Physiological Impacts of Catch-and-Release Angling Practices on Largemouth Bass and Smallmouth Bass

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Abstract.—We conducted a series of experiments to assess the real-time physiological and behavioral responses of largemouth bass *Micropterus salmoides* and smallmouth bass *M. dolomieu* to different angling related stressors and then monitored their recovery using both cardiac output devices and locomotory activity telemetry. We also review our current understanding of the effects of catch-and-release angling on black bass and provide direction for future research. Collectively our data suggest that all angling elicits a stress response, however, the magnitude of this response is determined by the degree of exhaustion and varies with water temperature. Our results also suggest that air exposure, especially following exhaustive exercise, places an additional stress on fish that increases the time needed for recovery and likely the probability of death. Simulated tournament conditions revealed that metabolic rates of captured fish increase with live-well densities greater than one individual, placing a greater demand on live-well oxygen conditions. The repeated handling of fish during tournament angling, including culling, the addition of fish or other live-well disturbances, and the final tournament weigh-in, which adds an additional several minutes of air exposure, further adds to already heightened stress levels. When these cumulative stressors do not result in death, the resultant energetic disruptions clearly have negative impacts not only on the short term health and condition of the fish, but also most likely on its biological fitness, i.e., its lifetime reproductive success. We also show that following angling, nest-guarding male bass face a reduction in their locomotory activity that may reduce their ability to successfully defend the nest. Although most concerns about catch-and-release angling occur at the population and community level, our assessment of various angling, handling and retention practices identifies ways to minimize the effects of angling upon individual fish, and to ensure that these effects do not manifest themselves as problems at the population level.

Introduction

When the first black bass *Micropterus* spp. symposium was convened in 1975, catch-and-release angling was not widely accepted and rarely practiced. In fact, only one of the 59 papers published in "Black Bass Biology and Management" dealt with catch-and-release issues (see Clepper 1975). In 1972, acting in response to increasing public pressure and concerns for the sustainability of bass populations, the Bass Anglers Sportsmen's Society (B.A.S.S.) began experimenting with techniques that would

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facilitate the live release of black bass from tournaments (Shupp 1978). Although B.A.S.S. had been involved in competitive angling events for some time, the live release of fish had not been emphasized. Some fish were returned to the water, but many of those fish died shortly thereafter. Fish that were moribund upon weigh-in often were donated to food collection organizations for dissemination to needy individuals (Holbrook 1975). Regulations mandating the release of numerous fish species, particularly black bass, have increased since the formal inception of catch-and-release angling in 1954 (Barnhart 1989). Even voluntary catch-and-release angling has increased substantially (Quinn 1996). For management agencies to encourage or mandate catch-and-release angling, it is expected that a large proportion of these fish will survive with no measurable impact on fitness either at the individual or the population level (Cooke et al., 2002).

Research programs directed towards elucidating the biological effects of black bass catch-and-release angling mirror the increase in concern for the live release of fish by the public and fisheries managers. Scientists and managers have made great advances since the mid 1970s in understanding what factors associated with catch-and-release angling practices contribute to injury, stress, and mortality. In addition to numerous articles in the primary literature and government technical reports, two catch-and-release symposia include a substantial number of bass-oriented research findings (Barnhart and Roelofs 1977, 1989). By identifying and understanding the factors associated with hooking injury and mortality (Muoneke and Childress 1994; Wilde 1998), fisheries managers, outdoor media, competitive angling groups and conservation organizations have been able to alter angling practices to increase fish survival following catch-and-release.

Many organizers of competitive angling events record the number of fish that are dead at weigh-in (initial mortality). This measure often underestimates total mortality because delayed mortality can be substantial in some cases. In fact, a recent synthesis (Wilde 1998) has shown that initial mortality is not correlated with delayed mortality. Unfortunately, the use of mortality as the sole endpoint to assess the effectiveness of catch-and-release strategies is inadequate; we need to consider sublethal impacts, as well (Cooke et al., 2002).

Although some information exists on how angling related stress may induce mortality (Wood et al. 1983), few studies have focused on what sublethal stress means to the organism, especially in relation to long-term individual fitness (Maltby 1999; Cooke et al., 2002). To date, most focus has concerned population level effects, but individual effects can also be important (Maltby 1999). Even though many ethical issues surround recreational angling, especially as it relates to catch-and-release and competitive angling events, animal welfare issues have largely been ignored (Balon 2000). There is increasing pressure not only to justify the use of catch-and-release angling, but also to eliminate it on the basis that angling for reasons other than consumption are cruel and inhumane (de Leeuw 1996; Chipeniuk 1997; Balon 2000). Fisheries scientists must work towards a more comprehensive understanding of catch-and-release angling, including the ecological risks and ethical concerns associated with this practice. In this paper, we summarize how catch-and-release angling affects largemouth bass *M. salmoides* and smallmouth bass *M. dolomieu* by synthesizing existing literature and presenting new data from our laboratory. Furthermore we outline what we believe are the highest priority research directions in this area.

Hooking Mortality

An assumption required for the catch-and-release strategy to be both sustainable and ethical is that the majority of the fish released in fact survive (Muoneke and Childress 1994). Hooking mortality is usually divided into immediate / initial and delayed mortality. Immediate / initial mortality is defined as death during or following capture, but prior to release. Delayed mortality represents death from catch-and-release angling at some point after the released fish swims away; this mortality is usually determined by holding fish in cages, pens, or hatchery ponds. Total hooking mortality is the sum of initial and delayed mortality minus the cross-product of initial and delayed mortality (see Wilde et al. 2001). There have been two major syntheses that have aided our understanding of hooking mortality. First, Muoneke and Childress (1994) reviewed studies on hooking mortality for both marine and freshwater fish and suggested that total hooking mortality estimates above 20 percent should generally be considered unacceptably high. The conclusions of these authors regarding black bass were often drawn from hooking mortality estimates generated from competitive angling events. Second, Wilde (1998) conducted a meta-analysis on tournament associated mortality in black bass and found that it was important to measure both initial and delayed mortality to determine total mor-

Table 1. Summary of smallmouth bass hooking mortality rates. Days represents the duration of the holding period, with Imm representing immediate hooking mortality. Habitat is classified as reservoir (Res), lake (Lake), raceway (Raceway), tank (Tank), ponds (Ponds), or river (Riv). Exhaust and Air exp. are the amount of time that the fish was angled (degree of exhaustion) and air exposure duration, respectively. Comp. event is a classification of whether the data was collected at a competitive angling event.

TL (mm)	*N*	Days	Temp (°C)	Habitat	Mortality rate (%)	Tackle	Exhaust (sec)	Air exp.	Comp. event	Reference
NA	458	NA	9–22	Lake-Res	0–8.5	Lure	Var	Var	Yes	Bennett et al. 1989
160–320	36	7	14–18	Raceway	11	Bait	5–20	Minimal	No	Clapp and Clark 1989
160–320	34	7	14–18	Raceway	0	Lure	5–20	Minimal	No	Clapp and Clark 1989
303–322	66	2	9–23	Lake	3	Lure	< 20	30–120	No	Cooke and Hogle 2000
Adult	43	2	15–16	Lake	0	Bait	< 30	< 60	No	Dunmall et al. 2001
Adult	195	2	15–16	Lake	0	Lure	< 30	< 60	No	Dunmall et al. 2001
Adult	164	2	18–26	Lake	5	Lure	Var	Var	Yes	Hartley and Moring 1995
Adult	428	Imm	18–26	Lake	7	Lure	Var	Var	Yes	Hartley and Moring 1995
300–419	61	2	23	Lake	4.9	Lure	Var	Var	Yes	Jackson and Willis 1991
< 300	634	20	17–22	Res	4.2–47.3	Bait	Var	Var	No	Weidlein 1989

Table 2. Summary of largemouth bass hooking mortality rates. Days represents the duration of the holding period, with Imm representing immediate hooking mortality. Habitat is classified as reservoir (Res), lake (Lake), raceway (Raceway), tank (Tank), ponds (Ponds), or river (Riv). Exhaust and Air exp. are the amount of time that the fish was angled (degree of exhaustion) and air exposure duration, respectively. Comp. event is a classification of whether the data was collected at a competitive angling event.

TL (mm)	*N*	Days	Temp (°C)	Habitat	Mortality rate (%)	Tackle	Exhaust (sec)	Air exp.	Comp. event	Reference
NA	60	14	22–29	Lake-Pond	7.1	Lure	Var	Var	Yes	Archer and Loyacano 1975
NA	261	Imm	24	Lake	16.1	Lure	Var	Var	Yes	Archer and Loyacano 1975
NA	140	14	20–28	Lake-Tank	4.5	Lure	Var	Var	Yes	Archer and Loyacano 1975
NA	1106	1-2	18–25	Lake-Res	3–16	Lure	Var	Var	Yes	Bennett et al. 1989
NA	230	2	18–26	Lake	3	Lure	Var	Var	Yes	Hartley and Moring 1995
NA	813	Imm	18–26	Lake	2	Lure	Var	Var	Yes	Hartley and Moring 1995
> 150	NA	2.5–2.9	< 25	Res	0	NA	Var	Var	No	Hightower and Gilbert 1984
> 150	NA	2.5–2.9	25–30	Res	0–20	NA	Var	Var	No	Hightower and Gilbert 1984
300–557	1767	Imm	14–26	Lake	0.9–2	Lure	Var	Var	Yes	Kwak and Henry 1995
300–557	496	3	14–26	Lake	2.7–4	Lure	Var	Var	Yes	Kwak and Henry 1995
> 305	60	6	NA	Lake	15	Lure	Var	Var	Yes	May 1973
229–508	20	1–23	NA	Lake	25	Lure	Exh	Var	No	May 1973
< 305	1422	Imm	NA	Lake	15.6	Lure	Var	Var	Yes	May 1973
> 457	380	Imm	24–33	Res	29	Lure	Var	Var	Yes	Meals and Miranda 1994
305–356	4032	Imm	24–33	Res	9	Lure	Var	Var	Yes	Meals and Miranda 1994
NA	1147	31	NA	Riv	17.2	Lure	Var	Var	Yes	Moody 1975
> 356	240	3	31–33	Res	13–33	Lure/Bait	Var	Var	No	Myers and Poarch, in press
Adult	NA	Imm	Var	Res	8.2	Lure	Var	Var	Yes	Neal and Lopez-Clayton 2001
Adult	NA	4	Var	Res	42.8	Lure	Var	Var	Yes	Neal and Lopez-Clayton 2001
140–264	285	60	9–15	Tanks	11.2	Hook	30	Var	No	Pelzman 1978
NA	1413	Imm	NA	Res	24.6	Lure	Var	Var	Yes	Plumb et al. 1975
215–535	90	1	11–33	Ponds	1.1	Lure	Var	Var	No	Plumb et al. 1988
215–535	172	1	11–33	Ponds	6.3	Lure	Var	Var	Yes	Plumb et al. 1988
< 305	1351	6	NA	Ponds	0–76.9	Lure/Bait	Var	Var	No	Rutledge and Pritchard 1977
> 305	3283	< 1	12–30	Lake	14	Lure	Var	Var	Yes	Schramm et al. 1985
> 305	NA	14–21	17–30	Lake	26.7	Lure	Var	Var	Yes	Schramm et al. 1987
300–515	200	28	NA	Pond	2–22	Lure	Var	Var	Yes	Seidensticker 1975
300–515	4220	Imm	68–70	Res	23–24	Lure	Var	Var	Yes	Seidensticker 1975
300–572	3129	28	NA	Res	32	Lure	Var	Var	Yes	Seidensticker 1977
> 305	> 933	Imm	27–34	Res	2.4–18	Lure	Var	Var	Yes	Weathers and Newman 1997
> 305	933	4	27–34	Res	1.3–50	Lure	Var	Var	Yes	Weathers and Newman 1997
Adult	1863	19	12–22	Res	14.3	Lure	Var	Var	Yes	Welborn and Barkley 1974

