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A review of the effects of catch-and-release angling on black bass, *Micropterus* spp.: implications for conservation and management of populations

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Abstract This paper summarises recent peer-reviewed literature addressing the effects of catch-and-release angling on black bass, *Micropterus* spp., to facilitate management and conservation of these fish. Traditionally, the effects of catch and release have been evaluated by measuring mortality. Many recent studies have measured sublethal effects on physiology and behaviour. There is also greater emphasis on adding more realism to sublethal catch-and-release experiments through angler involvement in research activities and by conducting studies in the field rather than in laboratory environments. Owing to these advances, there have been a number of recent findings, which are summarised here, related to air exposure, gear (e.g. circle hooks) and the weigh-in procedure that are particularly relevant to black bass anglers, tournament organisers and fishery managers. Additional research is particularly needed for: (1) population-level effects of angling for nesting fish; (2) population-level effects of tournament-associated mortality; (3) effectiveness of livewell additives for enhancing survival; (4) consequences of fish displacement in competitive events; (5) effects of weigh-in procedures and other organisational issues on fish condition and survival; and (6) reducing barotrauma.

KEYWORDS: angling, catch and release, largemouth bass, smallmouth bass, sublethal stress.

Introduction

Black bass *Micropterus* spp. are the most commonly sought sportfish in North America. Of the 28 million freshwater anglers in the USA, about 39% of them spend around 160 million days fishing for black bass each year (US Fish and Wildlife Service 2002). In addition, more than 30 000 competitive angling events occur annually on North American inland waters with about 80% of those events targeting black bass (Schramm, Armstrong, Funicelli, Green, Lee, Manns, Taubert & Waters 1991). Many recreational and tournament black bass anglers employ catch-and-release angling and typically believe it to be a positive measure for sustaining fish populations (*sensu* Quinn 1989). To maximise the effectiveness of catch and release as a management tool, fish caught and released by anglers should be subjected to minimal levels of

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stress in an effort to reduce negative effects on physiology and behaviour and to maintain the welfare status of angled fish.

Although recreational (i.e. non-tournament) and competitive (i.e. tournament) anglers practice catch and release, both subject fish to capture and handling stress; competitive angling also often subjects fish to additional stressors from livewell confinement and weighing (Fig. 1). These additional stressors may exacerbate capture-related physiological and behavioural changes in black bass (Cooke, Schreer, Wahl & Philipp 2002; Suski, Killen, Morrissey, Lund & Tufts 2003a; Suski, Killen, Cooke, Kieffer, Philipp & Tufts 2004). For example, when a recreational angler hooks a fish it is played for some variable time, landed, exposed to air, and then usually released immediately. This series of events associated with catch-and-release angling is relatively brief (< 5 min) when compared with what a fish may endure during a competitive angling event (Holbrook 1975). Anglers in competitive angling events not only play and land the fish, but they also usually hold fish in livewells, transport them to

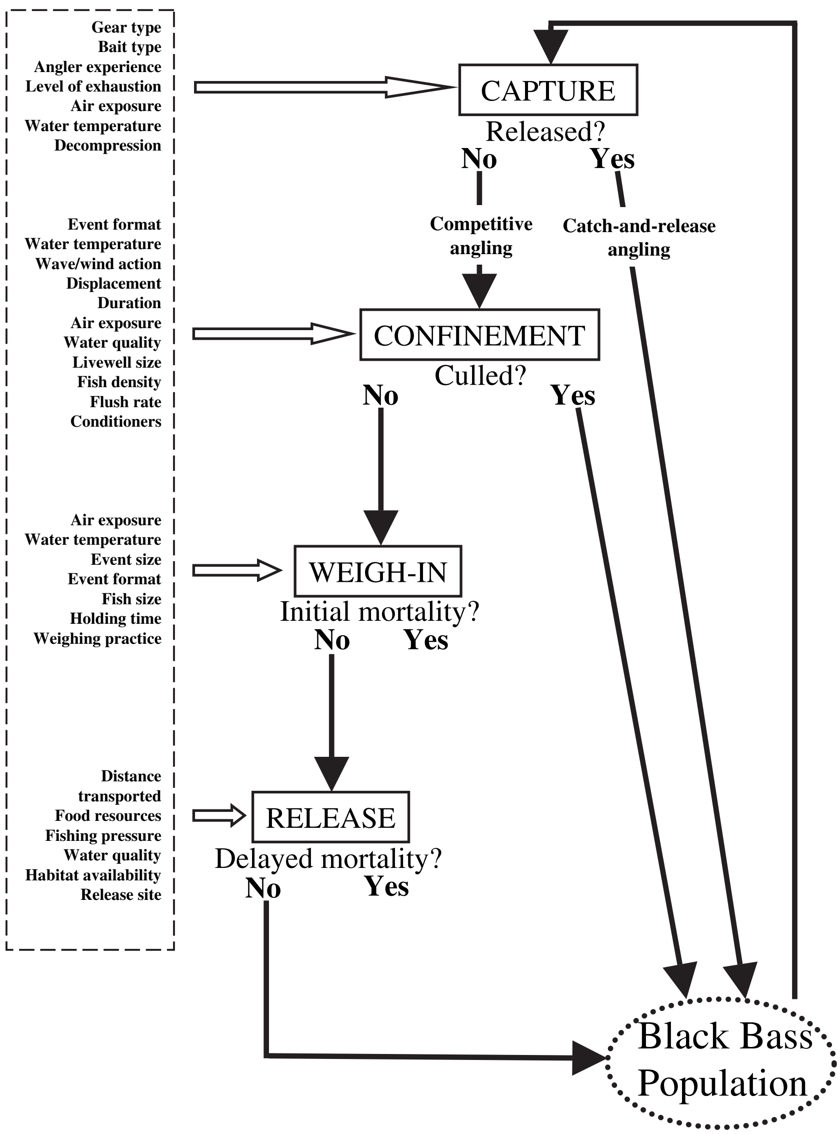

Figure 1. Conceptual model of events that occur during black bass catch-and-release and competitive angling that cause physiological response, stress or mortality among captured fish. Boxed items represent the four common activities that fish may experience during catch-and-release and competitive angling. Filled arrows are pathways for either release of a fish back into an aquatic system or to another event. If physiological response, stress or mortality occur important causal mechanisms are identified within the dash-lined box. Potential causal mechanisms related to one of the four common events are shown with non-filled arrows.

