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The Influence of Terminal Tackle on Injury, Handling Time, and Cardiac Disturbance of Rock Bass

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Abstract.—We studied the effects of catch-and-release angling on rock bass *Ambloplites rupestris,* a small but common centrarchid species in North America. A field study of hooking injury and mortality was conducted in Lake Erie at a water temperature of 16°C. We captured fish using one of four terminal tackle types: barbless worm, barbed worm, barbless jig, and barbed jig. No mortality was observed in any of the four treatments even after holding fish for 5 d. Fish captured using worms were hooked more deeply than fish caught on jigs. Fish captured on barbless jigs were unhooked most easily and more rapidly than with all other tackle types, resulting in an average of only 20 s of air exposure. Because they were more difficult to remove from the hook, fish captured on other terminal tackle experienced at least twice as much air exposure. To assess sublethal effects, we measured the cardiac responses of rock bass exposed to 30 s of simulated angling followed by 30 or 180 s of air exposure. These air exposure durations were intended to simulate the conditions faced by fish that were either easy or difficult to remove from the hook. Fish experienced arrhythmia during angling, although overall cardiac output increased. Fish experienced severe bradycardia during air exposure, but after being returned to the water, all fish exhibited elevated cardiac output. Fish exposed to 30 s of air exposure required 2 h for full recovery, whereas those exposed to 180 s of air required 4 h. During periods of cardiac disturbance, increases in cardiac output were due to both heightened heart rate and stroke volume. Our results suggest that hooking mortality did not vary with bait or hook type and that physiological disturbance of rock bass was influenced by the duration of air exposure, as influenced by bait and hook choice. We recommend that anglers attempt to minimize handling and air exposure of angled fish and keep pliers or other hook removal devices readily accessible to facilitate rapid release of fish not intended for harvest.

Panfish, including small centrarchids, are commonly angled and released (Coble 1988), and in some cases represent important recreational fisheries. These fishes are relatively easy to catch by anglers of all abilities and are frequently landed as both intentional and incidental catches. To date, assessments of angling induced injury, stress, and mortality have been concentrated on more popular game fish species, in particular, salmonids and centrarchids of the genus *Micropterus* (Barnhart 1989; Muoneke and Childress 1994). Rock bass *Ambloplites rupestris* are one of the most commonly captured panfish species in the Great Lakes basin of North America (Scott and Crossman 1979; Panek 1981; Storr et al. 1983). This species is generally regarded to be a tenacious and vigorous fighter during angling (Jenkins and Burkhead 1994), although they are known to tire quickly (Becker 1983). Despite their high abundance and capture frequency, there is no information on the effects of catch-and-release angling for this species.

Based on limited information on hooking injury and mortality for other panfish mortality rates for rock bass may be quite high (Muoneke and Childress 1994). Reported hooking mortality rates for centrachids have varied: 19–77% for black crappies *Pomoxis nigromaculatus* (Childress 1989), 3–29% for white crappies *Pomoxis annularis* (Childress 1989; Colvin 1991; Hubbard and Miranda 1991; Muoneke 1992a), 0–88% for bluegills *Lepomis macrochirus* (Burdick and Wydoski 1989; Siewert and Cave 1990; Muoneke 1992b), 11–38% for small (<320 mm) largemouth bass *Micropterus salmoides* (Rutledge 1975; Pelzman 1978; Rutledge and Pritchard 1977), and 0–11% for smallmouth bass *M. dolomieu* (Clapp and Clark 1989).

Although we have a basic understanding of the

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reasons why some fish that do not die immediately from hooking injuries may still die after catch-and-release angling (Wood et al. 1983), there have been few studies of the sublethal physiological effects of catch-and-release angling specifically on panfish. Different terminal tackle types may affect the ease of hook removal and influence air exposure durations. The effects of air exposure and handling are also poorly understood for panfish and most other nonsalmonid fishes (See Ferguson and Tufts 1992; Mitton and McDonald 1994a, 1994b). Studies examining the physiological effects and recovery of fish based on hematology and muscle biochemistry are common for important game fish; however, studies assessing real-time recovery are more limited. Recently, researchers have used electromyogram transmitters (Cooke et al. 2000), heart rate transmitters (Anderson et al. 1998), and cardiac output devices (Schreer et al., in press) to assess the real-time disturbances and recovery following angling-induced stress. Studies that integrate field and laboratory studies are also rare.

