RIVERINE SMALLMOUTH BASS SURVEYS

Final Report

MOUNTAIN FISHERIES INVESTIGATIONS

Federal Aid in Sport Fish Restoration Project F-24

Project Type: Survey

Period Covered: June 2007–September 2009

David W. Goodfred
Kevin J. Hining
Amanda M. Bushon
David L. Yow

Fisheries Biologists

North Carolina Wildlife Resources Commission
Division of Inland Fisheries
Raleigh

2012

This publication was funded under the Federal Aid in Sport Fish Restoration Program utilizing state fishing license money and federal grant funds derived from federal excise taxes on fishing tackle and other fishing related expenditures.

Funds from the Sport Fish Restoration Program are used for aquatic education, fisheries research and management, and boating access facilities. The program is administered cooperatively by the N.C. Wildlife Resources Commission and the U.S. Fish and Wildlife Service.

Abstract.—Rivers and streams containing viable smallmouth bass *Micropterus dolomieu* populations provide important fishery resources. However, little is known regarding the distribution and population dynamics of riverine smallmouth bass in North Carolina. Consequently, the North Carolina Wildlife Resources Commission (NCWRC) conducted a three-year study from 2007–2009 to obtain riverine smallmouth bass data in western North Carolina. Study objectives were to identify smallmouth bass resources, assess population dynamics, and evaluate management opportunities. Smallmouth bass samples were obtained during May through September of each year. Fish were collected using a variety of sampling gears, including boat and backpack electrofishing equipment, angling gear, and seines, with the objective of collecting 30 or more fish per stream reach. During summer 2007, 2008, and 2009, NCWRC personnel collected 1,061, 1,066, and 732 smallmouth bass, respectively. Total length (TL, mm) and weight (g) were recorded, and sagittal otoliths removed from all captured smallmouth bass for age and growth analyses. Smallmouth bass lengths ranged from 30 to 495 mm, with mean PSD, PSD-P, and PSD-M values of 24, 7, and 1, respectively. Relative weight values ranged from 59 to 140 (mean = 89; SE = 0.2). In general, smallmouth bass collections reflected poor condition, and relative weights declined with increased fish length. Sixteen age classes were observed; however, the majority (71%) of fish were younger than age 3. Annual mortality estimates ranged from 35% to 80% (mean = 60%; SE = 4.2%) and were highest between age 1 and age 3. Growth varied among smallmouth bass collections; however, fastest growth was observed among lower-elevation Atlantic Slope stream reaches. The von Bertalanffy growth model predicted 5.5 years, on average, for a smallmouth bass to reach harvestable size (305 mm). The FAST Dynamic Pool Model incorporated growth and mortality estimates to evaluate potential responses to four minimum size limits (254-mm, 305-mm, 356-mm, and 406-mm) and two protective slot limits (330–432 mm and 356–508 mm) under an array of conditional natural mortality (10 to 50%) and conditional fishing mortality (5 to 50%) levels. The models predicted North Carolina riverine smallmouth bass would benefit from an increased minimum size limit at moderate levels (≤30%) of conditional natural mortality. Future management efforts will use data from this study and angler feedback to guide potential regulation management decisions. In addition, information gathered through this research will serve as a public outreach tool, helping anglers and communities recognize importance of these valuable fisheries, while informing stakeholders of smallmouth bass fishing access locations and site descriptions.

Western North Carolina smallmouth bass *Micropterus dolomieu* streams provide an important recreational fishery resource (Finke and Van Horn 1993); however, little is known regarding the extent of fishable smallmouth bass populations, the variability in growth and mortality characteristics of these populations, or their resilience to increasing fishing pressure. It is often difficult for fisheries managers to collect adequate information for every managed fish population (Beamesderfer and North 1995), and this is especially true when trying to evaluate riverine smallmouth bass populations that are often inaccessible to traditional sampling techniques.

Historical information on riverine smallmouth bass populations in western North Carolina is limited. Initial efforts to assess smallmouth bass populations in northwest North Carolina were conducted in the late 1970s (Mickey 1980) and led to subsequent stockings of smallmouth bass fingerlings to establish and augment smallmouth bass populations throughout the study area. However, evaluation of stocked streams found little evidence of success (Mickey 1985). Most recent information on smallmouth bass in North Carolina results from collections in the New River where sampling efforts have occurred since 1997 (Hodges 2000, 2004, 2006), and an assessment of smallmouth bass stocking efforts in the Bridgewater tailrace of Catawba River where fingerling stockings ceased after subsequent monitoring revealed poor growth and low abundance of stocked smallmouth bass (Goudreau 1998; Besler 2003).

Recently, the Tennessee Wildlife Resources Agency sought to amass information on Tennessee's riverine smallmouth bass to guide future management actions (Fiss et al. 2001).

Information collected during their study led to the formation of a comprehensive smallmouth bass management plan that outlines the agency's goal of maintaining and improving smallmouth bass fisheries (Simonson 2000; Jordan 2001; Fiss and Churchill 2003). Unfortunately, North Carolina's current black bass management plan (NCWRC 1993) lacks a substantial smallmouth bass component due to the lack of available smallmouth bass information.

As public interest in North Carolina smallmouth bass fisheries continues to develop, objective and current information on smallmouth bass populations was needed to direct management activities and evaluate harvest regulations. Agency-sponsored fishing access improvements and improved communication among smallmouth bass anglers continue to introduce more people to western North Carolina smallmouth bass streams. Recent angler requests for more restrictive harvest regulations indicated an interest in increased and more diverse smallmouth bass fishing opportunities.

Because information on population dynamics of smallmouth bass fisheries does not exist for most western North Carolina stream systems, baseline data on a variety of streams is a prerequisite for evaluating future management needs, including special harvest regulations, supplemental stocking, and other population manipulations. More importantly, improved information on distribution of riverine smallmouth bass would allow evaluation of the potential of coolwater stream systems to support recreational smallmouth bass fisheries, and help to predict the resilience of riverine smallmouth fisheries to increasing public interest and fishing pressure.

The objectives of this three-year study were to: 1) identify riverine smallmouth bass resources in western North Carolina; 2) assess smallmouth bass size and age structure, condition, growth, and mortality; and 3) evaluate potential opportunities for enhanced management of riverine smallmouth bass fisheries.

Methods

Smallmouth Bass Collections

Between May 2007 and September 2009, smallmouth bass were sampled from selected reaches of 42 streams (referenced hereafter as "stream reaches") representing a variety of stream orders in western North Carolina (Figure 1). Sampling consisted on one to three annual smallmouth bass collections (referenced hereafter as "collections") within each stream reach. Stream reaches surveyed covered nine river basins, comprising Atlantic (N = 4; Broad, Catawba, Roanoke, and Yadkin) and Mississippi drainages (N = 5; French Broad, Hiwassee, Little Tennessee, New, and Watauga). Stream elevations varied between 180 m to 790 m above mean sea level, and widths ranged from 10 m to 200 m. Each stream reach was sampled in all available habitat types (riffle, run, and pool complexes). Sample sites for collections were distributed as evenly as possible throughout the entire stream reach where smallmouth bass likely occurred, but depended heavily on available access points. Four streams, the Yadkin River, Broad River, French Broad River, and Dan River were split into upper and lower reaches because they were divided by dams and contained distinct habitat differences among sections.

As a coarse measure of possible influences of longitudinal riverine trophic gradient (Vannote et al. 1980; Power and Dietrich 2002; McTammany et al. 2003) on smallmouth fishery characteristics, an arbitrary grouping of stream reaches was applied in which stream reaches were classified as either "mainstem" or "tributary" based on drainage area (km^2) in relation to sample reach locations. Mainstem stream reaches exhibited drainage areas of greater than or equal to 600 km^2, whereas the remaining stream reaches were associated with drainage areas substantially smaller than 600 km^2 and were classified as tributaries. Where possible, drainage areas were determined by United States Geological Survey (USGS) gauging station data. Remaining drainage areas were classified using ArcGIS software (ESRI 2008) and North Carolina hydrologic unit code layer files. Reaches in drainage areas divided by dams were classified as upper or lower reaches based on above- or below-dam sample locations, and drainage areas of lower reaches were cumulative except where upstream flows to those reaches were bypassed by hydropower projects.

Fish were collected using a variety of sampling gear, including angling gear, seines, and boat and backpack electrofishing equipment, with the objective of collecting 30 or more fish per stream reach. Due to the variety of sampling gears used, catch per unit effort was not quantified. Stream reaches within the Mississippi drainage were characterized by shallow riffles and deep pools that were not conducive to backpack or boat electrofishing. Therefore, the majority of collections in these stream reaches were taken by angling, supplemented where possible with backpack electrofishing and seining. Stream reaches in the Atlantic drainage were more accessible to backpack and boat electrofishing; however, manpower constraints and inefficiency of electrofishing gear for collecting stock-length fish (Bushon et al. 2009) resulted in the predominant use of angling gear during 2008 and 2009.

Size Structure and Condition

Total length (TL, mm) and weight (g) were recorded for each fish, and sagittal otoliths were removed and stored in plastic vials for age determination. Length-distribution histograms were constructed and stock indices were calculated for each smallmouth bass collection. Proportional size distributions (PSDs) of each collection, and of preferred (PSD-P)- and memorable (PSD-M)-sized fish within each collection, were calculated for each collection as described by Gabelhouse (1984) as modified by Guy et al. (2007). Relative weight (W_r) was used to index fish condition and was calculated for smallmouth bass greater than or equal to 150 mm using the standard weight (W_s) equation described by Kolander et al. (1993).

Age, Growth, and Mortality

The majority of stored otoliths were mounted on fully-frosted, cytological microscope slides using cyanoacrylate glue and sectioned transversely through the dorsoventral plane into two, 0.5-mm sections using a Buehler Isomet low speed diamond wheel saw (Allen et al. 2003). Sections then were mounted onto glass microscope slides using Thermo Shandon synthetic mountant, and annuli were counted using a compound microscope (Hoyer et. al. 1985; Heidinger and Clodfelter 1987) by two independent readers. A portion of the 2009 otolith samples were fractured or sectioned perpendicular to the transverse axis, polished with 400 grit wet-dry sandpaper, and read under a 10X dissecting scope using transmitted fiber optic light (Hammers and Miranda 1991). Regardless of method, if age discrepancy occurred between readers, the readers discussed the disagreement, and if no assigned age could be agreed upon, the otolith was discarded.

Collection dates ranged from May through September; thus, a 1 June birth date was assigned to all fish to standardize mean TL-at-age (years) estimates among stream reaches. This birth date was derived from compared annulus formation in relation to spring, summer, and late-summer collection dates among western North Carolina smallmouth bass collections. Heidinger and

Clodfelter (1987) observed Illinois smallmouth bass annulus formation between April and May. However, North Carolina annuli formation ranged throughout the survey period; therefore, the standard 1 June birth date represented our best effort to reduce seasonal annulus formation effects and evaluate relative growth comparisons.

Annulus formation was assumed to occur early during the smallmouth bass growing season. Each annulus indicated a new growth year (DeVries and Frie 1996), and sample dates were described in proportion to the year (each month equaled 0.083 of annual growth). Fish ages were assigned for each stream reach based on sample month of collection (e.g., age-3 fish sampled in July were assigned an age of 3.083 years). Mean TL at age was calculated for each stream reach, and pooled mean TL at age was determined for reaches where collections occurred during multiple years. Age-distribution histograms displaying age classes observed were constructed for each collection in each stream reach.

Instantaneous (Z) and annual (A) mortality rates were estimated using Robson and Chapman's (R-C) Maximum-Likelihood Estimates of Survival catch curves (Robson and Chapman 1961; Ricker 1975). Because most smallmouth bass collections included only a few qualifying age classes, the R-C method was used for all catch-curve analyses, due to the presumed difficulty of producing realistic upper and lower 95% confidence interval estimates from linearized models. The first age class was removed if it was not abundant in the age frequency as described by Miranda and Bettoli (2007), and older age classes were removed if they contained fewer than 5 fish (Ricker 1975; Van Den Avyle and Hayward 1999). Because variable recruitment was assumed in riverine smallmouth bass collections (Smith et al. 2005; Hodges 2006), estimates of A were derived by pooling successive years of annual collections to reduce the erratic recruitment influence and scatter points around the catch curve (Allen 1999), and to permit A estimation of older age classes (Miranda and Bettoli 2007). However, constant recruitment is a vital assumption for reliable mortality estimation (Ricker 1975; Miranda and Bettoli 2007); thus, our mortality estimates were applied to strong cohorts, rather than used to actually quantify mortality levels among smallmouth bass stream reaches. A was estimated using $A = 1 – S$, where $S = e^{-Z}$.

To examine the influence on smallmouth bass growth of water temperature patterns at different elevations, HOBO Pro v2 water temperature data loggers (Onset Computer Corporation, Bourne, ME) were deployed in July 2008 at lower Broad River and North Toe River smallmouth bass sampling locations and recorded water temperature (C°) every hour for 15 consecutive months. An additional water temperature logger was deployed during July through September at the lower Yadkin River smallmouth bass sampling location and recorded water temperature every hour for three consecutive months. Stream reaches selected for logger deployment not only reflected distinct elevation differences, but contained unique habitat conditions and were comparable in stream size. Water temperature data were downloaded for analysis using HOBO Pro software (Onset Computer Corporation, Bourne, ME).

Population Modeling

Fisheries Analyses and Simulation Tools (FAST) V. 2.1 software (Slipke and Maceina 2001) was used to express smallmouth bass growth fitting the von Bertalanffy growth model (von Bertalanffy 1938). This model consists of three parameters (K, L_∞, and t_0) where:

K = Brody growth coefficient,

L_{∞} = asymptotic length,

t_0 = theoretical time when length equals zero.

Asymptotic length was fixed at 508 mm for all growth curve analyses, based on responses to angler diaries distributed in March–October 2008 to local anglers (N = 3) fishing the French Broad River Basin that indicated an average seasonal maximum length for angler-caught smallmouth bass of 504 mm (Appendix 1). Additionally, smallmouth bass of 508 mm or larger have been documented in interagency fish population surveys (Dave Coughlan, Duke Energy, unpublished data). The fixed asymptotic length was therefore assumed to approximate maximum growth in larger systems. The 508-mm fixed asymptotic length estimate was also preferable to an unfixed asymptotic length estimate in smaller systems where insufficient numbers of larger fish could be collected to reliably project maximum smallmouth bass growth.

Von Bertalanffy growth models were fit to all stream reaches and averaged by river basin and drainage-area classification. Additionally, time (years) to reach the current 305-mm minimum size limit for North Carolina smallmouth bass was estimated for all categories to evaluate relative growth comparisons among smallmouth bass populations, using the following von Bertalanffy equation:

$$305 \text{ mm} = 508 \text{ mm} * (1\text{-}e^{-K\,(\text{age} - t_0)}).$$

The FAST Dynamic Pool Model was also used to evaluate how changes in growth, natural mortality, and fishing mortality would affect smallmouth bass responses (PSD, PSD-P, and yield in kg) to various length limits. The larger ‘mainstem’ stream reaches were used for modeling because they typically provided sufficient sample sizes over multiple years and represented the waters of greatest angler interest for new regulations; the Hiwassee and lower Dan rivers were not included in modeling analyses due to limited data. Fish growth in the models was represented by mean TL-at-age estimates, and conditional natural mortality (*cm*) rates of 10%, 20%, 30%, and 50% and conditional fishing mortality (*cf*) rates of 5%, 10%, 20%, 30%, and 50% were applied (Fiss et al. 2001). Since riverine smallmouth bass creel data are lacking and exploitation rates are not known, *cm* and *cf* combinations were selected to represent broad mortality estimate ranges; thereby, providing a best-fit length limit scenario under increased fishing pressure and/or natural mortality. Fish lengths were transformed to fish weights using weight-length equations described by Kolander et al. (1993). Constant recruitment to age-0 of 100,000 fish per year and *A* of 80% from ages 0 to 2 was fixed for all 15-year simulations, which allowed relative growth comparisons of model predictions among length limits without variable recruitment influences (growth was the determinate factor for model predictions). Model simulations protected fish from harvest if they were below the minimum length limit (Green et al. 1987; Clapp and Clark 1989). No minimum size limit (assuming no anglers harvested fish under 254 mm), three minimum size limits (305-mm, 356-mm, and 406-mm), and two protective slot limits (330–432 mm and 356–508 mm) were all used in model simulations. Simulated *cf* rates were modified for ages in and outside of the protected slots as described by Slipke and Maceina (2001). Simulated length limits used during this research represent common length-based regulations employed by southeastern fishery managers for riverine smallmouth bass management (Kauffman 1985; Austen and Orth 1988) and therefore comprise an array of harvest restrictions for comparison.

Results

Total Catch

A total of 2,859 smallmouth bass were collected from 42 stream reaches in western North Carolina, comprising 13 mainstem rivers and 29 tributaries (Figure 1). All smallmouth bass collections took place during May–September of 2007 (N = 1061), 2008 (N = 1066), and 2009 (N = 732). Due to absence of fish or low sample size, data were only analyzed from 35 of 42 stream reaches surveyed, accounting for 2,853 smallmouth bass. Of these 35 stream reaches, 9 (26%) were sampled two consecutive years and 7 (20%) were sampled all three years of the study, totaling 58 collections. Angling gear was used exclusively in 34 of the 58 collections, followed by electrofishing (N = 17), seines (N = 1), and a combination of gear types (N = 6). The majority (71%) of smallmouth bass were captured using angling (N = 2022), followed by electrofishing (N = 764), and seines (N = 48). The gear type used to collect 19 fish could not be determined.

Length Structure

Length-frequency distributions for 58 collections on 35 stream reaches (Figure 2) indicated that smallmouth bass ranged from 30 to 495 mm, with only 4% of the fish ≥350 mm. Proportional size distributions of quality (PSD)-length fish ranged from 0 to 63 (mean = 24), PSD-P from 0 to 28 (mean = 7), PSD-M from 0 to 8 (mean = 1), and no trophy-length bass (≥510mm) were observed, and size-structure indices were comparable between mainstems and tributaries (Table 1). Although length-frequency distributions and size-structure indices revealed a low proportion of quality-length fish (16%), fish greater than 350 mm were captured from 69% of the stream reaches surveyed and 17% contained fish greater than 430 mm.

A comparison of smallmouth bass total lengths captured during this study revealed that angling (85–495 mm) and electrofishing (30–442 mm) gear collected a similar range of fish lengths, whereas the range of fish collected with seines (53–261 mm) was restricted to smaller individuals (Figure 3). However, angling collected primarily fish 180 mm or larger (82% of total angling catch), whereas electrofishing and seines were more efficient at collecting smallmouth bass less than 180 mm (63% of total electrofishing catch; 94% of total seine catch). Disparity among the mean total lengths of fish collected with the different gear types was also observed (Figure 3). Although values obtained for PSD and PSD-P were higher for electrofishing than angling, visual inspection of length-frequency histograms of fish captured with each gear showed that angling collected larger fish than electrofishing gear.

Smallmouth Bass Condition

Relative weight (W_r) values calculated for 2,296 smallmouth bass (Table 2) ranged from 59 to 140 (mean = 89; SE = 0.2). Mean W_r values were similar between mainstem and tributary stream reaches (Figure 4) and among basins (Figure 5). Mean annual relative weight values declined during the study, from a high of 92 (SE = 0.4) in 2007, to 89 (SE = 0.3) in 2008, to 87

(SE = 0.3) in 2009. In general, condition for smallmouth bass decreased with increased fish length (Table 3; Figure 6), and this trend was apparent regardless of drainage-area classification (Figure 7) or river basin (Figure 8).

Age, Growth, and Mortality

Age determinations were made for 2,803 smallmouth bass and ranged from age 0 to age 16 (Figure 9). The majority (71%) of fish were younger than age 3, and less than 1% were older than age 10 observed (N = 13). Nine of the 13 fish older than age 10, including the oldest fish obtained (age 16), were captured from the North Toe River. Age classes observed varied between stream reaches regardless of gear type. However, electrofishing more efficiently collected age-0 fish; only 12% of surveys that exclusively used angling collected age-0 individuals, compared to 100% of surveys that used electrofishing.

Smallmouth bass collection growth rates for 30 stream reaches (86%) were fitted using von Bertalanffy growth models (Table 4; Table 5). Growth rates varied among stream reaches sampled; however, von Bertalanffy growth models (Table 4) predicted 5.5 years, on average, for smallmouth bass to reach North Carolina harvestable size of 305 mm. Mainstem estimates of time required to reach harvestable size ranged from 2.8 years at lower Broad River to 8.6 years at Hiwassee River (mean = 5.4 years; SE = 0.5); tributary estimates ranged from 4.1 years at upper Broad and Fisher rivers to 8.0 years at South Toe River (mean = 5.5 years; SE = 0.2), indicating smallmouth bass with relative slow and fast growth occurred within both drainage-area classifications. On average, mainstem smallmouth bass reached 305 mm only 0.1 years later than those in tributaries (Table 4), indicating that drainage area alone was a poor predictor of growth rates. Among river basins, predicted growth values ranged from 4.0 years within the Broad River basin to 8.6 years within the Hiwassee River, with highest growth estimates observed in the Atlantic Slope basins of the Broad and Yadkin rivers (Table 4; Table 5).

Water temperature patterns were consistently warmer at the lower Broad River than North Toe River stream reaches (Figure 10), which coincided with increased growth and decreased age longevity among Broad River smallmouth bass, as opposed to slow growth and increased age longevity exhibited by North Toe River fish (Table 4; Table 6; Appendix 2). Similar increased water temperatures were observed from data logger recordings at the lower Yadkin River during July through September 2007 (Figure 11), which also coincided with increased fish growth (Table 4; Table 5).

Instantaneous (Z) and annual (A) mortality rates were calculated for eleven (31%) smallmouth bass stream reaches, comprising five river basins (Table 6). In eight (73%) of these stream reaches, smallmouth bass were assumed fully recruited to the sampling gear at age 1, and age 10 was the oldest age class with at least five representatives. Estimated Z values (mean = 0.99%; SE = 0.1) ranged from 0.43% at Cane River to 1.62% at Pigeon River; thus, estimated A rates ranged from 35% to 80%, averaging 60% (SE = 4.2) for all stream reaches analyzed. River basin A estimates ranged from 58% at the Roanoke River basin to 64% for the Broad River basin. In general, high mortality was observed among younger age classes (ages 1–3) in all smallmouth bass stream reaches regardless of river basin and drainage-area classification.

