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Injury and Mortality Induced by Four Hook Types on Bluegill and Pumpkinseed

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Abstract.—Tackle manufacturers have responded to concerns regarding hooking injury and mortality by attempting to design and market hooks that are less damaging to fish (e.g., circle hooks). To date, studies investigating circle hooks have been primarily restricted to large marine species. We compared the injury and short-term (72-h) mortality of bluegills *Lepomis macrochirus* and pumpkinseeds *L. gibbosus* angled using number-6 circle hooks and three other conventional hook types (aberdeen, wide-gap, and baitholder) across three water temperatures (18, 22, and 26°C). Unlike other hook types, circle hooks were never lodged in the gullet, but they were frequently lodged in the eye. Some fish captured on conventional hooks were hooked deeply in the gullet, necessitating line cutting for release. Incidences of bleeding were low using all hook types, and when not lodged in the gullet, all hooks were generally easy to remove. Anatomical hooking locations differed among small (<145-mm) and large (>145-mm) bluegills for all hook types but not among pumpkinseeds. Hooking depth differed between small and large fish of both species captured on circle hooks; smaller fish were hooked more deeply. Mortality in both species was negligible at all water temperatures except for bluegills at 26°C (3% mortality). Bluegills that died were smaller than those that survived. Our results confirm the supposition that circle hooks are less susceptible to deeply hooking fish in the gullet. However, circle hooks permanently impaired vision of up to 22% of the fish, much more than for other hooks types. Although efficient at minimizing injury and mortality in marine fish, our study suggests that circle hooks perform similarly to more conventional hook types in fisheries for small sunfish.

The most common type of catch-and-release studies are assessments of hooking injury and mortality (Muoneke and Childress 1994). These studies generally attempt to describe and quantify the factors that contribute to injury and mortality and provide direction to minimize negative effects. Based upon the findings of this body of research and their subsequent dissemination to stakeholders, hooking mortality rates across species have generally been lowered to 10% or less (Muoneke and Childress 1994). Still, managers and anglers alike devote efforts and resources to further min-

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imize this mortality. To date, studies have examined the role that water temperature (Wilkie et al. 1997; Wilde 1998), angling duration (Schreer et al. 2001), air exposure duration (Ferguson and Tufts 1992; Cooke et al. 2001), and handling play in sublethal physiological effects (Cooke et al. 2002) and mortality (Muoneke and Childress 1994) of many species. In addition, the type of bait (lure, fly, organic; Clapp and Clark 1989; Cooke et al. 2001), presence of a barb (Titus and Vanicek 1988; Cooke et al. 2001), angler expertise (Dunmall et al. 2001), hook size (Burdick and Wydoski 1989; Weidlein 1989), and hook types (McEachron et al. 1985; Titus and Vanicek 1988) have also been examined with regard to both degree of injury and hooking mortality (Muoneke and Childress 1994).

Tackle manufacturers have been quick to respond to opportunities to further reduce mortality. A recent effort consistent with this goal is the development and vigorous marketing of circle hooks to anglers. Circle hooks are more circular in shape than the typical J hook (straight shank), with the point facing perpendicular to the hook shank (Soucie 1994). Although an ancient design (Soucie 1994), the circle hook has recently been used extensively in longline and trotline fisheries in marine (McEachron et al. 1985; Woll et al. 2001) and freshwater (Ott and Storey 1993). More recently, marine recreational anglers have begun to use these hooks (Montrey 1999), and use is quickly expanding into the freshwater market (Stange 1999). Studies have clearly documented reduced hooking mortality associated with this design in both longline (McEachron et al. 1985) and marine angling (Grover et al. 2002; Prince et al. 2002; Skomal et al. 2002) fisheries. Fish were frequently hooked in the upper maxilla, and circle hooks rarely penetrated vital tissues or organs (i.e., gills, gullet, eye). Circle hooks do not require aggressive hook sets, experience fewer snags, make it more difficult to hook oneself, and fish rarely shake free once hooked. To date, all circle hook studies have focused on large marine fishes. Anecdotal reports emanating from tackle manufacturers and media outlets (Montrey 1999; Stange 1999) indicate that circle hooks are also effective for freshwater fishes, although a quantitative rigorous assessment is lacking.

The hooking injury of small centrarchid fishes has been well studied due to their abundance in many freshwater systems and because of their recreational value. The bluegill *Lepomis macrochirus* is a popular hard-biting and hard-fighting (Scott and Crossman 1973) panfish targeted by anglers for both catch-and-release fishing and for harvest. Anglers harvesting fish often return smaller individuals to the water (Coble 1988). For this reason, several studies have investigated the hooking mortality of this species, focusing on bait type and water temperature (Burdick and Wydoski 1989; Siewert and Cave 1990; Muoneke 1992). The congeneric pumpkinseed *L. gibbosus*, which fight strongly and erratically (Scott and Crossman 1973), are also commonly captured and released by anglers. Pumpkinseeds, however, have not received the same level of study, with regards to the effects of catch-and-release, as have bluegill. In fact, we were unable to locate any studies that focused on pumpkinseeds.