tality accurately. We have added data from recent studies to the summaries compiled by Muoneke and Childress (1994) for smallmouth bass (Table 1) and largemouth bass (Table 2). Three studies that did not differentiate which black bass species were used (statewide analyses by Lee (1989) and Ostrand et al. (1999). and two studies involving other congenerics (i.e., Guadelupe bass *M. treculi*, Muoneke [1991]; spotted bass *M. punctulatus*, Muoneke [1992]) were not included. Several emergent patterns are evident in the tabular data summaries. Delayed mortality rates were highly variable for both species, 0–76.9 percent for largemouth bass and 0–47.3 percent for smallmouth bass. Many of the handling parameters in these studies, however, were poorly described; e.g., few studies provided information on the degree of exhaustion or air exposure for angled fish. Because both of these factors are important influences on the degree of physiological disturbance, we urge future studies to incorporate such information into methodologies to facilitate synthetic analyses. One tool that may help to minimize mortality and injury in black bass capture on live bait are circle hooks. Circle hooks have been advocated as effective tools for minimizing deep hooking in fish. Resent research conducted by our laboratories suggest that circle hooks baited with minnows hook largemouth bass less deeply than conventional hooks, however, circle hooks have 50 percent lower capture efficiency than conventional hooks (Cooke et al., in review). Additional research on novel terminal tackle tackle will occur opportunistically as tackle manufacturers continue to develop and market gear for anglers.

Angling Disturbance

Researchers have examined the physiological responses of fish to exercise using a variety of different approaches. Metabolic disturbance associated with angling may take as long as 8–12 hours to achieve full recovery (Keiffer 2000), although cardiovascular and respiratory parameters may recover more rapidly (1–3 hours). An increase in the duration of angling (exercise) increases the physiological disturbance, requiring an extended recovery period. Anglers typically adopt one of two quite different angling strategies; land the fish quickly to reduce the chance of losing the fish during the fight, or angle the fish to exhaustion so that the risk of losing the fish at the time of landing is reduced. Competitive events in which landing nets are prohibited often require anglers to adopt the latter tactic, resulting in fish being completely exhausted prior to landing. There is, however, a tradeoff with regards to exhaustion. Fish that are landed prior to being fully fatigued are more active when removed from the water, often increasing handling times or injuries to the fish.

Two major factors have repeatedly been identified as influencing the magnitude of stress experienced by the individual fish upon being hooked; water temperature and the degree of exhaustion (Gustaveson et al. 1991; Keiffer 2000). The typical pattern of cardiac disturbance experienced by a hooked black bass involves a bradycardia and arythmia during the period of severe exercise while the fish is angled followed by a period of heightened cardiac output (tachycardia) after the fish is released and begins to recover. From real-time traces of physiological disturbance for several cardiac parameters, it is possible to estimate the time required for metabolic rate to return to preangling levels (Figure 1). During recovery, following exercise, cardiac output typically doubled over resting values and that increase was almost entirely due to an increase in heart rate (Figure 1). Stroke volume either increased very little (20%), did not change, or actually decreased during recovery. Recovery times increased with longer angling durations, but were not affected in a consistent manner by temperature (Figure 2). The intensity of the cardiac response did not increase with angling duration, indicating that the cardiac response is maximized even with brief angling duration. As a result, more severe angling stress is not counterbalanced by a greater cardiac response, but rather by requiring a longer recovery period. We have examined the real-time cardiac disturbance and recovery in smallmouth bass at different water temperatures and for different degrees of exhaustion using angling simulations in respirometers (see Schreer et al. 2001). Results across temperatures indicate that fish may require shorter recoveries (for certain conditions and cardiac parameters) when held at 16°C as compared to 12 and 20°C (Figure 2).

Air Exposure

Upon capture, fish are exposed to air for varying lengths of time while anglers remove hooks, weigh and measure them, and / or hold fish for photographic opportunities. Several major physiological changes occur during air exposure, including the physical collapse of the gill lamellae and subsequent adhesion of the gill filaments (Boutilier 1990). Ferguson and Tufts (1992) examined air exposure effects on exhaustively exercised rainbow trout

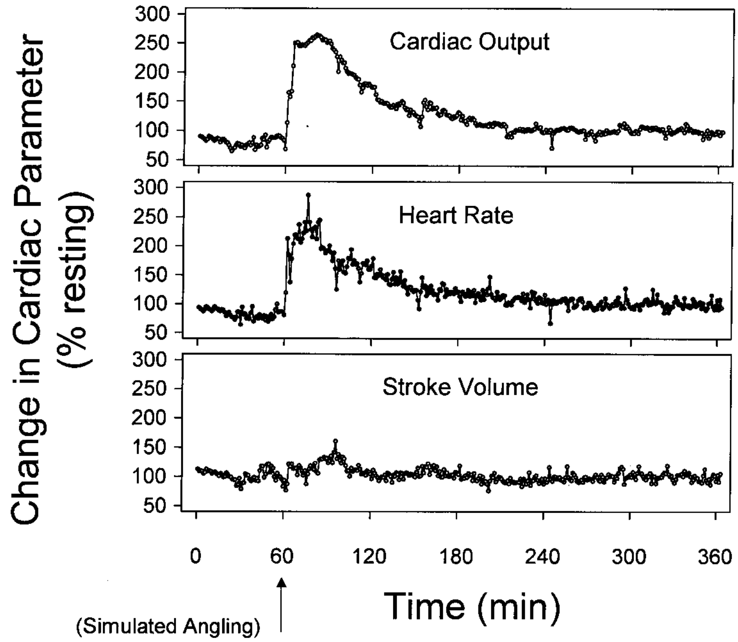

Figure 1. Typical cardiac disturbance and recovery pattern for single smallmouth bass following a simulated angling event. Doppler flow probes were affixed around the ventral aorta of fish as described by Schreer et al. (2001). In this case, the fish was held in 16°C water and exercised until exhaustion in a blazka respirometer. The time required for recovery can be assessed by examining when cardiac parameters return to preangling levels (*x*-axis). The *y*-axis represents the maginitude of disturbance (100% = predirsturbance levels) for cardiac output (upper panel), heart rate (middle panel), and stroke volume (lower panel).

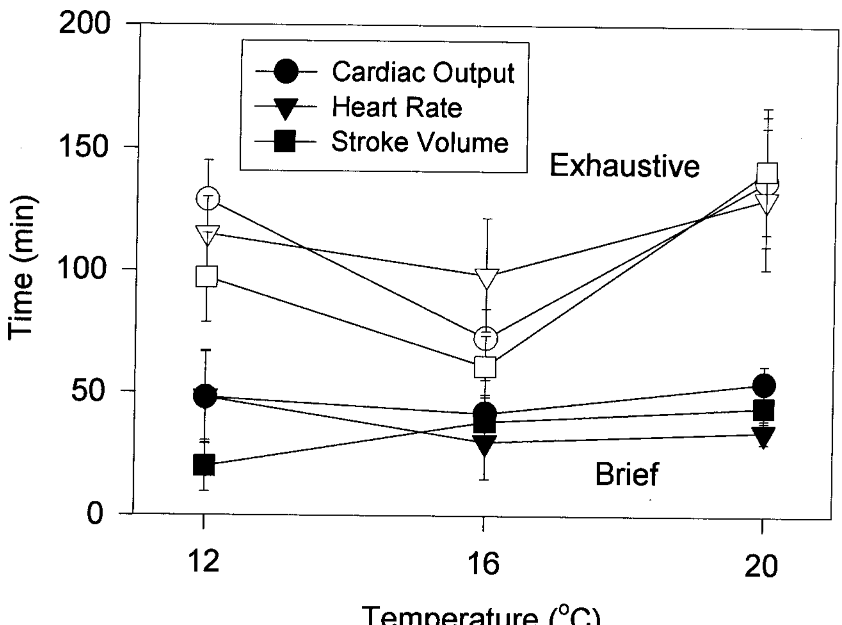

Figure 2. Angling simulation for smallmouth bass at three temperatures and two levels of exhaustion (N = 33). Adult smallmouth bass from Lake Erie were held in 12, 16, or 20°C water for two weeks prior to surgery. Doppler flow probes were affixed around the ventral aorta of fish as described by Schreer et al. (2001). Fish were exercised either briefly (~20 seconds) or until exhaustion (~150 seconds) in a respirometer. The time for each of three cardiac parameters (cardiac output, heart rate, stroke volume) to return to predisturbance levels was plotted to the nearest minute

Oncorhynchus mykiss. Short-term mortality (12 hours) was negligible for control fish and low for fish that were exercised to exhaustion but not exposed to air (12%). When fish were exposed to air for either 30 or 60 seconds following exhaustive exercise, mortality increased to 38 and 72 percent, respectively. During the air exposure period, although carbon dioxide was retained, oxygen tension and the ratio of hemoglobin to oxygen both fell by over 80 percent. Furthermore, those fish exposed to air experienced a larger initial extracellular acidosis than fish only exercised. More recently, Cooke et al. (2001) subjected rock bass *Ambloplites rupestris* to either 30 or 180 seconds of air exposure. When fish were exposed to air for longer periods, all cardiac parameters measured (cardiac output, stroke volume, heart rate) took significantly longer to return to basal levels. Based on a limited number of studies, it appears that air exposure, especially following exhaustive angling, can be extremely harmful for some species.

