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[Article]

Mortality Associated with Catch-and-Release Angling of Striped Bass in the Hudson River

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Abstract.—Catch-and-release fishing commonly occurs in recreational fisheries, including those for the striped bass *Morone saxatilis* of the Atlantic coast. The contribution of catch-and-release practices to overall fishing mortality is often not estimated. We estimated the catch-and-release mortality for the Hudson River spawning stock of striped bass in 2001. Volunteer anglers caught striped bass between April 30 and May 16, 2001. Fish were transferred to transport boats in live wells and placed in one of nine 15,000-L land-based holding tanks. Control fish were collected by electrofishing and otherwise handled similarly. Treatment and control fish were uniquely tagged and held together for 5 d. Hooking mortality was estimated via conditional rate and additive rates. These two estimation techniques partitioned total observed mortality into hooking mortality and handling mortality, the latter being estimated from control fish. Catch-and-release mortality for striped bass averaged 16% for traditional J hooks and 5% for circle hooks over the entire period. Hook location and the occurrence of bleeding were the most influential variables in determining the probability of death. Mortality rate increased when water temperatures reached 16°C. This mortality rate is significant and should be considered when accounting for Hudson River striped bass removals from their spawning population.

Catch-and-release fishing commonly occurs in recreational fisheries, including those of the striped bass *Morone saxatilis* of the Atlantic coast. The contribution of catch-and-release practices to overall fishing mortality is often not estimated. Recent national recreational fishing survey reports indicate that striped bass anglers released over 90% of their catch in 1997 and 1998 (National Marine Fisheries Service [NMFS], Fisheries Statistics and Economics Division, personal communication). Consequently, hooking mortality may contribute substantially to fishing mortality in the Atlantic coast striped bass fishery. Estimates from the NMFS recreational fishery survey indicated that an average of over 14.5 million striped bass were caught and released each year between 1996 and 2000 (NMFS, Fisheries Statistics and Economics Division, personal communication). The Atlantic States Marine Fisheries Commission (ASMFC) fishery management board for striped bass currently assumes an 8% hooking mortality rate. This rate infers a 5-year average annual mortality of over 1.3 million released fish along the U.S. Atlantic coast between 1996 and 2000. These estimates of hooking mortality exceed the estimates of directed commercial harvests in 1998, 1999, 2000, and 2001 (ASMFC 1999, 2000, 2001, 2002).

The overall hooking mortality of 8% currently accepted by ASMFC managers was a preliminary estimate from a study performed in a saltwater coastal system (Diodati and Richards 1996). Hooking mortality in striped bass may be inversely related to salinity (Wilde et al. 2000), although the exact relationship and the underlying cause remain unclear. The restoration of the striped bass fishery on the U.S. East Coast has increased opportunities

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for the recreational and commercial fishing communities. Fishery managers must routinely monitor sources of mortality and implement responsive prudent management actions to maintain this fishery. For this reason, we believed an evaluation of hooking mortality for striped bass in the primarily freshwater environment of the Hudson River was necessary.

The 8% hooking mortality rate for striped bass, estimated by Diodati and Richards (1996), is similar to the 7.3% (artificial lures) and 5.3% (live bait) estimates of Nelson (1998). Diodati and Richards (1996) employed a 58-d observation period in a saltwater system, whereas Nelson (1998) observed fish held in freshwater tanks for 3 d after capture. Employing a 2-week observation period, Harrell (1988) reported a hooking mortality rate for striped bass of 4% (artificial) and 6% (bait) in October, and 2% (artificial) and 0% (bait) in February; however, hooking mortality increased in June to 21% (artificial) and 17.6% (bait) and in August to 36% (artificial) and 40% (bait). Biologists working in brackish waters (approximately 5–10‰) of the Chesapeake Bay in 1999 found that striped bass caught with nonoffset circle hooks had markedly lower hooking mortality than did fish caught with traditional bait hooks (R. Lukacovic, Maryland Department of Natural Resources, Annapolis, unpublished data). A pilot study in the Hudson River by the authors indicated hooking mortalities for striped bass approached 30% and led to the experimental and procedural improvements employed in this study (Millard et al. 2003).

