Simulated Impacts of Tournament-Associated Mortality on Largemouth Bass Fisheries

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Abstract.—We used creel survey data combined with a simulation model to assess how tournament-associated mortality could increase exploitation of largemouth bass Micropterus salmoides and influence largemouth bass fisheries. We obtained estimates of total largemouth bass harvest (HARV) and total tournament catch (TC, i.e., the number of fish brought to judging stations) at nine lakes from Arkansas, Florida, and Texas. The ratio of TC to HARV exceeded 1.0 at five of the nine lakes studied and ranged from 0.35 to 5.18. We simulated potential tournament-associated mortality rates ranging from 0% to 70% applied to TC fish. Because exploitation was not known, we modeled harvest estimates to represent four potential exploitation rates (5, 15, 25, and 35%). The age-structured simulation model predicted that at three of nine lakes where TC/HARV ratios exceeded 3.0, tournament-associated mortality rates of 20–30% could cause 5–12% declines in the abundance of largemouth bass larger than 300 mm total length and resulted in declines in population size structure. At lakes with TC/HARV ratios of less than 1.0 (N = 4 lakes), the model predicted that tournament-associated mortality would have a negligible impact (i.e., <5%) on the abundance of adult fish and population size structure, regardless of the tournament-associated mortality rate. Tournament-associated mortality may not significantly influence most largemouth bass fisheries. However, in lakes where tournament catch was substantially higher than harvest, tournament-associated mortality could encompass a large portion of fishing-associated mortality and would influence largemouth bass fisheries if harvest estimates corresponded to exploitation rates of 15% or more. Exploitation measures based solely on harvest may not reveal significant portions of fishing-associated mortality for fisheries where tournament catch can exceed harvest.

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Live-release fishing tournaments of black bass Micropterus spp. have increased in number over the last 30 years (Duttweiler 1985; Schramm et al. 1991; Kwak and Henry 1995; Noble 2002), and fishery managers have been concerned that mortality associated with fishing tournaments could impact black bass fisheries. These concerns have led to copious research evaluating the factors that contribute to mortality of released black bass, including largemouth bass M. salmoides (reviewed by Wilde 1998), as well as suggestions to minimize mortality associated with tournaments (e.g., Gil-liland and Schramm 2002). Numerous studies have quantified initial, delayed, and total mortality of tournament-released black bass; few, however, have evaluated how tournament-associated mortality may influence black bass populations.

Catch-and-release mortality rates differ between tournament and nontournament fishing activities because fish caught in tournaments are retained for judging (Hayes et al. 1995). Hooking mortality of released nontournament fish generally is considered to be around 5–10% (Hayes et al. 1995), whereas reported tournament-associated total mortality rates have ranged from 2% to 98% (Champeau and Denson 1988; Lee et al. 1993; Wilde 1998; Neal and Lopez-Clayton 2001). Black bass tournament-associated mortality (TM) rates vary with water temperature (Schramm et al. 1987; Meals and Miranda 1994; Neal and Lopez-Clayton 2001), tournament size (Wellborn and Barkley 1974; Schramm et al. 1985; Bennett et al. 1989; Meals and Miranda 1994; Hartley and Moring 1995), fish length (Meals and Miranda 1994), and...
handling procedures (Meals and Miranda 1994; Hartley and Moring 1995; Kwak and Henry 1995; Weathers and Newman 1997; Neal and Lopez-Clayton 2001). Wilde (1998) reviewed estimates of black bass TM and found that total mortality averaged about 26–28%. However, many TM studies have not properly measured total TM, and the overall average of 26–28% is probably a slight overestimate (Wilde et al. 2003).

Despite numerous studies quantifying TM, the potential effects of this mortality source on black bass fisheries have seldom been considered. Several authors have suggested that tournaments are not likely to negatively impact bass populations because tournament catch rates involve only a small fraction of the population (Chapman and Fish 1985; Schramm et al. 1987; Lee et al. 1993). Kwak and Henry (1995) and Neal and Lopez-Clayton (2001) conducted empirical evaluations at lakes in Minnesota and Puerto Rico, respectively, and concluded that TM did not substantially affect largemouth bass population abundance. Hayes et al. (1995) simulated the impacts of tournament fishing on largemouth bass populations where tournament fishing was the sole source of fishing mortality. They concluded that TM probably did not affect largemouth bass population viability but could affect population size structure (Hayes et al. 1995). However, no previous studies have assessed the potential effects of TM on overall exploitation across a range of largemouth bass fisheries. We used empirical data from creel surveys and a simulation model to explore how TM could increase annual exploitation and thus influence the population size structure and abundance of adult-sized largemouth bass.