To assess the effects of air exposure on black bass, adult smallmouth bass from Lake Erie were held at 12°C in 100, l-individual holding tanks and then exposed to one of four treatments. One group of fish was chased for 60 seconds and then permitted to recover. The three other groups were also chased for 60 seconds and were then held out of the water in a wetted mesh sling for 30, 120, or 240 seconds. Basal cardiac values for smallmouth bass at 12°C were calculated to be: cardiac output = 19.7 ± 2.1 mL min^{-1} kg^{-1}, heart rate = 26.7 ± 3.6 bpm, and stroke volume = 0.78 ± 0.06 mL kg^{-1} (Schreer et al. 2001).

Cardiac recovery following the 60 seconds chase period was most rapid for fish that were angled and immediately released, intermediate for those exposed to angling and held for 30 or 120 seconds in air, and longest for those exposed to angling and held for 240 seconds in air (Figure 3). Cardiac output recovery times differed significantly among treatments (analysis of variance [ANOVA]

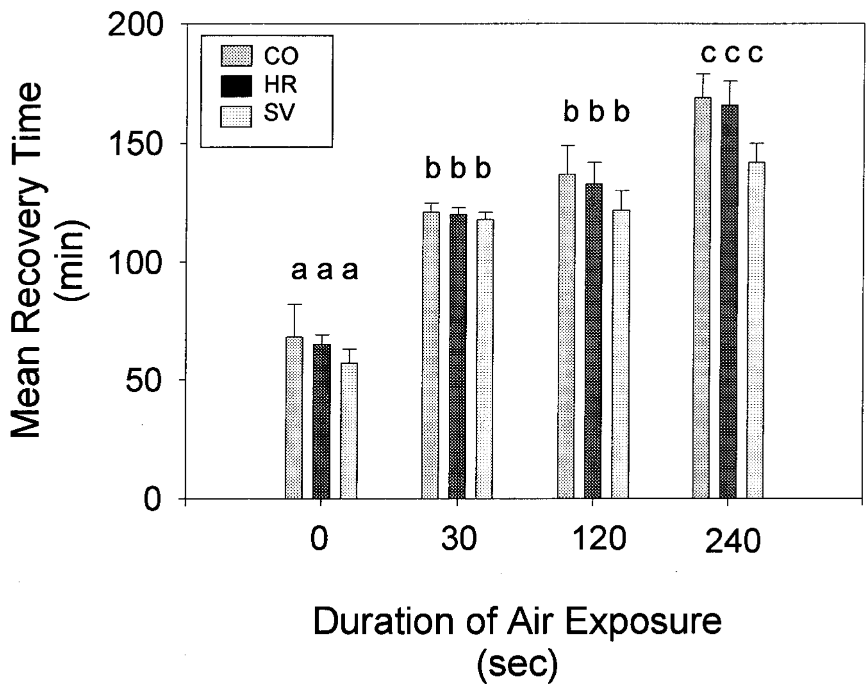

Figure 3. Air exposure effects on smallmouth bass cardiac recovery. Adult smallmouth bass from Lake Erie were held in 12°C water for two weeks prior to surgery. Doppler flow probes were affixed around the ventral aorta of fish as described by Schreer et al. (2001). After surgery fish were held individually in 100l tanks for 24 hours prior to experimentation. Fish were exposed to one of four treatments: 60 seconds of chasing (N = 4), 60 seconds of chasing and 30 seconds of air exposure (N = 4), 60 seconds chasing and 120 seconds air exposure (N = 4), and 60 seconds chasing and 240 seconds air exposure (N = 4). Chasing simulated the exercise experienced by fish during angling. Fish were held in a wetted sling during air exposure. The time for each of three cardiac parameters (cardiac output [CO], heart rate [HR], and stroke volume [SV]) to return to predisturbance levels was plotted to the nearest minute (Cooke et al. 2001). Dissimilar letters indicate statistically significant differences ($P < 0.05$). Bars represent means ± 1 SE.

F = 34.51, P < 0.001), except for fish angled and exposed to air for 30 seconds and 120 seconds. Cardiac output for fish angled and immediately released recovered most rapidly and those exposed to angling and 240 seconds of air took the longest to return to basal levels. Heart rate recovery times also differed significantly among treatments (ANOVA F = 25.19, P < 0.001), except for fish angled and exposed to air for 30 seconds and 120 seconds (P > 0.05). Heart rate for fish angled and immediately released recovered most rapidly, and those exposed to angling and 240 seconds of air took the longest to return to basal levels. Stroke volume recovery times showed similar patterns, and differed significantly between all treatments (ANOVA F = 36.30, P < 0.001) except for fish angled and exposed to air for 30 seconds and 120 seconds. Stroke volume for fish just angled recovered most rapidly and those exposed to angling and 240 seconds of air took the longest to return to basal levels.

These results highlight the importance of minimizing air exposure for angled fish. Cardiac disturbance increased with increasing duration of air exposure. The fact that even exposures of up to 240 seconds caused no short-term mortalities indicates that smallmouth bass may be more resilient to long duration air exposures than rainbow trout (Ferguson and Tufts 1992); however, the sub-lethal effects of such exposures, including assessments of permanent tissue damage, require further study. After most competitive angling events, the normal practice involves holding fish out of the water for display to a crowd of onlookers. At low to intermediate temperatures this may not kill fish, but it likely prolongs recovery and impairs the ability of those fish to deal with other stressful events.

Retention: stringers, fish baskets, and keep nets

Catch-and-release angling for black bass sometimes involves the retention of fish over a period of time (usually hours) prior to release. Professional anglers often hold fish in aerated live-wells, whereas recreational anglers commonly use more affordable, readily available, and convenient methods, including stringers, fish baskets and keep nets. Many anglers fish solely for recreation and practice strict catch-and-release or some degree of selective harvest (Quinn 1996), releasing bass only after some time to cull fish of certain sizes for harvest, to determine if enough fish can be caught to merit harvest, or to hold fish for photographs or to show to other individuals. Some management agencies have limited the use of retention gear, and most professional competitive angling organizers also have prohibited their use, requiring contestant anglers to use aerated live-wells. Previous research has investigated the effects of keep net retention on the growth, survival (Raat et al. 1997) and stress response and recovery (Pottinger 1997, 1998) of various cyprinid species. Additional research has also focused on the changes in water quality in keep nets during retention (Pottinger 1997).

We examined injury and short term mortality of 313 adult smallmouth bass on Lake Erie over a range of water temperatures (10.6–21.8°C; Cooke and Hogle 2000). Lure-caught fish were retained by one of six methods for three to five hours; metal stringer through lip, metal stringer through gill arch, cord through lip, cord through gill arch, wire fish basket, and nylon keepnet. Fish were then transferred to a holding pen, and their survival over a 48 h period was estimated relative to control fish. Control fish exhibited very little mortality (3%) and had negligible physical injury across all sampling periods (Figure 4). Most (95%) fish retained experienced some form of injury or mortality. In general, injury and mortality increased with increasing water temperatures, particularly when water temperatures exceeded 21.8°C. Survival and injury varied among retention gears, but gill damage or fungal lesions associated with abraision, and the cumulative stress of angling and retention appeared to be the precursor to most deaths. These results suggest that even at low temperatures, significant injury can occur in response to retention. At higher temperatures, these injuries often result in death. We suggest that the use of these gears should be restricted for only those fish that will be harvested and should not be used for temporarily retaining fish prior to release.

Retention: live-wells

Competitive angling events for black bass are very popular in North America. A survey conducted by the American Fisheries Society's Competitive Fishing Committee over a decade ago estimated the number of inland and marine events to be 31,000 annually, of which 73 percent targeted black bass (Schramm et al. 1991a). The majority of these events are catch-and-release and, therefore, require that fish be held in live-wells for extended periods of time until the fish are brought to the weigh-in (Holbrook 1975).

Even though many studies examined initial and delayed hooking mortality following competitive angling events (Schramm et al. 1985; Schramm et al. 1987; Weathers and Newman 1997), very few of them have investigated the physiological effects of live-well confinement, and what measures can be adopted to ameliorate those effects. Stress-induced physiological events alter the capacity of fish to perform various functions (Schreck 1990). If they are stressed, upon release fish may be unable to maintain position in a current, obtain food resources, or return to the site of capture. The increasing popularity of competitive angling and concern for its biological effects (Schramm et al. 1991b) has spurred recent research into the effects of retaining black bass in live-wells (Plumb et al. 1988; Hartley and Moring 1993; Steeger et al. 1994), as well as other tournament procedures that may alter survival (Weathers and Newman 1997).

