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[Article]

Factors Influencing the Hooking Mortality of Walleyes Caught by Recreational Anglers on Mille Lacs, Minnesota

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Abstract.—Recent implementation of size-based regulations in recreational fisheries for walleye *Sander vitreus* have led to more released walleyes and presumably to more losses of released fish. We conducted this study to estimate hooking mortality in Mille Lacs, Minnesota, and to determine factors that influence the survival of released walleyes. Volunteers and Minnesota Department of Natural Resources employees sampled walleyes with common angling methods in 2003 and 2004 on Mille Lacs (n = 1,246). Simple hooking mortality rates ranged from 0% (95% confidence interval = 0–1.8%; n = 204) in May, when lake water temperatures were less than 20°C, to 12.2% (9.2–15.9%; n = 392) in the July–August period, when lake water temperatures were at least 20°C. We used logistic regression within generalized linear or additive models to determine influential variables. Hooking mortality was most associated with water temperature, bleeding, fish length, hook location, and fish floating upon release. Mortality increased as the water warmed above 18°C and was higher for fish that bled at temperatures less than 24°C but similar for both bleeding and nonbleeding fishes at temperatures of 24°C or more. Fish hooked in the throat or stomach died at higher rates than fish hooked in the jaw, inner mouth, or gills and those that were externally foul-hooked, especially when they were smaller. Although fish of medium length (300–600 mm) were more likely to be deep hooked, they died less frequently than walleyes of other lengths. Cutting the line did not significantly improve survival in deeply hooked fish. Mortality was similar between live bait jigs and live bait regular hooks. Most observed hooking mortality was caused by damage to major internal organs. Hooking mortality is minimized when anglers fish in cool water, use active fishing methods, and catch medium-length walleyes.

Fisheries managers use length-based regulations for various reasons (Brousseau and Armstrong 1987), most of which presume that a significant proportion of released fish will contribute to the fishery or population, in some way, in the future. To contribute, fish must first survive being caught and released. High hooking mortality among protected fish will reduce the effectiveness of length-based or bag limit regulations. Therefore, fisheries managers must determine whether hooking mortality is low enough so that released fish can contribute to the fishery's future. Estimates of hooking mortality in nontournament fishing of walleye *Sander vitreus* in North America range between 0% and 19%, based on studies in which walleyes were caught by angling and then retained for 48 h or longer (Fletcher 1987; Payer et al. 1989; Schaefer 1989; Parks and Kraai 1991; Bruesewitz et al. 1993). Tournament-related mortality exceeds these estimates (Goeman 1991; Graeb et al. 2005); however, most walleyes are not caught and held under tournament conditions. Recreational fisheries managers have used past studies to justify the assumption that released walleyes can survive and contribute further to a fishery.

Walleye management strategy for Mille Lacs, one of Minnesota's most important fisheries, depends in part on high survival of released walleyes. The Minnesota Department of Natural Resources (DNR) used results from previous studies to estimate that 6% of walleyes at least 330 mm in total length (TL) and 10% of walleyes less than 330 mm TL were killed after each release event on Mille Lacs (R. E. Bruesewitz, 2000 report to the Minnesota 1837 Ceded Territory Fisheries Committee). Losses due to hooking mortality, as a percentage of the total kill by weight, ranged from 0.5% in 1992 and 1993 to 51.7% in 2002 (our unpublished data). The high loss in 2002 was caused by a restrictive 406–457-mm harvest slot limit and high catch rates of 0.75 walleyes per hour. Many anglers were concerned with large losses of unharvested walleyes. Fisheries managers believed that more accurate hooking mortality estimates could be developed for the Mille Lacs recreational walleye fishery during the open water season.

Many factors influence hooking mortality. Warm water (Hoffman et al. 1996) and internal damage from deep hooking (Schisler and Bergersen 1996; Jenkins 2003) are most often cited as reasons for high hooking mortality. Hooking mortality is higher for fish that are bleeding (Schisler and Bergersen 1996), played or handled longer (Schisler and Bergersen 1996; Bettoli and Osborne 1998), caught in deep water (Bruesewitz et al. 1993), caught with natural baits instead of

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actively fished lures or flies (Payer et al. 1989; Dunmall et al. 2001), smaller in length (Loftus et al. 1988), deeply hooked and the hook is removed rather than left in the fish (Schill 1996), and caught by inexperienced anglers (Diodati and Richards 1996). Alternatively, experienced anglers may induce more mortality (Dunmall et al. 2001) by allowing more time for fish to swallow the hook to ensure a successful hooking. This is a common technique used by experienced anglers on Mille Lacs. Hook location may also be related to hook type, fish length, and depth of capture. The objectives of this study were to (1) develop hooking mortality estimators from monthly averages and from a logistic regression model of two variables easily collected by creel clerks (length and water temperature) at Mille Lacs, (2) evaluate potential factors for mortality of released walleyes, and (3) evaluate factors that influence hook location in angled walleyes.

