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Physical injury, physiological stress, and behavior impairment of striped bass (*Morone saxatilis*) after catch-and-release by spin and fly angling

Lucas P. Griffin¹  | Heather M. Hollema¹ | Jeff Kneebone² | Stephen D. McCormick¹ | Gregory B. Skomal³ | Andy J. Danylchuk¹ 

¹Department of Environmental Conservation, University of Massachusetts Amherst, Amherst, Massachusetts, USA

²Anderson Cabot Center for Ocean Life at the New England Aquarium, Boston, Massachusetts, USA

³Massachusetts Marine Fisheries, New Bedford, Massachusetts, USA

Correspondence

Lucas P. Griffin, Department of Environmental Conservation, University of Massachusetts Amherst, Amherst, Massachusetts 01003, USA.
Email: lucaspgriffin@gmail.com

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Abstract

The striped bass (*Morone saxatilis*) is one of the most important species for anglers along the Atlantic coast and a subject of intensive fisheries management. To promote best catch-and-release practices, understanding the physical and physiological consequences of angling is critical. We assessed the injury and stress of striped bass captured using rod and reel spin and fly tackle in a New England embayment. During 2010–2011, of 95 striped bass captured, only one died immediately after release. Behavioral impairment measured through reflex action mortality predictors increased when hooked in the gullet or gills. While 11.6% were critically hooked (in gills, gullet, or eyes), hooking severity was not related to terminal tackle (lure or fly). However, the most severely impaired were all hooked with J hooks. Physiological stress indicators (sodium, chloride, blood lactate) increased with longer fight times. Our results suggested that different components of an angling event drove physiological and behavioral responses.

KEYWORDS

best handling, deep hooking, J hooks, post-release mortality, recreational fisheries, reflex action mortality predictors

1 | INTRODUCTION

Recreational fishing is one of the most widespread leisure activities worldwide, with average participation rates of ~10% of the adult population in industrialized nations (Arlinghaus et al., 2015). The striped bass (*Morone saxatilis*) is an anadromous and highly migratory species that is seasonally distributed from North Carolina to Maine (Kneebone et al., 2014; LeBlanc et al., 2020; Secor et al., 2020) and the focus of one of the largest and most economically valuable recreational fisheries (\$13 billion USD; Southwick Associates, 2019) along the east coast of the United States (U.S.). For recreational anglers, the wide geographic distribution provides extensive opportunities to

target striped bass, and total annual catch rates in U.S. waters have fluctuated from 20 to nearly 60 million individual striped bass during 2000–2020 (Atlantic States Marine Fisheries Commission, 2021). Even though over 90% of recreationally caught striped bass are released each year, either due to fisheries regulations or angler preference, many released striped bass die. For instance, of 30.4 million striped bass caught in 2021, ~28.6 million were released alive, but ~2.6 million of the released fish died (Atlantic States Marine Fisheries Commission, 2021).

Catch and release (C&R) angling exposes fish to varying degrees of physical injury and physiological stress that can cause mortality or impair fitness (Arlinghaus et al., 2007; Cooke & Cowx, 2004). Effects

of C&R on striped bass in freshwater and marine environments that influence mortality include anatomical hooking location (Diodati & Richards, 1996; Millard et al., 2000; Nelson, 1998), hook, lure, or bait type (Harrell, 1988; Wilde et al., 2000), angler experience (Diodati & Richards, 1996), air temperature (Bettoli & Osborne, 1998), and water temperature (Hysmith et al., 1994; Nelson, 1998). Recreational post-release mortality (PRM) of striped bass varies widely (0%–67%; reviewed in Graves et al., 2009), with higher mortality strongly correlated to deep hooking and warmer water temperature (Wilde et al., 2000). Hooking injury has also been associated with different types of terminal fishing tackle, such as treble hooks fished on artificial lures, and internal hooking damage caused by J hooks when using live bait (Wilde et al., 2000).

Given the magnitude of the recreational fishery for striped bass along the U.S. East Coast, C&R has long been preferred for reducing fishing mortality without overtly restricting angling opportunities. However, for C&R to be effective, the impacts of capture and handling on striped bass welfare must be well-known and translated into practical best-practice recommendations that are widely disseminated and used by recreational anglers (Brownscombe et al., 2019; Danylchuk et al., 2018). As prized gamefish, striped bass are often targeted by anglers using artificial lures on spinning gear (e.g., Millard et al. 2003) and fly tackle. However, the physical or physiological effects of fly fishing on striped bass captured in saltwater have not previously been quantified. Therefore, our objective was to determine if physical injury, physiological stress, and behavior impairment of striped bass differed between angling with spinning and fly-casting fishing gear. Our results would be helpful for developing or refining best practices for reducing PRM.

