North American Journal of Fisheries Management 15:621–630, 1995
American Fisheries Society

Largemouth Bass Mortality and Related Causal Factors during Live-Release Fishing Tournaments on a Large Minnesota Lake

THOMAS J. KWAK[1] AND MARY G. HENRY

National Biological Service, Minnesota Cooperative Fish and Wildlife Research Unit
Department of Fisheries and Wildlife, University of Minnesota, St. Paul, Minnesota 55108, USA

Abstract.—We quantified initial and delayed mortality of largemouth bass *Micropterus salmoides* during live-release fishing tournaments and identified probable causes of death in order to provide a biological basis for refining tournament guidelines and regulation. Mean estimates for two tournaments on Lake Minnetonka, Minnesota, were 1.42% weigh-in mortality, 3.35% 3-d delayed mortality, and 4.72% total mortality. Catch and total mortality rates during a May tournament were both over 1.5 times those of a September tournament, the difference presumably being related to reproductive behavior and condition. Tournament mortality of the population was minimal relative to other causes of mortality; total tournament mortality estimates for 1992 (11 tournaments) represented 2.3–6.3% of angling mortality and 1.3–3.0% of total mortality in Lake Minnetonka. Means of all water quality variables measured in live wells were significantly different from those of lake water, and relative differences were greatest for ammonia concentration. The percentage of dead fish in live wells was significantly and inversely correlated with pH, which may reflect effects of dissolved carbon dioxide. No relationship between mortality and live-well fish density, equipment, or holding techniques was detected. Our results suggest that most tournament mortality was due to the cumulative effects of sublethal stressors. Among other recommendations, we suggest that alternatives to traditional weigh-in tournaments during the spawning period be explored and that anglers maximize replacement of live-well water with lake water to reduce concentrations of metabolic waste products.

Competitive angling has become an increasingly popular and widespread use of fishery resources in the United States. The number of fishing tournaments and water bodies affected increased substantially from 1978 to 1989, and a progressively wider variety of species was involved (Shupp 1979; Duttweiler 1985; Schramm et al. 1991). Among the fishes sought, black bass *Micropterus* spp. are the most popular tournament taxa, and the number of black bass tournaments has exceeded those for other species by a factor of 10 (Duttweiler 1985). Interest in black bass tournaments has also followed this progressive trend, and there have been substantial increases in the number and regional distribution of black bass tournaments during the same period (Schramm et al. 1991). This pattern is particularly clear in the north-central United States, where the number of waters on which black bass tournaments occurred doubled from 1978 to 1983 (Duttweiler 1985).

The increased intensity and scope of competitive angling compels fishery managers to reexamine and evaluate the guidelines and regulation of fishing tournaments on an ongoing basis. Since 1972, the intent of black bass tournament officials and anglers has been to return fish alive after contests to minimize the effect on the black bass population and improve public perceptions (Holbrook 1975). A 1989 survey of natural resource managers revealed that tournament mortality and reductions in fish populations resulting from intensified effort were perceived, but generally unsubstantiated, biological problems associated with competitive fishing (Schramm et al. 1991). It is clear from successive surveys and status reports on competitive fishing that quantitative evaluation of the biological effects and identification of the causal factors of mortality are areas requiring additional research (Shupp 1979; Duttweiler 1985; Schramm et al. 1991). In response to this need, a considerable body of literature has been published on initial and delayed mortalities associated with black bass fishing tournaments, but few studies have included an assessment of effects at the population level or examined the causal factors of fish mortality. Furthermore, information on black bass tournaments conducted in north-central states is scarce in the literature.

In an early compilation of live-release black

---

[1] Present address: National Biological Service, Arkansas Cooperative Fish and Wildlife Research Unit, Department of Biological Sciences, University of Arkansas, Fayetteville, Arkansas 72701, USA.

bass tournaments held in the southern United States, Holbrook (1975) reported a mean initial mortality rate of 21% (range, 2–61%) and an additional mean delayed mortality of 12% (range, 2–36%), resulting in a mean total mortality of 36% (range, 16–76%). More recently, studies of black bass mortality during tournaments held throughout the United States have generally reported lower mortalities, possibly reflecting improvements in angler equipment, objectives, and knowledge. Recent estimates have ranged from 0 to 43% for initial mortality, from 0 to 27% for delayed mortality, and from 0 to 48% for total mortality, with mean mortality usually near or below half the reported maxima (Schramm et al. 1985, 1987; Bennett et al. 1989; Hartley and Moring 1991; Jackson and Willis 1991).

The wide ranges of mortality for tournament-caught black bass suggest that variation in causal factors associated with tournaments may contribute to mortality. Among the factors that have been examined are angling effects, holding and transport, and environmental conditions during tournaments. Survival of angled black bass has been related to hooking location (Pelzman 1978), hooking duration (Schramm et al. 1987; Gustaveson et al. 1991), fish size (Meals and Miranda 1994), length of tournaments (Bennett et al. 1989), water temperature (Holbrook 1975; Plumb et al. 1988; Gustaveson et al. 1991), water quality (Carmichael et al. 1984b; Hartley and Moring 1991, 1993), and use of chemical water conditioners in live wells (Carmichael et al. 1984a; Plumb et al. 1988). Once causal factors of fish stress and death are identified, they may be mitigated during future tournaments to improve the survival of released fish.