The purpose of this study was to compare the hooking injury and mortality of bluegills and pumpkinseeds angled with circle hooks and three other conventional hook types (aberdeen, baitholder, and wide-gap). By comparing a species that is well studied with regards to catch-and-release (bluegill) with a species that has never been examined (pumpkinseed), we hoped to draw on previous research while extending our understanding of hooking injury and mortality to a new species. Because hooking mortality can vary with water temperature (Muoneke and Childress 1994), we replicated the experiment at three water temperatures (18, 22, and 26°C).

Methods

Field site.—All angling experiments and retention of fish were conducted in Lake Opinicon, Ontario. Lake Opinicon is a mesotrophic natural lake in eastern Ontario with abundant populations of rock bass *Ambloplites rupestris*, largemouth bass *Micropterus salmoides*, smallmouth bass *Micropterus dolomieu*, bluegills, and pumpkinseeds. Angling was conducted from a 4-m barge or from docks that extended into the lake to a depth of at least 1 m. Experiments were conducted on May 18, June 6, and June 15, 2001, when the respective water temperatures were 18, 22, and 26°C. Due to natural variation in water temperatures (both temporally and spatially), we conducted experiments during periods when middepth water temperatures in the enclosure used for the hooking mortality study were within 1°C of the desired water temperature. These slight variations in water temperature are minimal relative to natural conditions that would be faced by free-swimming fish in other parts of the lake.

Experimental protocol.—We used four commer-

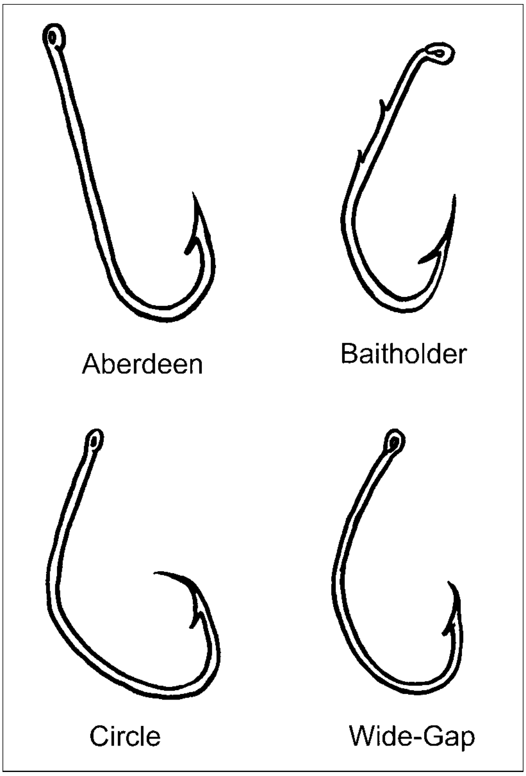

FIGURE 1.—Drawings of the four different hook types used in our study of hooking injury and mortality of bluegills and pumpkinseeds.

cially available hook types that are frequently used by anglers to target bluegills and pumpkinseeds (Figure 1): baitholder hook (size 6, bronze, offset, down eye; Model 3181UK, Eagle Claw Inc.), aberdeen hook (size 6, gold, light wire, ringed eye; Model 3202UK, Eagle Claw Inc.), circle hook (size 6, black and chrome, curved in point, mutu light; Model 5114–051, Owner Inc.), and wide bend (size 6, bronze, plain shank, offset, ringed eye; Model L042, Eagle Claw Inc.). All anglers used the same organic bait (Crappie Nibbles, silver glitter, Berkley Inc.) that measured 5 $\times$ 5 mm and weighed about 0.2 g each. Only one Crappie Nibble was used on an individual hook at any one time. All anglers fished with spring floats (3/8'' [10-mm] Pencil, 6'' [152-mm] stem) placed about 0.75 m above the hook. A single 3/0 lead split shot was placed 0.15 m above the hook. Anglers used both spinning and spin cast reels, but all anglers used medium action rods and 6-lb test line. Anglers rotated the rods at 10-min intervals to ensure that all participating anglers used different hook types.

Anglers were instructed to cast the bait and let the weight and Crappie Nibble settle until the float was upright. The anglers were then told to wait for the float to go under before collecting slack line and gently pulling up on the rod. Instructions on circle hook packaging indicated that strong hook sets were not required. This is atypical for other hook types so we opted for a light hook-set to satisfy all hook types. If upon setting the hook, a fish was on the line the angler reeled in the fish. We standardized the duration of time that the fish was reeled in to 15 s. This interval was sufficient to ensure that all fish could be easily landed without creating undue exhaustion.

We operated a two-person sampling crew that was responsible for the hook removal, handling, and enumeration of all fish that were captured. The same two individuals recorded the response variables for all fish to ensure consistency. Anglers immediately brought angled fish to the sampling crew. If the crew was occupied with another fish, the angler held the fish in a 10-L cooler for up to 1 min before enumeration. *Lepomid* hybrids and other nontarget species were returned to the lake without enumeration.