2 | MATERIALS AND METHODS

2.1 | Fish capture

To evaluate the impacts of C&R fishing on striped bass, fish were sampled during June 2010 and October 2011 while working with volunteer recreational anglers from small boats in Plymouth, Kingston, and Duxbury (PKD) Bay (42° 42'41.59" N, 70° 47'41.89" W), an 8240-ha coastal embayment located ~50 km south of Boston, Massachusetts. Anglers captured striped bass using spinning or fly-fishing gear with a variety of artificial lures or flies. Hooks ranged from 4 to 3/0 in size with single barbless or barbed hook points. Most lures were soft plastic swim baits. Anglers qualitatively assessed their experience level as entry-level, intermediate, or advanced anglers.

For each capture event, the date and time of hooking, angler, location of capture, and surface water temperature (°C) were recorded by an onboard observer. The duration of each angling event (fight time) and subsequent hook removal time were recorded to the nearest second. The total duration of handling was recorded (seconds) or determined by the difference between hook-up and release times (minutes). Fish were measured in total length (TL), fork length (FL),

and girth (cm). Blood was drawn to assess physiological stress, with fish being held by gloved hands before or after transfer to a water-filled V-shaped trough lined with neoprene. Gills were kept wet at all times during processing with only a minimal amount of air exposure to transfer the fish to and from the water-filled V-shaped trough for hook removal and measurement. Afterward, fish were either immediately released following a behavioral impairment assessment back in the water or implanted with an acoustic tag for a separate telemetry study ('tagged subset', Hollema et al., 2017). Behavior was not assessed for tagged fish, so all fish were air-exposed for no more than 5 s for the present study.

2.2 | Physical injury

Striped bass were examined for physical injuries after being landed. Hooking depth was measured (mm) from the tip of the snout to the point of hook entry and corrected for TL (i.e., hooking depth divided by TL) for comparison among fish of different sizes (Cooke et al., 2001). Hooking location was categorized as critical (gills, gullet, or eyes) or non-critical (jaw, hinge, the roof of the mouth, or foul hooked in the body; Meka, 2004; Arlinghaus et al., 2008). Angling-related injury was quantified as non-critical (minimal or no tissue damage; <2 cumulative non-critical injuries) or critical (critical hook location; ≥3 non-critical injuries, including tissue damage, foul hooking, and line abrasion). Bleeding (present or absent) at the hook insertion points was noted, and ease of hook removal (<30 s = easy; >30 s = difficult) was recorded (O'Toole et al., 2010). All hooks were removed by the observer.

2.3 | Physiological stress

For each fish, ~1.5 mL of blood was drawn from the caudal vessel using a 21-gauge needle into a 3 mL vacutainer containing lithium heparin (BD vacutainer blood collection tube). The time allowed for blood drawing was recorded (bleed time), with any blood sample taking more than 45 s being noted for potential added stress (Shultz et al., 2011). Blood samples were held in an ice-water slurry prior to analysis. Glucose was measured from whole-blood samples with ACCU-CHEK (Roche Diagnostics Corp.) and lactate was measured with Lactate Pro LT-1710 (Akray Inc.) analyzers. Appropriate standards and calibrations were used with handheld meters as per manufacturer guidelines. Hematocrit packed cell volume (PCV), was measured following centrifugation in a hematocrit spinner as the proportion of packed red blood cells to the total sample volume. The remaining whole-blood sample was centrifuged (Clay Adams Compact II Centrifuge) at 10,000x gravity for 5 min and plasma was transferred by pipette to two 0.5 mL standard microcentrifuge tubes and immediately stored in a liquid nitrogen dry shipper (at a minimum of –80°C) until laboratory analyses. In the laboratory, plasma cortisol was quantified using a fully validated direct enzyme immunoassay (Carey & McCormick, 1998). To assess plasma calcium,



potassium, sodium, pH, magnesium, and chloride levels, samples were analyzed with a Nova Biomedical StatProfile pHOX blood gas analyzer (Nova Biomedical Corporation).

2.4 | Behavior impairment

Prior to release, while fish were held in water at the vessel side, reflex action mortality predictors (RAMP) (Davis, 2010) were assessed to visually document the presence or absence of head, mouth, dorsal fin, gag, and body flex reflexes (Brownscombe et al., 2015; McLean et al., 2020; Raby et al., 2012). Tagged fish were not assessed for RAMP due to handling and surgery related to the other study (Hollema et al., 2017). RAMP assessment included: (1) head reflex was present if opercular movement was steady; (2) mouth reflex was tested by pulling the lower jaw open to see if the mouth closed after releasing downward pressure; (3) dorsal-fin reflex was present if the dorsal fin was raised after being laid flat against the body; (4) gag reflex was present if the esophagus contracted after the tongue was pushed down with a metal rod; and (5) body reflex was present if the caudal peduncle resisted gentle flexing to one side, or the tail was thrust. To indicate the relative condition of each fish, a reflex impairment index was calculated by dividing the total reflexes present by five total reflexes tested (Davis, 2010).

