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Hooking Mortality of Trophy-Sized Wild Brook Trout Caught on Artificial Lures

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Abstract.—The average hooking mortality per capture event for 630 trophy-sized wild brook trout *Salvelinus fontinalis* (mean total length, 33.9 cm) caught on five hardware lures was 4.3% during the first 48 h after capture. Mortality was 8.3% for brook trout caught on Mepps spinners and Cleo spoons equipped with a treble-pointed hook, whereas mortality was significantly lower (2.4% per hooking event; $P < 0.05$) for fish caught on the same lures with a single-pointed hook. The 10.9% mortality caused by treble-hook Mepps spinners was significantly higher than mortality caused by single-hook Cleo spoons (1.6%). Mortality for brook trout caught on single-hook Cleo spoons and single-hook Mepps spinners combined (2.4%) was also significantly lower ($P < 0.05$) than mortality of fish caught on Mepps spinners with treble hooks. There was no mortality among 126 brook trout caught with Rapala lures rigged with two treble hooks. We believe that the differences in mortality of brook trout caught with different lures are primarily attributable to differences in the frequency and extent of damage to the gill arches and esophagus area. Certain lures were more likely to be engulfed deeply, particularly by larger fish, and thus were more likely to cause death. Lures that exhibit vigorous wobbling action when retrieved appear less likely to be deeply engulfed and consequently cause less mortality. Hooking mortality estimates for brook trout caught on Mepps and Cleo lures combined were positively and significantly correlated with size of fish ($P < 0.003$). The probability of death within 48 h of capture for profusely bleeding brook trout that were hooked in the gills or throat increased rapidly with increasing water temperature. Fish that did not bleed profusely after capture with treble-hooked Mepps and Cleo lures that did not penetrate the gill or throat region were unlikely to die as a result of temperature effects, unless temperatures were above approximately 14°C. The probability of death was not significantly associated with temperatures ranging from 5.6 to 17.8°C when brook trout were hooked with single-pointed hooks at anatomical sites other than the gills or throat and did not bleed heavily. Present regulations on Michigan's trophy trout lakes, which restrict lures to single-pointed hooks and forbid harvest of fish less than 38.1 cm in total length, appear quite adequate to minimize losses due to hooking mortality.

Large minimum size limits and no-kill regulations are two methods fisheries managers use to increase both the size and number of fish caught. Twelve of Michigan's designated brook trout lakes have special regulations allowing only artificial lures with single hooks, a creel limit of two fish per day, and a minimum size limit of 38.1 cm (based on total length of the fish). These regulations are designed to provide opportunities to catch trophy brook trout *Salvelinus fontinalis*. Because brook trout in most inland lakes in Michigan do not grow to 38.1 cm until they have reached approximately age 4, they are subject to many years of catch-and-release angling before they can be harvested (Gowing 1986). Early studies on hooking mortality of Michigan brook trout focused on small fish, because minimum size limits in the past were lower than the 38.1-cm minimum size limit currently applied to trophy brook trout lakes in Michigan. Shetter and Allison (1958) reported 3.9% mortality overall for brook trout that averaged 17.9 cm in total length and that were caught on any of four hardware lures. Although many studies of salmonid hooking mortality have been reported, we could find no references concerning mortality of large brook trout. Most previous investigations have focused on relatively small salmonids (<25 cm in total length). The sample size (number of hooking events) in most studies we reviewed was generally far smaller than that of our study (630 hooking events). Moreover, many researchers have used hatchery trout as their test fish, whereas we used large wild brook trout in natural waters in this study.

This study focused on estimating the hooking mortality rates of trophy-sized brook trout caught on different hardware lures and hook types. The relationships between hooking mortality and anatomical hooking site, bleeding severity, temperature, and fish size were examined. Estimates of potential catch and hooking mortality of trophy-sized brook trout in a typical northern Michigan inland trout lake were made assuming catch-and-release regulations or trophy size limits.

Study Area

Fishing was done at three sites in the Hunt Creek fisheries research area in Montmorency County, Michigan. Fuller Pond is a shallow flowage of 6.07 hectares created by an earthen dike on the site of an old beaver dam. The outlet stream discharges at a rate of approximately 0.085 m^3/s through a fish trapping weir. Temperature and oxygen regimes are such that brook trout can frequent most areas of the pond throughout the year.

East Fish Lake, which is also located in the Hunt Creek research area, is an oligotrophic kettle lake of 6.48 hectares fed by one small tributary stream and numerous springs. The outlet of this lake discharges at a rate of approximately 0.042 m^3/s through a fish trapping weir. East Fish Lake becomes thermally stratified, with oxygen and temperature regimes that are satisfactory for brook trout from surface to bottom throughout the year. Spring Pond, where most of the hooking events occurred, is approximately 0.16 hectares. Surface water from the pond is discharged through a culvert at a rate of approximately 0.025 m^3/s. Because of the high discharge relative to pond value, temperatures are fairly uniform throughout the pond.