Given the importance of striped bass in New York, as well as the Atlantic coast, much scrutiny has been placed on East Coast spawning stocks. New York's Hudson River striped bass fishery is one of the few recreational fisheries that is directed on a spawning stock for the duration of the spawning season. In late March to early April, the recreational fishery begins in the downriver areas of Haverstraw Bay as bass begin to enter the river. The fishery follows the migration north as fish move into the spawning areas during May and winds down in early June as spawners begin to leave.

Our objectives were to estimate the mortality associated with catch-and-release practices that commonly occur in the spring recreational striped bass fishery in the Hudson River and to assess the influence of selected variables on hooking mortality rates (water temperature, hook type, playing and handling time, hook location, and fish length). This information is necessary to determine the contribution of hook and release mortality to the overall fishing mortality rate in the Hudson River striped bass fishery. The results are useful in developing guidelines for reducing mortalities of released fish and in formulating regulations designed to reduce the nonconsumptive mortality rates associated with recreational fishing. This information is particularly important because the fishery targets one of the largest concentrations of spawning striped bass in the Hudson River.

FIGURE 1.—Map showing the study site on the Hudson River, New York, for striped bass hooking mortality study.

Methods

Striped bass were collected from the Hudson River immediately upriver from the Kingston–Rhinecliff Bridge, north of Kingston, New York, in a popular angling area known as the Kingston Flats (Figure 1). Volunteer recreational anglers, recruited to fish between April 30 and May 16, 2001, reported to an anchored project boat upon arrival at the fishing site each day and received bait (primarily alewives *Alosa pseudoharengus*) and a supply of hooks. Each angler boat was randomly supplied with either traditional straight-shanked J hooks or nonoffset circle hooks and were requested to use the assigned hook-type throughout the day. Hooks provided were 3/0, 4/0, and 5/0 nickel-plated (Mustad 3406 O'Shaughnessy) and 5/0, 6/0, 7/0, and 8/0 black-finish (Mustad 39950BL Demon Circle). Some anglers chose to use their own J hooks or circle hooks, a small number of which had offset points.

The anglers were free to use live or chunk bait and to fish the bait in any manner they chose as long as they stayed within the approximately 2-km reach of the project boundary. All anglers used spinning or bait-casting gear. Three or four transport boats with aerated, flow-through live wells were distributed among the anglers each day and remained in contact with anglers either via radio or manual signal flags. Immediately after hook-up with a fish, an angler notified a transport boat, the transport boat noted the time of hook-up, and began approaching the angler's boat. Once the fish was brought to net, the project boat closed with the angler boat and retrieved the fish either directly out of the net or from the angler. Data initially recorded for each angled fish included playing time, transport time, hook type, bait type, line weight or test strength, hook location, and presence of bleeding.

Angled fish were placed in the transport boat live well, tagged (individually numbered T-bar anchor tag made by Floy Tag and Manufacturing, Inc., Seattle, Washington) near the anterior base of the dorsal fin, and immediately transported to a shore-based holding tank. Residence time in the live well for angled fish averaged 8 min and ranged between 3 min and 16 min. An array of nine holding tanks (4.6 m diameter, 15,000-L capacity) were provided with flow-through of river water at a turnover rate of 50% total volume per hour. Tanks were lined with black polypropylene and were covered with screening, which provided 70% light blockage.

Control fish were captured from the same river reach by electrofishing with pulsed DC produced via an array of bow-mounted dropper cables. Control fish were tagged and transported similar to angled fish. Residence time in the live well for control fish averaged 18 min and ranged between 5 min and 48 min. All fish captured on a given day were placed in the same holding tank, and a vacant tank was used each day; that is, fish from different days were not mixed within a tank. Fish were held in captivity for 5 d (6 d in one case), and visible mortalities were removed and recorded daily from each tank. After the holding time had elapsed, all remaining fish in a tank were removed, measured, and recorded as being angled or control fish, male or female, and alive or dead. All survivors were released back into the river. A subset of dead angled fish were necropsied to assess the presence or absence of gross physical trauma in the esophagus and surrounding tissues. Any trauma or hemorrhaging was assumed to be related to hooking or hook removal. Water temperature was continuously recorded in the river and in one holding tank throughout the duration of the project.