**Methods**

We surmised that the potential impacts of TM on largemouth bass populations could be described by relating estimates of total harvest (e.g., all fish harvested by nontournament anglers) to various TM rates as applied to estimates of the total number of fish brought to tournament weigh-ins. We used creel survey estimates of total harvest and the total number of fish brought to tournaments and then used a simulation model to assess how various mortality rates applied to tournament-caught (TC) fish would increase overall exploitation and thus influence largemouth bass populations in fisheries.

We sought creel survey data that questioned anglers on whether or not they were participating in a fishing tournament and obtained data for the number of fish per tournament and nontournament boat. We used stratified, uniform, and nonuniform probability creel survey sampling protocols (Malvestuto 1996) to estimate largemouth bass angler harvest and the number of caught fish kept in live wells by tournament anglers. Creel survey methods included both roving and access-point methods, depending on the lake and state. Sample days were randomly selected for each day-type strata (weekday and weekend), but uniform and nonuniform probabilities were used for each strata, depending on lake and state. For each sample day, temporal and spatial sampling units were chosen randomly by using uniform selection probabilities. Anglers interviewed during creel sampling were identified by angler type (tournament or nontournament) and questioned about their largemouth bass catch, harvest, and angling effort. Estimates of total harvest and total number of fish brought in for judging by tournament anglers were estimated separately for each angler group (tournament and nontournament) according to the procedures described by Pollock et al. (1994) and were expanded to lakewide estimates. We sought to obtain annual estimates of total harvest and tournament catch. However, in some cases, creel surveys were not conducted throughout the year, and we used seasonal estimates as an indicator of the magnitude of total harvest relative to the total number of fish caught during tournaments. If multiple years of creel survey data were available, we used correlation analysis to assess whether the ratio of harvested fish to fish brought to tournaments changed through time at each lake.

We used an age-structured simulation model (Allen et al. 2002) to assess how various rates of TM would influence largemouth bass fisheries. Fish growth in the model was expressed as gender-specific arrays of mean total length (TL) at age. We used mean TL-at-age from a review of largemouth bass growth rates in Florida (Allen et al. 2002) described as TL = 626(1 − e−0.246(age + 0.139)) for females and TL = 419(1 − e−0.435(age + 0.107)) for males, with TL in millimeters and age in years. These growth rates were similar to the “average" productivity values reported in a review of North American largemouth bass populations combined across males and females (Beamisderfer and North 1995). Fish TL values were transformed to fish weights in the model according to the standard weight equation (Wäge and Anderson 1978).

We simulated an exploitation rate adjusted for TM as follows:
Allen et al. 

\[ N = \text{HARV}/u_{\text{HARV}} \]  
\[ \text{TDEATHS} = \text{TC} \times \text{TM} \]  
\[ u_{\text{TOURN}} = \text{TDEATHS}/N \]  
\[ u_{\text{TOT}} = u_{\text{HARV}} + u_{\text{TOURN}} - (u_{\text{HARV}} \times u_{\text{TOURN}}), \]  

where \( N \) = number of largemouth bass in the population before harvest (no TM), \( u_{\text{HARV}} \) = exploitation rate from harvest, HARV = total number of fish harvested by anglers, TDEATHS = estimated total number of fish that died from TM, TC = total number of fish caught and brought to tournament judging stations, TM = total TM (both initial and delayed mortalities), \( u_{\text{TOURN}} \) = potential exploitation rate from tournament-associated mortality, and \( u_{\text{TOT}} \) = total exploitation, including fish harvested and deaths from all TM.

Thus, equation (4) increases annual exploitation to account for TM applied to the estimated number of TC fish. Equation (4) assumes that tournament sources of mortality are additive to angler harvest (i.e., no compensatory response), but that some fish caught from angler harvest would not be available for tournament catches, and vice versa, by the fraction \((u_{\text{HARV}} \times u_{\text{TOURN}})\) as per Wilde et al. (2003).

