Use of Mortality Caps to Determine Effectiveness of Black Bass Harvest Restrictions in Tennessee Reservoirs

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Abstract: Evaluations were made of management objectives across Tennessee for 25 largemouth bass (*Micropterus salmoides*) populations and 7 smallmouth bass (*M. dolomieu*) populations. Two models were used; one that calculated mortality caps based on target mean lengths and one based on minimum acceptable PSD or RSD. Mortality caps were calculated over a range of target mean lengths and PSD/RSD objectives and results from each model discussed. Both models suggested that current harvest restrictions for most populations were sufficient to protect fish up to at least 25.4 mm beyond current length limits and to maintain size structure balance within desired PSD ranges. Reservoir populations without size limits or low minimum length limits had mortality caps closest to observed total mortality, warranting additional sampling and possibly more stringent harvest restrictions. Smallmouth bass populations with more restrictive harvest regulations aimed at maintaining high-quality fishing also appeared adequate to reach PSD goals. Mortality caps provide black bass managers with a valuable tool to evaluate current population status using standard spring electrofishing data.

Key words: black bass, reservoirs, mortality caps, harvest restrictions

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Fishery managers began using length indices (e.g., PSD and RSD) and condition indices (e.g., Kn and Wr) for assessing black bass populations during the 1970s (Swingle and Shell 1971, Anderson 1978, Gabelhouse 1984). Although stock structural indices provide a sample-specific assessment of population balance and individual robustness, they do not allow managers to directly determine whether current harvest restrictions have effectively reduced mortality to the point where management objectives are met. More recently, Miranda (2002) developed two size-based mortality cap models that allow calculated values to be compared to total mortality estimates (A) calculated from standard population catch-curves. In the first model, threshold mortality caps are calculated for a given mean length at harvest objective (or catch objective for catch and release fisheries). The second model allows comparison of total mortality to threshold mortality caps given specific PSD or RSD objectives.

Use of mortality caps to assess management efforts can supplement other indices obtained from regular sampling of fish populations. Coupling such mortality assessments with other data sources (e.g., net surveys, electrofishing surveys, and creel surveys) provides additional basis for harvest restriction recommendations (Krueger and Decker 1999). Simple mortality models are most useful when manpower or funding limitations preclude more comprehensive population assessment over multiple sampling gears or survey types.

Systematic electrofishing protocols for black bass have provided unique opportunities for sampling standardization, and allowed for consistent estimation of stock density, growth, recruitment and mortality across large jurisdictional areas. Tennessee Wildlife Resources Agency (TWRA) fishery managers have followed standard electrofishing procedures and compiled black bass data into a statewide database since 1998 (TWRA 1998). Estimates of total black bass mortality are performed at a given reservoir on a three to five-year rotation, allowing biologists to calculate mortality caps for a large number of bodies of water. Agency biologists also follow a statewide management plan for largemouth bass that provides an RSD preferred (RSD-P) goal of 20%–40% for reservoir populations (Churchill and Reeves 2000).

Mortality cap analyses are relatively new and have only been reported for two species. Miranda (2002) used the example of crappies (*Pomoxis* spp.) to simulate the use of the mean length model after describing how the model was derived. Quist et al. (2004) applied both the mean length model and PSD-based model to eight walleye (*Sander vitreus*) populations in Kansas and found that total mortality for most populations did not exceed the mortality caps necessary to achieve mean length or PSD objectives. Our study reports the first use of mortality caps to evaluate harvest restrictions for largemouth bass (*Micropterus salmoides*) and smallmouth bass (*M. dolomieu*) at a statewide level. We discuss the utility of the models for determining the effectiveness of current regulation strategies for two species that are largely catch-and-release fisheries in Tennessee.