2.4.1 | Data analysis

Statistical analyses were in R version 4.2.2 (R Core Team, 2022), at $\alpha=0.05$ for declaring statistical significance using packages rstatix (Kassambara, 2019), ggeffects (Lüdtke, 2018), dplyr (Wickham et al., 2015) and ggplot2 (Wickham, 2011).

A Welch Two Sample *t*-test was used to determine if fight time significantly differed between striped bass caught with spinning and fly gear. The relationship between fight time and TL was tested using Pearson's *r* correlations. A linear model was used to test the interaction of TL and gear type on fight time.

Hooking-related injury was tested using a contingency table and a Fisher's exact test for relationships between gear type (spin or fly) and hook type (circle or J hook), and severity of injury (critical vs. non-critical), bleeding, hook placement, ease of hook removal, and length corrected hooking depth. A Mann-Whitney *U* test was used to test the effect of gear type or hook type (circle or J hook) on the mean length-corrected hooking depth ratio. Lures (spin fishing) had J hooks and flies (fly fishing) had either J hooks or circle hooks, as in the striped bass recreational fishery, but analyses related to hook type were collapsed together for both gear types. Finally, Fisher's exact test was used to test the relationship between angler expertise and injury severity.

For complete records, a binomial logistic regression model tested the dependence of reflex impairment index values (numbers of reflex successes, 0–5, versus failures, 0–5), on independent variables, treated additively, including fight time, handling time, gear type,

and hooking severity (critical or non-critical). The model was implemented with the glmmTMB package (Brooks et al., 2017), and interpreted using sjplot package (Lüdtke, 2021). Model assumptions were tested using the performance package (Lüdtke et al., 2021) or plotting simulated residuals (10,000 times) using the DHARMa package (Hartig, 2017).

Using quantiles for fight time, fish that were angled <76 s, baseline fish that were minimally stressed, were compared to stressed fish that were angled >155 s. Welch 2-sample *t*-tests were used to test if blood parameters from stressed fish differed from minimally stressed fish (Skomal, 2007). Subsequently, multiple linear regression, using the Mass package (Venables & Ripley, 2002), was used to determine if reflex impairment index values, fight time, or handling time significantly predicted each measured blood parameter.

To determine if blood parameters were related to aspects of angling events, principal component analysis (PCA) used the factoMineR package (Lê et al., 2008). However, some angling events had missing data, so missing values were first imputed using the missMDA package (Josse & Husson, 2016) and then PCA used reflex impairment index values, blood glucose, lactate, PCV, and plasma cortisol, chloride, potassium, calcium, sodium, pH, magnesium, TL, and water temperature. Subsequently, multiple linear regression used the first two principal component dimensions as dependent variables and reflex impairment index values, fight time, and handling time as independent variables. Linear models included only non-tagged fish with complete records for fight times, handling times, and RAMP.

3 | RESULTS

Size of 95 striped bass captured ranged 20–105 cm in TL (Mean $\pm$ SD = 57 ± 14 cm). Anglers mostly considered themselves advanced ($n=57$), with fewer beginners ($n=9$) and intermediate ($n=7$). More fish were captured with spinning gear lures ($n=57$) than with fly ($n=38$) at surface water temperatures that ranged 9.7–22.8°C ($17.0 \pm 2.1^\circ\text{C}$). Fight times of fish caught with spinning gear (120.7 ± 78.2 s, 53.6 ± 13.7 cm TL) and fly gear (141.6 ± 85.0 s, 61.2 ± 12.8 cm TL) did not differ significantly ($t=1.2$, $df=74.79$, $p=0.23$). Fight time was positively related to TL ($29\text{--}451$ s, 129.0 ± 81.2 s) (Pearson's *r* correlations, $r_{93}=0.45$, $p<0.001$). The interaction between TL and gear type did not significantly affect fight time ($R^2=0.19$, $F_{3, 91}=8.2$, $\beta=-1.19$, $t=-1.01$, $p=0.32$). For non-tagged fish ($n=60$), handling time ranged from 25 to 645 s (237 ± 115 s).

Hook depth ranged from 3 to 180 mm ($n=85$, 39 ± 35 mm) and length-corrected hooking depth ratio ranged from 0.004 to 0.261 ($n=89$, 0.07 ± 0.06). Most hooking locations were non-critical ($n=82$), while 11 were critical injuries (hooked in gullets or gills). Of the 11 critically hooked fish, one died after release, a 40.3 cm FL fish that was fought by an entry-level angler for 105 s, and hooked in the gills with a soft lure (J hook) that led to difficult hook removal and bleeding. Hook removal was difficult (>30 s) for eight (80%) fish