We simulated TM rates ranging from 0 to 70%, the reported range for total TM rates for largemouth bass (Wilde 1998). Allen et al. (1998) reviewed exploitation estimates (i.e., \( u_{\text{HARV}} \)) for largemouth bass and found that estimates averaged about 35% and ranged from 9% to 72%. However, their review covered studies from 1953 to 1989; because voluntary angler release of largemouth bass has increased in popularity (Quinn 1996; Noble 2002), we believed that most largemouth bass populations would experience annual exploitation of 35% or less. Therefore, we simulated estimates of \( u_{\text{HARV}} \) of 0.05, 0.15, 0.25, and 0.35.

Mortality in the model was expressed as age- and gender-specific arrays of annual natural mortality (\( v \)) and exploitation (\( u_{\text{TOT}} \)). Allen et al. (1998) found an average \( v \) of about 25%, which corresponds to an instantaneous natural mortality (\( M \)) of 0.379. We used an \( M \) of 0.379 for all simulations, but changes in \( u_{\text{TOT}} \) resulted in changes in \( v \) (i.e., some fish deaths from increased exploitation due to TM included fish that would have otherwise died from natural mortality). Age-specific values of \( u_{\text{TOT}} \) and \( v \) were input for each lake, \( u_{\text{HARV}} \) value (i.e., 0.05–0.35), and level of TM (i.e., \( u_{\text{TOT}} \) corresponding to tournament mortalities of 0–0.7). In cases where TC was very high relative to HARV, simulated tournament mortalities were set so that total deaths would not exceed the total population size (HARV/\( u_{\text{HARV}} \)). Such cases resulted either from an unrealistic TM rate (i.e., more deaths than the population size) or an exploitation estimate that was too high (i.e., underestimating population size).

Simulations began with 1,000 fish recruiting to age 1 per year, simulated ages ranging from 1 to 10. A 356-mm TL minimum size limit was used for all simulations because this is a common size limit for largemouth bass and was the statewide regulation in Texas and in the peninsula region of Florida. The model protected fish from \( u_{\text{HARV}} \) if fish were below the minimum length. We assumed that fish below 254-mm TL were not captured by anglers. For fish smaller than the minimum length limit but larger than 254 mm TL, fish were assumed to be caught at the given exploitation rate attributable to harvest (\( u_{\text{HARV}} \)), and a hooking mortality of 10% (Zagar and Orth 1986) was applied.

For each lake, exploitation rate, and tournament mortality rate, the model was allowed to run until a stable age distribution occurred, which indicated the average population response to various TM values. Because recruitment to age 1 was constant, stable age distributions were achieved after 10 years of simulations (i.e., the maximum age in the simulated populations). Values of \( u_{\text{TOT}} \) corresponding to TM = 0 were used as the predicted fishery responses without TM (e.g., \( u_{\text{HARV}} \)) for comparison with the various TM simulations. Fishery metrics used to assess impacts of TM were the percentage change in number of fish over quality-size (300 mm TL) in the population, and the change in proportional stock density (PSD = number of fish \( \geq 300 \) mm/number \( \geq 200 \) mm TL-100%; Anderson and Neumann 1996).

**Results**

We obtained creel survey data from nine lakes in three states (Table 1). Lake size ranged from 4,615 ha (Lake Somerville, Texas) to 74,899 ha (Toledo Bend Reservoir, Texas–Louisiana). Because state agencies generally allocated creel survey efforts to the most important fisheries, these lakes represent popular largemouth bass fisheries in each state and thus were not a random sample of fisheries. The total number of years of data obtained ranged from 1 to 11 across lakes (Table 1). Creel survey estimates for Millwood and Beaver lakes in Arkansas and Toledo Bend, Sam Rayburn, Richland Chambers, and Somerville lakes in Texas were based on estimates from year-round sam-
Table 1.—Lake, number of creel sample years (N), mean number of largemouth bass harvested, mean number of largemouth bass brought to tournaments (mean tournament catch), and the mean ratio of tournament catch to harvest across years. The range pertains to the annual ratios of tournament catch to harvest. Sam Rayburn Reservoir had the median ratio among the nine lakes.