Study Area

Mille Lacs provides one of Minnesota's premier walleye fisheries due to its self-sustaining productivity and its location just 2 h north of the St. Paul–Minneapolis metropolitan area. The lake covers 53,650 ha, has a maximum depth of 12.8 m, an average depth of 7.8 m, and is holomictic. Walleye angling occurs from early to mid-May (season opens) through late February (season closes). Most walleyes are caught during the first month of fishing at temperatures of 13–21°C. Anglers typically fish from boats, use live bait or hard-bodied artificial lures or crankbaits in shallow water in spring or fall, and use live bait in shallow or deep water in summer. Leeches (Hirudinea), minnows (Cyprinidae), and worms (Annelida) are often fished under bobbers or attached to bottom-bumping slip-sinker or spinner rigs. From 1985 through 2004, anglers caught an average of 531,600 walleyes per year (range = 133,788–1,273,308; our unpublished data).

Methods

Sampling methods.—Participants in this study caught walleyes using angling techniques common to Mille Lacs during May–October 2003 and May–August 2004. Anglers typically used spinning rods and reels with light-gauge fishing line and bobbers, slip sinker rigs, or crankbaits. Participants included volunteers and DNR personnel with various degrees of walleye angling experience on Mille Lacs. One to four DNR employees were assigned 5 days per week to act as creel clerks and to fish. Participants fished for 7,400 h: 4,200 h by temporary employees hired specifically for this project, 1,000 h by permanent DNR personnel, and 2,200 h by volunteers. We used common angling methods across the entire open water season and sought to catch at least 1,200 walleyes, based on a priori simulations to determine the sample size needed to detect a 50% change from 6% in hooking mortality estimates from a model with three variables. Our original hypothesis was that water temperature, water depth, and fish length were the most influential and most easily measured variables in estimating hooking mortality for Mille Lacs walleyes during the open water season. We ignored walleye hooking mortality in winter because the estimated total catch in winter accounted for only 6.8% (95% CI = 5.1–8.5%) of annual walleye catches in Mille Lacs in 1998–2005 (our unpublished data).

Participants caught walleyes and recorded fishing method and bait type, hook location, bleeding, cutting of line, water depth, and angler handling times. Most walleyes in this study were caught within 0.5 m of the bottom. Angler handling time, which corresponds to time out of water, began when the fish left the water and ended when the angler was finished handling the fish. Anglers were instructed to handle fish as they would during a normal fishing trip. Anglers were given the choices of whether to cut the line on deeply hooked fish, whether to use a hook removal tool, and which fishing method to use. After unhooking, anglers placed the fish into a 50-L plastic tote and signaled the creel clerk to retrieve the fish. The clerk measured the TL, marked the fish with a unique combination of fin punches, and transported the fish to a holding cage. Time from unhooking to placement into the cage averaged 180 s (range = 4–960 s). Fish placed into cages were determined to be dead when no opercular movement was noted. Floating fish were not presumed to be dead (Bettoli et al. 2000), but their presence and number were noted.

Each day's catch from a sampling area was loaded into one net, after which the net was closed and the top of the net was submerged 1 m below the surface to avoid propeller damage. Fish were held for 120 h to observe delayed deaths after release. Most catch-and-release mortality occurs within the first 24 h (Muoneke 1992; Muoneke and Childress 1994; Schill 1996), yet one-quarter of deaths can occur several days after release (Grover et al. 2002). The cages in this study were generally left unchecked for 120 h because rough weather during lifting was likely to induce additional stress on the fish. Upon retrieval, minimally decomposed fish were examined for damage to major internal organs. Most dead fish were too decomposed to examine. The cages were 2 m × 2 m in cross-section, up to 11 m deep, and ringed with 38-mm inside diameter schedule 40 polyvinyl chloride pipe every 2 m from top to bottom. The cage mesh was delta knotless nylon of 6-mm-bar mesh size. The deep cages allowed fish to return to the depth of capture. Cages were usually placed within 0.5 km of fishing locations to minimize transport times for captured walleyes. We were unable to directly evaluate the effects of the holding cages by adding a control set of walleyes captured with an alternative method such as electrofishing or trap netting and transported to the cages. In other studies with short-term holding times in mesh cages, control mortality was usually 0–2% (Fletcher 1987; Taylor et al. 2001; Burns et al. 2002; Millard et al. 2005). We attempted to evaluate cage effects indirectly by including cage density in exploratory models. Thirty fish escaped from the cages during this study, presumably through holes in the mesh of the cage. The fraction of lost fish that were classified as having experienced increased trauma was low, and lost fish were excluded from the dataset.

