varied among aquaria and, especially, between caught and uncaught fish, type III sum of squares was used. Statistical significance was set at $\alpha = 0.05$.

Results

Overall, there was no difference in growth between control and hooked rainbow trout, as measured by increased length and weight (Fig. 2). Among control fish, there was no significant difference in length ($P = 0.98$) or weight ($P = 0.83$) gained with the number of times fish were handled. Among hooked fish, there was no significant difference in length ($P = 0.59$) or weight ($P = 0.81$) gained with the number of times fish were hooked. Within each handling treatment (i.e. aquarium), there was no significant difference in length (1×, $P = 0.58$; 2×, $P = 0.74$; 4×, $P = 0.54$) or weight (1×, $P = 0.20$; 2×, $P = 0.79$; 4×, $P = 0.84$) gain between hooked and sham-hooked rainbow trout.

All negative control fish survived. Survival rates for handled rainbow trout were 100 ± 0% for 1× and 2× and 96 ± 4% for 4×. Survival rates of hooked and released trout were 92 ± 5%, 100 ± 0% and 96 ± 4% for 1×, 2× and 4× treatments respectively. Adjustment for losses of positive control fish (Wilde, Pope & Strauss 2003) indicates that hooking survival was 96.99 ± 2.47% for rainbow trout hooked in the mouth.

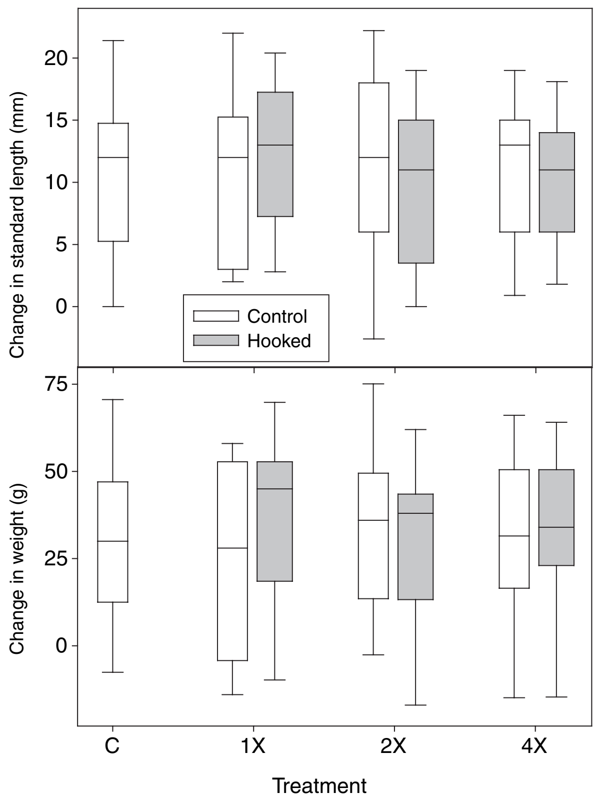

Figure 2. Differences in growth in standard length (top panel) and weight (bottom panel) of rainbow trout. The box encloses the 25th and 75th percentiles, the vertical bars denote the 5th and 95th percentiles, and the horizontal line in each box represents the sample median. Results are plotted separately for control (open boxes) and hooked (shaded boxes) rainbow trout in each treatment (i.e. the number of times fish were handled during the experiment). C = negative controls (not handled during angling and recovery period); 1×, 2× and 4× are one, two and four handling and hooking events respectively.

Discussion

Survival of captured and released fish varies substantially among species (Muoneke & Childress 1994) and many observations suggest that sublethal effects of catch-and-release angling are also variable. For example, Raat *et al.* (1997) and Pope & Wilde (2004) observed no effect of capture and release on growth of five cyprinids and largemouth bass, *Micropterus salmoides* (Lacepède) respectively. In contrast, Clapp & Clark (1989) observed diminished growth in repeatedly captured smallmouth bass, *Micropterus dolomieu* Lacepède, and Diodati & Richards (1996) documented negative effects of catch-and-release angling on growth of striped bass, *Morone saxatilis* (Walbaum). Based on results of this study, catch-and-release angling has no effect on growth of rainbow trout that are hooked in the mouth and maintained in 15–16 °C water. Likewise, Jenkins (2003) found no difference in growth of control rainbow trout and rainbow trout hooked with several types of barbless hooks that were removed. However, Jenkins (2003) did find reduced growth among rainbow trout hooked with barbless J-hooks that were left in the fish (i.e. line was cut) compared with control fish.

