

Use of external Indicators to Evaluate Stress of Largemouth (*Micropterus salmoides*) and Smallmouth (*M. dolomieu*) Bass at Tournaments

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Abstract: The popularity of catch and release tournaments targeting largemouth (*Micropterus salmoides*) and smallmouth (*M. dolomieu*) bass has continued to increase over the past few decades. In 2008, Lake Champlain hosted 95 tournaments, including several large-scale events hosted in Plattsburgh, NY. As in any catch-and-release fishery, released fish exhibit varying amounts and types of stress, potentially generating sub-lethal population-level impacts. Due to the large volume of fish that move through catch and release tournaments, blood chemistry analysis is generally outside of the temporal and financial constraints of tournament organizers. External indicators of stress can be used to determine stress levels in large numbers of fish. We adapted some of these indicators (e.g., wounding, response to stimuli) from research in marine and commercial fisheries to assess fish stress following weigh-in at Plattsburgh-based catch and release tournaments. Additionally, we collected data including fish measurements, lake temperature, fish capture locations, and information on tournament handling practices to determine which external factors influenced fish stress levels. Generalized linear models showed increased likelihood of elevated stress levels as a positive function of ambient lake temperature, fish size, and livewell transport distance. Comparison of results with existing research on bass stress are consistent with our models, indicating that external signs of stress can be used to evaluate black bass stress levels at catch-and-release tournaments.

Keywords: Catch and release, largemouth; *Micropterus*, smallmouth; stress, tournaments.

1. INTRODUCTION

Black bass (*Micropterus* spp.) are some of the most sought-after sport fish in North America. In the 2007 New York Statewide Angler Survey, 33% of anglers rated black bass as their top target fish, and 75% of anglers ranked black bass as one of their top five target fish [1,2]. Many bass anglers participate in catch-and-release fishing tournaments, ranging from local events with less than a dozen boats to international events with hundreds of boats. A recent report from Connecticut highlights the exponential growth in popularity of tournament bass fishing over the past few decades. In the 1980s, Connecticut hosted an average of 150 tournaments per year. That number increased to 600 tournaments per year in the 1990s, and in 2000, Connecticut hosted over 800 tournaments [2]. Ranked as one of the top ten bass fishing lakes in the United States [3], Lake Champlain has seen heavy tournament fishing pressure in recent years. In 2008, communities on Lake Champlain hosted 95 tournaments [4].

It is well documented that angling fish can have negative impacts on fish health and survival [5-8]. Stress levels can be influenced by a variety of factors including holding time

[9], air exposure [10], livewell conditions [11], fish size [12], and water temperature [13]. Recovery time from physiological stress for a variety of fish species ranges from 8 to 12 hours, depending on post-release conditions [14]. Immediate mortality from angling stress (i.e. angling induced injury, barotrauma, or exhaustion) is usually negligible in centrarchids, except in cases of extreme temperatures [15,16]; however, delayed mortality can still present a problem for catch-and-release anglers. Research into fish stress levels can help determine when and why fish experience the most stress, allowing catch-and-release anglers to take corrective actions and minimize sub-lethal impacts of angling on fish.

Much of the current research on sub-lethal stress in fish uses blood chemistry analysis to gauge stress levels [16-18]. However, recent research also suggests that blood chemistry alone might not be the best indicator of fish stress (i.e. angling induced injury, barotrauma, or exhaustion) and delayed (within five days of angling) mortality. In numerous studies, high levels of angling or hauling (transport in a livewell or other enclosure) induced stress was linked to an increased likelihood of delayed mortality [8, 9, 15]. Mortality due to air exposure did not correspond to changes in blood chemistry among commercially captured Pacific halibut (*Hippoglossus stenolepis*) [10]. A study of northern pike (*Esox lucius*) response to angling and handling showed that despite a dearth of significant changes in blood chemistry variables,

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Table 1. Physical Indicators of Stress Fish were Evaluated for