Hooking mortality estimation.—We estimated monthly hooking mortality as

$$P_m = y/n, \qquad (1)$$

where P_m = the probability of death, y = the number of fish that were dead after 120 h in a cage, and n = the total number of fish in a particular category that were caught and held. We also calculated binomial confidence limits (95%) in the R Statistical Package (hereafter referred to as R; R Development Core Team 2006). Monthly estimates are easy to apply and to understand, especially when water temperature and fish length data are not available for a fishery. We also developed an equation for estimating hooking mortality in the Mille Lacs walleye fishery. We developed a generalized linear model that included fish length and water temperature variables, which are readily measurable in creel surveys. We used logistic regression, which translates a binary response, dead or alive, into a linear equation with known statistical characteristics (Hosmer and Lemeshow 2000).

Analysis of influential variables.—We used logistic regression analysis (Hosmer and Lemeshow 2000) to evaluate the effects of angler-related variables on the mortality of released walleyes in Mille Lacs. The data were not balanced among the possible variables, and the analysis is exploratory rather than confirmatory (Burnham and Anderson 2002). We used generalized additive models to determine appropriate transformations for the continuous variables of water temperature, fish length, water depth, angler handling time, and cage density. We included cage density to determine whether mortality was independent of cage density. We used generalized linear models to analyze the dichotomous or multinomial variables of hook location, fishing method, bleeding, and occurrence of floating. We converted three variables to binary responses because of low sample sizes in some terms. These variables included hook location, bleeding, and bait type. We combined hook locations into two categories—deep hooking in the esophagus or stomach, and shallow hooking in the oral cavity or outside the body. We categorized bleeding as observed or not observed and categorized bait type as either including at least some live bait or as entirely artificial. Only 1 of 175 walleyes died after being caught on crankbaits, an inadequate sample size for determining interaction effects. We therefore assumed that walleyes rarely died when caught with crankbaits and removed fishing method as a predictor variable in the models.

We combined potentially influential main effects and biologically feasible two-way interactions into a full model, from which we reduced the model by a protected stepwise method. We included only two-way interactions because sample sizes for many combinations of main effects were too small. Hook location was assumed to be an important factor with possible interactions (Muoneke and Childress 1994), but because sample size was small for many combinations of hook location and other categorical effects, interactions were not included. We used the "drop1" procedure in R to sequentially remove terms for which the maximum likelihood ratio test (LRT) was not significant (χ^2; $P > 0.05$). To protect from removing influential terms that were significant in combination with other variables and nonsignificant as univariates, we reintroduced sets of related variables into the reduced model and tested for the significance of the combined variables ($P < 0.05$).

Department of Natural Resources employees were instructed to watch for floating fish at the time of release and to record whether the fish floated or not. On about one-fourth of the data sheets, floating was not recorded. We analyzed two models: in the first, records with unlisted float results were deleted; in the second, missing float data results were assumed to be null. The results were similar, so we used the model containing more records and assumed that nonrecorded floating should have been recorded as not floating.

The variables of cutting the line on deeply hooked fish and live bait hook types apply only to part of the data set. We considered subsets of the data and analyzed each variable individually within a generalized linear model of survival. For the hook comparison, we tested the assumption that survival was the same for barbed jigs as for barbed regular hooks. Two categories of hooks, barbed circle hooks and barbless regular hooks, were rare and were excluded from further evaluation in the Mille Lacs data set. Most walleyes were caught with #4, #6, or #8 octopus or walleye hooks, all of which are more circular than regular J hooks and less circular than circle hooks.