Below we present results of studies designed to examine the behavior and physiology of fish during live-well retention. Behavioral experiments were all conducted using EMG locomotory activity transmitters. Detail on their function and implantation can be found in Cooke et al. (2000, 2001). Physiologi-

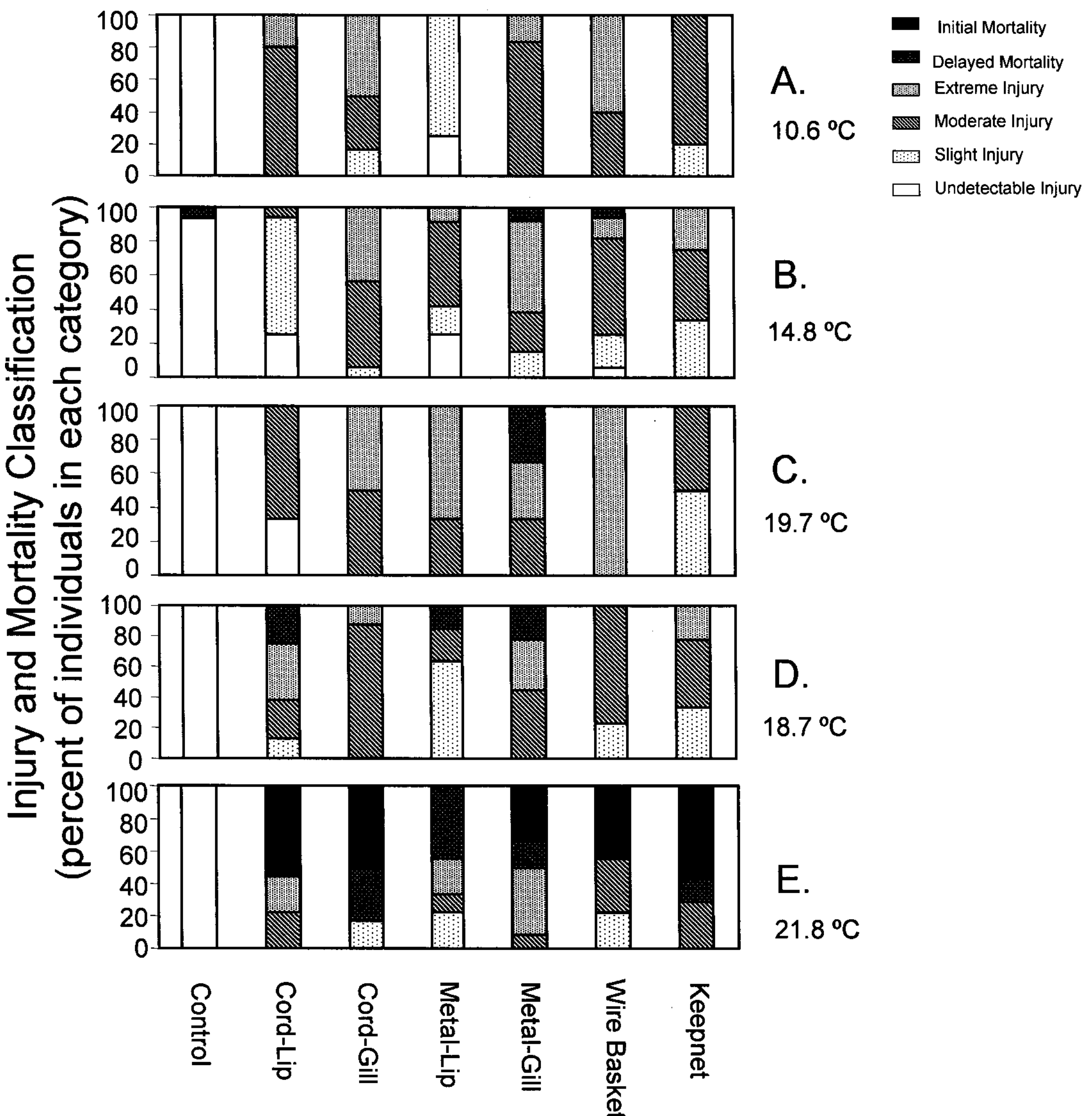

Figure 4. Effects of different retention gear types on injury and mortality of smallmouth bass. Detailed descriptions of the treatments are presented in Cooke and Hogle (2000). Corresponding water temperatures for each of the five sampling periods are located in the panels.

cal assessments were conducted using Doppler flow probes to assess cardiac responses (cardiac output, heart rate, stroke volume) to different retention conditions. Detail on cardiac output measurement can be found in Schreer et al. (2001). All live-well experiments were conducted at water temperatures of 25 ± 1°C using adult smallmouth bass in 75 l simulated live-wells. Basal cardiac values for this water temperature are: cardiac output = 41.1 ± 2.6 mL min^{-1} kg^{-1}, heart rate = 58.1 ± 1.4 bpm, and stroke volume = 0.71 ± 0.04 mL kg^{-1}.

Water quality parameters (water temperature and dissolved oxygen) in live-wells consistently have been deemed important influences on mortality (Carmichael et al. 1994b; see review by Muoneke and Childress 1994). Meals and Miranda (1994) studied prerelease mortality at major fishing tournaments on Sardis Reservoir, Mississippi and found that mortality increased with water temperature and mean number of fish per boat. In contrast, Schramm et al. (1985) concluded that largemouth bass mortality during tournaments depended more on poor practices by some anglers than on live-well density. Schramm and Heidinger (1988) established a set of guidelines for the biomass of largemouth bass that may be held in a given volume of water at a given temperature, based on the assumption that an increased weight of largemouth bass places an increased demand on available oxygen, as has been demonstrated for tournament caught walleye *Stizostedium vitreum* (Goeman 1991) and black bass (Hartley and Moring 1993).

Results indicate that as the number of smallmouth bass in a live-well increases beyond one individual, metabolic rates fail to return to preangling levels during six hours of live-well confinement. When angled and placed alone in a 75-L live-well, operated on continuous flow-through, a single

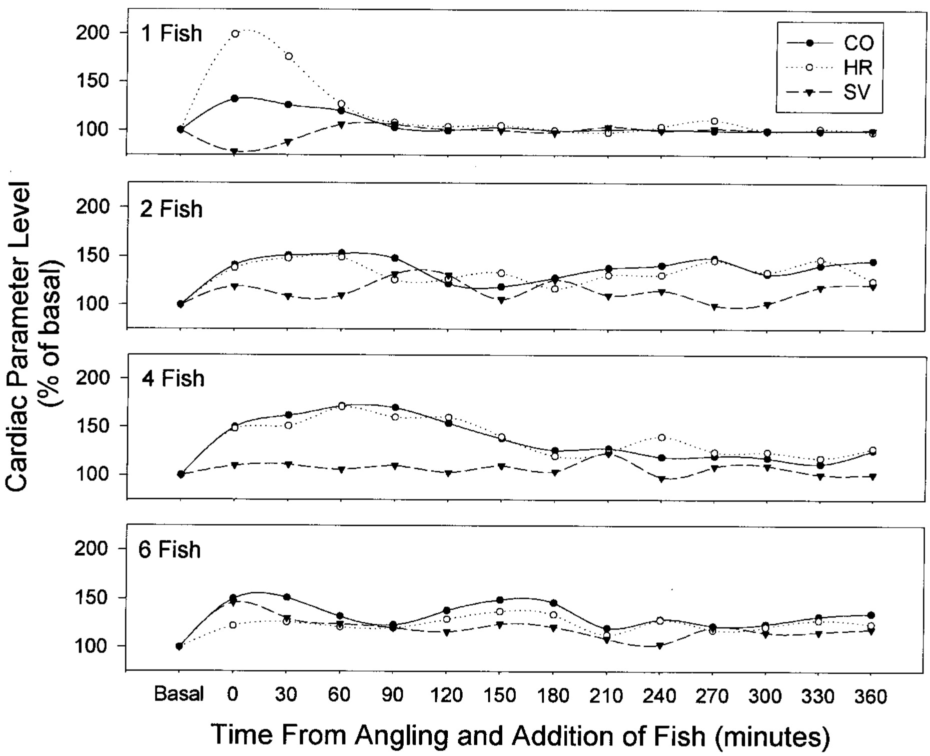

Figure 5. Cardiac disturbance of smallmouth bass during live-well confinement. Adult smallmouth bass captured from Lake Erie were held in a mobile field laboratory at a water temperature of (25°C) for one week prior to surgery. Doppler flow probes were affixed around the ventral aorta of fish as described by Schreer et al. (2001). After surgery fish were held individually in 75 L tanks for 24 hours prior to experimentation. Fish were exposed to one of four densities (1 [*N* = 5], 2 [*N* = 6], 4 [*N* = 5], or 6 [*N* = 5]) of conspecifics. In all cases, one of the fish in the live-wells was monitored with a Doppler flow probe. Fish were chased to simulate angling (time 0) and then either zero, one, three, or five fish were added. Cardiac output, heart rate, and stroke volume are expressed as a percentage of preangling levels (i.e., 100% of resting represents preangling levels) and was monitored for at six hours.

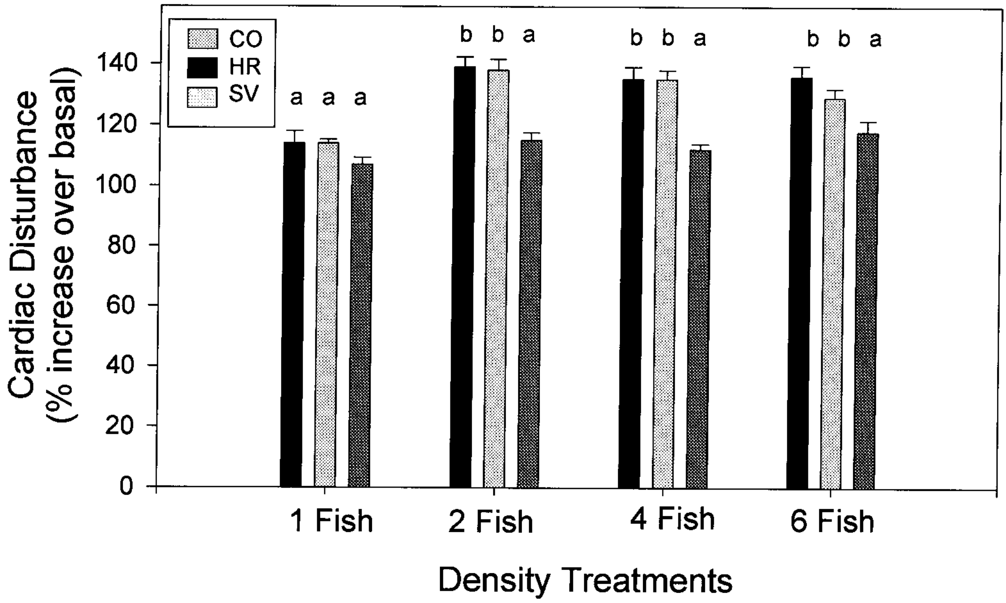

Figure 6. Mean cardiac disturbance of smallmouth bass exposed to one, two , four, or six fish per 75 L live-well for each of three cardiac parameters (cardiac output [CO], heart rate [HR], and stroke volume [SV]) over the entire retention period. See Figure 5 for additional detail including sample size. Dissimilar letters indicate statistically significant differences ($P < 0.05$). Bars represent means ± 1 SE.