We studied two black bass tournaments that took place during different seasons on a large Minnesota lake to assess fish mortality and identify the contributing causes of mortality. Our specific objectives were to (1) quantify weigh-in and 3-d delayed mortality, (2) assess the effect of tournament mortality at the population level, (3) describe angler equipment and holding techniques and live-well water quality, and (4) relate tournament mortality to angler equipment and techniques and live-well water quality in order to identify potential causes of mortality. We have incorporated our findings into recommendations for improving the survival of black bass during live-release fishing tournaments.

Methods

Tournaments and format.—We studied two live-release tournaments on Lake Minnetonka, a 5,900-ha lake in east-central Minnesota on the western edge of the Minneapolis-St. Paul metropolitan area (44°57′N, 93°34′W). This irregularly shaped, dimictic lake is composed of 15 morphologically distinct basins and has a mean depth of 9 m and a maximum depth of 34 m (Ebbers 1987). The first tournament was a 2-d contest that occurred on 6–7 September 1991; the second took place on a single day, 16 May 1992. Angling during the first tournament spanned 8 h each day and included 170 anglers (2 per boat); during the second tournament, 164 anglers (2 per boat) each fished for 7 h.

Both tournaments were conducted and officiated by the Minnesota Bass Federation, a state affiliate of the National Bass Anglers Sportsman Society Federation. A self-imposed minimum length limit of 305 mm total length was in place for both tournaments, as were daily limits of 5 and 6 fish for the September and May contests, respectively. Largemouth bass *Micropterus salmoides* and smallmouth bass *M. dolomieu* were allowed in the catch of the September tournament, but the May tournament was restricted to largemouth bass. The nominal September smallmouth bass catch (23 fish, 14 kg) was not included in our analyses. As an incentive to maintain fish in a condition suitable for release, tournament officials penalized anglers for each dead fish presented. Fishing tackle was restricted to artificial lures for both tournaments. Immediately prior to fishing, all boats were inspected by tournament officials to assure compliance with safety and equipment regulations, which included an adequate live well equipped with an operating aeration system.

Weigh-in procedures were generally well organized and were completed for most anglers within a 5-min period. Participants were divided into three groups that had staggered (by 30 min) starting and finishing times in order to expedite the weigh-in process for individual anglers. Each angler's catch was transported from the live well to the scale in a large (50 × 72-cm), clear-plastic bag filled with water. Large aerated water tanks were available for anglers to float the bag containing their catch if waiting was necessary. Tournament officials weighed the fish in aggregate in a plastic basket on an electronic scale, but extraordinarily large fish were weighed individually, and small fish were measured to confirm compliance with the minimum length limit. After official weigh-in, the fish were placed in large, oxygenated water tanks until they were processed by biologists.

Weather conditions during the tournaments were variable. Air temperatures during the September weigh-in were 25.5°C and 24.0°C, and winds were calm (<8 km/h) and moderate (<32 km/h) during the first and second days of the tournament, respectively; light rain fell during the final hour of weigh-in on the second day. Air temperature was slightly cooler during the May weigh-in (23.0°C), winds were gusty (>45 km/h) during the morning, and intermittent light rain fell during the final hour of weigh-in.

The date of the second tournament (16 May) was selected to generally coincide with the largemouth bass spawning season in Lake Minnetonka. This contest was organized and authorized to occur specifically during the closed fishing season in order to assess tournament mortality during the reproductive season. Because mortality associated with this tournament might have been influenced by reproduction, we recorded qualitative observations of spawning fish and other reproductive behaviors to document spawning chronology. We observed large aggregations of largemouth bass (12–15 fish) in shallow bays on 5 May, and a pair was observed spawning over a nest on 13 May (3 d before the tournament). Largemouth bass guarded nests continuously from 13 May through 8 June, and adults were observed guarding fry from 23 through 29 June.

Data collection and analysis.—Initial largemouth bass mortality at weigh-in was determined independently by a biologist and tournament officials at both tournaments. Fish were considered dead if no opercular movement was observed. We also recorded the number of fish at weigh-in that were considered "weak" and not likely to survive; these fish appeared inordinately stressed, but showed opercular movement. This group included fish that showed only intermittent opercular movement or that had obvious physical injuries. Total lengths (TL) of all fish were measured to the nearest millimeter by biologists after the official weigh-in.

Subsamples of largemouth bass judged by biologists to be alive at weigh-in (including those considered weak) were held in on-site holding cages for 3 d to assess postrelease, delayed mortality. Subsamples of 296 fish from the first tournament and 200 fish from the second tournament were retained, and all remaining live fish were released at the weigh-in site. The cages were constructed from modified hoop-nets of 2.5-cm-bar mesh as described by Goeman (1991). Each cage was 4 m long and enclosed a volume of about 1.7 m^3. Fish were transported by boat to the cages in covered 91-L coolers that contained water aerated with oxygen.

The cages were anchored on the lake bottom in areas with sand substrate near the corresponding weigh-in site and were checked by scuba divers to verify cage position and to ensure that no extraneous factors influenced fish mortality. No more than 30 fish were held in each cage. Following the September tournament, cages were anchored in water 2.7 m deep, where water temperature ranged from 21.8 to 22.6°C and the minimum dissolved oxygen concentration was 7.6 mg/L. Fish from the second tournament were held in water 3.4 m deep, with a temperature range of 14.5–16.0°C and a minimum dissolved oxygen concentration of 8.8 mg/L. After the 3-d holding period, fish were classified as dead or alive and measured for total length.