Abbreviation	Stress Indicator	Description
BF	Bloody fins	Hemorrhaging present in fins
DE	Absence of dorsal fin erection	Fins do not erect when fish is restrained
EE	Esophageal eversion	Eversion of esophageal tissue into buccal cavity
FD	Fin damage	Part of fin missing, frayed
HW	Hook wound	Hook embedded in fish or noticeable wounding in or around mouth
LW	Lamprey wound	Noticeable circular wounding from sea lamprey (<i>Petromyzon marinus</i>)
MC	Absence of mouth clamp	Mouth does not clamp shut when lifted or opened
OE	Ocular emphysema	Gas present in eye
PE	Exophthalmia (pop-eye)	Eyes protruding out of orbit
RR	Absence of restraint resistance	Fish does not exhibit muscle flex to escape
TA	Tight abdomen	Abdomen swollen, feels tight when touched

fish that were angled and handled for greater amounts of time took longer to recover post-release [19]. Research on black bass also suggests that blood chemistry responses to air exposure are inconsistent [16]. Blood chemistry analysis can be time consuming, expensive, and demanding of technical skills, making it impractical for use with large numbers of fish in a field (non-laboratory) setting. Recent studies conducted in the marine environment to evaluate fish stress following capture by trawling suggest that externally observable stress indicators such as wounding [20] and response to stimuli [21] can be used to predict mortality in a variety of fish species.

We set out to investigate the possibility of using external signs and behaviors as proxy indicators for the evaluation of stress in largemouth (*Micropterus salmoides*) and smallmouth (*M. dolomieu*) bass. If shown to be viable, such proxy measures of stress could be used by researchers, management agencies, and tournament directors to better manage bass stress levels (and thus, survival) associated with tournament angling, weigh-in, and subsequent release.

2. MATERIALS AND METHODS

Using metrics adopted from Davis [21] and Campbell *et al.* [22], we assessed fish for a battery of physical indicators of stress (Table 1) at nine catch-and-release bass tournaments based in Plattsburgh, NY. A typical catch-and-release tournament proceeds as follows: anglers depart from a starting point and spend several hours (up to 8) fishing. Fish are captured and held in a livewell onboard each fishing boat. Each angler may keep up to five fish, and usually each angler is paired with a co-angler. As many as ten fish may be held in each boat. The boats return to a designated weigh-in location where fish are removed from livewells and held in water-filled plastic bags submerged in a holding tank while the anglers wait for their turn to weigh in. When that time

comes, anglers carry the plastic bags to a scale, where fish are removed from the bags and weighed. After weighing-in, fish are brought to a release boat. Once the release boat is full to capacity, the fish are transported to the release point and dumped back into the lake.

We collected fish from anglers between the weigh-in stage and the release boat; fish evaluation occurred in oxygenated holding tanks with a flow-through rate of 378 liters / hour. Lake temperature was recorded for each individual tournament day (for a total of 13 temperature records). Each stress indicator was scored as present or absent (1 or 0). We assigned each fish a capture location based on information collected from cooperating anglers. Using Quantum GIS v1.8.0 [23], we assigned distances from each capture location to the weigh-in. Additionally, we measured temperature ranges at holding tanks used by Lake Champlain Research Institute (LCRI) staff to assess fish, tournament holding tanks (where fish are kept between the livewell and weigh-in), and holding tanks on the release boat (where fish are kept after weigh-in) on four tournament days. All data were managed using a database developed in Microsoft Access v12.

To test for variable independence, we tested for correlations between stress indicators (package “Hmisc”; Table 2). Correlations broke the indicators into two distinct groups and revealed only two independent indicators. Tight abdomen, exophthalmia, and ocular emphysema were grouped into “barotrauma indicators.” If a fish exhibited any one of these three indicators, it was counted as exhibiting barotrauma. Bloody fins, hook wounds, fin damage, absence of dorsal erection, absence of mouth clamp, and absence of restraint resistance were grouped into “wounds and indicators of exhaustion.” If a fish exhibited any one of these six indicators,

Table 2. Correlation Table Showing Relationships between Stress Indicators. Statistical Significance is Designated at the Following Levels: $p < 0.05$ (*), $p < 0.01$ (), $p < 0.001$ (***)**