locations distant from their original capture site, and then weigh, measure and release them. These additional events add and prolong (sometimes > 8 h) stress (Cooke *et al.* 2002; Suski *et al.* 2003a, 2004). As a result, throughout competitive angling events, fish can be subjected to a number of stressors above and beyond those associated with capture and release by a recreational angler, including additional air exposure, livewell anoxia or hypoxia, crowding and displacement (Fig. 1).

Until recently, the effects of both catch-and-release and competitive angling practices on black bass physiology or behaviour had not been examined extensively. As a result of the increased interest in black bass angling, anglers and fisheries agencies are concerned with survival of fish after recreational angling and tournaments (Wilde, Riechers & Ditton 1998), as well as sublethal consequences, such as physiological stress, relocation, behavioural alterations and fitness impairments (Schramm *et al.* 1991; Wilde *et al.* 1998; Kerr & Kamke 2003). These concerns, coupled with the fact that black bass can be caught and released multiple times (Burkett, Mankin, Lewis, Childers & Philipp 1986; Quinn 1989), have led to considerable research on the effects of catch-and-release angling on black bass.

Great strides have been made towards understanding how catch-and-release practices affect black bass biology and population dynamics. The objective of this paper was to review recent peer-reviewed literature addressing these effects and to include suggestions for future research to enhance black bass management and conservation. This synthesis is intended to apply to all of the fish in the *Micropterus* genus, but the majority of the research has been conducted on the largemouth bass *Micropterus salmoides* (Lacepède) and smallmouth bass *M. dolomieu* (Lacepède).

Capture-related mortality and stress

Hooking is a primary source of capture-related injury that potentially can cause mortality in black bass. Hooking mortality has been related to terminal gear type, bait type, and level of angler experience. Circle hooks tend to hook fish less deeply than J-style hooks (Cooke, Suski, Siepker & Ostrand 2003b), resulting in a lower incidence of injury. Although circle hooks reduce the likelihood of fish being hooked in potentially lethal locations (Cooke & Suski 2004), hooking and landing efficiencies of circle hooks are lower than for conventional hook types for largemouth bass (Cooke *et al.* 2003b). Ostrand, Siepker, Cooke, Bauer & Wahl (2005) found inline circle hook designs landed fish more often (46%) than offset designs (29%) but were more difficult to remove and caused a greater incidence of bleeding. Cooke *et al.* (2003b) found lower rates of capture using offset circle hook designs compared with J-style hooks. Because mortality rates were similar for circle hooks compared with conventional J-style hooks, benefits achieved with circle hooks would have to be based on reduced injury rates and lower rates of capture (Cooke *et al.* 2003b). Based on the collective findings of Cooke *et al.* (2003b) and Ostrand *et al.* (2005), circle hooks (both inline and offset) did not appear to reduce injury or mortality to a level to justify their use given that capture efficiency is half that of conventional hook types.

In addition to gear types, the type of bait (i.e. natural vs artificial) used during angling also can influence injury and mortality. Clapp & Clark (1989) found that smallmouth bass captured on natural bait had mortality rates of 11% vs 0% for fish captured on artificial baits. Dunmall, Cooke, Schreer & McKinley (2001) found that smallmouth bass angled with natural or artificial baits had similarly low mortality (0%) and incidence of injury, although both baits were fished actively on jig heads. Myers & Poarch (2000) also found no difference in mortality between largemouth bass angled with artificial or live bait in a Texas reservoir. Overall, regulating bait types in black bass fisheries may have limited applicability because differences in mortality rates of fish captured on both natural and artificial baits generally are low.

Angler experience may also affect angling-related injury. Although there were no differences in mortality of smallmouth bass captured by novice vs experienced anglers, Dunmall *et al.* (2001) noted that experienced anglers hooked fish more deeply in the mouth and in locations other than the upper jaw.

Barotrauma or rapid depressurisation of fish (i.e. fish hooked in deep water and quickly brought to surface) may also influence survival. Feathers & Knable (1983) found simulated depressurisation of largemouth bass from all depths resulted in bloating and some haemorrhaging, whereas largemouth bass from depths greater than 18.3 m experienced severe internal haemorrhaging and greater than 40% mortality. Morrissey, Suski, Esseltine & Tufts (2005) noted swim bladder overinflation and haemorrhaging in decompressed smallmouth bass captured from depths as shallow as 5 m. Although a large percentage of smallmouth bass captured from deep lakes exhibit signs of decompression (Morrissey *et al.* 2005), artificial deflation of the swim bladder with a hypodermic needle (fizzing) can allow fish to regain neutral buoyancy quickly and does not appear to decrease survival rates when done correctly as has been documented for largemouth bass (Lee 1992; Shasteen & Sheehan 1997). Unfortunately, fizzing may not always be done correctly. Future research should, therefore, examine alternative techniques to fizzing that are less invasive. Additional research should also encompass other variables (e.g. water temperatures) that could affect black bass and their ability to deal with sublethal effects of depressurisation.

