MORTALITY ASSOCIATED WITH CATCH-AND-RELEASE ANGLING: AN ANNOTATED REVIEW WITH SPECIAL EMPHASIS ON LIVEWELLS AND LARGEMOUTH BASS

by

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ABSTRACT

Modern catch-and-release angling can involve holding caught fishes for a period of time in livewells. This activity can be particularly important to fish survival in certain tournament-angling events that have become popular in recent years. High mortalities among fishes in livewells could translate to negative impacts on the resource in general. Additionally, survival of livewell-held fishes can be critical in tournaments where such survival is an integral part of the competition outcome. Because of the potential importance of livewell survival, Texas Parks and Wildlife's Heart of the Hills Research Station initiated a literature review of materials related to aspects of this situation and summarized findings in this report. Areas addressed include discussions of stress in fishes, sources of stress, types of tournaments, and mortality rates and types. Issues associated specifically with livewells such as water temperature, chemistry, contaminants, and additives as well as livewell construction and operation are included. Finally recommendations for improving survival are discussed. This report should serve as a source-book for fishery professionals who field answers from the angling public about these issues.

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INTRODUCTION

History of Competitive Fishing

It is probably impossible to determine when the first competitive fishing event occurred and its roots likely reach back into ancient history. However, a noteworthy increase in the number and scope of competitive fishing events has developed in recent decades, particularly in freshwater areas and especially for largemouth bass (*Micropterus salmoides*; LMB). Indeed, some events listing purses of $500,000 to $1,000,000 each, industry sponsors, and professional anglers, and as a result the competitive fishing phenomenon is clearly a major commercial force in the current American angling scene.

In early studies by Texas Parks and Wildlife Department (TPW), Seidensticker (1975a) reported that competitive black bass (*Micropterus* spp., BB) anglers comprised about 1.3% of the 1.5 million licensed anglers in Texas. Since then, competitive angling has become a much larger industry, with a growing use of fishery resources (Schramm et al. 1991a) by organized, commercially-competitive sport anglers, that has expanded dramatically from 1970 through 1990 (Schramm et al. 1991b) and into the present. The substantial growth of this industry, monetary importance, and political influence exerted by its use of sportfish resources has been described as both offering benefits and creating problems for fishery managers (Schramm et al. 1991a, b).

Prior to 1972, fish caught in tournaments were usually kept wet to prevent dehydration and subsequent weight loss, but otherwise, little was done to keep fish alive; most were dead at weigh-ins and few fish were released alive (Holbrook 1975). Because of the "bad press" associated with large numbers of dead and dying fish found following tournaments and fears of overfishing, B.A.S.S. (Bass Anglers Sportsman Society) began experimenting with ways to keep fish alive. Since that time, an array of handling and holding techniques have evolved. Some tournaments, but not all, now only accept live fish at weigh-ins and may also penalize anglers for dead fish. "No kill" concepts have also been expanded to include many other species.

Commercially-competitive anglers are still the minority of anglers. In Texas, 1999 estimates showed that 14% of licensed anglers participated in tournaments (K. Kurzawski, TPW; pers. comm.). Nonetheless, the large and growing number of tournament events and participants provokes concerns about impact on fishery resources among many anglers and outdoor enthusiasts, as well as some fishery scientists and managers.

Impacts: Potential, Perceived, and Actual

Tournament angling, by its very nature, can potentially cause some level of mortality among fishes caught. Whether this impact is significant to the tournament-caught fish or to the resource in general remains a subject of discussion. Potential adverse impacts discussed by Archer and Loyacano (1975) included intensified angling pressure on highly preferred species (e.g., LMB) by anglers who may be more proficient than the general public (and better equipped} and by the continued proliferation of these events. They noted, too, that catch-and-release policies help reduce this potential impact, but that the success of this approach depended upon relatively high survival of captured, held, and released fishes. Additionally, most tournament and some non-tournament angling is not truly catch-and-release, but rather catch-hold-and-release, often a significantly different concept. Fish may be held for potential culling or eventual weigh-in, but regardless, an additional stress factor is added to the basic catch-and-release concept.

The perceived impact of tournaments often differs between tournament and non-tournament anglers. King et al. (1978) found significant differences between these groups. Among non-tournament anglers, Wilde et al. (1998a) reported 51% believed that tournaments negatively affected fishing and 56% did not believe most fish released at tournaments survived, with many believing tournaments were detrimental to the fishery resource; conversely, only 27% of tournament anglers felt tournaments had a negative effect on their fishing and over 88% believed most fish survived after release.

A notable number of manuscripts have discussed tournament mortalities from the 1970s through the present (Welborn and Barkley 1974; Holbrook 1975; Moody 1975; Seidensticker 1975a,b; Chapman and Fish 1983; Steeger et al. 1994; Kieffer et al. 1995; Kwak and Henry 1995; Perry et al. 1995; Weathers and Newman 1997). Wilde (1998) analyzed and summarized tournament-mortality data for BB for this time period. Reported initial and latent (delayed) mortalities ranged from very low to very high with a bewildering number of contributing factors. Additionally, biases including variation between studies, sample sizes, investigator expertise and bias, and often limited-length latent observation periods (i.e., the time period following release during which a fish is monitored or observed) often clouded comparisons.

This Report

There are, of course, numerous possible sources of mortality among fishes captured during tournament angling. This report focuses primarily on aspects associated with fish losses in livewells. However, it also addresses aspects of mortality before and after livewell confinement, because stresses at all levels ultimately contributes to total mortality regardless of livewell conditions. Because mortalities associated with angling can affect fishery resources, any efforts that improve survival of caught and released fishes may ultimately help the resource and enhance fish availability, particularly for LMB.

MATERIALS AND METHODS

A literature review was conducted to determine what information has already been documented, including general angling, tournament angling, hatchery techniques, and basic fish physiology data sources. Data were combined and distilled to produce (1) a discussion of known details where possible, (2) what is not known about livewells, (3) events for consideration before and after livewell placement, (4) discussions of livewell and boat construction, and (5) elaboration on research needs on this subject. Where data for larger-size fishes was unavailable or limited, information from smaller specimens was presented in anticipation that it may provide general "ball park" guidelines that would be better than no data at all.

Although LMB was the primary species motivation and focus for this report, information on other sport and forage fishes is also included. Acronyms for black basses, subspecies of LMB, and other taxa discussed include:

BB	black bass (*Micropterus* spp.)
NLMB	northern or native largemouth bass (*M. s. salmoides*),
FLMB	Florida largemouth bass (*M. s. floridanus*),
SMB	smallmouth bass (*M. dolomieu*),
SPB	spotted bass (*M. punctulatus*),
STB	striped bass (*Morone saxatilis*),
WB	white bass (*M. chrysops*),
RBT	rainbow trout (*Oncorhynchus mykiss*), and
CC	channel catfish.

Other species referenced include: chinook salmon (*O. tshawytscha*), brook trout (*Salvelinus fontinalis*), minnows (Cyprinidae), walleye (*Stizostedion vitreum*), red drum (*Sciaenops ocellatus*), channel catfish (*Ictalurus punctatus*), muskellunge (*Esox masquinongy*), American shad (*Alosa sapidissima*), alewife (*A. pseudoharengus*), fathead minnow (*Pimephales promelas*), Chinese carps (mixed species), grass carp (*Ctenopharyngodon idella*), black carp (*Mylopharyngodon piceus*), bighead carp (*Aristichthys/Hypophthalmichthys nobilis*), silver carp (*H. molitrix*), common carp (*Cyprinus carpio*), and crappie (*Pomoxis* spp.).

Data obtained from manufacturer's advertisements and catalogues for boats and livewells, direct telephone and E-mail contacts with production companies, and a summary of livewells by Burch (2000) are presented in Table 1.

RESULTS AND DISCUSSION

Mortality Factors Associated with Tournaments

Stress – Definition and Aspects

Stress – Definition

Stress was defined by Wedemeyer et al. (1990) as something resulting from biotic and abiotic challenges or forces that extend the homeostatic or stabilizing processes of fishes beyond their ability to control routine physiological processes. In more simple terms, biological (e.g., disease organisms) or environmental factors (e.g., temperature extremes, handling, etc.) that disrupt a fish's ability to control normal bodily functions (e.g., respiration, digestion, etc.) are considered to be stress (or stressors). In extreme cases, death may directly or indirectly result from stress. Environmental stress is an inescapable part of the life of every fish and this is particularly important in fishes held in intensive-culture situations (Wedemeyer and McLeay 1981). However, stress experienced by fish caught and released by anglers may exceed normal day-to-day experiences. This is especially true of those fish caught, held, handled, and ultimately released hours later, or from other tournament-type catch-hold-and-release activities. Stress-induced mortalities may result from many factors (Feathers and Knable 1983).

Examination of blood and body tissue chemistry and associated functions provides a better understanding of the stress impacts on fish that have been caught and held. Mazeaud and Mazeaud (1981) indicated that fish have no equivalent of the mammalian adrenal gland; rather, chromaffin cells, that produce catecholamines (adrenaline and related substances), are scattered in different organs. Nonetheless, the adrenergic function in fish is very sensitive to stress. Adrenergic activation results in effects on circulation, osmoregulation, and energetics (Mazeaud and Mazeaud 1981). Mazeaud et al. (1977) described how primary response to stressors was the release of corticosteroid hormones, with secondary effects that include elevated plasma glucose concentrations and plasma electrolyte dysfunctions. They also stated the increase in plasma glucose was rapid and probably not caused by corticosteroids, but rather by actions of catecholamines related to the initial capture and struggle and that all types of stress resulted in an increase in circulating catecholamines (mainly adrenaline). For example, plasma corticosteroids are an indication of stress in fish and plasma chloride levels are a measure of osmoregulatory dysfunction (Davis et al. 1982).

Additionally, Wedemeyer et al. (1990) noted that physiological stress could be confused with psychological stress. Certainly behavioral responses of fishes to capture, holding, and handling add a behavioral or psychological element to the ultimate physiological impact of the experience on the fish.

Interrelationships Between Stressors

Robertson et al. (1987) indicated that the effects of multiple stressors are often additive even when individual stressors are sublethal. More correctly however, sublethal stressors may be additive, multiplicative, or have some other functional relationship, but the important concept is that they may interact in some way to create a combined effect that is lethal. Kwak and Henry (1995) reported most tournament mortality among LMB was due to cumulative effects of sublethal stressors. Carmichael et al. (1984b) noted that combinations of stressors particularly needed to be avoided.

Stress Acclimation

Several authorities have suggested genetic selection for stress-tolerant strains is possible and should be examined (Robertson et al. 1987). Indeed, the very development of domestic strains indicates some selection for stress tolerance, whether deliberate or accidental (Woodward and Strange 1987). Robertson et al. (1987) also indicated that it is possible to train or condition fish to exhibit a reduced stress response. They gave examples of cultivated fishes acclimating to repetitive handling or high-density feeding situations. No such research efforts appear to have been directed at angling-related stress tolerance. Theoretically, certain catch-and-release situations could have the impact of selection for stress-tolerant strains. However, this area appears not to have been scientifically examined. See additional discussion under Stress-tolerant Strains.

Physiological Indicators of Stress

Plasma Corticosteroid and Glucose Levels

After transport, LMB had plasma corticosteroid and glucose levels that remained high for 24 hours and juveniles required 64 hours or more of acclimation to recover from long periods of transit (Carmichael 1984). Carmichael et al. (1984a, b) also found that LMB plasma corticosteroids increased immediately after fish were crowded and loaded, and remained high throughout the hauling period.

Redding and Schreck (1983) found that among salmonids, plasma cortisol concentrations increased for all groups tested, but were lower when fish were placed in one-third sea water within 7 hours of the onset of stress. Strange and Schreck (1978) reported there was no change in plasma cortisol levels in chinook salmon due to handling when brief anesthesia was used; however, they did find prolonged exposure to a behavior-depressing dose of anesthetic could cause elevated cortisol levels relative to an immobilizing dose. Wedemeyer (1970) found activation of latent disease organisms as a result of immunosuppressive effects of corticosteroids that could cause death when fish were handled and hauled. Therefore, methods used to mitigate stress, including mild anesthesia, help reduce plasma corticosteroid levels and therefore reduce the threat of disease and improve poststress survival.

Gustaveson et al. (1991) found hyperglycemia (an indicator of stress hormone production) did not occur in LMB hooked and played 1-5 minutes at 11-13 °C (51.8-55.4 °F), was moderate at 16-20 °C (60.8 °-68.0 °F), and was severe at 28-30 °C (82.4-86.0 °F). Interestingly, they also found variation in the extent of hyperglycemia in fish from different water bodies. They also noted fish held in cages for latent studies suffered further hyperglycemia (presumably related to confinement stress, as could occur in a livewell). In muskellunge, Miles et al. (1974) found capture and holding caused increases in blood glucose concentrations, but that 0.3% sodium chloride could alleviate some such symptoms of stress. Strange (1980) reported CC stressed at lower temperatures had slower and less-marked increases in plasma cortisol and glucose that those stress at higher temperatures.

Plasma Chloride

Carmichael et al. (1984a, b) found that transported LMB had decreased levels of plasma chloride, and required many hours to return to normal levels (Carmichael 1984). Gustaveson et al. (1991) reported ion regulation (indicated by plasma chloride levels) was not immediately affected in LMB hooked and played at 11-13 °C (51.8-55.4 °F) or 28-30 °C (82.4-86.0 °F), but developed in fish at 16-20 °C (60.8-68.0 °F). Also in a study of handling stress in LMB, Williamson and Carmichael (1986) found FLMB and FLMB intergrades had significantly higher plasma chloride levels than the northern subspecies and, unlike NLMB, both began to die before the confinement period was ended. In muskellunge, Miles et al. (1974) found capture and holding caused decreases in blood chloride concentrations in muskellunge, but that 0.3% sodium chloride could alleviate some such symptoms of stress. However, Davis et al. (1982) found plasma chloride levels in STB were not affected by short-term confinement.