caught by beginner anglers (non-critical, easy=2; non-critical, difficult=2; critical, difficult=6), three (50%) fish caught by intermediate anglers (non-critical, easy=3 non-critical, difficult=3), and 12 (25%) fish caught by advanced anglers (non-critical, easy=33; non-critical, difficult=10, critical, easy=5; critical, difficult=3). Nine of 11 fish with critical hooking severity were hooked with J hooks, five by fly and four by lure. Blood from hooking injury was present in 22% of angled fish. Gear types (spin, fly) and hook types (J, circle) were not related to severity of injury (gear type, $p=0.35$; hook type, $p=1.00$), presence of bleeding (gear type, $p=0.80$; hook type, $p=0.58$), hook placement (gear type, $p=0.14$; hook type, $p=0.56$), or ease of hook removal (gear type, $p=0.16$; hook type, $p=1.00$). Gear type and hook type were not related to the mean length-corrected hooking depth ratio (gear type, $W=816$, $p=0.85$; hook type, $W=191.5$, $p=0.06$). Finally, angler-perceived expertise was not associated with the severity of injury ($p=0.54$).

Of 60 striped bass (19–100 cm fork length, 56 ± 14 cm fork length) assessed with RAMP (35 of 95 fish were tagged; Hollema et al., 2017), 20 (33%) had no sign of reflex impairment. In total, 1 fish failed the head reflex, 3 failed the mouth reflex, 21 failed the gag reflex, 5 failed the fin reflex, and 33 failed the body reflex. Furthermore, 21 (35%) fish had one impairment (4 gags, 17 body), 15 (25%) had two impairments (one mouth, 13 gags, 4 fins, 12 body), and four (7%) had three impairments (1 head, 2 mouths, 4 gags, 1 fin, and 4 body). Of the fish with three or more impairments, all had critical injuries (hooked in gills or gut) from J hooks (two on fly, two on lures). One mortality (1.7%) had only mouth and fin reflexes during the RAMP assessment. Hooking severity (critical or non-critical) was significantly related to reflex impairment for 58 fish with complete records ($\beta=1.43$, $p<0.001$, Figure 1, Table 1).

Several biochemical indicators (Table 2) of stressed fish ($n=24$, fight time >155 s) were higher than for minimally stressed fish ($n=24$, fight time <76 s) (Figure 2), including blood lactate (minimally stressed, $n=24$, 2.52 ± 0.81 mmol L⁻¹; treatment, $n=24$, 4.69 ± 1.31 ; $t=-6.89$, $df=38.28$, $p<0.001$), plasma sodium (minimally stressed, $n=23$, 169 ± 3.9 mmol L⁻¹; treatment, $n=22$, 173 ± 4.4 mmol L⁻¹; $t=-3.76$, $df=41.69$, $p<0.001$), and chloride (minimally stressed, $n=22$, 143 ± 2.0 mmol L⁻¹; treatment, $n=21$, 147.5 ± 2.87 mmol L⁻¹; $t=-6.02$, $df=35.26$, $p<0.001$). Glucose was positively related to the

reflex impairment index ($R^2=0.13$, $F_{3,56}=2.85$, $p=0.01$, $\beta=20.55$). Fight time was positively related to blood lactate ($R^2=0.36$, $F_{3,56}=10.56$, $p<0.001$, $\beta=0.01$), chloride ($R^2=0.20$, $F_{3,49}=4.14$, $p=0.002$, $\beta=0.02$), and sodium ($R^2=0.14$, $F_{3,52}=2.82$, $p=0.01$, $\beta=0.02$). Handling time was negatively related to calcium ($R^2=0.20$, $F_{3,52}=4.22$, $p=0.003$, $\beta<-0.001$) and positively related to pH ($R^2=0.12$, $F_{3,52}=2.43$, $p=0.02$, $\beta<0.001$).

Water temperature and TL explained 43% of variance in the first two PCA blood physiology dimensions (Table 3). PC1 accounted for 27% of variance, and was characterized by high positive factor loadings (ranked from highest to lowest) for sodium, chloride, and lactate. PC2 described 16% of variance and was characterized by high positive factor loadings for cortisol and negative factor loadings for water temperature and TL. The multiple linear model was significant for PC1 ($R^2=0.33$, $F_{4,53}=6.38$, $p<0.001$),