Smallmouth bass angled for longer durations require longer periods for cardiac recovery (Schreer, Cooke & McKinley 2001). The angling event also leads to depletion of tissue energy stores, accumulation of metabolites and disturbances in acid–base balance (Suski *et al.* 2004). Although most stress studies have been done in laboratory settings, the advent of 'field physiology' has enabled researchers to quantify black bass responses to angling stress in the wild (e.g. Cooke, Bunt, Ostrand, Philipp & Wahl 2004a). Research using heart rate telemetry revealed that laboratory studies do not always reflect fish responses in the wild. Fish exposed to simulated angling and allowed to recover in the laboratory had very clear cardiac recovery profiles (Cooke, Ostrand, Bunt, Schreer, Wahl & Philipp 2003a), whereas those captured with rod and reel in the wild did not exhibit clear cardiac recovery (Cooke *et al.* 2004a). Possibly, this result was because fish in the wild have to deal with other stressors or factors that affect heart rate (e.g. movement, predation threats and social interactions) that are minimised when experiments are conducted in a laboratory environment.

Reproductive success

Spring is a popular time for angling that coincides with the reproductive period of black bass. Because they provide parental care to their offspring (Coble 1975; Heidinger 1975), parental male black bass are extremely vulnerable to angling (Suski & Philipp 2004). Angling-related practices can remove male black bass from their nest for some period of time, allowing nest predation to occur (Philipp, Toline, Kubacki, Philipp & Phelan 1997). Angling during the reproductive period can increase nest abandonment rates by the parental male and, subsequently, reduce reproductive success (Philipp *et al.* 1997).

At present, most jurisdictions allow some type of angling during the black bass reproductive period (Quinn 2002). Angling practices used when capturing fish determine the rates at which parental males abandon their nests. Playing bass for longer periods of time before landing increases the time fish are away from their nests and increases the likelihood that the nest will be depredated in the absence of the male (Kieffer, Kubacki, Phelan, Philipp & Tufts 1995; Philipp *et al.* 1997). Increased time away from the nest, air exposure and brood reduction in the male's absence have all been linked to increased rates of nest abandonment in black bass (Philipp *et al.* 1997; Suski, Svec, Ludden, Phelan & Philipp 2003b). Of these, brood reduction has resulted in the highest levels of nest abandonment by parental male black bass (Suski *et al.* 2003b). Even when fish were angled, confined in a livewell for 2 h, and displaced 1 km from the nest before release (i.e. simulating some tournament conditions during the reproductive period), the reduction of the brood during this time influenced nest abandonment rates more than the angling-related stressors the fish experienced (Siepker 2005). Compared with smallmouth bass, largemouth bass take longer to return to nests once displaced and tend to abandon nests more quickly (Hanson, Cooke, Suski & Philipp 2007). Although lakewide estimates of angling effort did not explain differences in largemouth bass nest success among Michigan lakes (Wagner, Jubar & Bremigan 2006), additional research has suggested that other factors including predator burden (e.g. hyperabundant levels of round gobies *Neogobius melanostomus* (Pallas) in the Laurentian Great Lakes; Steinhart, Marschall & Stein 2004) and storms (Steinhart, Leonard, Stein & Marschall 2005) can interact with angling to decrease nest success of caught-and-released black bass.

Although the effects of angling on parental male nest abandonment have been well examined, the consequences of angling pre-spawn black bass are not well understood. Pre-spawn largemouth bass subjected to stressors commonly experienced during competitive angling events produced smaller offspring with later swim-up dates compared with controls (Ostrand, Cooke & Wahl 2004). Although this is the only study of its kind on black bass, research on other fish species (e.g. Campbell, Pottinger & Sumpter 1992, 1994; Contreras-Sanchez, Schreck, Fitzpatrick & Pereira 1998) has also revealed that stress can impair reproduction.

Growth

Investigations into the effects of stress on feeding and growth rates of fish have been limited to coldwater species of importance in aquaculture (Wedemeyer 1976; Fagerlund, McBride & Stone 1981) or saltwater species (Diodati & Richards 1996; Stockwell, Armstrong & Diodati 2002). It is currently not well understood how physical injury or stress from angling may influence feeding and growth of black bass. Because angling is stressful for bass (Cooke *et al.* 2002), and individual black bass can be recaptured multiple times throughout a season (Burkett *et al.* 1986; Quinn 1989), the potential exists for reduced growth of captured and released fish.

Of the three investigations examining growth of angled fish, two suggest that growth potential is reduced. Clapp & Clark (1989) related decreased growth to the number of hooking events in smallmouth bass. Siepker, Ostrand & Wahl (2006) observed decreased feeding by fish that were angled and, using a bioenergetic model, predicted that angled fish would exhibit less growth over a season than fish that were not angled. When these predictions were tested by angling fish from a pond, angled fish showed reduced summer growth compared with controls (Siepker *et al.* 2006). Angling practices employed, number of times a fish was captured and water temperature at the time of capture were all suggested as possible factors that can determine the degree to which growth is reduced.

In contrast, Pope & Wilde (2004) found that angling had no effect on the growth rates of largemouth bass. There were no differences in angling mortality or weight gain between caught and un-caught bass. Fish in this study were subjected only to catch-and-immediate-release angling, whereas Siepker *et al.* (2006) measured the effect of capture followed by fish handling practices typical of competitive fishing events.

Movement

Recreational anglers often catch and immediately release fish at the capture location allowing fish to easily return to their pre-capture position. In most competitive angling events, however, fish are captured, confined in a livewell and transported to a central location where all contestants weigh their catch (Holbrook 1975). After the weigh-in, anglers' catches are usually released near the weigh-in area. The biological effects of concentrating fish at the weigh-in site by anglers after competitive events have been recognised for some time by fishery managers (Schramm *et al.* 1991). In response to these concerns, several studies have investigated movements of black bass displaced during competitive angling events (reviewed in Wilde 2003).

Dispersal behaviour of black bass released after competitive angling events varies among species. Based on a review of post-tournament dispersal studies, Wilde (2003) found smallmouth bass dispersed greater distances (average 7.3 km) than largemouth bass (3.5 km) and a larger percentage of smallmouth bass (32%) returned to their capture location compared with largemouth bass (14%). Across studies, fish were observed back at their original capture locations from 4 days to 2 years after release. Dispersal did not differ between lakes and rivers (Wilde 2003). Although differences in dispersal behaviour between smallmouth bass and largemouth bass clearly exist, the basis for these differences is not known. In addition, there is little information on the consequences of concentrating fish at a release site on growth or survival. Information such as this would be useful in providing recommendations to tournament organisations on proper release of fish.