Blood Lactate

Gustaveson et al. (1991) found elevated blood lactate levels were directly related to hooking and playing time in LMB, with higher levels in fish played longer. They reported hyperlactemia was more severe in LMB from some water bodies than from others, but attributed this to the test fish being from "different populations". In muskellunge, Miles et al. (1974) found capture and holding caused increases in blood glucose concentrations, but that 0.3% sodium chloride could alleviate some such symptoms of stress.

Liver Glycogen

In muskellunge, Miles et al. (1974) found capture and holding caused decreases in liver glycogen concentrations, but that 0.3% sodium chloride could alleviate some such symptoms of stress.

Corneal Cloudiness

Brandt et al. (1986) described a condition of corneal cloudiness that developed in LMB subjected to simulated transport stresses. The condition developed in 46-83% of specimens examined, but cleared in 80% of fish within 20-36 hours. However, they noted that the impaired vision that resulted could impact subsequent survival during this time. This could be especially true in tournament caught and stressed fish released at unfamiliar sites long distances from capture locations. The extent to which this syndrome may occur in other species appears not to have been examined.

Types and Sizes of Tournaments

There are a number of different types of competitive fishing tournaments. Certain types of tournaments are potentially more stressful on captured fishes than others and subsequently can result in increased mortality (Wilde 1998). Ostrand et al. (1999) summarized initial mortality for four BB tournament types in Texas including: paper (1.1%), total weight (4.0%), big fish (4.7%), and road-runner (4.3%) tournaments. Wilde et al. (1998b) expanded on the number of different types of tournaments and their frequency including: total weight (87.8%), big fish award (26.0%), paper (10.2%), jackpot (4.5%), road-runner (1.7%), big fish per hour (0.9%), and tagged fish (0.4%), with some tournaments having combined characteristics.

Paper tournament procedures most closely approach true catch-and-release, and provide the best opportunity for post-release survival, with fish experiencing little or no time in a livewell. Other tournament types require long-term livewell holding of some or all captured fishes, with associated increased stresses. In particular, road-runner tournaments that allow anglers to fish multiple lakes may result in fish that have not only been held in livewells for extended periods, but have been transported across land as well, with even greater stress and reduced latent survivals. Paper tournaments lack the public spectacle typical of competitive angling events (Wilde et al. 1998b) and are often ill-regarded by tournament anglers, despite decreased negative impact on fish. Big fish and big fish per hour events often reduce the number of fish ultimately handled for weigh-in (Wilde et al. 1998b).

Tournament size can also impact mortality. Ostrand et al. (1999) reported initial mortality in BB was 4.1% for smaller events and 1.8% for larger tournaments. Wilde (1998) found a strongly negative relationship between tournament size and initial mortality, but a strongly positive relationship to latent mortality. Larger, well-organized and publicly-viewed events more often require live weigh-ins that improve initial mortality estimates, but require longer holding, transport, and handling stress that ultimately drives up latent mortalities. Hartley and Moring (1995) also found mortalities to be higher in larger tournaments, but reduced in tournaments that limited the number of fish handling steps.

Schramm et al. (1985) found a low portion of tournament anglers were responsible for the majority of documented mortality and that angling teams with the largest catches had the lowest proportion of dead fish. However, Hartley and Moring (1995) reported mortalities were highest when more fish were caught.

Preliminary and Latent Sources of Stress

Hooking, Playing Time, Landing, and Handling

General aspects

Stresses experienced by a fish prior to confinement can have a profound impact on subsequent survival regardless of livewell conditions. Considering stressors are often cumulative in impact on fishes, even slight degradation of livewell condition quality may also dramatically reduce survival in previously stressed fishes.

Hooking Mortality

Klein (1965), Clapp and Clark (1989), Muoneke (1991, 1992a, 1992b) and others have discussed specific aspects of hooking mortality and Muoneke and Childress (1994) provided a review of hooking-mortality reports. In a study of numerous LMB tournaments, Wilde (1998) suggested a substantial proportion of tournament-related mortality was the result of injuries sustained during hooking, playing, and landing fish. Wydoski et al. (1976) indicated hooking stress in RBT caused severe blood chemistry disturbances that were aggravated by warm water temperatures. Gustaveson et al. (1991) also found hooking mortality among tournament-caught LMB to be greatest in those fish caught and played in the warmest water (28-30 °C; 82.4-86.0 °F). In a compilation of results from published and unpublished studies on STB, Wilde et al. (2000) concluded that hooking mortality was positively related to water temperature. Types, sizes, and numbers of hooks, bait or lures, and hook removal (or not) can all impact hooking-related stress prior to livewell confinement.

Playing time

Although there is little in the published literature about playing time between hooking a fish and landing, general consensus reflects anglers should play and land a fish as quickly as possible to reduce mortality. Gustaveson et al. (1991) recommended walleye, for example, be played and landed within 2 to 3 minutes. Under tournament conditions, it is fortunately impractical to use light lines and gear that require playing fish to near total exhaustion. Among SMB caught during nest guarding, those individuals caught and played to exhaustion took four times longer to return to nests than other specimens caught and landed quickly (Kieffer et al. 1995). Extended playing times result in more exhausted fish and may reduce ultimate survival potential or impact behavior following release.

Landing and handling

There appears to be virtually nothing in the scientific literature about specific angler handling techniques most appropriate for LMB and other fishes. However, some competitive fishing organizations and even some fishery managers have offered recommendations in fliers and over Internet web sites. For LMB, most advise lifting the fish by grasping the lower jaw and using the other hand to support the belly. Some Australian Internet material (http://www/nativefish.asn.au/cr.html) recommended holding bass-like fishes on their sides and using the free hand to support the down-side of the fish. This method makes sense, particularly for large fish with very soft bellies and a great deal of proportional body weight. It seems reasonable to assume that the soft visceral cavity is more likely to be damaged by the body weight of a large fish than the trunk musculature. It should also be noted that many BB anglers in particular not only lift fish by their lower jaws, but also significantly hyperextend the lower jaw far beyond its natural gape. Such handling offers no survival advantage and may cause damage that will reduce long-term survival. Regardless of handling method, fish that have been improperly handled before placement in a livewell can be expected to have reduced survival rates, even under good livewell conditions.

Nets, gloves, and towels

Recommended methods of landing fish vary between species and the source of the advice. In most cases, there is little or no scientific data to support suggested methods or recommendations. Common sense and personal opinions prevail in this area. Most BB anglers and organizations recommend landing fish by grasping the lower jaw rather than with a dip net. Use of dip nets with other species may be more common. Landing nets made of stiff natural or synthetic fibers can damage fish by rubbing off mucus and scales. However, some brands of soft, synthetic-fiber meshes can be used with minimal damage (R.G. Howells, TPW; unpublished observation). Use of rubber landing nets has also been recommended (Gilliland undated). Indeed, the support such nets may give to exceptionally large, big-bellied fishes may be advantageous over lower jaw grasping that leave the visceral cavity hanging. Among particularly heavy LMB, excessive thrashing while being held by the lower jaw might result in damage to internal organs or skeleton. Whether it is better to allow a large fish to struggle while being held by the lower jaw or to place it on a soft, wet towel until it quiets seems not to have been studied. Another reason anglers may prefer to avoid landing nets may relate to problems entangling hooks, especially multiple treble hooks (common on many lures) in net meshes. Certainly additional stress may be incurred by a fish struggling in a net with tangled hooks that prevent quick removal and return to the water. However, recommendations for lower jaw grasping may reflect as much on convenience (less time untangling hooks from landing nets) than on the best outcome for the fish. Regardless, scientific examination of landing methods is still needed.

In some cases gloves or wet towels may or may not be recommended for grasping fish being handled. This has been a particular subject of debate among salmonid anglers. Synthetic or natural fiber gloves or towels may indeed rub off excess mucus and scales with subsequent impacts on infection and postrelease survival. Conversely, damage a fish may suffer while thrashing about during the unhooking or other handling processes may be equally damaging.

Repetitive use of such gloves or towels on multiple specimens has also been suggested as a method of spreading infectious diseases. Rubber or plastic gloves may provide a better grip with potentially less mucus and scale removal, but again, scientific comparison of handling methods and gear is lacking.

An additional factor especially relevant to tournament-boat situations relates to placing fish on deck carpeting. Most boat deck carpets are made to endure exterior conditions and rigorous use. As a result, most are rough and abrasive. Fish should not be placed on this carpet. If it is necessary to place a fish on the boat deck, using a soft and wet towel between the fish and carpeting is probably beneficial.

The issue of scale loss and subsequent mortality has been a subject of debate among numerous catch-and-release anglers. Handling techniques that cause limited loss of scales, especially when losses are not in concentrated patches, are not necessarily fatal to all fishes. For example, FLMB in one long-term growth and age study initiated at Heart of the Hills Research Station (HOH) includes specimens hatched in May 1985 and handled annually every October to determine weight and length measurements (TPW, unpublished data). When FLMB in this group die, scales are removed for reference. However, after repetitive years of handling, so many scales have been lost and regenerated that it often requires removal of 50-60 scales to locate an original scale; the vast majority of scales on these LMB have been lost and regenerated, yet in 15 years, no deaths attributed to handling have been recorded. Additionally, each fish is typically handled in a soft-mesh dip net at least twice each year as well as being lifted by the lower jaw during measuring and weigh-ing processes. It should be noted here, however, that despite annual handling, these fish have not been caught by angling, held in livewells for extended periods, subjected to jaw hyperextensions, or experienced tournament-type weigh-in procedures.

Seasonal Mortality Considerations

Gilliland (2000) found near-lethal concentrations of dissolved oxygen and stressful water temperatures in livewells during LMB tournaments held in summer; indeed, he indicated summer mortalities could be an order of magnitude higher than in spring or fall. Among tournament-caught LMB, Kwak and Henry (1995) found mortalities to be 1.5 times higher in May than in September. Seidensticker (1975b) and numerous others have reported increased mortality among tournament-caught LMB in summer related to high water temperatures. Plumb et al. (1988) indicated mortality to be lower during cool temperatures in fall and winter. Steeger et al. (1994) also found tournaments held in June, August, and early September had the poorer LMB survival than during other months. Hysmith et al. (1992) found mortality among STB was greater in spring (69%) and summer (47%) than in fall (8%) or winter (13%). Seasonal aspects of mortality may reflect aspects of spawning condition and water temperature, among other things (see discussion under individual topics).

Spawning Condition

Hartley and Moring (1995) indicated both LMB and SMB may be less able to endure the stress of being captured and handled following spawning, and noted that most states in the Northeast now limit harvest during spawning season (to reduce this problem). Kwak and Henry (1995) also presumed higher mortalities in tournament-caught LMB in May were related to spawning behavior and condition. Increased summer mortality in LMB tournaments documented by Gustaveson et al. (1991) was also attributed to decreased stress tolerance in postspawning fish.

In addition to direct or indirect mortality, Kieffer et al. (1995) indicated that physiological and behavioral effects of catch-and-release angling during spawning season of SMB could negatively affect spawning success.

Deep-water Catches

LMB and other fishes taken from deep waters often suffer from effects of rapid depressurization, a factor that is often not considered in mortality studies (Feathers and Knable 1983). Lee (1992) indicated nearly one third of the angled LMB he examined displayed pressure-related problems. Feathers and Knable (1983) indicated, for LMB caught in waters at depths ≥ 18.3 m (60 feet), at least 40% of mortality resulted from depressurization alone. They found bloating and external hemorrhaging in test fish at all depths studied and commented that release of fish taken at depths ≥ 9.1 m (30 feet) was probably of little use. They also noted that latent mortality related to depressurization was the major component of total mortality. Bettoli and Osborne (1998) also reported STB were often additionally stressed by delayed return to deeper waters, and they experienced difficulty in regulating air bladder pressure, even when such problems were not externally evident. Lee (1992) also reported that LMB released immediately could often submerge and reach deeper waters, but could not do so after being held in livewells. It appears that in cases of limited depressurization, fish may be better able to survive if released immediately, but the ability to return to deeper water and ultimate survival is compromised by livewell confinement.

Feathers and Knable (1983) stated that artificial deflation of the swim bladder in depressurized fish may enhance survival and has some practical merits. Lee (1992) and True et al. (1997) discussed field decompression techniques to reduce pressure-related stress and subsequent mortality, but Lee found no differences in returns of deflated and non-deflated LMB (suggesting no survival difference), and he too suggested deflation might not improve survival of released fishes. Even when livewell-held fish are surgically treated to reduce rapid depressurization impacts, such fishes have experienced additional stress and a corresponding increase in latent mortality can be expected. Poor livewell conditions can potentially further confound and enhance the negative impacts of depressurization on fishes taken from deep waters.

Livewell Removal and Weigh-in Impacts

Handling techniques discussed under landing fish also apply to removal from livewells for weigh-in. Aspects associated with the actual weigh-in procedures can obviously impact subsequent survival of fishes. Hartley and Moring (1995) reported mortalities were least in tournaments that limited the number of steps and time elapsed between removal from the livewell and subsequent release of the fish. They found that some weigh-ins took up to 2 hours, during which time stress in livewells or other containers continued. Indeed, they found that even in livewells designed to circulate "fresh" water, the concentration of boats in the weigh-in area resulted in increased levels of fuel and sediment in the water. Additional aspects of this process include fish being held in small plastic bags of water or in other similar containers for extended periods of time (some tournament organizers may supply tanks of cooled, oxygenated water in which to hold fish prior to weigh-in).