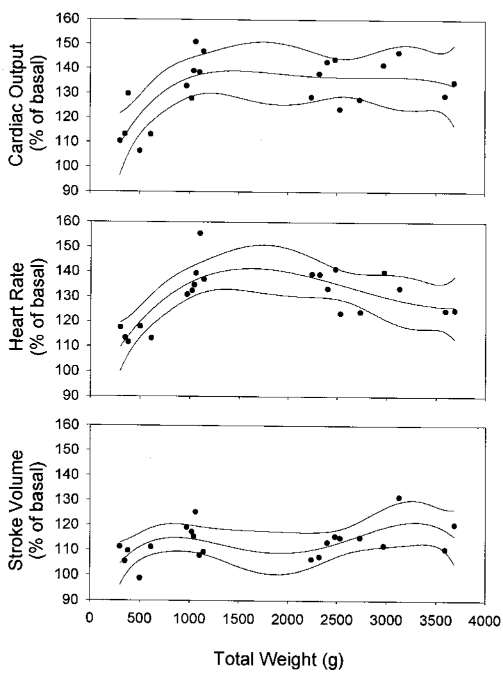

Figure 7. Relationship between cardiac parameters and live-well biomass for smallmouth bass. Fourth order regression lines and 95 percent confidence intervals are noted on the figure. See Figures 5 and 6 for additional detail on the experimental conditions.

smallmouth bass required only approximately one hour for its recovery of cardiac parameters. When two, four, or six fish were placed in the live-well, all fish had heightened and variable cardiac activity that never showed any consistent patterns of recovery during six hours of live-well retention, as observed for the single fish (Figure 5).

Cardiac output (ANOVA $F = 8.810$; $P = < 0.001$) and heart rate (ANOVA $F = 11.544$; $P < 0.001$) differed significantly among density treatments but stroke volume did not (ANOVA $F = 2.790$; $P = 0.072$; Figure 6). Mean increases in cardiac output were significantly lower for one fish than for treatments with more than one fish (Figure 6). There were no differences between mean cardiac output for two, four, or six fish treatments (All $P > 0.05$). Mean increases in heart rate were significantly lower for one fish ($P < 0.05$) than for treatments with more than one fish. There were no differences between mean heart rate for two, four, or six) fish treatments (All $P > 0.05$). Mean increases in stroke volume were similar for one, two, four, and six fish treatments (All $P > 0.05$; Figure 6).

The total biomass of fish in the live-well was related to cardiac disturbance (both cardiac output and heart rate) by fourth order regressions indicating what appears to be a break point with biomass at ~ 1,000 g (Figure 7). Although stroke vol-

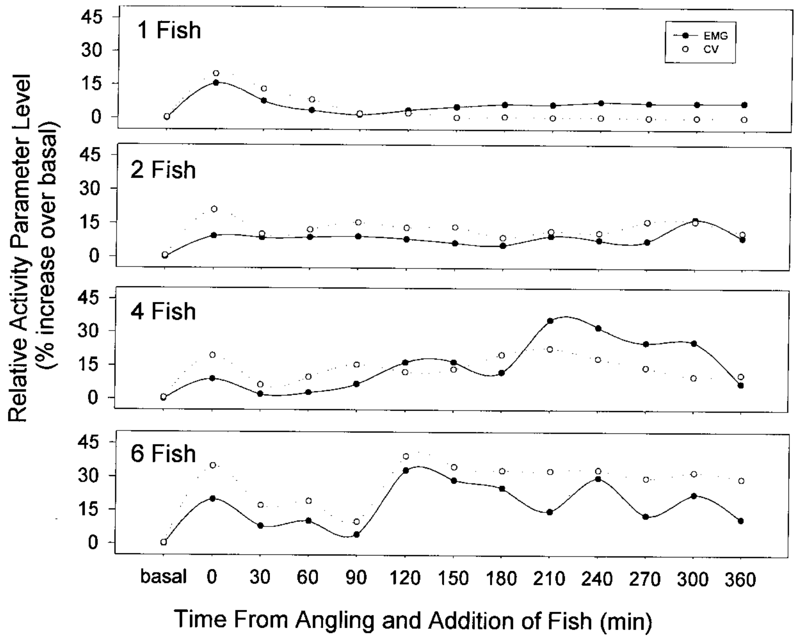

Figure 8. Locomotory activity of smallmouth bass during live-well confinement. Adult smallmouth bass captured from Lake Erie were held in a mobile field laboratory at a water temperature of (25°C) for one week prior to surgery. Fish were implanted with activity transmitters (electromyogram) to monitor levels of locomotory activity in live-wells. Surgical procedures are similar to Cooke et al. (2000). After surgery fish were held individually in 75 L tanks for 24 hours prior to experimentation. Fish were exposed to one of four densities (1, 2, 4, or 6) of conspecifics ($N = 4$ at each density). In all cases, one of the fish in the live-wells was equipped with an EMG transmitter (see Cooke et al. 2000 for similar detail). Fish were chased to simulate angling (time 0) and then either zero, one, three, or five fish were added. Locomotory activity is expressed as a percentage of preangling levels (i.e., 100% of basal represents preangling levels) and the EMG coefficient of variation. Activity was monitored for six hours.

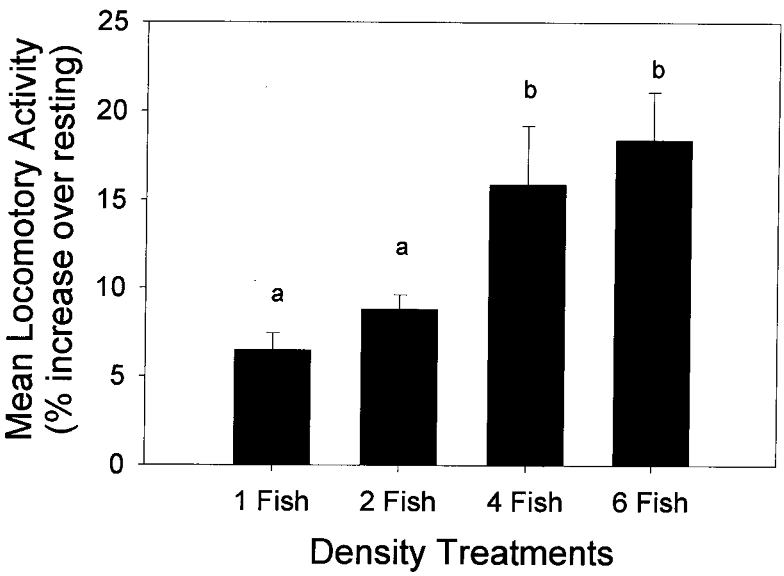

Figure 9. Mean locomotory activity of smallmouth bass exposed to one, two, four, or six fish per 75 L live-well over the entire retention period. See Figure 8 for additional detail including sample size. Dissimilar letters indicate statistically significant differences ($P < 0.05$). Bars represent means ± 1 SE.

ume also exhibits this same trend, the magnitude of the increase at ~ 1,000 g is substantially less. These data point toward the fact that biomass may influence cardiac disturbance, but it is unclear if an individual fish that weighs 1000 g would elicit the same response as five 200 g fish. To further evaluate the relationship between disturbance, recovery, and live-well density, it will be necessary to manipulate live-well size. Kwak and Henry (1995) reported that live-well capacity (15.1–189.2 L) was marginally correlated with the proportion of weak fish in the live-well at fish biomass of 81–96 g/L, indicating that larger capacity live-wells had greater proportions of weak fish. Larger size live-wells take longer to replace water following degradation, are subjected to more physical action, and fish may be more difficult to capture and remove from a larger live-well. The authors had insufficient evidence to propose live-well capacity limits, but hypothesized that intermediate sized live-wells may be optimal. For our study, the live-wells contained 75-L at 3.6–49 g/L, what we would consider intermediate and close to the standard 25 gal (~ 75-L) live-wells in many boats. Our results may have been more extreme if we in fact used larger fish.

Not only does increased fish biomass/density increase demands on available oxygen (as evidenced by increased cardiac output and heart rate), but it may also affect the activity levels of fish while being confined in a live-well. If fish are more active, they may experience additional physiological disturbance, leading to reduced survival rates. When fish were held alone, locomotory activity was above preangling levels only for a period of time similar to that seen for cardiac disturbance (Figure 8). When two, four, or six fish were held in the live-well, they were more active for the entire time, as indicated by the variable and heightened locomotory activity. Locomotory activity differed significantly at different fish densities (ANOVA, $F = 6.4221$, $P = 0.001$). Overall locomotory activity was significantly lower for one or two fish than for three or four fish (All $P < 0.05$; Figure 9). These data are the first insight into fish behavior and activity levels while they are being retained in live-wells. Additional studies that incorporate videography within the live-well may provide quantitative and qualitative insights into the specific behavioral responses to different conditions.