Analysis of hook location.—Hooking mortality has been closely associated with hook location (Loftus et al. 1988; Diodati and Richards 1996; Lindsay et al. 2004), and others have used this relationship to infer survival (Dunmall et al. 2001; Meka 2004). We used logistic regression analysis with generalized additive and linear models to determine the main effects associated with hook location. Hook locations were combined into one of two categories, deep and shallow, as described previously. Hook location was the binary response variable and was regressed against the following predictor variables: water temperature, depth, fish length, and hook type. Excluded predictor variables were floating fish, bladder expansion, bleeding, and cutting the line—variables that do not cause differences in hook location. Only one fish was hooked deeply with artificial methods, so we restricted further analyses to live bait methods.

Results

Catch and Effort

Participating anglers contributed 1,246 walleyes to this study, which were captured on 143 d from 17 May to 11 October 2003 and from 19 May to 18 August 2004. Walleyes were held in 152 cages, with a median of 5.5 fish per cage (range = 1–42 fish), at a median temperature of 19.7°C (range = 10.1–26.3°C) and a median depth of 5.9 m (range = 3.5–11.3 m). Complete data were recorded and included in models for 1,089 walleyes; the remaining fish were excluded in exploratory analyses with the assumption that the data were missing at random (van Belle 2002). Missing data occurred most often when weather conditions were rough, and the exchange of information between volunteers and crew members was difficult. Most fish were caught with live bait, especially with leeches and either bobbers or slip-sinker rigs (Table 1), except in spring and fall, when artificial lures were used, as is common on Mille Lacs.

Hooking Mortality Estimates

Monthly mortality was estimated to be 0% (95% confidence interval, 0–1.8%) for May, 3.5% (2.0–5.6%) for June, 12.2% (9.2–15.9%) for the July–August period, 2.6% (0.3–9.1%) for September, and 0% (0–4.6%) for October (Figure 1). Mortality was lowest when the water was cool, when fish were caught in shallow water, and when crankbaits were frequently used. We also modeled hooking mortality as a linear function of water temperature and a quadratic function of fish length. The interaction term was not significant (LRT: residual deviance = 408.8, 412.4, df = 1,083, 1,085, $P = 0.17$) and therefore was not included in the model. The predictive model was

$$P_m = \frac{e^{-4.487+0.3125\cdot \mathrm{WT}-0.02148\cdot \mathrm{TL}+0.00002264\cdot \mathrm{TL}^2}}{1+e^{-4.487+0.3125\cdot \mathrm{WT}-0.02148\cdot \mathrm{TL}+0.00002264\cdot \mathrm{TL}^2}}, \tag{2}$$

where P_m is the probability of death, WT is water temperature (°C), and TL is total length (mm).

Analysis of Influential Variables

The reduced exploratory model of hooking mortality for Mille Lacs included the variables in the predictive model, water temperature, and fish length as well as hook location, bleeding, and occurrence of floating fish (Table 1). Interactions were found between water temperature and bleeding and between fish length and hook location. For nonbleeding fish, hooking mortality was low at temperatures up to 20°C and then increased rapidly (Figure 2). For bleeding fish, mortality was higher at similar water temperatures up to 25°C, which was near the upper limit of our study. At the upper temperature limit, hooking mortality was similar regardless of whether or not the fish bled. The plot of the smoothed locally weighted scatterplot smoother (Lowess) function for the generalized additive model of death and cage density was U-shaped, indicating that cage density could not be transformed into a linear predictor of the response variable of death (Hosmer and Lemeshow 2000). Cage density was removed from consideration in the exploratory model.

Shallow hooking resulted in lower mortality than deep hooking; however, this relationship varied across lengths (Figure 3). The likelihood of dying decreased from a fivefold difference between deep and shallow hooking for a 300-mm fish to no difference for a 600-mm fish. Even for shallow hooked fish, survival was higher for 300–600-mm fish than for smaller or larger fish. Major internal organs were damaged in 24 of the 34 dead fish examined for internal injuries. Five of thirteen fish reported as being hooked in the jaw or inner mouth nonetheless had damage to major internal organs. Of the 34 internally examined fish, all 18 fish reported as deep hooked had damage to major internal organs. Among all fish, only 23 fish floated, and 11 of these died. Only 3.9% of nonfloating fish died.

Depth of capture, cutting of the line, and live bait hook type were not related to hooking mortality. Deeper water appeared to be associated with higher mortality in preliminary analyses (LRT: deviance difference = 21.26, df = 1,088, $P = 4.0 \times 10^{-6}$), but the final model included other variables that reduced the effects of depth, with the result that depth was

TABLE 1.—Variables used to assess 120-h survival of walleyes released during experimental fishing at Mille Lacs, Minnesota, during 2003 and 2004. The value $P(>|\text{chi}|)$ tested the likelihood that the variable reduces the deviance of the model over that of the model with the previous variables already included.