Population Modeling

The FAST Dynamic Pool modeling results predicted that increased minimum size limits of 356- and 406-mm consistently produced the highest PSD and PSD-P values at all levels of *cf* when *cm* was 30% or less (Figures 12–21). All modeled regulations were ineffective on PSD and PSD-P at high levels (50%) of *cm*, and preferred (350 mm) fish abundance decreased with increased *cm* levels; consequently, utility of length regulations to maintain preferred fish in smallmouth bass streams was limited in the presence of high natural mortality. Conversely, all minimum length limits produced similar PSD values at 10% *cm* when *cf* was low (< 10%). North Carolina's current minimum size limit of 305 mm generally produced similar PSD and PSD-P values to increased minimum size limits only at low levels of *cm* (10%) when *cf* was 10% or less; however, as fishing mortality and natural mortality increased, declines in PSD and PSD-P values and increases in yield were observed in all modeled smallmouth bass streams under this length limit. The 254-mm minimum size limit reflected the lowest PSD and PSD-P values among minimum-length limit regulations at all levels of *cm* and *cf*, indicating increased natural and fishing mortality would have detrimental effects upon smallmouth bass regulated under this length limit. Protective slot-limit regulations generally produced the lowest PSD and PSD-P values at all levels of *cm* and *cf*. Yield generally decreased with increased length limits at all levels of *cm* and *cf*. The 254-mm minimum size limit consistently reflected the highest yield values among minimum size limits at all levels of *cm* and *cf*. Protective slot limits generally produced the highest yield values at *cm* levels of $\leq$30% regardless of *cf*; however, yield was inversely related to *cm*. Based on these observations, yield generally decreased with increased *cm*, indicating that protective slot-limit regulations had little to no effect on yield at high levels of *cm* (50%).

Discussion

Length Structure

Mean stock indices were lower than values reported for rivers and streams in Tennessee (PSD = 34, PSD-P = 13, PSD-M = 3; Fiss et al. 2001) and Virginia (PSD = 33, PSD-P = 16, and PSD-M = 5; VDGIF 2003), and few quality-length fish (16%) were observed. However, fish greater than 350 mm were captured from 69% of the stream reaches surveyed and 17% contained fish greater than 430 mm, indicating the ability for some of these resources to produce preferred and memorable-length smallmouth bass. While there was very little difference in stock indices between mainstem and tributary systems, large differences were apparent between individual stream reaches. The variation in size structure between some stream reaches was likely due to insufficient numbers of smallmouth bass being collected to meaningfully apply stock indices. However, our goal was to document and describe smallmouth populations throughout western North Carolina; thus, a wide spectrum of stream habitats, water temperatures, and nutrient levels were surveyed. As a result, it is not surprising that a wide range of stock characteristics were observed. The variability in stock characteristics and small sample sizes also may have influenced the apparent inconsistencies between observed length distributions and calculated PSD and PSD-P values noted in comparisons of angling and electrofishing samples.

Attempts to use electrofishing gear for smallmouth bass collections during this study were problematic (Bushon et al. 2009). Deep pools and runs (>1.5 m in depth) often prevented the use of backpack electrofishing gear; conversely, shallow riffles and access limitations often prevented sampling with boat-mounted electrofishing gear. The use of an electrofishing barge was often not feasible due to remoteness of sample sites, and deeper pools were inaccessible with this gear as well. Consequently, angling was the most effective gear for the majority of collection sites.

Although standardized sampling methods are important for establishing long-term data sets for population monitoring (Willis and Murphy 1996), it is also important to effectively sample stock length and larger fish when changes in size structure and growth rates of the adult proportion of the population are being investigated (Neumann and Allen 2007). Angling and electrofishing gears collect similar size structures of fish and are commonly used for collecting stock-length fish (Ebbers 1987; Reed and Rabeni 1989; Santucci and Wahl 1991; Isaak et al. 1992). In this study, angling was better suited for collecting stock-length and larger fish, whereas electrofishing gear was more efficient at collecting smallmouth bass less than 180 mm.

Preferred habitats for riverine smallmouth bass have been described in detail by several studies (Coble 1975; Paragamian 1981; McClendon and Rabeni 1987; Walters and Wilson 1996). The capture of a higher percentage of stock-length smallmouth bass using angling may have been a result of our ability to more effectively locate and sample quality smallmouth bass habitats with this gear type. During our surveys, areas containing quality smallmouth bass habitats were often moderate (100-200 m) to long (≥ 1 km) distances from access areas. Hiking or canoeing to these areas with angling gear was relatively easy, whereas the use of electrofishing gear was often not feasible. Sole use of electrofishing equipment would have likely resulted in the sampling of available habitats near access areas, regardless of overall habitat quality, and may have precluded the sampling of some stream reaches. While angling was preferred for collecting stock-length fish, electrofishing and seines were more efficient at collecting young-of-the-year smallmouth bass and would likely be more appropriate gear types for indexing recruitment and year-class strength.

Smallmouth Bass Condition

In general, western North Carolina’s riverine smallmouth bass exhibited poor condition compared to national averages, and relative weights declined with increased fish length. However, fish conditions observed are similar to previous North Carolina smallmouth bass population surveys (Hodges 2000; Hodges 2004; Hining 2006). As with stock indices, sample sizes at several stream reaches limited applicability of condition values beyond simple visual comparison to other streams sampled. Analysis of 2007–2009 smallmouth bass collections showed a decline in mean W_r values during the 3-year period. Western North Carolina experienced below-average rainfall during 2007 and 2008, but rainfall totals were above average in 2009 (State Climate Office of North Carolina 2010). As a result, discharge rates from May–September of 2007 and 2008 ranged from 24% to 58% of the rates recorded during this same period in 2009 from major streams in western North Carolina (USGS 2010a). Suitable habitat elements (rocky substrate, cobble, and boulders) critical for smallmouth bass development and survival (Todd and Rabeni 1989) were possibly limited as a result of the low rainfall and subsequent low flows experienced in 2007 and 2008. Despite this, the low-flow, clear-water conditions observed in 2007 coincided with the highest mean W_r value, while the improved flows observed during 2009 coincided with the lowest mean W_r value. The decline in condition observed during the 2008 and 2009 survey periods may have been a consequence of extended periods of low flows. Hafs et al. (2010) stated that while flow reductions may concentrate food items for riverine smallmouth bass, intra- and interspecific competition likely outweighs any potential advantage from condensed forage. Although flows increased in 2009, condition did not. High turbidity levels as a result of the increased rainfall and stream discharge during 2009 may have affected the ability of smallmouth bass to forage efficiently. Carter et al. (2010) reported that turbidity levels were more important than cover in determining prey consumption, and turbidity significantly decreased the number of prey consumed per hour by smallmouth bass. While the cause of declining W_r values during 2008 and 2009 are unclear, changes in W_r can reflect a variety of physiological and environmental changes (Pope and Kruse 2007); and more importantly, may not indicate actual changes in fish health or growth (Gutreuter and Childress 1990).

Age, Growth, and Mortality

Smallmouth bass growth rates by stream reach, river basin, and drainage-area classification were compared during this study; however, wide variation in growth rates within classifications obscured small differences in von Bertalanffy growth curves among classifications. Growth curves reflected greatest differences and were most pronounced between Atlantic and Mississippi drainage smallmouth bass populations. Multiple factors may have contributed to these differences. Smallmouth bass feeding habits and growth may be influenced by available forage (Probst et al. 1984), temperature and latitude (Armour 1993; Beamesderfer and North 1995), and habitat and stream flow variations (Gwinner 1973; Smith et al. 2005).

In general, western North Carolina stream productivity is limited by underlying regional granitic geology, which may contribute to poor smallmouth bass growth and condition by influencing trophic state. However, nutrient levels can vary throughout the region. For example, the North Fork Catawba River population reflected relatively higher growth rate values due to the stream's limestone geology (Conrad 1960) which provides additional nutrients (CaCO3), buffers water pH, and increases fish yield (Arce and Boyd 1975). Similarly, other streams benefit from increased nutrient loads (phosphorous) via waste-water treatment plant effluent located within its watershed (deBruyn et al. 2003) or extensive agricultural activity within their watersheds.

Growth and condition of North Carolina's riverine smallmouth bass also may be influenced by elevation (Hubert 1988). Stream elevations varied from 180 m to 790 m above mean sea level. Streams and rivers at increased elevations may exhibit cooler temperature patterns, thereby influencing smallmouth bass condition and growth (Patton and Hubert 1996). Conversely, lower elevation water bodies may prolong growing seasons, providing more suitable foraging conditions (Stroud 1948; Slipke et al. 1998). For example, predicted growth estimates indicate that lower Broad River smallmouth bass attained 305 mm 2.7 years earlier than those in the North Toe (Table 4). Elevations of the Broad River sample sites ranged from 185 to 189 m, whereas the elevations of the North Toe River sites ranged from 524 to 749 m. Similar to the Broad River, smallmouth bass from the lower Yadkin River exhibited fast growth rates, and sample sites were located at relatively low elevations (mean elevation = 242 m).

Optimal smallmouth bass growth occurs between 26º and 29º C, slows at temperatures below 20º C, and terminates at water temperatures above 35º C (Coutant 1975; Coutant and DeAngelis 1983). Based on these data, optimal water temperatures occurred at the Broad River during July through September 2008 and June through September 2009, whereas the North Toe

River only achieved this temperature range during extreme low-water conditions in August 2008 (USGS 2010b).

Anthropogenic effects on water temperature may further affect the influence of water temperature on smallmouth bass growth rates. The discharge of cooling water from a steam electric plant into the lower Broad River elevated water temperatures year-round. Conversely, the Hiwassee River, where the slowest smallmouth bass growth rates were observed, is influenced by coldwater releases from the Chatuge hydroelectric project upstream. It is likely that a substantial portion of the observed difference in growth and condition values between Mississippi and Atlantic Slope drainages resulted from the extreme values that resulted from anthropogenic influences on these two stream reaches.

Overall, mean TL-at-age estimates observed in North Carolina were lower than values determined using otoliths from Tennessee and Virginia smallmouth bass populations (Fiss et al. 2001; VDGIF 2001). However, predicted growth estimates derived from our research were similar to slow-growing smallmouth bass populations in Tennessee where fish attained 305 mm in just over 6 years. These populations generally existed in high-elevation eastern Tennessee mountain streams and rivers (Fiss et al. 2001), which are similar to many systems surveyed in North Carolina. Virginia smallmouth bass growth estimates have been predominantly reported for large river systems (VDGIF 2001) and are comparable to some of the faster growth rates found in North Carolina's mainstem Atlantic drainage rivers (Table 6). Additionally, both Tennessee and Virginia have underlying geology that is limestone rich, which may provide additional nutrients and promote rapid fish growth (Arce and Boyd 1975).

Average smallmouth bass *A* rates observed during this research were high compared to those observed in other studies. Fiss et al. (2001) observed *A* rates of Tennessee smallmouth bass ranging from 15 to 55% with a mean of 38%. These values were determined from age-2 and older fish, and catch-curve data were not truncated. Additionally, Paragamian (1984a) observed smallmouth bass *A* rates in five, exploited Iowa streams ranging from 42 to 83%, averaging 55%; however, as is common to smallmouth bass literature (Fajen 1972; Carlander 1977; Orth et al. 1983; Austen and Orth 1988; Smith and Kauffman 1991), age estimates were assigned using scale impressions. Age estimates using scales likely underestimate true age, resulting in biased age-frequency and mean length-at-age data (Beamish and McFarlane 1987; Isely and Grabowski 2007). Also, both Tennessee and Virginia mortality estimates were based primarily on boat electrofishing samples from large streams, which likely increased the likelihood of capture of larger, older fish compared to smaller, younger fish. Therefore, *A* estimate comparisons with North Carolina data were limited, especially among young age classes.

Population Modeling

As abstractions of reality, all population models involve a measure of uncertainty (Haddan 2001). Our FAST modeling predictions were generated based on several assumptions about western North Carolina smallmouth bass collections, and model predictions are predicated upon input data and an understanding of limitations associated with the models. However, the data presented and used to generate modeling predictions represent our best effort to base management decisions on data from a wide and representative array of smallmouth bass fisheries. Additional riverine smallmouth bass data will be needed to test model predictions of effects of management activities such as more regulations. However, model predictions, coupled with population monitoring data, continued angler input, and professional judgment, should equip fisheries managers with the necessary tools to make regulatory management decisions pertinent to riverine smallmouth bass in western North Carolina.

Smallmouth bass modeling predictions suggested increased minimum size limits maximized quality (PSD)- and preferred (PSD-P)-fish abundance and minimized yield when natural mortality was moderate (*cm* = <30%) at all levels of *cf*. However, length limits were ineffective at high levels of *cm* (50%); thus, populations exhibiting high natural mortality would see minimal size-structural benefits from length limits and considerable decreases in yield. Regulations were most effective at moderate levels of *cm* ($\leq$30%) when *cf* rates were 20% or greater. Given the high overall mortality rates observed in the majority of stream reaches sampled, it is unlikely that harvest regulations of any kind will substantially affect smallmouth bass population structure, unless harvest-oriented fishing pressure and resulting fishing mortality increase from current levels. However, on North Carolina smallmouth bass streams with lower levels of natural mortality, or those with intensifying fishing pressure, increased minimum size limits provided the best fit for future management, regardless of growth rates. Although the 406-mm minimum size limit yielded slightly higher PSD and PSD-P values, the 356-mm minimum size limit reflected substantially higher yield predictions and minute differences in PSD and PSD-P values at all *cm* and *cf* levels (Figures 12–21). Several studies have demonstrated that smallmouth bass size structure can be improved using minimum length limits. Improved size structure in Wisconsin smallmouth bass populations was observed following implementation of a 356-mm minimum size limit regulation change (Lyons et al. 1996), and 305-mm minimum size limits have improved smallmouth bass fisheries in Missouri and Iowa (Fajen 1981; Paragamian 1984b). However, high natural mortality rates contributed to the ineffectiveness of a 305-mm minimum size limit in two Virginia Rivers (Kauffman 1985; Austen and Orth 1988). Our modeling predictions indicate the current North Carolina smallmouth bass length limit of 305-mm was less effective than increased minimum-length regulations due to declines in quality- and preferred-fish abundance with increased *cf* and *cm*. This indicates the inability of the current regulation to produce quality fish under increased natural mortality and fishing pressure.

Slot-limit modeling predictions also exhibited low PSD and PSD-P values generally at all *cm* and *cf* levels compared to increased minimum size limits. Slot-limit regulations are designed to prohibit harvest from a determined intermediate size range, protecting these intermediate-sized fish which then survive and grow to the specified harvestable size range (Anderson 1980). However, slot-limit effectiveness is determined by satisfactory growth rates and angler harvest, so fish will not gather in the protective slot range (Noble and Jones 1999). Slot limits are more effective for fish populations influenced by density-dependent factors (Wilde 1997; Smith and Kauffman 1991). Increased fishing mortality under protective slot limits lead to decreases in quality fish abundance at moderate ($\leq$30%) *cm* levels, further confirming that riverine smallmouth bass in western North Carolina are not heavily influenced by density-dependent mechanisms. Our modeling predictions resulting from relative slow growth rates suggest protective slot limits would be ineffective for North Carolina smallmouth bass fisheries.

Effects of stream productivity and harvest regulations on fish populations depend heavily upon growth and natural mortality (Anderson 1973; Rieman 1987; Haddan 2001). Our modeling simulations accounted for variable growth and mortality in smallmouth bass streams by applying ranges of simulated natural and fishing mortalities to smallmouth bass fisheries exhibiting a range of observed growth rates, and predictions indicate consistently higher fishery resource quality under increased minimum size limit regulations across a wide range of natural mortality and fishing pressure.

Conclusions

1) Smallmouth bass streams are widely distributed throughout the mountains, foothills, and northwestern Piedmont of North Carolina, including reaches with habitat conditions heretofore considered unfavorable for smallmouth bass survival.

2) Electrofishing was effective at capturing smallmouth bass below stock size; however, angling proved a more versatile and economical capture method that yielded a wider range of sizes of fish from more diverse habitats, and accurately reflected known information on fishing experiences of constituent anglers.

3) Generally, western North Carolina smallmouth bass exhibit poorer condition and slower growth than those of nearby states, likely due to several stream habitat characteristics including water temperature and length of growing season, regional geology, and anthropogenic impacts; von Bertalanffy growth models predicted 5.5 years, on average, for smallmouth bass to reach harvestable size (305 mm).

4) Although 16 age classes were identified, smallmouth bass older than age 10 were rare in western North Carolina streams. *A* estimates were highest among age-1 to age-3 year classes.

5) Some higher-order streams or nutrient-rich systems, particularly in the foothills and northwestern Piedmont of the Atlantic Slope region, exhibited somewhat better condition, more rapid growth, and better representation of larger fish in smallmouth bass collections.

6) All modeled smallmouth bass collections benefited from increased minimum size limits at moderate *cm* levels ($\leq$30%). The 356-mm minimum size limit best fit our data, in terms of maximizing PSD, PSD-P, and yield.

Recommendations

1) Increase the statewide smallmouth bass length regulation to optimize projected performance of riverine fisheries.

2) Use information gathered during this study and ongoing input from smallmouth anglers to direct site-specific recreational fishing enhancements (including potential special length and creel limits, boating and fishing access development, and angler outreach and education) toward waters with the greatest fishery management potential.

3) Establish standardized monitoring survey protocols for evaluating effects of regulation changes, habitat enhancements, increased angling pressure, and other management activities on riverine smallmouth bass fisheries.

4) Use study findings to develop outreach materials to inform stakeholders of smallmouth bass management issues, describe site-specific fishery resources and access locations, educate the public and government entities about the value of smallmouth bass fisheries, and recruit and retain anglers.

5) Prioritize high-quality smallmouth bass streams for development of public access through landowner and community partnerships.

Acknowledgements

Numerous Inland Fisheries staff members assisted with this project, including substantial contributions from Bob Brown, Bobby Buff, Marshall Evans, Kin Hodges, Jim Hollifield, Wes Humphries, Nick Shaver, Jake Rash, Brian Rau, Chris Wood, and Powell Wheeler. Personnel from Table Rock, Armstrong, and Setzer fish hatcheries also assisted with field collections. Steve Fraley, Ryan Heise, Thomas Russ, and other Aquatic Wildlife Diversity staff provided cooperation and assistance on many samples. This project was funded through Sport Fish Restoration.

References

Allen, M. S. 1999. Effects of variable recruitment on catch-curve analysis for crappie populations. North American Journal of Fisheries Management 17:202–205.

Allen, M. S., K. I. Tugend, and M. J. Mann. 2003. Largemouth bass abundance and angler catch rates following a habitat enhancement project at Lake Kissimmee, Florida. North American Journal of Fisheries Management 23:845–855.

Anderson, R. O. 1973. Application of theory and research to management of warmwater fish populations. Transactions of the American Fisheries Society 102:164–171.

Anderson, R. O. 1980. The role of length limits in ecological management. Pages 41–45 *in* S. Gloss and B. Shupp, editors. Practical fisheries management: more with less in the 1980s. American Fisheries Society, New York Chapter, Ithaca.

Arce, R. G., and C. E. Boyd. 1975. Effects of agricultural limestone on water chemistry, phytoplankton productivity, and fish production in soft water ponds. Transactions of the American Fisheries Society 104:308–312.

Armour, C. L. 1993. Evaluating temperature regimes for protection of smallmouth bass. U. S. Fish and Wildlife Service, Resource Publication 191,Washington, D.C.

Austen, D. J., and D. J. Orth. 1988. Evaluation of a 305-mm minimum-length limit for smallmouth bass in the New River, Virginia and West Virginia. North American Journal of Fisheries Management 8:231–239.

Beamesderfer, R. C. P., and J. A. North. 1995. Growth, natural mortality, and predicted response to fishing for largemouth bass and smallmouth bass populations in North America. North American Journal of Fisheries Management 15:688–704.

Beamish, R. J., and G. A. McFarlane. 1987. Current trends in age determination methodology. Pages 15–42 *in* R. C. Summerfelt and G. E. Hall, editors. Age and growth of fish. Iowa State University Press, Ames.

Besler, D. A. 2003. Performance of stocked fingerling brown trout in the Bridgewater tailrace, 2000–2002. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Project F-24, Raleigh.

Bushon, A. M., K. J. Hining, D. W. Goodfred, and D. L. Yow. 2009. Riverine smallmouth bass surveys. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Project F-24, Raleigh.

Carlander, K. D. 1977. Handbook of freshwater fishery biology, volume two. Iowa State University Press, Ames.

Carter, M. W., D. E. Shoup, J. M. Dettmers, and D. H. Wahl. 2010. Effects of turbidity and cover on prey selectivity of adult smallmouth bass. Transactions of the American Fisheries Society 139:353–361.

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

Coble, D. W. 1975. Smallmouth bass. Pages 21–33 in R. H. Stroud and H. Clepper, editors. Black bass biology and management. Sport Fishing Institute, Washington, D.C.

Conrad, S. G. 1960. Crystalline limestones of the Piedmont and mountain regions of North Carolina. North Carolina Department of Conservation and Development, Division of Mineral Resources Bulletin 74, Raleigh.

Coutant, C. C. 1975. Responses of bass to natural and artificial temperature regimes. Pages 272–285 *in* R. H. Stroud and H. Clepper, editors. Black bass biology and management. Sport Fishing Institute, Washington, D. C.

Coutant, C. C., and D. L. DeAngelis. 1983. Comparative temperature-dependent growth rates of largemouth and smallmouth bass fry. Transactions of the American Fisheries Society 12:416–423.

deBruyn, A. M. H., D. J. Marcogliese, and J. B. Rasmussen. 2003. The role of sewage in a large river food web. Canadian Journal of Fisheries and Aquatic Sciences 60:1332–1344.

DeVries, D. R. and R. V. Frie. 1996. Determination of age and growth. Pages 483–512 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

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 9:249–253.

ESRI. 2008. ArcGIS, version 9.3. ESRI, Redlands, California.

Fajen, O. F. 1972. The standing crop of fishes in Courtois Creek, Missouri. Missouri Department of Conservation, Federal Aid in Fish Restoration, F-1-R-20, Columbia.

Fajen, O. F. 1981. An evaluation of the 12-inch minimum length limit on black bass in streams. Dingell-Johnson Project F-1-R-30, Study 23, Final Report. Missouri Department of Conservation, Jefferson City.

Finke, J. R., and S. Van Horn. 1993. 1990 North Carolina Angler Opinion Survey. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Raleigh.

Fiss, F. C., T. A. Cleveland, B. D. Carter, R. D. Bivens, and J. M. Swearengin. 2001. Population characteristics of riverine smallmouth bass in Tennessee, simulated effects of length limits, and management recommendations. Tennessee Wildlife Resources Agency, Fisheries Report 01–19, Nashville.