Weigh-in mortality for each tournament was expressed as a percentage of largemouth bass weighed in, and delayed mortality was expressed as a percentage of fish that survived weigh-in. Total percent fish mortality (F_T) was estimated as the sum of the initial percent mortality (F_I) at weigh-in and the delayed mortality (F_D) expressed as a percentage of the total catch (C):

$$F_T = F_I + [F_D(100 - F_I)/100].$$

Thus, the total number of fish dying was $C \cdot F_T/100$.

As anglers arrived at the weigh-in site, some of them were interviewed about fish holding and transport techniques. The number of anglers interviewed and live wells examined was constrained by the number of personnel available and the need to avoid delays at weigh-in. Subsamples of 69 and 64 anglers were interviewed during the September and May contests, respectively. A series of questions was posed regarding live-well equipment, operating procedures, and fish density.

Water quality variables were measured in angler live wells during the interview and from a single sample of lake water collected near the weigh-in site during each tournament. Water temperature, dissolved oxygen concentration (YSI model 57 oxygen meter), pH (Orion model 399A analog pH meter), and conductivity (Horizon type 1484-10 conductivity meter) were measured directly in live wells. Water samples were returned to the laboratory, and total ammonia concentration was determined by the Nessler method with a Hach DR/2000 spectrophotometer (Hach 1992). Analyses of standard ammonia solutions at two concentrations (1.0 mg/L and 0.5 mg/L) yielded average readings within 4% of standard concentrations and a standard deviation of less than 3% of the standard (N = 15 for each concentration). Means of live-well

TABLE 1.—Summary of largemouth bass catch during two fishing tournaments held on Lake Minnetonka, Minnesota.

Statistic	6–7 Sep 1991	16 May 1992
Number of fish weighed	897	870
Total weight (kg)	800.06	846.58
Total length (mm)		
Mean	376	396
SD	48	49
Range	300–557	304–550
Mean weight (g)	892	973
Fishing effort (angler-hours)	2,720	1,148
Catch per effort (number of fish/angler-hour)	0.33	0.76
Anglers catching limits (%)	22.6[a]	67.7

[a] Two-day mean.

water quality variables were compared to those of lake water with a two-tailed *t*-test.

Ammonia in aqueous solution exists in two forms—ionized (NH_4^+) and un-ionized (NH_3). Both forms are toxic to fish, but the un-ionized form is generally considered the more toxic (Spotte 1979; Russo 1985). Therefore, we calculated concentrations of un-ionized ammonia with equilibrium equations developed by Emerson et al. (1975), which incorporate the effect of water temperature and pH on the proportions of each form in the measured total ammonia.

Results of angler interviews and live-well water quality analyses during the May tournament were related to fish mortality for individual anglers during that tournament. We used principal component analysis to derive three vectors that summarized water quality variables measured in live wells during the May tournament to relate a composite descriptor of water quality to fish mortality. The correlation matrix of water quality variables was factored with a varimax rotation, and component scores were calculated for each live well (Wilkinson et al. 1992).

Fish mortality within individual live wells during the May tournament formed a binomial distribution, owing to the predominance of low mortality encountered. Because an arcsine transformation or several modifications of that transformation (Zar 1984) failed to remedy the condition, we employed nonparametric tests to identify potential significant influences on fish mortality. The Kruskall–Wallis test was used to indicate significant effects of categorical variables from angler interviews (equipment and holding techniques) on fish mortality for independent variables comprising two or more categories, and the Mann–Whitney test was similarly used to test the effect of water flow system, a variable that included only two categories. Spearman rank correlation coefficients were calculated to identify significant associations between continuous variables (live-well capacity, fish density, and water quality), and fish mortality. Corrections for tied data were applied in each test according to procedures outlined by Zar (1984).

TABLE 2.—Largemouth bass mortality data and estimates for two fishing tournaments held on Lake Minnetonka, Minnesota. Data are numbers of dead or weak fish and mortality or morbidity percentages (in parentheses).

Measure	Sep 1991	May 1992
Initial mortality at weigh-in	8 (0.89)	17 (1.95)
Weak at weigh-in[a]	14 (1.56)	27 (3.10)
3-d delayed mortality	8 (2.70)	8 (4.00)
Estimated total mortality	32 (3.57)	51 (5.87)

[a] Not included in mortality estimates.

Results

Tournament Catch and Mortality

Angler catch rate during the May tournament was greater than during the September tournament (Table 1). Catch during the May tournament was similar to that of the September contest, but was accomplished in only one day of fishing. Thus, catch per effort during the May tournament was over twice as high as that of the September tournament, and the percentage of anglers who caught their limit was three times higher during the May tournament than during the September contest, even though the creel limit during the May tournament was one fish higher. The average size of fish caught in the May tournament was larger than that of the September tournament, but ranges and standard deviations of fish length were similar between contests.

Mean mortality estimates for the two tournaments were 1.42% weigh-in mortality, 3.35% 3-d delayed mortality, and 4.72% total mortality (Table 2). The percentages of fish assessed as weak at weigh-in and not likely to survive were an average of two-thirds the delayed mortality estimates, and delayed mortality averaged 2.5 times as high as initial mortality. All estimates of mortality during the May tournament were substantially higher than those during the September contest.