The sampling crew first determined the anatomical location of the hook (upper jaw, lower jaw, roof, eye, or gullet). The location of hook penetration was measured from the anterior aspect of the lower lip to the most posterior point of hook penetration (Dunmall et al. 2001). Hook type and species identity were also recorded. Ease of hook removal was categorized using slight modifications to the criteria proposed by Cooke et al. (2001). If hemostats were required to remove the hook, removal was categorized as ''difficult.'' If removal of the hook was not possible using hemostats, without causing substantial injury, the line was cut and removal was categorized as ''not possible.'' If hooks could be removed by hand with little effort, removal was categorized as ''easy.'' After categorizing ease of hook removal, the crew looked for the presence of blood and recorded responses as either ''none'' or ''some.'' Fish were also measured for total length (mm). We corrected the depth of hook penetration to total length to permit a comparison of hook penetration depth among fish of different sizes (Dunmall et al. 2001). Anglers were queried as to the number of casts required before a fish was successfully hooked and landed. We termed this the relative hooking difficulty index. Lower relative hooking difficulty values indicate that a particular hook is performing better. The index was reset to zero when the angler successfully landed a fish. Fish were sufficiently abundant and easy to catch that patchiness or angler ability were not considered to be important.

Pumpkinseed and bluegill were provided with a binary spine clip combination so that we could identify individuals. Including removal of hook and enumeration, air exposure durations were less than 60 s. Fish were then placed into a 300-L holding tank supplied with ambient lake water for no more than 2 h, at which time they were transferred, using a knotless nylon dip net, to a 16-m^3 enclosure in the lake. The bottom of the enclosure encompassed part of the littoral zone with its accompanying food sources. Floating macrophytes and scattered rock provided cover for the fish. The enclosure was monitored for 72 h for the presence of dead or severely injured fish. Moribund individuals were removed from the enclosure and inspected for binary clip pattern to determine identity.

Analysis.—Continuous data were not transformed because they were determined to be normally distributed with homogeneous variances. Homogeneity of variance assumptions were assessed using Levene's test, and normality was verified using normal probability plots and the Shapiro–Wilk test statistic (W). Differences in total length, depth of hook penetration, and relative hooking difficulty index values among different water temperatures and hook types were assessed for each species using two-way analysis of variance (ANOVA). When differences were observed, we used Fisher's least significant difference to compare means.

Categorical data were analyzed with logistic regressions and contingency tables. For each categorical (dependent) variable of bleeding, anatomical hooking location, and ease of hook removal, the factors included as independent variables in the analysis were the effect of water temperature and hook type. Logistic regressions were restricted to main-effects comparisons because of the sparsity of data in some categories when the combined effects of all factors in the analysis were included. Although this may be a limitation, this approach has been used elsewhere (Dunmall et al. 2001) in situations where main-effects comparisons were the focus of the study.

We explored size-specific differences in hooking depth and anatomical hooking location between two size-classes of bluegills and pumpkinseeds: small ($\leq$145 mm) and large ($>$145 mm). We generated length frequency distributions that were bimodal and crudely separated fish into large and small modes. The cutoff that we chose was also similar to the median total length values for each species. We compared hooking depths of small and large fish for each species and hook type using t-tests. We also compared, using contingency table analyses, the distributions of anatomical hooking location of fish in the two size-classes for each species and hook type. To increase power of these analyses, all water temperatures were pooled.

Mann–Whitney U-tests were used for exploring differences in hook penetration depths and sizes (continuous variables) of fish that died versus those that survived the 72-h retention period. Although data were normal and homogeneous, sample sizes were substantially different, necessitating the nonparametric approach. Chi square analysis was used to test for differences in the distribution of hooking locations, incidences of bleeding and ease of hook removal (categorical variables) between fish that died versus those that survived the 72-h retention period. All analyses were conducted using JMP 4.0 (SAS Institute, Inc.) and Systat 7.0 (SAS Institute, Inc.). All values reported are means $\pm$ SE. All tests were assessed for significance at $\alpha = 0.1$ to minimize type II errors. Data are reported separately for bluegills and pumpkinseeds, and formal comparisons between the two species were not conducted.

Results

Bluegills

We angled 685 bluegills across the three water temperatures (Table 1). Total lengths of the fish were similar across all temperatures and hook types (ANOVA: $F_{11,\,673} = 0.864$, $P = 0.550$). Relative hooking difficulty differed significantly among hook type and water temperatures ($F = 1.983$, $P = 0.072$). At 18°C, aberdeen hooks had a higher relative hooking difficulty index than circle hooks (Tukey's test, $P = 0.064$) and wide-gap ($P = 0.002$) hooks, and at 26°C, circle hooks had a higher hooking difficulty index than aberdeen hooks ($P = 0.053$; Figure 2).