Fiss, F. C., and T. N. Churchill. 2003. Tennessee smallmouth bass management plan. Tennessee Wildlife Resources Agency, Nashville.
Gabelhouse, D. W., Jr. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273–285.
Goudreau, C. J. 1998. Bridgewater tailrace survey – 1997. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Project F-24, Raleigh.
Green, D. M., B. J. Schonhoff III, and W. D. Youngs. 1987. Evaluation of hooking mortality of smallmouth and largemouth bass. Pages 229–240 *in* R. A. Barnhart and T. D. Roelofs, editors. Catch and release fishing – a decade of experience. California Cooperative Fishery Research Unit, Arcata.
Gutreuter, S., and W. M. Childress. 1990. Evaluation of condition indices for estimation of growth of largemouth bass and white crappies. North American Journal of Fisheries Management 10:434–441.
Guy, C. S., R. M. Neumann, D. W. Willis, and R. O. Anderson. 2007. Proportional size distribution (PSD): A further refinement of population size structure index terminology. Fisheries 32 (7):348.
Gwinner, H. R. 1973. A study of the redeye bass, *Micropterus coosae*, smallmouth bass, *Micropterus dolomieui*, and rock bass, *Ambloplites rupestris*, in Spring Creek, Tennessee. Master’s thesis. Tennessee Technological University, Cookeville.
Haddan, M. 2001. Modeling and quantitative methods in fisheries. Chapman and Hall/CRC, Boca Raton, Florida.
Hammers, B. E., and L. E. Miranda. 1991. Comparison of methods for estimating age, growth, and related population characteristics of white crappies. North American Journal of Fisheries Management 11:492–498.
Hafs, A. W., C. J. Gagen, and J. K. Whalen. 2010. Smallmouth bass summer habitat use, movement, and survival, in response to low flow in the Illinois Bayou, Arkansas. North American Journal of Fisheries Management 30:604–612.
Heidinger, R. C. and K. Clodfelter. 1987. Validity of the otolith for determining age growth of walleye, striped bass, and smallmouth bass in power plant cooling ponds. Pages 241–251 in R. C. Summerfelt and G. E. Hall eds. Age and growth of fish. Iowa State Univ. Press, Ames.
Hining, K. J. 2006. Biological survey of the Yadkin River fish community. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Project F-24, Raleigh.
Hodges, K. B. 2000. Summary of 1997, 1998, and 1999 fish community assessments in South Fork New River, Ashe County. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Project F-24, Raleigh.
Hodges, K. B. 2004. New River smallmouth bass survey summary – 2003. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Project F-24, Raleigh.
Hodges, K. B. 2006. New River smallmouth bass survey summary – 2005. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Project F-24, Raleigh.
Hoyer, M. V., J. V. Shireman, and M. J. Maceina. 1985. Use of otoliths to determine age and growth of largemouth bass in Florida. Transactions of the American Fisheries Society 114:307–309.
Hubert, W. A. 1988. Altitude as the determinant of distribution of largemouth bass and smallmouth bass in Wyoming. North American Journal of Fisheries Management 8:386–387.

Isaak, D. J., T. D. Hill, and D. W. Willis. 1992. Comparison of size structure and catch rate for largemouth bass samples collected by electrofishing and angling. The Prairie Naturalist. 24:89–96.

Isely, J. J. and T. B. Grabowski. 2007. Age and growth. Pages 187–228 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Jordan, R. M. 2001. Black Bass Management Plan. Maine Department of Inland Fisheries and Wildlife, Division of Fisheries and Hatcheries, Augusta.

Kauffman, J. 1985. Effects of a smallmouth bass minimum size limit on the Shenandoah River sport fishery. Proceedings of the Annual Conference Southern Association of Fish and Wildlife Agencies 37 (1983):459–467.

Kolander, T. D., D. W. Willis, and B. R. Murphy. 1993. Proposed revision of the standard weight (W_s) equation for smallmouth bass. North American Journal of Fisheries Management 13:398–400.

Lyons, J., P. D. Kanehl, and D. M. Day. 1996. Evaluation of a 356-mm minimum length limit for smallmouth bass in Wisconsin streams. North American Journal of Fisheries Management 16:952–957.

McClendon, D. D., and C. F. Rabeni. 1987. Physical and biological variables useful for predicting population characteristics of smallmouth bass and rock bass in an Ozark stream. North American Journal of Fisheries Management 7:46–56.

McTammany, M. E., J. R. Webster, E. F. Benfield, and M. A. Neatrour. 2003. Longitudinal patterns of metabolism in a southern Appalachian river. Journal of the North American Benthological Society 22:359-370.

Mickey, J. H., Jr. 1980. Survey and evaluation of selected smallmouth bass and marginal smallmouth bass streams located in District Seven, North Carolina. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Project F-24, Raleigh.

Mickey, J. H., Jr. 1985. Evaluation of smallmouth bass, rock bass, and spotted bass stocking program in selected streams in Wildlife District Seven, North Carolina. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Project F-24, Raleigh.

Miranda, L. E. and P. W. Bettoli. 2007. Mortality. Pages 229–277 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Neumann, R. M., and M. S. Allen. 2007. Size Structure. Pages 375–421 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Noble, R. L. and T. W. Jones. 1999. Managing fisheries with regulations. Pages 455–477 *in* C. C. Kohler, and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

North Carolina Wildlife Resources Commission (NCWRC). 1993. The North Carolina black bass management plan. North Carolina Wildlife Resources Commission, Raleigh.

Orth, D. J., D. D. Oakley, and O. E. Maughan. 1983. Population characteristics of smallmouth basin Glover Creek, southeast Oklahoma. Proceedings Oklahoma Academy of Science 63:37–41.

Paragamian, V. L. 1981. Some habitat characteristics that affect abundance and winter survival of smallmouth bass in the Maquoketa River, Iowa. Pages 45-53 *in* L. A. Krumholz, editor.

Warmwater streams symposium. American Fisheries Society, Southern Division, Bethesda, Maryland.

Paragamian, V. L. 1984a. Population characteristics of smallmouth bass in five Iowa streams and management recommendations. North American Journal of Fisheries Management 4:497–506.

Paragamian, V. L. 1984b. Evaluation of a 12.0-inch minimum size limit on smallmouth bass in the Maquoketa River, Iowa. North American Journal of Fisheries Management 4:507–513.

Patton, T. M, and W. A. Hubert. 1996. Water temperature affects smallmouth bass and channel catfish in a tailwater stream on the Great Plains. North American Journal of Fisheries Management 16:124–131.

Pope, K. L., and C. G. Kruse. 2007. Condition. Pages 423–471 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Power, M. E, and W. E. Dietrich. 2002. Food webs in river networks. Ecological Research 17:455-471.

Probst, W. E., C. F. Rabeni, W. G. Covington, and R. E. Marteney. 1984. Resource use by stream-dwelling rock bass and smallmouth bass. Transactions of the American Fisheries Society 113:283–294.

Reed, M. S., and C. F. Rabeni. 1989. Characteristics of an unexploited smallmouth bass population in a Missouri Ozark stream. North American Journal of Fisheries Management 9:420–426.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Rieman, B. E. 1987. Fishing and population dynamics of largemouth bass (*Micropterus salmoides*) in select northern Idaho lakes. Doctoral dissertation. University of Idaho, Moscow.

Robson, D. S., and D. G. Chapman. 1961. Catch curves and mortality rates. Transactions of the American Fisheries Society 90:181–189.

Santucci, V. J., Jr., and D. H. Wahl. 1991. Use of a creel census and electrofishing to assess centrarchid populations. Pages 481–491 *in* D. Guthrie, J. M. Hoenig, M. Holliday, C. M. Jones, M. J. Mills, S. A. Moberly, K. H. Pollock, and D. R. Talhelm, editors. Creel and angler surveys in fisheries management. American Fisheries Society, Symposium 12, Bethesda, Maryland.

Simonson, T. 2000. Wisconsin's black bass management plan. Wisconsin Department of Natural Resources, Administrative Report No. 54, Madison.

Slipke, W. J., M. J. Maceina, V. H. Travnichek, and K. C. Weathers. 1998. Effects of a 356-mm minimum length limit on the population characteristics and sport fishery of smallmouth bass in the Shoals Reach of the Tennessee River, Alabama. North American Journal of Fisheries Management 18:76–84.

Slipke, J. W. and M. J. Maceina. 2001. Fisheries Analyses and Simulation Tools (FAST 2.0). Department of Fisheries and Allied Aquacultures. Auburn University, Auburn, Alabama.

Smith, P. P., and J. W. Kauffman. 1991. The effects of a slot-limit regulation on smallmouth bass in the Shenandoah River, Virginia. Pages 112–117 *in* D. C. Jackson, editor. First international smallmouth bass symposium. Mississippi Agriculture and Forestry Experimental Station, Mississippi State University, Mississippi State.

Smith, S. M., J. S. Odenkirk, and S. J. Reeser. 2005. Smallmouth bass recruitment variability and its relation to stream discharge in three Virginia Rivers. North American Journal of Fisheries Management 25:1112–1121.

State Climate Office of North Carolina. 2010. Climate division data. Available: http://www.nc-climate.ncsu.edu/climate/climdiv.php. (December 2010).

Stroud, R. H. 1948. Growth of the basses and black crappie in Norris Reservoir, Tennessee. Journal of the Tennessee Academy of Science 23:31–99.

Todd, B. L., and C. F. Rabeni. 1989. Movement and habitat use by stream-dwelling smallmouth bass. Transactions of the American Fisheries Society 118:229–242.

United States Geological Survey (USGS). 2010a. Surface-water statistics for the nation, Available: http://waterdata.usgs.gov/nwis/sw. (December 2010).

United States Geological Survey (USGS). 2010b. Instantaneous Data Archive, USGS 03465500 Nolichucky River at Embreeville, TN. Available: http://ida.water.usgs.gov. (December 2010).

Van Den Avyle, M. J., and R. S. Hayward. 1999. Dynamics of exploited fish populations. Pages 127–166 *in* C. C. Kohler, and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Vannote, R. L., G. W. Minschall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Virginia Department of Game and Inland Fisheries (VDGIF). 2001. Aquatic Resources Investigations. Dingell-Johnson Grant F-111-R-9, Richmond.

Virginia Department of Game and Inland Fisheries (VDGIF). 2003. Aquatic Resources Investigations. Dingell-Johnson Grant F-111-R-9, Richmond.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Human Biology 10:181–213.

Walters, J. P., and J. R. Wilson. 1996. Interspecific habitat segregation by smallmouth bass in the Buffalo River, Arkansas. Transactions of the American Fisheries Society 125:284–290.

Willis, D. W., and B. R. Murphy. 1996. Planning for sampling. Pages 1–16 *in* B. R. Murphy and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Wilde, G. R. 1997. Largemouth bass fishery responses to length limits. Fisheries 22(6): 14–23.

TABLE 1.—Size-structure indices for total numbers of stock-length smallmouth bass (N) collected during NCWRC surveys, May 2007–September 2009. Indices describe the proportional size distribution of quality (PSD)-, preferred (PSD-P)-, and memorable (PSD-M)-length fish. The 95% confidence interval values are listed in parentheses.

Stream Reach	River Basin	Class	Year	N	PSD	PSD-P	PSD-M
Broad River (Lower)	Broad	Mainstem	2007	6	17 (30)	17 (30)	0
Broad River (Lower)	Broad	Mainstem	2008	80	26 (10)	3 (4)	1 (1)
Broad River (Lower)	Broad	Mainstem	2009	38	16 (12)	5 (7)	0
Broad River (Upper)	Broad	Mainstem	2008	41	5 (6)	0	0
Cove Creek	Broad	Tributary	2007	5	60 (43)	0	0
Broad Basin					**28 (71)**	**3 (12)**	**0**
Catawba River	Catawba	Tributary	2007	8	63 (33)	25 (30)	0
Catawba River	Catawba	Tributary	2008	18	6 (11)	0	0
Catawba River	Catawba	Tributary	2009	35	14 (12)	3 (6)	3 (6)
Henry Fork River	Catawba	Tributary	2007	10	30 (28)	0	0
Jacob Fork River	Catawba	Tributary	2007	9	11 (20)	0	0
Johns River	Catawba	Tributary	2007	19	42 (22)	5 (10)	0
Linville River	Catawba	Tributary	2007	16	44 (35)	13 (16)	0
Linville River	Catawba	Tributary	2008	1	0	0	0
Mulberry Creek	Catawba	Tributary	2007	8	25 (30)	13 (23)	0
North Fork Catawba River	Catawba	Tributary	2007	8	50 (35)	0	0
North Fork Catawba River	Catawba	Tributary	2008	31	32 (16)	3 (6)	0
Upper Creek/Warrior Fork	Catawba	Tributary	2007	10	30 (28)	0	0
Wilson Creek	Catawba	Tributary	2007	23	48 (20)	9 (11)	0
Catawba Basin					**31 (9)**	**5 (4)**	**0**
Cane River	French Broad	Tributary	2007	34	32 (16)	21 (13)	0
Cane River	French Broad	Tributary	2008	61	44 (12)	15 (9)	2 (3)
French Broad River (Lower)	French Broad	Mainstem	2007	13	46 (27)	0	0
French Broad River (Lower)	French Broad	Mainstem	2008	50	20 (11)	8 (15)	0
French Broad River (Lower)	French Broad	Mainstem	2009	137	15 (6)	2 (2)	0
French Broad River (Upper)	French Broad	Mainstem	2007	30	53 (18)	3 (6)	0
French Broad River (Upper)	French Broad	Mainstem	2008	10	10 (19)	0	0
North Toe River	French Broad	Mainstem	2007	22	50 (21)	9 (12)	5 (9)
North Toe River	French Broad	Mainstem	2008	113	42 (9)	9 (5)	0
North Toe River	French Broad	Mainstem	2009	161	27 (7)	6 (4)	3 (2)
Pigeon River	French Broad	Mainstem	2007	26	19 (15)	8 (10)	0
Pigeon River	French Broad	Mainstem	2008	3	0	0	0
Pigeon River (By-Pass)	French Broad	Tributary	2007	56	14 (9)	0	0
Pigeon River (By-Pass)	French Broad	Tributary	2008	16	0	0	0
South Toe River	French Broad	Tributary	2007	4	0	0	0
South Toe River	French Broad	Tributary	2008	12	42 (28)	8 (15)	0
French Broad Basin					**25 (12)**	**6 (6)**	**1 (1)**
Hiwassee River	Hiwassee	Mainstem	2009	7	29 (34)	0	0
Hiwassee Basin					**29**	**0**	**0**

TABLE 1.—Continued. Size-structure indices for total numbers of stock-length smallmouth bass (N) collected during NCWRC surveys, May 2007–September 2009. Indices describe the proportional size distribution of quality (PSD)-, preferred (PSD-P)-, and memorable (PSD-M)-length fish. The 95% confidence interval values are listed in parentheses.

Stream Reach	River Basin	Class	Year	N	PSD	PSD-P	PSD-M
Little Tennessee River	Little Tenn.	Mainstem	2007	3	33 (53)	0	0
Little Tennessee River	Little Tenn.	Mainstem	2008	22	14 (14)	5 (8)	0
Tuckaseegee River	Little Tenn.	Mainstem	2008	36	28 (14)	8 (9)	0
Little Tennessee Basin					**26 (29)**	**5 (35)**	**0**
Dan River	Roanoke	Mainstem	2007	67	36 (11)	12 (8)	0
Dan River	Roanoke	Mainstem	2008	110	16 (6)	12 (6)	0
Dan River	Roanoke	Mainstem	2009	84	8 (6)	4 (4)	0
Dan River (Lower)	Roanoke	Mainstem	2009	11	18 (23)	0	0
Roanoke Basin					**19 (13)**	**5 (59)**	**0**
Watauga River	Watauga	Tributary	2008	15	13 (17)	7 (13)	0
Watauga River	Watauga	Tributary	2009	19	11 (14)	5 (10)	0
Watauga Basin					**12**	**6**	**0**
Elk Creek	Yadkin	Tributary	2009	22	27 (19)	5 (9)	0
Fisher River	Yadkin	Tributary	2009	76	16 (8)	8 (6)	1 (3)
Hunting Creek	Yadkin	Tributary	2008	19	0	0	0
Mitchell River	Yadkin	Tributary	2008	65	26 (10)	2 (3)	0
Mulberry Creek	Yadkin	Tributary	2008	24	42 (20)	21 (16)	0
Reddies River	Yadkin	Tributary	2007	17	35 (23)	0	0
Reddies River	Yadkin	Tributary	2008	6	0	0	0
Reddies River	Yadkin	Tributary	2009	10	0	0	0
Roaring River	Yadkin	Tributary	2008	25	16 (14)	4 (8)	0
Stony Fork	Yadkin	Tributary	2007	15	13 (17)	7 (12)	0
Yadkin River (Lower)	Yadkin	Mainstem	2007	40	30 (14)	28 (14)	8 (8)
Yadkin River (Lower)	Yadkin	Mainstem	2008	53	19 (11)	9 (8)	2 (4)
Yadkin River (Lower)	Yadkin	Mainstem	2009	57	26 (11)	5 (6)	4 (5)
Yadkin River (Upper)	Yadkin	Tributary	2008	23	4 (8)	0	0
Yadkin Basin					**18 (9)**	**6 (5)**	**1 (1)**
		Mainstem			**23 (7)**	**5 (3)**	**1 (1)**
		Tributary			**25 (7)**	**5 (3)**	**0**
		All Basins			**24 (6)**	**5 (2)**	**0**

TABLE 2.—Mean relative weight (W_r) values, with associated condition statistics for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Standard error values are listed in parentheses. Sample sizes (N) indicate the number of individuals meeting total-length criteria described by Kolander et al. (1993).

Stream Reach	River Basin	Class	Year	N	Mean W_r	95% C.I.	Range	Median
Broad River (Lower)	Broad	Mainstem	2007	10	92 (2.78)	86–98	76–102	95
Broad River (Lower)	Broad	Mainstem	2008	81	85 (0.71)	84–87	73–108	85
Broad River (Lower)	Broad	Mainstem	2009	45	85 (1.10)	83–87	69–104	86
Broad River (Upper)	Broad	Mainstem	2008	44	86 (0.94)	84–88	74–99	86
Cove Creek	Broad	Tributary	2007	6	93 (3.45)	84–102	82–103	93
			Total	186	86 (0.51)	85–87	69–108	86
Catawba River	Catawba	Tributary	2007	11	96 (2.62)	90–101	84–115	95
Catawba River	Catawba	Tributary	2008	22	104 (2.19)	99–109	84–130	102
Catawba River	Catawba	Tributary	2009	47	91 (1.30)	90–92	66–114	93
Henry Fork River	Catawba	Tributary	2007	12	85 (1.88)	81–89	72–95	88
Jacob Fork River	Catawba	Tributary	2007	13	92 (1.54)	89–95	84–100	93
Johns River	Catawba	Tributary	2007	22	87 (1.23)	86–98	78–100	86
Linville River	Catawba	Tributary	2007	25	87 (1.64)	84–90	76–113	85
Linville River	Catawba	Tributary	2008	4	80 (2.13)	73–87	74–84	82
Mulberry Creek	Catawba	Tributary	2007	9	92 (2.55)	86–98	83–106	92
North Fork Catawba River	Catawba	Tributary	2007	14	94 (2.53)	89–99	77–109	93
North Fork Catawba River	Catawba	Tributary	2008	36	92 (1.03)	90–94	76–106	92
Upper Creek/Warrior Fork	Catawba	Tributary	2007	11	87 (1.72)	83–91	76–98	86
Wilson Creek	Catawba	Tributary	2007	26	87 (1.27)	84–90	80–104	85
			Total	252	91 (0.56)	90–92	66–130	90
Cane River	French Broad	Tributary	2007	37	92 (1.46)	89–95	70–116	92
Cane River	French Broad	Tributary	2008	62	84 (0.82)	82–86	68–104	83
French Broad River (Lower)	French Broad	Mainstem	2007	14	105 (2.40)	100–110	94–130	103
French Broad River (Lower)	French Broad	Mainstem	2008	62	85 (0.74)	84–86	73–100	84
French Broad River (Lower)	French Broad	Mainstem	2009	143	90 (0.53)	89–91	72–109	90
French Broad River (Upper)	French Broad	Mainstem	2007	68	99 (0.94)	97–101	81–118	98
French Broad River (Upper)	French Broad	Mainstem	2008	15	90 (2.25)	85–95	72–102	92
North Toe River	French Broad	Mainstem	2007	30	86 (1.43)	83–89	72–102	86
North Toe River	French Broad	Mainstem	2008	119	84 (0.57)	83–85	69–100	84
North Toe River	French Broad	Mainstem	2009	166	79 (0.45)	78–80	64–93	79
Pigeon River	French Broad	Mainstem	2007	58	91 (1.34)	88–94	73–135	90
Pigeon River	French Broad	Mainstem	2008	12	99 (2.64)	93–104	79–112	98
Pigeon River (By-Pass)	French Broad	Tributary	2007	81	90 (0.77)	88–92	74–108	89
Pigeon River (By-Pass)	French Broad	Tributary	2008	25	88 (1.30)	85–91	75–102	88
South Toe River	French Broad	Tributary	2007	4	91 (2.82)	82–100	83–95	93
South Toe River	French Broad	Tributary	2008	12	79 (2.22)	74–84	59–91	81
			Total	908	87 (0.31)	87–88	59–135	87
Hiwassee River	Hiwassee	Mainstem	2009	7	88 (4.48)	77–99	71–102	92
			Total	7	88 (4.48)	77–99	71–102	92

TABLE 2.—Continued. Mean relative weight (W_r) values, with associated condition statistics for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Standard error values are listed in parentheses. Sample sizes (N) indicate the number of individuals meeting total-length criteria described by Kolander et al. (1993).

Stream Reach	River Basin	Class	Year	N	Mean W_r	95% C.I.	Range	Median
Little Tennessee River	Little Tenn.	Mainstem	2007	13	90 (2.18)	85–95	76–100	92
Little Tennessee River	Little Tenn.	Mainstem	2008	27	89 (1.36)	86–92	76–103	89
Tuckaseegee River	Little Tenn.	Mainstem	2008	43	93 (1.35)	90–96	77–115	93
			Total	83	91 (0.91)	90–93	76–115	92
Dan River	Roanoke	Mainstem	2007	77	92 (0.74)	91–93	78–108	92
Dan River	Roanoke	Mainstem	2008	118	93 (0.72)	92–94	76–140	93
Dan River	Roanoke	Mainstem	2009	88	91 (0.79)	90–93	78–116	90
Dan River (Lower)	Roanoke	Mainstem	2009	12	85 (1.66)	81–88	76–92	86
			Total	295	92 (0.43)	91–93	76–140	91
Watauga River	Watauga	Tributary	2008	15	84 (1.00)	82–86	74–90	84
Watauga River	Watauga	Tributary	2009	28	84 (1.34)	81–86	68–95	84
			Total	43	84 (0.94)	82–86	68–95	84
Elk Creek	Yadkin	Tributary	2009	31	84 (1.31)	82–87	68–100	84
Fisher River	Yadkin	Tributary	2009	78	89 (0.83)	87–91	76–118	87
Hunting Creek	Yadkin	Tributary	2008	21	91 (1.30)	88–94	81–102	91
Mitchell River	Yadkin	Tributary	2008	69	96 (1.03)	94–98	76–119	95
Mulberry Creek	Yadkin	Tributary	2008	25	91 (1.53)	88–94	77–108	90
Reddies River	Yadkin	Tributary	2007	40	99 (1.37)	96–102	80–125	99
Reddies River	Yadkin	Tributary	2008	7	88 (2.34)	82–94	77–98	88
Reddies River	Yadkin	Tributary	2009	12	96 (1.84)	92–100	82–104	98
Roaring River	Yadkin	Tributary	2008	26	92 (1.38)	89–95	75–108	92
Stony Fork	Yadkin	Tributary	2007	20	97 (1.60)	94–100	86–110	95
Yadkin River (Lower)	Yadkin	Mainstem	2007	41	92 (1.11)	90–94	78–109	92
Yadkin River (Lower)	Yadkin	Mainstem	2008	72	95 (1.13)	93–97	72–119	92
Yadkin River (Lower)	Yadkin	Mainstem	2009	55	88 (1.00)	86–90	73–105	86
Yadkin River (Upper)	Yadkin	Tributary	2008	25	94 (1.08)	92–96	83–103	95
			Total	522	92 (0.37)	92–93	68–125	92
		Mainstem	Total	1,420	89 (0.24)	88–89	64–140	88
		Tributary	Total	876	91 (0.29)	90–91	59–130	90
		All Basins	Total	2,296	89 (0.19)	89–90	59–140	89

TABLE 3.—Mean relative weight (W_r) values for stock (S)-, quality (Q)-, preferred (P)-, and memorable (M)-size smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Standard error values are listed in parentheses. Length-class qualifications are presented as described by Gabelhouse (1984).