Analysis of mortality data followed that of Millard et al. (2003). For comparative purposes, mortality rates associated with hook and release of striped bass were estimated using two methods: conditional mortality rates, and additive finite mortality rates. The two methods differed in their assumptions about the relationship between the two possible sources of mortality: hook and release and experimental handling.

Conditional mortality rates.—This method assumes the two mortality components associated with hook and release and experimental handling acted simultaneously with each other and, in effect, competed with each other during the 5-d holding period. As such, this method assumed that the two mortality components, hooking and handling, acted on the treatment fish over the course of the 5-d observation period and that handling mortality alone acted on the control fish. The additive relationship for instantaneous rates is described as

$$\text{total observed mortality} \\ = \text{hooking mortality} + \text{handling mortality}. \quad (1)$$

No natural mortality was assumed during the 5-d observation period. An instantaneous handling mortality rate was estimated from the control group as

$$m_h = -\log_e(S_h), \quad (2)$$

where m_h is handling mortality, and $S_h = 1 - A_h$ or 1 − the fraction that die in control group.

An instantaneous total mortality rate in each treatment group was estimated as

$$m_t = -\log_e(S_t), \quad (3)$$

where m_t = total mortality in treatment group, and $S_t = 1 - A_t$, or 1 − the fraction that die in treatment group.

From equation (1), the instantaneous hooking mortality rate was calculated for each treatment as

$$m_{\text{hook}} = m_t - m_h. \quad (4)$$

This method assumes that both handling and hooking mortality acted on the treatment fish concurrently during the observation period, representing a situation similar to a type II fishery, in which natural and fishing mortality act concurrently on a stock (Ricker 1975). The estimate of the conditional mortality rate associated with hook and release ($m_{c\text{-hook}}$) that would occur in the absence of handling mortality, was computed as

$$m_{c\text{-hook}} = (A_t \times m_{\text{hook}})/m_t. \quad (5)$$

Equation (5) follows the traditional fisheries expression $u = A \cdot F/Z$, where A is the fraction of fish that die from all causes, F is instantaneous fishing mortality, and Z is instantaneous total mortality. This can be rewritten as

$$u = A - [A \cdot M / -\log_e(1 - A)], \quad (6)$$

where M is equivalent to the mortality rate in the control fish.

Confidence limits for u, as defined in equation (6), were generated using a variance term derived with the delta method (Oehlert 1992), in which

$$\widehat{\text{Var}}(\hat{u}) = (\partial\hat{u}/\partial A)^2 \times \widehat{\text{var}}(M) + (\partial\hat{u}/\partial M)^2 \times \widehat{\text{var}}(A)$$

with

$$(\partial\hat{\mu}/\partial A) = 1 - \left[\{A \cdot M/[\log_e(1 - A)]^2 \times (1 - A)\} + [M/\log_e(1 - A)]\right] \quad \text{and}$$

$$(\partial\hat{u}/\partial M) = A/-\log_e(1 - A).$$

This approach was employed with the assumption that capture by electrofishing did not cause mortality in the control fish.

Additive finite mortality rates.—This method assumes that the two mortality components associated with hook and release and experimental handling were independent. In this case, an additive relationship was assumed between the two rates observed at the end of the 5-d holding period, and hooking mortality was computed as the difference between the total mortality rate observed in the treatment fish and the handling mortality rate observed in the control fish. This is equivalent to the ''adjusted mortality rate'' reported by Nelson (1998) and the simple model described by Wilde et al. (2003), where delayed mortality in tournament-caught fish was corrected for control mortality by subtraction. Confidence limits for d, the simple difference between two proportions, were generated using the variance and associated standard error formulas found in Fleiss (1981).