Hooking location was influenced by water temperature ($\chi^2 = 26.93$, df = 8, $P < 0.001$) (Figure 3) and hook type ($\chi^2 = 36.30$, df = 12, $P < 0.001$; Figure 4). In general, fish were hooked most frequently in the upper jaw (low of 34.29% for circle hooks to high of 47.40% for baitholder hooks) and roof of the mouth (low of 32.37% for baitholder hooks to high of 42.78 for aberdeen hooks; Figure 4). Circle hooks had the highest incidence of eyehooking (22.8% or about twice as high as other

TABLE 1.—Number, mean total length (TL), and standard error (SE) of bluegills and pumpkinseeds angled at three different water temperatures (18, 22, and 26°C) using four different hook types (aberdeen, baitholder, circle, and wide-gap).

Water temperature (°C)	Hook type	Bluegill			Pumpkinseed		
		N	Mean TL (mm)	SE	*N*	Mean TL (mm)	SE
18	Aberdeen	50	141	4.3	8	171	12.6
	Baitholder	45	151	3.7	10	166	10.9
	Circle	36	138	3.6	11	183	7.9
	Wide-gap	36	143	3.9	7	173	13.6
22	Aberdeen	63	140	3.6	12	160	8.8
	Baitholder	59	139	3.8	11	165	13.1
	Circle	57	147	3.7	28	171	6.4
	Wide-gap	53	135	3.3	4	150	15.4
26	Aberdeen	74	140	4.2	18	157	8.4
	Baitholder	69	143	4.9	18	166	5.3
	Circle	82	143	2.9	18	155	6.4
	Wide-gap	61	137	3.9	30	149	4.6

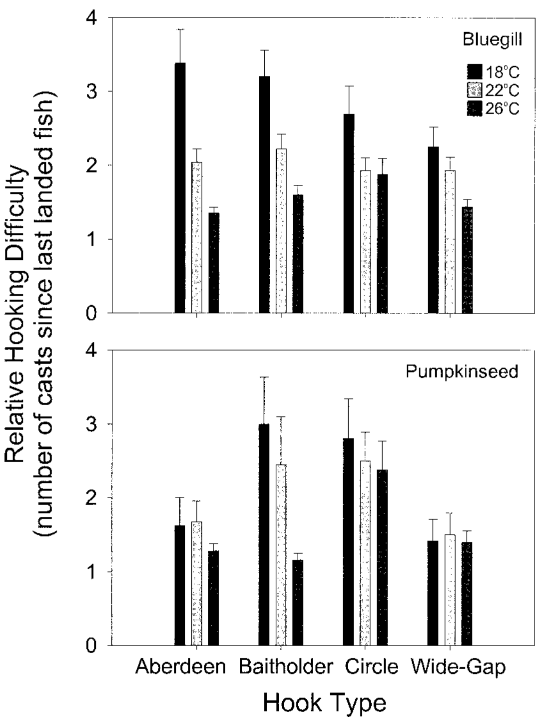

FIGURE 2.—Relative hooking difficulty of bluegills (top panel) and pumpkinseeds (bottom panel) for four different hook types (aberdeen, baitholder, circle, and wide-gap) and three water temperatures (18, 22, and 26°C). Relative hooking difficulty is the number of casts required to hook a fish with a specific hook type. Bars represent mean values; error bars represent the positive standard error.

hooks) and the lowest incidence of gullet hooking (0%). Gullet hooking rates for other hook types were about 4%. The depth of hook penetration did not vary with temperature and hook type (Figure 5; ANOVA: $F_{11,\ 673}$ = 0.688, P = 0.661). Incidences of bleeding were uniformly low (from 2.7% for wide-gap hooks to 5.1% for circle hooks) and were not influenced by water temperature (χ^2 = 0.01, df = 2, P = 0.939) or hook type (χ^2 = 1.50, df = 3, P = 0.683). Both hook type (χ^2 = 17.99, df = 6, P = 0.006) and water temperature (χ^2 = 27.25, df = 4, P < 0.001) influenced the ease of hook removal; however, most hooks (about 80%) were usually easy to remove. Circle hooks were the only hook type that was never assigned to the removal category ''not possible.''

For small (<145-mm) and large (>145-mm) bluegills, the distribution of anatomical hooking locations differed significantly for all hook types: aberdeen (χ^2 = 14.04, df = 4, P = 0.007), baitholder (χ^2 = 13.39, df = 4, P = 0.010), circle (χ^2 = 6.94, df = 4, P = 0.074), and wide-gap (χ^2 = 21.23, df = 4, P < 0.001). Smaller fish were consistently hooked in the eye more frequently than larger fish for all hook types: aberdeen (18.0% small, 5.4% large), baitholder (18.9% small, 4.8% large), circle (27.6% small, 16.9% large), and wide-gap (13.6% small, 1.6% large). Conversely, larger fish were consistently hooked in the gullet more frequently than smaller fish for all hook types except circle hooks, which hooked no fish of any size in the gullet hooked: aberdeen (1.8% small, 6.8% large), baitholder (2.2% small, 7.2% large), and wide-gap (0.0% small, 9.7% large). The depth of hook penetration did not differ among the two size-classes for aberdeen (t = −0.15, df = 183,