Stream Reach	River Basin	Class	Year	S	Q	P	M
Broad River (Lower)	Broad	Mainstem	2007	92 (4.40)		84	
Broad River (Lower)	Broad	Mainstem	2008	86 (0.72)	82 (1.43)	91	83
Broad River (Lower)	Broad	Mainstem	2009	84 (1.14)	78 (0.81)	84 (3.37)	
Broad River (Upper)	Broad	Mainstem	2008	85 (0.99)	84 (3.45)		
Cove Creek	Broad	Tributary	2007	98 (4.24)	87 (2.95)		
			Total	86 (0.53)	81 (1.15)	86 (2.14)	83
Catawba River	Catawba	Tributary	2007	100 (2.24)	90 (0.86)	86 (2.37)	
Catawba River	Catawba	Tributary	2008	104 (2.38)	84		
Catawba River	Catawba	Tributary	2009	90 (1.44)	88 (9.24)		77
Henry Fork River	Catawba	Tributary	2007	84 (2.68)	84 (2.37)		
Jacob Fork River	Catawba	Tributary	2007	92 (1.74)	84		
Johns River	Catawba	Tributary	2007	86 (1.61)	86 (1.36)	81	
Linville River	Catawba	Tributary	2007	88 (2.84)	88 (2.45)	88 (2.95)	
Linville River	Catawba	Tributary	2008	84			
Mulberry Creek	Catawba	Tributary	2007	91 (3.77)	94	98	
North Fork Catawba River	Catawba	Tributary	2007	91 (2.28)	93 (6.46)		
North Fork Catawba River	Catawba	Tributary	2008	92 (1.47)	92 (1.82)	87	
Upper Creek/Warrior Fork	Catawba	Tributary	2007	89 (1.95)	82 (3.15)		
Wilson Creek	Catawba	Tributary	2007	87 (1.49)	86 (2.30)	82 (2.06)	
			Total	91 (0.77)	88 (1.11)	87 (1.85)	77
Cane River	French Broad	Tributary	2007	90 (1.45)	94 (3.73)	90 (3.57)	
Cane River	French Broad	Tributary	2008	85 (1.06)	85 (1.78)	82 (1.69)	75
French Broad River (Lower)	French Broad	Mainstem	2007	110 (3.67)	98 (1.25)		
French Broad River (Lower)	French Broad	Mainstem	2008	84 (0.84)	84 (2.41)	84 (3.95)	
French Broad River (Lower)	French Broad	Mainstem	2009	90 (0.56)	89 (1.63)	91	
French Broad River (Upper)	French Broad	Mainstem	2007	96 (1.69)	94 (1.84)	88	
French Broad River (Upper)	French Broad	Mainstem	2008	90 (3.49)	92		
North Toe River	French Broad	Mainstem	2007	85 (2.43)	83 (2.56)	82	91
North Toe River	French Broad	Mainstem	2008	85 (0.71)	81 (1.04)	82 (1.39)	
North Toe River	French Broad	Mainstem	2009	80 (0.45)	75 (0.88)	70 (2.52)	75 (2.64)
Pigeon River	French Broad	Mainstem	2007	86 (1.98)	87 (6.68)	86 (0.83)	
Pigeon River	French Broad	Mainstem	2008	89 (4.95)			
Pigeon River (By-Pass)	French Broad	Tributary	2007	90 (1.06)	92 (2.78)		
Pigeon River (By-Pass)	French Broad	Tributary	2008	86 (1.38)			
South Toe River	French Broad	Tributary	2007	91 (2.82)			
South Toe River	French Broad	Tributary	2008	82 (1.85)	80 (2.17)	59	
			Total	86 (0.34)	84 (0.73)	82 (1.40)	77 (3.18)
Hiwassee River	Hiwassee	Mainstem	2009	92 (5.37)	79 (3.50)		
			Total	92 (5.37)	79 (3.50)		

TABLE 3.—Continued. Mean relative weight (W_r) values for stock (S)-, quality (Q)-, preferred (P)-, and memorable (M)-size smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Standard error values are listed in parentheses. Length-class qualifications are presented as described by Gabelhouse (1984).

Stream Reach	River Basin	Class	Year	S	Q	P	M
Little Tennessee River	Little Tennessee	Mainstem	2007	86 (3.19)	76		
Little Tennessee River	Little Tennessee	Mainstem	2008	90 (1.69)	87 (4.10)	76	
Tuckaseegee River	Little Tennessee	Mainstem	2008	92 (1.67)	87 (2.49)	91 (2.37)	
			Total	91 (1.15)	86 (2.12)	87 (4.01)	
Dan River	Roanoke	Mainstem	2007	93 (0.81)	89 (1.53)	85 (1.90)	
Dan River	Roanoke	Mainstem	2008	94 (0.62)	84 (2.36)	86 (1.32)	
Dan River	Roanoke	Mainstem	2009	91 (0.80)	86 (2.09)	84 (2.37)	
Dan River (Lower)	Roanoke	Mainstem	2009	85 (1.82)	80 (3.62)		
			Total	92 (0.43)	87 (1.16)	86 (1.14)	
Watauga River	Watauga	Tributary	2008	84 (1.15)	82	86	
Watauga River	Watauga	Tributary	2009	81 (1.32)	79	70	
			Total	82 (1.04)	83 (1.62)	78 (8.00)	
Elk Creek	Yadkin	Tributary	2009	83 (1.61)	81 (5.38)	84	
Fisher River	Yadkin	Tributary	2009	89 (0.93)	90 (2.23)	86 (2.82)	79
Hunting Creek	Yadkin	Tributary	2008	92 (1.32)			
Mitchell River	Yadkin	Tributary	2008	98 (1.13)	91 (2.37)	95	
Mulberry Creek	Yadkin	Tributary	2008	93 (1.57)	85 (2.48)	86 (3.03)	
Reddies River	Yadkin	Tributary	2007	96 (3.59)	92 (3.12)		
Reddies River	Yadkin	Tributary	2008	88 (2.77)			
Reddies River	Yadkin	Tributary	2009	96 (1.84)			
Roaring River	Yadkin	Tributary	2008	92 (1.62)	92 (2.82)	83	
Stony Fork	Yadkin	Tributary	2007	96 (2.06)	94	89	
Yadkin River (Lower)	Yadkin	Mainstem	2007	94 (1.33)	84	88 (1.85)	85 (1.13)
Yadkin River (Lower)	Yadkin	Mainstem	2008	92 (1.01)	84 (3.51)	89 (2.90)	103
Yadkin River (Lower)	Yadkin	Mainstem	2009	89 (1.02)	83 (2.71)	86	77
Yadkin River (Upper)	Yadkin	Tributary	2008	95 (1.11)			
			Total	92 (0.42)	87 (1.13)	87 (1.04)	86 (3.78)
		Mainstem	Total	88 (0.26)	84 (0.59)	84 (0.84)	83 (2.82)
		Tributary	Total	91 (0.37)	88 (0.68)	85 (1.25)	77 (1.15)
		All Basins	Total	89 (0.21)	85 (0.46)	85 (0.70)	81 (2.29)

TABLE 4.—von Bertalanffy growth model estimated parameters using 508 mm total length (TL) fixed asymptotic length (L_∞) for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Time to reach harvestable size (l_t) values derived from the von Bertalanffy growth equation also are shown for each stream reach and averaged for each river basin. Standard error values are listed in parentheses.

		$l_t = L_\infty (1-e^{-K(t-t_0)})$			
Stream Reach	**River Basin**	**K**	**t_0**	**R^2**	**$l_{t = 305\ mm\ TL}$ (years)**
Broad River (Lower)	Broad	0.285	-0.409	0.98	2.8
Broad River (Upper)	Broad	0.141	-2.358	0.97	4.1
Cove Creek	Broad	0.140	-1.324	0.98	5.2
	Mean				4.0 (0.7)
Catawba River	Catawba	0.152	-1.240	0.92	4.8
Henry Fork River*	Catawba	-	-	-	-
Jacob Fork River	Catawba	0.124	-1.287	0.99	6.1
Johns River	Catawba	0.153	-0.993	0.99	5.0
Linville River	Catawba	0.121	-1.417	0.96	6.2
Mulberry Creek	Catawba	0.118	-2.137	0.93	5.6
North Fork Catawba River	Catawba	0.130	-1.856	0.97	5.2
Upper Creek/Warrior Fork*	Catawba	-	-	-	-
Wilson Creek	Catawba	0.131	-1.365	0.98	5.6
	Mean				5.5 (0.2)
Cane River	French Broad	0.136	-1.300	0.95	5.4
French Broad River (Lower)	French Broad	0.140	-1.562	0.96	5.0
French Broad River (Upper)	French Broad	0.094	-3.920	0.85	5.9
North Toe River	French Broad	0.124	-1.86	0.97	5.5
Pigeon River	French Broad	0.080	-3.444	0.53	8.0
Pigeon River (By-Pass)	French Broad	0.146	-0.879	0.99	5.4
South Toe River	French Broad	0.068	-5.521	0.97	8.0
	Mean				6.2 (0.5)
Hiwassee River	Hiwassee	0.060	-6.725	0.96	8.6
	Mean				8.6

* convergence criteria not met for von Bertalanffy growth equation

TABLE 4.—Continued. von Bertalanffy growth model estimated parameters using 508 mm total length (TL) fixed asymptotic length (L_∞) for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Time to reach harvestable size (l_t) values derived from the von Bertalanffy growth equation also are shown for each stream reach and averaged for each river basin. Standard error values are listed in parentheses.

		$l_t = L_\infty (1-e^{-K (t-t_0)})$			
Stream Reach	**River Basin**	K	t_0	R^2	$l_{t\,=\,305\text{ mm TL}}$ **(years)**
Little Tennessee River	Little Tennessee	0.120	-1.648	0.86	6.0
Tuckaseegee River	Little Tennessee	0.112	-1.861	0.90	6.3
	Mean				6.2 (0.2)
Dan River (Lower)*	Roanoke	-	-	-	-
Dan River (Upper)	Roanoke	0.162	-1.466	0.92	4.2
	Mean				4.2
Watauga River	Watauga	0.113	-1.292	0.98	6.8
	Mean				6.8
Elk Creek	Yadkin	0.150	-1.063	0.90	5.1
Fisher River	Yadkin	0.154	-1.891	0.88	4.1
Hunting Creek*	Yadkin	-	-	-	-
Mitchell River	Yadkin	0.110	-3.249	0.72	5.1
Mulberry Creek	Yadkin	0.155	-1.145	0.98	4.8
Reddies River	Yadkin	0.141	-1.200	0.97	5.3
Roaring River	Yadkin	0.152	-1.206	0.99	4.8
Stony Fork	Yadkin	0.120	-1.394	0.99	6.3
Yadkin River (Lower)	Yadkin	0.199	-1.308	0.95	3.3
Yadkin River (Upper)*	Yadkin	-	-	-	-
	Mean				4.9 (0.3)
	Mainstem				5.4 (0.5)
	Tributary				5.5 (0.2)
	All Basins				5.5 (0.2)

* convergence criteria not met for von Bertalanffy growth equation

TABLE 5.—von Bertalanffy predicted mean total length (TL, mm)-at-age values for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. River basin predicted mean TL-at-age values with standard errors in parentheses also are listed.

		Age (years)									
Stream Reach	**River Basin**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Broad River (Lower)	Broad	168	252	316	363	399	429	447	462	473	482
Broad River (Upper)	Broad	192	233	269	301	328	352	372	390	406	419
Cove Creek	Broad	141	189	231	267	298	326	350	370	388	404
	Mean	167 (14)	225 (19)	272 (25)	310 (28)	342 (30)	369 (31)	390 (29)	407 (28)	422 (26)	435 (24)
Catawba River	Catawba	147	198	241	229	311	339	363	383	401	416
Henry Fork River*	Catawba	-	-	-	-	-	-	-	-	-	-
Jacob Fork River	Catawba	125	170	209	244	275	302	326	347	366	383
Johns River	Catawba	134	187	232	271	305	334	358	380	398	414
Linville River	Catawba	129	172	210	244	274	301	325	345	364	380
Mulberry Creek	Catawba	157	196	231	262	289	314	335	354	372	387
North Fork Catawba River	Catawba	158	200	238	271	300	325	347	367	384	399
Upper Creek/Warrior Fork*	Catawba	-	-	-	-	-	-	-	-	-	-
Wilson Creek	Catawba	135	181	221	256	287	314	338	359	377	393
	Mean	141 (5)	186 (5)	226 (5)	255 (6)	292 (5)	318 (6)	342 (6)	362 (6)	380 (6)	396 (5)
Cane River	French Broad	136	184	225	261	292	320	344	365	383	399
French Broad River (Lower)	French Broad	153	199	240	275	305	332	355	375	392	407
French Broad River (Upper)	French Broad	188	216	243	266	288	308	326	342	357	371
North Toe River	French Broad	182	203	223	242	260	276	291	305	319	331
Pigeon River	French Broad	152	179	205	228	249	269	288	305	320	335
Pigeon River (By-Pass)	French Broad	122	174	220	259	293	322	347	369	388	404
South Toe River	French Broad	182	203	223	242	260	276	291	305	319	331
	Mean	159 (10)	194 (6)	226 (5)	253 (6)	278 (8)	300 (10)	320 (11)	338 (12)	354 (13)	368 (13)
Hiwassee River	Hiwassee	188	207	225	241	257	271	285	333	310	322
	Mean	188	207	225	241	257	271	285	333	310	322
Little Tennessee River	Little Tennessee	138	180	217	250	279	305	328	348	366	382
Tuckaseegee River	Little Tennessee	139	178	213	245	272	297	320	340	357	373
	Mean	139 (1)	179 (1)	215 (2)	248 (3)	276 (4)	301 (4)	324 (4)	344 (4)	362 (5)	378 (5)

* convergence criteria not met for von Bertalanffy growth equation

TABLE 5.—Continued. von Bertalanffy predicted mean total length (TL, mm)-at-age values for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. River basin predicted mean TL-at-age values with standard errors in parentheses also are listed.

		Age (years)									
Stream Reach	**River Basin**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Dan River (Lower)*	Roanoke	-	-	-	-	-	-	-	-	-	-
Dan River (Upper)	Roanoke	167	218	262	298	330	356	379	398	415	429
	Mean	167	218	262	298	330	356	379	398	415	429
Watauga River	Watauga	116	158	195	229	258	285	309	330	349	366
	Mean	116	158	195	229	258	285	309	330	349	366
Elk Creek	Yadkin	135	187	232	270	303	332	356	378	396	411
Fisher River	Yadkin	183	229	269	303	332	357	379	397	413	427
Hunting Creek*	Yadkin	-	-	-	-	-	-	-	-	-	-
Mitchell River	Yadkin	190	223	253	279	303	324	343	361	376	390
Mulberry Creek	Yadkin	144	196	241	279	312	340	364	385	403	418
Reddies River	Yadkin	135	184	227	264	296	324	348	369	387	403
Roaring River	Yadkin	145	196	240	278	310	338	362	383	400	416
Stony Fork	Yadkin	127	170	208	242	272	299	322	343	362	379
Yadkin River (Lower)	Yadkin	187	245	292	331	363	389	411	428	443	454
Yadkin River (Upper)*	Yadkin	-	-	-	-	-	-	-	-	-	-
	Mean	156 (9)	204 (9)	245 (9)	281 (9)	311 (9)	338 (9)	361 (9)	381 (9)	398 (9)	412 (8)
	Mainstem	169 (6)	210 (8)	246 (11)	276 (13)	303 (14)	326 (16)	346 (16)	366 (15)	378 (16)	391 (16)
	Tributary	144 (5)	189 (4)	229 (4)	261 (4)	293 (4)	320 (5)	342 (5)	363 (5)	380 (5)	396 (5)
	All Basins	153 (4)	197 (4)	235 (5)	266 (5)	297 (6)	322 (6)	344 (6)	364 (6)	379 (7)	394 (6)

* convergence criteria not met for von Bertalanffy growth equation

TABLE 6.—Instantaneous (*Z*) and annual (*A*) mortality estimates derived from Robson and Chapman catch-curve models for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Standard error values are listed in parentheses.

Stream Reach	River Basin	Class	Year (s)	Age-classes	*Z*	95% C.I.	*A* (%)	95% C.I.	Max Age (years)
Broad River (Lower)	Broad	Mainstem	2007–2009	1–3	1.03 (0.09)	1.21–0.84	0.64 (0.03)	0.71–0.58	6.3
Catawba River	Catawba	Tributary	2007–2009	1–3	0.90 (0.10)	1.10–0.71	0.59 (0.04)	0.67–0.52	9.2
North Fork Catawba River	Catawba	Tributary	2007–2008	1–3	1.10 (0.20)	1.49–0.71	0.67 (0.07)	0.80–0.54	8.0
Cane River	French Broad	Tributary	2007–2008	2–7	0.43 (0.05)	0.52–0.34	0.35 (0.03)	0.41–0.29	10.3
French Broad River (Upper)	French Broad	Mainstem	2007–2008	1–3	1.56 (0.19)	1.93–1.20	0.79 (0.04)	0.87–0.71	9.2
North Toe River	French Broad	Mainstem	2007–2009	2–10	0.48 (0.03)	0.54–0.43	0.38 (0.02)	0.42–0.35	16.2
Pigeon River	French Broad	Mainstem	2007–2008	1–3	1.62 (0.20)	2.00–1.23	0.80 (0.04)	0.88–0.73	8.2
Pigeon River (By-Pass)	French Broad	Tributary	2007–2008	2–5	0.97 (0.10)	1.17–0.77	0.62 (0.04)	0.70–0.55	6.2
Dan River (Upper)	Roanoke	Mainstem	2007–2009	1–3	0.86 (0.06)	0.98–0.75	0.58 (0.02)	0.63–0.53	9.9
Reddies River	Yadkin	Tributary	2007–2009	1–4	1.00 (0.12)	1.23–0.77	0.63 (0.04)	0.72–0.55	6.3
Yadkin River (Lower)	Yadkin	Mainstem	2007–2009	1–3	0.90 (0.08)	1.04–0.75	0.59 (0.03)	0.65–0.53	10.3
						Mean	0.60 (4.21)	0.70–0.51	9.1

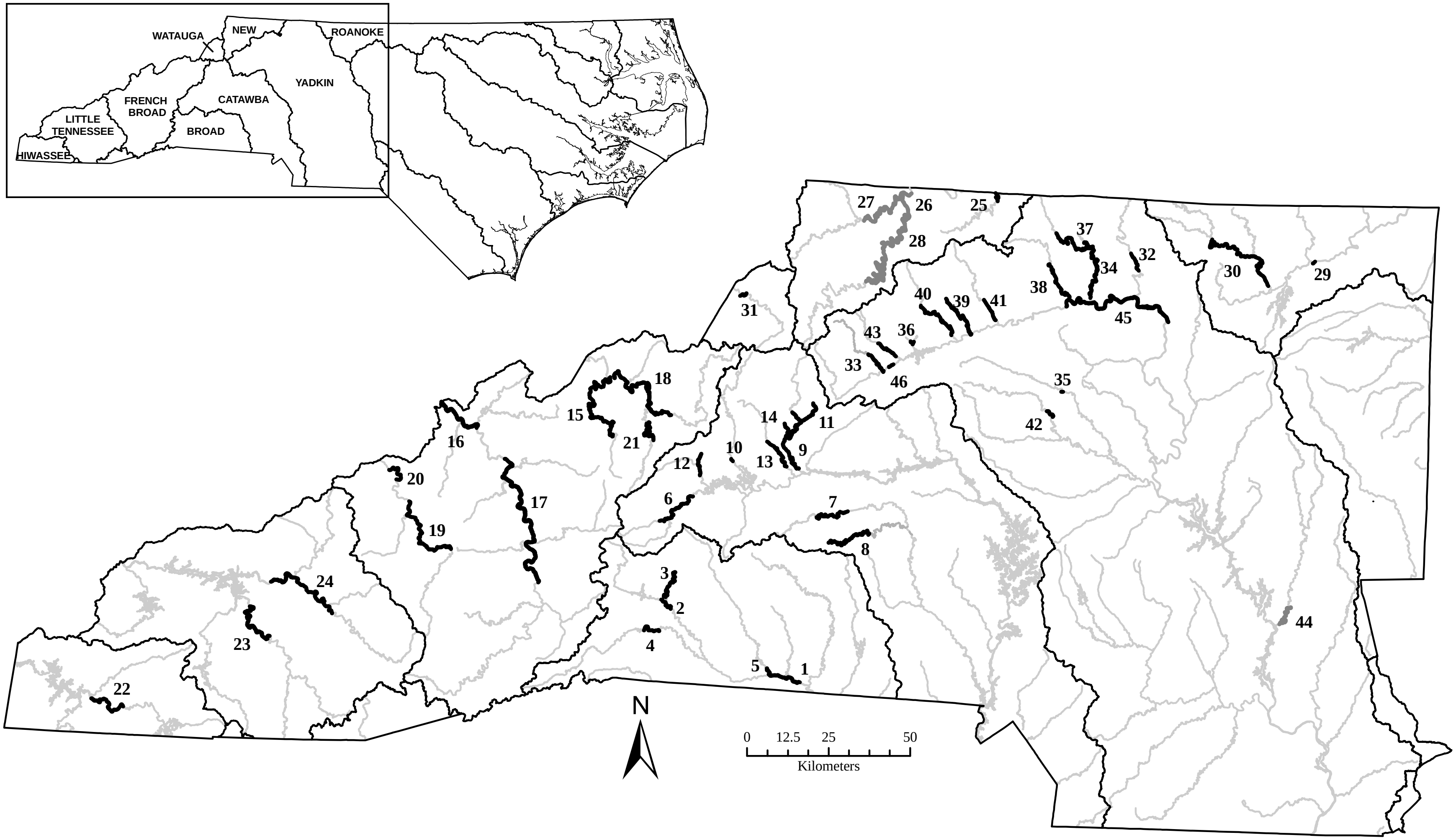

FIGURE 1.—Map of study area and stream reach information. Smallmouth bass were sampled at 46 stream reaches within nine river basins (see upper left map) throughout western North Carolina. Black highlighted portions of streams represent stream reaches where smallmouth bass collections occurred during 2007–2009. Historic smallmouth bass sample stream reaches (* in legend table) are highlighted in gray on the map. Numbers next to the highlighted reach on the map correspond to site information in the table.