Tournament retention survival and stress

With the continued frequency of competitive angling (Kerr & Kamke 2003), interest in increasing survival of fish captured and released during these events has developed among anglers and fisheries personnel alike. Research examining survival rates among species (Hartley & Moring 1995), across a range of fish sizes (Meals & Miranda 1994; Weathers & Newman 1997), at different temperatures (Schramm, Haydt & Portier 1987), among differing tournament procedures (Weathers & Newman 1997), and with various livewell chemical conditioners (Plumb, Grizzle & Rogers 1988; Cooke *et al.* 2002) led to the development of new methods to reduce angling-related mortality of fish (e.g. reduced limits, earlier starts in warm weather, continuous water flow in livewells; Kwak & Henry 1995). Even with improved methods of fish care, only minimal decreases in mortality rates were observed through the 1980s and 1990s (Wilde 1998). Although bass caught in recent tournaments can have high survival rates (Edwards, Neumann, Jacobs & O'Donnell 2004a), other recent tournaments still exhibit mortality rates that exceed 50% (Neal & Lopez-Clayton 2001; Gilliland 2002; Wilde, Larson, Redell & Wilde 2002).

With continued high mortality rates for competitive angling events, research continues to explore potential ways to reduce mortality resulting from these events. Gilliland (2002) found addition of salt and ice improved the survival of tournament catches in Oklahoma. Cooke *et al.* (2002), however, found increased cardiac recovery times for fish held in livewells containing chemical conditioner (0.5% Catch-and-Release Formula) compared with fish held in livewells containing only lake water. Suski, Killen, Kieffer & Tufts (2006) found that cooling or warming livewell water (ambient water temperature 25 °C, test temperatures of 14, 20, and 32 °C) resulted in delayed physiological recovery. As such, the practice of adding ice to livewells may be less valuable than trying to maintain water temperatures near the levels of the lake from which fish were angled (Suski *et al.* 2006). The effectiveness of livewell additives for keeping fish alive during competitive angling events requires further investigation. Evaluations at various water temperatures and chemistries can determine if either regional or general recommendations for livewell operation and treatment can be utilised. Replication of treatments with similar biomass present in the livewell should provide insight into proper livewell management. At present, disparate information is being provided to anglers regarding whether or not to use chemical additives and chill the water.

Another important consideration during livewell retention is the need to ensure that fish are provided with adequate oxygen. Provided that livewell water quality is good, most bass will recover quickly from the stress of capture and handling while in the livewell (Furimsky, Cooke, Suski, Wang & Tufts 2003; Suski *et al.* 2004). There has been a recent trend in bass fishing tournaments for anglers to supplement livewell oxygen concentrations through the use of on-board compressed oxygen. Oxygen-supersaturated water, however, can actually cause physiological impairment (Suski *et al.* 2006). As a result, instead of infusing the livewell waters with supplemental oxygen, Suski *et al.* (2006) suggested that it is better to provide continual aeration using a livewell aerator in an effort to avoid hypoxia. These findings also emphasise the need to couple scientific research with innovations in tournament procedures to ensure that practices adopted by anglers and tournament organisers are indeed best for the fish.

Research using videography has revealed that largemouth bass are quite active while retained in livewells (Suski, Cooke, Killen, Wahl, Philipp & Tufts 2005), often interacting with other fish and trying to escape, particularly after they have recovered from the initial stress of capture (Cooke *et al.* 2002; Suski *et al.* 2004). Although currently not approved as an anaesthetic for use on food fish, and therefore illegal for use with tournament-caught bass, the low concentrations of clove oil were effective for sedating fish during retention while enabling them to maintain equilibrium, which provided physiological benefits to the fish (Cooke, Suski, Ostrand, Tufts & Wahl 2004b). The specific concentration was important because too much clove oil caused fish to lose equilibrium and struggle, whereas too little provided no benefit. Additional research should be conducted to understand better the effectiveness of livewell additives, including anaesthetics, in reducing angling-related mortality in competitive angling events.

Although proper handling of fish when confined in the livewell is vital to survival of the day's catch, additional practices may also be effectively employed during the weigh-in process to improve fish survival. Low-level swimming has been used to improve physiological recovery rates of trout (Meyer & Cook 1996; Milligan, Hooke & Johnson 2000) and post-capture survival of saltwater species (Farrell, Gallaugher, Fraser, Pike, Bowering, Hadwin, Parkhouse & Routledge 2001a; Farrell, Gallaugher & Routledge 2001b). A recent study on largemouth bass revealed that low velocity swimming (0.5 body length per second) enhanced recovery relative to static water for the first hour, but thereafter (and especially at 4 h), the swimming actually required anaerobic metabolism as evidenced by elevated levels of metabolites (Suski, Cooke & Tufts 2007). Given these findings, the usefulness of continuous low flow in promoting survival of livewell-retained largemouth bass should be examined further, with an emphasis on evaluating slower velocities.