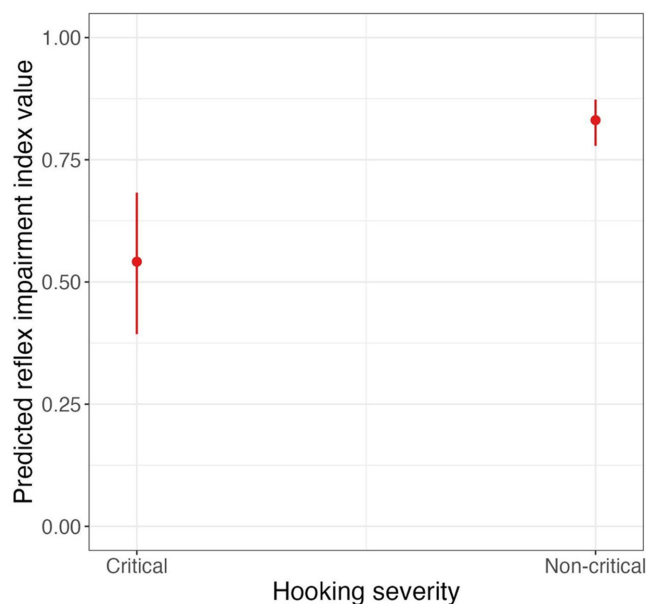


FIGURE 1 Marginal effect of hooking severity reflex impairment index for striped bass (*Morone saxatilis*) caught-and-released by volunteer anglers from small boats in Plymouth, Kingston, and Duxbury Bay near Boston, Massachusetts during June 2010 and October 2011.

TABLE 1 Effects of fight time, handling time, gear type, and hooking severity (critical vs. non-critical) on reflex impairment (success or failure) caused by catch-and-release angling on striped bass (*Morone saxatilis*) by volunteer anglers from small boats in Plymouth, Kingston, and Duxbury Bay near Boston, Massachusetts during June 2010 and October 2011.

Parameter	Coefficient	95% CI	z	p	Std. Coef.	Std. Coef. 95% CI
Intercept	0.01	[-0.97, 0.99]	0.02	0.99	0.17	[-0.43, 0.77]
Fight time	0.00	[0.00, 0.00]	-0.49	0.63	-0.07	[-0.36, 0.22]
Handling time	0.00	[0.00, 0.00]	0.87	0.38	0.13	[-0.17, 0.44]
Hooking severity [non-critical]	1.43	[0.73, 2.12]	4.02	<0.001	1.43	[0.73, 2.12]
Observations	58					
Marginal R ²	0.08					

Note: Columns indicate model parameters (Parameter), effect sizes (Coefficient) and their 95% confidence intervals (CI), z-score (z), p-value (p), and standardized coefficient (Std. Coef.) and their 95% confidence intervals (Std. Coef. 95% CI).



TABLE 2 Biochemical indicators of striped bass (*Morone saxatilis*) classified as stressed (fight time >155 s) or as minimally stressed (fight times <76 s) after catch-and-release angling by volunteer anglers from small boats in Plymouth, Kingston, and Duxbury Bay near Boston, Massachusetts during June 2010 and October 2011.

Classification	Variable	n	Min	Max	Mean	SD
Minimally stressed	Calcium	23	1	1.9	1.4	0.2
	Chloride	22	139.6	146.6	143	2
	Cortisol	24	0	17.4	2.3	4.6
	Glucose	24	59	97	76.7	12.2
	Lactate	24	1.4	4.6	2.5	0.8
	Packed cell volume	22	0.2	0.5	0.3	0
	Potassium	23	3.7	6.5	4.5	0.6
	Sodium	23	161.6	176.8	168.8	3.9
Stressed	Calcium	22	1.2	1.8	1.4	0.1
	Chloride	21	142.8	151.4	147.5	2.9
	Cortisol	23	0	7.9	1.1	2.2
	Glucose	24	56	101	73.6	11.8
	Lactate	24	2.6	7.7	4.7	1.3
	Packed cell volume	12	0.3	0.4	0.3	0
	Potassium	22	3.6	6.1	4.5	0.6
	Sodium	22	166.9	185	173.5	4.4