ID	Basin	Stream Reach	Class	N	Years Sampled	ID	Basin	Stream Reach	Class	N	Years Sampled
1	Broad	Broad River (Lower)	Mainstem	128	2007, 2008, 2009	25	New	Little River	Tributary	2	2007
2	Broad	Broad River (Upper)	Mainstem	65	2008	26	New	New River*	Mainstem	221	1997-1999, 2003, 2005
3	Broad	Cove Creek	Tributary	11	2007	27	New	North Fork New River*	Tributary	267	2003, 2005
4	Broad	Green River	Tributary	2	2009	28	New	South Fork New River*	Mainstem	485	1998, 1999, 2003, 2005
5	Broad	Second Broad River	Tributary	0	2009	29	Roanoke	Dan River (Lower)	Mainstem	12	2009
6	Catawba	Catawba River	Tributary	117	2007, 2008, 2009	30	Roanoke	Dan River (Upper)	Mainstem	286	2007, 2008, 2009
7	Catawba	Henry Fork River	Tributary	39	2007	31	Watauga	Watauga River	Tributary	45	2008, 2009
8	Catawba	Jacob Fork River	Tributary	49	2007	32	Yadkin	Ararat River	Tributary	0	2007
9	Catawba	Johns River	Tributary	48	2007, 2008	33	Yadkin	Elk Creek	Tributary	31	2009
10	Catawba	Linville River	Tributary	47	2007, 2008	34	Yadkin	Fisher Creek	Tributary	78	2009
11	Catawba	Mulberry Creek	Tributary	17	2007	35	Yadkin	Hunting Creek	Tributary	24	2008
12	Catawba	North Fork Catawba River	Tributary	68	2007, 2008	36	Yadkin	Lewis Fork (North and South Prongs)	Tributary	1	2009
13	Catawba	Upper Creek/Warrior Fork	Tributary	34	2007	37	Yadkin	Little Fisher River	Tributary	1	2009
14	Catawba	Wilson Creek	Tributary	49	2007	38	Yadkin	Mitchell River	Tributary	71	2008
15	French Broad	Cane River	Tributary	112	2007, 2008	39	Yadkin	Mulberry Creek	Tributary	32	2008
16	French Broad	French Broad River (Lower)	Mainstem	259	2007, 2008, 2009	40	Yadkin	Reddies River	Tributary	114	2007, 2008, 2009
17	French Broad	French Broad River (Upper)	Mainstem	106	2007, 2008	41	Yadkin	Roaring River	Tributary	29	2008
18	French Broad	North Toe River	Mainstem	328	2007, 2008, 2009	42	Yadkin	Rocky Creek	Tributary	0	2008
19	French Broad	Pigeon River	Mainstem	130	2007, 2008	43	Yadkin	Stony Fork	Tributary	30	2007
20	French Broad	Pigeon River By-pass	Tributary	142	2007, 2008	44	Yadkin	Uwharrie River*	Tributary	162	2007
21	French Broad	South Toe River	Tributary	16	2007, 2008	45	Yadkin	Yadkin River (Lower)	Mainstem	174	2007, 2008, 2009
22	Hiwassee	Hiwassee River	Mainstem	7	2009	46	Yadkin	Yadkin River (Upper)	Mainstem	26	2008
23	Little Tennessee	Little Tennessee River	Mainstem	49	2007, 2008						
24	Little Tennessee	Tuckaseegee River	Mainstem	85	2008						

FIGURE 1.—Continued. Map of study area and stream reach information. Smallmouth bass were sampled at 46 stream reaches within nine river basins (see upper left map) throughout western North Carolina. Black highlighted portions of streams represent stream reaches where smallmouth bass collections occurred during 2007–2009. Historic smallmouth bass sample stream reaches (* in legend table) are highlighted in gray on the map. Numbers next to the highlighted reach on the map correspond to site information in the table.

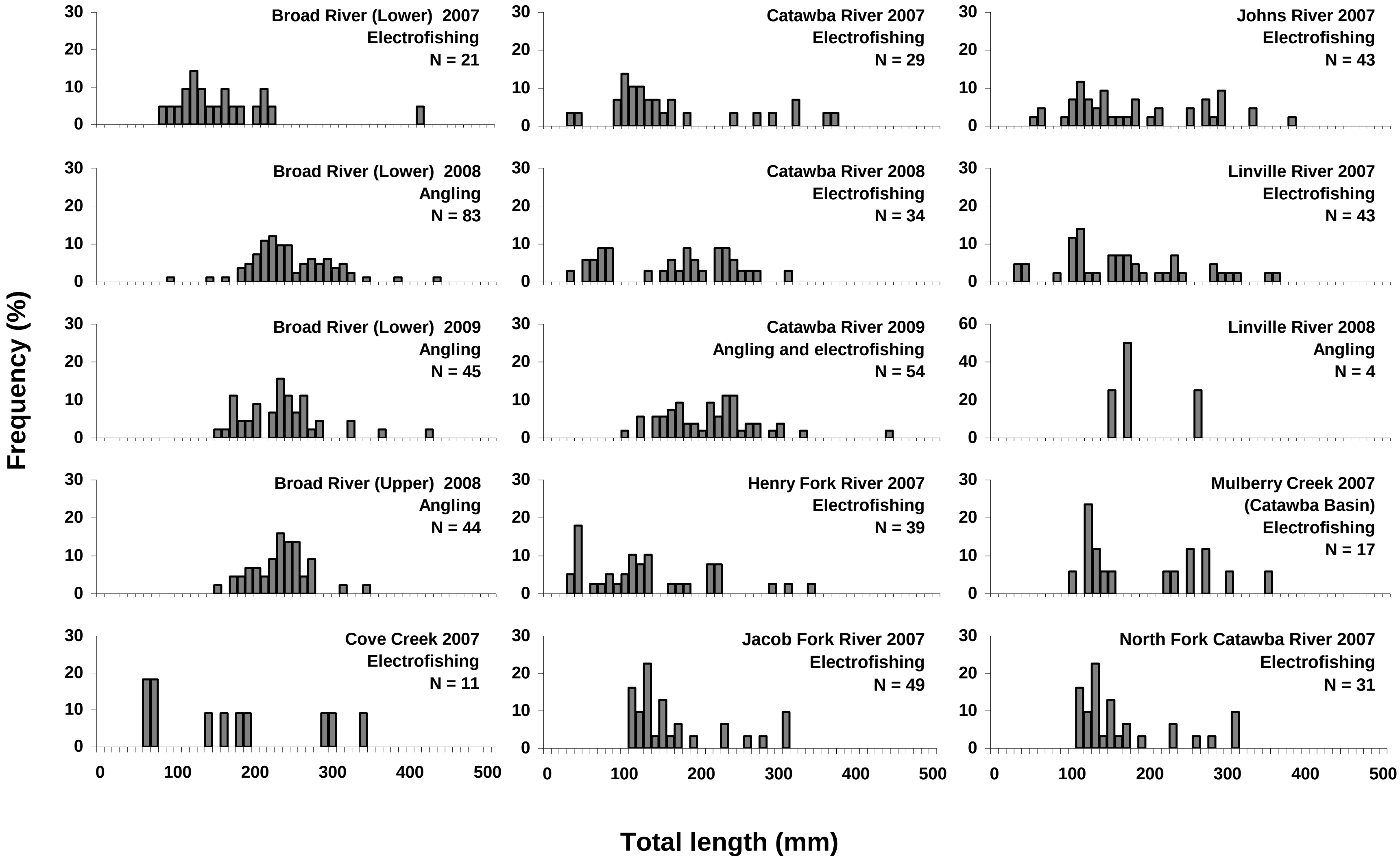

FIGURE 2.—Length-frequency distributions of smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Stream reach name, collection year, gear type, and sample sizes are included.

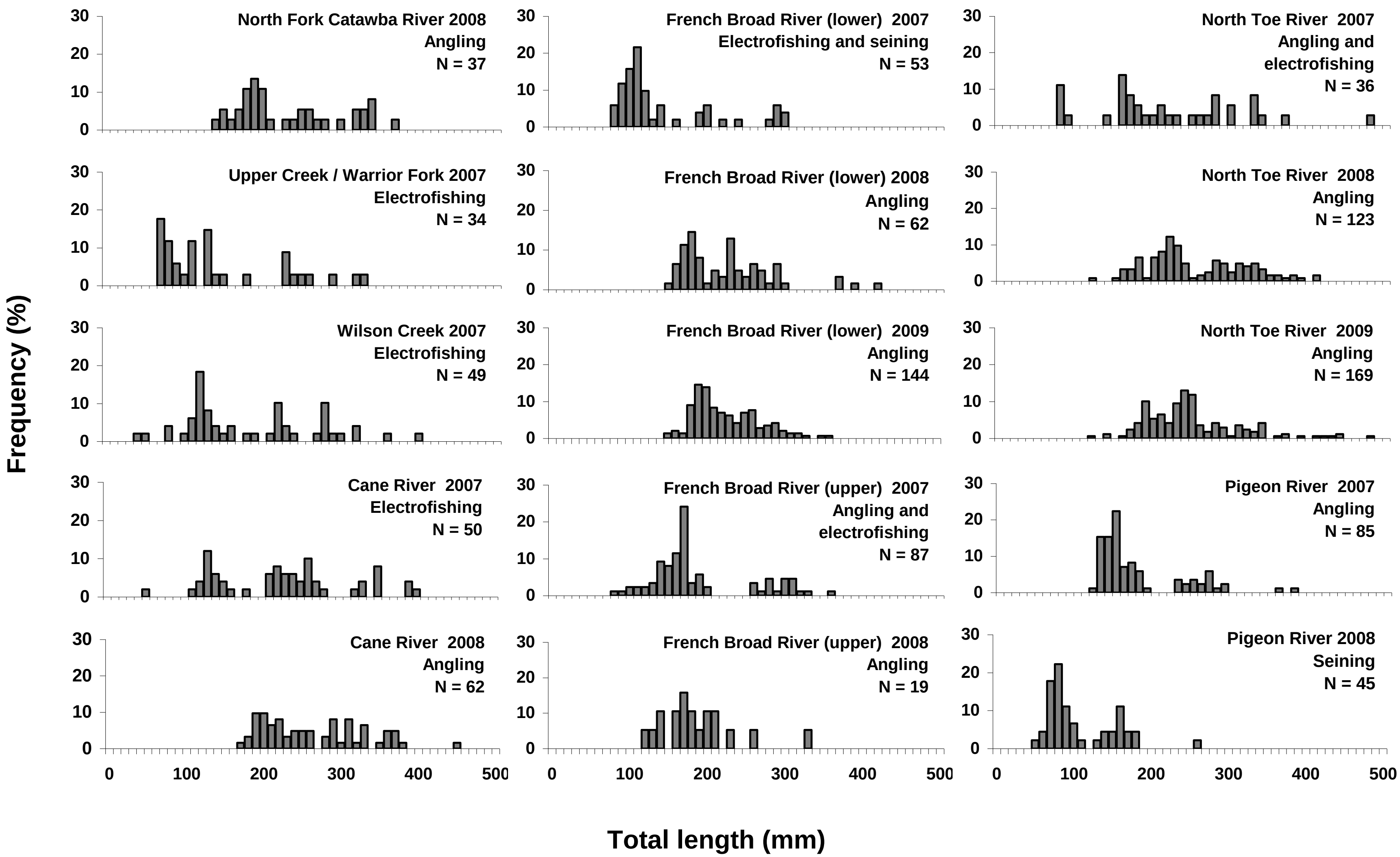

FIGURE 2.—Continued. Length-frequency distributions of smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Stream reach name, collection year, gear type, and sample sizes are included.

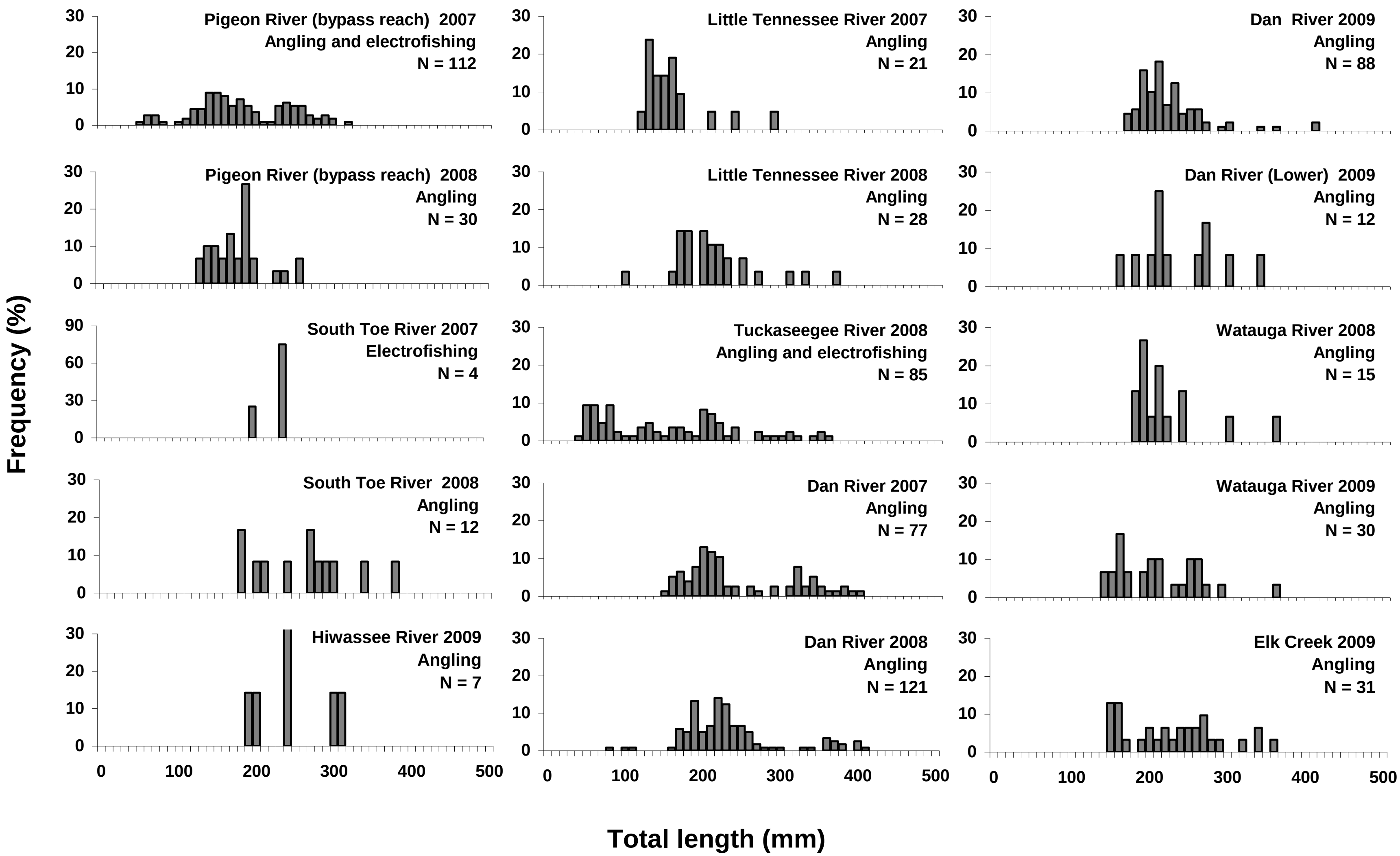

FIGURE 2.—Continued. Length-frequency distributions of smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Stream reach name, collection year, gear type, and sample sizes are included.

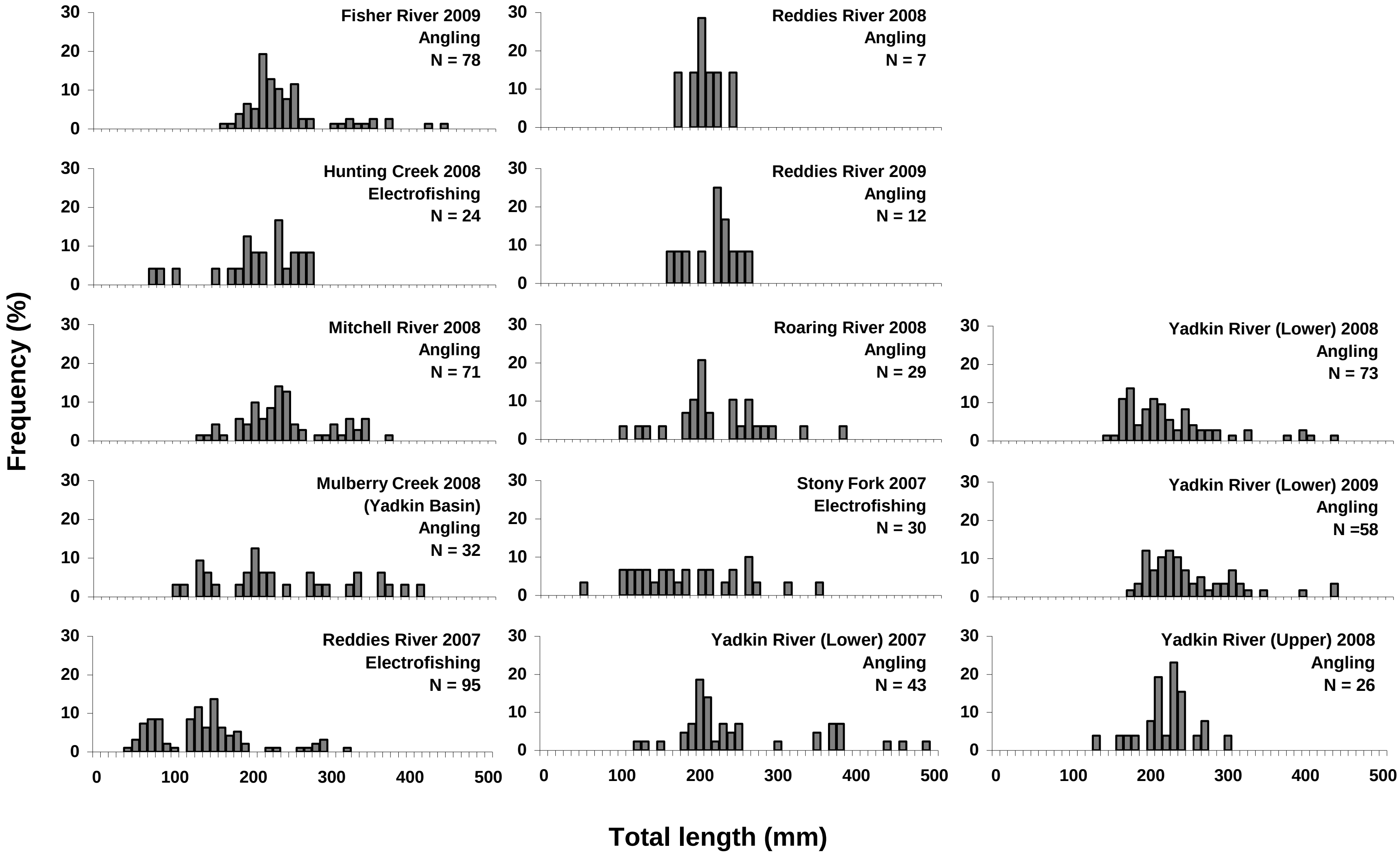

FIGURE 2.—Continued. Length-frequency distributions of smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Stream reach name, collection year, gear type, and sample sizes are included.

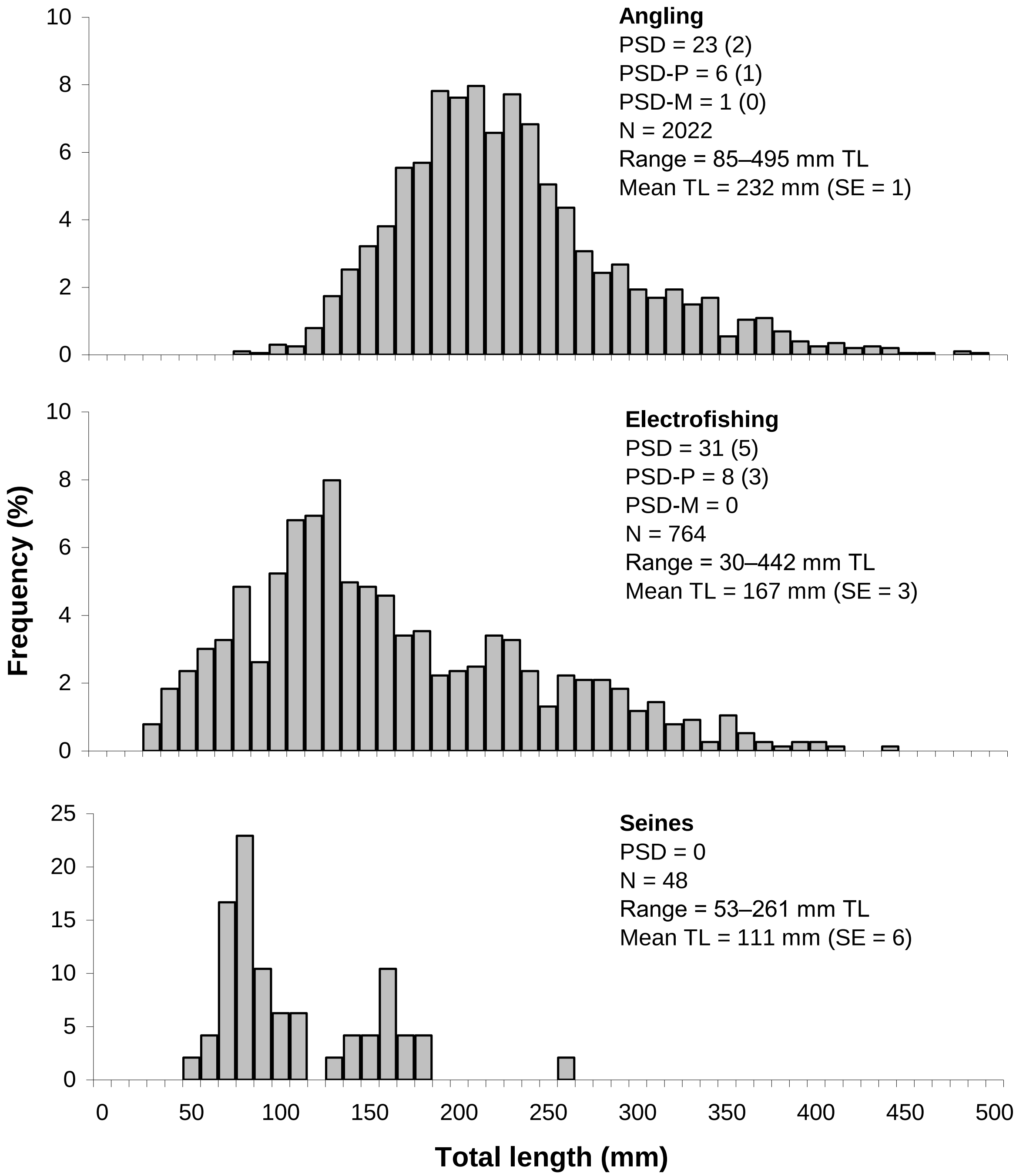

FIGURE 3.— Length-frequency distributions and size-structure indices (±95% confidence intervals) for smallmouth bass collected using angling, electrofishing, and seining gear during NCWRC surveys, May 2007–September 2009. Sample size, range, mean total length (TL), and associated standard error (SE) for each gear type is also provided.