We examined angling-induced stress in rock bass by means of complementary field and laboratory studies. Using two bait (jig, worm) and hook (barbed, barbless) types in the field, we assessed the physical injury, short-term hooking mortality, and handling time of angled rock bass in Lake Erie. In the laboratory, we assessed cardiac disturbance and recovery patterns of rock bass exposed to simulated angling and various air exposure treatments. We hypothesized that different terminal tackle types would alter air exposure duration and that these differences would alter the time required for cardiac recovery.

Methods

All fish used for this study were captured in the forebay of the Nanticoke Thermal Generating Station on Lake Erie. The forebay is supplied with water via two intakes in the lake. The forebay has an abundant population of rock bass and provides a secure site that is monitored continuously for temperature. Additional site descriptions are included in Wiancko (1981).

Field study.—The gear and angling methods chosen were intended to reflect common tactics used by anglers. Discussions with tackle shop proprietors, fisheries enforcement staff, and anglers revealed two baits that were commonly used to fish for rock bass in Lake Erie: ⅛-oz jig heads baited with 2-in plastic grubs and live dew worms baited on number-4 hooks. Although most anglers in Lake Erie probably use barbed hooks, we wanted to determine if barbless hooks reduced handling time and injury.

Over a 3-d period, 80 rock bass were caught, 20 per angled treatment. Once hooked, rock bass were brought directly to the angler and landed after 30 s. The rock bass became exhausted quickly, allowing for easy handling. The location of the hook was measured from the anterior aspect of the (lower) lip to the deepest point of hook penetration (Dunmall et al. In Press). The anatomical hooking location was recorded as either being the upper lip, lower lip, roof of mouth, floor of mouth, tongue, nose, cheek, or gullet. Hook removal difficulty was characterized by the relative degree of difficulty in removing the hook. If hemostats were required, or if the line had to be cut, it was categorized as ‘‘difficult.’’ Hooks that slipped out easily with little force or could be removed without hemostats were categorized as ‘‘easy.’’ Once the hook was removed, the amount of bleeding was noted as absent, slight, or heavy, and the total length of the fish was measured. Because the location of the hook penetration was recorded relative to the total length of the fish, a comparison of hook penetration depth was possible among fish of different sizes. We also recorded the amount of time that fish were held out of the water (±15 s), not including processing or tagging procedures. The fish were then tagged using individually numbered anchor tags inserted on the left side of the fish between the spiny and soft dorsal fins. Tags were assumed to have no effect on the survival of rock bass (Tranquilli and Childers 1982; Noltie 1986).

Once processed, fish were placed in covered coolers for a maximum of 30 min before being released into a 12-m^3 holding pen ($2 \times 2 \times 3$ m) that was submerged in the forebay at a minimum of 1 m below the surface of the water. The temperature and dissolved oxygen content of the water in the holding pen were measured twice daily at a depth of 1.5 m. Both the coolers and the retention cages had a continuous influx of fresh water from Lake Erie, which reduced the risk of confounding mortality estimates with the effects of stagnant water and degraded water quality. Fish were held for 120 h in the holding pen, and mortality was assessed at 24, 48, 72, 96, and 120 h after capture. In addition, all fish were examined for disease or injury before their release into the forebay.

Because barbless and barbed hooks probably would not influence the depth of hooking or the location of hooking, we grouped worm and jig treatments to assess differences in hooking depth and location. Two-sample *t*-tests were used to compare the depth of hooking; contingency table analysis was used to examine the distribution of hooking locations (Zar 1996). Pearsons correlations were used to assess the influence of fish size on the length-corrected hooking depth for jigs and worms. For the remainder of the analysis all four treatments were compared independently. Contingency table analysis was used to assess the influence of the four treatments on the amount of bleeding and the ease of hook removal. The influence of terminal tackle on air exposure duration was assessed using a one-way analysis of variance (ANOVA). The conservative Tukey post hoc analysis (Day and Quinn 1989) was used when results were significant, and ANOVA was used to test for differences in fish sizes among the four treatments.