High survival and minimal effects on growth are necessary for caught and released individuals to obtain trophy size. Multiple captures of individual fish are common in some trophy trout fisheries (Nuhfer & Alexander 1992). Schill, Griffith & Gresswell (1986) documented that adult cutthroat trout, *Oncorhynchus clarkii* (Richardson), were recaptured an average of 10 times during one fishing season in an area with substantial fishing pressure. In contrast to Clapp & Clark (1989) who found growth of individual smallmouth bass was inversely related to the number of times they were captured, this study supports the hypothesis that adult salmonids can be captured multiple times with high survival and no effect on growth rates. However, fish condition factors may be reduced for salmonids with serious jaw injuries, even when these injuries are healed (Fulmer & Ridenhour 1967).

Post-release survival of fishes varies with the anatomical location in which the fish are hooked (May 1973; Pelzman 1978; Jenkins 2003; Lindsay *et al.* 2004), which is at least partly related to the bait or lure used and the presentation technique. All of the fish captured in the present study were intentionally hooked in locations for which survival is generally high (>95%), because the primary interest was measuring sublethal effects that cannot be assessed on dead fish. Survival of rainbow trout captured with spinners containing either barbed or barbless single or treble hooks was >96% (Dubois & Dubielzig 2004), and survival of rainbow trout captured with barbless single hooks that were removed, and barbless single and treble hooks that were not removed (i.e. line was cut) was ≥98% (Jenkins 2003). Survival of rainbow trout caught by trolling different gears, which captured fish at different depths, varied from 84.7% to 97.8% with the greatest survival occurring for fish caught on gear in shallow water (Dedual 1996). No difference existed in return rates, a surrogate of survival, between non-hooked migrating sea-run rainbow trout and migrating trout that had been hooked, played to exhaustion and released (Reingold 1975). Thus, field studies support the conclusion that the survival rate for hooked and released rainbow trout is generally high.

Although results of this study provide experimental evidence that catch-and-release angling has no effect on growth of rainbow trout hooked in the mouth, physiological responses of salmonids to stress vary with life stage (Sumpter, Carragher, Pottinger & Pickering 1987). This study only assessed effects of catch and release on growth of young adult, non-spawning rainbow trout, preventing speculation as to whether differences in growth might have occurred between caught and un-caught rainbow trout at different life stages, especially if captured during periods of post-spawn and smoltification (e.g. Reingold 1975). Campbell, Pottinger & Sumpter (1992) repeatedly stressed adult rainbow trout over 9 months, using 3 min of air exposure at random times as the stressor, and found no difference in somatic growth between stressed and control rainbow trout. However, they did find that gonadal growth (i.e. sperm count and egg size) was reduced for stressed rainbow trout, resulting in delayed ovulation and reduced survival of progeny. Similarly, Contreras-Sanchez, Schreck, Fitzpatrick & Pereira (1998) found a reduction in progeny size of rainbow trout that were stressed prior to spawning during late ovarian development.

There are several limitations to the analysis that warrant mention. First, length and wet weight may not be the most appropriate measures of growth (Busacker, Adelman & Goolish 1990). Fish that do not feed or that have the inability to assimilate food may still maintain length and maintain or increase weight in the short term by increasing tissue water content (Brett 1979). Second, the experimental subjects used were domesticated animals that likely have acclimated to handling and, therefore, may have been less affected by handling stress than wild conspecifics (Vincent 1960; Woodward & Strange 1987). Nonetheless, hatchery fish used in this experiment were not exempt from stress response as three fish died after experiencing a catch-and-release event. In a comparison of wild and hatchery-reared rainbow trout subjected to catch-and-release stress, Wydoski, Wedemeyer & Nelson (1976) determined that blood chemistry differences were more severe for hatchery fish, and they theorised that the wild rainbow trout were more physically fit and therefore more able to deal with catch-and-release stress than hatchery-reared conspecifics. Further, Casillas & Smith (1977) determined that wild rainbow trout required less time to recover from catch-and-release stress than did hatchery fish. Third, the experimental environment was a laboratory setting in which fish were provided a daily ration of prepared food and maintained at a relatively constant temperature. Nonetheless, the experimental design provided insights into sublethal effects from catch-and-release angling that would have been difficult to elucidate from an uncontrolled field study. Regardless, further tests on wild rainbow trout in natural environments will be critical for greater understanding of the sublethal effects of catch-and-release angling.