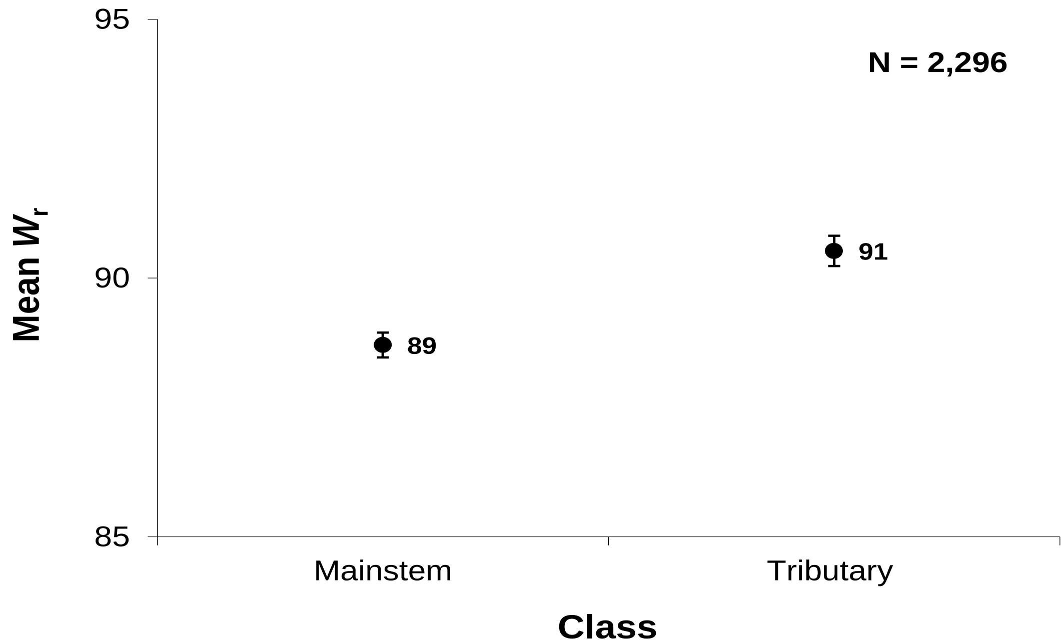

FIGURE 4.—Mean relative weight (W_r) values by class for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Standard error bars with associated mean values are shown.

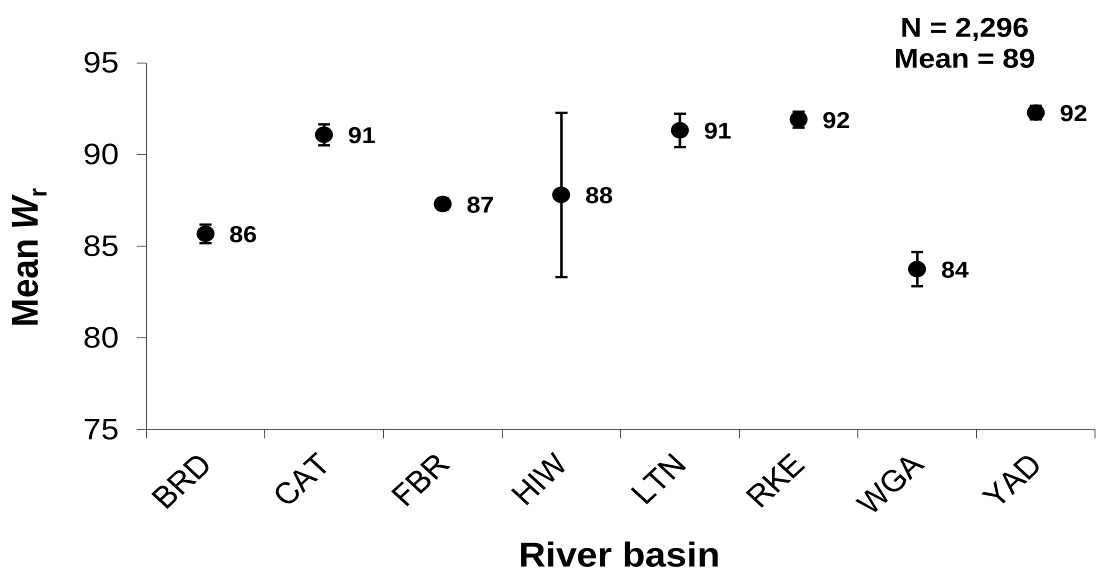

FIGURE 5.—Mean relative weight (W_r) values by river basin [BRD = Broad (N = 186), CAT = Catawba (N = 252), FBR = French Broad River (N = 908), HIW = Hiwassee (N = 7), LTN = Little Tennessee (N = 83), RKE = Roanoke (N = 295), WGA = Watauga (N = 43), YAD = Yadkin (N = 522)] for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Standard error bars with associated mean values are shown.

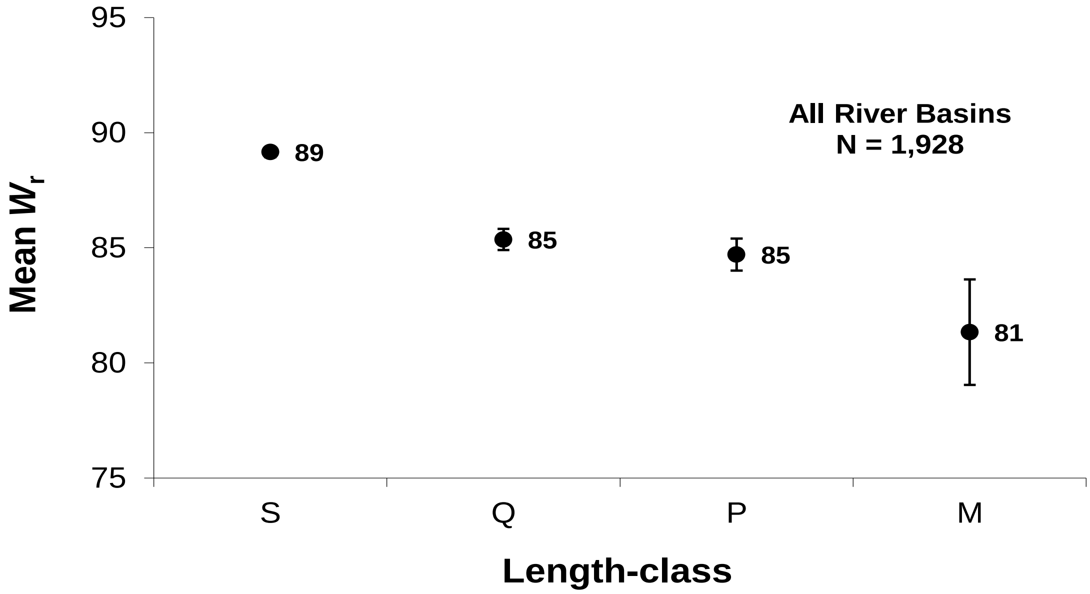

FIGURE 6.—Cumulative mean relative weight (W_r) values for stock (S)-, quality (Q)-, preferred (P)-, and memorable (M)-size smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Standard error bars with associated mean values are shown.

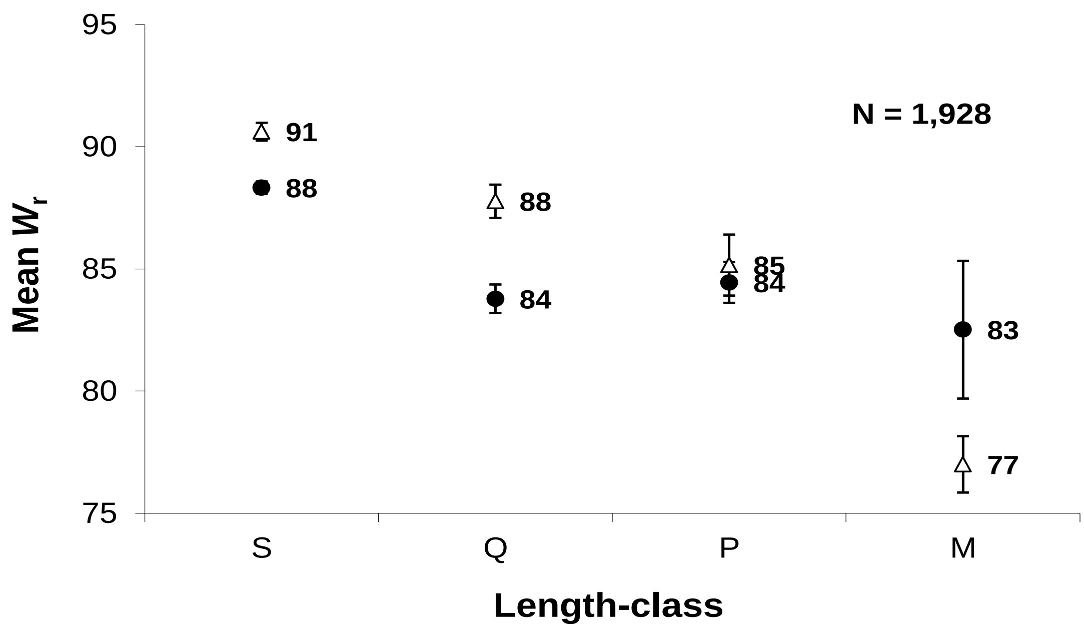

FIGURE 7.—Mean mainstem (black circles) and tributary (white triangles) relative weight (W_r) values for stock (S)-, quality (Q)-, preferred (P)-, and memorable (M)-size smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Standard error bars with associated mean values are shown.

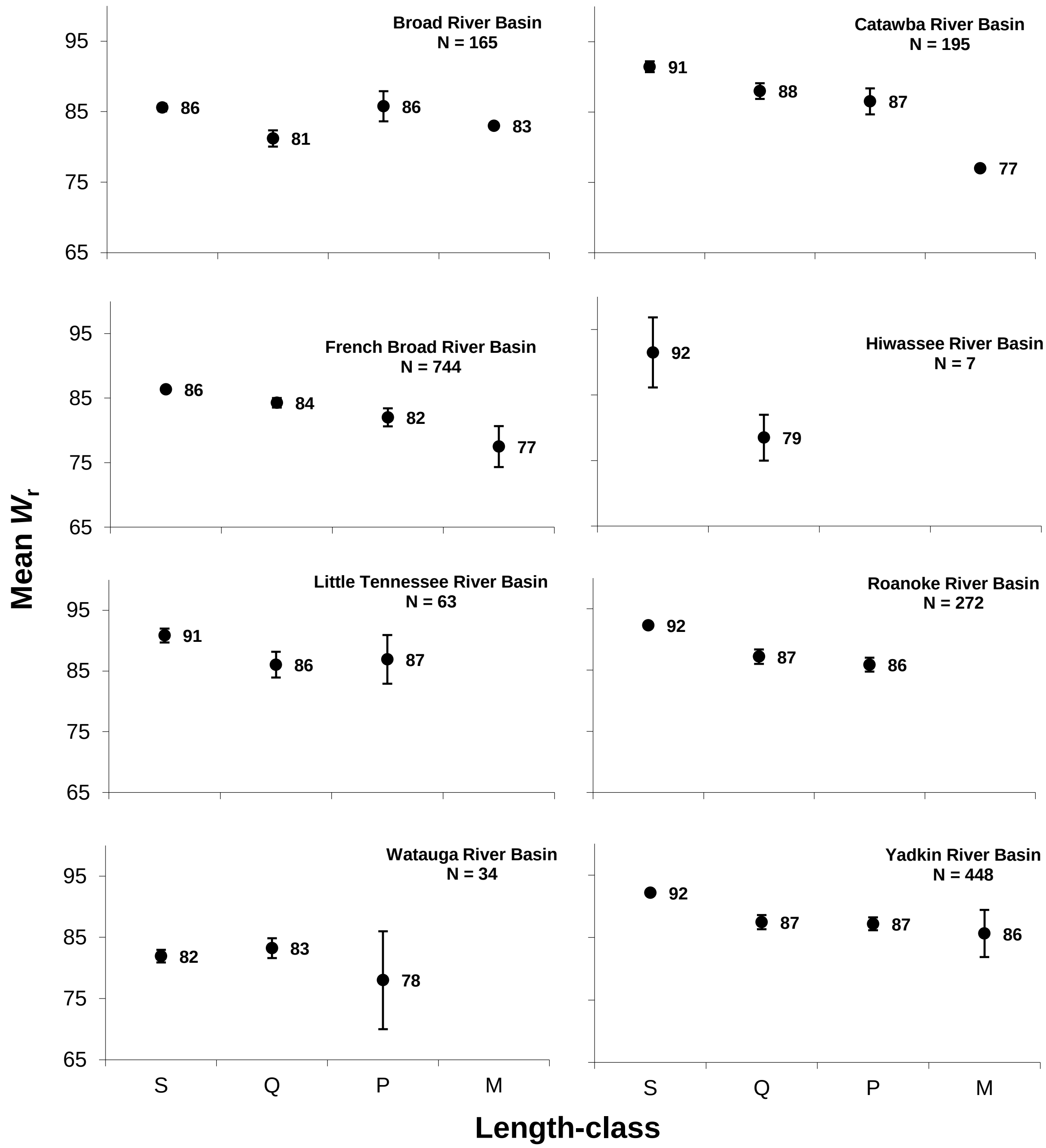

FIGURE 8.—Mean relative weight (Wr) values by river basin for stock (S)-, quality (Q)-, preferred (P)-, and memorable (M)-size smallmouth bass collected during NCWRC surveys, May 2007–October 2009. Standard error bars associated with mean values are shown.

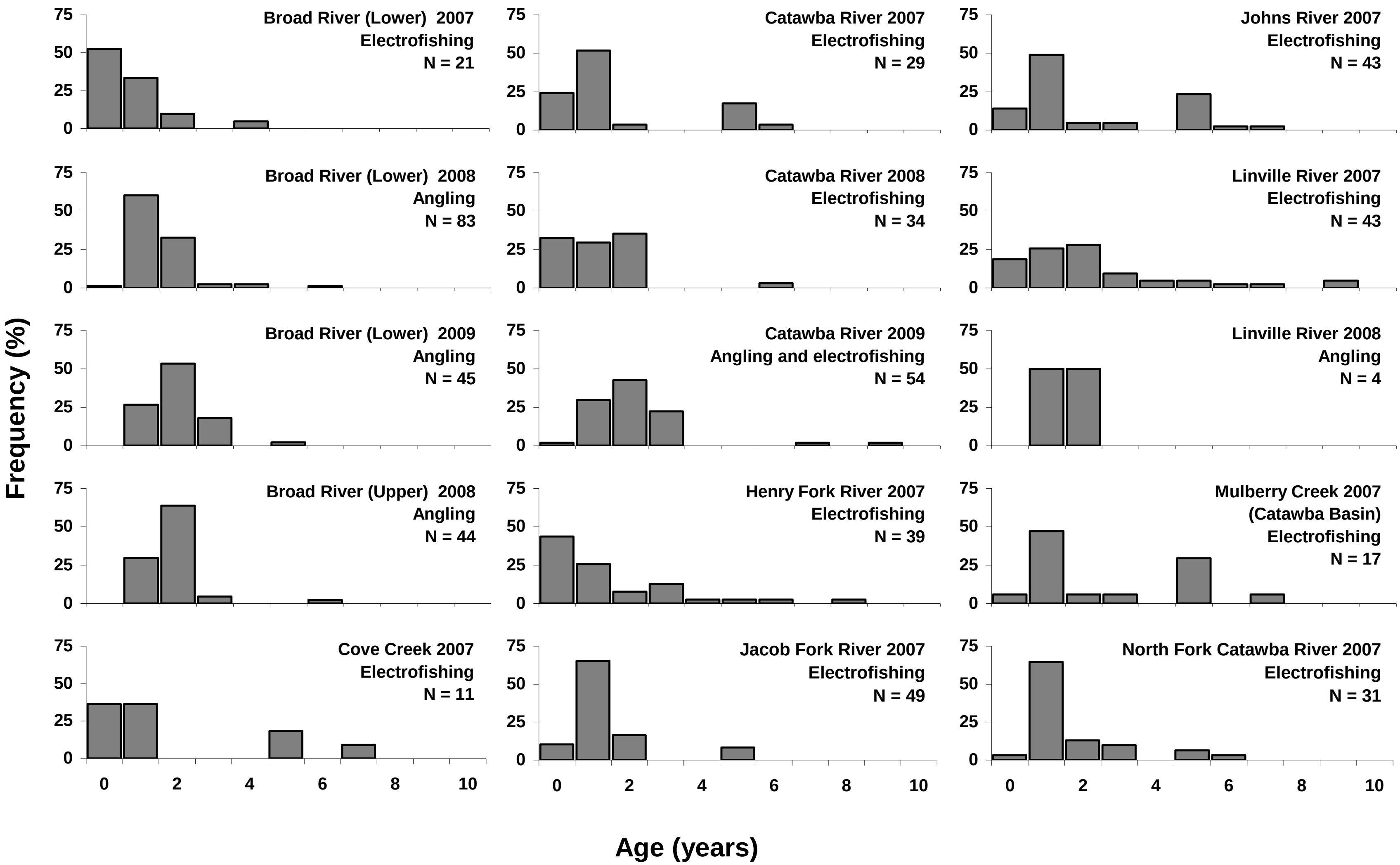

FIGURE 9.—Age distributions of smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Basin name, stream reach name, collection year, gear type, and sample sizes are included. Sample sizes denoted with an asterisk (*) contained fish older than age 10.

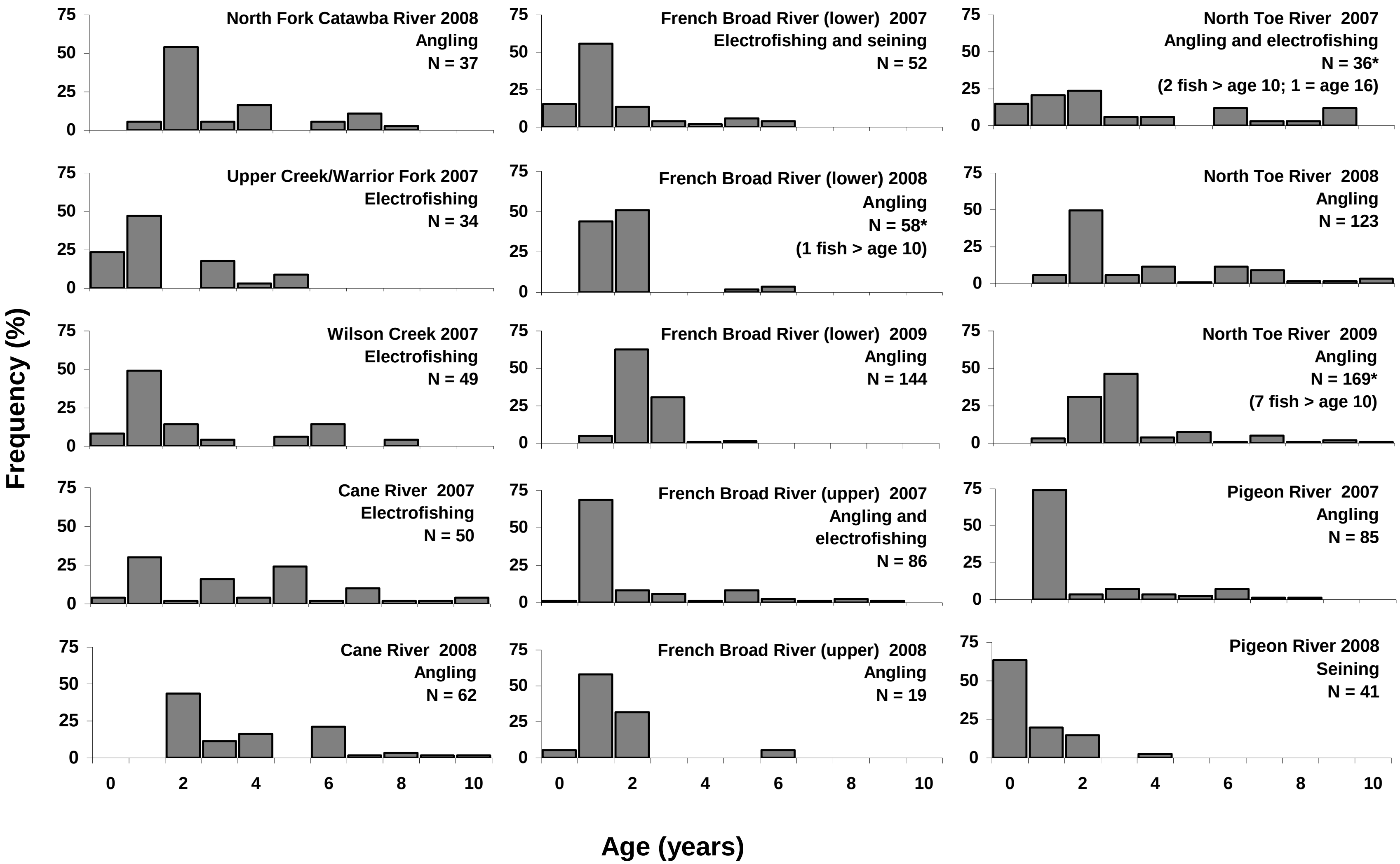

FIGURE 9.—Continued. Age distributions of smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Basin name, stream reach name, collection year, gear type, and sample sizes are included. Sample sizes denoted with an asterisk (*) contained fish older than age 10.