Retention of bass in livewells coupled with angling-related stress during competitive angling events could lead to an increased prevalence of largemouth bass virus (LMBV) and ultimately increased mortality rates. A recent study examined the susceptibility of juvenile largemouth bass to mortality from LMBV infection as a result of angling and on the transmission of LMBV from infected to uninfected fish through simulated tournament retention (Grant, Inendino, Love, Philipp & Goldberg 2005). Interestingly, infected fish exposed to simulated angling did not experience higher mortality or have higher viral loads relative to those not angled. During tournament retention simulations, however, LMBV was transmitted from infected to uninfected juvenile largemouth bass through water, even when bass were not in direct contact. These findings revealed that although angling alone likely does not result in mortality of bass infected with LMBV, angling-related practices that confine infected and uninfected largemouth bass in a limited water volume may enhance viral transmission. Schramm & Davis (2006) observed extremely high rates of mortality in adult largemouth bass 5 days after simulating common tournament conditions. Although mortality was slightly lower (75%) in livewells obtaining treatment (i.e. water cooled 3 °C from ambient, 0.3% uniodised salt) compared with control livewells (85%), the authors suggested that high mortality across livewells could be a result of LMBV because all bass were collected from lakes known to be infected with the virus. Schramm, Walters, Grizzle, Beck, Hanson & Rees (2006) documented rapid transfer of LMBV from infected largemouth bass to uninfected conspecifics held during a number of competitive angling events. Prevalence of LMBV in tournament-angled bass increased as duration of time that fish were collectively held in facilities to monitor mortality increased; however, prevalence of LMBV in confined fish was reduced by altering livewell conditions (i.e. cooling water, adding salt) during the competitive events (Schramm *et al.* 2006). To remedy this problem, anglers may adopt formats that allow them to document and release their catch without retaining them in a livewell with other angled bass, especially in waters where LMBV has been documented (Grant *et al.* 2005; Schramm *et al.* 2006). Additional research on the immunological consequences of catch-and-release angling and handling practices is needed.

Population-level effects

Most research on the effects of catch-and-release angling on black bass has been at the individual-fish level, with very few studies addressing population-level concerns. By modelling bass populations, Allen, Rogers, Myers & Bivin (2004) showed tournament-related mortality had little effect on the population when recreational harvest rates exceeded tournament catch, but tournaments could potentially reduce the numbers of adult fish in a population when tournament catches exceeded harvest and mortality rates were high. Edwards, Neumann, Jacobs & O'Donnell (2004b) predicted that tournaments had a low impact on largemouth and smallmouth bass populations in Connecticut lakes when average tournament mortality rates ranged from 2.4% to 8.4% and about 26 tournaments per year were fished on each lake. Kwak & Henry (1995) also suggested negligible population-level effects based on angling-related mortality (4.7%) occurring as a result of 11 competitive events on Lake Minnetonka. Hayes, Taylor & Schramm (1995) modelled population dynamics of largemouth bass and predicted that competitive angling had minimal effects on the number of bass in a population, but individual and population growth rates were important in determining the level of fishing that was sustainable. Further investigations into the effects of competitive angling on bass populations are warranted, especially in systems with high levels of exploitation or high numbers of competitive angling events. Future simulations should also include variable recruitment rates in the models, as recent investigations were based on constant recruitment levels (Hayes *et al.* 1995; Allen *et al.* 2004).

The effect of angling on reproductive success of black bass is another topic largely limited to studies examining only individual-level effects. Although several studies document angling-induced increases in nest abandonment of individual parental male bass (Kieffer *et al.* 1995; Philipp *et al.* 1997; Siepker 2005), they only suggest the potential negative population-level effects of increased levels of nest abandonment by angled males. Ridgway & Shuter (1997), however, used an individual-based model to indicate that the relative abundance of age-0 smallmouth bass would decrease as the likelihood of capture increased in catch-and-release fisheries. One assumption of this simulation was that fall abundance of age-0 fish was related to the number of spawning adults and the number of nests successfully producing offspring, an assumption that has remained largely untested. One exception is a long-term study on smallmouth bass in a lake–river system in southern Ontario (Svec 2000; Barthel 2004) that showed a high correlation between the number of offspring produced (assessed as free-swimming fry) each year from successful nests and the abundance of age-1 individuals in that population the following year. There is a clear need for information on the consequences of catch-and-release angling on reproduction at the population level.

Conclusions and recommendations for future research

Additional advances in fish-catching technology in combination with continued popularity of black bass angling suggest the effects of angling on black bass will continue to concern anglers and management biologists alike. Although the effectiveness of anglers and popularity of the sport may increase, the amount of water available to anglers to pursue black bass is nearly fixed. Maintaining what anglers would deem as acceptable angling opportunities will continue to challenge fishery managers. Assuming continued use of catch and release by anglers and fishery managers, there is a need for additional research on this topic so that fisheries professionals can provide science-based recommendations on fish handling and care to anglers in an effort to conserve these important fisheries.

Although many questions remain, this review has identified six priorities for future research: (1) population-level effects of angling for nesting fish; (2) population-level effects of tournament-associated mortality; (3) effectiveness of livewell additives for enhancing survival; (4) consequences of fish displacement in competitive events; (5) effects of weigh-in procedures and other organisational issues on fish condition and survival; and (6) reducing barotrauma. If these issues are addressed, fisheries management biologists will have a much better understanding of the effect of angling on black bass biology and be able to make science-based recommendations to their agencies and to anglers.

It is, however, important to recognise that there may be substantial variation in responses to angling among the various black bass species and even among populations within a species (Cooke & Suski 2005). For example, Furimsky *et al.* (2003) found that largemouth bass and smallmouth bass have different sensitivities to hypoxia. This is problematic because smallmouth bass and largemouth bass are grouped collectively as black bass by anglers, tournament organisers and even fishery managers. Prescribed livewell oxygen levels should be based on values for smallmouth bass as they are more conservative and would therefore ensure adequate oxygen for largemouth bass. Earlier work by Bennett, Dunsmoor, Rohrer & Rieman (1989) and Hartley & Moring (1995) also revealed that post-tournament survival rates differed markedly between smallmouth bass and largemouth bass. Yet, many early studies combined all species and failed to consider interspecific variation. Finally, with the proposed elevation of Florida bass to the species level (earlier a subspecies of largemouth bass, *Micropterus salmoides floridanus*; Kassler, Koppelman, Near, Dillman, Levengood, Swofford, VanOrman, Claussen & Philipp 2002), there is also a need to understand the effects of catch and release on the species and on some intergrades.

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References

Allen M.S., Rogers M.W., Myers R.A. & Bivin W.M. (2004) Simulated impacts of tournament-associated mortality on largemouth bass fisheries. *North American Journal of Fisheries Management* **24,** 1252–1261.

