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Behaviour of walleye, *Sander vitreus*, and largemouth bass, *Micropterus salmoides*, exposed to different wave intensities and boat operating conditions during livewell confinement

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Abstract During live-release angling tournaments in North America, fish are typically retained in livewells onboard boats during the angling day. Mortality of fish occurs at some tournaments, and wave intensities and livewell conditions may influence mortality levels. This study used two species of fish targeted in live-release angling tournaments in North America (largemouth bass *Micropterus salmoides* L. and walleye *Sander vitreus* L.) to quantify the response(s) of fish in livewells to different wave treatments. Video analyses revealed that largemouth bass were active during low intensity disturbances, but during violent boat movements tended to settle to the bottom of the livewell and orient to face the direction of the disturbance. Walleye were less active than bass for all treatments, and additionally did not orient to face the direction of disturbance, consequently contacting the side of the livewell during boat rocking. These results are considered in the context of mortality at live-release tournaments.

KEYWORDS: activity, behaviour, largemouth bass, livewell, tournament, videography, walleye.

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Introduction

Competitive angling events are extremely popular in North America (Schramm, Armstrong, Funicelli, Green, Lee, Manns, Taubert & Waters 1991a), and rapidly are becoming more common in other parts of the world. Many competitions practice a live release format, recognising that the majority of fish angled by hook and line can survive following release (See review by Muoneke & Childress 1994). Depending upon the target species and the format of the angling event, anglers use a variety of different types of retention equipment to keep fish alive, either until the conclusion of the angling day (typically 6–8 h) or until heavier individuals are captured and smaller fish are released. The devices used to hold fish include fish baskets (Cooke & Hogle 2000), larger keep nets (Pottinger 1997; Raat, Klein Breteler & Jansen 1997; Pottinger 1998), buckets and coolers, and elaborate livewells (Schramm & Heidinger 1988; Gilliland 2002).

In North America, by far the most common means of retaining fish in both amateur and professional fishing competitions is in livewells (Schramm, Armstrong, Fedler, Funicelli, Green, Hahn, Lee, Manns, Quinn & Waters 1991b). A livewell is essentially a portable fish tank that is built into the floor of a boat and is supplied with fresh water by means of a pump. Water is generally sprayed into the tank to provide aeration, and an overflow exists near the top of the tank allowing water to drain from the livewell when full. The theory behind this design is that fish being held on board a boat are able to receive fresh, aerated water and any accumulated waste products can be diluted and/or removed. Logistically, livewells permit the angler to be mobile, and their benefits to fish over other retention devices are evident from mandatory livewell requirements in most events, frequently including daily operating checks by event officials (Schramm *et al.* 1991b).

Several studies have examined the underlying causes of the mortality that result from angling tournaments (e.g. Welborn & Barkley 1974; Bennett, Dunsmoor, Rohrer & Rieman 1989), but few studies have examined livewell conditions and the physiological disturbances that result from retention in a livewell. Factors that may heighten stress and increase mortality include water temperature (See Schramm *et al.* 1991b; Muoneke & Childress 1994; Wilde 1998; Cooke, Schreer, Wahl & Philipp 2002) and the cumulative effects of multiple stressors (Cooke *et al.* 2002; Suski, Killen, Morrissey, Lund & Tufts 2003), but there have been few attempts to identify behavioural patterns during retention and to determine how fish respond to different stressors while confined in a livewell.

One aspect of the impact of livewell retention on mortality is the effect of weather conditions and subsequent wave intensities (Wilde 1998; Cooke *et al.* 2002). Studies on walleye, *Sander vitreus* L. (Goeman 1991; Fielder & Johnson 1994) and largemouth bass, *Micropterus salmoides* L. (Kwak & Henry 1995) suggest that extreme wave action may heighten mortality. Despite these observations, many studies of tournament mortality fail to report information on weather and wave conditions, with no studies to date designed to test this possible relationship. Laboratory studies investigating sublethal effects have used stationary mock livewells that are not influenced by boat operation or wave action, although this limitation has been identified (Plumb, Grizzle & Rodgers 1988).