Laboratory study.—Rock bass ($N = 18$) angled from Lake Erie were held at a mobile field station for a minimum of 5 d before experimentation. Water temperatures at capture were 16 ± 1°C. Fish were held, under natural photoperiod conditions, in a 1,000-L flow-through tank continuously supplied with lake water.

Fish were anaesthetized before surgery in 60 mg clove oil/L (emulsified with 9 parts ethanol : 1 part clove oil) until they lost equilibrium and were nonresponsive (about 5 min; Anderson et al. 1997; Keene et al. 1998). The anaesthetized fish was placed on its side on a wetted sponge; anaesthetization was maintained during surgery by irrigating the gills with water containing 30 mg clove oil/L. An oval shaped plastic cover was placed behind the first gill arch, and the gills and the operculum were held open to expose the area underneath. The ventral aorta was usually visible just posterior to the first gill arch at the point where the gill arch begins to run anteriocaudally. The connective tissue surrounding the vessel was carefully removed using blunt forceps. A flexible silicone cuff-type Doppler flow probe (subminiature 20 MHz piezoelectric transducer; Iowa Doppler Products, Iowa City, Iowa), sized to match the diameter of the vessel, was placed around the aorta. Internal diameter of the cuffs ranged from 1.1 to 1.6 mm. Using a flowmeter (545C–4 Directional Pulsed Doppler Flowmeter; Bioengineering, The University of Iowa, Iowa City) and a digital stripchart recorder (LabVIEW, version 4.0.1; National Instruments Corporation, Austin, Texas), the cuff was checked for adequate signal strength and subsequently secured around the vessel with a single suture. The lead wire from the probe was then sutured to the skin just anterior to the origin of the pectoral fin. The length of lead wire from the cuff to this first suture was slack so that muscular movements would be unlikely to alter the position of the cuff. Three to five additional sutures were used to secure the wire to the body wall. The entire procedure took 15–30 min for each fish.

The Doppler transducer emits a pulsed sonic signal that is reflected from a moving object in the blood (e.g., a red blood cell), which results in a signal frequency shift. This shift in frequency represents a velocity and is measured as a change in voltage. Peaks in voltage (velocity) represent a heart beat and counting peaks per unit time yields heart rate (HR). The mean voltage per unit time is an index of flow or cardiac output (CO). Flow can also be calculated directly in milliliters per unit time (see postmortem calibration section). The quotient of CO divided by HR yields stroke volume (SV).

Following surgery, individual fish were placed immediately into a 70-L tank (50 × 50 cm) and monitored until they had regained equilibrium. Fish were allowed to recover from surgery and to acclimate to the tank for at least 12 h. A darkened area covering approximately 30% of the tank provided cover and ensured that fish were not disturbed by general laboratory activity. The experimental tanks were continuously supplied with lake water.

To simulate exhaustive angling, fish were chased around the tank by hand (Ferguson and Tufts 1992) for 30 s. While being chased, the fish exhibited several rapid bursts of activity and within approximately 20 s became fatigued; at this point they would no longer swim and began to lose equilibrium. Fish were then removed from the water and exposed to the air for either 30 ($N = 6$) or 180 ($N = 6$) seconds while being held horizontally by hand (one hand holding the mouth, the other gently supported the ventral body surface). Cardiac parameters were recorded continuously for at least 1 h before the simulated angling (resting), during the angling simulation, and for at least 6 h of postangling recovery. An additional group of control fish ($N = 6$) were maintained in tanks during the air exposures experienced by the other groups of fish but were not chased nor exposed to air.