TA	PE	BF	OE	EE	DE	MC	RR	HW	FD	LW	
1	0.15***	-0.02	0.05**	-0.01	0.06**	-0.04	-0.03	-0.01	-0.04	-0.02	TA
	1	-0.02	0.06**	0.00	-0.02	-0.01	0.00	-0.02	0.00	-0.01	PE
		1	0.10***	-0.01	0.08***	0.07***	-0.03	0.14***	0.36***	-0.03	BF
			1	-0.01	0.07***	0.03	0.03	0.01	0.10***	-0.01	OE
				1	-0.01	0	0.01	-0.01	0.02	-0.01	EE
					1	0.16***	0.15***	0.07***	0.10***	-0.04	DE
						1	0.46***	0.03	0.15***	-0.02	MC
							1	-0.02	0.02	0.00	RR
								1	0.2***	-0.02	HW
									1	-0.03	FD
										1	LW

Table 3. Summary of Models for Barotrauma, Wounding/Exhaustion, lamprey Wounds, and Esophageal Eversion. Models were Compared using Akaike's Information Criterion (AIC). The Lowest AIC in each Category is the Best Fitting Model. Models with $\Delta AIC < 2$ are Considered Reasonable Alternatives. If no Models are Significantly Better than the Null (random) Model, the Relationship is Meaningless

Model	k	Smallmouth Bass			Largemouth Bass		
		AIC	ΔAIC	Weight	AIC	ΔAIC	Weight
Baro Null model	0	795.97	5.4	0.02	773.02	46.66	< 0.001
Baro ~ SqrtDist	1	797.14	6.57	0.01	763.28	36.92	< 0.001
Baro ~ Temp	1	791.48	0.91	0.23	729.97	3.61	0.07
Baro ~ Length	1	794.73	4.16	0.04	771.07	44.71	< 0.001
Baro ~ SqrtDist + Temp	2	792.75	2.18	0.12	726.36	0	0.42
Baro ~ SqrtDist + Length	2	796.08	5.51	0.02	763.72	37.36	< 0.001
Baro ~ Temp + Length	2	790.57	0	0.36	728.89	2.53	0.12
Baro ~ SqrtDist + Temp + Length	3	792.02	1.45	0.17	726.56	0.2	0.38
WoundEx Null model	0	1099.4	29.1	< 0.001	569.25	51.62	< 0.001
WoundEx ~ SqrtDist	1	1091.8	21.5	< 0.001	538.94	21.31	< 0.001
WoundEx ~ Temp	1	1078.7	8.4	0.01	547.88	30.25	< 0.001
WoundEx ~ Length	1	1100.4	30.1	< 0.001	556.75	39.12	< 0.001
WoundEx ~ SqrtDist + Temp	2	1070.3	0	0.66	522.42	4.79	0.08

Table 3. contd...

Model	k	Smallmouth Bass			Largemouth Bass		
		AIC	Δ AIC	Weight	AIC	Δ AIC	Weight
WoundEx ~ SqrtDist + Length	2	1093.0	22.7	< 0.001	533.29	15.66	< 0.001
WoundEx ~ Temp + Length	2	1080.0	9.7	0.005	535.72	18.09	< 0.001
WoundEx ~ SqrtDist + Temp + Length	3	1071.7	1.4	0.32	517.63	0	0.91
LW Null model	0	299.48	7.64	0.01	266.46	0	0.29
LW ~ SqrtDist	1	301.18	9.34	0.004	267.95	1.49	0.13
LW ~ Temp	1	301.33	9.49	0.004	267.31	0.85	0.19
LW ~ Length	1	291.84	0	0.46	268.2	1.74	0.12
LW ~ SqrtDist + Temp	2	303.02	11.18	0.001	268.97	2.51	0.08
LW ~ SqrtDist + Length	2	293.31	1.47	0.22	269.48	3.02	0.06
LW ~ Temp + Length	2	295.02	3.18	0.09	269.01	2.55	0.08
LW ~ SqrtDist + Temp + Length	3	293.54	1.7	0.19	270.48	4.02	0.03
EE Null model	0	31.732	0	0.28	56.525	0.663	0.19
EE ~ SqrtDist	1	33.729	1.997	0.10	58.102	2.24	0.08
EE ~ Temp	1	31.987	0.255	0.25	55.862	0	0.26
EE ~ Length	1	33.634	1.902	0.11	58.014	2.152	0.09
EE ~ SqrtDist + Temp	2	33.977	2.245	0.09	56.965	1.103	0.15
EE ~ SqrtDist + Length	2	35.633	3.901	0.04	59.355	3.493	0.04
EE ~ Temp + Length	2	35.908	4.176	0.03	57.441	1.579	0.12
EE ~ SqrtDist + Temp + Length	3	33.921	2.189	0.09	58.34	2.478	0.07

it was counted as exhibiting wounds and exhaustion. Lampry wounds and esophageal eversion were not correlated with any other stress indicators, so each was evaluated individually.