Effect on the Fishery

Annual mortality of largemouth bass in Lake Minnetonka due to tournament angling can be imprecisely estimated from estimates of the population size, mortality, and fishing effort. Within-season population estimates of largemouth bass (>305 mm TL) in Lake Minnetonka during 1981–1983 ranged from 21,000 to 29,000 fish, and no significant differences were detected among years (Ebbers 1987). Estimates of annual total mortality (converted from instantaneous rates) for the same population and years ranged from 38.1 to 64.6% and comprised 19.7–28.8% natural mortality and 18.4–35.8% angling mortality (Ebbers 1987). These mortality ranges produce an estimate of 8,001–18,734 annual total fish deaths, consisting of 4,137–8,352 natural deaths and 3,864–10,382 angling deaths.

During the 1992 fishing season, 11 live-release black bass tournaments were permitted by the Minnesota Department of Natural Resources (MDNR) on Lake Minnetonka, including the tournament that we studied in May. The total cumulative catch reported from those tournaments was 5,135 fish (MDNR, unpublished data). Applying our estimate of mean total mortality from the two tournaments that we studied (4.72%) to the total 1992 tournament catch, we estimate that 242 fish died that year from tournaments. Assuming tournament catch was primarily largemouth bass, as we observed in the September tournament, total tournament mortality during 1992 represented 2.3–6.3% of angling mortality and 1.3–3.0% of total mortality in Lake Minnetonka.

TABLE 3.—Largemouth bass densities in and other features of live wells used by anglers to contain and transport fish during two fishing tournaments held on Lake Minnetonka, Minnesota.

Fish density or live-well feature	Sep 1991 (N = 69)	May 1992 (N = 64)
Fish density (number/well)		
Mean	3.9	6.6
SD	2.0	2.6
Range	1–9	2–12
Well capacity (L)		
Mean	59.5	80.5
SD	32.0	31.8
Range	18.9–189.2	15.1–151.4
Fish density (number/L)		
Mean	0.091	0.099
SD	0.084	0.075
Range	0.011–0.423	0.021–0.396
Live-well location on boat (%)		
Stern	65.2	70.3
Bow	27.5	25.0
Side	4.4	3.1
Center	2.9	1.6
Water flow system (%)		
Freshwater	84.1	68.8
Recirculating	15.9	31.2
Aeration system (%)		
Concentrated water stream	66.7	70.3
Bubbler	26.1	25.0
Agitator	0.0	3.1
None	7.2	1.6
Cooling system (%)		
None	52.2	75.0
Insulated live well	44.9	21.8
Ice added	2.9	1.6
Electric cooler	0.0	1.6
Chemical water conditioners (%)		
None	88.4	93.7
Manufactured product	11.6	4.7
Table salt	0.0	1.6

Factors Affecting Mortality

The equipment and holding techniques that anglers used to confine and transport fish in live wells were similar between tournaments (Table 3). The majority of tournament anglers that we sampled used live wells located at the stern of the boat (mean, 67.8%), a freshwater flow system (mean, 76.4%), a concentrated water stream aeration system (mean, 68.5%), and no cooling system (mean, 63.6%) or chemical water conditioners (mean, 91.0%). None of these categorical descriptions of equipment and holding techniques explained significant proportions of variance in percentages of dead fish, weak fish, or the sum of dead and weak fish observed in angler live wells during the May tournament ($P > 0.05$).

The mean number of fish per live well at weigh-in during the May tournament was over 1.5 times as high as that during the September tournament (Table 3)—an expected finding given the disproportionate catch rates between the tournaments (Table 1). The mean water capacity of live wells used by anglers during the May tournament, however, was greater than that of anglers participating in the September contest, and accounted for similar mean fish densities estimated per volume of live wells in the two contests (Table 3). Mean fish biomass per volume in live wells, estimated as the product of average fish weight and the number of fish per volume, was 81.2 g/L in September and 96.3 g/L in May.

Water quality of samples collected from live wells differed significantly ($P < 0.05$) from that sampled from Lake Minnetonka during tournaments for all measured variables, but the magnitude of the differences varied (Table 4). With the exception of water temperature during the September tournament, no values for variables measured in the lake fell within 95% confidence intervals of the corresponding mean measured in live wells. Compared with lake water, live-well water sampled in both tournaments was significantly higher

TABLE 4.—Comparison of water quality variables measured from boat live-well water with those measured in Lake Minnetonka, Minnesota, at weigh-in sites during two fishing tournaments. Significant differences ($P < 0.05$) between live-well means and corresponding lake measurements for each tournament were determined with a two-tailed t-test. Parenthetic numbers in data columns are 95% confidence intervals (CI).