Fishing-day Length

Seidensticker (1975b) reported shorter fishing days improved survival among tournament-caught LMB. In one example, he found 31% mortality in a 10-hour event, but only 11% over 7 hours on the second day of the same tournament. In a second example, 8-hour tournaments produced 27.5% and 30.5% mortality, but a final 7-hour day of the same tournament yielded only 12.2% mortality. It should be noted that although numerous biases may be reflected in these data (e.g., different anglers and distinct conditions on each day, some anglers may have dropped out by the last day of the tournament, etc.), the shorter the time a fish remains in a livewell, the less stress it will experience and greater its chances for survival.

Latent Infections

Numerous studies have discussed the impact of latent infections as a cause of mortality during postrelease periods (*e.g.*, May 1973; Archer and Loyacano 1975). May (1973) found most tournament-caught LMB held to study latent mortality demonstrated increased fungal infections. Moody (1975) also found overall mortality values following tournament handling and a 5-day latent period were primarily due to bacterial and fungal infections. Plumb et al. (1976) indicated bacterial infections in channel catfish often occur following a decline in dissolved oxygen with a concurrent increase in carbon dioxide and ammonia. Steeger et al. (1994) also concluded bacterial diseases associated with fish released from tournaments were potential problems. Welborn and Barkley (1974) described mortality among LMB over a 4-day latent period after a tournament where (1) 5.6% of fish were lost to *Chondrococcus columnaris*; (2) 38.9% to a mixed infection of *C. columnaris* and *Aeromonas liquefaciens* and another unidentified bacterium, or both; and (3) 11.1% to *A. liquefaciens* alone.

These issues are discussed in greater depth under Aspects of Livewell Mortality, particularly regarding Antibiotics.

Recovery Time

Death can occur as long as several weeks after a stress experience, often without warning (Mazeaud and Mazeaud 1981). The "recovery time" required for a fish to return to normal physiological and behavioral functions following stress can be important and lengthy. Indeed, Carmichael et al. (1984a) noted that the most serious consequence of hauling stress in LMB was not observed until the recovery period. Carmichael (1984) found juvenile LMB required ≥ 64 hours to recover from long periods of transit and, further, that when fish were not permitted to recover completely, a second, normally nonfatal, stressful occurrence, was fatal. Based on blood chemistry studies with LMB and other fishes, Carmichael et al. (1984b) found that the osmoregulatory system in fishes does not recover quickly from stress and osmoregulatory dysfunction continues long after the stressor is removed. These delayed osmoregulatory effects can last for several weeks (Carmichael et al. 1984b). On water bodies where one tournament is quickly followed by a second or third tournament, or where tournaments fish the same waters for more than one day, some fish may not be able to fully recover from one stress experience before exposure to another. Ultimately, total mortality on a given water body could be reduced by organizing shorter tournaments and providing longer intervals between tournaments.

Mortality Rates and Types

General Aspects of Mortality

Certainly many things may contribute to mortality among tournament-caught, or otherwise landed, fishes and these issues are often interrelated. However, for purposes of discussion, mortality is often divided into several distinct areas: hooking and initial handling mortality before being place in a livewell, initial mortality (including hooking, handling, and livewell holding), prerelease mortality (includes stresses), and latent or postrelease mortality (also delayed mortality), as well as total mortality (includes all mortality sources associated with the particular angling experience). Impact assessments of tournaments based only on initial mortality estimates can be expected to underestimate true losses. Similarly, efforts to define latent mortality based on excessively short latent time periods can also be expected to provide unrealistic and unrepresentative results.

Latent mortality

Mortality reported for tournament catches reflecting very limited losses often include only deaths that occurred between hooking and weigh-in or at post- release. However, mortality may occur for an extended period of time following release and can be a substantial proportion of total mortality. Complete recovery from hooking alone can take several days (Wydoski and Wedemeyer 1976), and this long-term recovery period can be lengthened by additional stresses of handling and holding. Indeed, death may occur several weeks after the application of stress, often without warning (Mazeaud and Mazeaud 1981), because metabolic disturbances from short-term stress may be of relatively long duration. Inclusion of latent mortality values in total losses can elevate total impact significantly, but more accurately accounts for overall mortality. May (1973) reported individuals tampering with cages during latent mortality studies; whether due to simple curiosity or concerns among some members of the competitive-angling community about the real extent of such latent mortality, such interference can compromise subsequent results.

In LMB, Schramm et al. (1985) reported initial mortalities in tournaments to range between 0 and 100% (mean of 9%) and a total mortality of 14%. However, they considered latent mortality to include dead fish and any that remained at the surface over 1 minute after being released, without documentation of actual losses over an extended (latent) period of days. Seidensticker (1975b) found initial mortality among LMB in East Texas tournaments of 24%, with total mortalities (including latent mortality) over 28 days of 32%. Similarly, Steeger et al. (1994) found LMB had 8.3% (2.4-14.9%) mortality before and postrelease losses of 25.4% over a 4-day latent period (total mortality through 4 days was 33.1%). May (1973) found 15.6% initial LMB mortality and 15.0% 6-day latent mortality for a total mortality of 30%. Weathers and Newman (1997) restricted their latent study period for LMB caught in summer tournaments to 4 days and found total mortalities of as high as 68.4%. Archer and Loyacano (1975) held LMB from tournament catches 14 days and found latent mortalities actually began on the fourth day, increased on the fifth day, had a 2-day recession, then resumed on the eighth day producing a total 14-day mortality of 10.7% for fish held in ponds and 37.9% for fish held in pools. Welborn and Barkley (1974) found over 70% of latent mortality, following release of tournament-caught LMB, occurred between days 10 and 15. In a review of LMB tournament mortality data by Wilde (1998), recently reported latent and total mortalities were given as 23.3% and 28.5%, with little evidence of declines in these figures since the 1970s. Schramm et al. (1987) studied latent mortality among tournament-caught LMB for 21 days and found most losses occurred within the first 6 days. In one recent Texas study, TPW (J.W. Schlechte; pers. comm.) found initial mortality among tournament-caught LMB at weigh-in of 1.4%, but total mortality following a subsequent holding period of 6-7 days increased to 39.1%. Goeman (1991) found initial mortality as low as 1.0% among tournament-caught walleye, but postrelease mortality documented over a 5-day period reached as high as 41.7%.

Gilliland (1997) found initial mortality had little relationship to latent (delayed) or total (initial + latent) mortality. Among pressure-stressed LMB captured in deep waters, Feathers and Knable (1983) found latent mortality was the major component of total mortality. The same conclusion was reported by Goeman (1991) for tournament-caught walleye.

Culling

Very few estimates of any of the above types of mortality include fish that are caught, held for a period of time in a livewell, and then released later to be replaced by a larger fish before weigh-in (Wilde 1998), for either tournament or non-tournament angling. Culled fish may include both smaller, rejected fish that are released alive as well as those fish that die during livewell confinement and are then removed before weigh-in (particularly in situations where attempts to weigh-in dead fish results in point deductions). In some situations, mortality among such culled fish could be significant, but estimates are largely unavailable. Clearly improvements in handling and livewell holding will also improve the survival potential of culled fishes.

Size-related Mortality

Weathers and Newman (1997) found a significant increase in mortality related to size of tournament-caught LMB, with fish > 510 mm (20.1 inches) over twice as susceptible to postrelease mortality. Meals and Miranda (1994) also found a significant increase in losses among larger, tournament-caught LMB (mean 29%, range 11-57%) over smaller fish (mean 9%, range 3-12%). Recent unpublished research by TPW (J.W. Schlechte; pers. comm.) on LMB revealed that mortality was higher among larger fish brought to a tournament weigh-in (but not among control LMB) and lower for smaller fish, with < 10% mortality for LMB < 400 mm (15.7 inches), an average mortality of 44% for fish > 400 mm (15.7 inches), and 100% mortality for specimens >650 mm (25.6 inches). Meals and Miranda (1994) found that larger LMB were often held and stressed in livewells longer than smaller fish. Goeman (1991) found losses in tournament-caught walleye were unrelated to the size of fish. Conversely, Hysmith et al. (1992) found a positive relationship between mortality and size of STB, while Bettoli and Osborne (1998) did not. Among RBT, Wydoski et al. (1976) found hooking stress was greater for larger hatchery trout than for smaller specimens. In red drum, Weirich and Tomasso (1991) found larger specimens were more tolerant of confinement than smaller fish. In general, for most fish species of catchable sizes, larger fish are usually less tolerant of handling and stress than smaller ones. Tournaments that usually focus on larger animals ultimately place the greatest stress (and potentially the greatest losses) on the most-desirable size groups.

Species, Subspecies, and Strain Differences in Mortality

Hayes et al. (1995) reported that LMB populations could tolerate greater fishing-related mortality than could walleye based upon maturation times, and age and size at which fish enter tournaments. Hartley and Moring (1995) compared tournament mortalities between LMB and SMB (3.2% and 8.9%, respectively) and found SMB less tolerant of tournament-related stresses.

Among subspecies of LMB, Williamson and Carmichael (1986) found young-of-the-year FLMB and their intergrades were less tolerant of confinement stress than NLMB, regardless of rearing or experimental conditions. Unfortunately, no similar studies are available to provide indication if this lesser tolerance to stress is retained in older or tournament-sized fishes. Similarly, Hart (1952) and Guest (1985) reported FLMB to be less tolerant of high water temperatures than NLMB.

Differing degrees of stress tolerance have been reported among wild and domestic stocks in some fish species. Among RBT, Casillas and Smith (1977) found that wild fish required less time to recover from hook-and-line stress than hatchery trout. Woodward and Strange (1987) reported stress-induced blood chemistry changes were more extreme in wild RBT than in hatchery fish. Wydoski et al. (1976), however, found hyperglycemia responses to hook-and-line capture stress greater in hatchery fish, concluding wild strains may be more physically fit and better able to deal with the acute stressor. It should be noted that a difference in severity and duration of net confinement between Woodward and Strange's work (12 hours) and that of Wydoski et al. (72 hours) may have contributed to the difference in results. Additionally, Wydoski et al. (1976) noted the differences they found between hatchery and wild strains of RBT were not large.

Aspects of Livewell Mortality

General

Gilliland (1997) reported that the Oklahoma Department of Wildlife Conservation studied ways to improve tournament-related mortality in LMB and concluded livewell operation and conditions were very important because " 'first-aid' at weigh-in would not save fish that were mistreated and stressed in livewells." In another study of LMB tournament livewells, Kwak and Henry (1995) found all water-quality parameters measured in livewells differed significantly from lake water, with differences greatest for ammonia concentrations. Clearly, livewell conditions are an important element relating to the survival of captured and held fishes.

Water Temperature

Welborn and Barkley (1974) studied mortality of tournament-caught LMB and concluded that water temperature was a critical factor in the survival of released fish, but cautioned other factors needed to be taken into account as well. Meals and Miranda (1994) indicated mortality among tournament-caught LMB increased with water temperature elevation. Wilde (1998) reported that water temperature accounted for 20-30% of the variation in mortality in his review of BB tournament data. He also indicated that the relationship between water temperature and mortality had been recognized since the 1970s, but the strength of the relationship had been previously underestimated and Gilliland (2000) agreed. Among STB, Wilde et al. (2000) found mortality increased rapidly as water temperatures exceeded 25 °C (77.0 °F). They also concluded 67% of STB caught on natural baits at 27 °C (80.6 °F) would die and 50% mortality would occur at 29 °C (84.2 °F) among fish taken on lures.

In their studies of LMB and SMB caught in tournaments, Hartley and Moring (1995) concluded that water temperature alone was not the major factor contributing to mortality; other variables like stress associated with removing fish from spawning beds may have been significant at certain times. Bettoli and Osborne (1998) found no relationship between mortality and water temperature for STB caught and released, but positive relationships were reported by Harrell (1992) and Hysmith et al. (1992). However, failure to find a relationship between mortality and water temperature often indicates other factors were more significant in a particular study or water temperature ranges were not great enough to cause differences. Regardless, water temperature remains one of the most significant elements relating to survival of angled fishes.

Upper Lethal and Other Temperature Ranges

Coutant (1975) reported an increase in LMB feeding activity between 10 °C (50.0 °F) and 20 °C (68.0 °F), uniformly high feeding rates to 27 °C (80.6 °F), and a decline at higher temperatures. He also noted that capacity for LMB exercise also increased with water temperature to a peak of about 30 °C (86.8 °F), but then declined rapidly. LMB survival at high temperatures relates to several factors including a) acclimation temperature, b) test or exposure temperature, and c) duration of exposure, with other factors such as fish condition applying as well. Coutant (1975) cited work of Hart (1952) that reported upper temperature limits for long-term survival were 36.5 °C (97.7 °F) for NLMB and 34.0 °C (93.2 °F) for FLMB. The highest recorded upper lethal temperature for LMB was 37.0 °C (98.6 °F) (Mraz et al. 1961), but fish acclimated to very cool waters may die at even lower upper lethal temperatures. Hartley and Moring (1995) found mortalities between tournament-caught LMB and SMB were greatest above 24 °C (75.2 °F), but did note some acceptable levels of mortality above 21 °C (69.8 °F). Schramm and Heidinger (1988) recommended when fishing at 26.7 to 32.2 °C (80-90 °F) livewell temperatures should be kept 2.8 °C (5 °F) cooler than lake water, but when lake waters exceeded 32.2 °C (90 °F), livewells should be maintained at 30.0 °C (86 °F). In addition to thermal tolerance limits, abrupt changes in temperature can be harmful to fishes (Carmichael et al. 1984b).

By combining the concepts above, livewell temperatures should be cooler than ambient levels (except perhaps during cold winter conditions), but rapid, dramatic changes in water temperature between water body and livewell should be avoided. Water temperature can be one of the most important elements of livewell mortality, and is also one of the easiest to control. Nonetheless, Gilliland (2000) found many BB-tournament anglers did not control livewell temperature unless specifically instructed.