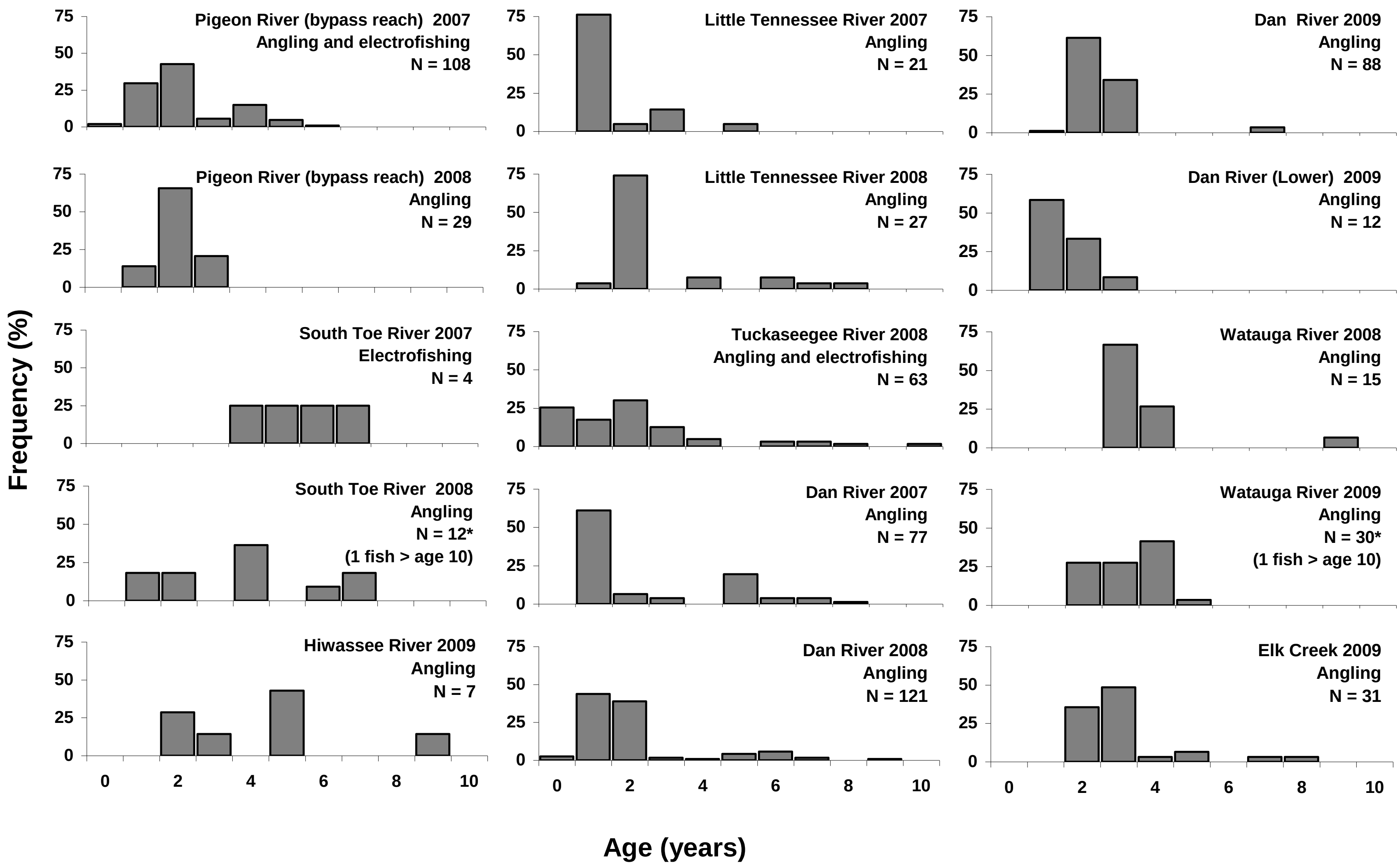

FIGURE 9.—Continued. Age distributions of smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Basin name, stream reach name, collection year, gear type, and sample sizes are included. Sample sizes denoted with an asterisk (*) contained fish older than age 10.

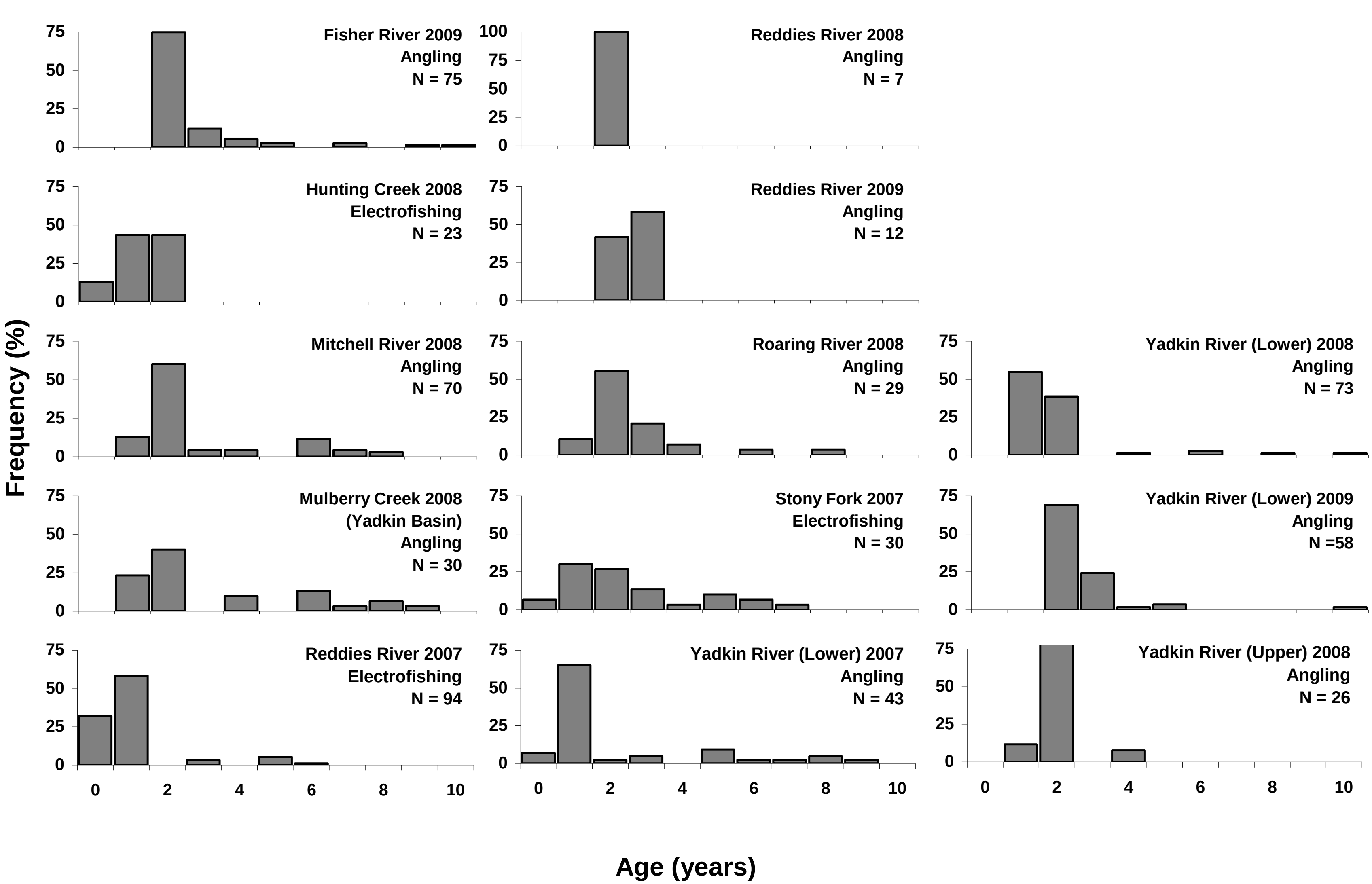

FIGURE 9.—Continued. Age distributions of smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Basin name, stream reach name, collection year, gear type, and sample sizes are included. Sample sizes denoted with an asterisk (*) contained fish older than age 10.

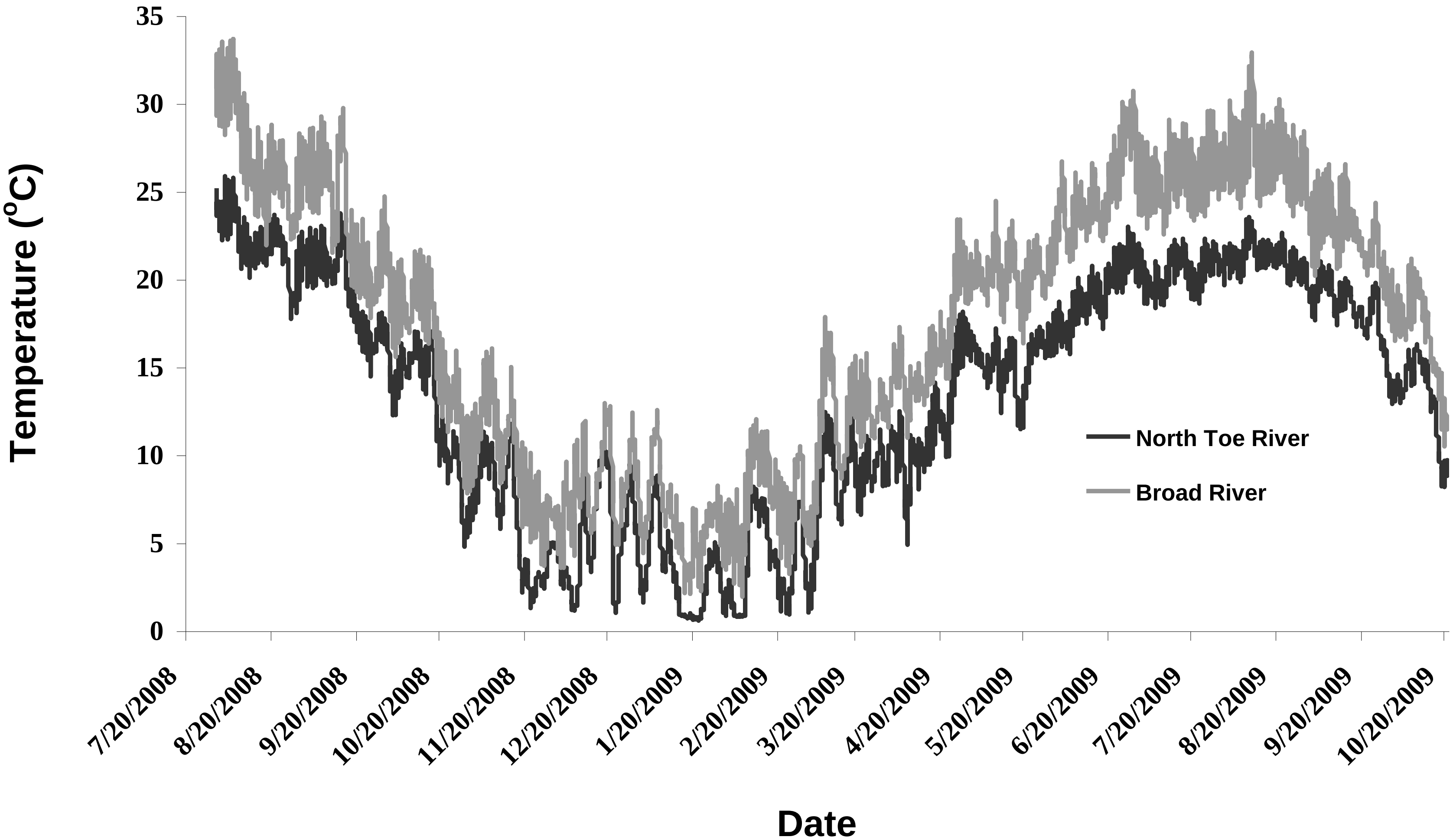

FIGURE 10.—Time series indicating hourly water temperature recordings for North Toe River and Broad River collected July 2008 through October 2009.

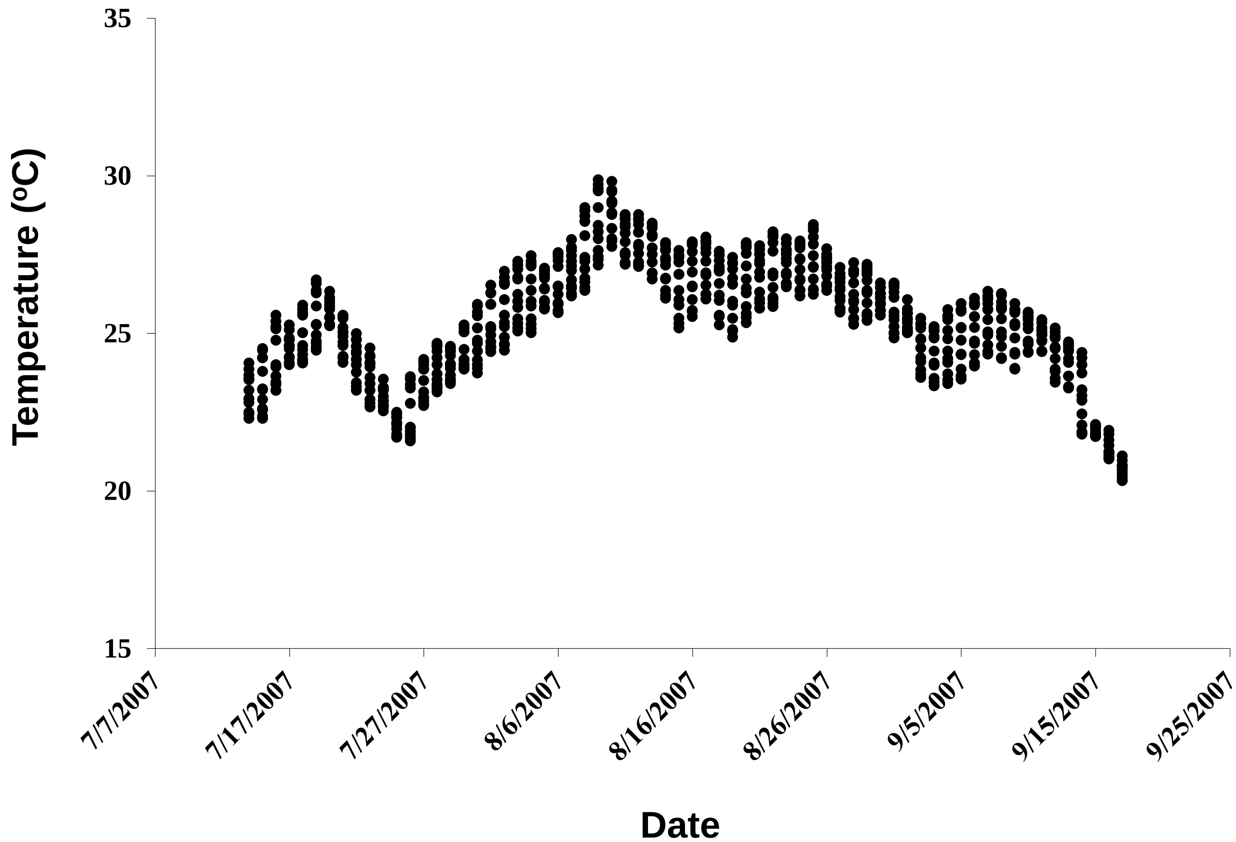

FIGURE 11.—Time series indicating hourly water temperature recordings for Yadkin River collected July 2007 through September 2007.

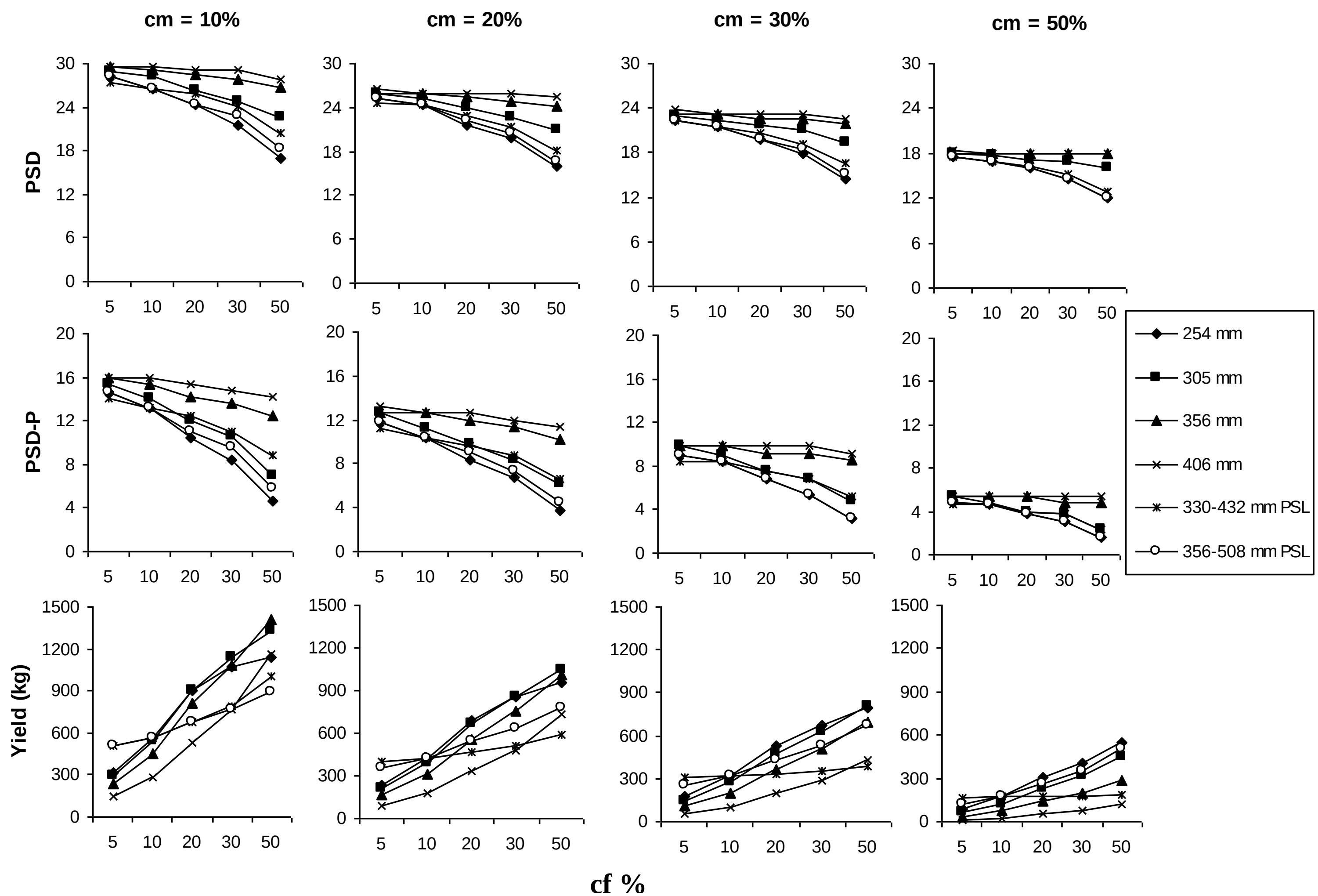

FIGURE 12.—Predicted proportional size distribution (PSD), PSD-preferred (PSD-P), and yield values for lower Broad River smallmouth bass at four levels of conditional natural mortality (*cm*), as a function of four minimum size limits (mm TL) and two protective slot limits (PSL; mm TL) over a range of conditional fishing mortality rates (*cf*).

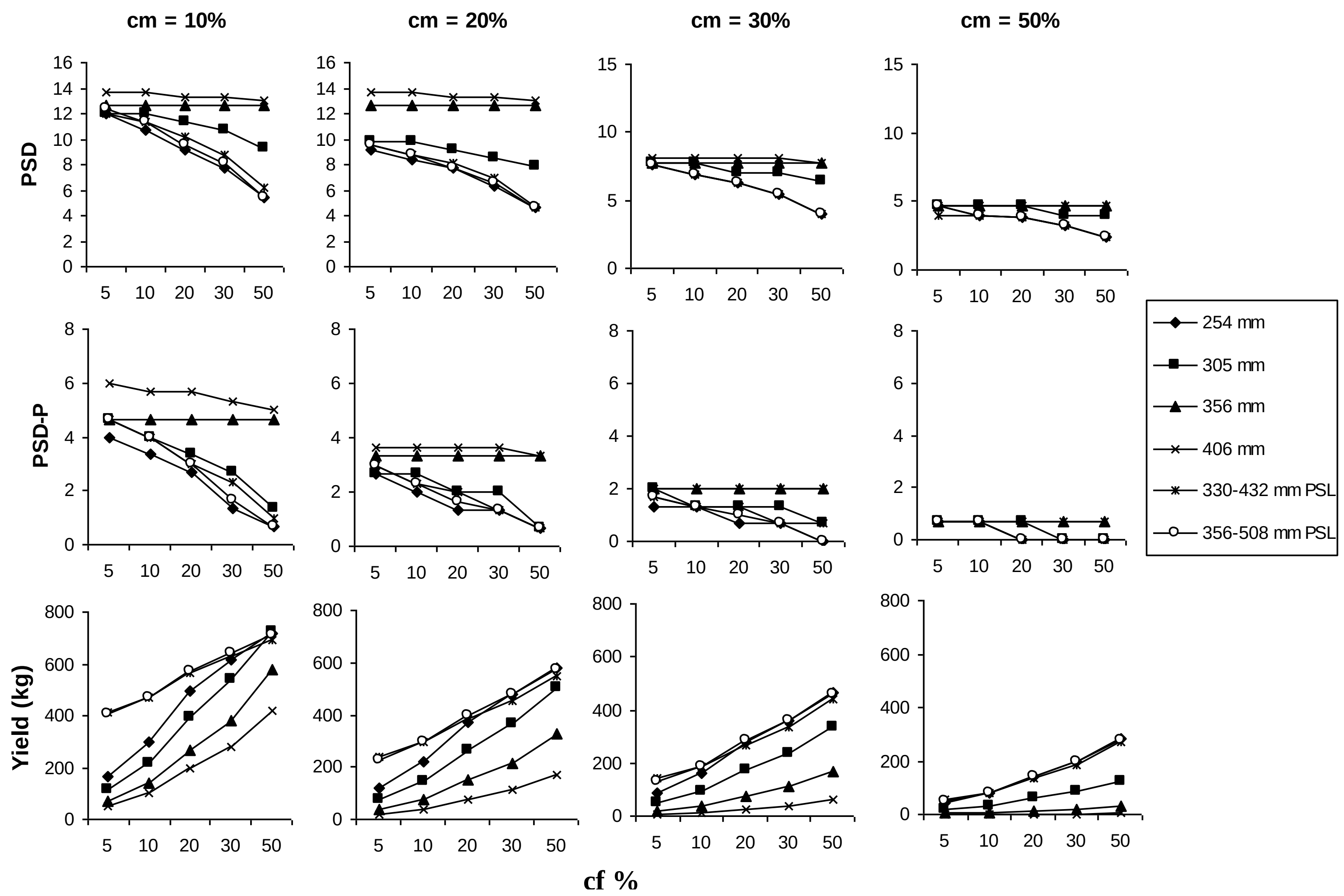

FIGURE 13.—Predicted proportional size distribution (PSD), PSD-preferred (PSD-P), and yield values for upper Broad River smallmouth bass at four levels of conditional natural mortality (*cm*), as a function of four minimum size limits (mm TL) and two protective slot limits (PSL; mm TL) over a range of conditional fishing mortality rates (*cf*).