Variable	Sep 1991 (N = 69)				May 1992 (N = 64)			
	Lake	Live well Mean (CI)	Live well Range	P	Lake	Live well Mean (CI)	Live well Range	P
Temperature (°C)	23.0	23.2 (23.0–23.3)	22.0–25.6	0.0355	15.0	17.0 (16.7–17.3)	14.0–19.6	<0.0001
Dissolved oxygen (mg/L)	8.50	5.73 (5.39–6.07)	1.40–7.70	<0.0001	9.90	6.56 (6.11–7.00)	1.90–13.6	<0.0001
pH	7.60	7.40 (7.33–7.46)	6.90–8.10	<0.0001	7.75	7.99 (7.86–8.13)	7.10–9.20	0.0008
Conductivity (μS/cm)	450	475 (466–484)	400–625	<0.0001	440	460 (455–466)	400–540	<0.0001
Total ammonia (mg/L)	0.30	1.02 (0.66–1.39)	0.24–12.70	0.0002	0.15	0.62 (0.50–0.74)	0.16–2.63	<0.0001
Un-ionized ammonia (mg/L)	0.006	0.011 (0.008–0.012)	0.003–0.049	<0.0001	0.002	0.029 (0.020–0.037)	0.001–0.160	<0.0001

in temperature, lower in dissolved oxygen concentration, higher in conductivity, and higher in total and un-ionized ammonia concentrations. Live-well water pH values were lower than that of lake water during the September tournament, but were higher than lake water pH during the May tournament. Relative differences between lake and live-well values of ammonia concentration (both forms) were substantially greater than those of other measured variables. The greatest difference occurred in measurements of un-ionized ammonia during the May tournament, where the mean live-well concentration was over 14 times as high as that in lake water.

Three principal components cumulatively described 79% of the variance in water quality variables measured from angler live wells during the May tournament (Table 5). The first component, describing the most variance in water quality variables, contained significant loadings ($P < 0.05$) of total ammonia, temperature, un-ionized ammonia, and conductivity. The second component described significant loadings of pH, un-ionized ammonia, and conductivity, and the third component included significant dissolved oxygen, conductivity, and total ammonia loadings.

TABLE 5.—Significant principal component (PC) loadings (N = 64, $P < 0.05$, $r > |0.24|$) presented as the correlation (r) of a water quality variable with each component. Percent of variance explained by each component is listed in parentheses. Water quality variables were measured from angler live wells during a tournament held on Lake Minnetonka, Minnesota, May 1992.

Variable	PC1 (34%)	PC2 (27%)	PC3 (18%)
Total ammonia (mg/L)	0.87		−0.25
Temperature (°C)	0.78		
Un-ionized ammonia (mg/L)	0.59	0.73	
Conductivity (μS/cm)	0.56	−0.47	0.47
pH		0.89	
Dissolved oxygen (mg/L)			0.85

The percentage of dead fish in a live well during the May tournament was significantly ($P < 0.05$) and inversely correlated with pH, un-ionized ammonia, and the second water quality principal component (Table 6). A significant, positive rank correlation was detected between the percentage of weak fish in a live well and live-well water capacity, and significant, inverse rank correlations occurred between the percentage of dead or weak fish in a live well and pH, un-ionized ammonia, and the second principal component. The rank correlations between fish status and the second principal component were no more significant than the corresponding correlations that included only pH (most significant loading of the second component). No significant rank correlations were detected among percentages of dead fish, weak fish, or the sum of dead and weak fish and live-well fish density, water temperature, conductivity, concentrations of dissolved oxygen or total ammonia, or the first and third water quality principal components.

Discussion

The mean tournament mortalities that we estimated were generally lower than those reported for black bass tournaments held in the southern United States (Holbrook 1975; Schramm et al. 1985, 1987), but they are similar to those estimated for other northern states (Bennett et al. 1989; Hartley and Moring 1991; Jackson and Willis 1991). These comparisons may reflect improvements over time (1967–1992) in anglers' willingness and ability to maintain and transport fish in live wells.

TABLE 6.—Spearman rank correlation coefficients (r_s) and their probabilities (P) for comparisons of percentages of dead and weak fish to the water capacity, fish density, and water quality variables of live wells and to the scores of three principal components (PC1–PC3) derived from water quality measurements of angler live wells during a fishing tournament held on Lake Minnetonka, Minnesota, May 1992 (N = 64). Principal component loadings are reported in Table 5.

Live-well variable	Dead fish		Weak fish		Dead or weak fish	
	r_s	P	r_s	P	r_s	P
Water capacity (L)	0.11	0.51	0.34	0.04	0.32	0.06
Fish density (fish/L)	0.08	0.63	−0.14	0.38	−0.09	0.57
Temperature (°C)	0.02	0.89	0.06	0.63	0.08	0.52
Dissolved oxygen (mg/L)	0.06	0.65	0.20	0.12	0.14	0.27
pH	−0.26	0.04	−0.11	0.40	−0.29	0.02
Conductivity (μS/cm)	<0.01	1.00	0.18	0.16	0.16	0.19
Total ammonia (mg/L)	−0.22	0.09	0.08	0.53	−0.03	0.81
Un-ionized ammonia (mg/L)	−0.32	0.01	−0.08	0.53	−0.27	0.03
PC1	−0.12	0.36	0.12	0.35	0.06	0.64
PC2	−0.25	0.05	−0.14	0.26	−0.30	0.02
PC3	0.06	0.66	0.19	0.14	0.14	0.27

Additionally, lower tournament mortality at northern latitudes may be related to water temperature. Several studies of black bass tournaments have found a positive relationship between fish mortality and water temperature on the day of the contest, noting consistently low mortality at temperatures below 18–20°C (Bennett et al. 1989; Schramm et al. 1985, 1987). Other investigators have documented a progressive increase in survival of tournament-caught black bass over time, which has been attributed to a reduction in warm weather tournaments and improvements in equipment, tournament procedures, and angler attitudes and education (Holbrook 1975; Schramm et al. 1987).