Temperature and Blood Chemistry

Abrupt temperature changes can cause elevations in plasma corticosteroids and glucose concentrations, and reduction in plasma chloride at 12 °C (21.6 °F) temperature increases (10 ° to 22 °C; 50.0 ° to 71.6 °F), but not for 6 °C (10.8 °F) elevations from 16 ° to 22 °C (60.8 ° to 71.6 °F) (Carmichael et al. 1984b). In RBT, Wydoski et al. (1976) found that high temperatures delayed hyperglycemia and hyperchloremia in both wild and hatchery fish.

Ice

The addition of ice to maintain or reduce water temperature has been commonplace in hatchery fish-hauling methodology and livewell temperature control methods. A number of sources discuss amounts of ice required to change water temperatures in hauling tanks and live wells for defined periods of time including: Dupree and Huner (1984), Oklahoma Department of Wildlife Conservation (G. Gilliland unpublished), Honey Hole Magazine (reported by D. Campbell and S. Magnelia at http://www.honeyholemagazine.com/fish.htm), and Schramm and Heidinger (1988). However, none defined the numerous variables (initial livewell temperature, air temperature, amount of solar radiation, livewell insulation, and similar elements) that factor into such estimates and are needed for practical application or reported values..

Ice made from tap water containing chlorine or chloramines may release these harmful chemicals into livewells where it is used. Making ice from hot or boiled water or allowing tap water to stand in open containers (usually about 24 hours for small volumes of water) can help reduce or eliminate chlorine. However, chloramines in tap water may require chemical neutralization before being frozen. Types of sterilizing agents in local water supplies should be determined before that water is used to make ice intended for livewells, or additives that can neutralize both chlorine and chloramines should be utilized before freezing (however, such additives may not be federally authorized for use on food fishes).

True et al. (1997) used ice in bags to reduce and maintain water temperatures when handling marine fish where dilution of salt content in holding tanks was undesirable. Some tournament handling recommendations also suggest placing ice in plastic milk jugs or similar bottles. Again, isolating ice from holding tank water prevents uncontrolled addition of chlorine or other chemicals that may otherwise be released from the ice as it melts. Conversely, potential dilution of accumulating metabolic wastes in the livewell is also lost (but can be remedied by partial water exchanges) when ice is confined to bags or bottles. Fish may also collide with ice blocks or bottles floating in livewells and could be injured. Maximum benefits and tradeoffs need to be considered in selecting the best method to use. Some anglers have modified livewell circulation systems to allow a water-circulation hose to pass through an ice-filled ice chest before returning to the livewell.

One caution with the use of ice, however, relates to cooling water too quickly. Rapid temperature changes are potentially stressful, even when livewell water temperatures are dangerously high. For example, Dupree and Huner (1984) recommended tempering or acclimation times for transported hatchery fishes of 5.6 °C (10 °F) over 20 minutes. Biologists working with fish exposure to thermally-heated discharge waters from power plants and similar industries often consider changes ≤ 10 °C (18 °F) from ambient to be tolerable to most species, but water temperature changes > 10 °C (18 °F) over very short time periods may create harmful temperature shock problems. Abrupt temperature change problems can be confounded during long tournament days when ice may be added several times to a livewell resulting in temperatures that rise, drop rapidly, then rise and fall again several times. Temperature stability is important, but studies of specific limits are unavailable.

Water Chemistry and Additives

Oxygen

LMB have greater oxygen demands for survival and growth than many other fish species (Bulkley 1975). Lower lethal concentrations are slightly lower at cooler temperatures (Bulkley 1975), often at or below 1.0 ppm (note; ppm = mg/L); critical levels for larger specimens at 35° C (95.0° F) ranged from 1.20 to 1.32 ppm (Moss and Scott 1961). Moss and Scott (1961) also indicated the incipient lethal level for resting fish was not often reached until oxygen concentration was lowered to levels that are rapidly fatal, so the zone of resistance in resting fish may be very narrow (e.g., narrower than for active specimens). Swimming ability of LMB is impaired at 5 - 7 ppm at 25.0 °C (77 °F) and LMB can also sense and avoid dissolved oxygen levels as low as 1.5 ppm (Bulkley 1975). Logically, when dissolved oxygen levels become low enough to impair swimming ability or reach the 1.5-ppm avoidance level, confined fish may struggle to maintain balance or escape, with potential impacts on latent mortality levels. Low dissolved oxygen levels can also enhance the harmful effects of other toxicants (Smart 1981).

Oxygen requirements are affected by water temperature, pH, ammonia, carbon dioxide, fish size, fish species, activity, and length of transit [or holding] time (Blahm 1961; Dupree and Huner 1984). Additionally, fish with empty digestive tracts consume less oxygen than fish digesting food and small fish consume more oxygen than large fish, as do active or excited fish (Dupree and Huner 1984; Moss and Scott 1961). In practical application, confined LMB whose guts are filled with food may require more oxygen than specimens that have empty digestive tracts.

Dupree and Huner (1984) reported more oxygen was required in the first 15 minutes of confinement than at other times; further, they noted it was critical to supply additional oxygen in holding tanks before adding fish to avoid starting with an oxygen deficiency. Similarly, Piper et al. (1983) also indicated oxygen flow into holding and transport tanks should be twice the normal flow rate for the first hour of confinement, and then reduced

Piper et al. (1983) generally recommended dissolved oxygen levels for most fishes should be maintained at 7 ppm, but less than saturation, during holding and hauling. They indicated failure to maintain sufficient oxygen levels could result in latent mortalities associated with a buildup of blood lactic acid. Schramm and Heidinger (1988) advised livewells used to hold BB should be maintained above 5 ppm dissolved oxygen. For cyprinids, Brown and Gratzek (1980) recommended dissolved oxygen levels ≥ 3 ppm, but cautioned that 10 ppm was both wasteful and potentially harmful. Oxygen requirements for LMB increase 10 times between 5 ° and 30 °C (41.0 ° and 86.0 °F) (Coutant 1975). Schramm and Heidinger (1988) indicated BB consume more than twice as much oxygen at 38 °C (86 °F) than at 20 °C (68 °F), and also that oxygen levels can decline from 75% saturation to stressful levels in only 14 minutes when 4.5 kg (10 pounds) of BB are held in 56.4 L (15 gallons) of water at 30 °C (86 °F). Carmichael et al. (1984b) indicated LMB subjected to elevated levels of oxygen had plasma values similar to control fish, but brief exposure to decreased oxygen caused elevations in corticosteroids and glucose, but not chloride; fish recovered from low-oxygen stress in 24 hours.

It should be noted that dissolved oxygen levels in natural systems usually vary throughout the day. Oxygen levels are usually highest in late afternoon on sunny days and lowest around dawn on overcast days. Livewells filled at dawn, especially after several consecutive overcast days, could have low dissolved oxygen levels and additional agitation, aeration, or oxygenation may be needed before fish are placed in the livewell.

The amount of oxygen that water can hold is related to water temperature and salinity. Warmer waters and more saline waters hold less oxygen. Under livewell conditions, this again reflects back to water temperature being one of the most critical parameters associated with fish survival. Similarly, while the addition of some salts to livewells may help with osmoregulatory problems and improve survival, excess salt will reduce the oxygen carrying capacity of the water.

Aside from oxygen concerns in livewells, low oxygen impacts can occur in many tournaments where fish are removed from the livewell and placed in plastic bags for weigh-in. Schramm and Heidinger (1988) found that 4.5

kg (10 lbs) of LMB placed in 7.5 L (2 gallons) of water in a plastic bag at 30 °C (86 °F) could reduce the dissolved oxygen to stressful levels (< 3 ppm) in only 2 minutes. Long waiting periods between removal from livewells and actual weigh-in can cause dramatic dissolved oxygen- and temperature-stress problems. Some have advised holding waiting BB in perforated plastic bags in cooled tanks of water during such waiting periods (Gilliland 2000).

Finally, potassium permanganate, used at fish hatcheries for disease treatment since 1904, can also be used to improve dissolved oxygen levels (Smith et al. 1995). It does not add oxygen to the water, but oxidizes organic matter (forming brown magnesium oxide). Elimination of excessive organic material reduces the amount of oxygen that would otherwise be required to oxidize these organics and makes that oxygen more available to fishes. Although potassium permanganate is approved for use on some food fishes and is exempted from registration by the U.S. Environmental Protection Agency (EPA), there appears to be little suggestion this material has been used by tournament anglers to date. See additional discussion under potassium permanganate.

Anglers have utilized a variety of ways of providing oxygen to fishes in livewells. However, when resorting to pressurized oxygen or liquid oxygen, it is critical to note that more is not always better. McDonald et al. (1993) found that increased oxygen levels (due to oxygenation rather than aeration) proved successful in reducing some stress in trout, but they noted that high dissolved oxygen levels could cause blood acid-base and electrolyte imbalances, largely as a consequence of hypoventilation and increase in carbon dioxide (because fish do not need to breathe as rapidly in high oxygen situations, they may not discharge carbon dioxide fast enough and may experience a build up in the blood).

Another dissolved gas-related problem can occur when holding tank water has been chilled with concurrent intense oxygenation or aeration, then rapidly warmed. Levels of oxygen and other dissolved gasses that may be acceptable at cold-water temperatures may be supersaturated at warm temperatures. Rapid warming may cause gas bubbles to form in a fish's blood stream with ultimate physical damage and even death. Rapid temperature changes should always be avoided, especially a shift from cold to warm under highly oxygenated or aerated conditions.

Carbon Dioxide

Bulkley (1975) noted that BB may not be able to use available oxygen if carbon dioxide levels are high and resistance to low levels of dissolved oxygen may be less; however, he also indicated they have the ability to adapt quickly to non-lethal levels of carbon dioxide. Carmichael et al. (1984b) found that elevated levels of carbon dioxide caused increased plasma corticosteroid and glucose levels and with both confinement and carbon dioxide stresses, elevations in plasma values were even greater in LMB. They also found plasma levels returned to normal in 24 hours, except for chloride. Kwak and Henry (1995) found livewell mortalities inversely related to water pH values for LMB and suggested this may have reflected the impact of dissolved carbon dioxide. Thus, it is not sufficient to simply supply oxygen to fish in livewells, but to remove carbon dioxide as well, given that high carbon dioxide levels can confound oxygen uptake even when oxygen is available.

Ozone

Ozone has been utilized in water reuse systems along with beds of granular charcoal and found to support as many as six times more fish than conventional systems with oxygen and standard biofilters (Paller and Lewis 1988). Although this system has been used in hatchery holding and transport situations, there is no indication of application to livewell conditions. Nonetheless, it may represent a factor that could contribute to livewell survival.

Sodium Chloride

Numerous sources in aquacultural, hatchery-transport, and tournament-livewell literature discuss use of sodium chloride to improve survival of handled and transported fishes (Murai et al. 1971; Miles et al. 1974; Strange and Schreck 1978; Guest and Prentice 1982; Davis et al. 1982; Carmichael et al. 1984a; Carmichael and Tomasso 1988; Mazik et al. 1991; Harrell 1992). Mazeaud and Mazeaud (1981) stated the simple practice of manipulating osmoregulation results in excellent survival in heavily stressed fishes, and the addition of sodium chloride to holding-tank waters can be the most elementary method of addressing this issue. Mazik et al. (1991) indicated sodium chloride increased transport and recovery survival by decreasing the rise in plasma cortisol and glucose concentrations and reducing osmoregulatory dysfunction. Sodium chloride may also serve a secondary purpose in suppressing production of bacteria and other infectious agents in holding and transport waters.

Osmoregulatory problems, due to blood electrolyte disturbances, can cause death when fish are handled or hauled (Wydoski and Wedemeyer 1976), including LMB (Carmichael et al. 1984a,b). Davis et al. (1982) found osmoregulatory dysfunction was a major cause of mortality in STB that were handled and transported. In salmonids, Redding and Schreck (1983) also reported confinement stress greatly amplified osmotic imbalance problems. However, the simple practice of regulating environmental osmorlarity (through the addition of sodium chloride) results in excellent survival in heavily stressed fishes (Mazeaud and Mazeaud 1981). Mazik et al. (1991) recommended 1.0% sodium chloride for general use, noting it provided better survival and lower stress than 0.1% calcium chloride (often added to holding and hauling water to increase hardness). Miles et al. (1974) used 0.3% sodium chloride to reduce stress in handled muskellunge.

Murai et al. (1971) reported addition of sodium chloride improved transport survival of American shad, except where scale loss was the cause of mortality. Again, this reflects how handling prior to holding and transport can impact survival regardless of holding conditions. Among chinook salmon tested by Strange and Schreck (1978), sodium chloride was less effective than anesthesia in reducing mortality during handling. During work with alewife, Stanley and Colby (1971) found increasing salinity did not impact ability to tolerate acute temperature stress (sodium chloride added to water may improve survival in general, but will not increase heat or cold tolerance).

In addition to sodium chloride added to holding water, salt dips (actually dipping a fish by hand or in a net into a saltwater solution) commonly used in handling hatchery fish, also promote additional mucus production that may replace mucus lost during handling and help prevent subsequent infections. Some tournament guidelines recommend a fish be dipped in a 3% non-iodized sodium chloride solution for 10-15 seconds before release (Gilliland 1997). It is likely similar salt dips prior to placement in livewells or before culled fishes are released would enhance survival as well.

Finally, it should be noted that although LMB have been taken at salinities up to 29 ppt (parts per thousand), few are found above 3.6 ppt, and other species, like SPB, are even less salt tolerant (Bulkley 1975). Sodium chloride can be one of the most-beneficial additives to reduce livewell losses, but excess salt can cause mortality.