Barthel B.L. (2004) *Life History Strategies of Smallmouth Bass*. MSc Thesis, Urbana, IL, USA: University of Illinois Urbana-Champaign, 66 pp.

Bennett D.H., Dunsmoor L.K., Rohrer R.L. & Rieman B.E. (1989) Mortality of tournament-caught largemouth and smallmouth bass in Idaho lakes and reservoirs. *California Fish and Game* **75,** 20–26.

Burkett D.P., Mankin P.C., Lewis G.W., Childers W.F. & Philipp D.P. (1986) Hook-and-line vulnerability and multiple recapture of largemouth bass under a minimum total-length limit of 457 mm. *North American Journal of Fisheries Management* **6,** 109–112.

Campbell P.M., Pottinger T.G. & Sumpter J.P. (1992) Stress reduces the quality of gametes produced by rainbow trout. *Biology of Reproduction* **47,** 1140–1150.

Campbell P.M., Pottinger T.G. & Sumpter J.P. (1994) Preliminary evidence that chronic confinement stress reduces the quality of gametes produced by brown and rainbow trout. *Aquaculture* **120,** 151–169.

Clapp D.F. & Clark R.D. Jr (1989) Hooking mortality of smallmouth bass caught on live minnows and artificial spinners. *North American Journal of Fisheries Management* **9,** 81–85.

Coble D.W. (1975) Smallmouth bass. In: R.H. Stroud & H. Clepper (eds) *Black Bass Biology and Management*. Washington, DC, USA: Sport Fishing Institute, pp. 21–33.

Contreras-Sanchez W.M., Schreck C.B., Fitzpatrick M.S. & Pereira C.B. (1998) Effects of stress on the reproductive performance of rainbow trout (*Oncorhynchus mykiss*). *Biology of Reproduction* **58,** 439–447.

Cooke S.J. & Suski C.D. (2004) Are circle hooks effective tools for conserving freshwater and marine recreational catch-and-release fisheries? *Aquatic Conservation: Marine and Freshwater Ecosystems* **14,** 299–326.

Cooke S.J. & Suski C.D. (2005) Do we need species-specific guidelines for catch-and-release recreational angling to conserve diverse fishery resources? *Biodiversity and Conservation* **14,** 1195–1209.

Cooke S.J., Schreer J.F., Wahl D.H. & Philipp D.P. (2002) Physiological impacts of catch-and-release angling practices on largemouth and smallmouth bass. *American Fisheries Society Symposium* **31,** 489–512.

Cooke S.J., Ostrand K.G., Bunt C.M., Schreer J.F., Wahl D.H. & Philipp D.P. (2003a) Cardiovascular responses of largemouth bass to exhaustive exercise and brief air exposure over a range of water temperatures. *Transactions of the American Fisheries Society* **132,** 1154–1165.

Cooke S.J., Suski C.D., Siepker M.J. & Ostrand K.G. (2003b) Injury rates, hooking efficiency and mortality potential of largemouth bass (*Micropterus salmoides*) captured on circle hooks and octopus hooks. *Fisheries Research* **61,** 135–144.

Cooke S.J., Bunt C.M., Ostrand K.G., Philipp D.P. & Wahl D.H. (2004a) Angling-induced cardiac disturbance of free-swimming largemouth bass (*Micropterus salmoides*) monitored with heart rate telemetry. *Journal of Applied Ichthyology* **20,** 28–36.

Cooke S.J., Suski C.D., Ostrand K.G., Tufts B.L. & Wahl D.H. (2004b) Behavioral and physiological assessment of low concentrations of clove oil anesthetic for handling and transporting largemouth bass (*Micropterus salmoides*). *Aquaculture* **339,** 509–529.

Diodati P.J. & Richards R.A. (1996) Mortality of striped bass hooked and released in salt water. *Transactions of the American Fisheries Society* **125,** 300–307.

Dunmall K.M., Cooke S.J., Schreer J.F. & McKinley R.S. (2001) The effect of scented lures on the hooking injury and mortality of smallmouth bass caught by novice and experienced anglers. *North American Journal of Fisheries Management* **21,** 242–248.

Edwards G.P., Neumann R.M., Jacobs R.P. & O'Donnell E.B. (2004a) Factors related to mortality of black bass caught during small club tournaments in Connecticut. *North American Journal of Fisheries Management* **24,** 801–810.

Edwards G.P., Neumann R.M., Jacobs R.P. & O'Donnell E.B. (2004b) Impacts of small club tournaments on black bass populations in Connecticut and the effects of regulation exemptions. *North American Journal of Fisheries Management* **24,** 811–821.

Fagerlund U.H.M., McBride J.R. & Stone E.T. (1981) Stress-related effects of hatchery rearing density on coho salmon. *Transactions of the American Fisheries Society* **110,** 644–649.

Farrell A.P., Gallaugher P.E., Fraser J., Pike D., Bowering P., Hadwin A.K.M., Parkhouse W. & Routledge R. (2001a) Successful recovery of the physiological status of coho salmon on board a commercial gillnet vessel by means of a newly designed revival box. *Canadian Journal of Fisheries and Aquatic Sciences* **58,** 1932–1946.

Farrell A.P., Gallaugher P.E. & Routledge R. (2001b) Rapid recovery of exhausted adult coho salmon after commercial capture by troll fishing. *Canadian Journal of Fisheries and Aquatic Sciences* **58,** 2319–2324.

Feathers M.G. & Knable A.E. (1983) Effects of depressurization upon largemouth bass. *North American Journal of Fisheries Management* **3,** 86–90.

Furimsky M., Cooke S.J., Suski C.D., Wang Y. & Tufts B.L. (2003) Respiratory and circulatory effects of hypoxia in largemouth bass and smallmouth bass: an application to 'live-release' angling tournaments. *Transactions of the American Fisheries Society* **132,** 1065–1075.