The higher mortality that we observed during the May tournament occurred at a cooler water temperature (15°C) than that of the September tournament (23°C), suggesting that water temperature was not a critical factor in fish mortality on Lake Minnetonka or that reproductive stress might have superseded water temperature as a cause of deaths. Live-well fish density was also probably not a critical influence on mortality, because mean live-well densities estimated in our study (81.2 and 96.3 g/L) were substantially lower than those recommended for adult fish transport (333–500 g/L; Berka 1986) and those found to induce significant effects on largemouth bass blood chemistry (180 g/L; Carmichael et al. 1984a). Furthermore, we found no significant correlation between mortality and live-well fish density (per volume) during the May tournament. It is probable that the higher mortality that we observed during the May tournament was due to a weakened state of largemouth bass associated with spawning. This is a stressful period in largemouth bass life history, during which weak individuals die at a higher rate (Heidinger 1975). This elevated mortality is probably exacerbated by angling effects.

We quantified the number of fish that we considered weak at weigh-in and likely to die soon as a potential indicator of delayed mortality. This index was consistently lower than delayed mortality, varying from 44 to 78% of delayed mortality among the three days of tournament fishing. Because of its subjectivity and variability, we cannot recommend assessing the proportion of weak fish as a means to estimate delayed mortality. Delayed mortality calculated as a percentage of initial mortality also varied widely over the three days (205–891%) and thus does not provide a reasonable estimate of delayed mortality from initial mortality.

Our estimates of the proportion of total annual largemouth bass mortality due to tournament angling were low (1–3%) and indicate that the direct effects of tournament mortality on the Lake Minnetonka population were minimal. Caution should be exercised in extrapolating this conclusion to other waters. Differences in relative mortality may occur on smaller bodies of water or in different population densities. Additional studies of largemouth bass population dynamics would be required to determine if the angling mortality on Lake Minnetonka is sustainable, but our results suggest that direct effects from intense seasonal tournament fishing are minimal relative to other causes of mortality.

None of the equipment and holding techniques that anglers used to transport fish in live wells was significantly related to largemouth bass mortality, but live-well capacity was weakly correlated (P = 0.04) with the proportion of weak fish in a live well during the May tournament. This positive relationship indicated that larger-capacity live wells contained greater proportions of weak fish. Although this finding may appear contrary to expectations, the volume of a live well may influence water quality in the well and physical disturbance to contained fish. Water in larger live wells may be subject to more physical action and would take longer to replace with fresh lake water. Additionally, fish may be more difficult to collect from large live wells at weigh-in, which may increase fish physical exertion and injury. Although we have insufficient evidence to suggest limiting live-well capacity in fishing boats, an intermediate volume may prove optimal.

Mortality of tournament-caught fish in this study may not be attributed to any single water quality variable, based directly on acute exposure to measured values (Table 4). Water temperatures in live wells were well below the range of upper incipient lethal limits for adult largemouth bass (28.9 to 38.9°C; Wismer and Christie 1987). Dissolved oxygen concentrations below or approaching 1.0 mg/L are frequently lethal to largemouth bass (Moss and Scott 1961; Bulkley 1975), but only the lowest extreme found in live wells (1.4 mg/L) approached a lethal concentration. Largemouth bass are known to have survived acidic waters with pH as low as 3.9 but cannot maintain osmotic homeostasis in water below pH 5.0 (McCormick and Jensen 1992) and generally are not found in waters below pH 4.7 (Bulkley 1975). These critical pH values are much lower than any encountered in live wells in our study. Concentrations of un-ionized ammonia (the most toxic form) in live wells were also well below the range of tolerance limits determined for largemouth bass in laboratory studies (0.7–1.2 mg/L; Roseboom and Richey 1977).

Although the scales of measured water quality variables may not be directly comparable, the general trends and magnitude of comparisons between live-well water and fresh Lake Minnetonka water may provide insight into the relative changes in the ambient environment that may be detrimental to fish. Relative differences in ammonia concentration (both total and un-ionized) were substantially greater than for any other measured variable, which suggests that the effects of ammonia toxicity may be an important contributing factor to cumulative stress and mortality during tournaments. Furthermore, ammonia toxicity is magnified in water of low oxygen content (Spotte 1979).

Mortality in live wells during the May tournament was significantly and inversely correlated with pH and un-ionized ammonia concentration (Table 6). The negative correlation with un-ionized ammonia has no biological basis and almost certainly does not imply a cause of mortality. That correlation is probably an artifact of an intercorrelation with pH by virtue of the equations used to estimate un-ionized ammonia from total ammonia concentrations, which incorporate pH values (Emerson et al. 1975). The observed lack of improvement in correlation of the second principal component (significant loadings of pH and un-ionized ammonia) with mortality is further evidence that the ammonia–mortality correlation is due to intercorrelation of variables.