Methods

Twenty-eight largemouth bass and 17 smallmouth bass populations were sampled with electrofishing in April and May from 1998 to 2003. Study reservoirs ranged in size from 919 to 43,852 surface hectares. All bass collected were enumerated and otoliths were extracted from subsamples for subsequent age analyses. An age-length key was used to assign ages to all fish sampled based on the known-age subsamples for each population (DeVries and Frie 1996). Total annual mortality estimates were calculated for each sample with simple catch-curves (Ricker 1975). Catch-curves were plotted to determine the age at which fish were fully recruited to the electrofishing gear, and regressions were weighted to minimize bias associated with influential year classes (Slipke and Maceina 2000). A value of one was added to all age classes in samples containing one or more missing year classes. This procedure was followed to allow complete logarithmic transformation of the data. Number per age group in each reservoir population were pooled over different sampling years to minimize the influence of year class strength in total mortality estimates (Quist et al. 2004).

Mortality caps were calculated over a range of target mean length objectives with the equation:

$$Z = K \frac{L_{\infty} - L_{mean}}{L_{mean} - L_{x}} \quad (1)$$

Instantaneous mortality caps (Z) were converted to annual interval mortality with A = 1 – e^{-z}; K is the von Bertalanffy growth constant; L_{∞} is the hypothetical maximum length; L_{mean} is the mean length objective; and L_x is the minimum length available for harvest. L_x was a minimum length limit (MLL) for most populations. We assumed a minimum length harvested of 305 mm for those populations with no size limit in place. L_{mean} values covered a range of MLLs in one-inch increments that are commonly proposed for Tennessee waters. Mortality caps were calculated only for populations where N ≧ 100 bass and the slopes of catch-curve regression models were significant ($P \leqq 0.01$).

Mortality caps were also calculated for a range of target PSD and RSD objectives with the equation:

$$Z = -\frac{\log_e \text{PSD}\textit{(or RSD)}}{t_x - t_x}, \quad (2)$$

where t_x is the time in years required to reach a specific PSD or RSD size class (e.g., t_q = time to reach quality size, t_p = time to reach preferred size) and t_s is the time in years required to reach stock size. Explanations and of how equations 1 and 2 are derived, how to use them, and assumptions for appropriate use are detailed in Miranda (2002).

PSD goals in our study were set at the desired level of 40%–60% for smallmouth bass population balance (Anderson and Neumann 1996) for systems managed with standard MLLs (none to 381 mm MLL) and with higher desired PSD goals of 50%–80% for populations managed for a higher level of fishing quality (≧406 mm MLL or slot limit). TWRA's largemouth bass management RSD-P objective of 20%–40% was also evaluated with mortality caps. No RSD-P mortality caps were calculated for smallmouth bass because no agency goals have been defined for this species.

Results

Largemouth bass total annual mortality (A) ranged from 17% to 48% ($\bar{x}$ = 33%) for 25 reservoir populations (Table 1), with three additional populations dropped from analysis due to high variance in catch curve values. All largemouth bass mortality caps exceeded population mortality estimates (equation 1) at mean length objectives for existing MLLs. Total mortality for the Douglas Reservoir population exceeded the mortality cap at 381 mm, indicating that survival of older, larger fish was relatively low.

Mortality caps calculated for the same largemouth bass populations under PSD objectives were mostly indicative of balanced bass populations (Table 2). All mor-

Table 1. Mortality caps calculated over a range of mean length at harvest objectives (Eq. 1). Mortality cap values were calculated only for length objectives exceeding minimum length limits. LMB = largemouth bass; SMB = smallmouth bass; and A = total annual mortality (%).