Some references advise that sodium chloride used in holding tanks or as salt dips should be non-iodized, but with no elaboration (e.g., Gilliland 2000). Gorbman's (1969) review of thyroid function and iodine metabolism in fishes indicates a wide range of variation between species and environmental conditions. Based on this summary, it seems unclear if iodized salt would be harmful or helpful under livewell conditions. Indeed, Gorbman's (1969) compilation suggests that increased iodine (or iodide) in the environment (needed to make thyroxine) may suppress thyroid activity and that nitrogen metabolism and ammonia excretion may be increased by elevated thyroxine levels. If true, the use of iodized sodium chloride in livewells may be beneficial. In any case, existing data suggest variation between studies makes drawing positive conclusions difficult or impossible. More study is needed to define how iodized sodium chloride impacts livewell mortality.

Calcium Chloride and Hardness

Calcium chloride has also been used as a water additive to reduce stress and latent mortality of fishes (Dupree and Huner 1984; Carmichael and Tomasso 1988). In particular, calcium chloride has been used to make transport water harder when fish are held or transported from very soft-water areas. The inclusion of calcium chloride along with sodium chloride in very soft waters (e.g., some East Texas reservoirs) may enhance survival, but dosages and appropriate conditions remain to be defined.

Potassium Permanganate

Potassium permanganate has been used in fish hatcheries to treat diseases, as well as to reduce organic loads and thus improve dissolve oxygen levels (Smith et al. 1995). It has been approved for use in certain food fishes and is exempted from registration by EPA (Smith et al. 1995). Tucker and Boyd (1977) reported the addition of 2-8 ppm decreased chemical oxygen demand (COD) of pond water. Because potassium permanganate oxidizes organic materials and inorganic substances, it can improve both biological oxygen demand (BOD) and COD (these refer to the amount of oxygen that is required for biochemical and chemical reactions, respectively; if both of these are very high, there may be little dissolved oxygen remaining for fish to use). They noted the chemical was toxic to bacteria, but pond waters containing large amounts of organic material often rendered it much less effective as a bactericide. Tucker and Boyd (1977) also reported toxicity levels for most fish species in 24-hour LC_{50} (i.e., the lethal concentration that causes 50% of the test animals to die in 24 hours) tests were 2-4 ppm with low organic concentrations, and that 4-8 ppm can typically be used safely with organics present. In practical application, a pristine trout stream flowing over clean gravel may have low levels of organic materials and low BOD and COD; however, a weedy reservoir embayment with dead vegetation on the bottom or livewell with fish slime and regurgitated stomach contents likely have high organic levels and high BODs and CODs. Potassium permanganate can be applied to each situation accordingly even without a detailed water chemistry analysis. Use of potassium permanganate has potential application in livewell situations, but has the negative aspect of staining or oxidizing many materials with which it comes in contact, including boat decks and carpeting designed specifically to have an attractive appearance.

Ammonia

Aside from water temperature and dissolved oxygen concentration, ammonia is probably next in significance in livewell water quality. In water, ammonia reacts to form ammonium and ultimately changes to nitrite and eventually nitrate. Ammonia is toxic to fishes, but even sublethal concentrations of ammonia can increase susceptibility of fish to other stress factors (Marking and Bills 1982). A variety of other physiochemical factors can impact the toxicity of ammonia. Smart (1981) reported that as salinity increases, there is a reduction in the percentage of unionized ammonia; low dissolved oxygen levels may increase the toxicity of ammonia; and ammonia toxicity increases as water temperature decreases, but this may only be a function of the reduced rate of ammonia detoxification at cooler temperatures. Thurston et al. (1983) also found toxicity decreased as temperatures changed from 12 to 22 °C (53.6 to 71.6 °F).

Rosenboom and Ritchey (1977) reported tolerance limits of LMB to unionized ammonia (the most toxic form) to be 0.7-1.2 ppm. Thurston et al. (1983) found the 96-hour lethal concentration levels were 0.75-3.4 ppm of unionized ammonia (34-108 ppm total ammonia nitrogen), there was no significant relationship of toxicity and temperature over the 3-9 ppm range, and no relationship of toxicity to the size of the test fish (fathead minnows). They reported 96-hour LC_{50} values for many freshwater fishes to be 0.14-4.2 ppm. At high levels, ammonia can literally cause chemical burning to gill filaments and fin membranes, which in turn, can result in reduced survival.

Many hatchery-produced fishes are held and transported without feeding (empty guts) to reduce ammonia concentrations and subsequent negative impacts (Dupree and Huner 1984). However, angler-caught fishes may have full guts when captured. Not only can digestive and excretory processes continue after capture, but regurgitation of stomach contents into the livewell is common. All can contribute to elevated ammonia levels.

Maintaining livewell waters at cool temperatures reduces metabolic rates of both the fish and bacteria in the water, thus reducing ammonia production rates. Additionally, replacing livewell water also helps dilute ammonia concentrations. Generally, the more frequently water is replaced, the better. Another method of ammonia reduction concerns the use of ammonia-absorbing materials like clinoptilolite, a naturally occurring silicate zeolite and ion-exchange resin that can remove up to 97-99% of ammonia (Marking and Bills 1982; Piper et al. 1983). It is commercially available in a granular form. Large granules are less efficient at absorbing ammonia, but smaller granules may clog drain and circulation lines more easily in certain situations (Marking and Bills 1982). Clinoptilolite does not remove nitrate, nitrite, or appreciably change hardness, but does have a good affinity for ammonium ions (Piper et al. 1983). Use of this material as part of inline livewell filter or circulation systems, or even in mesh bags suspended in the livewell, could improve survival of held fish. Amend et al. (1982) recommended 14 g/L (0.11 pounds/gallon).

More recently, other commercial products have been sold to reduce ammonia levels in livewells and hauling tanks. Some are package labeled specifically for ammonia control, while others are components of general water conditioner additives (often removes chlorine and chloramines also). These are largely unstudied and undescribed in the scientific literature, but appear to be chelate-type molecules that "lock up" ammonia and drop out of solution. Other than limited manufacturer or dealer claims, effectiveness, toxicity, side effects, and the like remain unconfirmed. Additionally, the legality of use on food fishes, destined to be released, may not be in accordance with aquaculturally approved chemicals, and several product labels state they are not Food and Drug Administration (FDA) approved.

Working with WB, Ashe et al. (1996) found ammonia uptake was similar in soft, hard, and dilute seawater; however, exposure time did affect plasma concentrations of ammonia. The longer the exposure, the lower the ammonia level required to cause mortality. Under livewell-holding conditions, the amounts of ammonia tolerated will be higher when fish are held for shorter times (i.e., shorter fishing days). Thus, fish may be able to tolerate lower water quality in livewells during tournaments with short fishing days than, in some cases, slightly improved water quality in livewells during very long fishing days.

pH

The pH value of water can also impact fish survival, both directly and indirectly by affecting other variables. Bulkley (1975) indicated LMB are rarely found below pH 4.7 and SMB below 6.0. Calabrese (1969) indicated pH below 3.9-4.2 and above 10.3-10.8 were lethal to LMB in 24 hours. McCormick and Jensen (1992) also noted LMB may survive below pH 3.9, but cannot maintain osmotic homeostasis below pH 5.0. However, Bulkley (1975) indicated even rapid changes within the acceptable pH ranges like those indicated above were not harmful.

Harrell (1992) found anesthetics like MS-222 may depress pH in poorly buffered waters, pH itself can be an additional stressor, and pH shock can cause plasma corticosteroid levels to remain high longer. Kwak and Henry (1995) found livewell mortality to be inversely proportional to pH, possibly reflecting impacts of dissolved carbon dioxide. Tomasso et al. (1980) found the 24-hour ammonia-nitrogen LC_{50} levels in CC to be much higher at lower pH (263.6 ppm at pH 7) than at higher pH (4.5 ppm at pH 9); but for unionized ammonia, lethal levels were highest at pH 8 and less at higher and lower pH.

Other parameters like carbon dioxide and decaying organic material can alter pH values, especially in small livewells with high densities of fish. Although chemical additives are available to increase or decrease pH, frequent water exchanges typically make such additives unnecessary. Caution should be exercised when fishes are taken from waters where ambient pH values are near upper or lower lethal limits (such as those given above for LMB and SMB) where livewell water quality may degrade more rapidly. Additionally, LMB taken from very soft, acid waters (< pH 5.0) may benefit from chemicals added to increase pH above ambient levels.

Buffers like TRIS (tris-hydroxymethyl-amino-methane) and sodium bicarbonate are sometimes used to avoid rapid changes in pH (Dupree and Huner 1984; Piper et al. 1983). Piper et al. (1983) recommended TRIS at 1.3 g/L (0.011 pounds/gallon). Amend et al. (1982) also found TRIS controlled accumulation of free carbon dioxide. Schnick et al. (undated) indicated sodium bicarbonate is FDA approved as a general purpose food additive; however, TRIS was not so listed.

Hydrogen Sulfide

Hydrogen sulfide serves as a respiratory depressant that may prevent BB from effectively using dissolved oxygen (Bulkley 1975). It can sometimes be a consideration in livewell waters, especially when water exchange occurs during weigh-ins where numerous boats are present in very warm, shallow waters waiting their turn to unload. Bottom substrate agitation and turbulence may elevate hydrogen sulfide levels in the immediate area with resulting uptake by pumps supplying livewells. Livewells should never be filled or refilled under such conditions.

Anesthetics

Numerous authorities have discussed the value of anesthetics in enhancing fish survival during holding and transport (Strange and Schreck 1978; Mazeaud and Mazeaud 1981; Carmichael et al. 1984a; and others). Adrenergic activation (the fight or flight reaction) in fishes results in effects on circulation, osmoregulation, and energetics, and anesthesia has been shown to sometimes reduce adrenergic responses to stress (Mazeaud and Mazeaud 1981). Anesthesia spares the full cortisol stress response experienced by non-anesthetized fish (Strange and Schreck 1978). Indeed, when fish were anesthetized during severe handling, the anesthesia later reduced the impact of a second stressor when fish were no longer anesthetized (Strange and Schreck 1978). Additionally, anesthetics can reduce respiration rate and activity, allowing greater loading capacity and better water quality

(Brown and Gratzek 1980). Anesthetics also reduce activity and may reduce mechanical damage to confined fishes (Collins and Hulsey 1963).

Guest and Prentice (1982) and Piper et al. (1983) defined states of anesthesia. Understanding these states can be important because, although limited sedation is desirable in handling, holding, and transport of fishes in many instances, deep sedation is not (Dupree and Huner 1984). Deeply sedated fish may settle to the bottom and suffocate or block water circulation openings.

Numerous anesthetics have been used in fish transport and holding, but nearly all are not approved for use on food fishes and should never be added to livewells. These include the following: quinaldine or 2-methylquinoline (Davis et al. 1982; Guest and Prentice 1982; Lambert 1982; Carmichael and Tomasso 1988), metomidate (Ross et al. 1993), thiouracil (Brown and Gratzek 1980), urethane or ethyl carbamate (Brown and Gratzek 1980), sodium amytal (Brown and Gratzek 1980), sodium seconal (Brown and Gratzek 1980), etomidate (Davis et al. 1982; Limsuwan et al. 1983; Carmichael et al. 1984a); diazepam (Carmichael et al. 1984a), tertiary amyl alcohol (Dupree and Huner 1984), carbonic acid (Dupree and Huner 1984), sodium bicarbonate (Dupree and Huner 1984), benzocaine (Limsuwan et al. 1983), valium (Murai et al. 1979), and sodium barbital (Bardach et al. 1972).

Among anesthetics that can be used are the following: carbon dioxide (Taylor and Roberts 1999), MS-222 or methane tricainesulfonate (Collins and Hulsey 1963; Strange and Schreck 1978; Murai et al. 1979; Brown and Gratzek 1980; Davis et al. 1982; Guest and Prentice 1982; Sylvester and Holland 1982; Carmichael and Tomasso 1988; Harrell 1992), and clove oil (Taylor and Roberts 1999). However, MS-222 requires a 21-day withdrawal period before exposed fishes can be harvested and used for food (Carmichael and Tomasso 1988). Thus, although MS-222 could be used on food fishes like LMB, the required withdrawal period is impractical in most cases.

Sylvester and Holland (1982) found MS-222 resistance (resistance to anesthetic affects) increased with water hardness and increasing fish density, and induction of loss-of-equilibrium decreased with increasing temperature. Carmichael et al. (1984a) tested MS-222 on transported LMB and found improved survival. Dupree and Huner (1984) recommended MS-222 as the anesthetic of choice for salmonids. Guest and Prentice (1982) reported fin hemorrhaging and water quality problems with the use of quinaldine on blueback herring.

Clove oil is the distilled oil of the clove tree (*Eugenia aromatica*) and is composed of phenols, eugenol, eugenol acetate, and cariofilen-5 (Taylor and Roberts 1999). Clove oil is cleared for use in medicine and dentistry, and at 25 - 120 ppm (up to 1,000 ppm in some cases) can produce anesthesia in fish. Although anesthetic use of clove oil in other countries occurs, there has been limited application in fishery work in the U.S. to date, and no apparent utilization in fishing tournaments. Considering only carbon dioxide and MS-222 are approved for use on food fishes (and MS-222 requires a long withdrawal period), use of clove oil under various conditions and for different fish species sought by tournament anglers should be evaluated.