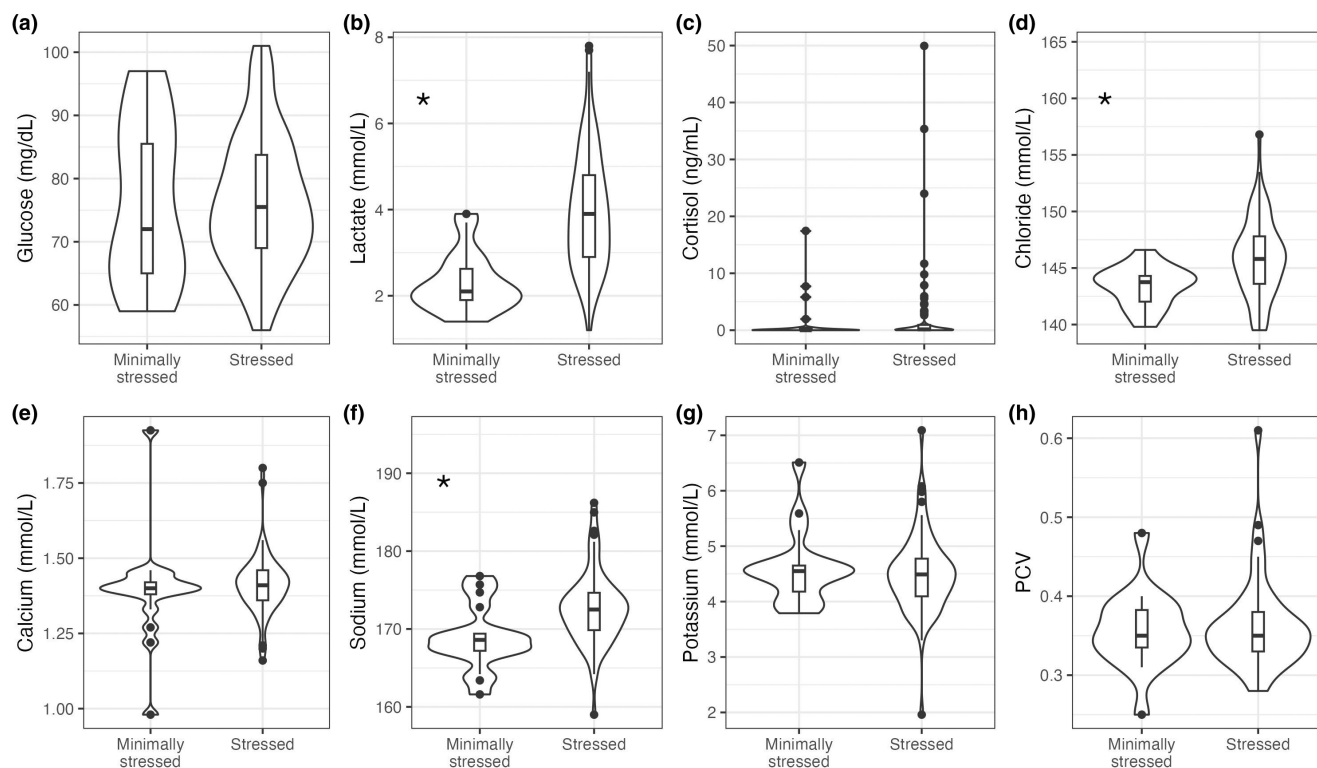


FIGURE 2 Blood parameter measurements (glucose, lactate, cortisol, chloride, calcium, sodium, potassium, and packed cell volume) for minimally stressed (fight time <76 s) and stressed (fight time >155 s) striped bass (*Morone saxatilis*) caught-and-released by volunteer anglers from small boats in Plymouth, Kingston, and Duxbury Bay near Boston, Massachusetts during June 2010 and October 2011. Medians are horizontal black lines, outliers are black dots, and * indicates a significant difference.

but not for PC2 ($R^2=0.09$, $F_{4,53}=0.29$, $p=0.29$). Specifically, reflex impairment index values, handling time, and hooking severity (critical vs. non-critical) were not significant (Table 4), but fight time was significantly related to PC1 ($\beta=0.01$, $p<0.001$) (Figure 3) and PC2 ($\beta=0.004$, $p=0.03$).

4 | DISCUSSION

We found that striped bass with more severe behavioral responses had been hooked in critical locations (such as the gullet or gills) with J hooks, although small sample size limited power to detect a difference

TABLE 3 Factor loadings for the first two principal components (Dimension 1 and Dimension 2) for: blood physiology parameters (glucose, lactate, cortisol, chloride, calcium, sodium, potassium, and packed cell volume), water temperature, and total length of striped bass (*Morone saxatilis*) caught-and-released by volunteer anglers from small boats in Plymouth, Kingston, and Duxbury Bay near Boston, Massachusetts during June 2010 and October 2011.

Parameter	Dimension 1	Dimension 2
Sodium	0.52	-0.06
Chloride	0.46	-0.19
Lactate	0.43	0.16
Calcium	0.34	0
Packed cell volume	0.32	0.24
Total length	0.21	-0.52
Glucose	0.2	0.33
Potassium	0.13	0.2
Cortisol	0.11	0.43
Water temperature (°C)	0.1	-0.53

between hook type (J hook, circle hook) and fishing terminal tackle (lure, fly) on the severity of injury, presence of bleeding, or hook placement. Injury of fish during angling is likely caused by the way a fish strikes the bait or lure and the way an angler reels the fish to the boat, beach, or jetty, so hooking injuries are most likely to hinder survival when internal esophageal or organ tissues are damaged (Bartholomew & Bohnsack, 2005; Muoneke & Childress, 1994). In prior studies of striped bass, the extent of a hook-related injury and likelihood of damage to vital organs was influenced by terminal tackle used (Millard et al. 2003). For example, most striped bass caught on artificial lures were generally hooked in the jaw and mouth, whereas fish caught with live bait were more likely to be deep hooked in critical locations (Nelson, 1998). Furthermore, circle hooks, specifically inline circle hooks, greatly reduced deep hooking and post-release mortality of striped bass (Cooke & Suski, 2004). Larger samples are needed to model striped bass hooking injury in relation to hook size and fly versus lure methods. Finally, we also found no relationship between angler expertise and severity of injury, which suggests that hooking injury was not related to artificial tackle, although we found greater impairment when fish were hooked in critical locations using J hooks.