<table>
<thead>
<tr>
<th>Lake</th>
<th>N</th>
<th>Years</th>
<th>Mean harvest (HARV)</th>
<th>Mean tournament catch (TC)</th>
<th>Mean TC/HARV</th>
<th>Range in TC/HARV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kissimmee (Florida)</td>
<td>11</td>
<td>1989–1999</td>
<td>11,334</td>
<td>3,625</td>
<td>0.35</td>
<td>0.18–0.58</td>
</tr>
<tr>
<td>Tohopekaliga (Florida)</td>
<td>10</td>
<td>1989–1998</td>
<td>3,702</td>
<td>1,395</td>
<td>0.37</td>
<td>0.13–0.60</td>
</tr>
<tr>
<td>Toledo Bend (Texas)</td>
<td>2</td>
<td>2001–2002</td>
<td>70,923</td>
<td>27,408</td>
<td>0.37</td>
<td>0.28–0.46</td>
</tr>
<tr>
<td>Richland Chambers (Texas)</td>
<td>1</td>
<td>2002</td>
<td>865</td>
<td>763</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>Sam Rayburn (Texas)</td>
<td>2</td>
<td>2001–2002</td>
<td>22,523</td>
<td>26,307</td>
<td>1.15</td>
<td>0.96–1.34</td>
</tr>
<tr>
<td>Palestine (Texas)</td>
<td>1</td>
<td>2001</td>
<td>245</td>
<td>627</td>
<td>2.56</td>
<td></td>
</tr>
<tr>
<td>Millwood (Arkansas)</td>
<td>2</td>
<td>2001–2002</td>
<td>5,594</td>
<td>17,067</td>
<td>3.32</td>
<td>2.15–4.5</td>
</tr>
<tr>
<td>Beaver (Arkansas)</td>
<td>3</td>
<td>1998–2000</td>
<td>2,566</td>
<td>5,981</td>
<td>3.71</td>
<td>1.89–6.07</td>
</tr>
<tr>
<td>Somerville (Texas)</td>
<td>1</td>
<td>2001</td>
<td>218</td>
<td>1,130</td>
<td>5.18</td>
<td></td>
</tr>
</tbody>
</table>

In Florida, creel survey estimates for Lake Tohopekaliga were collected from August to November each year, and Lake Kissimmee samples were collected during summer (May–August) and winter (November–February) each year. Winter and summer estimates of total harvest and number of fish caught in tournaments were averaged for each year at Lake Kissimmee (i.e., the winter period was included in the November calendar year) before we estimated among-year means.

Mean harvest estimates (HARV) across lakes ranged from 218 to 70,923, and mean TC ranged from 763 to 27,408 (Table 1). The mean ratio of TC to HARV across lakes ranged from 0.35 to 5.18, with a median value of 1.15 at Sam Rayburn Reservoir (Table 1). Thus, tournament catch was smaller than total harvest at four lakes but exceeded harvest at five lakes. Tournament catch at Lake Somerville exceeded harvest by more than fivefold (Table 1). For simulations, we used TC/HARV values from four lakes including Lake Kissimmee (lowest ratio), Sam Rayburn Reservoir (median value), and Beaver and Somerville reservoirs (the two highest ratios; Table 1).

The influence of simulated tournament-associated mortality on total exploitation ($u_{TOT}$) from equation (4) varied with exploitation and TC/HARV ratio. For example, simulations for Lake Somerville indicated that increases in TM would greatly increase largemouth bass total exploitation (Figure 1) because the TC/HARV ratio was high (Table 1). For the 35% $u_{HARV}$ simulations, the model predicted that at Lake Somerville $u_{TOT}$ would reach 100% if TM surpassed 60% (Figure 1b). This result suggests either that the simulated exploitation rate of 35% was too high for this population, that the actual tournament mortality value did not exceed 50%, or both. At lakes with low TC/HARV ratios (e.g., Lakes Kissimmee, Tohopekaliga, and Toledo Bend), the effects of TM on $u_{TOT}$ were nil because the number of TC fish was well below the number harvested (e.g., high TM did not significantly increase $u_{TOT}$). As expected, effects of TM on $u_{TOT}$ increased with the simulated rate of exploitation (i.e., if observed harvest was assumed to be a high $u_{HARV}$ in absence of TM; Figure 1a, b).