Factors influencing mortality.—The effect of angling-related variables on mortality of hooked fish was evaluated with logistic regression analysis (Menard 1995). We assessed how the probability of mortality was affected by the following explanatory variables: hook type, bait type, hook location, presence of external bleeding, playing time, sex, and fork length. The standard logistic regression model $p_i = e^\lambda/(1 + e^\lambda)$ was fit, where p_i is probability of mortality and e^λ is a linear function of the explanatory variables mentioned above. Maximum likelihood estimates of the coefficients and their associated odds ratios, plus logistic regression diagnostics were generated with SAS software (SAS Institute, Inc. 1989). Variables were included in the final model when the likelihood-ratio test of their coefficient was significant ($\alpha = 0.1$). Odds ratios are helpful in interpreting logit model coefficients because of the nonlinear relationship between the probability and the explanatory variables. This property precludes the straightforward interpretation of coefficients that one normally encounters with linear regression. A common helpful approach to interpreting odds ratios is to subtract 1 from the odds ratio and multiply by 100; the result provides the percent change in the odds (of mortality, in this case) for each 1 unit increase in the explanatory variable. A probability-based interpretation of the logit model, as opposed to ratio-based odds, was also provided via the equation (Allison 1999)

$$\frac{\partial p_i}{\partial x_i} = \beta p_i(1 - p_i). \quad (7)$$

This allows for the interpretation of the average change in probability of mortality given a 1-unit increase in the explanatory variable X having parameter estimate β.

Results

Overall Catch and Mortality

Participating anglers contributed 159 striped bass during the 13 angling days between April 30 and May 16, and 143 control fish were captured via electrofishing. Mortality of the control fish was low; only 4 (2.8%) died within the 5-d observation window, whereas 26 (16.3%) of the angled fish died. Angled and control fish had similar characteristics. The mean fork length of angled females was 831 mm and that of control females was 882 mm; angled males averaged 697 mm and control males 723 mm. However, the length distribution of male controls appeared to be bimodal, peaks being at 660 mm and 820 mm. Of the 287 fish for which sex was identified, 88% of the controls were male and 71% of the angled fish were male.

The overall handling time for angled fish consisted of angler play time plus transport handling time. Mean angler play time was 5 min, and mean transport time was 8 min. Of the 26 total mortalities suffered by angled fish, 14 (54%) occurred in fish that had been played 5 min or less, and 13 (50%) occurred in fish with a transport time of 8 min or less (Figure 2). The mean overall play time

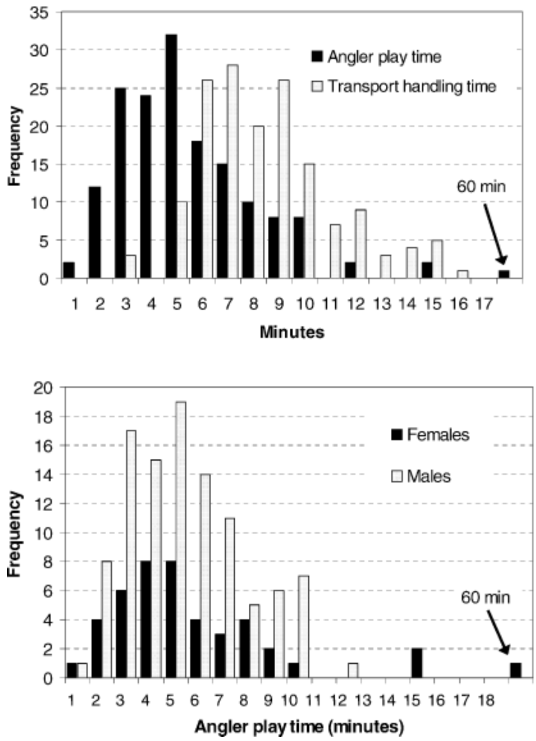

FIGURE 2.—Frequency distribution of angler play time and subsequent transport time to holding tanks for all striped bass combined (top panel) in a hooking mortality study on the Hudson River, New York, and distribution of angler play time for male and female fish (bottom panel).