						Mortality caps			
Reservoir	Species	Min. size limit	K	L_∞	A	356 mm	381 mm	406 mm	432 mm
Barkley	LMB	381 mm	0.346	523	48	—	—	80	46
Boone	LMB	381 mm	0.366	480	25	—	—	66	29
Center Hill	LMB	381 mm	0.401	488	30	—	—	73	36
Cheatham	LMB	356 mm	0.134	652	28	—	77	48	32
Cherokee	LMB	381 mm	0.368	507	42	—	—	78	42
Chickamauga	LMB	381 mm	0.227	566	17	—	—	77	45
Cordell Hull	LMB	None	0.181	609	25	59	42	31	22
Dale Hollow	LMB	381 mm	0.308	522	36	—	—	76	42
Douglas	LMB	None	0.281	538	45	63	44	31	21
Ft. Loudoun	LMB	356 mm	0.152	631	26	—	78	50	33
Great Falls	LMB	None	0.216	544	32	55	37	26	17
J. Percy Priest	LMB	381 mm	0.169	597	44	—	—	73	42
Kentucky	LMB	381 mm	0.259	582	32	—	—	84	53
Melton Hill	LMB	356 mm	0.168	576	33	—	73	44	27
Nickajack	LMB	381 mm	0.470	439	32	—	—	46	6
Normandy	LMB	381 mm	0.301	516	35	—	—	73	39
Norris	LMB	356 mm	0.232	554	41	—	80	50	31
Old Hickory	LMB	356 mm	0.146	620	35	—	75	47	30
Pickwick	LMB	381 mm	0.427	485	43	—	—	74	36
Reelfoot	LMB	381 mm	0.291	548	39	—	—	81	48
South Holston	LMB	None	0.310	512	22	61	42	28	18
	SMB	None	0.256	573	35	66	48	35	25
Tellico	LMB	356 mm	0.152	633	34	—	79	50	33
Tims Ford	LMB	381 mm	0.323	481	28	—	—	62	27
	SMB	381 mm	0.268	568	50	—	—	82	51
Watauga	SMB	305 mm	0.304	534	38	65	46	32	22
Watts Bar	LMB	381 mm	0.237	556	17	—	—	76	44
Woods	LMB	None	0.328	518	37	65	45	31	20
	SMB	None	0.390	526	33	73	52	37	25

tality estimates were below the caps calculated for the minimum PSD value of 40% except for J. Percy Priest Reservoir, suggesting that total mortality exceeded the threshold that would allow the population to achieve minimum balance. Twenty-four percent of largemouth bass populations exceeded the mortality caps to achieve a PSD of 50% and 64% exceeded mortality caps for PSD = 60%. Only three populations, (Chickamauga, South Holston, and Watts Bar reservoirs) had mortality estimates that were below mortality caps at PSD = 70%.

Mortality caps calculated for largemouth bass under the RSD-P modification of equation 2 also indicated that our objective RSD-P values could largely be met with existing regulations (Table 3). Only populations at Douglas, J. Percy Priest, Norris, and Old Hickory reservoirs had mortality estimates at or above the mortality caps at the minimum 20% RSD-P objective set in TWRA's largemouth bass management plan. Total mortality for most largemouth bass populations exceeded caps at some point within the desired RSD-P range of 20% to 40%.

Smallmouth bass populations in seven reservoirs were included in mortality cap analyses and mortality estimates ranged from 33% to 60%, with a mean of 42% (Tables 1 and 2). Ten other populations were rejected for analyses due to insignificant catch curve regression slopes ($P \geqq 0.01$). Four of the seven populations analyzed were managed with standard TWRA black bass size limits (none to 381 mm MLL) and three were managed with high quality or trophy harvest restrictions (≧406 mm MLL and slot limit). Mortality estimates for populations with standard size limits were all below mortality caps at target mean length categories above the minimum length limits. The mortality cap for Tims Ford smallmouth bass was not exceeded even at the 432 mm mean length objective. Mortality estimates were below mortality caps at the target PSD value of 40% by all of the four populations in this subgroup.

Table 2. Mortality caps calculated over a range of PSD objectives (Eq. 2). LMB = largemouth bass; SMB = smallmouth bass; and A = total annual mortality (%).