The objective of this study was to describe, quantify, and compare the behaviour and activity of two species of fish while confined in livewells that were exposed to different wave intensities and boat operating conditions. The study compared largemouth bass and walleye, two species of fish that are commonly targeted in competitive angling events, and for which there is some evidence that mortality rates may be influenced by the degree of wave action. Videography was used to detail a variety of response variables for each species while exposed to different livewell conditions. By understanding how fish respond to different wave intensities and boating operations, the influence that confinement in a livewell has on mortality at angling tournaments can be better understood and perhaps addressed.

Materials and methods

Experiments were carried out during September 2001 at the Queen's University Biological Station (QUBS) on Lake Opinicon, Ontario (44°31′ N, 76°20′ W). During the experiment, daily water temperature averaged 22 ± 1°C, and wind speed averaged 3.6 m s^{-1}. Walleye used in the experiment were supplied by Leonard's Walleye Culture (Hartington, ON) and fish were collected from outdoor, earthen ponds by both angling and seining. Immediately following capture, walleye were transported to the aquatic holding facility at QUBS. Walleye were allowed to acclimate for 48 h in tanks continuously supplied with lake water. Largemouth bass used in the experiment were collected by angling from Lake Opinicon using standard gear and methods. Largemouth bass were also held for 48 h in tanks continuously supplied with lake water to permit recovery from angling.

The livewells used in the experiment mimicked livewells on many specialised angling boats, and consisted of eight rectangular plastic containers (approximately 70 L in volume, 60 × 40 cm), each with a tight-fitting lid. The livewells were oriented such that the longest side of the livewell was parallel to the front of the boat. Each livewell was outfitted with a section of plastic tubing passing through the lid of the container, and the pieces of tubing from four livewells were connected in series to a fountain pump submerged into Lake Opinicon at a depth of approximately 0.75 m. The plastic tubing was positioned in such a way that, when the fountain pumps were turned on, water could be sprayed into the livewell providing aeration along with fresh water with the lids of the tanks remaining closed. Overflow holes were drilled into the side of the plastic containers so that the volume of water contained in the livewell remained at approximately 50 L. Throughout the experiment, fish were supplied with fresh, aerated water three times per hour for approximately 10 min each period.

To monitor fish during experimental manipulations, a 4-cm hole was cut in the side of each livewell, and a sheet of transparent plastic was glued over the hole to provide a watertight seal. A high resolution 0 Lux black and white video camera with infrared illumination (AU 401; J.J. Communications Inc., Englewood, NJ, USA) was positioned outside of each livewell, and fish were discretely monitored during experimental manipulations through the sheet of clear plastic. A 2 × 2 grid dividing the livewell into four equal quadrants was drawn on the inside of each livewell to determine a fish's relative position within the livewell, and a video recorder (SRT 7072; Sanyo, Inc., Tokyo) was used to record fish behaviour for subsequent analyses.

Experimental procedures were carried out on board a 6-m pontoon boat. Each livewell on the boat contained one subject fish (mean weight largemouth bass = 381 ± 44.7 g, mean weight walleye = 638 ± 253 g) that was monitored for behavioural response to treatments, and one companion fish (mean weight largemouth bass = 608 ± 40.5 g, mean weight walleye = 292 ± 13.9 g) added to the livewell to replicate the crowded conditions often seen inside of livewells during live-release tournaments. Subject fish were chased in a circular tank for 1 min to replicate the exercise that accompanies hook-and-line angling before being transferred to the livewell.

Experimental procedures consisted of eight different manipulations, each lasting approximately 30 min in length. The experimental procedures and the order in which they were carried out are described in Table 1. Each subject fish was videoed for at least 1 min during each manipulation. A series of eight response variables was transcribed during play-back on a monitor, and the speed of playback during transcription ranged between normal and 1/10th speed. The eight response variables measured in the study were: caudal fin rate; opercular rate; amount of time the fish were positioned above the mid-line of the livewell; amount of time the fish spent swimming; the number of times a fish turned (turns considered changes in orientation >45°); the number of times that the fish interacted with each other (an interaction resulted in a change in position or orientation of the fish being monitored and included nips and nudges); pectoral fin rates; amount of time spent facing the front of the livewell; and the amount of time spent facing the side of the livewell.