for angled fish was 5.6 min; there was no significant difference between playing time for male and female fish (*t*-test, $P > 0.35$). Total handling time (angler play time plus transport time) averaged 14 min. Twelve (46%) of the 26 total mortalities among angled fish occurred in fish experiencing less than the average handling time of 14 min (Figure 3). These results suggest that angler playing time and transport handling time had little influence on observed mortality.

Although hook-specific effort was not recorded, attempts to exert approximately equal effort with

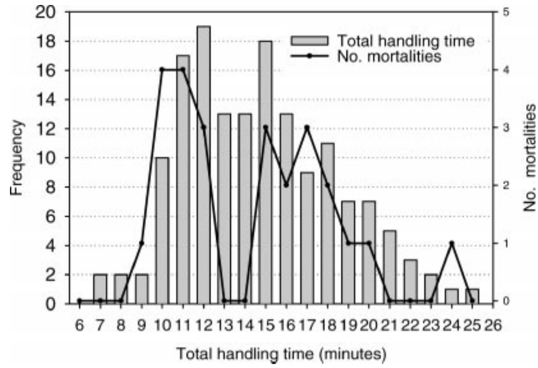

FIGURE 3.—Distribution of total handling time (angler play time and transport time) and frequency of mortalities for angled striped bass in the Hudson River, New York.

circle hooks and J hooks were generally unsuccessful, primarily due to the unwillingness of volunteer anglers to employ circle hooks. Consequently, only 37 of the 159 angler-caught fish were captured on circle hooks, and 3 (8.1%) of these died within the observation period. Of the 122 fish caught with J hooks, 23 (18.9%) died within 5 d (Table 1).

Hooking Mortality Estimates

Mortality estimates using the simple additive model were 16.1% for J hooks and 5.3% for circle hooks (Table 2). Adjusting the observed mortality of angled fish to account for the effects of transport, handling, and holding resulted in slightly higher estimates of hooking mortality. The conditional rate mortality estimates were 16.3% for J hooks and 5.4% for circle hooks. The results of the two estimation techniques are similar due to the fact that our control fish exhibited low mortality (2.8%).

Factors Influencing Mortality

Hook location and the occurrence of bleeding were the most influential variables in determining the probability of death of a hooked and released

TABLE 1.—Descriptive statistics for catch and mortality of Hudson River, New York, striped bass by hook type and bait type. Bait type was unreported for one fish, resulting in one fewer fish in the overall sample size for the bait-type data.

Variable	Hook type		Bait type	
	Circle	J hook	Cut	Live
Total number caught	37	122	147	11
Mortality (%)	8.1	18.9	17.0	9.0
Bleeding observed (%)	5.4	7.4	7.5	0.0
Lip hooked (%)	54.1	22.1	26.5	63.6
Gut hooked or swallowed hook (%)	29.7	51.6	48.3	27.3

TABLE 2.—Estimates of catch-and-release mortality of striped bass in the Hudson River, New York, associated with two hook types, uncorrected and corrected for handling mortality via additive and conditional rate estimators. The 95% confidence interval (95% CI) for the conditional and additive rate estimators are provided in parentheses. Mortalities for that gear type are provided by number (*N*) and percent.

Gear	Total caught	Mortalities		Catch-and-release mortality estimates (%)	
		N	Percent	Additive (95% CI)	Conditional (95% CI)
J-hooks	122	23	18.9	16.1 (8.8–23.4)	16.3 (9.7–22.5)
Circle hooks	37	3	8.1	5.3 (0–12.3)	5.4 (0–14.1)
Electrofishing	143	4	2.8		

fish ($P < 0.05$, Table 3). The odds ratio for the bleeding variable was 15.77; thus, the odds of death for a fish that bled around the hooking site was about 15 times greater than for a fish with no observable bleeding. In a probabilistic framework, the probability of death, on average, was 0.38 higher for fish that exhibited bleeding compared with those that did not show bleeding.