Likewise, the impact of TM on simulated largemouth bass populations varied with TC/HARV ratios among lakes. Effects of TM on the abundance of fish larger than 300 mm TL was low at lakes with low TC/HARV ratios such as Lakes Kissimmee, Tohopekaliga, and Toledo Bend, regardless of the assumed rate of exploitation (Figure 2a–d). However, TM reduced the simulated number of quality-sized fish at Lake Somerville by 5–15% when TM exceeded 30% and observed harvest rates were indicative of $u_{HARV}$ of 15% or greater (Figure 2). Lake Sam Rayburn had the median TC/HARV ratio among lakes and showed a 5% reduction in the number of quality-sized fish in the population if TM reached 40% and harvest estimates reflected 25% $u_{HARV}$ (Figure 2c). If empirical harvest estimates from the creel surveys corresponded to only 5% $u_{HARV}$, the model predicted a 2% decline in the number of quality-sized fish at Sam Rayburn if TM rates were 50% (Figure 2a). Thus, effects of TM on the populations ranged from very low in most lakes to about 12–15%.

Simulated effects of TM on PSD also varied among lakes and exploitation rates (Figure 3). Changes in PSD with TM were minimal if exploitation was 5%, regardless of the TC/HARV ratio (Figure 3a). If harvest estimates reflected exploitation of 25%, PSD declined from 62 to 56 and 52 at Beaver and Somerville lakes, respectively, as TM increased from 0 to 70%. For lakes with low TC/HARV ratios such as Lakes Kissimmee,
Figure 1.—Total exploitation ($u_{TOT}$) with the increasing levels of total tournament-associated mortality (TM) used in the simulations. The simulations in panel (a) assume that harvest estimates from the creel surveys (Table 1) corresponded to a harvest exploitation rate ($u_{HARV}$) of 15% in the absence of TM; those in panel (b) assume that $u_{HARV}$ in the absence of TM was 35%.

Tohopekaliga, and Toledo Bend, influences of TM on PSD were low regardless of the assumed exploitation rate or the tournament-associated mortality level (Figure 3).

We found some evidence that TC/HARV ratios increased through time. The TC/HARV ratios at Beaver Lake, Arkansas, were 1.9, 3.2, and 6.1 from 1998 to 2000 and averaged 3.71 (Table 1). At Lake Kissimmee, Florida, mean annual TC/HARV ratios were positively correlated with year from 1989 to 1999 ($r = 0.62$, $P = 0.04$). However, at Lake Tohopekaliga, Florida, mean TC/HARV ratios were not related to year ($r = 0.05$, $P = 0.9$). Most of the lakes we evaluated did not have enough years to assess trends, but two of three lakes with multiple years of data suggested increasing TC/HARV ratios through time.

Discussion

Simulations suggested that effects of TM on largemouth bass fisheries could range from nil to about 12–15% in simulated population metrics. At four of nine lakes, tournament catches were lower than total harvest estimates, and TM did not substantially increase exploitation or alter simulated populations. In the other five lakes, tournament catch exceeded harvest and TM more greatly affected the abundance of fish larger than 300 mm TL and PSD, particularly if harvest estimates corresponded to $u_{HARV}$ of 25% or greater. When TC/HARV ratios exceeded 3, such as at Beaver, Millwood, and Somerville lakes, TM of 20–30% or greater caused 5–12% declines in the number of fish larger than 300 mm TL in the simulated populations if harvest estimates corresponded to $u_{HARV}$ of 25% or higher. Thus, the simulations suggested that in three of nine lakes TM could exert over largemouth bass abundance and size structure a 5% change, but in most lakes the impacts would be less.

Exploitation due to harvest ($u_{HARV}$) of largemouth bass was not known for the lakes simulated, so we made relative comparisons among lakes by using a range of potential $u_{HARV}$ estimates. Allen et al. (1998) found that $u_{HARV}$ estimates for largemouth bass averaged 35% and ranged from 9% to
FIGURE 2.—Percent change in the number of fish of at least 300 mm TL in simulated populations at various levels of total tournament-associated mortality. Harvest estimates from the creel surveys (Table 1) were assumed to correspond to (a) 5%, (b) 15%, (c) 25%, and (d) 35% exploitation in the absence of TM ($u_{HARV}$).

