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Mortality of Striped Bass Hooked and Released in Salt Water

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Abstract.—Despite the importance of the recreational fishery for striped bass *Morone saxatilis* along the eastern coast of the United States, little is known about the survival rates of caught and released striped bass. We predicted long-term (58-d) hooking mortality of striped bass after catch and release in saltwater using a logistic regression model. Experimental fishing was conducted on fish (27–57 cm) in a 2-ha saltwater impoundment in Salem, Massachusetts. Depth of hook penetration in the oral cavity, anatomical site of hooking, gear type (treble or single hooks), and angler experience were significantly related to mortality ($P < 0.05$). The logistic regression model was developed with backwards stepwise selection to predict probability of death from hooking. The final model included depth of hook penetration, gear type, and angler experience as predictor variables. Predicted mortality ranged from 3% under the most favorable conditions to 26% for the worst set of conditions. Predicted as well as observed mortality for the entire experimental group was 9% which is generally much lower than reported in striped bass hooking mortality studies conducted in freshwater. At the end of the experiment, condition factors were significantly lower for surviving hooked fish than for fish that had not been hooked.

During the 1970s, landings of striped bass *Morone saxatilis* along the eastern coast of the United States began a steep decline (Richards and Deuel 1987), caused chiefly by poor production of the Chesapeake stock (Boreman and Austin 1985). In response to the decreasing landings, coastal states from Maine to North Carolina began implementing regulations in 1984 to reduce fishing mortality (Weaver et al. 1986). The most significant regulation changes were major increases in minimum size requirements and implementation of one-fish-per-day creel limits (ASMFC 1981, 1989; Weaver et al. 1986). In bays and estuaries, size limits generally increased from 36 cm total length to 46 cm, and in coastal areas from 41 cm total length to 91 cm.

These regulations were highly successful in increasing abundance of sublegal-size fish (USDOI and USDOC 1990) but also increased catch-and-release fishing (USDOI and USDOC 1990; USDOC 1991). During 1979–1983, an estimated 374,000 striped bass (38% of the striped bass recreational catch) were caught and released annually along the eastern seaboard (USDOC 1984, 1985a, 1985b). By 1989–1992, this number had risen to over 2,600,000 per year (93% of the striped bass recreational catch) (USDOC 1991, 1992; USDOI and USDOC 1994). These statistics raised concerns about potential mortality of released fish.

Despite the importance of the striped bass recreational fishery in coastal waters (Richards and Deuel 1987), little is known about survival of caught and released striped bass in saline environments. In freshwater, Harrell (1988) estimated the hooking mortality of striped bass to average 15.6% for fish taken on artificial lures and 30.7% for fish taken on natural baits. Hysmith et al. (1993), also working in freshwater, found mortality of striped bass to be significantly related to fish length, season, and bait type. There was a positive relation between hooking mortality and length-class. Overall, hooking mortality was 38% but was higher when live baits were used (58%) and was higher in summer (47%) than winter (13%). Experiments on striped bass in brackish-water environments suggest that salinity may have an important ameliorating effect on hooking mortality (RMC, Inc. 1990). However, there have been no previous studies of striped bass hooking mortality in saline environments.

Given the importance of marine recreational fishing for striped bass and the relatively high abundance of sublegal-size fish, information on catch-and-release mortality is critical to management efforts. The objectives of our study were to estimate hooking mortality of sublegal-size striped bass in a marine environment and to examine factors influencing hooking mortality.

Study Site

The study site was a 2-ha saltwater pond at the Massachusetts Division of Marine Fisheries (DMF) Cat Cove Marine Laboratory in Salem, Massachusetts. The pond is a dammed inlet with an average depth of approximately 3 m (4.5 m maximum depth). It is not subject to tidal fluctuations but can be partially drained via two sluice gates. During the experiment, surface water temperature ranged from 15 to 28°C; bottom temperature never exceeded 25°C. Dissolved oxygen ranged from 6.0 to 9.0 mL/L at the surface and 3.8 to 8.4 mL/L at the bottom. Salinity (31‰) and pH (7.0) were stable throughout the study. Indigenous populations of finfish and invertebrates available for striped bass to feed upon included fourspine stickleback *Apeltes quadracus,* Atlantic silverside *Menidia menidia,* mummichog *Fundulus heteroclitus,* mysid shrimp *Mysis stenolepus,* and sand shrimp *Crangon septemspinosa* (P. J. Diodati, unpublished). Between 40 and 50 untagged striped bass remained in the pond from an earlier experiment.