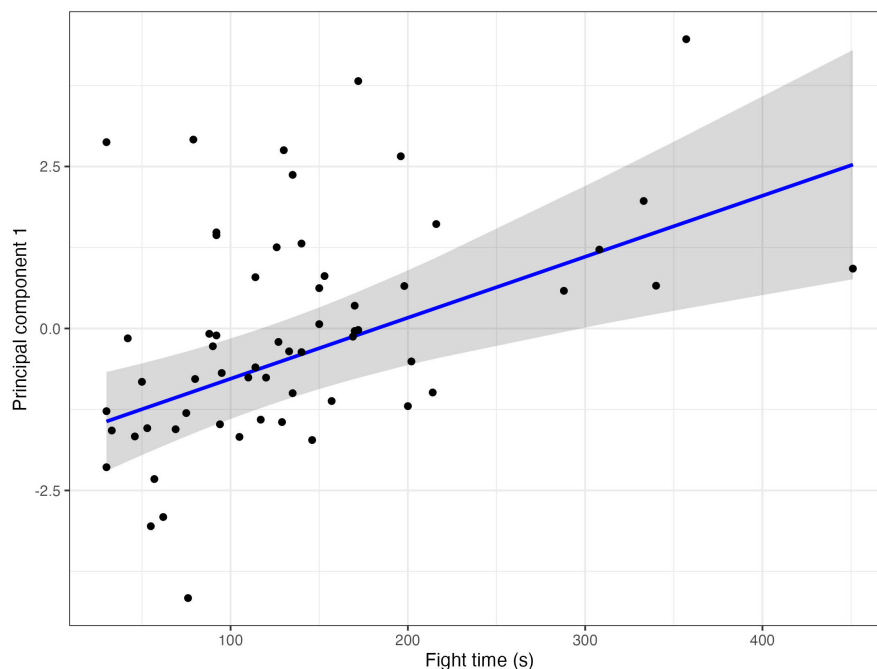
TABLE 4 Parameters of linear regression models explaining effects on the first two principal component scores describing blood physiology (glucose, lactate, cortisol, chloride, calcium, sodium, potassium, and packed cell volume), water temperature, and total length in relation to reflex impairment index (success or failure), fight time, handling time, and hooking severity (critical or non-critical) for striped bass (*Morone saxatilis*) caught-and-released by volunteer anglers from small boats in Plymouth, Kingston, and Duxbury Bay near Boston, Massachusetts during June 2010 and October 2011.

(a) Dimension 1						
Parameter	Coefficient	95% CI	t	p	Std. Coef.	Std. Coef. 95% CI
Intercept	-1.57	[-3.41, 0.27]	-1.72	0.09	-0.52	[-1.20, 0.15]
RAMP	-0.80	[-3.17, 1.56]	-0.68	0.50	-0.09	[-0.36, 0.18]
Fight time	0.01	[0.01, 0.01]	4.52	<0.001	0.51	[0.29, 0.74]
Handling time	0.00	[0.00, 0.00]	-0.06	0.95	-0.01	[-0.24, 0.22]
Hook severity [non-critical]	1.01	[-0.22, 2.24]	1.65	0.10	0.62	[-0.13, 1.37]
Degrees of freedom	53					
Multiple R ²	0.33					
Adjusted R ²	0.27					
F-statistic	6.38					
(b) Dimension 2						
Parameter	Coefficient	95% CI	t	p	Std. Coef.	Std. Coef. 95% CI
Intercept	0.01	[-1.52, 1.54]	0.1	0.99	0.02	[-0.76, 0.80]
RAMP	0.46	[-1.50, 2.43]	0.47	0.64	-0.07	[-0.24, 0.39]
Fight time	0.00	[-0.01, 0.00]	-2.18	0.03	-0.29	[-0.55, -0.02]
Handling time	0.00	[0.00, 0.00]	0.15	0.88	0.02	[-0.25, 0.29]
Hook severity [non-critical]	-0.03	[-1.05, 0.99]	-0.05	0.96	-0.02	[-0.90, 0.85]
Degrees of freedom	53					
Multiple R ²	0.09					
Adjusted R ²	0.02					
F-statistic	0.29					

Note: Models were performed for (a) dimension one and (b) dimension two values. Columns indicate model parameters (Parameter), effect sizes (Coefficient) and their 95% confidence intervals (CI), t-statistic, p-value (p), and standardized coefficient (Std. Coef.) and their 95% confidence intervals (Std. Coef. 95% CI).