Term (sample size)	Estimated parameter	SE	Residual deviance	df	$P(>\|\text{chi}\|)$
Variables used to estimate hooking mortality					
Intercept	−4.48	1.70	470.1	1,085	
Water temperature (°C) (1,089)	0.312	0.0477	420.5	1	1.8×10^{-12}
Length (mm) (1,089)	−0.0215	0.000690	420.2	1	0.56
Length^2	0.0000226	0.00000774	412.4	1	0.01
Variables associated with hooking mortality					
Intercept	−1.99	1.74	470.1	1,078	
Hook location (shallow [895], deep [194])	0.782	1.89	436.5	1	6.7×10^{-9}
Water temperature (°C) (1,089)	0.276	0.0556	402.5	1	5.5×10^{-9}
Bleeding (no [931], yes [158])	2.60	1.17	395.8	1	0.01
Floating fish (no [1,066], yes [23])	2.49	0.559	372.7	1	1.5×10^{-6}
Length (mm) (1,089)	−0.0275	0.00836	372.7	1	0.95
Length^2	0.0000288	0.00000879	362.4	1	0.0014
Hook location : length (1,089)	0.0165	0.00827	356.0	1	0.01
Hook location : length^2	-4.91×10^{-6}	0.00000871	356.0	1	0.89
Water temperature : bleeding (no, yes)	−0.102	0.0533	352.4	1	0.06
Variables associated with hook location					
Intercept	−4.50	0.505	1,004.1	968	
Hook type (jig [386], regular [586])	1.02	0.194	964.9	1	3.8×10^{-10}
Water temperature (°C) (972)	0.107	0.0213	938.7	1	3.1×10^{-7}
Length					
<330 mm (183)			919.0		5.4×10^{-5}
330–482 mm (411)	0.751	0.267		1	
483–752 mm (378)	0.335	0.282		1	
Evaluation of line cutting in deeply hooked walleyes					
Intercept	−1.58	0.229	169.0	199	
Cutting the line (no [135], yes [66])	0.532	0.461	167.6	1	0.23
Evaluation of live bait hook type					
Intercept	−2.56	0.196	455.3	967	
Hook type (jig [389], regular [579])	−0.249	0.266	454.4	1	0.35
Variables not significantly associated with or not tested against hooking mortality at Mille Lacs					
Depth (mean = 5.4 m, range = 1–11.3 m)		na	na		0.27
Angler handling time (mean = 44.0 s, range =7–210 s) (1,089)	na	na	na		0.64
Fishing method (artificial lures [169], live bait methods [bobber {665}, slip sinker rig {190}, straight line {103}, other {10}])	na	na	na		0.002[a]
Gas bladder expansion (no [1085], yes [4])	na	na	na		Not tested
Cage density (median = 6, range = 1–42)	na	na	na		Not tested

[a] Only one fish died when caught with artificial lures; artificial lures were not used above 20°C.

excluded (deviance difference = 1.23, df = 1,088, P = 0.27) in the drop1 procedure. Additionally, most walleyes are caught in water less than 10 m deep at Mille Lacs. Cutting the fishing line did not increase survival of released walleyes in this study (deviance difference = 1.42, df = 199, P = 0.23). Anglers chose to cut the line or not and the choice may have at times been made after the fish was already damaged. Conversely, the anglers may have been proficient at removing deep hooks such that damage was limited. At Mille Lacs, fish caught on barbed jigs and on barbed regular hooks died at similar rates (deviance difference = 0.87, df = 967, P = 0.35). Gas bladder expansion or the eversion of stomach or esophagus into the buccal cavity was observed in only four cases, so this variable was not included in the models.