The correlation between pH and mortality, however, may be based on a physiological response. The toxicity of many substances is affected by pH; consequently, it is difficult to identify the direct effects of pH on fish (Bulkley 1975). For example, ammonia toxicity decreases with declining pH (Russo 1985), but low pH can indicate a high carbon dioxide concentration, which reduces the oxygen carrying capacity of a fish's blood regardless of ambient oxygen concentrations (Bulkley 1975; Piper et al. 1983; Berka 1986). Carbon dioxide production shifts water pH toward acidity, and rapid changes in pH can also stress fish (Berka 1986). If the correlation between pH and mortality indicates a cause-and-effect relationship, it is more likely related to aqueous carbon dioxide concentrations or interactive effects of other substances than directly to pH toxicity.

We suggest that most of the tournament mortality that we estimated in this study was due to the cumulative effects of sublethal stresses that occurred during capture, confinement, transport, and weigh-in. Even though our water quality investigations did not clearly reveal a single acute stressor to fish that may have directly caused mortality, the cumulative and interactive effects of sublethal stress factors may eventually lead to death, even if the individual factors do not exceed physiological tolerance limits (Carmichael et al. 1984b; Wedemeyer et al. 1990). Carmichael et al. (1984b) found immediate and delayed blood chemistry indications of stress in largemouth bass exposed to poor water quality for brief periods, and the effect was greater when fish were confined.

Mortality from severe injury or acute stressors should result in rapid death, whereas additive effects of sublethal stressors are more likely to result in delayed mortality. Hooking stress on largemouth bass is considered to be well within physiological tolerance limits and can be mitigated by limiting landing time (Gustaveson et al. 1991), a practice followed by most tournament anglers. The preponderance of delayed tournament mortality (72% of total mortality) supports our cumulative-stress hypothesis, but injury or acute stressors (e.g., live-well equipment failure) certainly accounted for a minor portion of the estimated mortality in Lake Minnetonka tournaments.

Recommendations

The results of our study and similar research on tournament mortality suggest obvious and direct ways to improve survival of fish caught in live-release tournaments. We propose the following recommendations for consideration in the development of guidelines and the regulation of tournaments in order to mitigate biological impacts of tournament fishing.

Conservative tournament regulations should be continued and strengthened. Such practices include point incentives for maintaining live fish, tackle restrictions, reduced fish limits, limited angling hours, and required operational live wells. Procedures should be refined to minimize weigh-in time for individual anglers and to expedite fish release. This may include dividing anglers into groups for staggered commencement and conclusion of angling, having large, shaded holding tanks with flow-through circulation systems available at weigh-in, and providing bags to transport fish from live wells to weigh-in. Alternatives to traditional weigh-in tournaments (Schramm and Heidinger 1988) should be explored by tournament organizers and state agencies, especially during the spawning period and excessively warm weather.

When ambient water quality is adequate, anglers should maximize flow-through water circulation in live wells to simulate lake water conditions, rather than creating a closed, artificial environment, dependent on aerators, cooling devices, and chemical additives. Sufficient inflow of high-quality lake water, in combination with proper aeration, will reduce the concentrations of carbon dioxide and ammonia—two metabolic waste products that are potentially serious stressors to contained fish.

Although the use of water conditioners has been shown to increase survival of transported largemouth bass in certain situations (Carmichael et al. 1984a; Plumb et al. 1988), high survival can be achieved without their use if fish are handled properly (Plumb et al. 1988). Furthermore, because rapid changes in the ambient fish environment can be detrimental to fish, the environment should be slowly adjusted (i.e., tempered; Piper et al. 1983; Berka 1986). However, tempering water during tournaments is not a practical technique. Thus, we recommend, as a practical routine for tournament anglers, maximum replacement of live-well water with lake water when ambient water quality is adequate, continuous aeration, and minimal or no use of water conditioners.

Acknowledgments

Many students, staff, and faculty of the Department of Fisheries and Wildlife at the University of Minnesota graciously volunteered to assist with the intensive task of collecting field data during tournaments; their time and effort are appreciated. Don Jaschke provided valuable assistance throughout this study in the field and laboratory and with data compilation. Tim Goeman gave administrative assistance, loaned equipment, offered helpful suggestions, and reviewed an earlier draft of this manuscript. Bruce Vondracek assisted in the field and provided a manuscript review. Tom Heming assisted in data collection and provided methodological suggestions. Henry Drewes, Duane Shodeen, and other MDNR staff contributed productive discussion and suggestions, field assistance, and unpublished data.

Dick Nelson served as liaison between researchers and angling groups. He, along with Don Knutson, Gary Larson, John Schneider, and other members of the Minnesota Sportfishing Congress and Minnesota Bass Federation contributed insightful suggestions and discussion and were accommodating in supporting research at tournaments. Finally, we thank the many anglers that cooperated with this study and allowed and encouraged us to study their avocation. Their cooperation and insight improved the quality of this research. Funding for this study was provided by the Minnesota Future Resources Fund and was approved by the Minnesota Legislature (M.L. 1991, Chap. 254, Art. I, Sec. 14, Subd. 8f) as recommended by the Legislative Commission on Minnesota Resources.

References

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

Berka, R. 1986. The transport of live fish: a review. EIFAC (European Inland Fisheries Advisory Commission) Technical Paper 48.

Bulkley, R. V. 1975. Chemical and physical effects on the centrarchid basses. Pages 286–294 *in* H. Clepper, editor. Black bass biology and management. Sport Fishing Institute, Washington, D.C.

Carmichael, G. J., J. R. Tomasso, B. A. Simco, and K. B. Davis. 1984a. Characterization and alleviation of stress associated with hauling largemouth bass. Transactions of the American Fisheries Society 113: 778–785.