Selected morphological and limnological characteristics of the above waters are summarized in Table 1. All three experimental waters are closed to public fishing.

TABLE 1.—Depth, total alkalinity, and pH of the three experimental waters.

Site	Depth (m) Maximum	Depth (m) Average	Total alkalinity (mg/L)	pH
Fuller Pond	2.4	0.6	149	8.1
East Fish Lake	12.2	8.6	175	8.2
Spring Pond	1.8	0.6	170	8.1

Methods

Brook trout were captured with the following lure types and barbed hooks.

(1) A Mepps spinner, size number 1 (4.7 cm long), with a French-style blade and treble hook (6-mm gap, tip of hook to shank)
(2) The same Mepps spinner as described in (1), except with two points removed from the treble hook (6-mm gap)
(3) A 3.6-g, 4-cm-long Cleo spoon with a treble hook (6-mm gap)
(4) The same Cleo spoon as described in (3), except with a number-6 Eagle Claw medium shank hook (11-mm gap)
(5) A 5-cm floating Rapala lure with two treble hooks (5-mm gap)

Hooking events were recorded from April 6, 1987, to June 10, 1989. During April 1987, brook trout were captured by angling from East Fish Lake and Fuller Pond, and they were transferred to Spring Pond. The brook trout had to be removed from East Fish Lake and Fuller Pond so that these lakes could be prepared for a new study. After transfer, these "original" brook trout were then caught repeatedly over the course of the study along with native brook trout already residing in Spring Pond. Approximately 90% of the fish sampled were captured by us. The remainder of the fish were caught by five other volunteer anglers.

The original 78 brook trout were hooked, played until they could be easily netted, and unhooked with fingers or pliers. Pliers were used only when hooks could not be readily reached or extracted by hand. Fish were immediately transferred to a 19-L water bucket in the boat, and shifted within 5 min to cylindrical floating nets (1.0 m in diameter, 1.8 m deep) near the center of the lake. Separate holding nets were used for fish caught on each lure. The type of lure used, anatomical hooking site, surface water temperature, number of hook points penetrating the fish, and degree of bleeding were recorded for each hooking event. Three categories of bleeding intensity were defined. Fish were assigned to the first category when there was no bleeding or no flow of blood from the hook wound. Fish were assigned to a second category when there was a light to moderate flow of blood and to a third category when heavy bleeding occurred.

The holding nets in East Fish Lake and Fuller Pond were checked for brook trout mortalities 24 and 48 h after capture. Dead brook trout were examined closely to determine where hook points had penetrated. After 48 h, all fish were weighed and measured and the survivors were transferred to Spring Pond. Recaptured fish (identified by fin clips) and resident fish in Spring Pond were hooked, played, and netted in the same manner described above. However, because angling was conducted from shore at this site, captured fish were immediately transferred to rectangular wire mesh liveboxes (1.2 by 0.8 m) at the edge of the pond. These

TABLE 2.—Percentage of brook trout captures where at least one hook point penetrated the anatomical site indicated.

Anatomical site	Artificial lure type[a]				
	MT	CT	MS	CS	RAP
Upper jaw	45	52	30	18	67
Lower jaw	56	56	38	49	80
Roof of mouth	35	25	14	10	25
Eye or orbit	0	4	0	2	0
Gill arches	10	5	1	2	0
Deep in throat	6	3	7	1	0
Cheek	13	13	5	13	5
Tongue	8	8	5	3	10
Foul hooked[b]	2	2	0	2	43
Sum[c]	175	168	100	100	230

[a] MT = Mepps spinner with treble hook; MS = Mepps spinner with single hook; CT = Cleo spoon with treble hook; CS = Cleo spoon with single hook; RAP = floating Rapala lure with two treble hooks.
[b] Hooked outside the mouth by at least one hook point.
[c] Summed percentages exceed 100 for lures with multiple hook points.

boxes were checked for fish mortalities 24 and 48 h after capture. Fish were kept in separate live-boxes according to the type of lure with which they were caught. Because of the high flow rate of spring water through the pond, water temperatures in the live-boxes were approximately the same as temperatures in deeper waters of the pond. Fish that survived the holding period were returned to Spring Pond after they were weighed and measured.