Methods

Striped bass were obtained from a trap-net operator based in Newport, Rhode Island. Three fish traps (55 × 26 × 21 m) were set within 3 km of shore and tended daily over a 20-d period. When large numbers of striped bass were caught, they were netted from the traps and placed in a 760-L holding tank supplied with running seawater. During the trip to shore, each fish was tagged with a uniquely coded Floy internal anchor tag and transferred to a second holding tank. Fish were on board the vessel for a maximum of 2 h. At dockside, they were transferred to a tank truck for delivery to the study site. The truck carried a 1,900-L circular tank with a water pump for aeration. Transfer time from fish trap to study site averaged 5 h (range, 4.5–6 h). Five batches of about 200 fish per batch were delivered on different days between 22 and 28 April 1989. An additional delivery of 17 fish on 13 June brought the total number of tagged fish released into the pond to 1,015. Subsamples of fish measured at the beginning (N = 64) and end (N = 432) of the experiment ranged from 27 to 55 cm fork length, with a mode of 32 cm at the beginning of the experiment and 33 cm at the end.

To estimate mortality from tagging and transport, the first (175 fish) and last (158 fish) batches of striped bass received in April were released from the truck into a net-pen in the pond. The pen was 3 m long × 5 m wide × 2 m deep and was constructed of 2.5-cm-mesh nylon netting stretched over a polyvinyl chloride frame attached to wood and styrofoam docks. The pen was anchored in 3 m of water and the top was covered with netting to exclude predators. The first batch of fish was held for 24 h and the last batch was held for 5 d before being released into the pond.

Precautions were taken to prevent unauthorized angling. Public access to the laboratory grounds was limited by fencing, no-trespassing signs were posted, and the grounds were patrolled by DMF personnel during daylight hours and for several hours after dark. As a further deterrent, a floating snagline was anchored about 6 m from shore around the pond's perimeter to prevent retrieval of gear cast from shore.

The hooking experiment was conducted from 21 June through 30 July, thus allowing a 50-d acclimation period for most of the fish. Two weeks before hooking began, 20 striped bass were captured from the pond with gill-nets to serve as controls. The nets were tended immediately after being set, and fish caught appeared in excellent condition. These fish were placed in the covered net-pen which was moved to deeper water (4.5 m), fed dead American sand lances *Ammodytes americanus,* and checked daily for mortality. The control fish were held for the remainder of the study period.

Fifty volunteers, primarily from Massachusetts-based fishing clubs, were selected to conduct the fishing. Anglers used their own light- to medium-weight rods equipped with either spin- or bait-casting reels. The breaking strength of fishing line averaged 5 kg and ranged from 3 to 9 kg. Anglers were asked to complete a questionnaire to rate their level of angling experience. They were limited to terminal gear consisting of unbaited lures with one to three treble hooks, single-hook rubber jigs, or baited single hooks. Only barbed hooks were used. Live seaworms *Nereis virens* and dead American sand lances were used for bait. Three methods were used to capture fish: casting from boats or shore (lures or jigs), trolling from boats (lures or jigs), and bait fishing from boats (single hooks). Hooks were always removed from landed fish regardless of how deeply they were embedded.

All fishing activity occurred between 0500 and 2100 hours. Anglers were accompanied by a trained technician who recorded playing and handling time, handling technique, depth of hook penetration into the oral cavity, anatomical site of hooking, degree of bleeding, gear characteristics, and tag number. When striped bass left from previous stockings were caught, their capture events were disregarded. They were easily identified by their lack of tags or tag scars.

Most hooked fish were returned to the pond. Forty-four fish caught on the first day of fishing were released into the net-pen and held there for the rest of the experiment. They were checked daily to evaluate short-term mortality and were fed dead American sand lances.

Hooked fish released to the pond were used to assess long-term mortality. Eight weeks after the fishing period, we lowered the water level in the pond to about 1.2 m by opening the sluices and pumping water out. The outlet was covered with chain-link fence to prevent escape of fish. A 61-m haul seine with 3.8-cm mesh was used to recover the striped bass. To ensure that all striped bass had been recovered, the pond was subsequently pumped dry. Each recovered striped bass was examined for a tag or tag scar, then released to the neighboring bay. Fish that could not be accounted for were presumed dead.