Following experimentation, fish were euthanatized with an overdose of anesthetic (180 mg clove oil/L clove oil), and a postmortem calibration was conducted to convert Doppler shift to flow (mL/min). For this calibration, the head, including the pericardial cavity, was removed. The pericardial cavity was opened with a caudalventral incision

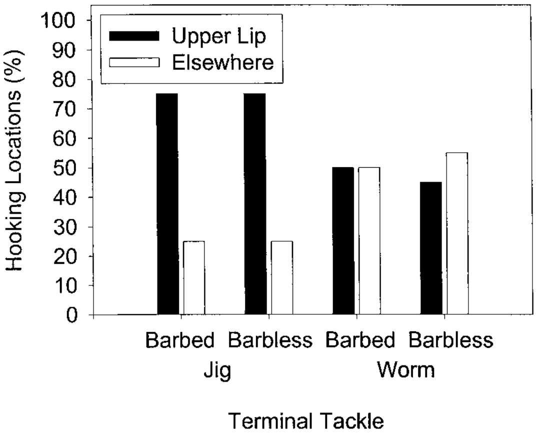

FIGURE 1.—Anatomical hooking location of rock bass captured in Lake Erie by angling with four types of terminal tackle: barbless jig, barbed jig, barbless worm, and barbed worm. Fish were classified as being hooked in the upper lip or in other locations (i.e., lower lip, roof of mouth, floor of mouth, tongue, nose, cheek, or gullet).

to expose the heart. The sinus venosus, atrium, and ventricle were removed and the bulbus arteriosus was catheterized with polyethylene (PE-100) tubing for perfusion of the ventral aorta. Using a constant infusion pump (Harvard Apparatus, South Natick, Massachusetts), anticoagulated blood (2 g sodium oxalate + 0.4 g sodium chloride + 10 mL distilled water per liter cows' blood) was perfused through the aorta to calibrate the probes over a range of flow rates encompassing those recorded during the trials. Reference flow rates were analyzed with linear least-squares regression.

To determine recovery times, traces for CO, HR, and SV were adjusted to resting (100%), plotted for each fish, and evaluated visually. A fish was considered to be recovered when values returned to resting and became stable (within 10% of resting values). The maximal disturbance was determined as the highest value attained during the recovery period. Effects of air exposure duration (30 and 180 s) on cardiac recovery and maximal disturbance were assessed with two sample *t*-tests. The maximum change in cardiac output during the experimental treatment and 5-h recovery period was also calculated for control fish ($N = 6$). All statistical tests were conducted using Systat, version 7.0 (Wilkinson 1997) and significance was evaluated at $\alpha = 0.05$.

Results

Field Study

Rock bass were angled over a 3-d period ($N = 80$, mean total length ± SE = 207.1 ± 2.9 mm). The 20 fish captured by each of the four terminal tackle types had similar total lengths ($F = 2.08$, df = 76, $P = 0.11$). Fish captured using the jig (both barbed and unbarbed) were most frequently hooked in the upper lip (Figure 1), whereas fish captured on worms (barbed and unbarbed) were hooked in the upper lip at a rate similar to all other locations combined (hereafter referred to as ''other locations''). Fish captured on worms were more frequently hooked in other locations than in the upper lip ($\chi^2 = 5.33$, df = 2, $P = 0.02$) than were fish caught on jigs. The only fish hooked in the gullet were captured using worms.

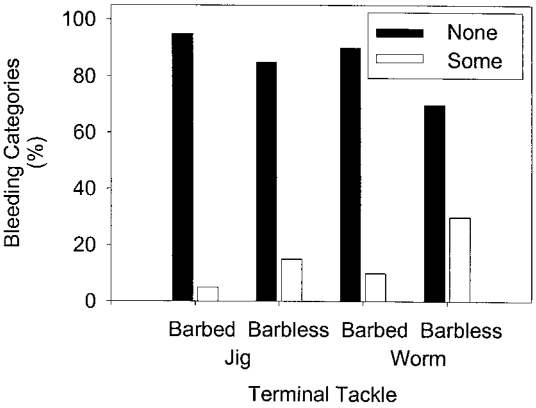

FIGURE 2.—Proportion of rock bass that either bled (''some'') or did not (''none'') after being angled in Lake Erie by four types of terminal tackle (as described in Figure 1).