Antibiotics

Bacteria and other microorganisms occur naturally in river and lake water typically used to fill livewells. These microorganisms consume oxygen and release toxic metabolites (Amend et al. 1982). In doing so, they degrade livewell water quality resulting in additional stress to confined fishes and potential reduction in subsequent survival. Some such organisms may directly cause infections and disease conditions in exposed fishes under livewell holding conditions (Plumb et al. 1976; Robertson et al. 1987). Additionally, stress associated with confinement and exposure to lower-quality water can lower disease resistance and activate latent disease organisms already present in held fishes (Wedemeyer 1970). Indeed, numerous studies have mentioned infections among tournament-caught fishes as significant sources of mortality. Esch and Hazen (1980) discussed associations between elevated temperatures, blood chemistry, and stress to red-sore disease (*Aeromonas hydrophila*) in LMB. Among tournament-caught LMB studied by Moody (1975), over-all mortality ranged from 22.3 to 43.8% and was primarily due to bacterial and fungal infections associated with handling. In a study of bacterial diseases associated with mortality in LMB after tournament capture, stress, and release, Steeger et al. (1994) indicated bacterial diseases were potential problems for fish released from tournaments and conditions detrimental to fish well being were found during tournaments. They further reported bacterial pathogens present in 42 of 76 tournament LMB included *A. hydrophila* complex, *Pseudomonas* spp., *Edwardsiella tarda*, and *Flexibacter* (*Cytophaga*) *columnaris*.

Antibiotics added to livewell water can certainly reduce numbers of microorganisms in the water and reduce the potential of infection among held fishes. However, most antibiotics are typically not federally authorized for use on food fishes under typical tournament conditions. Maintaining good dissolved oxygen levels in livewells can also help reduce the potential impact of bacteria, fungi, and related organisms, as can the addition of sodium chloride and potassium permanganate. Collectively, as better water conditions within a livewell are maintained, the less significant many concerns associated with microorganisms will be. However, some seriously virulent viruses, bacteria, and other agents may still be very infectious, even under the best of conditions. Simply confining fish together and exposing them to these organisms may be sufficient to result in infections and death. Road-runner tournaments where anglers fish multiple sites and combine fish for weigh-ins are particularly risky, as is rapid relocation of a boat and livewell from one location to another in a short period of time (without attempts to clean or dry the livewell).

Infectious diseases are common consequences of stress factors and are stressors themselves (Robertson et al. 1987). Activation of latent disease organisms as a result of immunosuppressive effects of stress-related corticosteroids can cause death when fish are hauled and handled (Wedemeyer 1970). Losses related to bacterial diseases were noted as potential problems by Steeger et al. (1994) for fish released from tournaments. In addition to infection-related mortality factors in fish that are handled, held, and subsequently released, bacteria in hauling and holding water consume oxygen and release toxic metabolites (Amend et al. 1982), which also confound fish survival. As a result, hatchery holding and transport techniques have long utilized antibiotics. Antibiotics have also been used by tournament anglers. In one study, Kwak and Henry (1995) found over 10% of tournament anglers used antibiotics. Other unpublished observations suggest that nearly all competitors in some events may use water additives containing antibiotics. A variety of antibiotics have been used for holding and transport situations including the following: oxytetracycline or terramycine (Welborn and Barkley 1974; Archer and Loyacano 1975; Seidensticker 1975b; Plumb et al. 1975; Carmichael and Tomasso 1988; Pitman and Gutreuter 1993; Peterson and Carline 1996), neomycin (Amend et al. 1982), acriflavin (Carmichael and Tomasso 1988), furacin or nitrofurazone (Carmichael and Tomasso 1988), and nitromersol (Plumb et al. 1988), among others. Additionally, biological stains like methylene blue (Amend et al. 1982), Victoria green, and malachite green (TPW, unpublished observations) have also been used as antibiotics. Despite common and widespread use to enhance fish survival, none of the antibiotics or biological stains listed above are FDA or EPA approved for use on food fish without at least a 21-day withdrawal period, and most are not authorized at all (Schnick et al. undated).

Ultraviolet sterilizers used in aquarium culture could be adapted for livewell use, but many problematic microorganisms probably occur on held fish rather than free in the water, so impact on fish survival would probably be minimal. Additionally, bacteria-laden waters can be eliminated in most cases by simply flushing the livewell with fresh water and with the use of sodium chloride and potassium permanganate as discussed previously.

Defoamers

As slime, released metabolites, and other organic materials accumulate and decay in holding tank water, surface foaming often results. Because thick layers of surface foam can block oxygen and carbon dioxide exchange and obscure observation of fish condition, efforts are often made to reduce foam accumulation. Commercial defoamers are typically food-grade silicon-based materials. These substances are generally not considered toxic and their utilization can improve water quality and enhance fish survival.

Charcoal

Use of activated charcoal to improve water quality in aquaria has long been practiced. Paller and Lewis (1988) discussed use of charcoal beds to increase holding tank capacity. Although charcoal (perhaps as inline filter cartridges) could be helpful in improving water quality in livewells, simply exchanging water within the livewell reduces the necessity of charcoal filters in most situations.

Fuel and Oil Contamination

Hartley and Moring (1995) found that when LMB and SMB tournaments had long weigh-in periods (up to 2 hours), livewells recirculating water at the weigh-in site often had elevated levels of fuel and oil. Procedures that have long waiting periods, where numerous boats are crowded in small areas and shallow waters, can result in reduced livewell water quality and subsequent reduced fish survival after release. Livewell waters should not be exchanged under these conditions.

Turbidity

Wallen (1951) indicated lethal turbidity levels for LMB ranged from 52,000 to 150,000 ppm (mean 101,000 ppm). Hartley and Moring (1995) found for LMB and SMB in tournaments that had long weigh-in periods (up to 2 hours), livewells recirculating water at the weigh-in site often had elevated levels of sediment. Procedures that have long waiting periods where numerous boats are crowded in small areas and shallow waters can result in increased turbidity and sediment loads in livewells and in subsequent reduced survival after release. Livewell waters should not be exchanged under these conditions.

Chlorine and Chloramines

In most cases, livewells are not filled with tap water containing chlorine or chloramines, but rather with lake or river waters that lack these substances. Consequently, water conditioners and additives focused on removing chlorine and chloramines are unnecessary. An exception, however, may occur when ice made from chlorine- or chloramines-treated tap water is added to livewells to reduce water temperature. See additional comments under Ice.

Commercial Water Conditioners

Numerous commercial water-conditioning products are available on the market to improve water quality and fish condition in livewell and bait bucket situations. Some that address specific aspects of water quality like pH and ammonia removal have already been addressed herein. Others contain a number of components and are designed to perform several functions. These products may be seeing increased use in tournament angling.

Manufacturers were unwilling to discuss the contents of their water conditioners when contacted as part of this study. Although reluctance to discuss their products was usually labeled as a "trade secret," some compounds used in such water conditioners are clearly problematic in both a legal and medical sense.

Only one paper in the scientific literature appears to elaborate on water conditioners. Plumb et al. (1988) indicated water conditioner contents included unspecified amounts of sodium chloride, potassium chloride, sodium thiosulfate, pyrogenic silica, dimethylketone, alpha-methylquinoline, methylene blue, nitromersol, ethylenediaminetetraacetate [EDTA], triethyleneglycol, and acriflavin. Among these, sodium and potassium chlorides help with osmoregulation, sodium thiosulfate removes chlorine (if present), pyrogenic silica is a defoamer, alpha-methlyquinoline or quinaldine is an anesthetic and dimethylketone or acetone is needed to dissolve quinaldine, nitromersol and methylene blue are antibacterials, acriflavin is an antibiotic as well, and EDTA is a buffering agent. The inclusion of triethyleneglycol is less clear. This substance is most frequently used in polyester resins as an antioxidant coating. It is reasonable to assume that all water conditioner manufacturers use similar chemicals to achieve similar goals. However, information provided by Schnick et al. (undated) indicates virtually all of these components are not federally authorized for use on food fishes.

Behavior in Livewells/Confinement

Fish behavior after being confined in a livewell or other hauling or holding tank often relates to subsequent mortality or survival. Mazeaud and Mazeaud (1981) discussed how fright was a very common stress factor and, although important, was not quantified. Working with American shad, Backman and Moss (1990) found the intensity of excitement following capture to be a primary determinant of posthandling mortality. Excitement-related injuries and increased mortality rates can apply to any species of fish. Ideally, confined fishes need to be calm and not additionally stressed by undesirable temperatures, oxygen levels, or other water chemistry problems. Similarly, confined fishes may be either agitated or calmed by the presence of other fishes. Although some strongly-schooling fishes may be less excited and less stressed when large numbers of their kind are held together (Backman and Moss 1990), most tournament-caught species would not be expected to display this behavior. Indeed, situations may occur when one particularly agitated fish may promote struggling or reactive behavior in other fishes confined in the same livewell or hauling tank. In some situations, survival may be improved by placing extremely agitated species or individuals in separate livewells.

Another aspect of tournament-related mortality involves fish being held in livewells or other tanks that are too small. Such fish may struggle to maintain a natural position (e.g., where the body is straight or upright). Such struggling can dramatically exhaust the fish or cause physical injury, both of which can reduce subsequent survival. Yet another aspect of behavior in confinement relates to aggressive actions between confined species or individuals. In most cases, this is usually not problematic under livewell conditions. When two or more fishes are caught and placed in livewells, they are generally sufficiently stressed and disoriented that aggression is typically not problematic. Exceptions can occur and need to be considered.

Anesthetics often depress respiratory rates of confined fishes otherwise elevated by behavioral excitement (Blahm 1961). See additional discussions under Anesthetics.

Light Levels

Light levels during holding may also have an impact on survival. Many fish may become calm when held in darkened or reduced-light livewells, as opposed to those that are brightly lighted or uncovered. Additionally, fish in uncovered livewells may be frightened or disturbed by activity in their vicinity. Such fish may collide with the sides of the container or attempt to jump and sustain injury in either case. Carmichael et al. (1984b) examined blood chemistry conditions indicative of stress and suggested handing in the dark may be less stressful than in daylight, but went on to note that handling in the dark was still stressful. Given these points, livewells should probably be kept darkened while fish are being held. Additionally, care should be taken to avoid frightening fish by rapidly opening the lid of darkened livewells and abruptly exposing fish to bright sunlight or abruptly turning on artificial lighting (resulting violent responses could cause injuries).

Loading

Water quality is a function of loading density (Amend et al. 1982). Robertson et al. (1987) reported that crowded conditions caused alterations in a variety of variables associated with stress responses. Meals and Miranda (1994) discussed how mortality increased with the number of fish held in livewells during LMB tournaments and the impacts of temperature change at high densities also caused more fish to die.

Dupree and Huner (1984) also indicated the number of 35.6-cm (14-inch) "food fish" per L (0.26 gallon) at 18.3 °C (65 °F) was as follows: 1.1/1-6 hours of transport, 0.8/12 hours, and 0.5/24 hours. They also stated this rate could be increased by 25% if pure oxygen was added and for each 5.6 °C (10 °F) rise in water temperature, density should be reduced by 25%.

In a study of tournament mortality in LMB, Kwak and Henry (1995) found fish density in two tournaments ranged from 0.011 to 0.43/L (0.042 to 1.629/gallon). These values were calculated from the 1-12 LMB/livewell documented. Many studies have found a direct relationship between numbers of fish held and mortality (Dupree and Huner 1984; Hartley and Moring 1995; and others). However, Schramm et al. (1985, 1987) conversely indicated larger catches among tournament teams catching LMB had lower proportions of dead fish. Backman and Moss (1990) found a significant inverse relationship between the numbers of American shad held and mortality, but associated this with stress-mitigating schooling behavior. In general, water quality can be expected to decrease and mortalities increase as livewell loads of fishes are increased.

Holding/Transport Time

Water quality is also a function of transport [or holding] time (Amend et al. 1982). Additionally, hauling [and holding] has a significant effect on blood plasma characteristics related to stress (Carmichael et al. 1984a, b). In a study of mortality among hatchery-produced and transported fishes including LMB, Pitman and Gutreuter (1993) found hauling time to be the most important variable Seidensticker (1975b) also report reduced handling and hauling stress improved survival of LMB. Seidensticker (1975b) also described how shorter fishing days (i.e., shorter times in livewells) actually improved survival of LMB in tournaments; however, incorporation of mortality data from different days, conditions, and other variables confounds definitive conclusions from this report. Miles et al. (1974) found a reduction in the frequency and duration of handling improved survival in muskellunge.

Transport Conditions

In their study of LMB mortality after containment in livewells, Plumb et al. (1988) reported that during tournaments, fish in livewells were subjected to often-traumatic rides in rapidly moving boats. Some tournament anglers allow livewells to drain completely or partially during travel from one angling location to another (TPW, unpublished observations). Not only is the physical violence fish must endure potentially damaging with subsequent reductions in survival, but chemicals added to the livewell to reduce stress and enhance survival may be completely drained out every time the boat moves to another location. Similarly, Goeman (1991) found tournament-caught walleye had poorer survival during rough-water conditions.

Dead Fish

Fish that die in livewells should be removed immediately (Schramm and Heidinger 1988). Dead fish begin to decay quickly and cause water quality to deteriorate rapidly. Additionally, regurgitated food should also be removed or flushed from the livewell for the same reasons.

Livewell Size, Construction, and Operation

Overview

In general, there is a wide array of livewell characteristics among commercial brands of boats (Table 1). In addition to the physical differences and mechanical abilities of commercial livewells, operator control over function is an unquantifiable variable. Even large-volume, insulated livewells with excellent oxygenation and circulation capabilities may not be operated to provide the best opportunity for fish survival under tournament conditions. Tournament operators may check for the presence of an operating livewell at the onset of activities, but then rarely if ever monitor use during the event and may only penalize points for dead BB brought to the weigh-in. Gilliland (2000) found that tournament LMB anglers often failed to run their livewell systems to full capability and best benefit to confined fish, even when boats were equipped with recirculation-aeration systems. He also found many tournament anglers did not use ice or salt in livewells without being specifically instructed to do so.