Table 1. Treatments used during experiment to simulate different weather conditions and wave actions experienced by largemouth bass and walleye during a live-release angling tournament. Treatments were performed in the order listed in the table using a 6 m pontoon boat, and each treatment lasted for approximately 30 min. Eight fish were videotaped for 1 min during each treatment, and videotapes were analysed for behavioural responses to the various treatments

Treatment	Description
Initial	Boat was parked at dock, and fish remained in livewell without any motion of boat, but boat motor was running
Side (rocking)	Boat was rhythmically rocked from port to starboard obtaining an angle of approximately 15–20° from horizontal
Slow (driving)	Boat was driven around the lake at approximately 15 km h^{-1} – average wave height was approximately 0.25 m
Fast (driving)	Boat was driven around the lake at approximately 25 km h^{-1} – average wave height was approximately 0.25 m
Chop	Boat was driven around the lake at approximately 25 km h^{-1} – average wave height was approximately 0.5 m
Boat wake	Boat was driven around lake at approximately 25 km h^{-1} through the wake of another boat. As a result, fish were violently and unpredictably rocked both side-to-side and front-to-back in a random fashion
Front (rocking)	Boat was rhythmically rocked from bow to stern obtaining an angle of approximately 15–20° from horizontal
End	Boat was parked at dock, and fish remained in livewell without any motion of boat, and boat motor was turned off

Statistical analyses

Differences in response variables were compared both within and across species using a two-way repeated measures ANOVA (main effects: species and treatment) followed by a Tukey HSD *post hoc* test (Sokal & Rohlf 1995). Analyses within species compared a response following a particular treatment to the initial value, and comparisons across species examined the behavioural response of both walleye and largemouth bass following a particular treatment. All statistical analyses were performed using JMP IN version 4.0 (SAS Institute, Inc.), and the level of significance (α) for all tests was 0.05. Mean values are reported ±1 SE.

Results

The opercular rate of largemouth bass did not vary significantly throughout the experiment from initial values (Fig. 1a, Table 2, Tukey HSD test, $P > 0.05$), and was significantly lower than that of walleye for four of the treatments (Fig. 1a, Table 2, Tukey HSD test, $P < 0.05$). During the entire experiment, the caudal fin rates of largemouth bass did not differ significantly from initial values (Fig. 1b, Table 2, Tukey HSD test, $P > 0.05$), while the caudal fin rates of walleye decreased following the side rocking, and slow driving treatments (Fig. 1b, Table 2, Tukey HSD test, $P < 0.05$). For all treatments except initial, walleye did not spend any time above the middle of the livewell (Fig. 1c, Table 2, Tukey HSD test, $P > 0.05$), and spent significantly less time below the livewell midline than largemouth bass following two different treatments (Fig. 1c, Table 2, Tukey HSD test, $P < 0.05$).

Regardless of the treatment, the number of interactions between walleye did not differ significantly from initial levels (Fig. 2a, Table 2, Tukey HSD test, $P > 0.05$). The number of interactions performed by largemouth bass were greater than those of walleye for all treatments in the experiment, but differences were statistically significant only for the chop treatment (Fig. 2a, Table 2, Tukey HSD test). Additionally, largemouth bass spent significantly more time swimming than walleye (Fig. 2b, Table 2), although the amount of time largemouth bass spent swimming decreased relative to initial values following the front treatment (Fig. 2b, Table 2, Tukey HSD test, $P < 0.05$). Several treatments during the experiment caused a statistically significant increase in the turn rate of largemouth bass (Fig. 2c, Table 2, Tukey HSD test, $P < 0.05$). The turn rate of walleye, however, did not vary from initial levels (Fig. 2c, Table 2, Tukey HSD test, $P > 0.05$), and was significantly lower than