FIGURE 3 The predicted linear relationship, with non-focal variables set to their mean (numeric variables) or averaged over the levels (factor variables), and observed values between fight time and principal component 1 summarizing water temperature, total length, and measured blood parameters (glucose, lactate, cortisol, chloride, calcium, sodium, potassium, and packed cell volume) of striped bass (*Morone saxatilis*) caught-and-released by volunteer anglers from small boats in Plymouth, Kingston, and Duxbury Bay near Boston, Massachusetts during June 2010 and October 2011.



Angling-related exercise in our study caused significant physiological elevation of lactate, sodium, and chloride, similar to other studies of C&R angling that found angling unavoidably elicited physiological disturbance in individual fish (Cooke & Suski, 2005). Furthermore, when values, water temperature, and fish size were summarized using PCA, fight time had an overarching effect on physiological responses of striped bass. Similarly, angling time and water temperature influenced physiological response and mortality of striped bass (Thompson et al., 2002; Tomasso et al., 1996). When fish are fought to exhaustion, lactic acid builds up in the tissues of fish from increased anaerobic muscle activity and accumulates in plasma (Skomal & Mandelman, 2012; Wang et al., 1994; Wood, 1991). Sodium and chloride, major salts present in seawater, passively increase in plasma when gill perfusion increases in response to greater oxygen demand during angling, a phenomenon known as osmorepiratory compromise (Randall et al., 1972). Absence of changes in some physiological parameters that are known to increase in response to angling and handling stress (hematocrit, cortisol, glucose; Wendelaar Bonga, 1997; Schreck & Tort, 2016) may have been due to relatively short periods after angling event our study. This observation is similar to a peak in glucose and lactate in dusky kob (*Argyrosomus japonicus*) 30–40 min after simulated angling (Arkert et al., 2020). While typical for C&R studies, especially for large fish that are difficult to hold long-term, future research should sample in situ long enough to allow secondary physiological markers to peak and consider the effects of fight time (Butler et al., 2022).

Although we did not measure the physiological recovery of striped bass, some fish in our study (not assessed for RAMP) survived angling and surgical implantation of acoustic transmitters (Hollema et al., 2017), which suggests that striped bass were able to recover from physical and physiological impacts of angling, in

addition to the added stress of tagging (Donaldson et al., 2008). Post-release mortality of striped bass varies widely among studies in marine environments. For example, post-release survival was 100% for a small number ($n=8$) of striped bass tagged with pop-up satellite archival tags that were released after recreational angling in winter during a pre-spawning aggregation near the mouth of Chesapeake Bay (Graves et al., 2009). Similarly, predicted long-term post-release mortality averaged 9% and ranged 3%–26% for 27–57 cm striped bass in a Massachusetts saltwater impoundment in summer (Diodati & Richards, 1996). By comparison, the only immediate mortality in our study coincided with angling conditions (single hook, deeply hooked, and inexperienced angler) that were previously linked to the highest likelihood of mortality (Diodati & Richards, 1996). Last, the 9% average hooking mortality estimated by Diodati and Richards (1996) was used as discard mortality rate for recreational fisheries in striped bass stock assessments, despite the author's assertion that “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 on mortality.” Therefore, a more comprehensive assessment of potential impacts of capture and handling on post-release activity, behavior, and survival of striped bass caught in the recreational fishery is critical for informing stock assessment models.

Overall, our study highlighted that each component of an angling event (hooking severity, fight time) impacted each physiological and behavioral response differently. Specifically, when striped bass are critically hooked, behavior impairment increases, and when fight time is long, physiological stress responses increase. Here, immediate post-release survival were high (98.3%) when using artificial single-hook terminal tackle. To minimize sub-lethal

and lethal effects of C&R, our results suggest that anglers should avoid J hooks to minimize behavior impairment related to critical hooking (Cooke & Suski, 2004). While replacing treble hooks, which were not tested in our study, on spoons, crank-baits, and top-water lures with single circle hooks may be possible, many soft plastic lures have built-in J hooks that cannot be replaced. We suggest that anglers minimize fight time to reduce physiological disturbance. We did not allow air exposure of angled striped bass for more than 5 s, which is likely shorter than typical for the striped bass recreational fishery. Long air exposure can detrimentally impact fish welfare and PRM (Cook et al., 2015). Finally, additional stressors, e.g., blunt trauma from dropping a fish onto the deck or differing release strategies, as well as their cumulative effects should continue to be assessed. Given the diversity of angling techniques, locations, and handling used when fishing for striped bass, more research is needed to quantify physical impacts, behavioral impairment, and PRM of striped bass, including effects of air exposure.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

All associated code can be found on <https://github.com/lucasgriffin?tab=repositories>

ETHICS STATEMENT

All handling procedures were conducted in accordance with the American Association for Laboratory Animal Science (IACUC protocol 2010-0004, University of Massachusetts).

ORCID

Lucas P. Griffin  <https://orcid.org/0000-0002-8560-0683>

Andy J. Danylchuk  <https://orcid.org/0000-0002-8363-0782>

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