Lure types used were varied randomly with the constraint that roughly equal numbers of fish be caught on each lure over time. Pairwise comparisons of means were used to determine significant differences in hooking mortality between lure and hook types. Binomial 95% confidence limits for mortality estimates were determined from tables in Mainland et al. (1956). Because the Rapala lure had two treble hooks and a different action when retrieved, fish captured with this lure were excluded from the analysis of differences in mortality of brook trout caught on treble and single hooks. Mortality estimates and confidence limits were computed for brook trout of all lengths (21.6–49.8 cm), for those that were 38.1 cm long or smaller, and for those that were larger than 38.1 cm; here and elsewhere in this article, fish lengths represent total lengths.

Logistic regression techniques were used to identify variables most useful for predicting fish death after hooking and to determine what factors are most important for predicting whether fish will be hooked in the esophagus and gill arches. Least-squares linear regression was also used to examine possible relationships between variables. Both logistic and linear regression were done according to procedures in the SPSS/PC+ software package (Norusis 1988, 1990).

Results

Mortality and Anatomical Hooking Site

On average, 2.2 of the 3 treble hook points on the Mepps spinner and Cleo spoon penetrated brook trout captured with these lures, whereas 3.2 of the 6 points penetrated fish caught by the Rapala lure, which had two treble hooks. Hooks on all five lures penetrated the upper and lower jaws or roof of the mouth in the majority of hooking events (Table 2). Of the 27 brook trout that died, only 1 was hooked solely in the jaws or roof of the mouth. Of the brook trout that were hooked in the gill arches or deep in the throat, 61% died. Of the fish that were hooked in the gill or throat, over 70% hooked with treble hooks died, and 50% hooked with the single hook lures died. No Rapala-caught brook trout were hooked in either the throat or gill arches, and none of the 126 fish caught on this lure died. Rapala-caught trout were hooked outside the mouth (foul hooked) by at least one hook point 43% of the time. In nearly all cases, these fish were first hooked in the mouth by either the front or rear treble hook. The second treble hook then became embedded externally during the course of fighting, netting, or unhooking the fish.

Logistic regression analysis showed that the probability that a fish would be hooked in the gills or throat was positively correlated with fish size (Figure 1). The logistic regressions were highly significant for Mepps spinner and Cleo spoon treble-hooked lures either singly ($P \leq 0.02$) or in combination ($P < 0.001$). Although regressions of hooking site versus fish size for lures equipped with single hooks also suggested that larger fish were more likely to be hooked in the throat or gills, these regressions were not significant ($P > 0.05$). Of the five lures tested, treble-hooked Mepps spinners were the most likely to penetrate this area and the Rapala lures were least likely to be embedded in the throat or gills (Table 2).

Mortality and Bleeding Severity

The severity of bleeding associated with capture by each of the lure types is summarized in Table 3. Severe bleeding was closely associated with hook damage to the gill arches or throat. Over 80% of the severely bleeding brook trout caught on Mepps

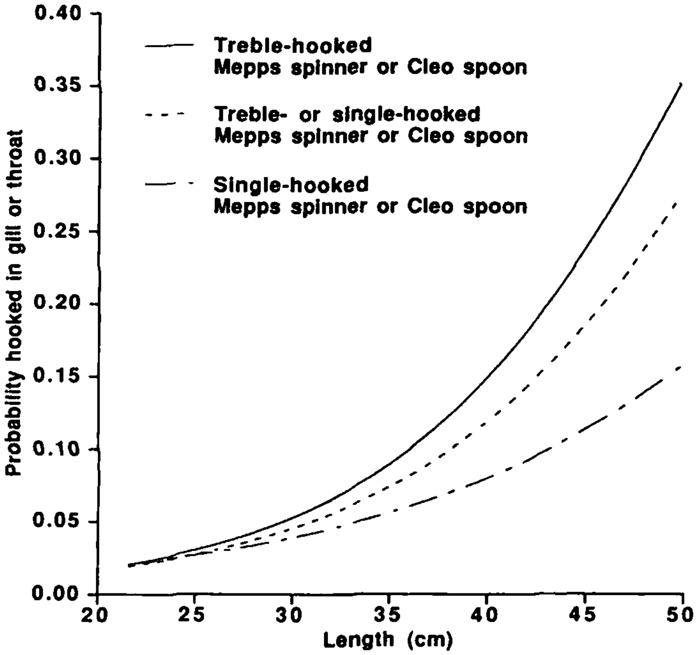

FIGURE 1.—Probability of a brook trout being hooked in the gill or throat region as a function of fish total length, given that the fish is captured with a Mepps spinner or Cleo spoon. No fish were hooked in the gill or throat region with a Rapala lure.

spinner or Cleo spoon lures with treble hooks died within 48 h of capture. The mortality of severely bleeding fish caught on the same lures equipped with single hooks was 42%. More fish caught on Rapala lures were classified in the second category of bleeding intensity (light to moderate bleeding) than were fish caught on any other lure because, in many cases, the second treble hook penetrated external body areas. The increased difficulty in maneuvering and unhooking two treble hooks from a struggling fish also increased bleeding from hooks penetrating the inside of the mouth. Despite these factors, Rapala-caught fish had the lowest incidence of severe bleeding. Logistic regression analysis indicated that bleeding intensity exhibited by fish caught on Mepps spinner or Cleo spoon lures was most strongly influenced by hook type (treble or single) and the size of fish (Figure 2; $P < 0.0001$). The probability of heavy bleeding increased sharply for fish over 40 cm long.