Gilliland E.R. (2002) Livewell operating procedures to reduce mortality of black bass during summer tournaments. *American Fisheries Society Symposium* **31,** 477–487.

Grant E.C., Inendino K.R., Love W.J., Philipp D.P. & Goldberg T.L. (2005) Effects of practices related to catch-and-release angling on mortality and viral transmission in juvenile largemouth bass infected with largemouth bass virus. *Journal of Aquatic Animal Health* **17,** 315–322.

Hanson K.C., Cooke S.J., Suski C.D. & Philipp D.P. (2007) Effects of different angling practices on post-release behavior of nest-guarding male black bass, *Micropterus* spp. *Fisheries Management and Ecology* **14,** 141–148.

Hartley R.A. & Moring J.M. (1995) Differences in mortality between largemouth and smallmouth bass caught in tournaments. *North American Journal of Fisheries Management* **15,** 666–670.

Hayes D.B., Taylor W.W. & Schramm H.L. Jr (1995) Predicting the biological impact of competitive fishing. *North American Journal of Fisheries Management* **15,** 457–472.

Heidinger R.C. (1975) Life history and biology of the largemouth bass. In: R.H. Stroud & H. Clepper (eds) *Black Bass Biology and Management*. Washington, DC, USA: Sport Fishing Institute, pp. 11–20.

Holbrook J.A. II. (1975) Bass fishing tournaments. In: R.H. Stroud & H. Clepper (eds) *Black Bass Biology and Management*. Washington, DC, USA: Sport Fishing Institute, pp. 408–414.

Kassler T.W., Koppelman J.B., Near T.J., Dillman C.B., Levengood J.M., Swofford D.L., VanOrman J.L., Claussen J.E. & Philipp D.P. (2002) Molecular and morphological analyses of the black basses (*Micropterus*): implications for taxonomy and conservation. *American Fisheries Society Symposium* **31,** 291–322.

Kerr S.J. & Kamke K.K. (2003) Competitive fishing in freshwaters of North America. *Fisheries* **28,** 26–31.

Kieffer J.D., Kubacki M.R., Phelan F.J.S., Philipp D.P. & Tufts B.L. (1995) Effects of catch-and- release angling on nesting male smallmouth bass. *Transactions of the American Fisheries Society* **124,** 70–76.

Kwak T.J. & Henry M.G. (1995) Largemouth bass mortality and related causal factors during live-release fishing tournaments on a large Minnesota lake. *North American Journal of Fisheries Management* **15,** 621–630.

Lee D.P. (1992) Gas bladder deflation of depressurized largemouth bass. *North American Journal of Fisheries Management* **12,** 662–664.

Meals K.O. & Miranda L.E. (1994) Size-related mortality of tournament-caught largemouth bass. *North American Journal of Fisheries Management* **14,** 460–463.

Meyer W.F. & Cook P.A. (1996) An assessment of the use of low-level aerobic swimming in promoting recovery from handling stress in rainbow trout. *Aquaculture International* **4,** 169–174.

Milligan C.L., Hooke G.B. & Johnson C. (2000) Sustained swimming at low velocity following a bout of exhaustive exercise enhances metabolic recovery in rainbow trout. *The Journal of Experimental Biology* **203,** 921–926.

Morrissey M.B., Suski C.D., Esseltine K.R. & Tufts B.L. (2005) Incidence and physiological consequences of decompression in smallmouth bass after live-release angling tournaments. *Transactions of the American Fisheries Society* **134,** 1038–1047.

Myers R.A. & Poarch S.M. (2000) Effects of bait type and hooking location on post-release mortality of largemouth bass. *Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies* **54,** 39–45.

Neal J.W. & Lopez-Clayton D. (2001) Mortality of largemouth bass during catch-and-release tournaments in a Puerto Rico reservoir. *North American Journal of Fisheries Management* **21,** 834–842.

Ostrand K.G., Cooke S.J. & Wahl D.H. (2004) Effects of stress on largemouth bass reproduction. *North American Journal of Fisheries Management* **24,** 1038–1045.

Ostrand K.G., Siepker M.J., Cooke S.J., Bauer W.F. & Wahl D.H. (2005) Largemouth bass catch rates and injury associated with traditional and offset circle hook configurations. *Fisheries Research* **74,** 306–311.

Philipp D.P., Toline C.A., Kubacki M.F., Philipp D.B.F. & Phelan F.J.S. (1997) The impact of catch-and-release angling on the reproductive success of smallmouth bass and largemouth bass. *North American Journal of Fisheries Management* **17,** 557–567.

Plumb J.A., Grizzle J.M. & Rogers W.A. (1988) Survival of caught and released largemouth bass after containment in live wells. *North American Journal of Fisheries Management* **8,** 325–328.

Pope K.L. & Wilde G.R. (2004) Effect of catch-and-release angling on growth of largemouth bass, *Micropterus salmoides*. *Fisheries Management and Ecology* **11,** 39–44.

Quinn S.P. (1989) Recapture rates of voluntarily released largemouth bass. *North American Journal of Fisheries Management* **9,** 86–91.

Quinn S. (2002) Status of seasonal restrictions on black bass fisheries in Canada and the United States. *American Fisheries Society Symposium* **31,** 455–465.

Ridgway M.S. & Shuter B.J. (1997) Predicting the effects of angling for nesting male smallmouth bass on production of age-0 fish with an individual based model. *North American Journal of Fisheries Management* **17,** 568–580.

Schramm H.L. Jr & Davis J.G. (2006) Survival of largemouth bass from populations infected with largemouth bass virus and subjected to simulated tournament conditions. *North American Journal of Fisheries Management* **26,** 826–832.

Schramm H.L., Haydt P.J. & Portier K.M. (1987) Evaluation of prerelease, postrelease, and total mortality of largemouth bass caught during tournaments in two Florida lakes. *North American Journal of Fisheries Management* **7,** 394–402.