Livewell Size, Shape, and Number

All built-in livewells among commercially produced boats examined were rectangular in shape with straight, vertical sides (Table 1). Clearly, livewells need to be of sufficient size and volume to accommodate angler catches (especially quality- or trophy-size fishes), but most manufacturer's built-in livewells are far too small. Several livewells are less than 30.5 cm (12 inches) in width and depth, with some only 25.4 cm (10 inches) deep, and others were less than 50.8-61.0 cm (< 20-24 inches) in length, with volumes less than 60.1 L (16 gallons), and some under 45.1 L (12 gallons). However, several others use designs over 91.4 cm (36 inches) long and in excess of 112.7 L (30 gallons). One add-on livewell was also rectangular, but had sloping sides (designed to be added to flat-bottomed boats with sloping sides). Other plastic, add-on tanks were rectangular, round or oval with straight sides.

During two LMB tournaments, Kwak and Henry (1995) reported livewell volumes in actual use ranged from 15.1 L to 189.2 L (4.0-50.0 gallons), with mean capacities of 59.5 L (15.7 gallons) for the first event and 80.5 L (21.3 gallons) for the second. The optimum livewell size and shape for a particular type of fish or tournament remains undefined. In general terms, larger water volumes are more stable than smaller volumes and should be better for overall fish survival. However, Kwak and Henry (1995) did find a larger proportion of "weak" LMB in tournament-boat livewells that were large; they suggested this could reflect more physical action within the well or longer times required to exchange livewell water with fresh lake water. Kwak and Henry (1995) postulated fish in larger livewells may be subject to more physical exertion and injury, especially during removal of fish for weigh-ins, and suggested that intermediate capacity tanks may prove optimal.

Use of either one or two livewells per boat was typical among boat builders. Additionally, where one or two wells were installed at the factory, many were also available with dividers.

Actual shape and volume generally appear to reflect physical considerations associated with other aspects of boat layout (e.g., seats, rod compartments, gas tanks, weight and boat speed), and not designed to focus on construction for the best survival of fish being held. Fish holding tanks ideally have high surface area to volume rations. The greater the surface area, the more rapidly oxygen and carbon dioxide can be exchanged. In this regard, some livewells that approach a cube shape are less desirable than longer, wider, and shallower rectangular tanks. However, an additional aspect of surface area to depth consideration is that tanks should not be too shallow to hold larger fish or groups of fish. Tanks under 30.5 cm (12 inches) in depth barely hold enough water to allow a large, trophy-size LMB or STB to maintain an upright position. Large fish in water too shallow to allow a natural upright position can exhaust themselves attempting to stay upright and may be physically injured in the process. Interestingly, despite the competitive-angling industry's obsession with large fish, few boats have livewells designed to handle truly trophy-size fish.

An additional aspect of livewell size relates to weight when filled with water. Even a meager 41.3-L (11-gallon) livewell adds 41.7 kg (92 pounds) of additional weight to a boat when it is filled with water. Livewells of 142.8 L (38 gallons), or more, add over 136.1 kg (300 pounds) of weight when filled. Because tournament anglers often range as far and as fast as possible during events, excessive livewell weight that slows boat speed and limits range is undesirable. Given this concern, it is easy to understand why some of the most-popular tournament bass boats have livewells that are functionally too small for optimum fish survival.

Other Livewell Construction Aspects

Few manufacturers describe the actual construction materials used in their livewells. Some state that their livewells are insulated, but most do not specify. Smooth interior walls help reduce abrasive injuries. Presumably, most livewells are designed with few internal abrasive surfaces, but again, most do not specify. Backman and Moss (1990) found injury risk was lessened for American shad when the hauling tank was lined with soft material. None of the livewell descriptions examined indicated any particular effort to provide soft-sided construction that can help reduce damage when fish contact the walls.

Livewell standpipe position can also impact livewell utility and fish survival. Standpipes that are placed in the most advantageous positions for fish survival (centrally located and away from walls or recessed into sides) can be obstacles to easy fish removal. Conversely, standpipes placed close to walls or corners may actually trap fish and result in struggling and injury or exhaustion-related losses. Manufacturers do not generally describe standpipe position other than to mention the functional drain height of the standpipe.

Operational Aspects

Timing of Operation

Regardless of whether a particular livewell is equipped for circulation, agitation, aeration, oxygenation, or combinations of these features, timing of their application varies. Historically, most boats have not been designed to allow constant running of this equipment. Boat batteries could only support a limited amount and duration of electrical use before boat engines must be restarted to recharge the batteries. Controllers were specifically developed to regulate the frequency and duration of peripheral equipment associated with the livewell. For example, electric power may be supplied for 60 seconds every 3 to 5 minutes. Schramm and Heidinger (1988) found that these timers frequently did not run long enough to supply sufficient oxygen to large number of BB in a livewell. More recently, equipment designed for continual operation has reportedly become available, but how rapidly it gains wide use remains to be seen.

Circulation, Agitation, Aeration, and Oxygenation

There are, of course, countless designs used to circulate water and add oxygen to livewells. Water pumps may circulate water within the livewell, fill and empty the well, or perform all three functions. Some units use agitators to stir water and increase oxygen levels, others may spray water from jets or bubble air through the tank, and still others may be designed to directly add oxygen from bottles of compressed gas or liquid oxygen. Gilliland (2000) indicated that oxygen systems were only available on two brands of bass boats. There appears to be almost no studies designed to examine which of these varied methods ultimately provides the best results in terms of dissolved oxygen and carbon dioxide levels and general water quality. In their study of LMB tournaments, Kwak and Henry (1995) found 68.8-84.1% of boats had water flow systems to add fresh water and 15.9-31.2% had the ability to recirculate water within the livewell. They also reported 66.7-77.3% had water-stream aeration, 25.0-26.1% used bubblers, 0.0-3.1% used agitators, and 1.6-7.2% had no setup for agitating or oxygenating their livewells. Gilliland (2000) reported total mortality among livewell-held LMB, with a subsequent 6-day holding period, was 21.6% for livewells using continuous, flow-through aeration and water exchange; 18.0% for livewells with constant recirculation of tank water, additions of ice and salt, and half tank volume water exchanges twice daily; and 32.3% when anglers were given no instructions and permitted to operate livewells in any fashion. Gilliland (2000) also compared 6-day total mortality among LMB held in livewells with ambient, flow-through water (15.6%) and others receiving compressed oxygen (6.7%).

Gilliland (2000) pointed out an advantage related to use of compressed oxygen in livewells. When gases are released from pressurized containers and expand, they become cooler. Thus, use of compressed oxygen may improve survival in livewells by helping to maintain cooler water temperatures in addition to the benefits of oxygen itself.

In situations where bubbles are used to add oxygen and remove carbon dioxide from holding tanks, bubble size can be important. Very small bubbles may not provide good circulation within the tank and very large bubbles have less surface area to bubble volume ratios with which to add oxygen and take away carbon dioxide. Intermediate-sized bubbles that enhance water circulation and still have good surface to volume ratios are most desirable (Emmens 1974). When hauling tanks are aerated with running water, Brown and Gratzek (1980) recommended flows of 3.8 L (1 gallon) per minute for each 95 L (25 gallons) of water with one pressure jet for every 95 L (25 gallons). Schramm and Heidinger (1988) recommended a livewell containing 0.6 kg/L (0.5 pounds/gallon) of water should have a 37.6-L (10-gallon) water exchange every 2 hours when water temperatures are below 26.7° C (80° F) and every hour when above 26.7° C (80° F) to keep metabolic waste buildup to acceptable levels.

Regardless of equipment or efficiency, some anglers complain that aerators drain boat batteries and make noise that frightens fish and reduces their catch (Gilliland 1997). Even if true, if all anglers use the same equipment in the same way, any handicap impacts all equally. Educating manufacturers, tournament organizers, and anglers about the importance of proper livewell operation and tournament regulations requiring appropriate operation can enhance fish survival.

Water Temperature in Livewells

Given that water temperature is so critical in simply maintaining fish alive, as well as reducing stress, it is one of the primary concerns in livewell operation. Some livewells are insulated to better maintain temperature stability and avoid shifts to hot or cold extremes; however, some livewells completely lack such insulation. Commercial cooling units are available, but few boat or livewell manufacturers provide them. High cost and electric demands are problematic. A number of homemade cooling units are sometimes added to livewell setups. A commonly used example involves running one of the water circulation system hoses though an ice-filled ice chest and back to the livewell. This allows livewell water to be cooled without placing ice directly in the livewell where it takes up room, dilutes additives, and may add chlorine or other chemicals.

Exchanging livewell water with ambient water may help moderate temperature extremes. However at best, this method usually provides water at ambient surface temperature. Maintaining livewell temperatures below this level is often desirable. Although Kwak and Henry (1995) recommended that water in livewells during LMB tournaments should be exchanged with lake water as frequently as possible to reduce the buildup of metabolic wastes, others only advise this frequent lake-water exchange at or below 23.9 °C (75 °F). Above 23.9 °C (75 °F), some tournament supporters prefer to use ice to maintain temperature and disregard metabolic waste buildup. Ice added to the livewell is nearly always the method of choice to reduce or maintain temperature. See previous discussions under Ice and Water Temperature.

It should be noted, that some pumps can actually increase holding tank temperature. Dupree and Huner (1984) indicated one 7.6-cm (3-inch) gasoline pump circulating water in a 4,698-L (1,250-gallon) tank could elevate temperature by 1.4 °C (2.5 °F) per hour. Smaller electric motors associated with boat livewells would be expected to be of little concern in this regard, but it remains a point to be considered.

Livewell Position

Livewells may be positioned at many different places in boats. Kwak and Henry (1995) reported livewell-held fish were often subjected to stressful rides during rapid runs from one fishing location to another during tournaments. It is generally believed that fish in bow-mounted livewells experience greater damage during rough travel than in wells in other boat positions (though data is generally lacking). Kwak and Henry (1995) reviewed tournament boat livewell positions and found them to be stern (65-70%), bow (25-28%), side (3-4%), and center (2-3%). Logically, stern-positioned tanks probably do experience a smoother ride than those in other positions, but scientific confirmation is lacking.

Sterilization

Hatchery holding and hauling procedures have long involved cleaning and sterilization of hauling tanks with products like calcium hypochlorite (Dupree and Huner 1984), potassium permanganate (Smith et al. 1995), and others. However, none of the BB tournament procedures reviewed or competitive angling events considered during preparation of this report were found to stress this point. This seems particularly peculiar in view of how livewells may hold fish and water from a given lake on one day, then be used on a second water body only hours or days later.

At the very least, fish slime and other organic materials, as well as bacteria and other microorganisms, will be left behind in the livewell and circulation systems when fish have been removed, the livewell drained, and the fishing day has ended. When the livewell is filled again, these substances can immediately initiate a decline in water quality. The very nature of competitive fishing suggests it could be a vector for transportation of fish diseases from one water body to another. With current concerns over LMB virus losses known to occur in tournament lakes (Plumb et al. 1999; TPW, unpublished data), sterilization of livewells between uses should be considered mandatory by both anglers and tournament organizers.

A final aspect of livewell sterilization relates to inadvertent transportation of undesirable organisms from one location to another. For example, zebra mussels (*Dreissena polymorpha* and *D. bugensis*) invaded the Great Lakes from eastern Europe and have become an aquatic pest of great importance (Howells 1999). They have microscopic larval and juvenile stages that can easily go undetected in livewells and associating plumbing. Transportation of these mussels can be illegal under both federal and state laws, not to mention the potential devastating ecological damage they can inflict on an aquatic ecosystem if introduced. Similarly, spiny waterflea (*Bythotrephes cederstroemi*) and spiny daphnia (*Daphnia lumholtzi*) are Old World crustaceans that have also invaded the U.S. (Howells 1999). Spiny waterflea directly consumes other small organisms needed for food by young BB and other fishes. Spiny daphnia appears to be able to replace native waterfleas in some situations and is probably less palatable than more-desirable native species. Again, these tiny animals and their eggs can be easily transported by anglers in uncleaned livewells. Among all aspects of livewell operation and maintenance, sterilization is one thing that should be done after use and does not require time during a tournament. Livewells should never be placed in new water bodies until and unless they have been thoroughly cleaned and sterilized.

Additional Considerations

Drug Approval

A wide array of chemicals including anesthetics, antibiotics, biological stains, and salts are regularly added to livewells to improve survival of held fishes. Although there is little doubt that many of these agents do indeed improve the survival of caught and held fishes, most are not legally authorized for use on food fishes. For example, in their paper on clove oil, Taylor and Roberts (1999) indicated that only one anesthetic, MS-222, was approved for use on food fishes, and it had a 21-day withdrawal period before exposed fishes could be consumed [carbon dioxide can also be used]. Schnick et al. (undated) provided lists of chemicals approved for aquaculture and fisheries resource management work by the EPA and FDA. Their lists indicate most reagents regularly included in commercial water additives used during tournament angling are not approved.

Only one major reference on live release of BB (Schramm and Heidinger 1988) clearly refused to recommend use of livewell additives based on FDA restrictions. Other sources continue to boldly advise their use, but they need to consider the potential moral and legal ramifications of those recommendations. True, the use of quinaldine dissolved in acetone as an anesthetic in livewells can be expected to improve survival rates of treated fishes, but neither substance is approved for use on food fishes, and acetone is a known carcinogen. The concept of releasing fish that have been treated with illegal or carcinogenic chemicals with the possibility that such fish could be caught and eaten by another angler shortly after release needs to be examined more closely. Potential legal consequences of placing the general public at risk by allowing anglers to release such fish in public waters also needs to be evaluated.

Selection of Tolerant Strains

Numerous authorities have suggested development of stress-tolerant strains of fish. Woodward and Strange (1987) commented that years of artificial selection have resulted in impacts on primary and secondary responses to stress, with intensively-cultured fishes being inadvertently and advertently selected for their insensitivity to stressors. Mazeaud et al. (1977) and Mazeaud and Mazeaud (1981) also suggested genetic selection for strains of fish with low-reactions to stress, as did Robertson et al. (1987). Gustaveson et al. (1991) specifically called for production of strains of LMB better adapted to handling and catch-and-release stresses.