Mortality per Capture Event

For all lures combined, the average mortality of large brook trout (mean length, 33.9 cm; range, 21.6–49.8 cm) per hooking event was 4.3% during the first 48 h after capture (Table 4). Of the five lure types, Mepps number-1 spinners with treble hooks killed the most brook trout (10.9%), where-

TABLE 3.—Percentage of captured brook trout in three bleeding severity classes.

	Blood flow		
Lure	None	Light to moderate	Heavy
Mepps number-1 spinner with treble hook	54.8	33.3	11.9
Mepps number-1 spinner with single hook	78.5	16.7	4.8
Cleo spoon with treble hook	54.0	40.5	5.5
Cleo spoon with single hook	69.0	26.2	4.8
Rapala lure with two treble hooks	41.3	57.1	1.6
Treble-hooked Mepps and Cleo lures combined	54.4	36.9	8.7
Single-hooked Mepps and Cleo lures combined	73.8	21.4	4.8

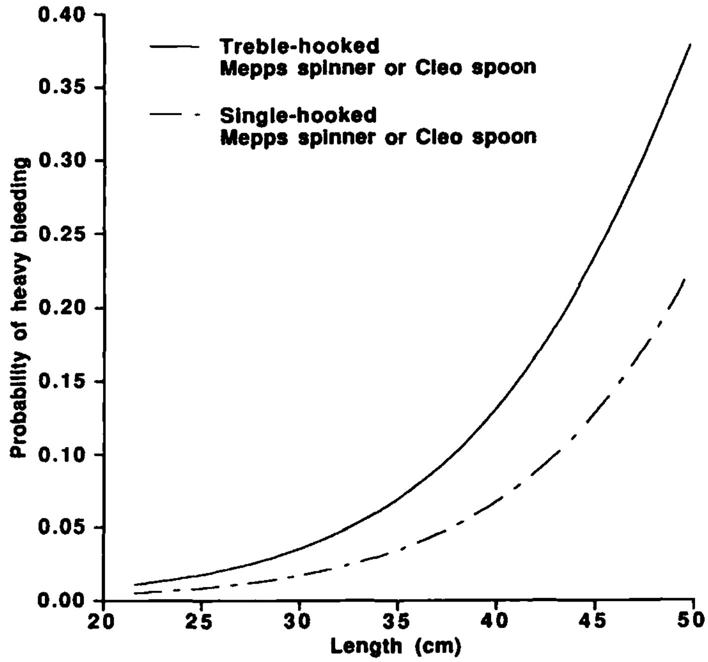

FIGURE 2.—Probability of heavy bleeding by brook trout caught on single- and treble-hooked lures as a function of fish total length, given that the fish is captured with a Mepps spinner or Cleo spoon. Only 1.6% of fish hooked with a Rapala lure exhibited heavy bleeding.

as none of the 126 brook trout caught on Rapala lures with treble hooks died. The other three lures induced intermediate levels of mortality ranging from 1.6 to 5.6%. Mepps spinners with treble hooks caused significantly greater mortality than Rapala lures with two treble hooks or Cleo spoons with single hooks ($P < 0.05$). Mepps treble-hooked spinners also caused significantly higher mortality than Cleo and Mepps single-hooked lures combined ($P < 0.05$).

TABLE 4.—Number and percent mortality (with 95% confidence limits in parentheses) of brook trout caught by five different artificial lures and held for 48 h.

		Percent mortality of:		
Lure	Number of fish caught	All fish	Fish ≤38.1 cm in total length	Fish >38.1 cm in total length
Mepps number-1 spinner with treble hook	128	10.93 (6.12–17.66)	8.79 (3.87–16.59)	16.22 (6.19–32.02)
Mepps number-1 spinner with single hook	127	3.15 (0.87–7.81)	4.08 (1.12–10.13)	0.0 (0.0–11.95)
Cleo spoon with treble hook	125	5.60 (2.28–11.20)	3.53 (0.73–9.98)	10.00 (2.80–23.68)
Cleo spoon with single hook	124	1.61 (0.19–5.71)	0.0 (0.0–4.11)	5.56 (0.68–18.68)
Rapala lure with two treble hooks	126	0.0 (0.0–2.89)	0.0 (0.0–3.08)	0.0 (0.0–33.63)
Treble-hooked Mepps and Cleo lures combined	253	8.30 (5.28–12.35)	6.25 (3.16–10.91)	12.99 (6.41–22.59)
Single-hooked Mepps and Cleo lures combined	251	2.39 (0.88–5.13)	2.15 (0.59–5.41)	3.08 (0.38–10.69)
All five lures combined	630	4.29 (2.67–5.79)	3.13 (1.77–4.86)	7.95 (4.17–13.47)