Hook location was a significant variable, but it was somewhat more difficult to quantitatively interpret because the response had four possible outcomes: lip, mouth, gill, or gut. Recoding the data so that each of the four possible outcomes becomes a separate, binary variable allows us to compare three of the responses against the remaining fourth response. When the hook location classifications of mouth, gill, and gut were compared against the lip classification, only the gut variable was significant ($P < 0.05$), the odds ratio estimate being 5.8, which indicated that the odds of death for a fish that swallowed the hook are 5.8 times the odds of death for fish that are lip-hooked. Of the 47 fish that were lip-hooked, only 2 (4.5%) exhibited bleeding, and neither fish died within the 5-d observation period. Two of the 36 fish hooked in the mouth ($N = 34$) or gill ($N = 2$) area died; neither had exhibited bleeding. Of the 74 fish that swallowed the hook, 7 (9.5%) exhibited bleeding and died.

Interestingly, hook type was not significantly related to the mortality of a hooked and released fish ($P > 0.3$). Because hooking location and bleeding were important determinants of the ultimate fate of the fish, it is particularly inviting to attempt to predict hooking location or bleeding as a function of hook or bait type. Traditional J hooks were swallowed with greater frequency than were circle hooks, although the differential was not statistically significant.

Fork length category was nearly significant ($P = 0.058$; Table 3) in predicting mortality. The negative parameter estimate suggests that the odds of mortality decreased as fork length increased. Fish equal to or smaller than the 10th percentile in fork length (615 mm) suffered 19.2% of the total mortality observed in the study, whereas fish longer than the 90th percentile (865 mm) exhibited no mortality (Figure 4). In general, larger fish were less likely to die.

The average daily water temperature steadily increased from 12°C on April 30 to 17°C on May 12 and then varied between 16°C and 17.5°C through the end of the study period. Water temperature in the tanks generally deviated 2°C or less

TABLE 3.—Logistic regression results assessing the variables influencing the mortality of striped bass caught with hook and line. The categorical data coding scheme for each variable is shown in parentheses below the variable. The last column shows the average change in the probability of mortality stemming from a 1-unit increase in the explanatory variable.

Variable	Likelihood ratio χ^2	*P*	Odds ratio	Parameter estimate	Average change in probability of mortality
Hook type (circle = 0; J-hook = 1)	0.94	0.333	1.97	0.679	0.09
Bait type (cut = 0; live = 1)	0.01	0.910	1.15	0.138	0.02
Hook location (lip = 0; mouth = 1; gill = 2; gut = 3)	12.29	<0.001	2.10	0.739	0.10
Presence of bleeding (no = 0; yes = 1)	11.27	<0.001	15.77	2.758	0.38
Sex (unknown = 0; female = 1; male = 2)	2.02	0.155	2.44	0.891	0.12
Fork length (mm) category (<500 = 0; 500–600 = 1; 600–700 = 2; 700–800 = 3; 800–900 = 4; >900 = 5)	3.60	0.058	0.54	−0.622	−0.09
Play time (<5 min = 0; >5 min = 1)	1.96	0.162	2.17	0.773	0.11

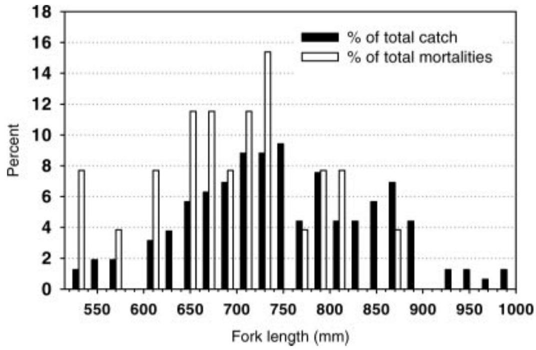

FIGURE 4.—Relative distribution of fork length and mortalities of angled striped bass in the Hudson River, New York.