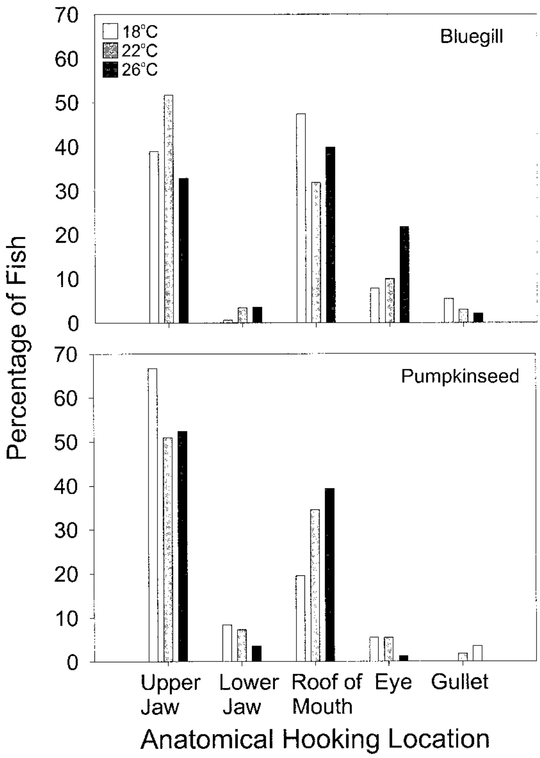

FIGURE 3.—Anatomical hooking location of bluegills (top panel) and pumpkinseeds (bottom panel) captured at three water temperatures (18, 22, and 26°C). Data for all hook types (aberdeen, baitholder, circle, and wide-gap) were pooled for each temperature.

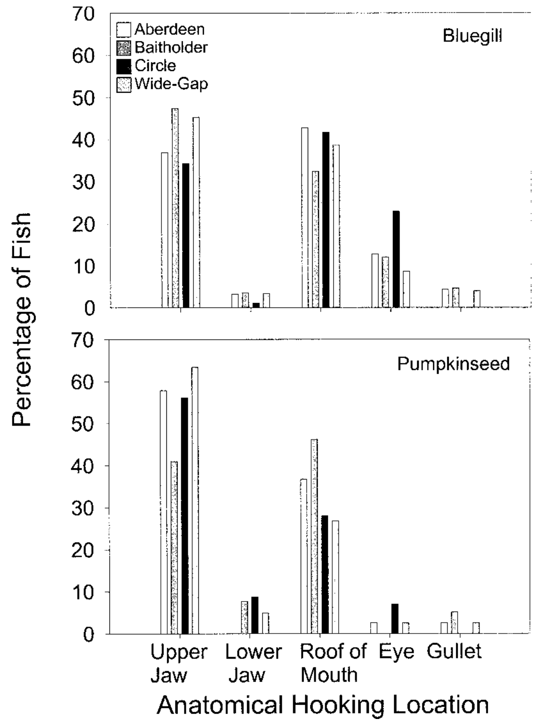

FIGURE 4.—Anatomical hooking location of bluegills (top panel) and pumpkinseeds (bottom panel) captured with four different hook types (aberdeen, baitholder, circle, and wide-gap). Data for all water temperatures (18, 22, and 26°C) were pooled for each hook type.

$P = 0.880$, $N = 111$ small, $N = 74$ large), baitholder ($t = -1.08$, df = 171, $P = 0.283$, $N = 90$ small, $N = 83$ large), or wide-gap hooks ($t = 0.33$, df = 148, $P = 0.741$, $N = 88$ small, $N = 62$ large; Figure 6). However, the depths of hook penetration for circle hooks were deeper in small fish (0.058, $N = 98$) than in large fish (0.049, $N = 77$; $t = -2.30$, df = 173, $P = 0.022$).

No fish died immediately following angling or before being introduced into the enclosure. Nine bluegills died—all captured at 26°C—and most of those died within 12 h of retention (Table 2). At 26°C, bluegill hooking mortality was 3.2%, and over all temperatures this translates to a total of 1.3% hooking mortality for all of the bluegill that we angled during our study. All bluegills that survived appeared healthy after the 72-h retention period and did not exhibit fungal lesions or fin erosion.

Bluegill that died at 26°C were significantly smaller (mean TL ± SE = 123 ± 10 mm, $N = 9$) than those that survived (141 ± 2 mm, $N = 277$) the 72-h retention period ($U = -2.03$, df = 284, $P = 0.042$). Depth of hooking was similar among fish that died (0.064 ± 0.011, $N = 9$) and lived (0.054 ± 0.002, $N = 277$; $U = 0.78$, df = 284, $P = 0.434$). Similarly, ease of hook removal ($\chi^2 = 2.81$, df = 2, $P = 0.245$) and hooking location ($\chi^2 = 5.96$, df = 4, $P = 0.202$) did not differ significantly between fish that died or survived. Bleeding, however, was more prevalent in fish that died (22.2%, $N = 9$) than in those that survived (5.24%, $N = 277$; $\chi^2 = 2.87$, df = 1, $P = 0.091$).