In order to reduce the skewed nature of the distance traveled data, we used a square-root transformation to tighten the distribution [24]. To determine the effects of water temperature, fish length, and distance traveled in a livewell on fish stress, we used generalized linear modeling (GLM) [25]. We ran eight logit link GLMs for each indicator group (barotrauma, wounding/exhaustion, esophageal eversion, and lampry wounds) for each species, totaling 64 models (Table 3). Following model creation, we used AIC values to determine the most appropriate models for each indicator group (Δ AIC = AIC - AIC_{min} ≤ 2). Stress indicators for which the null model had the lowest AIC value or for which AIC_{null} - AIC_{min} ≤ 2 were treated as being insignificant. To determine the if tournament handling practices were exacerbating stress via

temperature shock, we tested for significant differences in temperature between different pieces of tournament infrastructure using Mann-Whitney U tests. All statistical analysis was conducted using the R Project for Statistical Computing v2.14.1 [26] in the RStudio v0.97 environment [27].

3. RESULTS

In total, we analyzed 1245 smallmouth bass and 1349 largemouth bass. A majority of largemouth bass exhibited bloody fins (64%), fin damage (59%), and / or an absence of dorsal fin erection (69%; Fig. 1). More than one quarter of largemouth bass exhibited hook wounds (36%) and / or an absence of mouth clamp (28%). A majority of smallmouth bass exhibited bloody fins (55%). Nearly half of smallmouth bass exhibited an absence of dorsal erection (49%) and over a quarter exhibited fin damage (33%). Lake temperatures on tournament days ranged from 15.2°C to 22.2°C. Total lengths (TL) of fishes ranged from 300 mm to 545 mm.

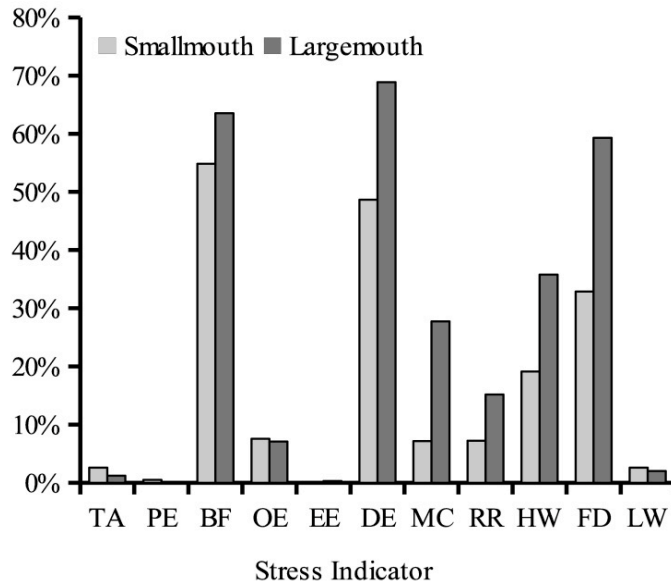


Fig. (1). Percent occurrence of stress indicators by species. Stress indicators are tight abdomen (TA), exophthalmia (PE), bloody fins (BF), ocular emphysema (OE), esophageal eversion (EE), absence of dorsal fin erection (DE), absence of mouth clamp (MC), absence of restraint resistance (RR), hook wounds (HW), fin damage (FD), and lamprey wounds (LW).