Condition factors (weight/length^3, Ricker 1975) were calculated for subsamples of striped bass at the beginning (N = 64) and at the end (N = 432) of the experiment. Age and sex were determined for 24 fish that died either from hooking (N = 5) or seining activities (N = 19). Age was estimated from scales, and sex was determined by inspection of gonadal tissue. Most striped bass (75%) were age 3; 67% were females.

Two-way log-likelihood ratio tests (G-tests, Sokal and Rohlf 1981) were used to identify factors affecting the survival of hooked and released striped bass. Multiway tests incorporating all independent variables could not be used reliably because of the large number of empty cells that would have resulted from the many independent variables considered.

A logistic regression model was fit with maximum-likelihood estimation to develop estimates of hooking mortality:

$$P(H) = e^{u}/(1+e^{u}); \qquad (1)$$

$P(H)$ is the probability of mortality and u is a linear combination of the independent variables. We used backwards stepwise selection (BMDP/LR software, Dixon et al. 1990) to arrive at the final model. All variables significant ($P < 0.10$) in the G-tests as well as in their two-way interactions were initially included. Factors were dropped from the model if their removal did not significantly ($P <$ 0.20) decrease the ratio of the log-likelihood functions for the reduced model and the previous model. Only hooked fish released to the pond were used to estimate the model (net-pen fish were not included).

To examine probability of mortality in relation to specific combinations of hooking conditions, we divided the fish into best, worst, and intermediate categories according to severity of the conditions under which they were hooked. We judged severity by examining mortality for different levels of the factors included in the model. Fish were assigned to the best category if they had experienced best conditions for two of three factors, to the intermediate category if they experienced a best, a worst, and an intermediate condition, and to the worst category if they had experienced worst conditions for two of three factors. We examined these scenarios by taking 400 bootstrap samples (Efron 1982) from the original observations and fitting the logistic regression to each of the 400 sample sets.

Results

Immediate mortality from tagging and transport appeared low. None of the first batch of 175 fish delivered to the net-pen died during the first 24 h. Six of the last batch of 158 (3.8%) held in the net-pen had died at the end of 5 d. We assumed that all nonhooking loss occurred during the acclimation period and thus did not affect our estimates of hooking mortality.

During the experiment, striped bass were hooked 281 times by 36 different fishermen; however, not all hooking events could be used in the analysis. Thirty-nine hooked fish were not landed, 14 were landed but had no tags or lacked sufficient capture information, and 11 were landed twice. For the 11 landed twice, only their last hooking event was included in the analysis. The 44 striped bass captured on the first day of fishing and released to the net-pen were not used in model analysis because of their different holding conditions. Thus, a total of 173 hooking events were used in the logistic regression model. When the pond was drained at the end of the experiment, 868 striped bass were recovered. Of these, 198 had been hooked and released. The remaining 670 fish had not been hooked, or if hooked, could not be counted for the reasons given earlier. Thirty-seven were without tags but clearly showed tag scars. Of the 11 fish that were hooked twice, 2 (18.2%) were not recovered.

Of the 64 fish held in the net-pen throughout the experiment, none lost their tags, and none of the

TABLE 1.—Categorical explanatory variables recorded for each striped bass hooking event, where N is the number of times each level was observed in 215 hooking events and M is the number that died. Asterisks indicate significance level of G-tests for effect of factor on survival; $P \le 0.10$*, $P \le 0.05$**.

Explanatory variable	Level	N	M	G
Gear type	One to three sets of treble barbed hooks	107	3	8.22**
	Single barbed hook with bait or jig	108	14	
Hook size	Large (1, 1/0, 2/0, 3/0, 4/0, 5/0)	77	7	0.23
	Small–medium (2–8, 10, 12)	138	10	
Hooking site	Head, jaws, fins, body	190	11	7.31**
	Eyes, gills, esophagus	25	6	
Depth of hooking	Anterior to pharynx	188	10	9.85**
	Pharynx or posterior to pharynx	27	7	
Bleeding	None	177	11	3.32*
	Bleeding present	38	6	
Angler experience	Expert	54	1	6.00**
	Average	129	11	
	Inexperienced	32	5	
Handling technique	Fish body supported	16	2	1.55
	Fish held by lip	97	9	
	Fish held over eyes or gill covers	92	5	
	Fish kept in water for hook removal	10	1	
Release technique	Tossed or dropped into water	139	11	0.00
	Slipped into water or never removed from water	76	6	

20 control fish died. Two (4.5%) of the 44 fish that were caught and released died, both within 12 h of being landed.