A number of techniques have been attempted to reduce stress (and hence maximize survival) when fish are held in live-wells, addition of water conditioners and antibacterial treatments being the most common. Previously published studies have provided contradictory conclusions into the effects of water conditioners on black bass. Plumb et al. (1988) simulated tournament conditions to examine the effects of holding largemouth bass in live-wells, with and without water conditioner and found that mortality was higher for fish held in live-wells for three to nine hours than fish released within 30 minutes of capture. They also reported that the addition of a commercially available water conditioner to the live-well may enhance survival. Unfortunately, most of these studies combined several treatments, including prophylactics, fungicides, anesthetics, and salt (i.e., Barton and Peter 1982; Carmichael et al. 1984a), which makes it difficult to separate the merits of using these products independently. However, our results indicate that for fish held individually, the use of salt and commercial conditioner more than doubled the time required for cardiac parameters to normalize during angling. A period of heightened metabolic activity resulting from the addition of the water conditioner occurred during a

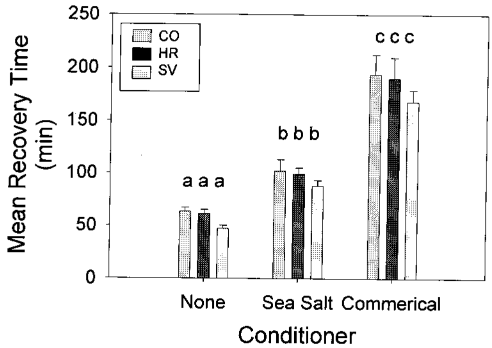

Figure 10. Effects of water conditioners on cardiac recovery times following angling. Adult smallmouth bass captured from Lake Erie were held in a mobile field laboratory at a water temperature of (25°C) for one week prior to surgery. Doppler flow probes were affixed around the ventral aorta of fish as described by Schreer et al. (2001). After surgery fish were held individually in 75 L tanks for 24 hours prior to experimentation. Fish were exposed to one of three treatments ($N = 3$ for each treatment): 60 seconds of chasing then recovery in lake water, 60 seconds of chasing and recovery in a bath of sea salt, and 60 seconds chasing followed by recovery in a commercially available water conditioner bath. Chasing simulated the exercise experienced by fish during angling. The concentrations of both conditioning agents were highest upon completion of chasing and decreased as the live-well gradually flushed with water at a rate of 2.5 L per minute. The time for cardiac parameters to return to predisturbance levels was plotted to the nearest minute.

time that fish were dealing with the recovery from exercise and an oxygen debt (the angling event). During this time oxygen consumption was heightened, leading to increased demand on live-well oxygen conditions.

We tested a variety of conditioners using cardiac disturbance as a response variable. For individual smallmouth bass angled for 30 seconds at 25°C, cardiac disturbances recovered most rapidly in fish that were provided with a continuous flow of fresh lake water and was delayed for fish in conditioned water (Figure 10). All cardiac parameters monitored recovered most quickly for control fish (~ 60 minutes), least quickly for water with commercial conditioner (0.5% Catch-and-Release Formula; ~ 180 minutes), and at intermediate rates for sea salt (0.5% NACL; ~ 100 minutes; cardiac output, ANOVA, F = 103.59, P < 0.001; heart rate, ANOVA F = 62.8324, P < 0.001; stroke volume, ANOVA, F = 75.4701, P < 0.001; Figure 10).

The use of water conditioners is perhaps better understood in aquacultural settings where such materials are commonly used during frequent handling or during transport in an attempt to ameliorate the loss of homeostatis and maximize survival (Pickering 1992). Barton and Zitzow (1995) examined the effects of salt on the recovery of juvenile walleye. They reported that the use of salt (0.5% NaCl) with walleyes did not attenuate the corticosteroid responses to handling at similar concentrations to our study. The use of salt, however, may allow the fish to recover more rapidly by eliminating the osmoregulatory imbalance often associated with acute stress. Our results were somewhat counterintuitive (i.e., delayed recovery in conditioned water) and inconsistent with these previous studies.

In competitive angling events, it has been suggested that the use of water conditioners is not required at lower temperatures, because fungal infection risk is low. Similarly, at low to intermediate

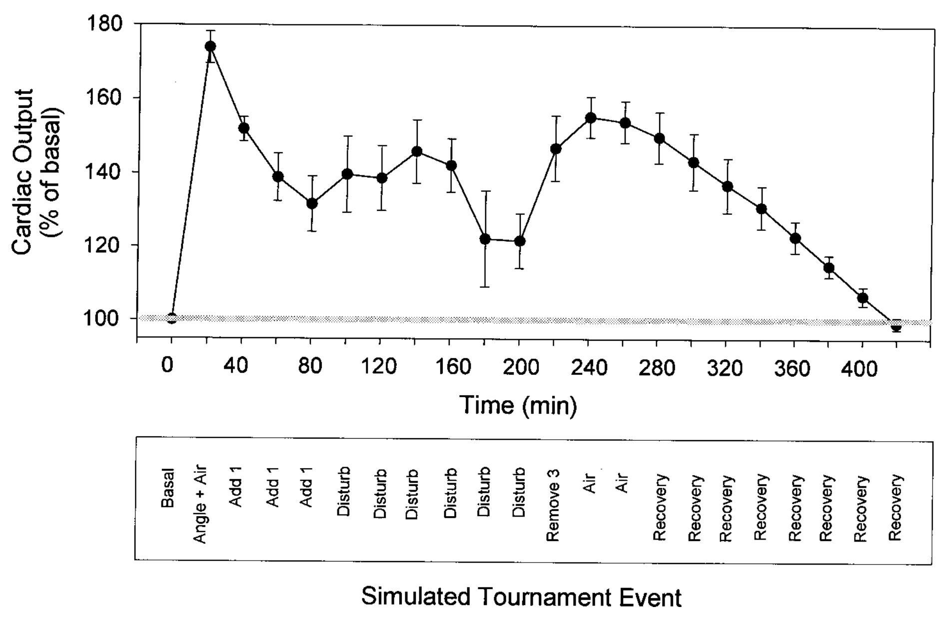

Figure 11. Effects of a simulated tournament on smallmouth bass cardiac disturbance. Adult smallmouth bass captured from Lake Erie were held in a mobile field laboratory at a water temperature of (25°C) for one week prior to surgery. Doppler flow probes were affixed around the ventral aorta of fish as described by Schreer et al. (2001). After surgery fish were held individually in 75 L tanks for 24 hours prior to experimentation. After fish had recovery from surgery, fish were chased to simulate angling and then held out of the water to simulate capture and hook removal. Fish were then returned to the live-well. At 20 minutes intervals additional individual fish were added until a density of four fish per 75 L was achieved. Next, fish in the live-well were disturbed at 20-minute intervals. This involved a combination of manual disturbances to simulate culling of the fish that did not have Doppler flow probes affixed. Following six disturbances, the three additional fish were removed, returning the density to one fish per 75 L. That fish was exposed to air twice (twenty minutes apart) to simulate removal from live-well and then the weigh-in. Fish were then returned to the live-well to recover undisturbed. Cardiac output levels were recorded before, during and after the disturbances (N = 6 fish). Cardiac output is expressed as percentage of basal level. The horizontal gray line represents the resting level.

temperatures, fish recover more rapidly from angling disturbance. At higher temperatures, fish are more likely to develop fungal infections, which may have been impetus for the recommendation that water conditioners be used. At these higher temperatures, however, the recovery from the angling disturbance is slower than at lower temperatures and seems to be further delayed by the use of water conditioners. Further study is required to ascertain the physiological effects of different duration's of exposure to water conditioners. The most common uses of conditioners at present incudes: maintaining high levels of conditioner in the live-wells throughout the competitive angling event by switching to a recirculating water regime and by changing both water and replacing conditioner simultaneously at regular intervals; using water conditioners while holding fish after the weigh-in and prior to release; or by just exposing the fish to a brief (< 15 seconds) salt dip (Gilliland 1997). Because our results indicate that water conditioners delay cardiac recovery, these results need further confirmation.

Antibiotic treatments may also reduce postrelease mortality of fish held in live-wells. Although Holbrook (1975) concluded that antibiotic treatment is not a practical method for preventing or minimizing mortality of tournament-caught bass, Steeger et al. (1994) reported that tournament caught largemouth bass held for four days had significantly higher mortality rates (25.4% postrelease) than control fish (2.9% postrelease). Furthermore, 55 percent of tournament fish necropsied exhibited pathogen presence, whereas only 31 percent of control fish had pathogens. Despite the prevalence of pathogens isolated from skin lesions, the occurrence of systemic infections was low. Few other studies have been conducted to provide systematic information of the effects of bacterial diseases on tournament caught bass. Those that have been conducted have generally concluded that bacterial diseases are not an important factor in survival of tournament-caught bass as inferred from the inability of antibiotic treatments to increase survival rates (Plumb et al. 1975; Seidensticker 1975; Schramm et al. 1987). Only Welborn and Barkley (1974) and Archer and Loyacano (1975) reported improved survival rates when antibiotics were used. Taken together, these results still suggest that antibiotics do not appear to appreciably increase survival. Furthermore, the extra handling required to treat fish with antibiotics may in fact be detrimental. It is our opinion that efforts should focus on minimizing dermal disturbance during the handling of fish.

Simulated Tournament

To examine the effects of what smallmouth bass might encounter during a tournament, i.e., repeated disturbances in the live-well, we exposed fish to a simulated tournament regime. The cardiac output for individual fish that were placed in the live-wells following surgery was monitored to determine basal levels, and then assess the impacts of the simulated tournament. Fish were chased to simulate angling and then held out of the water to simulate capture and hook removal. Fish were then returned to the live-well. At 20 minute intervals additional individual fish were added until a density of four fish per 75-L was achieved. To simulate culling of fish during angling, fish in the live-well were briefly disturbed at 20 minute intervals. Following six disturbances, the three additional fish were removed, returning the density to one fish per 75-L. That fish was exposed to air twice (20-minutes apart) to simulate removal from live-well and then the weigh-in. It was then returned to the live-well and allowed to recover undisturbed.

The most extreme cardiac disturbance occurred during the initial angling event and air exposure period (simulated capture and handling), when cardiac output increased 75 percent over resting levels (Figure 11). Cardiac activity decreased over the next hour, even as additional fish were added, but it remained 20–45 percent higher than resting levels. The sequential air exposures resulted in an additional spike in cardiac output to levels up to 60 percent higher than resting. When the fish were returned to the live-well and left undisturbed, the cardiac output gradually declined, but about three hours was required for the fish to recover. For fish that were only angled and held in the live-well by themselves, recovery occurred approximately three times more rapidly (Figure 5).