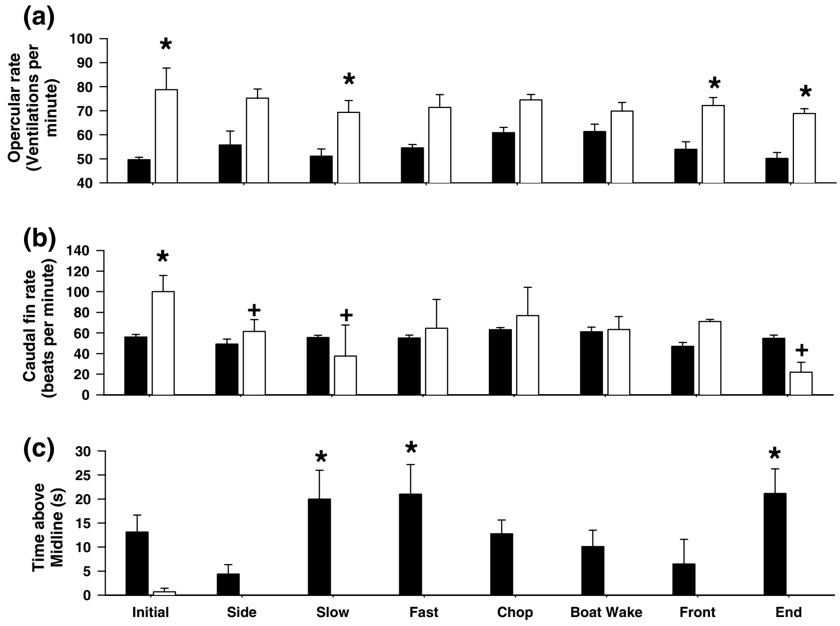

Figure 1. Effects of different treatments on the opercular rate (a), caudal fin rate (b) and time spent above the midline (c) for largemouth bass (filled bars) and walleye (open bars) contained in a livewell. Descriptions of the various treatments are given in Table 1. An asterisk (*) denotes significant behavioural differences between bass and walleye at a particular treatment, and a plus sign (+) denotes significant difference in a parameter from the Initial measurement within a species (Tukey HSD *post hoc* test). Error bars show ±1 SE.

Table 2. Two-way repeated measures analysis of variance for behaviour of largemouth bass and walleye during livewell confinement. Descriptions of the treatments used during the experiment are given in Table 1

Response Variable	Source	SS	d.f.	*F*	*P*-value
Opercular rate	Species	7242.2	1	102.9	0.01
	Treatment	654.7	7	1.3	0.2
	Species × treatment	711.0	7	1.4	0.2
	Individual	83.4	2	0.6	0.6
	Error	5630.2	80		
Caudal fin rate	Species	343.6	1	1.0	0.4
	Treatment	14902.9	7	6.4	< 0.0001
	Species × treatment	11709.4	7	5.0	0.0001
	Individual	23800.9	2	35.6	< 0.0001
	Error	21407.1	64		
Time above midline	Species	5648.9	1	70.5	0.01
	Treatment	1122.5	7	2.0	0.06
	Species × treatment	1127.8	7	2.0	0.06
	Individual	681.4	2	4.3	0.02
	Error	8255.7	103		
Interactions	Species	95.2	1	64.5	0.02
	Treatment	12.3	7	1.2	0.3
	Species × treatment	17.0	7	1.6	0.1
	Individual	5.5	2	1.9	0.2
	Error	155.0	105		
Time spent swimming	Species	5235.4	1	87.0	0.01
	Treatment	1699.3	7	4.0	0.0006
	Species × treatment	1861.9	7	4.4	0.0002
	Individual	570.7	2	4.7	0.01
	Error	6440.7	107		
Turning rate	Species	1721.4	1	180.1	0.006
	Treatment	269.2	7	4.0	0.0006
	Species × treatment	441.7	7	6.6	< 0.0001
	Individual	0.0	2	0.0	1.0
	Error	1032.4	108		
Pectoral fin rate	Species	1227.3	1	1.6	0.3
	Treatment	7916.0	7	1.5	0.2
	Species × treatment	6140.9	7	1.2	0.3
	Individual	14024.3	2	9.3	0.0002
	Error	65465.4	87		
Time facing front	Species	105.1	1	0.2	0.7
	Treatment	3541.7	7	1.1	0.3
	Species × treatment	3846.6	7	1.2	0.3
	Individual	1266.1	2	1.4	0.2
	Error	48493.5	110		
Time facing side	Species	537.2	1	1.3	0.4
	Treatment	3833.2	7	1.3	0.2
	Species × treatment	4171.3	7	1.4	0.2
	Individual	1403.8	2	1.7	0.2
	Error	43081.3	106		

that of largemouth bass for all treatments except side and front rocking (Fig. 2c, Table 2, Tukey HSD test, $P < 0.05$). For the final three response variables (pectoral fin rate, amount of time facing the front of the livewell and amount of time spent time facing the side of the livewell), there were no significant differences either within or between species during the experiment. As a result, data were not visualised, but the results of the repeated measures ANOVA models are given in Table 2.