Carmichael, G. J., J. R. Tomasso, B. A. Simco, and K. B. Davis. 1984b. Confinement and water quality-induced stress in largemouth bass. Transactions of the American Fisheries Society 113:767–777.

Duttweiler, M. W. 1985. Status of competitive fishing in the United States: trends and state fisheries policies. Fisheries 10(5):5–7.

Ebbers, M. A. 1987. Vital statistics of a largemouth bass population in Minnesota from electrofishing and angler-supplied data. North American Journal of Fisheries Management 7:252–259.

Emerson, K., R. C. Russo, R. E. Lund, and R. V. Thurston. 1975. Aqueous ammonia equilibrium calculations: effect of pH and temperature. Journal of the Fisheries Research Board of Canada 32:2379–2383.

Goeman, T. J. 1991. Walleye mortality during a live-release tournament on Mille Lacs, Minnesota. North American Journal of Fisheries Management 11:57–61.

Gustaveson, A. W., R. S. Wydoski, and G. A. Wedemeyer. 1991. Physiological response of largemouth bass to angling stress. Transactions of the American Fisheries Society 120:629–636.

Hach. 1992. Hach water analysis handbook, 2nd edition. Hach Co., Loveland, Colorado.

Hartley, R. A., and J. R. Moring. 1991. Initial and delayed mortality of largemouth and smallmouth basses due to tournaments. Pages 269–272 *in* J. L. Cooper and R. H. Hamre, editors. Warmwater fisheries symposium I. U.S. Forest Service General Technical Report RM-207.

Hartley, R. A., and J. R. Moring. 1993. Observations of black bass (Centrarchidae) confined during angling tournaments: a cautionary note concerning dissolved oxygen. Aquaculture and Fisheries Management 24:575–579.

Heidinger, R. C. 1975. Life history and biology of the largemouth bass. Pages 11–20 *in* H. Clepper, editor. Black bass biology and management. Sport Fishing Institute, Washington, D.C.

Holbrook, J. A., II. 1975. Bass fishing tournaments. Pages 408–415 *in* H. Clepper, editor. Black bass biology and management. Sport Fishing Institute, Washington, D.C.

Jackson, J. J., and D. W. Willis. 1991. Short-term mortality of smallmouth bass caught during a live-release tournament at Lake Oahe, South Dakota. Prairie Naturalist 23:201–204.

McCormick, J. H., and K. M. Jensen. 1992. Osmoregulatory failure and death of first-year largemouth bass (*Micropterus salmoides*) exposed to low pH and elevated aluminum, at low temperatures in soft water. Canadian Journal of Fisheries and Aquatic Sciences 49:1189–1197.

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

Moss, D. D., and D. C. Scott. 1961. Dissolved-oxygen requirements of three species of fish. Transactions of the American Fisheries Society 90:377–393.

Pelzman, R. J. 1978. Hooking mortality of juvenile largemouth bass, *Micropterus salmoides*. California Fish and Game 64:185–188.

Piper, R. G., I. B. McElwain, L. E. Orme, J. P. McCraren, L. G. Fowler, and J. R. Leonard. 1983. Fish hatchery management. U.S. Fish and Wildlife Service, Washington, D.C.

Plumb, J. A., J. M. Grizzle, and W. A. Rogers. 1988. Survival of caught and released largemouth bass after confinement in live wells. North American Journal of Fisheries Management 8:324–328.

Roseboom, D. P., and D. L. Richey. 1977. Acute toxicity of residual chlorine and ammonia to some native Illinois fishes. Illinois State Water Survey Report of Investigation 85.

Russo, R. C. 1985. Ammonia, nitrite, and nitrate. Pages 455–471 *in* G. M. Rand and S. R. Petrocelli, editors. Fundamentals of aquatic toxicology. Hemisphere, New York.

Schramm, H. L., Jr., P. J. Haydt, and N. A. Bruno. 1985. Survival of tournament-caught largemouth bass in two Florida lakes. North American Journal of Fisheries Management 5:606–611.

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

Schramm, H. L., Jr., and R. C. Heidinger. 1988. Live release of bass: a guide for anglers and tournament organizers. Tennessee Wildlife Resources Agency, Nashville.

Schramm, H. L., Jr., and seven coauthors. 1991. The status of competitive sport fishing in North America. Fisheries 16(3):4–12.

Shupp, B. D. 1979. 1978 status of bass fishing tournaments in the United States: a survey of state fishery management agencies. Fisheries 4(6):11–19.

Spotte, S. 1979. Fish and invertebrate culture: water management in closed systems, 2nd edition. Wiley, New York.

Wedemeyer, G. A., B. A. Barton, and D. J. McLeay. 1990. Stress and acclimation. Pages 451–489 *in* C. B. Schreck and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Wilkinson, L., M. Hill, and E. Vang. 1992. SYSTAT: statistics, version 5.2 edition. SYSTAT, Inc., Evanston, Illinois.

Wismer, D. A., and A. E. Christie. 1987. Temperature relationships of Great Lakes fishes: a data compilation. Great Lakes Fishery Commission, Special Publication 87-3, Ann Arbor, Michigan.

Zar, J. H. 1984. Biostatistical analysis, 2nd edition. Prentice-Hall, Englewood Cliffs, New Jersey.