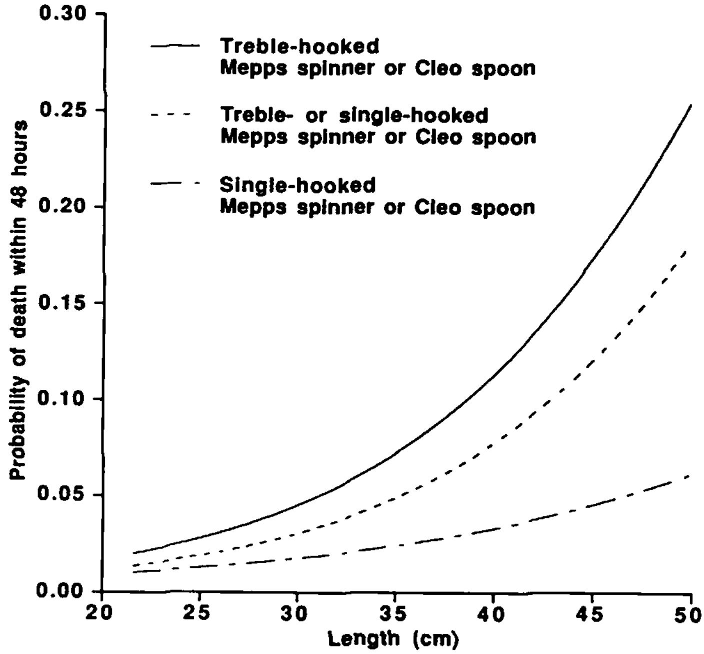

FIGURE 3.—Probability of brook trout death within 48 h of capture as a function of fish total length, given that the fish is captured with a Mepps spinner or Cleo spoon. No fish hooked with a Rapala lure died within 48 h of capture.

Brook trout larger than 38.1 cm experienced higher mortality than the smaller brook trout after capture by treble-hooked Mepps spinners, and by treble- and single-hooked Cleo spoons (Table 4). Logistic regression analysis showed that there was a highly significant positive relationship between size of fish and probability of death after hooking for all Cleo spoon and Mepps spinner lures combined ($P < 0.003$) and also for Mepps spinner and Cleo spoon treble-hooked lures combined ($P = 0.009$) (Figure 3). Although larger brook trout caught on single-hooked lures also appeared more likely to die than smaller brook trout caught on these lures, the logistic regression model's significance level was low ($P = 0.34$). In addition, the magnitude of the increase in mortality with increasing fish size was much smaller than for treble-hooked lures (Figure 3). The increase in mortality with increasing fish size was greatest for Mepps spinner treble-hooked fish, and the logistic regression was significant ($P < 0.05$). Larger brook trout may be more likely to die when caught on Cleo treble-hooked spoons ($P = 0.07$) and Cleo single-hooked spoons ($P = 0.06$). Mortality of brook trout hooked with Mepps single-hooked spinners did not appear to be related to trout size.

Treble versus Single Hooks

Mortality of the 128 brook trout caught on Mepps spinners with treble hooks was not significantly higher ($P > 0.05$) than the mortality of those caught on Mepps spinners with single hooks. Cleo spoons with treble hooks were not significantly more lethal than the same spoon with a single hook ($P > 0.05$). However, when sample size was increased by combining lure types, the 8.3% mortality for the 253 fish caught on either Mepps spinner or Cleo spoon lures with treble hooks was significantly higher than the 2.4% death rate for the 251 trout caught with these same lure types equipped with single hooks ($P < 0.05$).

Mortality data associated with the Rapala lure were not included in the analysis of single versus treble hooks because of the different design and action of the lure.