For analysis, gear types were classified as either treble hook (one to three treble hooks) or single hook (single-hook rubber jigs, single-hook lures, or baited single hooks). The single-hook gear types were combined because they resulted in similar mortality (χ^2 goodness-of-fit test, $P = 0.14$ for treble hooks and $P = 0.28$ for single hooks). Gear type, anatomical site of hooking, depth of hook penetration in the oral cavity, and angler experience were significantly related to mortality of caught and released striped bass (G-tests, $P < 0.05$; Table 1). The highest mortality was associated with single hooks, hooks lodged deep in the oral cavity, and inexperienced anglers. Bleeding (presence or absence) was significant at the 0.07 level. Hook size, handling technique, release technique, and the time from hook-up to release (mean = 93 s, SE = 4.3) were not significantly related to mortality.

The independent variables retained in the logistic regression model after backwards selection were depth of hook penetration in the oral cavity, gear type, and angler experience (Table 2). The model provided an adequate fit to the data (Hosmer–Lemeshow goodness-of-fit χ^2, $P = 0.75$) and performed well at predicting proportional mortality for each cell (Table 3) despite the unbalanced distribution of hooking conditions.

The predicted probability of mortality for the entire group of hooked fish in the pond was 0.09. However, mortality varied with severity of hooking conditions. Mean predicted mortality was 26% for the worst set of conditions, 9% for the intermediate set, and 3% for the best set (Table 4). The bootstrap distributions of predicted probabilities for the three hooking scenarios are shown in Figure 1.

The condition factors of control fish held in the net-pen did not change significantly during the experiment (paired t-test, $P > 0.05$; $N = 8$), but condition factors of hooked fish held in the net-pen were significantly lower at the end (paired t-test, $P < 0.05$; $N = 21$). For striped bass recovered from the pond at the end of the experiment, condition factors of both hooked and not-hooked fish had decreased significantly from the start of the

TABLE 2.—Parameter estimates for the logistic regression describing striped bass hooking mortality. The number of parameter estimates for each factor equals $N - 1$, where N is the number of levels for that factor.

Factor	Coefficient	SE
Constant	−4.59	1.17
Depth of hook penetration	1.49	0.62
Gear type	1.16	0.68
Angler experience		
Level 1	1.03	1.09
Level 2	1.91	1.15

TABLE 3.—Observed and predicted striped bass hooking mortalities for combinations of hook type, depth of hook penetration, and angler experience where O = observed, P = predicted from the logsitic regression model, SE = standard error of predicted probability, and N = number of observations in a given cell.

Hook type and penetration	Statistic or attribute	Angler experience		
		Expert	Average	Inexperienced
Treble hooks				
Shallow	N	7	46	14
	O	0.00	0.02	0.00
	P	0.01	0.03	0.06
	SE	0.01	0.02	0.05
Deep	N	2	6	
	O	0.00	0.33	
	P	0.04	0.11	
	SE	0.05	0.08	
Single hooks				
Shallow	N	23	47	12
	O	0.04	0.11	0.17
	P	0.03	0.08	0.18
	SE	0.03	0.04	0.09
Deep	N	1	11	4
	O	0.00	0.09	0.75
	P	0.13	0.29	0.49
	SE	0.12	0.11	0.17

experiment, but condition factors of hooked fish were significantly lower than those of fish not hooked. To reach this conclusion, we used a two-sample t-test, $P < 0.05$, comparing baseline condition factors at the beginning ($N = 64$) with hooked ($N = 88$) and not-hooked fish ($N = 315$) at the end, and a two-sample t-test, $P < 0.05$, between hooked ($N = 88$) and not-hooked ($N = 315$) at the end.