Discussion

Live release competitive angling events constitute a large global industry. Although most fish are released alive following these events, mortality has been

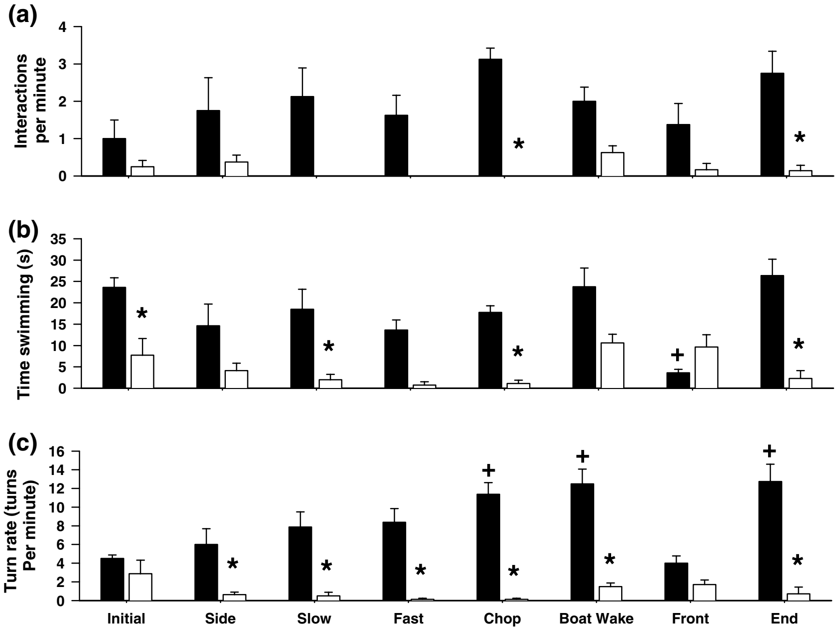

Figure 2. Effects of different treatments on the number of interactions (a), amount of time spent swimming (b) and the turn rate (c) for largemouth bass (filled bars) and walleye (open bars) contained in a livewell. Descriptions of the various treatments are given in Table 1. An asterisk (*) denotes significant behavioural differences between bass and walleye at a particular treatment, and a plus sign (+) denotes significant difference in a parameter from the Initial measurement within a species (Tukey HSD *post hoc* test). Error bars show ±1 SE.

reported following some tournaments (Goeman 1991; Wilde 1998), suggesting that tournaments have the potential to impact negatively on fish populations. While many studies suggested that the retention of fish in a livewell may contribute to tournament-observed mortality (Goeman 1991; Hartley & Moring 1993; Kwak & Henry 1995), this study is the first to document behaviour in a livewell of two fish species commonly targeted in North America, and the first to infer how physical disturbance during confinement can influence observed mortality.

During the rhythmic rocking treatments, (either bow-stern rocking or port-starboard rocking), the amount of time largemouth bass spent swimming decreased relative to initial levels, and their turn rates and caudal fin rates remained at low initial values. In addition, the amount of time largemouth bass spent above the midline of the livewell was lowest during these two treatments, although differences from initial values were not statistically significant. Furthermore, anecdotal observation indicated that during these treatments largemouth bass worked to adjust their orientation and face into the direction of the physical movement of the water. By reducing activity level and orienting themselves to face into the direction of wave action, largemouth bass may reduce the amount of energy expended during violent movements, and rely on their pectoral fins to stop their forward movement (Alexander 1967), generate forward thrust (Gibb, Jayne & Lauder 1994) and counteract their movement in the water. As a result, largemouth bass essentially work to remain motionless in the livewell and stay free of contact with the sides of the livewell during rhythmic rocking treatments.