						Mortality caps			
Reservoir	Species	Min. size limit	t_s	t_q	A	PSD 40%	PSD 50%	PSD 60%	PSD 70%
Barkley	LMB	381 mm	1.41	2.52	48	56	46	37	28
Boone	LMB	381 mm	1.44	2.69	25	52	43	34	25
Center Hill	LMB	381 mm	0.92	2.02	30	56	47	37	28
Cheatham	LMB	356 mm	1.31	3.24	28	38	30	23	17
Cherokee	LMB	381 mm	1.15	2.26	42	56	47	37	28
Chickamauga	LMB	381 mm	1.74	3.19	17	47	38	30	22
Cordell Hull	LMB	None	1.66	3.26	25	44	35	27	20
Dale Hollow	LMB	381 mm	1.14	2.39	36	52	43	34	25
Douglas	LMB	None	0.98	2.28	45	51	42	33	24
Ft. Loudoun	LMB	356 mm	1.32	3.11	26	40	32	25	18
Great Falls	LMB	None	1.70	3.35	32	43	34	27	20
J. Percy Priest	LMB	381 mm	0.90	2.66	44	41	33	25	18
Kentucky	LMB	381 mm	1.49	2.70	32	53	44	34	26
Melton Hill	LMB	356 mm	1.38	3.28	33	38	31	24	17
Nickajack	LMB	381 mm	1.52	2.72	32	53	44	35	26
Normandy	LMB	381 mm	1.22	2.54	35	50	41	32	24
Norris	LMB	356 mm	1.18	2.66	41	46	37	29	21
Old Hickory	LMB	356 mm	1.31	3.23	35	38	30	23	17
Pickwick	LMB	381 mm	1.09	2.14	43	58	48	38	29
Reelfoot	LMB	381 mm	1.11	2.31	39	53	44	35	26
South Holston	LMB	None	1.21	2.50	22	51	42	33	24
	SMB	None	1.51	2.67	35	55	45	36	27
Tellico	LMB	356 mm	1.51	3.29	34	40	32	25	18
Tims Ford	LMB	381 mm	0.91	2.33	28	48	39	30	22
	SMB	381 mm	1.48	2.59	50	56	46	37	27
Watauga	SMB	305 mm	2.17	3.27	38	57	47	37	28
Watts Bar	LMB	381 mm	1.59	3.02	17	47	38	30	22
Woods	LMB	None	1.22	2.41	37	54	44	35	26
	SMB	None	1.48	2.36	33	65	55	44	33

Table 3. Mortality caps calculated over a range of TWRA's RSD-P objectives for largemouth bass (modified Eq. 2).

						Mortality caps			
Reservoir	Species	Min. size limit	t_s	t_p	A	RSD-P 20%	RSD-P 30%	RSD-P 40%	RSD-P 50%
Barkley	LMB	356 mm	1.41	3.76	48	50	40	32	26
Boone	LMB	381 mm	1.44	4.24	25	44	35	28	22
Center Hill	LMB	381 mm	0.92	3.36	30	48	39	31	25
Cheatham	LMB	356 mm	1.31	5.08	28	35	27	22	17
Cherokee	LMB	381 mm	1.15	3.54	42	49	40	32	25
Chickamauga	LMB	381 mm	1.74	4.72	17	42	33	27	21
Cordell Hull	LMB	None	1.66	4.84	25	40	32	25	20
Dale Hollow	LMB	381 mm	1.14	3.79	36	46	37	29	23
Douglas	LMB	None	0.98	3.68	45	45	36	29	23
Ft. Loudoun	LMB	356 mm	1.32	4.86	26	37	29	23	18
Great Falls	LMB	None	1.70	5.12	32	38	30	24	18
J. Percy Priest	LMB	381 mm	0.90	4.44	44	37	29	23	18
Kentucky	LMB	381 mm	1.49	3.95	32	48	39	31	25
Melton Hill	LMB	356 mm	1.38	5.24	33	34	27	21	16
Nickajack	LMB	381 mm	1.52	4.51	32	42	33	26	21
Normandy	LMB	381 mm	1.22	4.02	35	44	35	28	22
Norris	LMB	356 mm	1.18	4.23	41	41	33	26	20
Old Hickory	LMB	356 mm	1.31	5.12	35	35	27	21	17
Pickwick	LMB	381 mm	1.09	3.43	43	50	40	32	26
Reelfoot	LMB	381 mm	1.11	3.60	39	48	38	31	24
South Holston	LMB	None	1.21	3.97	22	44	35	28	22
Tellico	LMB	356 mm	1.51	5.02	34	37	29	23	18
Tims Ford	LMB	381 mm	0.91	4.08	28	40	32	25	20
Watts Bar	LMB	381 mm	1.59	4.54	17	42	34	27	21
Woods	LMB	None	1.22	3.75	37	47	38	30	24