Analysis of Hook Location

Only one fish was deep-hooked with artificial plugs or crankbaits. Walleyes caught on crankbaits are expected to die infrequently because few of them are hooked in critical areas. Because too few other artificial lures, and no synthetic baits, were included in the sample, no further evaluation was possible. For fish caught with live bait methods, hook location was most influenced by hook type, fish length, and water temperature (Table 1). Deep hooking occurred more often with regular barbed hooks than with jigs, with 300–600 mm fish than with smaller or larger fish, and in warmer water temperatures than in cooler ones (each LRT $P < 0.01$; overall residual deviance = 1,004.1,

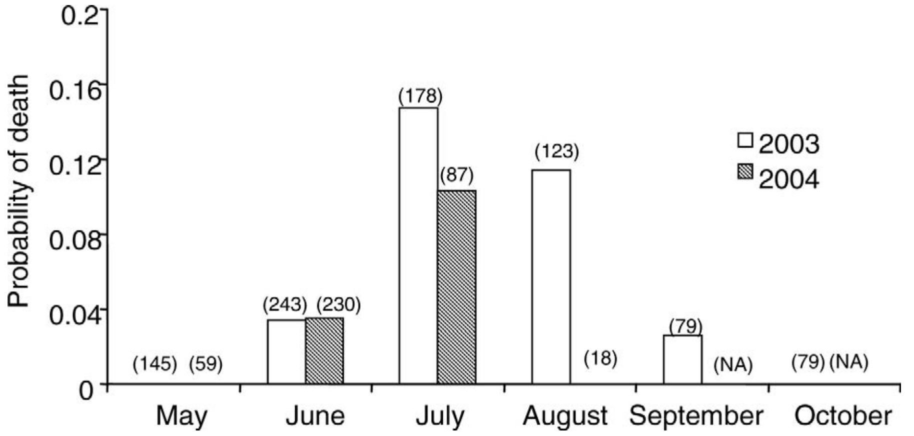

FIGURE 1.—Hooking mortality by month and year for walleyes caught during experimental fishing on Mille Lacs, Minnesota. Sample size is listed above each category (NA = no sample collected). The total sample size was 1,241 walleyes. Missing bars indicate mortality was not observed in that month and year.

df = 972; Figure 4). No interaction terms were associated with hook location (LRT $P < 0.05$).

Discussion

Hooking mortality in the recreational, nontournament walleye fishery at Mille Lacs, Minnesota, was generally less than 5%. During the cool water fishing in May, hooking mortality was estimated at 0%. Even during the highest water temperatures in summer, when most anglers are using live bait, we estimated hooking mortality to be less than 15%. Previously, hooking mortality in the open water angling season was estimated to be 6–10%, based on the proportion of fish above or below 330 mm TL. Hooking mortality was only a function of the walleye length distribution and the estimated numbers of released walleyes for the season. Our new mortality rates can now be adjusted within the season as fish lengths and lake water temperatures change. For 2002 through 2004, the use of the predictive equation resulted in decreases in estimated overall

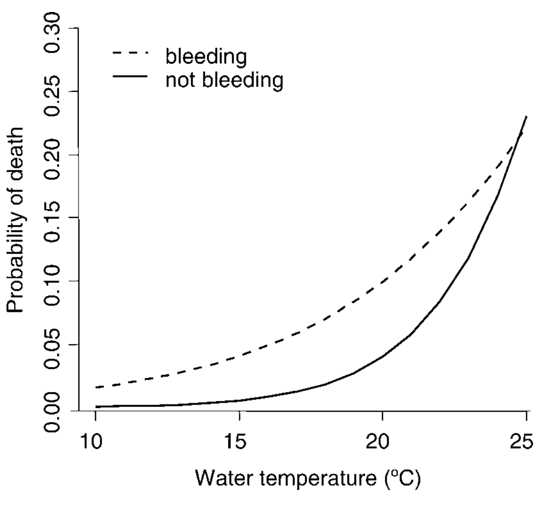

FIGURE 2.—Predicted hooking mortality, by water temperature and occurrence of bleeding, of released walleyes at Mille Lacs, Minnesota, in 2003 and 2004. This example is derived from the explanatory logistic regression model (Table 1) with fish length set to a constant 467 mm and assuming that fish were deeply hooked and not floating.