Discussion

Our estimates of striped bass hooking mortality (3–26%, 9% overall) are lower than others reported for striped bass: 36% in summer (Harrell 1988), 47% in summer (Hysmith et al. 1993). However, our study differed in several respects. Perhaps most importantly, both earlier studies were conducted in freshwater, whereas ours was in a high-salinity environment (mean salinity, 31‰). Although striped bass are euryhaline, freshwater may pose osmotic challenges that add to the stress of capture. In a 1990 study, RMC Inc. (1990) found that catch-and-release mortality of striped bass caught on artificial lures ("buck-tails") depended on salinity of 0–8 ppt. Hooking mortality of fish less than 46 cm at the lower-salinity sites (0–4‰) averaged 34%, but it was only 1% at the 8‰ site.

Temperature was another potentially important

TABLE 4.—Observed and predicted probabilities of hooking mortality for striped bass grouped according to severity of hooking conditions. Predicted mortality is from the logistic regression model; observed mortality is the proportion of fish which died in each category. Standard error of the outcome of 400 bootstrap replicates of the logistic regression model appears in parentheses.

Hooking conditions	N	Predicted mortality (SE)	Observed mortality
Worst	28	0.26 (0.07)	0.21
Intermediate	53	0.09 (0.03)	0.13
Best	92	0.03 (0.01)	0.02
Overall	173	0.09 (0.02)	0.09

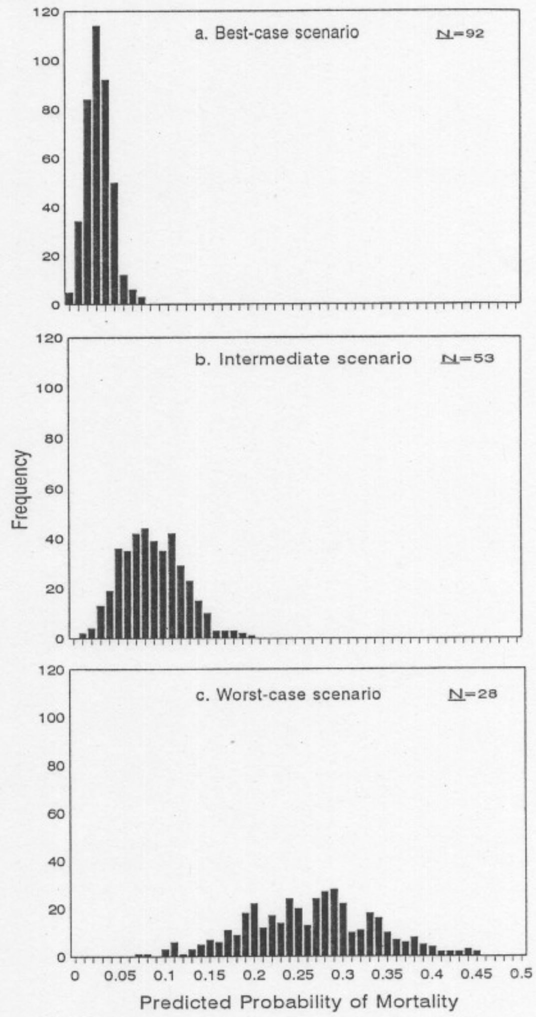

FIGURE 1.—Distribution of predicted probabilities of striped bass mortality from 400 bootstrap replicates of the logistic regression model for three scenarios of hooking mortality.

factor that differed between our study and the studies of Harrell and Hysmith et al. Although their studies provided sparse details on temperature, Harrell mentioned that holding facilities often exceeded 25°C during June and August and reported having problems with fungal and bacterial infections on striped bass during those times. Coutant (1985) hypothesized temperatures higher than 25°C can cause thermal stress in large striped bass. In our study, fish probably did not experience a "temperature–oxygen squeeze" (Coutant 1985), because bottom temperatures did not exceed 25°C and dissolved oxygen remained above critical levels.

In most studies of catch-and-release mortality, fish have been caught from a natural population, placed in tanks or pens, and observed for mortalities over various lengths of time. This approach has the advantages of being logistically simple and easy to control; however, it has the disadvantages that hooked fish are held in a highly unnatural environment, usually for relatively short periods (e.g., 1–5 d). Whether this affects probability of mortality (e.g., increasing it by increasing stress, or decreasing it by decreasing susceptibility to predation) is unknown.