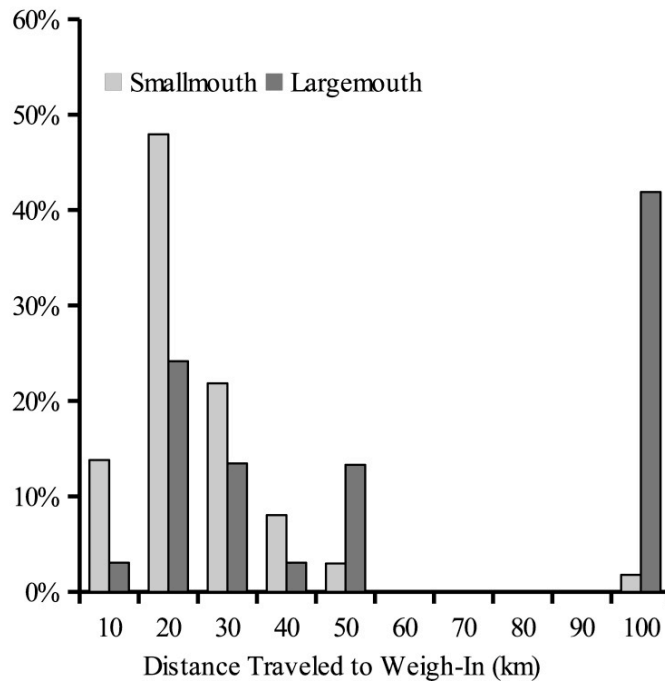


Fig. (2). Percent of fish traveling certain distances to weigh in. Most smallmouth bass were captured within 50 km of Plattsburgh, while nearly half of all largemouth bass were captured 100 km from Plattsburgh.

Fishes were transported as little as 0.3 km and as much as 100 km from point of capture to the weigh-in station (Fig. 2).

Barotrauma indicators were defined as tight abdomen, exophthalmia, or ocular emphysema. In both smallmouth and largemouth bass, the most important predictor of barotrauma was lake temperature (Table 4). Fishes captured on warmer days were more likely to exhibit indicators of barotrauma (SM $p_{avg} = 0.0126$; LM $p_{avg} < 0.01$) . For largemouth bass, fish transported farther were also more likely to exhibit barotrauma indicators ($p_{avg} = .0305$). There was a trend towards

longer smallmouth bass being more likely to exhibit barotrauma ($p_{avg} = 0.09$), but it was not statistically significant.

Distance traveled, fish length, and water temperature were not significant predictors of the occurrence of esophageal eversion. None of the models generated for this stress indicator were significantly better than the null (random) model (Table 4). There were also no significant predictors of the occurrence of lamprey wounds in largemouth bass. In smallmouth bass, however, longer fish were more likely to be victims of a lamprey attack ($p < 0.01$).

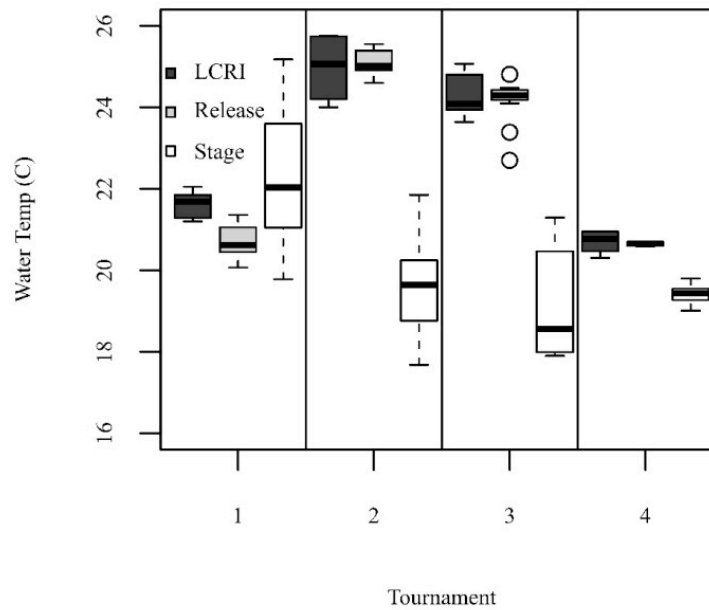


Fig. (3). Boxplot showing ranges of water temperatures in tournament infrastructure on four tournament days. “LCRI” refers to tanks used by LCRI staff to monitor fish stress. “Release” refers to holding tanks on the release boat, and “Stage” refers to holding tanks at the weigh-in facility. Tournament 2 had the highest *in situ* lake temperature, followed by Tournament 3 and Tournament 4. Tournament 1 had the lowest *in situ* lake temperature. All water temperatures were measured in °C.