Pumpkinseeds

We angled 175 pumpkinseeds across the three water temperatures (Table 1). Total lengths of the fish were similar among hook types (ANOVA: $F_{3,\,171} = 1.033$, $P = 0.37$); however, total length decreased significantly with increasing water temperature ($F_{2,172} = 6.866$, $P = 0.010$). Fish captured at 26°C (Tukey' test, $P < 0.001$) and 22°C ($P < 0.013$) were smaller than those captured at 18°C. The relative hooking difficulty index differed among water temperatures (ANOVA: $F_2 = 3.115$,

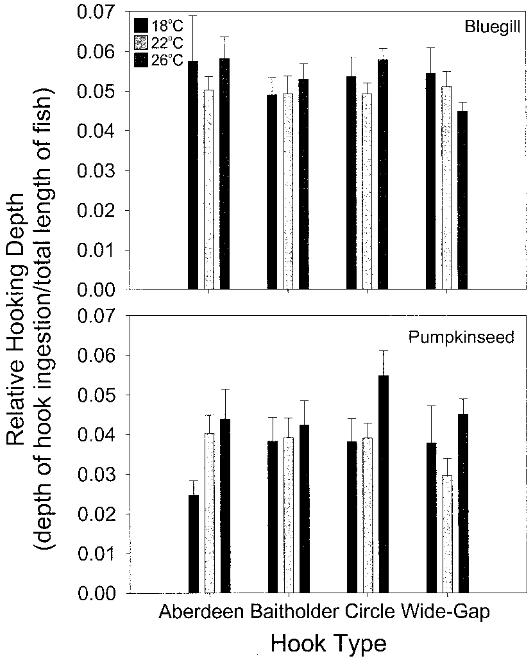

FIGURE 5.—Relative depth of hook penetration for all sizes of bluegills (top panel) and pumpkinseeds (bottom panel) for four different hook types (aberdeen, baitholder, circle, and wide-gap) and three water temperatures (18, 22, and 26°C). Relative hooking depth is the depth of hook ingestion divided by the total length of the fish. Bars represent mean values; error bars represent the standard error.

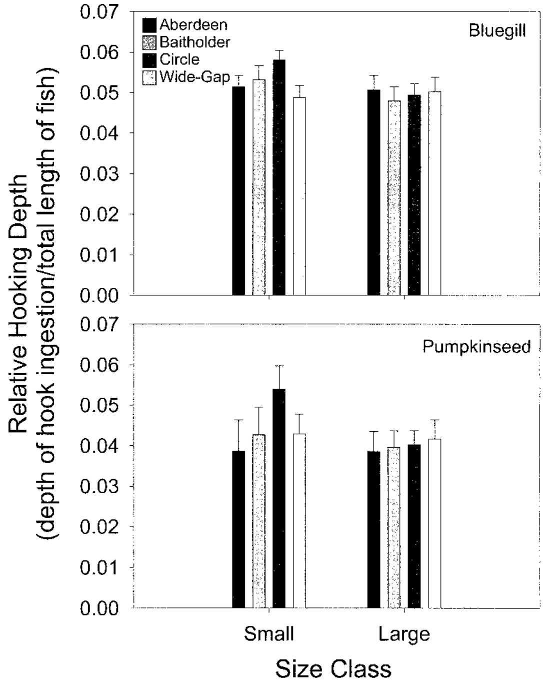

FIGURE 6.—Relative depth of hook penetration in small (<145-mm) and large (>145-mm) bluegills (top panel) and pumpkinseeds (bottom panel) by four different hook types (aberdeen, baitholder, circle, and wide-gap) that are pooled over three water temperatures (18, 22, and 26°C). Relative hooking depth is the depth of hook ingestion divided by the total length of the fish. Error bars represent the standard error; bars represent mean values.

$P = 0.047$) and hook type ($F_3 = 5.207$, $P = 0.002$), and the interaction term suggests that individual factors were independent ($F_{6,\ 174} = 1.198$, $P = 0.310$; Figure 2). Overall, circle hooks had significantly higher relative hooking difficulty index values than aberdeen (Tukey's test, $P < 0.001$) and wide-gap ($P < 0.001$) hooks, and baitholder hooks had significantly higher index values than aberdeen hooks ($P = 0.043$). Hooking difficulty index values were higher at 18°C than at 26°C ($P = 0.022$) (Figure 2).