LMB production and research efforts have historically focused on growth rates, hybridization and intergradation, ploidy, gynogenesis, and catchability to improve BB fisheries, but no published efforts appear to have been directed toward more-stress tolerant LMB. Given (1) the current focus on LMB fisheries in general and tournament-BB angling specifically, (2) the desire for larger BB and FLMB, (3) increasing tournament activity and impacts on fishery resources, and (4) documented reduced stress tolerance in larger LMB and among FLMB and their intergrades, an important aspect for study should be research creating more stress-tolerant strains.

Educational Concerns

Like others, Gilliland (2000) found that initial mortality observed in LMB tournaments had little relationship to latent or total (initial + latent) mortalities seen 6 days later. He found that because most anglers did not see losses following release at the end of the tournament, they did not believe significant mortality was occurring. He also suggested LMB-tournament anglers may be ignorant of water quality needs of the fish they caught and held, and further that many simply assumed modern bass boats were adequate to keep fish healthy.

Previous Tournament-related Recommendations

A number of authorities have offered suggestions concerning reducing the impact of tournament angling on LMB populations and other species. As early as 1975, in the early days of intense BB tournament angling, Seidensticker (1975b) advised tournaments should not be held when water temperatures were 21 °C (69.8 °F) or greater. He also noted the value of reduced angling-day lengths or multiple weigh-ins and noted that reduced handling and hauling stress improved survival. Plumb et al. (1988) examined livewell mortalities and also recommended against catch-and-release of LMB in warm weather, as did Bennett et al. (1989). Schramm et al. (1987), Weathers and Newman (1997), and Wilde (1998) indicated BB tournament organizers schedule events for cooler months. Gustaveson et al. (1991) and others also cautioned about reduced stress tolerance associated with spawning or disruption of reproductive activities.

Gustaveson et al. (1991), following a study of LMB responses to angling stress, recommended 1) fish should be played and landed within 2 to 3 minutes, 2) tournaments should be held when water temperatures are cool and fish are in shallows, and 3) use of aerated livewells should be required.

Despite cautions that span over a quarter-century about LMB losses during summer conditions, no restrictions on warm-weather tournaments are in place in Texas. Indeed, Wilde (1998) noted that throughout the southern states where surface water temperatures regularly exceed 30 °C (86.0 °F), many organizations continue to sponsor tournaments during the summer months. Similarly, although some northern states and provinces restrict angling during spawning seasons, Texas and other southern states, where spawning seasons are more protracted, generally do not regulate tournament or non-tournament angling during major reproductive periods.

Schramm and Heidinger (1988) offered a number of alternatives to typical weigh-in tournaments. Unfortunately, tournament procedures that provide the best survival opportunities for fish and result in the least damage to the resource lack the desired spectacle of fish being displayed before a large crowd that many tournament anglers desire.

TPW Recommendations

A set of guidelines have been prepared by TPW Inland Fisheries related to recommendations to improve fish survival at the initial onset of angling activity and fish capture, livewell management techniques, and weigh-in and subsequent release procedures (available from the department). Sources consulted in preparing these recommendations include: the Oklahoma Department of Wildlife Conservation's Fish Care Guidelines for Tournament Anglers, Texas Sports Guide's Fish Care Guidelines for Bass Fishing Tournament Anglers, Kansas Angler's Fish Care Guidelines for Tournament Anglers, Georgia B.A.S.S. Chapter Federation's Recommended Bass Handling Procedures to Reduce Delayed Mortality Following Release, Honey Hole's Live Catch & Release Begins with You, Schramm and Heidinger (1988), and Gilliland (1997, 2000).

Research Needs

1. Obtain better tournament postrelease mortality data for LMB and other tournament fish species (other BB, temperate basses, crappie, etc.).

2. Obtain better information on the long-term, post-release survival of culled fish.

3. Obtain better data on dead fish removed from livewells and discarded before weigh-in, including numbers involved and conditions related to these losses.

4. Examined the use of barbless hooks to increase survival of LMB and other non-salmonid fishes.

5. Scientifically examine landing and handling methods to determine the best survival scenario for BB.

6. Perform capture, mark, release, and recapture studies on tournament fishes to better define the extent of multiple recaptures or caught-and-released fishes (proof that released large and trophy fishes are recaptured by numerous anglers is largely lacking despite general acceptance of catch-and-release philosophy).

7. Comparatively examine circulation, agitation, aeration, and oxygenation methods for livewells to determine which provide the highest survival rates.

8. Evaluate the best and minimum-acceptable livewell water exchange rates.

9. Determine the best and minimum-acceptable livewell dilution rates. Dilution of accumulated metabolic wastes can enhance fish survival, but during this same process, beneficial water additives, like sodium chloride, will be diluted as well.

10. Evaluate methods to maintain desired livewell water temperature (including wall insulation) and determine livewell heating and cooling rates relative to wall insulation and use of ice or other cooling methods. Define the relationship between ice and livewell volumes and temperatures of air and water relating to livewell heating and cooling rates.

11. Evaluate the use of potassium permanganate to improve water quality and dissolved oxygen levels in livewells.

12. Evaluate the use of clinoptilolite or other ammonia-absorbing compounds for use in livewells.

13. Monitor livewell pH changes and examine use of buffers to mitigate these changes (if necessary).

14. Evaluate the use of clove oil as an anesthetic in livewells for tournament-related fishes.

15. Better evaluate livewell loading levels. Develop defined relationships between fish species, fish size, livewell volume, water exchange rate, and water temperature.

16. Determine optimum livewell size (volume, dimensions, shape) required by fishes subjected to tournament capture.

17. Evaluate livewell liners to reduce wall-impact injuries.

18. Perform microbiological examination of drained livewells following tournaments to evaluate the risk-potential associated with residual bacterial, other infections organisms, or ecologically harmful species that may remain.

19. Study the possibility of developing stress-tolerant strains of LMB and other fishes that are subjected to tournament angling.

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Table 1. Livewell characteristics in selected boats. Data has been pooled from manufacturer advertising, telephone and E-mail contacts with makers, and information presented in Burch (2000). Abbreviations include: standard (std), recirculation (recirc), gallons (gal), pounds (lbs), inches (in), gallons per hour (GPH), optional (opt.).

Boat type	Live well capacity (gal)	Filled weight (lbs)	Well size (in)	*N* Wells	Dividers	Pump out	Aerator	GPH	Cooling	Comments
BUILT-IN LIVEWELLS										
Allison	30	250	31x12x19	1	yes	no	Attwood (x2)	500 each	no	2 Flow-rite Powerstream aerator heads one for freshwater, one for recirc
Alumacraft	57 total 36/21 each	475 total 300/175each	54x17x12.5 35.9x10.8x13	2	yes	no	spray head recirc pump	500 360	no	Live well lighted
Bass Cat Jaguar	28.5 total 14.25 each	238 total 119 each	26.75x11.25x11 26.75x11.25x11	2	yes	std	spray bar Mayfair	750	no	Lights opt
Blazer Boats	30 total 15 each	250 total 125 each	34x19x16 34x19x16	2	yes	no	Mayfair recirc Air Venturi	750 750	no	Lights opt
Bullet Boats	30	250	29.5x15.5x15	1	yes	std	Attwood fill Attwood recirc	500 500	no	Recirc pump pumps out
Bumblebee	31	259	18x29x20	1	yes	std	Attwood	500	no	-
Champion Elite	35	292	38x18x15.5	1	yes	opt	Mayfair Mayfair recirc	500 750	no	Includes opt light
Charger VTF	40.6 total 20.3 each	339 total 169.5 each	24x13x15 (12" to overflow)	2	no	opt	Mayfair Pro-Air	750	yes	Lights, recirc air system opt
Crestliner 182	54 total 25/29 each	340 total 157/183 each	43x12x12 43x12x12 *	2	yes	gravity drain	spray head	2570 each	no	Lights and recirc std freshwater pickup opt
G3, Pro G 185	27 total 13.5 each	225 total 112.5 each	15.5x21x13	2	yes	NA	Rule 360 (2 each)	360x4	no	rounded corners standard
Javelin, Renegade 20	25	209	27.25x16.5x14.5	1	yes	no	Flow-Rite Power jet Rule Hi-flow	- -	no	Power-stream nozzle std

Table 1. (continued)

Boat type	Live well capacity (gal)	Filled weight (lbs)	Well size (in)	*N* Wells	Dividers	Pump out	Aerator	GPH	Cooling	Comments
Lowe 17 Bass	22.8 total 11.4 each	190 total 95 each	30x16x17	2	yes	no	Mayfair	500	no	Anti-spill cover and recirc std
Monark Pro 860	33 total 17/16 each	275 total 141.7/133.3	12x30x12 13.5x35.5x9	2	yes	no	spray head	350	no	-
Nitro, Tracker	38 total 19 each	317 total 158.5 each	18x24.5x14	2	yes	std	Rule Hi-Flow (2/well)	500	no	Anti-slosh baffles, auto-fill, insulation std
Pinecraft, Super Pro	20	167	44x12x11	1	yes	no	Powerstream	500	no	Lights and insulated lid std
ProCraft, Super Pro	45	375	30.5x21x20	1	yes	std	Rule Hi-Flow	800 recirc 500 fill	no	Lights optional; 2 aerators and recirc pumps std
Ranger (all larger)	25	209	28.5x15.5x8	1	yes	opt	Mayfair venturi air bubbler	750 each	no	Insulation std; lights opt
SeaArk ZV177	22 total 11 each	184 total 92 each	31x11x11.5	2	yes	no	Johnson	500	no	Dividers opt
Skeeter ZX202	30 total 15 each	250 total 125 each	26x16.25x10	2	yes	opt	Direct/Air Induced	360	no	Lights and remote drain std 1 fill and 1 recirc pump/well
Starcraft, Starcaster	35 total 19/16 each	292 total 158.5/133.5 each	12x30x12 13.5x35.5x9	2	yes	no	spray head	350	no	Lights std
Stealth VIP	31 total 15.5 each	258 total 129 each	13x38x15 13x38x15	2	yes	no	Attwood	750	no	Air venturi 750 gpm std
Storm	40 total 15/25 each	233 total 125/209 each	20x16x12 19.5x26x12	2	yes	std	cartridge type	500	no	T-H Air Bubbler pumps opt
Storm Extreme	40 total 20 each	333 total 167 each	23.75x14.75 x14.75	2	yes	no	Flow-Rite Power-jet; Rule Hi-Flow	-	no	Flow-rite auxillary air , Powerstream nozzle, and LED lights std
Stoker	30	250	29x16x17	1	yes	no	Mayfair	750	no	Cooler plumbed for livewell opt

Table 1. (continued)

Boat type	Live well capacity (gal)	Filled weight (lbs)	Well size (in)	*N* Wells	Dividers	Pump out	Aerator	GPH	Cooling	Comments
Stratos Vindicator 268	34 total 11/23 each	284 total 92/192	unreported	2	?	?	Pro-Air	-	-	2-4 pump system
Stratos Vindicator 273	25	208	unreported	1	yes	yes	Pro-Air	-	-	Tournament aeration; 4 pump system and timer; twin Flow-Rite drain valves
Stratos Vindicator 217	30	250	unreported	1	?	yes	Pro-Air	-	-	2-4 pump system, twin Flow-Rite drain valves
Stratos Vindicator 273	25	208	unreported	1	yes	yes	Pro-Air	-	-	2-4 pump system, twin Flow-Rite drain valves
Stratos Vindicator 283	38	317	unreported	1?	yes	yes	Pro-Air	-	-	2-4 pump system, twin Flow-Rite drain valves
Stratos Pro Elite285	38	317	unreported	1	yes	yes	Pro-Air	-	-	Tournament aeration, 4 pump system and timer; twin Flow-Rite drain valves
Stratos Extreme 215	38	317	unreported	1	yes	yes	Pro-Air	-	-	Tournament aeration, 4 pump system and timer; twin Flow-Rite drain valves
Triton	43	359	"18x16x12" "18x16x12"*	2	yes	std	T&H Max Air Venturi System pump out	750 500	no	T-H Max Air oxygenator std; lights opt
Viper Cobra	30-60 total 30 each	250-500 total 250 each	32x19x12	1-2	yes	std	Mayfair	750 each	no	Lights std
Waco PSV-18	22	183.48	44.5x14.5x9	1	yes	no	Mayfair	500	no	-
Xpress	30	250	41x13.25x13.25	1	yes	std	Mayfair	750	no	Drain std

Table 1. (continued)

Boat type	Live well capacity (gal)	Filled weight (lbs)	Well size (in)	*N* Wells	Dividers	Pump out	Aerator	GPH	Cooling	Comments
ADD ON LIVEWELLS										
Toho-Rig Livewell	ca 33	25 empty 300 full	top: 44, bottom: 31x16x13	1	yes	no	Pump spray bar	350	no	Triple wall insulation
Bait and Tackle Station	12	100	24x132x12	1	-	no	Pump spray bar	360	no	Rounded ends; for small boats
Cabela's Molded Plastic Livewell	24	200	47x12.75x11	1	-	no	none std	-	no	Can be fitted with recirculation and aeration kits
Aqua World Universal Livewells	24-round	200	20x18x(15.0)	1	no	no	none	-	no	Molded plastic
	19-oval	158	22x16x15	1	no	no	none	-	no	Molded plastic
	30-round	250	23x17x(15.4)	1	no	no	none	-	no	Molded plastic
	50-round	417	29x18x(21.8)	1	no	no	none	-	no	Molded plastic

* Crestliner 182 and Triton well capacities, weights, and dimensions are not consistent and must include incorrect values.