FIGURE 3.—Change in the proportional sock density (PSD = number of fish ≥300 mm/number ≥200 mm TL) in simulated populations at various levels of total TM. Harvest estimates from the creel surveys (Table 1) were assumed to correspond to (a) 5%, (b) 15%, (c) 25%, and (d) 35% exploitation in absence of TM ($u_{HARV}$).
72% across studies from 1953 to 1989. However, because of increased voluntary angler release of largemouth bass in recent years (Quinn 1996; Noble 2002), more recent estimates of largemouth bass exploitation are less than 35%. For example, Henry (2003) estimated 11% \( u_{\text{HARV}} \) of largemouth bass at Rodman Reservoir, Florida, in 2001. Renfro et al. (1999) found largemouth bass \( u_{\text{HARV}} \) of 16% and 17% at two Florida lakes in 1991–1992. O’Bara et al. (2001) estimated the \( u_{\text{HARV}} \) of large-mouth bass was 23% in 1996 and 16% in 1997 at Norris Reservoir, Tennessee. Thus, we believe that for most large reservoir/lake largemouth bass fisheries, \( u_{\text{HARV}} \) is less than 35%. Conversely, \( u_{\text{HARV}} \) estimates of 5% or less have not been reported in the literature for exploited largemouth bass populations. Therefore, we surmise that the simulations of \( u_{\text{HARV}} \) at 15% and 25% would be most similar to existing largemouth bass fisheries. At \( u_{\text{HARV}} \) of 15–25%, simulations predicted that TM of 20–30% could reduce abundance of largemouth bass larger than 300 mm TL by 5–15% in three of nine lakes, but the other lakes were predicted to show declines of less than 5%.

Hayes et al. (1995) used simulations to conclude that population growth rate was important to the resiliency of largemouth bass populations with regard to TM. However, Hayes et al. (1995) modeled TM as the sole component of fishing mortality. We used empirical catch data from creel surveys and modeled TM as being additive to the simulated exploitation rates. Population growth rates are difficult to measure in existing populations and were not available for our study lakes. Nevertheless, similar to Hayes et al. (1995), we also found that potential consequences of high TM values were reduced numbers of adult fish and the population size structure (i.e., PSD) in three of nine lakes in this study.

Although many studies have measured TM for largemouth bass (reviewed by Wilde 1998), few have assessed the population implications of TM. Kwak and Henry (1995) estimated about 5% total TM for largemouth bass in a Minnesota lake and surmised that this mortality increased exploitation by 2–6%. However, their estimate of total TM (5%) was substantially lower than the 26–28% average values reported in the review by Wilde (1998). Neal and Lopez-Clayton (2001) estimated the total TM in a Puerto Rican reservoir as 42% but concluded that this loss increased total annual mortality by only about 6% because of the high natural mortality for this population. Similar to these field evaluations, we found that for most lakes in this study, TM was not predicted to substantially increase exploitation and thus did not influence the simulated largemouth bass fisheries. However, in lakes with TC/HARV ratios greater than 3.0, TM was predicted to decrease abundance and population size structure if \( u_{\text{HARV}} \) estimates corresponded to 15% or more.

We found some evidence that TC/HARV ratios are increasing through time, suggesting that tournament catches are increasing, harvest rates are declining, or both. Thus, TM may encompass a larger component of fishing mortality through time. Increased voluntary release of legal largemouth bass suggests that harvest rates are probably declining (Quinn 1996; Noble 2002), and \( u_{\text{HARV}} \) estimates have declined through time (summarized above). Schramm et al. (1987) noted that estimates of tournament catch relative to harvest were low for studies in the 1970s and 1980s. If TC/HARV ratios are increasing through time, measuring impacts of TM on largemouth bass populations will be increasingly important for fishery managers in the future.

Tournament-associated mortality increases with water temperature (Schramm et al. 1987; Meals and Miranda 1994; Neal and Lopez-Clayton 2001); our simulations used TM values ranging from 0 to 70%. Wilde (1998) found that total TM, including initial and delayed rates, averaged 26–28% but increased with water temperature. Using Wilde’s (1998) average rates, our model predicted reductions of at least 10% in the number of fish larger than 300 mm TL in only one out of nine lakes (i.e., Lake Somerville). However, in situations where tournament activity is concentrated during periods of warm water, higher TM rates could increase the likelihood of population-level impacts.

Because impacts of TM on the simulated populations were less than 15%, detecting the effects of this mortality source on populations will probably be difficult. Variation around estimates of electrofishing catch rates is often high and can be influenced by several environmental factors (Reynolds 1996). High variation in field measures would reduce the statistical power of the study and make detecting small changes in populations metrics unlikely (Peterman and Bradford 1987). Changes in PSD with TM were usually less than 5% and did not exceed about 10% (i.e., 62 declined to 52 in the most extreme case); the fish sample sizes required to detect small changes in PSD would often exceed 500–1,000 fish (Miranda 1993). Thus, given the small changes in population characteristics, standard sampling practices would
probably not detect population changes of largemouth bass in response to TM. Our simulations used constant recruitment to assess the equilibrium effects of TM on largemouth bass populations. Recruitment variation in lakes and reservoirs influences both population size structure and abundance (Allen and Pine 2000), which would also make detecting TM impacts difficult. Thus, although the population model suggested that impacts of TM on largemouth bass populations could be significant at some lakes, detecting these impacts in field studies would be difficult.