Bloody fins, hook wounds, fin damage, absence of dorsal spine erection, absence of mouth clamp, and absence of restraint resistance were all counted towards scoring fish as “wounded or exhausted.” Lake temperature and distance traveled in a livewell were significant predictors of wounding and exhaustion (Table 4). Fishes captured on warmer days were more likely to be wounded or exhausted by the time they reached weigh in (SM $p_{avg} < 0.01$; LM $p < 0.01$). Additionally, the farther fishes were transported, the more likely they were to exhibit wounds or indicators of exhaustion at the weigh-in (SM $p_{avg} < 0.01$; LM $p < 0.01$). Another important predictor of wounding and exhaustion in largemouth bass was fish length. Longer fish were more likely to be wounded or exhausted ($p < 0.01$).

We sampled water temperature ranges in tournament holding tanks (where fish are kept between livewell and weigh-in), LCRI tanks (where we evaluated fish), and release boat tanks (where fish are kept between weigh-in and release) on four tournament days in 2012 (Fig. 3). Tournament holding tanks were treated with ice by tournament staff on the three warmest days. Temperatures of LCRI tanks were similar to release boat temperatures on all four days. Temperatures of the tournament holding tanks were lower than those of the release boat ($p < 0.001$) and LCRI tanks ($p < 0.001$) on the three warmest days when ice was used.

4. DISCUSSION

The purpose of this study was to evaluate whether or not physical indicators of stress could be used to reliably assess black bass condition at catch and release tournament events.

Fishes of both species were more likely to exhibit barotrauma during tournaments with higher lake temperatures. Incidences of barotrauma increase dramatically if fish are angled from depths $> 5\text{-}6\text{m}$ [28, 29]. Both conventional fish-

eries management texts [30,31] and research into barotrauma [29] indicate that black bass move into epilimnetic waters in the summer months. As the epilimnion continues to warm over the course of the summer season, black bass, especially smallmouth bass, may retreat to deeper water near the thermocline [32]. In many areas of Lake Champlain, the thermocline sets up at a depth greater than 10m [LCRI, unpublished data], well beyond the 5-6m threshold for increased likelihood of barotrauma. Thus, one would expect to see higher levels of barotrauma during the warmest periods of the year.

In largemouth bass, distance traveled was also a predictor of barotrauma, with fish that were transported greater distances being more likely to exhibit signs of barotrauma. Tournament-captured fish are likely to have high levels of plasma lactate due to intense exertion [29,33,34]. In these studies, aspartate aminotransferase (AST) and other blood chemistry indicators of stress were highest among fish with severe barotrauma. Fish with severe barotrauma were often those that died post-release. High AST concentrations indicate tissue damage, and internal damage to fish experiencing barotrauma may be increased by the amount of time spent in a livewell on the surface [33]. According to our results, largemouth bass that spent longer time in a livewell were more likely to exhibit indicators of barotrauma than largemouth bass that traveled less time in a livewell. A study on Australian bass (*Macquaria novemaculeata*) found that the severity of barotrauma increases the longer a fish is confined in a livewell [35]. A similar effect could be manifested in our models.

Signs of barotrauma rarely appeared in both species ($< 10\%$) during this study. The percentage of fish exhibiting barotrauma in Lake Champlain tournaments was comparable to percentages observed in other studies, which indicate that instances of severe barotrauma can range from 1.9% on shallow lakes to 56.5% on deeper lakes [28,29,33]. Although

Table 4. Standard Deviation, z-values, and p-values for Model Parameters. The Best Fitting Model is Displayed in Bold Font