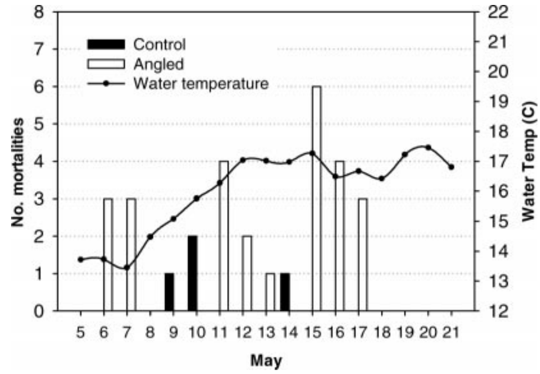

FIGURE 5.—Daily mortality (bars) of angled and electrofished (control) striped bass on the Hudson River, New York, and coincident holding-tank thermograph (line) by date in May.

from that of the river. Although no strong correlation between temperature and mortality was seen when daily mortality of angled fish was compared with the tank thermograph, our data suggest a possible threshold temperature of 16°C, at or above which mortality was elevated. Of the 26 total mortalities of angled fish, 20 (77%) were recorded when mean daily water temperature on the final holding day was at or above 16°C (Figure 5).

Inspection of 14 of the 26 dead angled fish suggested that physical damage to the esophagus and surrounding organs during hooking or hook removal was the probable cause of death. This appeared to be true regardless of hook type. Everted and lacerated esophageal tissue, internal hemorrhaging, lacerated liver tissue, and damage to the heart and pericardial tissue was observed in 13 of the 14 inspected mortalities.

Discussion

A preliminary catch-and-release study was conducted jointly by the U.S. Fish and Wildlife Service and the New York State Department of Environmental Conservation in spring 1999 (Millard et al. 2003). Results from this study indicated that mortality for striped bass approached 30%, which is consistent with an overall mortality rate of 29% reported by Wilde et al. (2000) for striped bass in freshwater. Major difficulties identified in the preliminary study included distortion and partial collapse of the submerged net pens due to accumulation of detritus and flotsam, the effect of tidal currents, and a relatively small sample size of angled fish (N = 47). The current study circumvents these problems and, we believe, refines the estimates reported in Millard et al. (2003).

Many factors can affect the likelihood of hooking mortality due to physical damage to organs and tissue, such as the use of barbed hooks or J hooks instead of circle hooks (Taylor and White 1992; Orsi et al. 1993). Our results suggest that the catch-and-release mortality of striped bass in freshwater can approach 16% with conventional J hooks and that the impact can be mitigated by the use of circle hooks. Our results for conventional hooks are consistent with other reported mortality rates in freshwater systems (Hysmith et al. 1994; Nelson 1998; Wilde et al. 2000). Most studies found hooking mortality varies with season and temperature, higher mortality occurring at higher temperatures (Harrell 1988; Nelson 1998; Wilde et al. 2000). Water temperatures during our observation period were less than 20°C. Nelson (1998) observed a distinct increase in hooking-related mortality at 22°C. The 5-d observation period for our study was longer than the 72-h period used by Nelson (1998).

Our results suggest that use of circle hooks is a viable technique for decreasing angling-related mortality in the Hudson River striped bass fishery. While not statistically significant, the use of circle hooks appeared to decrease the incidence of gut-hooked fish. This is consistent with the findings of a meta-analysis by Cooke and Suski (2004), who concluded that circle hooks result in more jaw-hooked fish and less damage to vital organs for selected fish species, including striped bass. Nelson (1998) and Diodati and Richards (1996) found that the location of hooking had a significant effect in the probability of death, the odds of death for gut-hooked fish being almost six times the odds of death for fish hooked in the lip. The occurrence of bleeding associated with gut-hooked fish was also associated with high mortality. These findings are also consistent with Nelson (1998) and Cooke and Suski (2004). Although external bleeding was not always observed in fish hooked in the esophagus, this hooking location appeared to increase greatly the opportunity for internal damage to organs and blood vessels located near the esophagus (e.g. the heart, liver and ventral aorta).