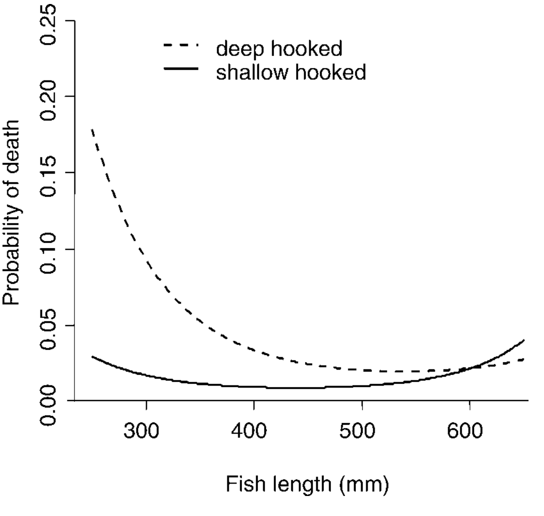

FIGURE 3.—Predicted hooking mortality, by length and hook location, of released walleyes at Mille Lacs, Minnesota, in 2003 and 2004. This example is derived from the explanatory logistic regression model (Table 1) with water temperature set at a constant 18.5°C and assuming that fish were not bleeding and not floating.

hooking mortality numbers from 6.1% to 4.1% in 2002, from 6.2% to 2.7% in 2003, and from 7.5% to 3.8% in 2004. Such changes in estimated mortality may influence management decisions. For example, use of the new predictive equation would have reduced the estimated walleye harvest in 2002 by 12.6% and eliminated the estimated overharvest in 2002. Changes in the rates of hooking loss have much less effect when catch is low, as occurred in 2003 and 2004. For the new predictive equation, we chose water temperature and fish length as predictor variables because they are readily measured in annual creel surveys. Other variables such as depth of capture, bait type, and hook location may add to the understanding of hooking mortality but are not as easily measured in the fishery.

This study supports the findings that higher water temperature (Edwards et al. 2004) and damage to major internal organs via deeper hooking (Taylor et al. 2001; Aalbers et al. 2004) are associated with higher hooking mortality. In our study, hooking mortality was low when water temperatures were less than 18°C and increased with increasing water temperature. Most mortalities occurred with deeply hooked fish. Death from deep hooking may have also occurred in fish that we classified as shallow-hooked; a substantial proportion of the dead and presumably shallow-hooked fish we examined also had internal hook injuries. Aalbers et al. (2004) observed that 32% (7/22) of the white seabass *Atractoscion nobilis* reported to be hooked in the jaw or mouth also sustained internal damage. Thus, bleeding is more often associated with deep hooking than is indicated in the exploratory model. Walleyes that were hooked in the jaw or inner mouth and were not bleeding were very likely to survive being caught and released.

Fish length, hook style, and angling method influenced the occurrence of damage to internal organs. Although deep hooking occurred less often in smaller fish, deeply hooked smaller fish were more likely to die (Figure 3). The use of relatively small hooks (numbers 4 and 6) is less likely to cause severe damage to the larger fish. As fish size increases, relative hook size decreases, penetration decreases, and organ damage is minimized. Others have suggested using larger hooks to prevent deep hooking (Carbines 1999; Schaeffer and Hoffman 2002). In our study, jigs deep-hooked less often, yet mortality rates were similar between jigs and plain hooks. Hooking mortality may vary by hook type, or not, depending on the hook's effect on internal organs but not on the proportion of hooks that are deeply imbedded. Mortality appeared to increase for the largest walleyes (Figure 3), even when these fish were shallow-hooked. These larger fish are more difficult to land and may have become exhausted (Sobchuk and Dawson 1988), potentially increasing stress from which they do not recover. The least damage to internal organs, and least mortality, was observed from active fishing methods, specifically from crankbaits. Our observations were similar to others who have observed that a fish's ability to swallow the bait is diminished if the lure or bait is fished actively (Schill 1996; Schisler and Bergersen 1996; DuBois and Kuklinski 2004).

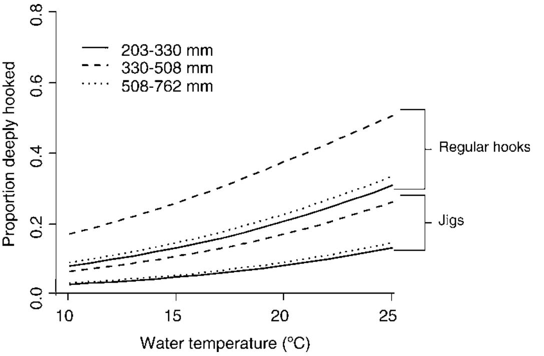

FIGURE 4.—Proportion of walleyes that were deeply hooked, by water temperature and hook type, in a hooking study at Mille Lacs, Minnesota, in 2003 and 2004. This example is from the explanatory model (Table 1), which describes the association between hook location and the predictor variables water temperature, hook type, and three categories of fish length.