Table 4. Mortality caps for smallmouth bass in quality and trophy-regulated waters calculated over a range of mean length at harvest objectives (Eq. 1).

						Mortality caps			
Reservoir	Species	Min. size limit	K	L_∞	A	483 mm	508 mm	533 mm	559 mm
Norris	SMB	457 mm	0.241	560	46	51	22	8	<1
Watts Bar	SMB	457 mm	0.161	712	60	76	47	32	21

Mortality caps were not exceeded by mortality estimates for smallmouth bass populations under quality and trophy regulations (Table 4). Because the Dale Hollow population was protected by a 406–533 mm slot limit, its L_x value in calculating the mortality caps was set at the upper end of the slot limit. Mortality caps could not be calculated in this case because the calculated L_∞ was exceeded by the management objective, reflecting a lack of larger, older fish in the Dale Hollow electrofishing samples. Mortality caps calculated for high-quality PSD objectives were

Table 5. Mortality caps for smallmouth bass in quality and trophy-regulated waters calculated over a range of PSD objectives (Eq. 2).

						Mortality caps			
Reservoir	Species	Min. size limit	t_s	t_q	A	PSD 50%	PSD 60%	PSD 70%	PSD 80%
Dale Hollow	SMB	406–533 mm slot	1.65	2.79	35	46	36	27	18
Norris	SMB	457 mm	1.48	2.76	33	42	33	24	16
Watts Bar	SMB	457 mm	1.48	2.79	60	41	32	24	16

not exceeded by mortality estimates at the minimum objective (PSD = 50%) except at Watts Bar Reservoir (Table 5). Mortality estimates for all three reservoirs under quality-trophy regulations exceeded the PSD = 70% mortality cap.

Discussion

Black bass mortality caps calculated for Tennessee reservoirs indicate that current minimum length at harvest and PSD objectives were largely achieved. Our analysis included all reservoir populations of largemouth bass and smallmouth bass for which sufficient age data were available to construct significant catch curves. Other sampled populations were omitted when catch-curve slopes did not differ significantly from zero ($P \geqq 0.01$). This was especially true for smallmouth bass, reflecting the difficulty in effectively sampling larger, older individuals with boat-mounted electrofishing (Lott 2000).

Using a range of mortality caps for different mean length targets allowed us to see whether TWRA's current harvest restrictions were adequately conserving fish for anglers. We were able to demonstrate that observed total annual mortality was below the minimum caps for the majority of largemouth bass and smallmouth bass populations studied. Mortality for both species managed under standard TWRA harvest restrictions did not exceed target mean length mortality caps at 381 mm at any lake except for Douglas Reservoir largemouth bass. This was probably attributable to a lack of an MLL there. In fact, the only black bass populations where A exceeded the 406-mm mortality cap were those that either had no MLL or a 305-mm MLL. This suggests that populations with minimum protection by harvest restriction have less potential for achieving higher mean length-at-harvest objectives.

Mortality caps calculated over the range of PSD values indicated that PSD objectives could be met for most of our study populations managed with standard MLLs. Only the mortality estimate calculated for the J. Percy Priest largemouth bass population was in excess of the mortality cap set for the minimum PSD (40%) of a balanced population. J. Percy Priest has consistently ranked with some of the highest values in the state for targeted black bass fishing effort per acre (Broadbent et al. 2004).