Schramm H.L. Jr, Armstrong M.L., Funicelli N.A., Green D.M., Lee D.P., Manns R.E. Jr, Taubert B.D. & Waters S.J. (1991) The status of competitive sport fishing in North America. *Fisheries* **16,** 4–13.

Schramm H.L. Jr, Walters A.R., Grizzle J.M., Beck B.H., Hanson L.A. & Rees S.B. (2006) Effects of live-well conditions on mortality and largemouth bass virus prevalence in largemouth bass caught during summer tournaments. *North American Journal of Fisheries Management* **26,** 812–825.

Schreer J.F., Cooke S.J. & McKinley R.S. (2001) Cardiac response to variable forced exercise at different temperatures - an angling simulation for smallmouth bass. *Transactions of the American Fisheries Society* **130,** 783–795.

Shasteen S.P. & Sheehan R.J. (1997) Laboratory evaluation of artificial swim bladder deflation in largemouth bass: potential benefits for catch-and-release fisheries. *North American Journal of Fisheries Management* **17,** 32–37.

Siepker M.J. (2005) Effects of Recreational Angling on Reproductive Success and Feeding Rates of Largemouth Bass (*Micropterus salmoides*) and Smallmouth Bass (*M. dolomieu*). MSc Thesis, Urbana, IL, USA: University of Illinois Urbana-Champaign, 41 pp.

Siepker M.J., Ostrand K.G. & Wahl D.H. (2006) Effects of angling on feeding by largemouth bass. *Journal of Fish Biology* **69,** 783–793.

Steinhart G.B., Marschall E.A. & Stein R.A. (2004) Round goby predation on smallmouth bass offspring in nests during simulated catch-and-release angling. *Transactions of the American Fisheries Society* **133,** 121–131.

Steinhart G.B., Leonard N.J., Stein R.A. & Marschall E.A. (2005) Effects of storms, anglers, and predators on smallmouth bass nest success. *Canadian Journal of Fisheries and Aquatic Sciences* **62,** 2649–2660.

Stockwell J.D., Armstrong M.P. & Diodati P.J. (2002) A bioenergetics evaluation of the chronic-stress hypothesis: can catch-and-release fishing constrain striped bass growth? *American Fisheries Society Symposium* **30,** 144–147.

Suski C.D. & Philipp D.P. (2004) Factors affecting the vulnerability to angling of nesting male largemouth and smallmouth bass. *Transactions of the American Fisheries Society* **133,** 1100–1106.

Suski C.D., Killen S.S., Morrissey M.B., Lund S.G. & Tufts B.L. (2003a) Physiological changes in largemouth bass caused by live-release angling tournaments in southeastern Ontario. *North American Journal of Fisheries Management* **23,** 760–769.

Suski C.D., Svec J.H., Ludden J.B., Phelan F.J.S. & Philipp D.P. (2003b) The effect of catch-and-release angling on the parental care behavior of male smallmouth bass. *Transactions of the American Fisheries Society* **132,** 210–218.

Suski C.D., Killen S.S., Cooke S.J., Kieffer J.D., Philipp D.P. & Tufts B.L. (2004) Physiological significance of the weigh-in during live-release angling tournaments for largemouth bass. *Transactions of the American Fisheries Society* **133,** 1291–1303.

Suski C.D., Cooke S.J., Killen S.S., Wahl D.H., Philipp D.P. & Tufts B.L. (2005) Behaviour of walleye, *Sander vitreus*, and largemouth bass, *Micropterus salmoides*, exposed to different wave intensities and boat operating conditions during livewell confinement – insights from videography. *Fisheries Management and Ecology* **12,** 19–26.

Suski C.D., Killen S.S., Kieffer J.D. & Tufts B.L. (2006) The influence of environmental temperature and oxygen concentration on the recovery of largemouth bass from exercise: implications for live-release angling tournaments. *Journal of Fish Biology* **68,** 120–136.

Suski C.D., Cooke S.J. & Tufts B.L. (2007) Failure of low-velocity swimming to enhance recovery from exhaustive exercise in largemouth bass (*Micropterus salmoides*). *Physiological and Biochemical Zoology*, in press.

Svec J.H. (2000) Reproductive Ecology of Smallmouth Bass, *Micropterus dolomieu* (*Centrarchidae*), in a Riverine System. MSc Thesis, Urbana, IL, USA: University of Illinois Urbana-Champaign, 74 pp.

US Fish and Wildlife Service (2002) *2001 National Survey of Fishing, Hunting, and Wildlife-associated Recreation*. Washington, DC, USA: US Department of the Interior and US Department of Commerce, 116 pp.

Wagner T., Jubar A.K. & Bremigan M.T. (2006) Can habitat alteration and spring angling explain largemouth bass nest success? *Transactions of the American Fisheries Society* **135,** 843–852.

Weathers K.C. & Newman M.J. (1997) Effects of organizational procedures on the mortality of largemouth bass during summer tournaments. *North American Journal of Fisheries Management* **17,** 131–135.

Wedemeyer G.A. (1976) Physiological response of juvenile coho salmo (*Oncorhynchus kisutch*) and rainbow trout (*Salmo gairdneri*) to handling and crowding stress in intensive fish culture. *Journal of the Fisheries Research Board of Canada* **33,** 2699–2702.

Wilde G.R. (1998) Tournament-associated mortality in black bass. *Fisheries* **23,** 12–22.

Wilde G.R. (2003) Dispersal of tournament-caught black bass. *Fisheries* **28,** 10–17.

Wilde G.R., Riechers R.K. & Ditton R.B. (1998) Differences in attitudes, fishing motives, and demographic characteristics between tournament and nontournament black bass anglers in Texas. *North American Journal of Fisheries Management* **18,** 422–431.

Wilde G.R., Larson D.H., Redell W.H. & Wilde G.R. III. (2002) Mortality of black bass captured in three fishing tournaments on Lake Amistad, Texas. *Texas Journal of Science* **54,** 125–132.