We attribute the extended period of heightened cardiac output during the simulated tournament to several factors. First, fish were not able to fully recover from the initial capture and handling before an additional stressor was presented (the addition of other fish), which increased locomotory activity and maintained cardiac output above basal levels. The repeated disturbances seemed to elicit a similar cardiac response, which also resulted in increased oxygen consumption rates, as has been shown for salmonids (Davis and Schreck 1997) and for black bass (Hartley and Moring 1993). To counteract the increased oxygen consumption, Hartley and Moring (1993) recommended continuous aeration in the live-well. Second, when exposed to simu-

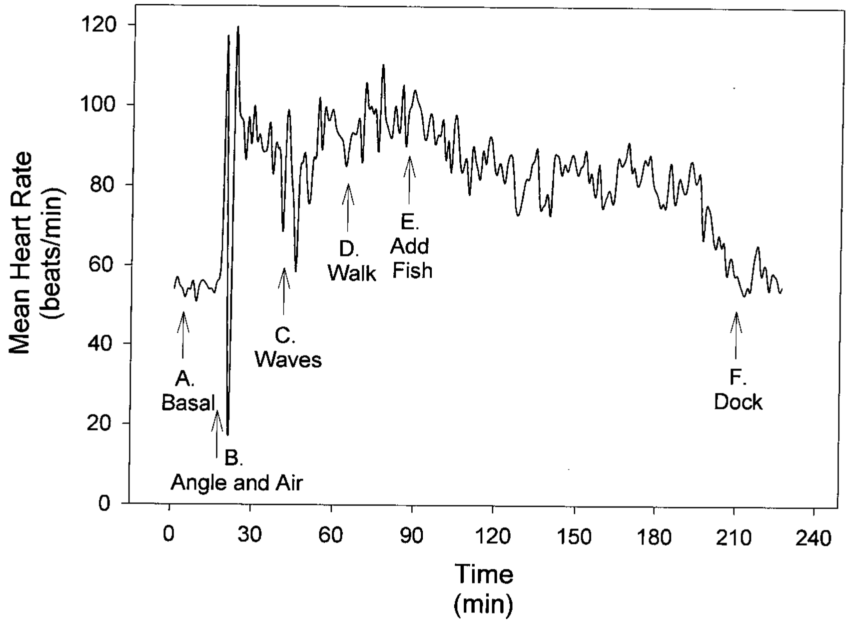

Figure 12. Patterns of heart rate from a largemouth bass (296 mm) exposed to a series of angling related disturbances. The fish was affixed with a Doppler flow probe (See Schreer et al. 2001) and permitted to recover at 26°C. First, the fish was chased until exhaustion and then exposed to air for 90 seconds. The fish was then introduced to a factory live-well in a 17 foot aluminum deep-v hull bass boat moored at a dock. The boat was then driven around slowly for 20 minutes. At this point, the boat was then driven rapidly (~ 60 km / h) through moderate waves (0.75 m height). The boat was then stopped and the two anglers aboard began to fish. During this time they walked around the boat. When the anglers walked on the deck with the live-well below, changes in heart rate were detected (audibly using the Doppler chassis). One largemouth bass was captured and added to the live-well (~ 325 mm). The anglers continued to fish for two additional hours, using only the trolling motor. No additional fish were captured and the boat and live-well containing two fish returned to the dock where it was moored and sat for 30 minutes. The live-well was operated continuously (flow through and aeration) during the retention period.

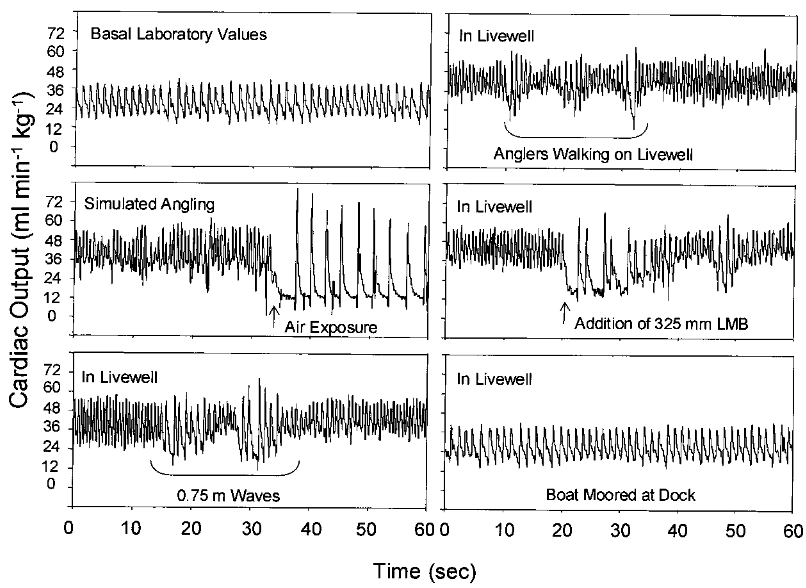

Figure 13. Patterns of cardiac activity during different angling and retention related stresses in a 296 mm largemouth bass. Detailed description of these data are provided in the caption for Figure 12. Each panel in the figure corresponds to a 60 seconds period indicated on Figure 12.

lated handling and weigh-in conditions, cardiac output again increased to levels approaching those observed during the angling disturbance, reiterating the deleterious effects of air exposure. The weigh-in stress may be particularly deleterious, because following these last air exposures fish are released. As a result, in tournament situations, fish are often in their worst condition in terms of cardiac disturbance immediately prior to release. We were unable to determine exactly which factors caused the increase in time required for cardiac output to recover following release of simulated tournament fish compared to fish that were just angled, but it is likely attributable to the cumulative effects of capture, handling, and air exposure.

We suggest too, that the conditions of our simulated tournament represent a minimal disturbance compared to actual tournament angling situations. Many tournaments have larger bag limits, leading to more fish in a live-well (generally between five and six). The duration of our simulated tournament was also shorter than many tournaments. Only 4 hours and 20 minutes elapsed between initial capture and the final release, whereas many tournaments can last up to 8 hours. In addition, the amount of air exposure experienced by our fish may have been less than typical conditions because repeated culling often occurs throughout the day when many fish are caught and removed from the live-well. Furthermore, the weigh-in procedure may take longer, with some fish being exposed to air for longer periods for photographic opportunities. Finally, the lack of movement with our stationary live-wells (as compared to ones in moving boats) may also have resulted in lower than normal stress levels. In a recent study of rainbow trout locomotory activity during truck transport, fish exhibited heightened and complex locomotory dynamics, suggesting that the wave action created by movement can also be energetically costly (Chandroo et al., in review). Goeman (1991) reported that excessive wave action in walleye tournaments did indeed increase mortality. Similar assessments for black bass competitive angling events are still lacking largely due to nonreporting of weather and wave conditions (Wilde 1998).

To address the need for conducting in situ assessments, we provide some preliminary data on the cardiac response of a largemouth bass held in a live-well (50-L) on an aluminum bass boat. We exposed a single largemouth bass to a variety of different conditions (e.g., waves, deck activity, addition of fish) and monitored cardiac responses in real time (Figure 12). First, we collected basal cardiac values during which time heart rate was remarkably consistent (Figure 13). When chased until exhaustion, the fish experienced increased and erratic heart rates (Figures 12 and 13). When exposed to air, the fish experienced a massive bradycardia (Figure 13). When introduced to the live-well the heart rate was heightened. As suggested above, waves induced marked changes in heart rate typified by arrhythmia (Figure 13). Similar responses were also observed when anglers walked on the live-well lid (Figure 13). When another largemouth bass was captured and introduced to the live-well, the heart rate of the fish we were monitoring initially decreased and then became erratic for some time thereafter (Figure 13). When the boat was moored at the dock and the other fish was removed, the heart rate eventually slowed to near preangling levels (Figures 12 and 13). Indeed, these data provide some further, albeit preliminary evidence that wave action and general boat activity (walking around) can induce changes in heart rate, indicating heightened stress that may increase oxygen demand and prolong recovery. Similar to the smallmouth bass data we presented above, the addition of an additional largemouth bass to the live-well also disturbed the fish already retained.

Our results suggest that allowing individual fish to recover in either individual or partitioned live-wells will suppress overall metabolic activity by permitting fish to recover from the oxygen debt encountered during angling. Individual retention of fish would also help to minimize the transmission of pathogens or diseases through direct contact. It would also prevent additional abrasion from either direct contact with other fish, or from the live-well (see McLaughlin et al. 1997). The logistics of such changes may be difficult, but could be easily remedied through reduced bag limits.

Angling of Nesting Fish

Black bass spawn in shallow nests in the spring, and following egg deposition the males remain alone to provide all parental care for the brood. Because they likely only forage opportunistically while defending their nest (Hinch and Collins 1991), and because parental care can be energetically costly (Hinch and Collins 1991; Mackereth 1995; Gillooly and Baylis 1999), physiological disturbances are particularly detrimental to parental male black bass. During the parental care period, which may last up to five to six weeks, males are particularly vulnerable to angling because they vigorously defend their offspring from potential brood

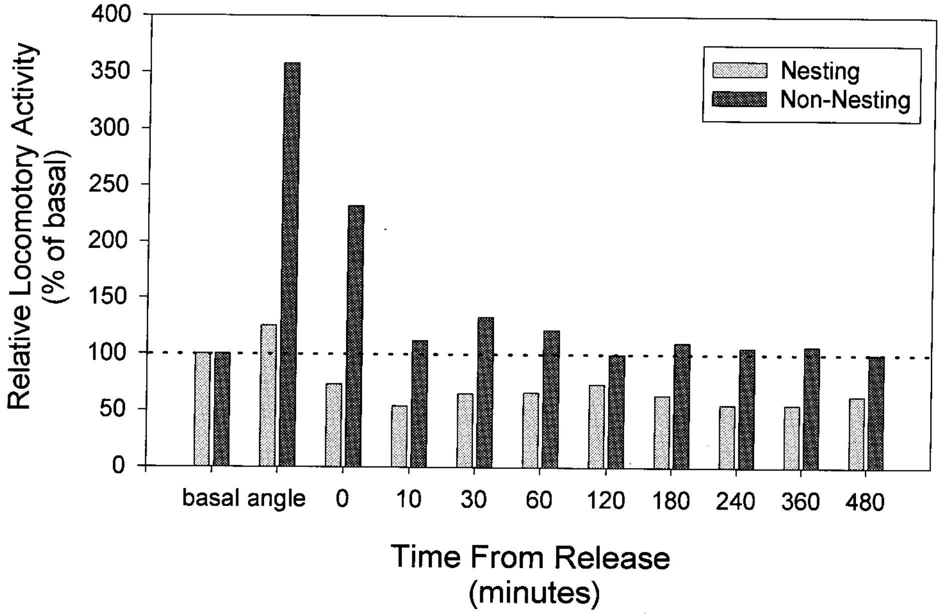

Figure 14. Activity patterns of nesting and nonnesting male largemouth bass during and following angling. Nesting (N = 4) and nonnesting (N = 2) adult largemouth bass were implanted with activity transmitters (electromyogram) to monitor levels of locomotory activity. Surgical procedures and data analysis are discussed in Cooke et al. (2000). Fish were angled for 150 seconds, held out of the water for 60 seconds, and then released. Locomotory activity is expressed as a percentage of preangling levels (i.e., 100% of basal represents preangling levels and is indicated by the dashed line).

predators (Ridgway 1988; Philipp et al. 1997). When guarding males are removed by anglers, even for short periods of time, predators such as other small centrarchids or percids may quickly consume the offspring (Neves 1975) with cumulative predation levels being proportional to the length of time the fish is absent from the nest (Keiffer et al. 1995; Philipp et al. 1997). If that male is harvested before his offspring are independent of parental care, these offspring are totally eliminated by predation.