During treatments such as chop, boat wake and fast driving, largemouth bass were more active than during the other rocking treatments such as side or slow driving. During the non-rocking treatments, the direction of physical disturbance from the water was unpredictable and irregular because of the variation in wave size encountered by the boat, and largemouth bass were disturbed in a random fashion. During these periods, largemouth bass adjusted their position often as they attempted to face into the direction of water disturbance, evident from elevated turn rates and interaction rates. Upon touching either the side of the livewell or another fish, or following a change in the direction of water disturbance, largemouth bass would quickly change direction, attempting to either move away from the object they touched or re-orient into the direction of disturbance. Because of repeated movements of fish during these treatments, differences in time facing the front of the livewell, and time spent facing the side of the livewell did not differ significantly from initial levels. As a result, during the non-rocking treatments, the turn rates and interactions of largemouth bass were elevated relative to initial levels as largemouth bass expended energy to move and orient themselves better to face the direction of disturbance.

For almost all treatments, walleye had significantly fewer interactions, spent significantly less time swimming, had lower turn rates, and had fewer interactions than largemouth bass. Additionally, during some treatments, the caudal fin rates of walleye decreased relative to initial values, and anecdotal observation revealed that they did not adjust their orientation to face into the disturbance and align themselves to face parallel to the direction of the physical movement of the water (i.e. walleye did not face the side of the livewell when the boat was being rocked from side to side). As a result, rather than working to adjust their orientation and use their pectoral fins to control their positions, violent movements of the boat resulted in walleye repeatedly striking the side of the livewell.

The results may help explain many previous studies of mortality in live release angling tournaments. Both Fielder & Johnson (1994) and Goeman (1991) suggested that walleye mortality at tournaments may increase with adverse weather conditions. This may be partially because of the high basal metabolic rate of walleye in livewells (as indicated by high opercular rates relative to largemouth bass), but also an apparent increase in physical damage during violent livewell conditions. Because walleye do not orient to face into the disturbance, coming in contact with the side of the livewell can increase physical damage. Contact with the side of the livewell may increase the likelihood of either ocular lesions (McLaughlin, Grizzle & Whitely 1997) or dermal lesions (Steeger, Grizzle, Weathers & Newman 1994). Contact can also remove the mucous layer that protects fish from colonisation by foreign organisms and possesses anti-fungal properties (Tiffney 1939). In contrast, largemouth bass settle to the bottom of the livewell during adverse conditions, orient to face the disturbance, and may be less affected by adverse wave conditions and livewell confinement than walleye.

Livewell design may have the potential to play a role in reducing stress and maximising survival in tournament-caught largemouth bass and walleye. For some fish caught during angling tournaments, the period of livewell confinement may exceed 7 h duration and represents the longest period of the tournament-related disturbance for these fish (Carmichael, Tomasso, Simco & Davis 1984; Plumb *et al.* 1988; Goeman 1991; Hartley & Moring 1993; Kwak & Henry 1995). At present, however, the design of livewells (i.e. shape, placement, location, size) varies between boat manufacturers, and does not appear to be based on scientific studies. Factors such as livewell shape, volume and position within the boat, wave height and fish density may all influence the behaviour of retained fish, and future studies should investigate how some or all of these factors can translate into physiological disturbances or mortality of retained fish. Future studies should probably also attempt to control for the effects of confinement time on the behaviour of retained fish. Over time, results of future livewell studies should be combined to improve livewell design to minimise disturbances in fish. For example, in an effort to minimise water movement during transportation, Winkler (1987) used a series of in-tank baffles during hauling of mosquitofish (*Gambusia* spp.), and found that the presence of baffles helped reduce stress levels of transported fish. Similarly, boat manufacturers may wish to design different livewells depending on the species of fish to be retained. Livewell design for walleyes, for example, may be better wider rather than deeper because walleye appear to spend most of their time on bottom rather than swimming and adjusting their position.

Wave action and boat operating strategies influenced the behaviour of largemouth bass and walleye being held in livewells. These results may partially explain the higher mortality observed during at least some angling events that are held during rough water conditions. Wave-induced disturbance is energetically costly to fish, and may delay their recovery from other disturbances such as angling. Future research on the effects of wave action on fish are encouraged, together with livewell studies, to provide information on weather and wave conditions, and facilitate data syntheses.

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