Effect of Temperature

Surface water temperatures over the course of the study ranged from 5.6 to 17.8°C, and the mean was 11.8°C. The least-squares regression of hooking mortality versus temperature for all fish caught by any lure type indicated a significant positive

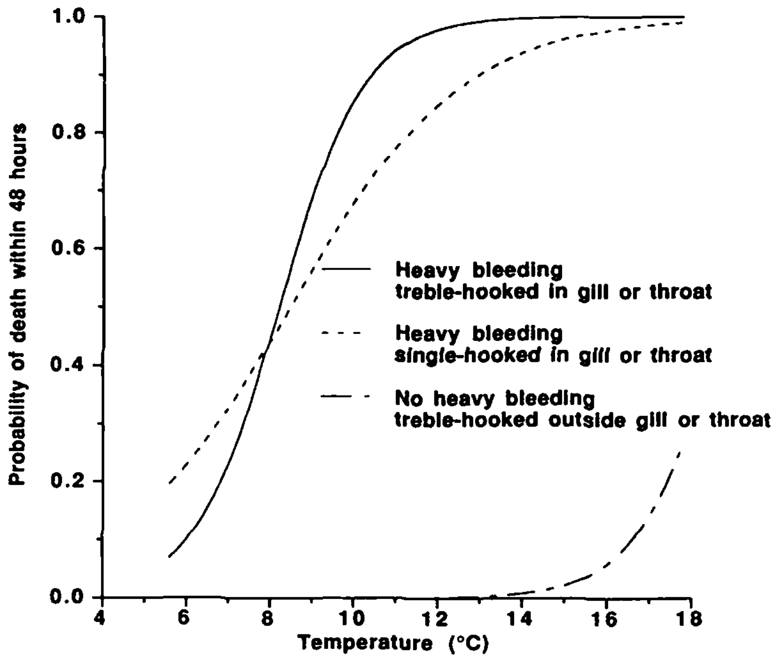

FIGURE 4.—Probability of brook trout death within 48 h of capture as a function of temperature, hook penetration site, and bleeding intensity, given that the fish is captured with a Mepps spinner or Cleo spoon. No fish hooked with a Rapala lure died within 48 h of capture.

correlation and slope ($P < 0.05$). The linear regressions of death rate versus temperature for all fish caught with either Mepps spinners or Cleo spoons and for fish caught with treble-hooked Mepps spinners alone likewise had significant positive correlations and slopes ($P < 0.05$). Among the multiple logistic regression models examined for predicting the probability of death, those that contained the independent variables of bleeding severity, hook penetration site, and temperature were highly significant ($P < 0.0001$) for fish hooked on either single- or treble-hooked Cleo spoons or Mepps spinners. Figure 4 illustrates that the predicted probability of death increased rapidly with increasing temperature when fish bled heavily and were hooked in the gill or throat regions with either single or treble hooks. From the logistic model, the predicted effect of increasing temperature on mortality of fish that did not bleed heavily and were caught with single-hooked Mepps spinners or single-hooked Cleo spoons that penetrated in areas other than the throat and gills was approximately zero within the range of temperatures tested (5.6–17.8°C; Table 5). By contrast, the model predicted that mortality for fish caught by treble-hooked Mepps spinners and treble-hooked Cleo spoons would approach 1.0% at 14°C and increase rapidly to 26.6% at 17.8°C, even when hooks did not penetrate the gill or throat regions or cause heavy bleeding. Because no fish caught on Rapala lures died, there was no temperature–mortality relationship to test.

Timing of Mortality

Of the 27 brook trout that died within 48 h of capture, 66.6% died during the first 24-h period. We did not measure mortality after 48 h. However, many brook trout survived for long periods after being hooked. This survival was indicated by the fully healed hook scars that were found on most of the fish caught after the study was well underway. Conversely, dead brook trout were occasionally observed on the bottom of Spring Pond and some of these fish may have died from long-term effects of hooking.

Discussion

The 4.3% hooking mortality for brook trout caught on artificial lures (five types) was very close to the average mortality rate of 6.1% reported by Wydoski (1977) in his review of many hooking mortality studies. It was also in close agreement with the 4.6% mortality for a large sample of wild trout caught on hardware lures (four types) re-

TABLE 5.—Logistic regression coefficients relating total length of caught brook trout or water temperature to the estimated probability of events associated with hooking mortality. The probability, P, of the event occurring is estimated by the logistic equation $P = 1/[1 + \exp(-Z)]$, where $Z = a + bx$, and x is the independent variable, either total length (cm) of fish or water temperature (°C). These estimated probabilities assume that the brook trout is captured with a Mepps spinner or Cleo spoon; no fish that was hooked with a Rapala lure was hooked in the gill or throat region or died within 48 h of capture.