Although research on other species indicates that cutting the line may reduce hooking mortality (Schisler and Bergersen 1996), we did not find increased survival of walleyes by cutting the line. Damage may already have been done before line cutting, or it may have occurred through attempted hook extraction. In some cases, the choice to extract the hook or to cut the line may be based on seeing blood, at which point damage to major internal organs has already occurred.

Depth was also not associated with hooking mortality. Most fish were caught in water less than 10 m deep. Depth will influence hooking survival in deeper lakes by increasing the probability that anglers do not feel bites and thus let the fish swallow the hook, increasing the stress induced from decompression (Childress 1988; Bruesewitz et al. 1993; Burns et al. 2002), and probably increasing stress with rapid temperature changes. On Mille Lacs, some anglers expressed concern that most small walleyes caught from deeper water were dying from gas bladder expansion. This observation was not supported by our study, nor by Bettoli et al. (2000), who experimentally caught and released sauger *Sander canadensis*, a smaller congeneric of the walleye.

Improper handling is the more likely cause when numerous fish are observed floating.

Management that protects 300–600-mm walleyes via length limits will minimize total hooking mortality. Despite lower survival when fish were hooked critically in warm water, 300–600-mm walleyes still survived at a higher rate than smaller or larger walleyes. For example, using results from the explanatory model (Table 1), the probability of death for a walleye with a length of 467 mm, caught at 24°C, that is deeply hooked and bleeding, and does not float when released is just $P_m = 0.19$. By comparison, probability of death is higher for a 300-mm walleye ($P_m = 0.46$) or a 711-mm walleye ($P_m = 0.27$) under the same conditions. For an individual angler, increasing survival of caught-and-released fish will include using numerous methods and techniques that reduce stress on the fish. Anglers who are oriented toward reducing damage to their quarry will choose methods that reduce mortality. Anglers who seek methods with the highest retention or hooking rates may actually increase mortality. Regardless of the findings of any one study, techniques that reduce catches in warm or deep water, hooking damage to critical organs, and handling time are likely to increase the survival of released fish. Angler attitude and experience are probably important factors in how well a fish survives. Meka (2004) observed that novice anglers injured proportionately more rainbow trout *Oncorhynchus mykiss* than did experienced anglers, primarily during hook removal. Dunmall et al. (2001) observed that experienced anglers hooked smallmouth bass *Micropterus dolomieu* more deeply in the mouth than novice anglers did. The effects of experience depend on how that experience is applied. Grover et al. (2002) noted that circle hooks were mandated in a salmon *Oncorhynchus* spp. fishery, yet hooking mortality was estimated to be high because anglers modified the hooks to increase the prevalence of deep hooking, thereby circumventing the protection assumed with circle hooks. Nearly all walleyes will survive being caught and released if steps are taken to reduce deep hooking, avoid fishing in very warm or deep water, and handle fish with care.

Management Implications

Catch and release fishing for walleyes can lead to substantial changes in population structure (Brousseau and Armstrong 1987). We believe that annual walleye hooking mortality in most northern North American fisheries is generally less than 5%, as most walleyes are caught in relatively cool water, frequently by active fishing methods, and primarily by more experienced anglers.

Although hooking mortality was historically unimportant because length-based regulations were rare and most walleyes were kept, fisheries managers should now account for this added source of fishing mortality, especially when release rates are high. The predictive equation (2) can be used in fisheries with similar distributions of fishing methods, hook types, and water depths. Depth is probably a critical factor in fisheries where walleyes are caught in water over 10 m deep. In fisheries with more active methods, hooking mortality may be lower. Temperature can be measured periodically, such as bimonthly or monthly. Mean fish length can be used when individual fish lengths are unknown. For example, on Mille Lacs during this study, most walleyes were caught during cool weather, averaged 467 mm TL, and had low hooking mortality. Higher mortality can be expected when fish are substantially smaller or larger and continue to bite in warmer weather. Changes in terminal tackle and fishing methods may also influence hooking mortality. Anglers may follow the advice of fisheries managers and sportfishing writers (Skomal et al. 2002; Cooke et al. 2005; Quinn 2005), and switch to circle hooks, although some anglers may believe circle hook requirements to be unacceptable (Jones 2005). Anglers may switch to more active methods, catch more walleyes in warmer or cooler weather, or use new techniques of hook removal (Stange 2005), each of which may increase or decrease hooking mortality. Anglers' choices will ultimately affect how well released fish survive; therefore, survival rates will be enhanced through continued education about the best catch-and-release methods available to anglers.

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