In some northern states and several Canadian provinces, seasonal closures are used to restrict angling and/or harvest of black bass during the reproductive period (Quinn 1993). In some jurisdictions catch-and-release angling for nesting bass is permitted. In others, however, it is illegal to even attempt to angle for bass during this closed period. Compliance with such regulations has been observed to be minimal in many areas (Schneider et al. 1991; Kubacki 1992; Philipp et al. 1997), likely because anglers often assume that as long as the fish are released, they will return to the nest and raise a successful brood. Recent studies, however, indicate that the behavioral and physiological effects of exhaustive exercise, such as catch-and-release angling during the spawning period, may be stressful enough to cause abandonment of broods (Keiffer et al. 1995; Philipp et al. 1997). Even for those fish that do not abandon their nests following an angling event, it is not known how much the physiological disturbance associated with the catch-and-release angling experience might impair the ability of that fish to guard its brood effectively.

To examine the extent of this physiological disturbance, we assessed the relative energetic expenditures of nesting (n = 4) and nonnesting (n = 2) male largemouth bass exposed to staged angling events in experimental ponds. Information on fish locomotory activity was remotely collected using electromyogram transmitters (Cooke et al. 2000). During angling, nonnesting males fought with a higher intensity than nest guarding males, likely expending significantly more energy than did the nesting fish. In addition, although the locomotory activity of nonnesting fish appeared to recover as early as 2 hours post angling, the locomotory activity of nesting fish was still impaired more than 24 hours post angling (Figure 14). Overall mean activity during the 24 hours post release period was 98 percent of basal for nonnesting fish, but only 63 percent for nesting fish. Following catch-and-release angling, the reduced energetic capability of a nesting male largemouth bass, together with the brood predation incurred as a result of the temporary removal of that fish from its nest, increase the likelihood of that male abandoning his brood prematurely. The management implications of these results echo those of Keiffer et al. (1995) and Philipp et al. (1997); if captured during the nesting phase, fish should be angled for as short a duration as possible and released immediately near the nest.

Conclusions and directions for future research

It has been more than 100 years since Dr. James Henshall concluded his famous tome "Book of the Black Bass" (Henshall 1881) with the capitalized words "ALWAYS KILL YOUR FISH AS SOON AS TAKEN FROM THE WATER; AND EVER BE SATISFIED WITH A MODERATE CREEL." Henshall recognized three important points; first, removing fish from their aquatic environment is indeed stressful; second, if fish are to be harvested humanely, they should be killed rapidly; third, because bass can be over-harvested, conservation may require creel limits. Even though black bass in North America ARE the penultimate sportfish that Henshall promoted, we are still dealing with many of the same fundamental issues associated with ethics and conservation.

King's (1975) summation of the previous Black Bass Symposium had no references to the effects of catch-and-release angling. None of his "top nine" research directions captured what would in a relatively short time become one of the most pervasive practices and attitudes in bass fishing—catch-and-release. There has been a great deal of research on catch-and-release fishing over the past 25 years, but more is needed. We list below a series of topics related to black bass catch-and-release angling and provide brief summaries of what are priority areas for additional research.

Air Exposure

For an angled fish to be released, it is usually exposed to air; when captured in competitive angling events, however, fish may be exposed to air repeatedly. Although we present some of the first information on the short-term effects of air exposure on black bass, very little is known about the long-term effects of air exposure, e.g., permanent tissue damage, reduced reproductive capacity, even delayed mortality. Because there is insufficient evidence to invoke widespread management strategies that minimize air exposure for fish, anglers will continue to hold fish out of the water to show other anglers or to take photographs, a practice that is observable repeatedly in the outdoor media. It is clear that there are "points of no return" at which air exposure will be long enough to result in long-term problems or death. Research to determine these relationships is critical, and we predict that this research will have substantial implications for how such things as outdoor television shows and tournament weigh-ins are conducted.

Live-well Design, Live-well Operations, and Competitive Event Format

Many opportunities exist for conducting controlled experiments and then validating results in the field. We believe that it is important to improve the design and operation of live-wells to minimize disturbance and to facilitate recovery (i.e., tempering, oxygen infusion, conditioners). Equally important are streamlined weigh-in procedures to minimize disturbance. Alternative competitive events formats are available (See review by Wilde et al. 1998; Ostrand et al. 1999) that may help to minimize stress and maximize survival. Efforts must be made to ensure that fish are treated humanely, and that the evidence available to anglers, competitive events organizers, boat manufacturers, and fishery managers is heeded. Lay summaries are widely available that provide guidelines for fish care (Schramm and Heidinger 1988; Gilliand 1997a, b). These summaries will require frequent updates to incorporate new findings.

Simple measurements of dissolved oxygen in live-wells have provided evidence that oxygen in live-wells can be reduced to harmful levels rapidly (Hartley and Moring 1993). Some authors have suggested ways to improve live-well oxygen concentrations before they reach stressful levels (i.e., Schramm and Heidinger 1988). These guidelines, however, were based upon overly-simplistic data generated from small fish that were held individually (e.g., Moss and Scott 1961; Beamish 1970; Niimi and Beamish 1974). More effective guidelines should be developed that account for the high densities and repeated disturbances associated with tournament angling. Indeed, this document (i.e., Schramm and Heidinger 1988) has recently been revised (Gilliland et al. 2001) and incorporates oxygen requirement estimates based upon relationships developed in our laboratory between cardiac activity and oxygen consumption. Research is needed to determine how different water quality conditions, live-well design, and fish density is related to oxygen demand and ultimately, fish condition in the live-well and after release.

Trophy Fish

Some bass fisheries are managed exclusively for trophy fish, and the strategy of these programs depends heavily on there being minimal negative effects of catch-and-release angling, handling, and retention practices. Trophy size fish may have different responses to anaerobic exercise and stress than smaller individuals (Schmidt-Nielsen 1984; Goolish 1991). Recent studies have suggested that size-specific mortality trends may exist in black bass that are exposed to angling and live-well retention (Meals and Miranda 1994; Weathers and Newman 1997; Wilde 1998; Ostrand et al. 1999). Although Keiffer et al. (1996) found that anaerobic capacity and white muscle acid–base and metabolite status were independent of fish size for disturbed individuals, the small (100–125 mm) and large (290–360 mm) size classes used in their study did not approach “trophy scale,” which for largemouth bass can be lengths of 600 mm and weights of 8 kg. Research on trophy size fish seems critical in this age of bass fishing.

Intraspecific and Interspecific Variability

A problem pervasive in many aspects of biology and management of black bass is a failure to recognize intraspecific and even interspecific differences; catch-and-release studies are no exception. Smallmouth bass and largemouth bass for example have different behaviors (Miller 1975), thermal preferences and tolerances (Armour 1993; Wismer and Christie 1987), metabolic rates (Cooke and Schreer, unpublished data), different hooking mortality rates from the same waterbody (Hartley and Moring 1995), and different physiological adaptations that likely result in different responses to physiological disturbances. Fish from the same species but different geographic regions, populations, or environments (Nelson et al. 1994; Philipp and Claussen 1995) may also respond differently to exercise and handling stress. We urge that researchers differentiate between appropriate species and subspecies whenever possible.

Behavior and Physiology

Classic measures for monitoring the condition, stress levels, and physiological disturbances of fish in the field (e.g., Iwama et al. 1995; Keiffer 2000) are appropriate in some instances, but also have numerous limitations (Wydoski and Wedemeyer 1976). There is no question that additional baseline studies that ascribe different magnitudes of physiological disturbances to different angling stressors for black bass are desperately needed. In addition, novel technologies that permit the detailed simultaneous assessment of both the behavior and physiology of free-swimming fish (Lucas et al. 1993) have particular relevance to catch-and-release angling (See review by Cooke et al., 2002). These remote technologies should be used to assess long-term behavioral changes induced bycatch-and-release angling, changes that may have profound impacts on reproductive behavior and hence biological fitness of individuals. Studies that integrate conventional laboratory measures of metabolic disturbance using blood and tissue assays with field studies using remote collection of physiological and behavioral parameters of free-swimming fish will provide the most comprehensive and relevant data for the conservation and management of black bass.

Fitness

The fitness consequences of stress in general, and in particular, angling related stressors, have received very little attention from researchers. Disparate results obtained from the few existing studies create a continuing need for studies that investigate fitness impacts. There is no doubt that conducting field studies to investigate fitness impacts are extremely challenging but there are numerous different ways in which fitness could be altered by stress (see Cooke et al., 2002). Because of their parental care period and high nest site fidelity, black bass provide one of the best models for assessing potential fitness impacts. Although we know that angling has clear fitness impacts for nesting males, it is less clear what angling does to the fitness of females and nonnesting males. Knowledge of the fitness impacts of catch and release angling is an important requirement for fisheries managers when developing models of population dynamics. There is a clear opportunity for substantial future research focused on determining if there are any negative fitness impacts resulting from catch and release angling.

Last Words

Black bass are an exciting group of recreational fishes with an informed and knowledgeable group of users (i.e., tournament organizers, anglers). It is almost certain that these stakeholders will embrace small research-driven changes that minimize disturbance, facilitate recovery, and enhance survival of caught-and-released black bass. With this in mind, there is much opportunity for researchers and anglers alike to develop and test different techniques to ensure the sustainability of black bass recreational fisheries. With so many developments in black bass recreational angling since the last black bass conference, it is for certain that new needs and opportunities will arise rapidly, many of which will be directed by changes in technology. We anticipate many changes between now and the next black bass conference when a similar synthesis will surely be needed and desired.

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