Event	Conditions	Coefficient a	Coefficient b	Independent variable (x)[a]
Hooking in the gill or throat region	All treble-hooked lures	−6.3435	0.1151	Length***
	All single-hooked lures	−5.5112	0.0768	Length
	All spinner and spoon lures	−6.1889	0.1047	Length***
Heavy bleeding	All treble-hooked lures	−7.5568	0.1417	Length****
	All single-hooked lures	−8.2952	0.1417	Length****
Death within 48 h of capture	All treble-hooked lures	−6.0399	0.0996	Length**
	All single-hooked lures	−5.9715	0.0650	Length
	All spinner and spoon lures	−6.4075	0.0983	Length**
	Fish treble-hooked in gill or throat and bleeding heavily	−8.2042	0.999	Temperature****
	Fish single-hooked in gill or throat and bleeding heavily	−4.164	0.4913	Temperature****
	Fish treble-hooked outside gill and throat and not bleeding heavily	−18.7956	0.999	Temperature****
	Fish single-hooked outside gill and throat and not bleeding heavily	−20.6345	0.4913	Temperature****

[a] Asterisks denote $P < 0.01$**, $P < 0.001$***, or $P < 0.0001$**** for the model's χ^2 significance level.

ported by Shetter and Allison (1958). However, our mortality estimate was substantially higher than the 0.3% hooking mortality reported for wild cutthroat trout *Oncorhynchus clarki* caught on artificial flies and lures from the Yellowstone River (Schill et al. 1986). Possibly, trout in rivers are more likely to attack from the side, and hence are less likely to follow and deeply engulf lures and flies.

The effects of hooking or handling on delayed mortality (beyond 48 h) was, in all likelihood, not significant. Hunsaker et al. (1970), who held wild cutthroat trout (mean total length, 35.6 cm) for 2 weeks after capture, found that all mortalities occurred within 48 h of capture. Both the size of fish and the water temperature range were very similar to these variables in this study. Although time to death after hooking varies between studies, there is a strong tendency for the majority of seriously injured fish to die within 48 h of hooking (Wydoski 1977; Mongillo 1984).

Mortality of brook trout caught on Mepps spinner and Cleo spoon treble-hooked lures was 3.5 times greater than mortality of brook trout caught on the same lures with single-pointed hooks. This greater mortality is probably related to increased tissue damage and associated bleeding among brook trout hooked in the gill arch or esophagus areas. During our study we generally had greater difficulty unhooking a fish impaled on a treble hook in these anatomical locations than we had unhooking fish caught with a single hook. In addition, while unhooking one embedded point of a treble hook, another point would sometimes become embedded. Unhooking treble hooks also took more time, and thus exerted greater physical pressure on brook trout, than did unhooking single-pointed hooks.

Mepps spinners with treble hooks were found in the esophagus or gill arches of fish in 13.5% of the hooking events, whereas Mepps spinners with single hooks were found in these anatomical sites in 7.9% of the captures. We anticipated that both treble-hooked and single-pointed Mepps spinners would be equally likely to be engulfed deeply by large brook trout but that during hook setting the single-pointed hook was probably more likely to be jerked away from the gill arches or esophagus without becoming embedded. Although no records were kept on strikes missed, it appeared that more fish evaded capture after striking at lures with a single-pointed hook. Many investigators (Shetter and Allison 1955; Stringer 1967; Hunsaker et al. 1970; Pelzman 1978; Warner and Johnson 1978; Hulbert and Engstrom-Heg 1980; Loftus et al. 1988; Payer et al. 1989) have found that hook penetration into the gills or esophagus is clearly associated with high hooking mortality.

In this study, the probability of hooking in the throat or gill region, the probability of heavy bleeding, and the probability of death within 48 h of capture were all positively related to size of fish (Table 5). Bigger fish apparently can more easily engulf lures deeply into the mouth because of their larger gapes. Investigators working with smaller salmonids than tested in this study found single hooks more lethal than treble hooks and suggested that the small fish had more difficulty engulfing a treble hook (Klein 1965; Warner 1976). The large brook trout used in this study had large mouths relative to lure size and thus were not as physically constrained from deeply engulfing a treble-hooked lure. Shetter and Allison (1955) suggested that fish longer than 17.5 cm suffered higher hooking mortality than those less than 17.5 cm. Mongillo (1984) noted that in most experiments wild fish are usually longer than hatchery fish and tend to be hooked more deeply. Previous investigators have had difficulty finding a significant relationship between size of fish and hooking mortality, probably because their test fish were generally less than 30 cm long and their sample sizes were small. The difference between the probability of being hooked in the gill or throat region with treble versus single hooks is small until fish grow over 35 cm long (Figure 1).

Differences in hooking mortality for brook trout caught with different lures also appear to be related to where the hook tends to penetrate the mouth (Table 5). The Rapala lure, which killed no fish, was slightly larger than other lures tested and had a vigorous wobbling action when retrieved. Apparently, this action effectively prevented any of the 126 brook trout caught on Rapala lures from taking the lure deep into the mouth. Conversely, Mepps spinners, which track in a relatively straight line when retrieved, were more frequently taken deeply enough into the mouth to damage gill arches or the esophagus region. Percentages of fish hooked in the throat or gill arches with Cleo spoons were intermediate between the percentages for Mepps spinners and Rapala lures. The likelihood of a hook penetrating deep into the esophagus or gill arches was again probably dictated in part by the action of the lure. Although Cleo spoons do not wobble as vigorously as Rapala lures, they do not travel in the relatively straight path characteristic of a spinner.