The availability of the salt pond at Cat Cove afforded us an unusual opportunity to combine features of laboratory and field techniques in conducting a hooking mortality study. We were able to establish a population of individually marked fish, fish it experimentally, and then census the entire population. Thus, the population was manageable, but fish were at large in a relatively natural environment for a prolonged period (up to 8 weeks after hooking). The disadvantage to our approach was that the population could not be as closely monitored as a laboratory population; thus, we had potentially confounding effects such as fish that were hooked but not landed, multiple captures, and tag loss. In addition, a decline in condition factors of pond fish suggests that food supply was not optimal.

Fish hooked but lost before being landed (N = 39) could have increased mortality estimates if the same fish were subsequently landed and had a higher probability of mortality from the earlier hooking. However, because these fish were lost within 30 s of capture and fishing gear was retrieved intact after each event, the lost fish likely were hooked superficially (e.g., lip-hooked); if so, the first hooking probably resulted in little injury.

Similarly, fish landed twice could have had a higher probability of dying on the second capture because of their earlier hook-and-release event. The mortality of these 11 fish (18%) was higher than that for the overall population. On the basis of severity of the second hooking events, our model would predict 12% mortality from the second capture alone. If we overestimated mortality for these 11 fish by 6%, then our overall estimate of mortality for the population is inflated by only about 0.3%.

Another potential source of error in our estimates is tag loss that might have occurred after a fish had been caught and released. A fish that lost its tag after being caught would be falsely counted as dead at the end of the experiment. However, we assume that most tag loss occurred during the 50-d acclimation period before hooking began. Dunning et al. (1987) found that most loss of internal anchor tags by striped bass occurred within the first 3 weeks after tagging. Loss rates were 3.7–4.5% during the first 18 d after tagging (calculated from Tables 2 and 3 in Dunning et al. 1987), and were 0 from 18 to 180 d. We found tag loss rates of 4.3% at the end of our study, similar to findings of Dunning et al. (1987) for the first 18 d. Furthermore, none of the 44 fish placed in the net-pen 50 d after tagging lost their tags.

Several factors that we found to be significantly related to hooking mortality (gear type, anatomical site of hooking, and depth of hooking) have been shown to influence mortality in other species (Wydoski 1977; Taylor and White 1992). In addition, we found angler experience to have a significant influence on hooking mortality. Angler experience has not been included explicitly in previous studies of hooking mortality, perhaps because of its subjectivity. However, it undoubtedly influences many facets of the hooking event, and its effect on the fate of a hooked fish could be substantial. Fish caught by experienced anglers had far lower probability of dying than fish caught by inexperienced anglers. Some of the factors that might be expected to vary with experience (e.g., handling and release techniques) did not significantly affect mortality in our study; however, these two factors were significantly correlated with angler experience ($P <$ 0.05, Spearman's rank correlation). Thus, their aggregate effect may have been manifested as angler experience.

Declines in condition factors of hooked fish suggest that hooking may affect the general health of fish that survive being hooked and released. In the net-pens, condition of control fish did not change, whereas condition of hooked fish declined significantly; in the pond, condition of both hooked and not-hooked fish declined, but condition of hooked fish declined significantly more than not-hooked fish. These results support Wydoski's (1977) suggestion that sublethal hooking stress may contribute indirectly to mortality in fish through increased susceptibility to predators, diseases, or parasites.

Hooking mortality estimated from an experiment cannot predict population mortality unless experimental conditions represent those encountered in the wild. For species with a broad geographic range, such as anadromous Atlantic striped bass, it seems unlikely that mortality recorded from an experiment would equal that of the population over a time period of interest (typically a year). However, experiments can identify critical factors influencing hooking mortality and can be used to develop models to predict mortality, given values of those critical parameters. To estimate population mortality, information would be needed on regional patterns in recreational fishing over the time period of interest. One could collect such information by adding questions regarding significant hooking parameters to existing creel surveys (e.g., USDOC 1991). Our present model would not be sufficient for estimating coastwide hooking mortality of striped bass, as it does not include effects of such factors as fish size and environmental variables (temperature, salinity) on mortality. Developing a comprehensive model and applying it to coastal populations could be useful in shaping appropriate management strategies for important recreational species such as striped bass.

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