Hooking location was influenced by water temperature ($\chi^2 = 8.30$, df = 8, $P = 0.081$; Figure 3) and hook type ($\chi^2 = 18.59$, df = 12, $P = 0.050$; Figure 4). In general, most hooking locations were in the upper jaw (from 41.03% for baitholder hooks

TABLE 2.—Fish and hooking data for nine bluegills that died during a 72-h posthooking retention period at 26°C; bluegills were held in a 16-m^3 enclosure in the lake from which they had been caught.

Hook type	Total length (mm)	Hook location	Bleeding	Ease of removal	Hooking depth	Posthooking death at (in hours)
Baitholder	108	Upper jaw	None	Easy	0.027	12
Wide-gap	109	Upper jaw	None	Easy	0.046	12
Aberdeen	109	Eye	Some	Easy	0.055	12
Aberdeen	110	Upper jaw	None	Easy	0.073	12
Circle	126	Upper jaw	None	Easy	0.048	12
Aberdeen	173	Gullet	None	Not possible	0.179	12
Baitholder	116	Roof of mouth	None	Easy	0.036	12
Aberdeen	120	Upper jaw	None	Easy	0.050	18
Circle	135	Eye	Some	Easy	0.066	56

to 63.41% for wide-gap hooks) and roof of the mouth (26.83% for wide-gap hooks to 46.15% for baitholder hooks; Figure 4). Aberdeen hooks were never located in the lower jaw, baitholder hooks never in the eye, and circle hooks never in the gullet. The depth of hook penetration did not vary significantly with hook type (ANOVA: $F_{3,\ 171}$ = 0.560, P = 0.646) but did vary significantly with water temperature ($F_{2,\ 172}$ = 7.995, P = 0.005; Figure 5). Hooks penetrated more deeply in fish angled at 26°C than at 22°C (Tukey' test, P = 0.037) and at 18°C (P = 0.010). Incidences of bleeding were generally low (from 1.8% for circle hooks to 10.3% for baitholder hooks) and were not influenced by water temperature (χ^2 = 0.06, df = 2, P = 0.815) or hook type (χ^2 = 3.43, df = 3, P = 0.330). Ease of hook removal was influenced by both hook type (χ^2 = 11.18, df = 6, P = 0.083) and water temperature (χ^2 = 6.11, df = 4, P = 0.047). In general, most fish were easily removed from the hook (from 76.92% for baitholder to 95.12% for wide-gap). Baitholder and circle hooks were considered difficult to remove more frequently than the other two hook types. Some fish were hooked too deeply for removal, resulting in cutting the line; however, circle hooks were never hooked that deeply.

The distribution of anatomical hooking locations for all hook types did not differ significantly between small and large pumpkinseeds (aberdeen: χ^2 = 3.19, df = 4, P = 0.362; baitholder: χ^2 = 6.04, df = 4, P = 0.110; circle: χ^2 = 2.51, df = 4, P = 0.473; wide-gap: χ^2 = 7.42, df = 4, P = 0.115). The depth of hook penetration did not differ between the two size-classes for aberdeen (t = −0.05, df = 36, P = 0.99; N = 11 small, N = 27 large), baitholder (t = −0.38, df = 37, P = 0.71; N = 10 small, N = 29 large), or wide-gap hooks (t = −0.18, df = 39, P = 0.86; N = 20 small, N = 21 large; Figure 6). However, hook penetration by circle hooks was deeper in small fish (0.054, N = 15) than in large fish (0.040, N = 42; t = −2.06, df = 55, P = 0.045; Figure 6).

None of the pumpkinseeds that we captured at any temperature died immediately following angling or during the 72-h retention period. All fish were in good condition, exhibiting no fungal lesions or fin erosion at the conclusion of the retention period.

Discussion

The type of hook used can influence several different aspects of how fish are hooked, each of which can independently influence survival, injury, and ultimately fitness. For these reasons, we measured several different response variables in the way that fish were hooked in an effort to ascertain the effects of hook type on angled bluegills and pumpkinseeds.

The depth of hook penetration, which can delay or prohibit hook removal and may increase the potential for damaging vital organs, has been shown to vary with bait type in smallmouth bass (Clapp and Clark 1989), rock bass (Cooke et al. 2001), and bluegills (Siewert and Cave 1990). Overall, we found that bluegills (about 0.052) were hooked more deeply than pumpkinseeds (about 0.041) for all hook types, and that the depth of hook penetration did not vary in bluegills with hook type or temperature. In pumpkinseeds, however, hooks penetrated more deeply at 26°C than the other two temperatures. These hooking depth values were lower than rock bass captured on worms at 16°C (0.086; Cooke et al. 2001) but similar to rock bass captured on jigs (0.047) at 16°C (Cooke et al. 2001) and smallmouth bass captured on a variety of different baits and plastics on jig heads (about 0.040–0.055) at 15°C (Dunmall et al. 2001). In our study, fish size influenced the depth of hook penetration in bluegills and pumpkinseeds; however, these differences were only present for circle hooks. Circle hooks were located deeper in small fish. All other hook type and fish size-groups had hook penetration depths that were similar to the depth of the larger circle hook fish. Bluegills, therefore, appear to be more susceptible to deep hooking than pumpkinseeds, especially if anglers are targeting bluegills with circle hooks.