No heavy bleeding was observed in any of the captured fish. Slight bleeding was observed most frequently in the barbless–worm catch (30%) and least frequently in the barbed–jig catch (5%; Figure 2). The hook–bait treatments did not significantly alter the frequency of bleeding ($\chi^2 = 5.49$, df = 2, $P = 0.15$). The length-corrected hooking depth did not vary between the barbed and barbless catch by either jigs ($t = -0.41$, df = 38, $P = 0.69$) or worms ($t = -1.26$, df = 38, $P = 0.21$), so we grouped hook types to compare the hooking depth of the two bait types. Fish captured using worms were hooked more deeply (length-corrected hooking depth ± SE = 8.64 ± 1.34) than those captured using jigs (4.69 ± 0.58; $t = -2.71$, df = 78, $P = 0.01$). The size of the fish was not correlated to the depth of hooking for either jigs ($r = -0.13$, df = 38, $P = 0.43$) or worms ($r = 0.00$, df = 38, $P = 0.99$).

The terminal tackle type affected the ease of hook removal ($\chi^2 = 9.07$, df = 2, $P = 0.03$; Figure 3) and, hence, the duration of air exposure ($F =$

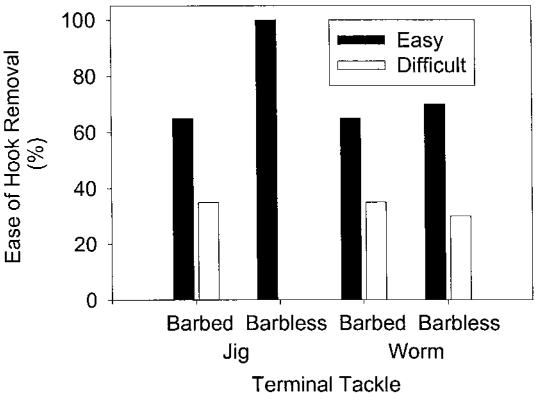

FIGURE 3.—Ease of hook removal for rock bass angled in Lake Erie (terminal tackle codes as described in Figure 1). Hooks removed from the fish without a need for hemostats or significant force were termed "easy," whereas those requiring the use hemostats or cutting of the line were classified as "difficult."

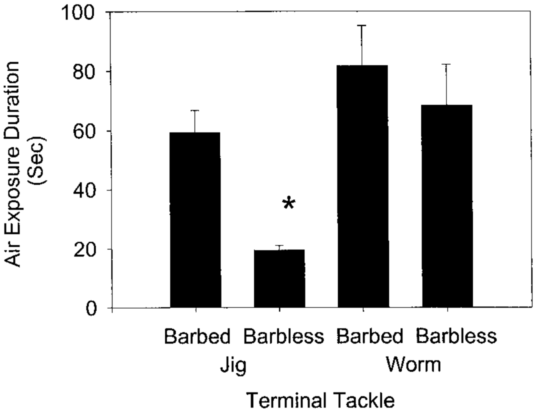

FIGURE 4.—Mean air exposure duration (+SE) for rock bass angled in Lake Erie (terminal tackle codes as described in Figure 1). Air exposure was recorded and did not include time for measuring and tagging. The asterisk denotes significant difference from other treatments.

6.69, df = 76, P < 0.001; Figure 4). Barbless jigs were removed from all fish within 30 s (mean ± SE = 19.5 ± 1.6 s); the resultant air exposure for fish caught on this tackle was significantly less than all other terminal tackle ($P < 0.007$; Figure 4). Hook removal for fish captured on barbed jigs on average took 40 s more than the unbarbed jigs (59.3 ± 7.5 s). The barbless–worm catch averaged 68.5 ± 13.7 s to remove the hook, and the barbed–worm catch took the most time (81.8 ± 13.5 s). The barbed–worm catch were also the most difficult to remove from the hook, being held out of water an average of 48-s longer than fish caught on the barbless jig. No immediate, short-term, or delayed (5 d) mortality was observed for any of the fish captured using any of the four hook–bait treatments.

Laboratory Study

Fish in each of the three laboratory treatments were of similar weight ($F = 0.064$, df = 15, $P = 0.938$) and total length ($F = 0.272$, df = 15, $P = 0.766$). When combined, mean (±SE) weight and total lengths were 331.9 ± 22.5 g and 226.5 ± 4.1 mm. Reference flow rates determined from postmortem calibrations had a mean r^2 of 0.96 ($N = 18$). Resting values at 16°C averaged 10.4 ± 1.1 mL · min^{-1} · kg^{-1} for CO, 48.7 ± 3.3 beat/min for HR, and 0.179 ± 0.012 mL/kg for SV.