This work was based on the paradigm that physiological responses of fish to stressful stimuli is cumulative (Donaldson 1981; Wedemeyer, McLeay & Goodyear 1984; Barton, Schreck & Sigismondi 1986); and, thus, survival from catch-and-release angling decreases from the additive responses to multiple non-lethal stresses. However, much of the mortality associated with deeply hooked rainbow trout is a result of punctures to the heart or liver (Mason & Hunt 1967). In several assessments of catch-and-release survival (e.g. Diodati & Richards 1996; Schill 1996), authors noted that mortality events generally occurred quickly (< 12 h) after the capture event, which likely were the result of a fatal wound to a vital organ. These findings suggest that short-term hooking mortality results when a stress-severity threshold is exceeded, such as a mortal wound to the heart that results in excessive internal bleeding. Furthermore, reduced fish survival occurred in the two studies that documented negative effects of catch-and-release angling on growth of fishes (Clapp & Clark 1989; Diodati & Richards 1996). In contrast, high fish survival occurred in the two studies that documented no effects of catch-and-release angling on growth of fishes (Pope & Wilde 2004; this study). Collectively, these studies suggest that sublethal effects of catch-and-release angling are negatively correlated with catch-and-release survival. This correlation is perhaps caused by hooking condition, as described by Diodati & Richards (1996). Thus, ideal hooking conditions (e.g. trout hooked with a single hook in the mouth region, captured from shallow, cool water and handled carefully) would result in 100% survival and no reduction in growth. In contrast, unfavourable hooking conditions (e.g. trout hooked with a treble hook in the oesophagus or gills, captured from deep or warm water and not handled carefully) would result in low hooking survival and a reduction in growth for fish surviving the event. However, these studies combined provide no insight about the nature (e.g. linear, curvilinear or quadratic) of the relationship between survival and sublethal effects or the causal mechanism. Greater insight will be gained through examining intermediate responses in this correlation. Thus, three models with competing intermediate responses are proposed (Fig. 3). When tested, these models should provide greater understanding of the mechanism(s) causing a reduction in individual fish growth and other sublethal effects associated with catch and release.

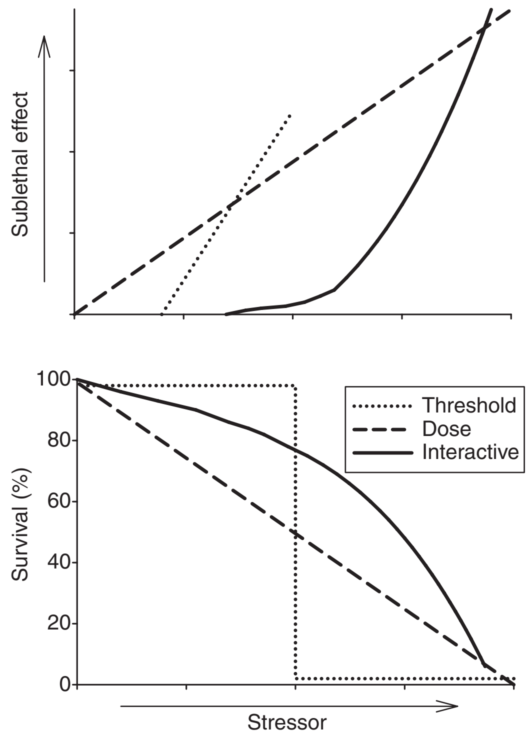

Figure 3. Three competing hypothesised relationships between sublethal effects (including the range of primary, secondary and tertiary responses, such as elevated plasma concentrations of cortisol, altered plasma concentrations of glucose and reduced gonadal and somatic growth) and hooking survival with increasing severity of stressor(s) (including a mortal wound and other injuries) from catch-and-release angling. The cumulative threshold and simple dose models suggest that sublethal and lethal effects on fish are additive (i.e. linear) and dependent on the intensity and number of stressors. In contrast, the interactive model suggests that effects on fish are multiplicative (nonlinear) and depend on interactions between stressors.

Variation in catch-and-release survival exists among salmonids (Muoneke & Childress 1994). It appears that survival generally is less for rainbow trout than for Atlantic salmon, *Salmo salar* Linneaus, brook trout, *Salvelinus fontinalis* (Mitchill), brown tout, *Salmo trutta* Linnaeus, chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), coho salmon, *Oncorhynchus kisutch* (Walbaum), cutthroat trout and lake trout, *Salvelinus namaycush* (Walbaum), although assessments have been completed under a variety of conditions. If survival is less for rainbow trout, then based on the negative correlation between sublethal effects and survival described above, the greatest reduction in growth is also expected for rainbow trout. Given that there were no negative effects of catch-and-release angling on growth of rainbow trout hooked in the mouth, no negative effects on growth are expected for other salmonids hooked in the mouth.

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