Hooking mortality also tends to be greater at higher water temperatures (Klein 1965; Hunsaker et al. 1970; Dotson 1982; Plumb et al. 1988). In this study higher temperatures were clearly associated with much higher mortality when brook trout bled heavily after being hooked in the gills or throat (Table 5). Fish that did not bleed heavily after capture with Mepps or Cleo lures equipped with treble hooks that did not penetrate the gill or throat region were unlikely to die as a result of temperature effects, unless temperatures were above approximately 14°C. However, predicted mortality rose sharply to nearly 27% at 17.8°C, possibly because of greater handling stress. By contrast, the logistic model predicted a probability of death of only 0.0006% at 17.8°C when brook trout did not bleed heavily after capture by the same lures equipped with single hooks that did not penetrate the gill or throat region (Table 5). When gill arches were broken, fish died 100% of the time regardless of temperature. Furthermore, of the 27 fish that died, 93% were hooked in either the gill arch or throat region. However, an additional 16 brook trout were hooked in these regions but did not die during the holding period. The differential survival between these groups appears to be mainly attributable to a combination of temperature and degree of tissue damage as measured by bleeding severity. Greater bleeding from a given wound could be expected at higher temperatures because of higher metabolic rates and slower coagulation rates.

The effect of hooking on growth rates was not assessed because individual fish were not identified. Clapp and Clark (1989) found an inverse relationship between growth rate and the number of times an individual smallmouth bass *Micropterus dolomieu* was caught and released. Fulmer and Ridenhour (1967) found a significant negative relationship between serious jaw injuries that had been caused by a troll fishery and had healed and condition factor for fall-run chinook salmon *O. tshawytscha*. However, they found no significant relationship for slightly injured fish. There was probably little lasting injury to the brook trout in this study, although stress or minor injury could have affected growth.

Management Implications

Brook trout stocked in lakes that are subject to general regulations are frequently caught and harvested within a year after stocking. Alexander and Shetter (1969) found that nearly all the seasonal harvest of brook trout occurred during the first 10 d of the season. In an earlier study, Alexander and Shetter (1961) found that anglers caught slightly more than half of the available brook trout during the first 2 weeks of the season. This harvest occurred at the moderate annual fishing pressure level of 53 angler-hours per hectare.

Few brook trout survive long enough to grow to trophy size in inland trout lakes subject to standard Michigan regulations, which allow use of bait and harvest of fish 25.4 cm or longer. Past investigations showing mortalities ranging from 35 to 48.5% (Shetter and Allison 1955; Stringer 1967; Hunsaker et al. 1970; Warner and Johnson 1978) for fish caught on baited hooks indicate that the use of bait would cause too high of a mortality of released fish to allow significant numbers of these fish to reach trophy size in Michigan lakes. Hence, the use of flies and artificial lures with single hooks has been mandated on lakes designated as trophy brook trout lakes. It has been well demonstrated that small inland lakes in Michigan not subject to angling mortality can produce, per hectare, from 40 to 80 brook trout that are approximately 33 cm long and from 15 to 50 brook trout that are approximately 38 cm long (Gowing 1986). Use of only artificial lures, combined with regulations restricting harvest to trophy-sized trout, could result in each trout being caught and released 10 times over its lifetime. Given an expected annual natural mortality rate of about 34% during the first 3 years after stocking (Gowing 1986), hooking mortality losses would be negligible if fish were caught an average of twice a year and died at the rate found in this study (4.3% per capture). The greater mortality for brook trout caught on Mepps spinner and Cleo spoon treble-hooked lures (8.3%), which is 3.5 times the mortality of fish caught on these same lures equipped with single hooks (2.4%), could substantially reduce the number of times the largest brook trout could be recycled to anglers. Mortality could be minimized by requiring the use of larger lures and hooks, which would reduce the probability that trout would be hooked in the throat or gill region. Similarly, lures that exhibit vigorous wobbling action when retrieved, such as Rapala lures, would reduce mortality because they do not typically penetrate the gills and throat. However, because many brook trout were foul hooked with the Rapala lure and were more likely to suffer eye damage, fish caught with this lure may have lower long-term survival and growth. In addition, the external tissue damage and scarring caused by this lure is aesthetically displeasing.

The present regulations used on Michigan trophy brook trout lakes, which restrict lures to single-pointed hooks and forbid harvest of fish less than 38.1 cm, appear to be adequate to achieve management goals.

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