No mortality was observed among fish used in the experiments. Fish responded as expected to the simulated angling, exhibiting a series of rapid swimming bursts. By the end of the chasing period, fish were visibly exhausted, to the point that they could be easily grasped by hand and removed from the tank. Most fish remained motionless during air exposure, probably because they were being held by the lower lip. Cardiac output increased during simulated angling, but was somewhat arrhythmic and then fell drastically (bradycardia) during air exposure. Heart rate fell to less than 5 beats/min during air exposure. Fish held out of the water for 180 s exhibited reduced cardiac output for the entire period. Upon being returned to the water, fish that were exposed to air for 30 s resumed upright swimming immediately and usually experienced hyperactivity for several seconds. Fish exposed to air for 180 s required up to 60 s to regain equilibrium. During the experiment, control fish exhibited little activity and were relatively unresponsive to activity around the tanks, and their cardiac parameters remained stable, usually within 10% of basal levels.

Fish exposed to air for 180 s required more time for cardiac measurements to recover than fish exposed for 30 s (Figure 5). Recovery from angling and air exposure was characterized by a rapid increase in CO, followed by a gradual decline. Recovery time for CO was shorter for the 30-s treatment (range 64–120 min) than for the 180-s treatment (range 186–340 min; $t = -5.00$, df = 10, $P = 0.004$). Heart rate followed a similar pattern. Fish in the 30-s treatment (70–130 min) recovered more rapidly than those in the 180-s treatment (140–350 min; $t = -2.74$, df = 10, $P = 0.03$). Recovery times for stroke volume after 30 s of

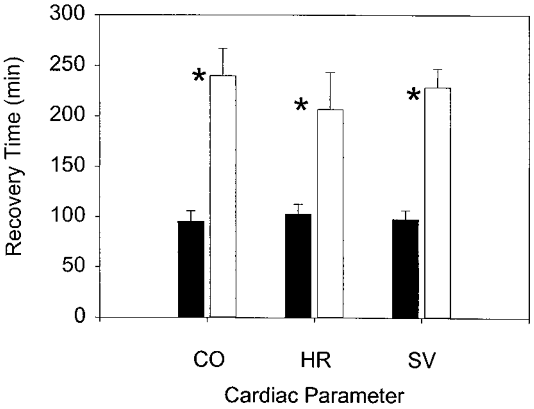

FIGURE 5.—The influence of 30 s of simulated angling and variable air exposure periods (short = 30 s, shaded bars; long = 180 s, unshaded bars) on rock bass held at 16°C, as examined by the mean duration of recovery for three cardiac measures. Significant differences between air exposure periods within a cardiac measure ($P < 0.05$) are denoted by asterisks.

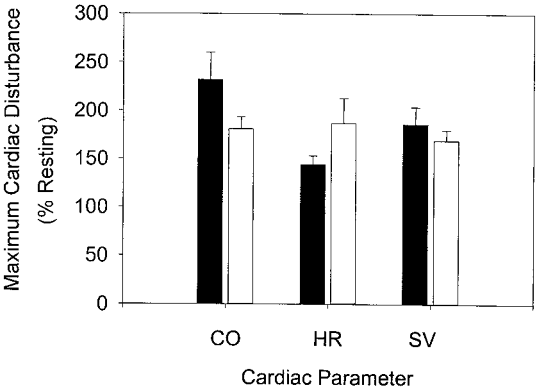

FIGURE 6.—The influence of 30 s of simulated angling and variable air exposure periods (short = 30 s, shaded bars; long = 180 s, unshaded bars) on rock bass at 16°C, as examined by the maximum increase in three cardiac measures during the recovery. No significant differences ($P < 0.05$) were found.

exposure ranged from 75 to 115 min and from 180 to 290 min after 180 s of exposure. Stroke volume returned to basal levels more rapidly in fish exposed for 30 s than for 180 s ($t = -6.450$, df = 10, $P = 0.001$).