Smallmouth Bass				Largemouth Bass			
Model Parameters	SE	z	p	Model Parameters	SE	z	p
<u>Baro ~ Temp</u>				<u>Baro ~ SqrtDist + Temp</u>			
Intercept	0.744	-5.477	< 0.01	Intercept	0.972	-8.620	< 0.01
Temp	0.039	2.533	0.011	SqrtDist	0.042	2.326	0.02
				Temp	0.047	5.639	< 0.01
<u>Baro ~ Temp + Length</u>				<u>Baro ~ SqrtDist + Temp + Length</u>			
Intercept	1.175	-4.764	< 0.01	Intercept	1.345	-7.142	< 0.01
Temp	0.039	2.469	0.013	SqrtDist	0.042	2.048	0.041
Length	0.002	1.691	0.091	Length	0.002	1.337	0.181
<u>Baro ~ SqrtDist + Temp + Length</u>				Temp	0.047	5.656	< 0.01
Intercept	1.197	-4.831	< 0.01				
SqrtDist	0.065	0.743	0.457	<u>WoundEx ~ SqrtDist + Length + Temp</u>			
Length	0.002	1.637	0.102	Intercept	1.428	-3.838	< 0.01
Temp	0.039	2.450	0.014	SqrtDist	0.056	4.246	< 0.01
				Length	0.003	2.586	< 0.01
<u>WoundEx ~ SqrtDist + Temp</u>				Temp	0.051	4.061	< 0.01
Intercept	0.669	-3.075	< 0.01				
SqrtDist	0.587	3.198	< 0.01				
Temp	0.332	4.738	< 0.01				
<u>WoundEx ~ SqrtDist + Length + Temp</u>							
Intercept	0.976	-2.655	< 0.01				
SqrtDist	0.058	3.178	< 0.01				
Length	0.001	0.755	0.451				
Temp	0.033	4.717	< 0.01				
<u>LW ~ Length</u>							
Intercept	1.991	-4.713	< 0.01				
Length	0.004	2.973	< 0.01				

Lake Champlain has an average depth of 19.5 m, that number is skewed by the deep trenches in the Main Lake, an area rarely frequented by bass anglers (<1% of fishes in this study came from that area of the lake). Discounting the Main Lake, Lake Champlain's average depth is approximately 6 m. On the St. Lawrence River, incidence of barotrauma began to

increase gradually at 6 m and did not increase dramatically until depths over 10 m [28]. Only 30% of fish in that study exhibited barotrauma. Studies of the relationship between barotrauma and mortality in catch and release, freshwater settings have found that between 10-20% of fish exhibiting signs of barotrauma (external indicators as well as blood

chemistry changes) die as a result [29, 35]. Given the relatively low percentage of fish arriving at Plattsburgh tournaments exhibiting barotrauma, it is likely a minimal contributor to tournament-related mortality.

A majority of both species (64% of largemouth and 55% of smallmouth) exhibited bloody fins. In many studies, hemorrhaging in fish fins is categorized as an indicator of barotrauma [28,29,33]. In our study, bloody fins were not significantly correlated with any other indicators of barotrauma. Rather, instances of bloody fins were correlated with wounds (e.g. fin damage) and indicators of exhaustion (e.g. absence of restraint resistance). From our models, it is apparent that wounding and exhaustion in both species are closely related to the water temperature and the square-root of distance traveled, which raises the possibility that bloody fins may actually be a result of transportation in a livewell. Further literature surveys revealed differences in methodology that lend further credence to this hypothesis. A comparison of three studies on waters in northeastern North America (Morrissey *et al.* [33] on Lake Erie, Gravel and Cooke [29] on Rainy Lake in Ontario, and Schreer *et al.* [28] on the St. Lawrence River) found similar levels of bloating (27% - 41%). Morrissey *et al.* [33] and Gravel and Cooke [29] also had similar levels of hemorrhaging (62% - 66%), but Schreer *et al.* [28] had much lower levels of hemorrhaging (< 4%). These studies differed in methodology such that Morrissey *et al.* [33] and Gravel and Cooke [29] both evaluated fishes following transportation from their point of capture to a central weigh-in location. In contrast, Schreer *et al.* [28] evaluated fish immediately after capture, before they were placed into a livewell. Our observations of hemorrhaging (59%) are similar to those of Morrissey *et al.* [33] and Gravel and Cooke [29], and we also evaluated fish after livewell transport. The combination of the low occurrence of hemorrhaging in Schreer *et al.* [28] as well as our modeling showing a relationship between bloody fins, other wounds, indicators of exhaustion, and distance traveled in a livewell all suggests that hemorrhaging may be associated with livewell stress rather than barotrauma.