Although there is a high release rate for largemouth bass caught at J. Percy

Priest Reservoir, high fishing pressure may still cause substantial post-release mortality and, ultimately, a length distribution skewed toward smaller length classes (Schramm et al. 2004). Malvestuto and Black (2005) reported that the 2004 fishing pressure at J. Percy Priest was the highest (46.8 hours/acre) for any reservoir in the state in 2004, and Kaintz and Bettoli (2005) estimated a high number of fishing tournaments (471) during that same year. Despite a 92% total release rate reported for J. Percy Priest largemouth bass anglers during 2004, high post-release mortality may have adverse effects to population size structure when angler exploitation is high (Allen et al. 2004).

The evaluation of TWRA's RSD-P goals for largemouth bass followed a similar trend. Mortality estimates were low enough for most populations that mortality caps were not exceeded in the management objective goal range of RSD-P = 20%–40% (Churchill and Reeves 2000). Populations with mortality that was near or in excess of caps calculated at RSD-P = 20% (Douglas, J. Percy Priest, Norris, Old Hickory) were the same populations that were close to minimum PSD objectives. However, only the J. Percy Priest population had a mortality estimate exceeding the RSD-P = 20% cap by more than 1%. This may be the only population for which it may be difficult to meet the Agency's RSD-P objective.

All mortality estimates for smallmouth bass populations managed under high quality-trophy regulations were well below the high quality PSD-based mortality caps (PSD = 60%) except for the Watts Bar population. Watts Bar's high total mortality estimate of 60% may either reflect sampling error or a lack of potential to reach the higher PSD standard for balance (range of 50%–80%) used by fishery biologists as a guidepost for bass when lakes are managed for larger fish (Anderson and Neumann 1996). We were only able to use PSD-based mortality caps to evaluate Dale Hollow smallmouth bass because the high-end slot limit present on the lake did not allow us to set an L_{mean} value below the theoretical maximum length (L_∞) calculated by the von Bertalanffy growth model.

Miranda (2002) urged caution in interpreting results for populations where observed mortality approaches calculated mortality caps. For this reason, we acknowledge that there may be times when TWRA's regular cycle of 3–5 years between total mortality estimates may not be frequent enough to provide robust evaluations using mortality caps. We recommend that when observed mortality is ≤5% of the mortality cap at a desired mean harvest length goal, more frequent estimation of total mortality is needed before decisions on new harvest restrictions are made. Because PSD and RSD values are calculated on a more regular basis by TWRA biologists, mortality caps analyses can be performed more frequently with equation 2. Values for t_s and t_x should be stable because black bass lengths-at-age have generally exhibited low variability across years for reservoir populations (TWRA, unpublished data).

Unlike previous population studies based on mortality caps, our analyses focused on a statewide scale and two species that are largely catch-and-release fisheries in Tennessee. Creel surveys conducted by TWRA in 2002 and 2003 estimated that largemouth bass and smallmouth bass release rates varied from 75% to 99% across the state (Malvestuto and Black 2003, 2004). Examining a range of mortality caps allowed us to evaluate results for values of L_{mean} that might be desirable to bass anglers. Previous use of mortality caps to evaluate crappie and walleye populations focused on species that are typically harvested as soon as they are caught at legal size (Miranda 2002, Quist et al. 2004).

We found mortality caps to be a powerful new tool for black bass managers, allowing them to quickly assess the effectiveness of current or proposed harvest restrictions. Managers are very likely to have access to long-term datasets for a population that allows for calculation of mean length-at-age, catch curves, and growth curves enabling them to calculate mortality caps with some frequency. The PSD-based mortality cap formula is especially useful since it allows analysis for populations managed with slot limits for which a single L_x value cannot be determined. Although predictive power of the mortality caps may be imprecise, the models do not require managers to speculate for variables that are often unknown. Other fishery population models rely on frequently unknown values (e.g., natural mortality), forcing managers to make harvest restriction decisions based upon a range of possible and uncertain outcomes.

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