The maximal increase of cardiac measurements over basal levels was highly variable among both treatments. Mean maximal cardiac output was not significantly different between the 30-s and 180-s treatments ($t = 1.64$, df = 10, $P = 0.16$; Figure 6). Maximal cardiac output after air exposure ranged from 162% to 303% in the 30-s treatment and from 160% to 205% for 180-s treatment. Mean maximal heart rate did not differ significantly between the 30-s (118–175%) and 180-s (140–245%) treatments ($t = -1.54$, df = 10, $P = 0.20$). Mean maximal stroke volume also did not differ significantly between the 30-s (140–185%) and 180-s (150–200%) treatments ($t = 0.81$, df = 10, $P = 0.45$).

Discussion

The degree of damage, bleeding, handling time, and mortality is usually lower among fish captured on barbless hooks than on barbed hooks (Muoneke and Childress 1994); however, there is rarely a difference in the point of hook penetration (e.g., Falk et al. 1974; Falk and Gillman 1975). Although no mortality was observed in our study, fish captured on barbless hooks were easier to unhook than those caught on barbed hooks, as effected by the barb rather than anatomical hooking location. There were also no significant differences in the amount of bleeding between barbed and barbless hooks. Barbed hooks did, however, increase handling time and air exposure.

Anatomical location of hooking did not influence mortality, as observed in other studies (May 1973; Pelzman 1978; Dunmall et al. in press). Siewert and Cave (1990) reported 100% mortality in bluegills hooked in the esophagus, gills, tongue, or eye, whereas mortalities were less than 40% for those hooked in the jaws and lips. Only four of the rock bass captured in our study were hooked in the esophagus and the hooks were not removed from these fish. Hooking mortality may have been minimized by not attempting to remove deeply ingested hooks; other studies have found that removal of these hooks increased mortality. For example, mortality was 33% less for Atlantic salmon *Salmo salar* when deeply ingested hooks were not removed (Warner and Johnson 1978; Warner 1979), and was 60% less for rainbow trout *Oncorhynchus mykiss* (Mason and Hunt 1967). Weidlein (1989) also reported up to a 43% increase in mortality for smallmouth bass that had deeply ingested hooks removed rather than left in the fish. No fish in our study were hooked in the gills or other vital organs, which may help to account for the lack of observed mortality.

We assumed that if a fish was easily removed from the hook, it could be returned to the water within 30 s and that if a fish was hooked deeply or removal tools were not readily available, then handling would be longer, approaching 180 s. Fish held for photography may be handled and exposed to air for even longer periods (Ferguson and Tufts 1992; Muoneke and Childress 1994). The two air exposure times we selected for our laboratory study were longer than we experienced in our field study, but nevertheless probably reflected normal angling release times. For this study, we had hemostats and scissors readily available so that upon capture, fish could be removed from the hook and processed as rapidly as possible. Other researchers have reported that inexperienced anglers handled fish cautiously, leading to extended periods of air exposure and subjecting fish to additional stress (Newman and Storck 1986).

Although we observed no mortality in our study, others have reported more latent mortalities in fish exposed to exercise and air. Ferguson and Tufts (1992) report that both exercise and brief air exposure affected the survival of rainbow trout after 12 h. In their study, no control fish died, 12% of exercised fish died, and those exposed to exercise and air exposures of 30 and 60 s experienced 38% and 72% mortality, respectively. Although the effects of air exposure on fish have been rarely addressed, previous studies suggest significant physiological and behavioral implications of air exposure. This is further exacerbated when combined with exhaustive exercise, as is common with catch-and-release angling.

Anatomical changes in the gills may occur during air exposure, including collapse of the gill lamellae and adhesion of adjacent gill filaments (Boutilier 1990; Mitton and McDonald 1994a). Ultrastructural changes reduce available gill surface area and inhibit gas exchange in the primary respiratory exchange organ (Hughes 1984). Brief air exposure of rainbow trout, for example, causes an almost complete inhibition of gas exchange across the gills (Ferguson and Tufts 1992). Additionally, the effects of prolonged air exposure may alter swimming performance of rainbow trout (Mitton and McDonald 1994b). The combined effects of air exposure and angling may also increase nest abandonment by male smallmouth bass (Philipp et al. 1997) and decrease the locomotory activity of nest-guarding male largemouth bass (Cooke et al. 2000a).