The likelihood of fish exhibiting wounding and indicators of exhaustion increased with distance traveled in a livewell ($p < 0.01$ for both species). Previous studies using blood chemistry and video footage have documented that hauling is stressful for fish. Transported fish were found to have higher levels of plasma glucose and corticosteroids [9]. Corticosteroids are produced in response to exertion and stress, so elevated levels of these compounds is consistent with research that documents considerable energy expenditure by largemouth bass while avoiding collisions with other fish or livewell walls during transport [11]. Such collisions can result in dermal and ocular lesions, opening a vector for infections (a potential source of delayed mortality). Additionally, poor water quality and hypoxic conditions in livewells are often contributors to post-release mortality during tournaments [8,13].

Lamprey wounding was rare in this study (< 2% of fishes), and the majority of fishes exhibiting lamprey wounds were smallmouth bass. Low rates of lamprey wounding were expected because sea lamprey preferentially feed on fish with cycloid scales (e.g. salmonids) rather than fish with ctenoid scales (e.g. centrarchids) [36]. Addition-

ally, in our models, length was a significant predictor ($p < 0.01$) of exhibiting lamprey wounds in smallmouth bass. This is consistent with laboratory studies that show lamprey preferentially feeding on larger fish [37]. As expected, lamprey wounding was not related to distance traveled in a livewell or water temperature, because whether a fish has lamprey wounds or not is unrelated to its capture and handling in a tournament.

Temperature was a significant predictor of stress (both barotrauma and wounding/exhaustion) in both species (Table 4). This finding is consistent with current research using blood chemistry. Lower temperatures during fish hauling resulted in lower levels of stress (lower concentrations of corticosteroids and plasma glucose) post-release [9]. Furthermore, Ostrand *et al.* [13] found that initial physiological disturbance and delayed mortality were both higher when angling was conducted at higher ambient water temperatures. Although some studies found that other factors (e.g. levels of temperature changes, air exposure time) may play a larger role in fish stress than *in situ* lake temperature, a review and synthesis of numerous studies suggests there is a strong relationship between higher water temperatures and higher levels of tournament induced mortality, resulting from the cumulative effect of sub-lethal stressors [38]. Other studies report even low levels of stress resulting from increased water temperature can cause noticeable changes in behavior (e.g. loss of equilibrium, impaired swimming ability) [15, 17].

Another way water temperature can influence stress is by impacting tournament organizers' abilities to keep water temperatures consistent across infrastructure (i.e. livewells, storage tanks, release boats). Other research has found that being transferred to water that has significantly elevated or significantly reduced temperatures impaired recovery of tissue lactate and tissue ATP in largemouth bass [17]. In our study, fishes were evaluated in our holding tanks after having passed through livewells and tournament holding tanks, but before entering the release boat. On all 2012 tournament days, temperatures in our holding tanks were statistically similar to temperatures in the release boat (Fig. 3). However, on the three hottest tournament days temperatures in the tournament holding tanks were significantly lower than temperatures in our holding tanks and the release boat. Tournament organizers on those days added ice to their holding tanks in an effort to keep them from overheating. However, this practice may do more harm than good [13].

5. CONCLUSION

Our findings are consistent with existing research on fish stress using blood chemistry, indicating that physical signs of stress can be used to evaluate fish condition at tournaments, where the need to process large numbers of fish may make blood chemistry financially or temporally prohibitive. Further research should address the relationships between stress indicators and mortality (both immediate and delayed) as well as relationships between physical indicators of stress and physiological indicators of stress. These relationships could be assessed by evaluating fish in a variety of conditions at tournaments using physical metrics and blood chemistry analysis, and following the fish for several days after release using telemetry. Knowledge of these relationships

would enable tournament organizers to evaluate fish prior to release. This would ensure that only healthy fish with a good chance of recovering would be released, reducing the likelihood of fish kills following tournament events.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

ACKNOWLEDGEMENTS

We would like to acknowledge funding support from the NYSDEC and the Lake Champlain Basin Program. Additionally, we would like to thank Siobhan Levere, Erin Malchoff, Erica Gorey, Rick Perry, Erin Hayes-Pontius, Gayan-Jayasinghe, MarkLaMay, the City of Plattsburgh, SUNY Plattsburgh students who volunteered, and all anglers and tournaments who allowed us access to their fish.

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