The use of live bait, as opposed to artificial lures, has been shown to result in increased hooking mortality rates (Hysmith et al. 1994; Wilde et al. 2000), although this has not always been detected (Bettoli and Osborne 1998). We found no significant differences between live bait versus cut, natural bait. Our results were hampered by the fact that few participating fishermen used whole, live bait once they found that cut bait worked well. We hypothesize that any bait configuration that facilitates swallowing of the terminal gear will exacerbate mortality due to physical trauma associated with hooking and hook removal. All seven study fish with visible bleeding associated with a swallowed hook suffered mortality. We observed that many anglers, upon encountering a swallowed hook, simply cut the line at some point inside the buccal cavity; the effect of this practice is unknown but we assume that is does little to prevent mortality due to hook-induced trauma. We hypothesize that much of the physical trauma from swallowed hooks occurs during the initial hook penetration and subsequent playing of the fish; any mitigative actions taken after that point may be ineffective. However, cutting the line and leaving the hook in place was found to significantly increase the survival of deeply hooked rainbow trout (Mason and Hunt 1967).

We found that mortality due to hooking was inversely related to the length of the fish, although the association was weak. Nelson (1998) and Bettoli and Osborne (1998) did not observe any relation between length and mortality, and Wilde et al. (2000) discounted a weak association between mortality and an interaction term involving bait type and fish length. Contrary to these results, Hysmith et al. (1994) found a relationship between mortality and fish length, although the nature of the relationship differed between seasons. Our results were similar to their cool-season data, showing smaller fish exhibited higher mortality.

Our estimation techniques require assuming that mortality due to the method of capture in the control group was negligible (i.e. electrofishing for control fish did not impart any mortality in that group). Harrell and Moline (1992) investigated the stress physiology of striped bass captured by electrofishing and noted that the mature fish recovered from the stress of capture within 48 h. Use of control fish to adjust overall observed mortality for the effects of handling and confinement has been employed (Nelson 1998), but we believe this is the first use of conditional rates for the correction, where independence between mortality of angled and control fish is not assumed. Wilde et al. (2003) noted that angling-related mortality models that do not assume independence between treatment (angled) and control fish are probably more realistic, but lacking a framework for the form of such dependence, they recommended the simpler model that assumes independence. We believe the use of the conditional mortality framework (i.e. estimating the angling-related mortality that would have occurred in the absence of confinement-related mortality) is a reasonable approach for incorporating mortality data from control fish. We strongly endorse the recommendation by Wilde et al. (2003) that control fish be used in all studies of catch-and-release mortality where handling or confinement may contribute to observed mortality. It is difficult to imagine a study where control fish would not be an essential component of the experimental design. The modest mortality rate exhibited by the control fish in our study resulted in similar estimates for hooking mortality for both the conditional rate technique and the additive finite rate technique. However, in studies where control fish exhibit more significant mortality due to handling and confinement, we recommend the conditional rate estimator as a more appropriate technique. This technique accounts for the probability that the two sources of mortality, angling-related trauma and stress and stress due to handling and confinement, occur simultaneously over the observation period.

Our results suggest that the mortality of fish released in the recreational fishery in the Hudson River is a significant component of total mortality of striped bass and, as such, should be considered in accounting for removals from the spawning population. Periodic estimates of angling effort and associated catch-and-release rates are needed to incorporate this mortality into stock assessments and subsequent management decisions. Prescribed use of circle hooks in the fishery may reduce this mortality and should be considered as a conservation strategy. However, the term ‘‘circle hook’’ encompasses a wide variety of configurations; some may be less effective than others for reducing catch-and-release mortality and this presents a problem for regulatory agencies (Cooke and Suski

2004). Future studies should attempt to identify circle hook configurations that result in minimal mortality for fish that are caught and released.

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