Although there have been no physiological studies of cardiac performance of rock bass, studies have been conducted on other closely related species, but most of these have not focused on basal cardiac values. Basal values reported here for rock bass cardiac output are the first reported for this species. At similar water temperature (16°C), rock bass CO and SV were approximately 33% and 20% of the values reported for smallmouth bass (Schreer et al., in press). Rock bass heart rate, however, was 1.5 times higher than that of the smallmouth bass (Schreer et al., in press). Bidwell and Heath (1993) held rock bass and pumpkinseeds *Lepomis gibbosus* in cages and found no appreciable change in the variables examined, suggesting that the basal cardiac output values reported here are probably similar to free-ranging fish in the wild.

Sutterlin (1969) examined the effects of exercise on the cardiac and ventilation frequency of pumpkinseeds at 20°C. During 10 min of forced exercise (1 body length/s) in a respirometer, the heart rate increased to approximately 128% of resting levels (less of a response than we observed in rock bass). The heart rate stabilized and then decreased gradually over 60 min to preexercise levels of approximately 75 beats/min. This basal heart rate value for pumpkinseeds at 20°C was greater than the 49 beats/min that we observed for rock bass at 16°C. Ventilation rates of pumpkinseed doubled during exercise, followed by a rapid decline during the first 5 min of recovery.

Heath and Pritchard (1962) swam bluegill to severe exhaustion (mean swimming duration 11 min at 20°C) in a respirometer. Following exercise, fish remained motionless for several hours, (as has also been noted by Scarabello et al. 1991), despite having high metabolic rates (165% of resting levels) during the recovery period. In our study, cardiac output increased more than the increase in metabolic rate that was reported by Heath and Pritchard (1962), even though our water temperatures were 4°C lower. The oxygen debt incurred by the fish during exercise was probably being repaid during this period (Gaesser and Brooks 1984; Scarabello et al. 1991). Because recovering fish remain motionless or experience impaired swimming performance (Mitton and McDonald 1994b), they may be more vulnerable to predation.

None of the fish we angled in the field study or chased in the laboratory study died as a result of the exercise or air exposures, which suggests that these levels of exercise and air exposure are not severe enough to cause death. However, increases in water temperature (Muoneke and Childress 1994; Wilde 1998), air exposure duration, or both may have caused mortality. The disturbance encountered from air exposure probably would have been more extreme if the fish were not restrained during air exposure. We held fish by the lower mandible and then gently gripped and supported the fish from the ventral surface, so the fish were fairly calm during handling. Had the fish been allowed to flail, physiological disturbance would have increased.

Our results indicate that short-term mortality is not the best indicator of the total effect of catch-and-release angling. Another recent study suggests that initial mortality is not an appropriate indicator of delayed mortality in black bass tournaments (Wilde 1998). Furthermore, some authors have argued that simple mortality assessment is not an appropriate indicator of the success of catch-and-release angling programs. Assessments of catch-and-release angling should also focus on sublethal effects and, in particular, fitness-related effects (Cooke et al., in press). Although mortality was negligible in our field study, the laboratory study identified differences in recovery attributed to variable handling and air exposure times. Although this study is not exhaustive in its assessment of factors that may increase mortality or physiological disturbance (e.g., higher water temperatures, longer air exposure), it does highlight the need to undertake more comprehensive studies of the effects of catch-and-release angling. Incorporating field and laboratory studies will ensure that the methodologies utilized more accurately reflect the type of gear and handling experienced by wild fish during angling. Although our results will probably not produce widespread policy or regulatory revisions, they will hopefully reaffirm the need to educate the angling public on the rapid and humane handling of all fish species. Similarly, all practitioners of fisheries science that commonly handle fish in the laboratory or field should heed the same advice and attempt to minimize air exposure and recognize the recovery costs associated with prolonged exposure. Our results also suggest that hemostats or pliers are an important tool for catch-and-release anglers. Managers may wish to consider regulations that require anglers to possess and have quick access to appropriate devices to enhance rapid and safe removal of hooks from fish. Perhaps these devices could eventually be viewed as standard gear for all anglers.

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