Nevertheless, future studies could measure impacts of TM on largemouth bass fisheries. Large-scale tagging studies could assess the fraction of adult fish obtained in tournaments, which when combined with estimates of TM would indicate the extent of exploitation attributable to tournaments ($\mu_{\text{TOURN}}$). However, such studies would require intensive monitoring of tournament weigh-in stations. Similar to this study, creel survey data could be used to assess the magnitude of tournament catches relative to largemouth bass harvest. Measuring TC/HARV ratios would indicate the potential for TM to influence largemouth bass exploitation, which would be relatively inexpensive to measure or could be obtained from some existing creel survey databases. However, estimates of TC/HARV alone would not directly measure impacts, because high TC/HARV ratios could occur in populations where neither harvest nor TC represent a significant portion of the population. Estimates of $\mu_{\text{HARV}}$ combined with TC/HARV ratios would be required to fully understand how TM influences a largemouth bass population. Thus, a comprehensive assessment of tournament catches, TM, and traditional exploitation studies to document $\mu_{\text{HARV}}$ would be required to fully elucidate impacts of TM on largemouth bass fisheries.

We modeled 10% hooking mortality of fish below the minimum size limit but did not consider the hooking mortality of legal-sized fish released by anglers. Because voluntary release of legal-sized fish is increasing, future studies should consider the population impacts of mortality from catch and release by nontournament anglers. Clark (1983) used simulations to conclude that 10% or more voluntary release rates of legal fish could change interpretations of fishing mortality. Voluntary release of legal-sized largemouth bass was 75% at Rodman Reservoir, Florida, in 2001 (Henry 2003); in 1999, it was 85% and 52% in Sam Rayburn and Toledo Bend reservoirs, respectively (unpublished data, Texas Parks and Wildlife Department).

Thus, given high rates of voluntary release and high incidence of tournament activity, exploitation estimates based solely on harvest may not reveal significant components of fishing-associated mortality for largemouth bass populations. Such exploitation studies could therefore underestimate fishing-associated mortality on largemouth bass populations if both tournament and catch-and-release components of fishing mortality are not included (Clark 1983). Underestimates of total exploitation, when combined with estimates of total mortality, could cause investigators to conclude that natural mortality is artificially high, possibly influencing decisions about harvest restrictions and leading to improper management strategies. Thus, there is a need to evaluate all fishing-associated sources of mortality in populations with high rates of voluntary catch and release, high tournament activity, or both.

We found that potential impacts of TM varied widely among the nine lakes, as mean TC/HARV ratios ranged from less than 0.5 to more than 5.0. In cases where TM could impact largemouth bass populations (e.g., TC/HARV > 3 according to our results), management options may be difficult to implement. Regulating tournament numbers and total participation, or restricting tournaments to certain seasons (e.g., winter), could reduce tournament impacts but probably would cause conflicts between agencies and tournament-associated user groups. Use of size limits to protect a large range of fish sizes could protect fish from tournaments but would also be unpopular with some angler groups. Conversely, significant impacts from tournament fishing would aggravate other angler groups that do not participate in tournaments. Before considering regulations targeting tournament angling groups, measures of TC/HARV ratios could be collected by using creel surveys. If the TC/HARV ratio exceeded 3.0, field studies (summarized above) would be needed to quantify impacts of TM on existing largemouth bass fisheries.

Many studies have measured TM and factors related to this mortality, including a meta-analysis of combined results among studies (Wilde 1998). However, relatively few studies have attempted to estimate the population impacts of TM. We conclude that TM probably has small impacts to most largemouth bass populations but could be an important component of mortality in fisheries where tournament catches greatly exceed harvest. In some cases, TM could impact largemouth bass
fisheries. Future studies of largemouth bass exploitation should quantify not only angler harvest but also impacts of catch-and-release mortality and TFM as potentially significant components of the total annual exploitation.

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