The anatomical hooking location provides information on potential or actual vital tissue damage. In our study, fish were frequently hooked in the eye region, which may directly increase mortality rate (Siewert and Cave 1990) and may also affect ability to locate food, avoid predators, and compete with other fish, all of which would have clear impacts on fitness. Few fish—and none captured on circle hooks—were hooked in the gullet. In our study, bluegill size influenced the anatomical hooking location for all hook types. Smaller fish were hooked more frequently in the eye, and bigger fish were hooked more frequently in the gullet. These trends, however, were not observed in pumpkinseed. One of the factors that probably contributed to this interspecific variation in hooking location and depth are other differences in mouth morphology. Pumpkinseeds possess molariform teeth for grinding, whereas bluegill have pharyngeal pads covered with fine needle-like teeth (Keast and Webb 1966). Thus, the roof of the bluegill mouth may be more susceptible to hook penetration than that of the pumpkinseed. The molariform teeth also may provide protection to the eye in pumpkinseeds, resulting in the less eye-hooking rates than in bluegills. When fish are not hooked in the gills or heart, incidences of bleeding are typically low (e.g., Cooke et al. 2001; Dunmall et al. 2001). For this reason, incidences of bleeding were low in both bluegills and pumpkinseeds. Differences in buccal anatomy, therefore, suggest that bluegills may be more susceptible to hook-induced injuries in vital tissues than are pumpkinseeds.

Ease of hook removal will strongly influence air exposure duration and mechanical injury potential and may create additional difficulties for anglers inexperienced with handling fish (Cooke et al. 2001). In this study, baitholder hooks were considered to be the most difficult to remove, and all hook types except circle hooks had instances where they were too deep to remove. Circle hooks could always be removed from fish probably because they never hooked any fish in the gullet, suggesting an advantage to the use of circle hooks over the other hook types examined. Because the point of the circle hook points towards the shank of the hook, gut hooking with this hook is rare among a variety of fish (e.g., Prince et al. 2002; Skomal et al. 2002).

The hooking mortality levels that we observed were low compared with those for many other fish species (Muoneke and Childress 1994) and other studies conducted on bluegills (bluegill mortality rates have ranged from 0% to 88%; Burdick and Wydoski 1989; Siewert and Cave 1990; Muoneke 1992). Bluegills experienced mortality only at the highest water temperature (26°C); however, the mortality levels were extremely low (~3%). In contrast, pumpkinseeds did not exhibit any mortality across the range of water temperatures that we examined (18–26°C). Siewert and Cave (1990) reported that bluegills angled at 22 ± 2°C and held for 10 d experienced substantial mortality. Even control fish captured with seines had mortality of about 12%. We did not have control fish in our study, but even our most extreme treatments (angling at 26°C) had extremely low mortality. We suggest that several factors may account for these differences. First, Siewert and Cave (1990) held their fish for 10 d, a period substantially longer than the period that we used. Second, Siewert and Cave (1990) apparently kept fish in some form of artificial tank or raceway. We held fish in an enclosure within the lake they were captured that incorporated natural substrate, cover, and food. Holding bluegills in an artificial system may have heightened mortality due to crowding, confinement stress (Chiszar et al. 1972), or other factors. Although anatomical hooking location is generally associated with mortality in angled fish, we observed very little mortality in our study, even in fish hooked in the gullet and eye. Indeed, there was no difference in the anatomical hooking location between the bluegills that died during the 72-h retention period and those that survived. One reason why overall mortality in our study was low may be due to the fact that deeply ingested hooks were not removed. Other studies have indicated that mortality is reduced when deeply ingested hooks are not forcibly removed from vital tissue or organs (Warner and Johnson 1978; Warner 1979; Mason and Hunt 1967; Weidlein 1989).

If managers recommend different hook types to anglers based upon scientific findings, anglers will have questions regarding the capture efficiency of different gears. Our hooking difficulty index indicated that both water temperature and hook type influenced our capture efficiency for both bluegills and pumpkinseeds. However, we feel that these results are not sufficiently disparate that anglers for bluegills or pumpkinseeds would have reservations with using any of the hook types we tested. Preliminary assessments in marine environments are showing substantial promise for circle hooks, which have reduced injury and mortality in species ranging from billfish (Prince et al. 2002) to chinook salmon *Oncorhynchus tshawytscha* (Grover et al. 2002). Our freshwater assessment indicates that the benefit of circle hooks may not be ubiquitous across all fish species and sizes, and in some cases may provide little conservation benefit. Although we found no fish were hooked in the gut using circle hooks, many were hooked in the eye, resulting in an obvious fitness impairment. Variation in feeding mode and mouth morphology may affect the performance of different fish hook designs suggesting that findings from hooking injury and mortality studies may not be applicable to other organisms, even if they are closely related species.

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