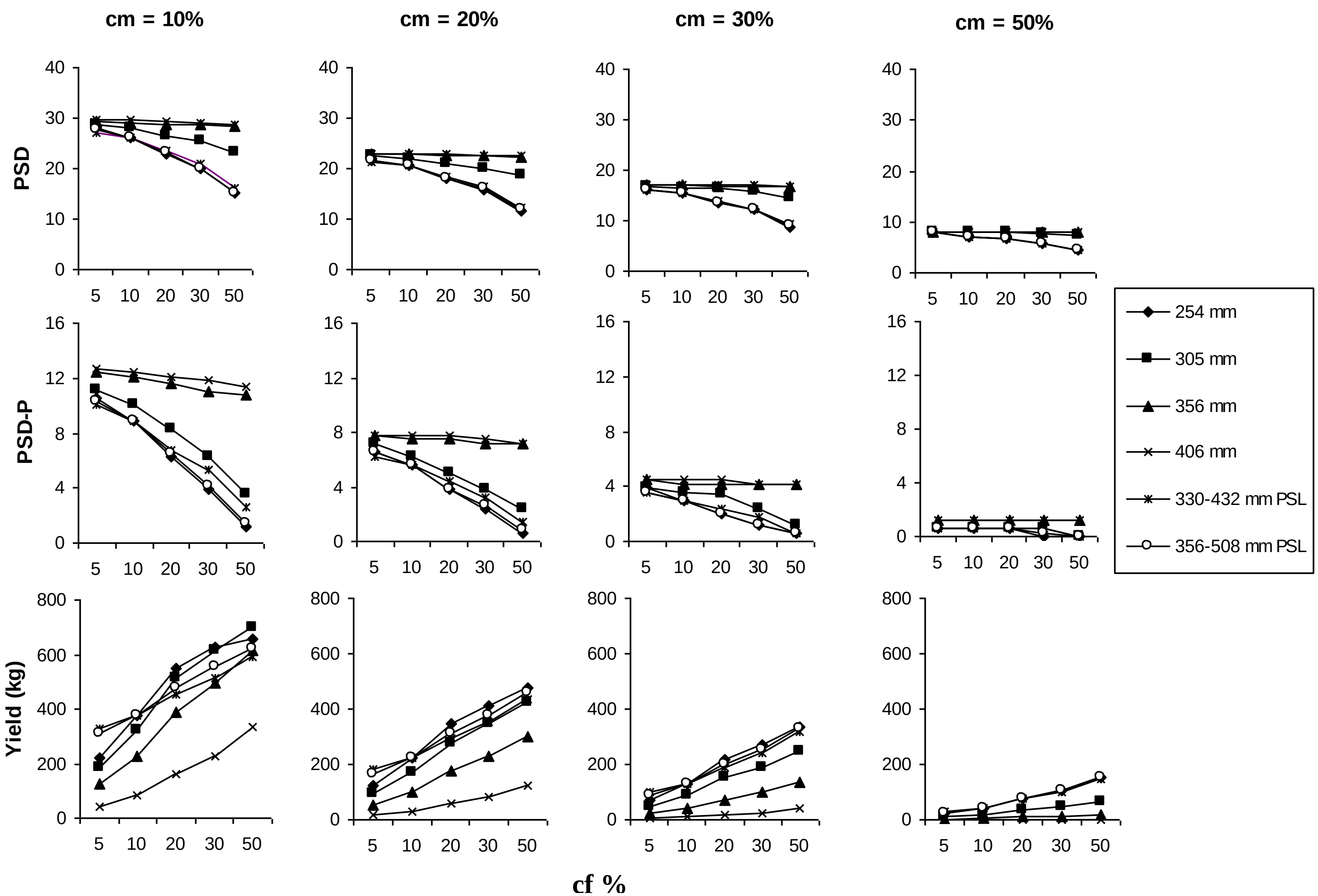

FIGURE 14.—Predicted proportional size distribution (PSD), PSD-preferred (PSD-P), and yield values for lower French Broad River smallmouth bass at four levels of conditional natural mortality (*cm*), as a function of four minimum size limits (mm TL) and two protective slot limits (PSL; mm TL) over a range of conditional fishing mortality rates (*cf*).

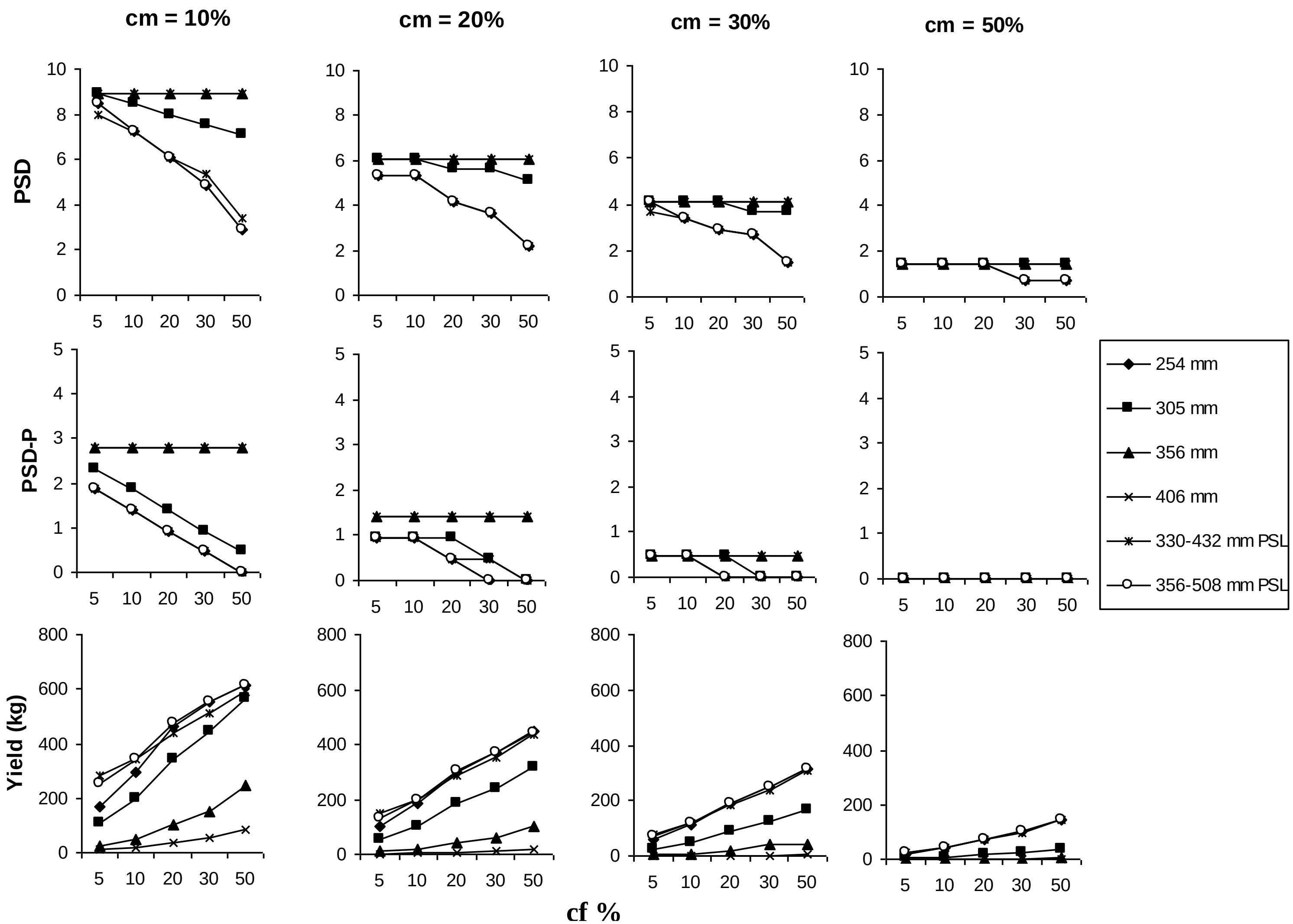

FIGURE 15.—Predicted proportional size distribution (PSD), PSD-preferred (PSD-P), and yield values for upper French Broad River smallmouth bass at four levels of conditional natural mortality (*cm*), as a function of four minimum size limits (mm TL) and two protective slot limits (PSL; mm TL) over a range of conditional fishing mortality rates (*cf*).

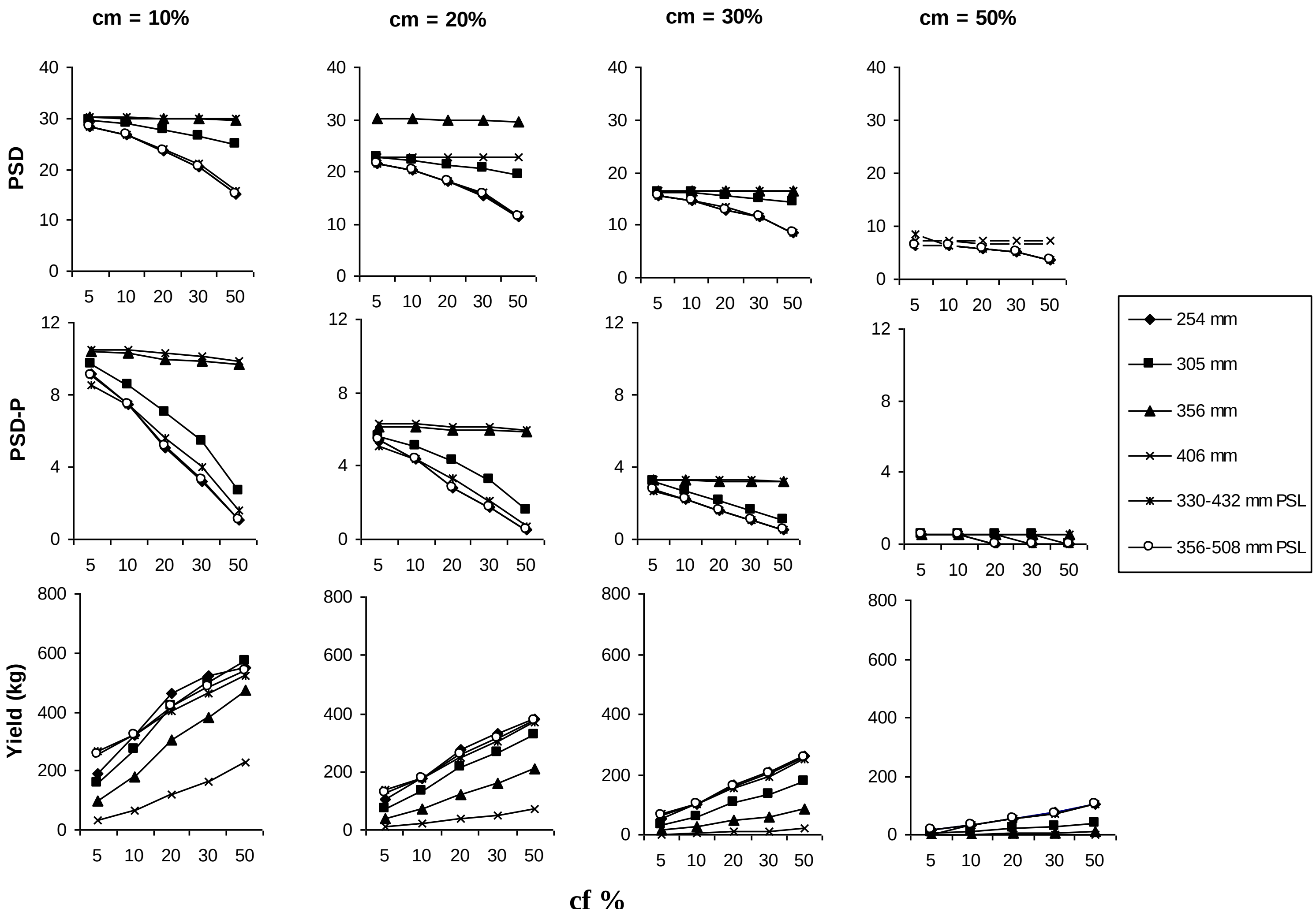

FIGURE 16.—Predicted proportional size distribution (PSD), PSD-preferred (PSD-P), and yield values for North Toe River smallmouth bass at four levels of conditional natural mortality (*cm*), as a function of four minimum size limits (mm TL) and two protective slot limits (PSL; mm TL) over a range of conditional fishing mortality rates (*cf*).

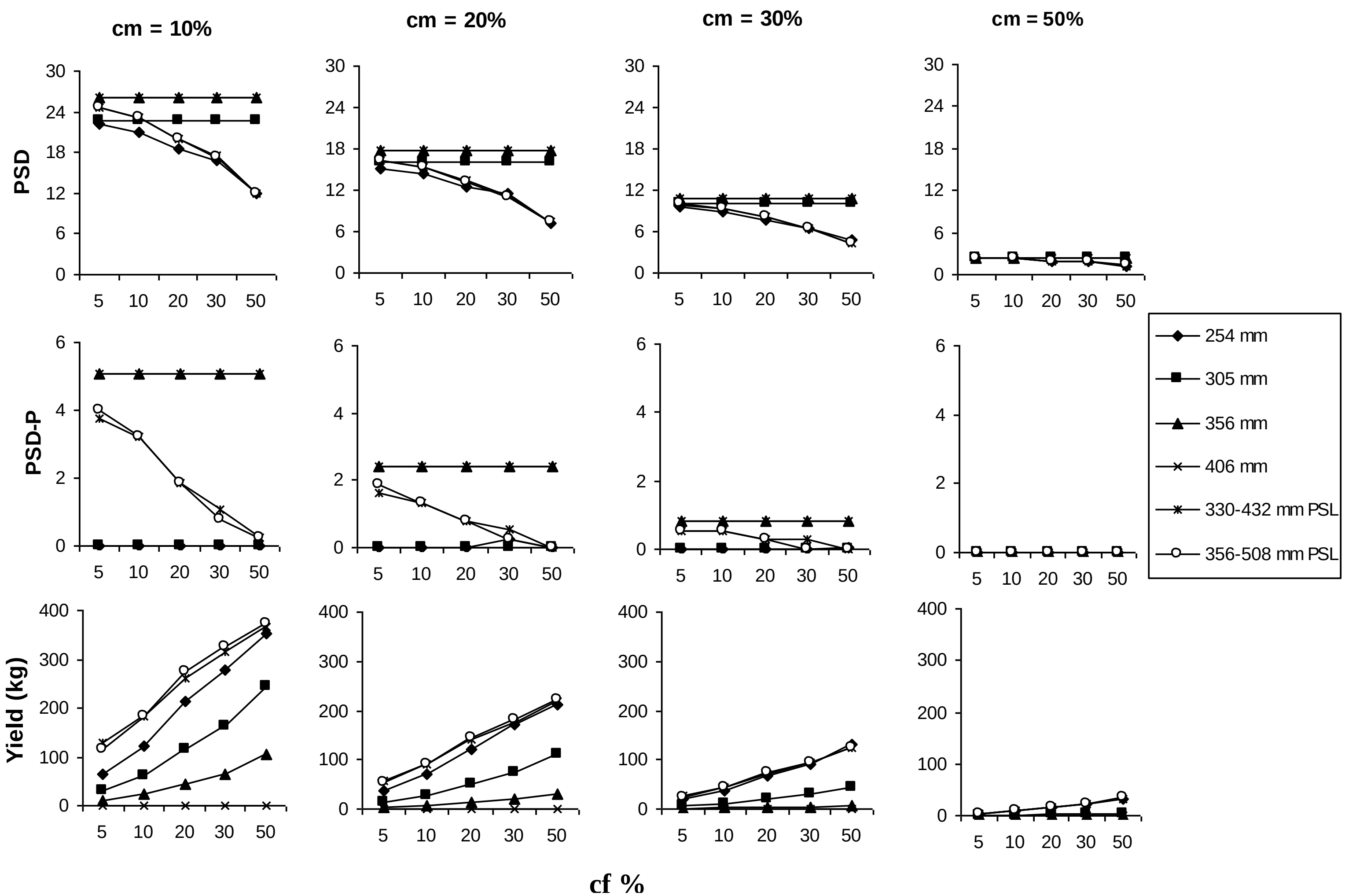

FIGURE 17.—Predicted proportional size distribution (PSD), PSD-preferred (PSD-P), and yield values for Pigeon River smallmouth bass at four levels of conditional natural mortality (*cm*), as a function of four minimum size limits (mm TL) and two protective slot limits (PSL; mm TL) over a range of conditional fishing mortality rates (*cf*).

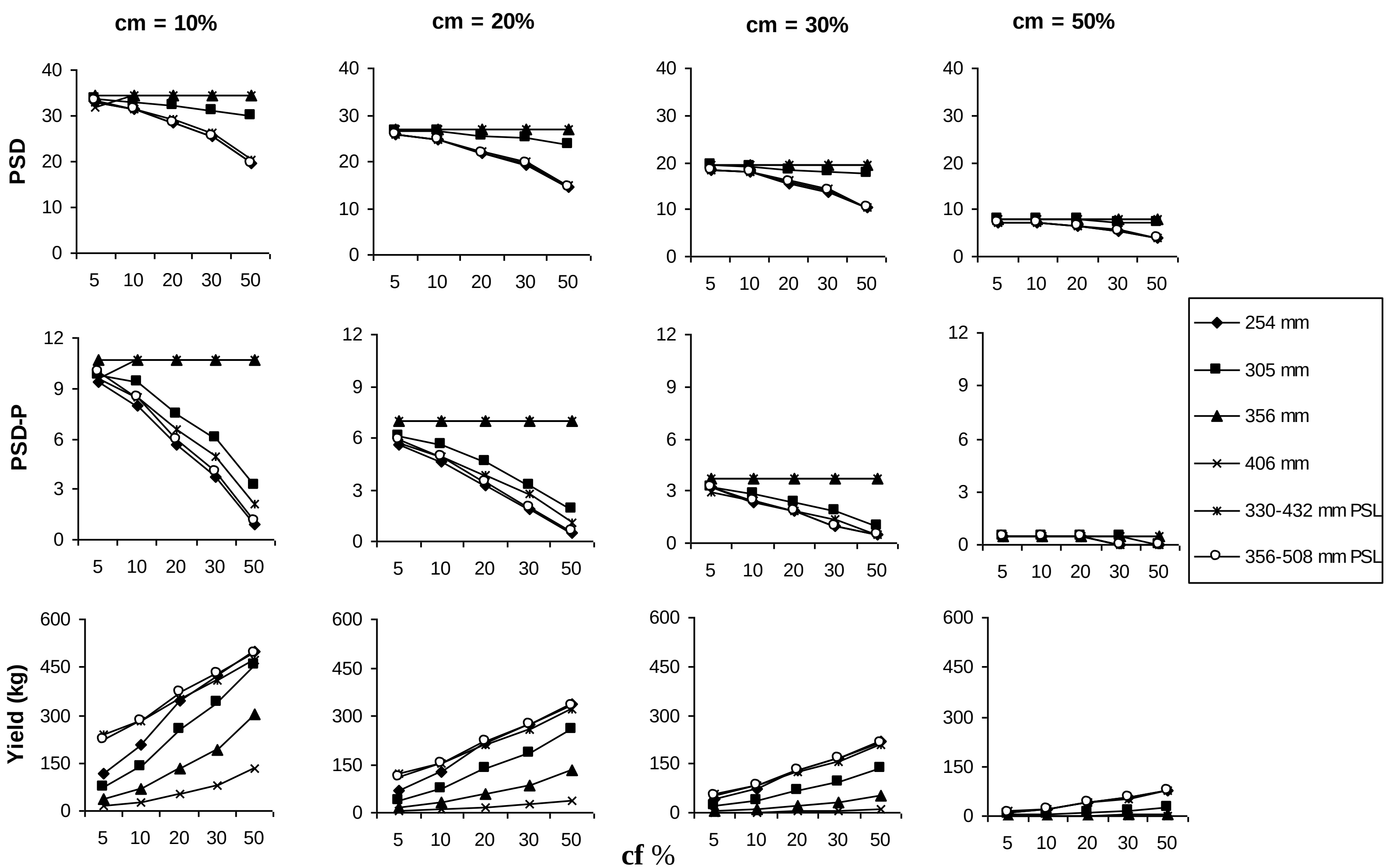

FIGURE 18.—Predicted proportional size distribution (PSD), PSD-preferred (PSD-P), and yield values for Little Tennessee River smallmouth bass at four levels of conditional natural mortality (*cm*), as a function of four minimum size limits (mm TL) and two protective slot limits (PSL; mm TL) over a range of conditional fishing mortality rates (*cf*).

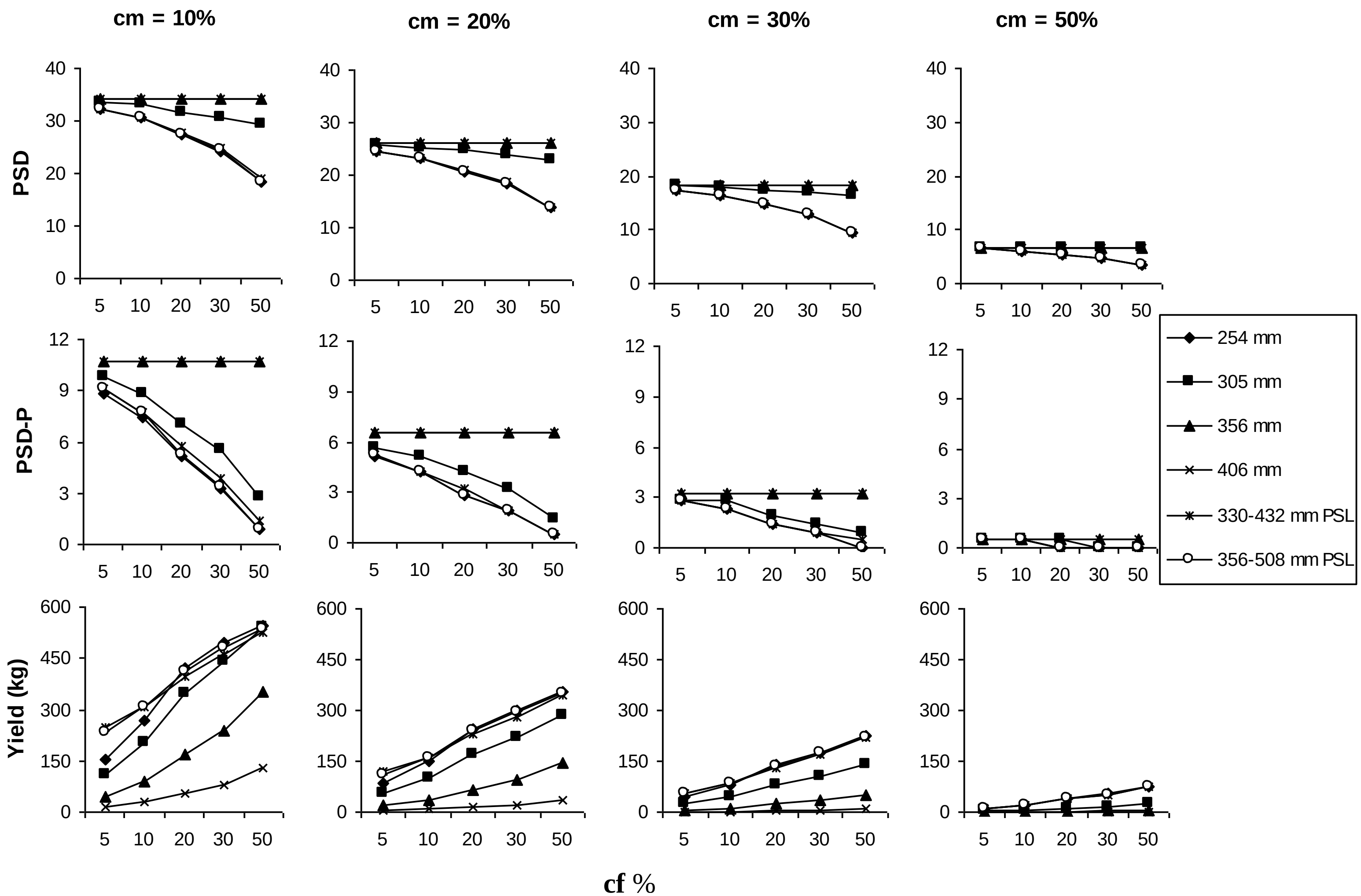

FIGURE 19.—Predicted proportional size distribution (PSD), PSD-preferred (PSD-P), and yield values for Tuckaseegee River smallmouth bass at four levels of conditional natural mortality (*cm*), as a function of four minimum size limits (mm TL) and two protective slot limits (PSL; mm TL) over a range of conditional fishing mortality rates (*cf*).

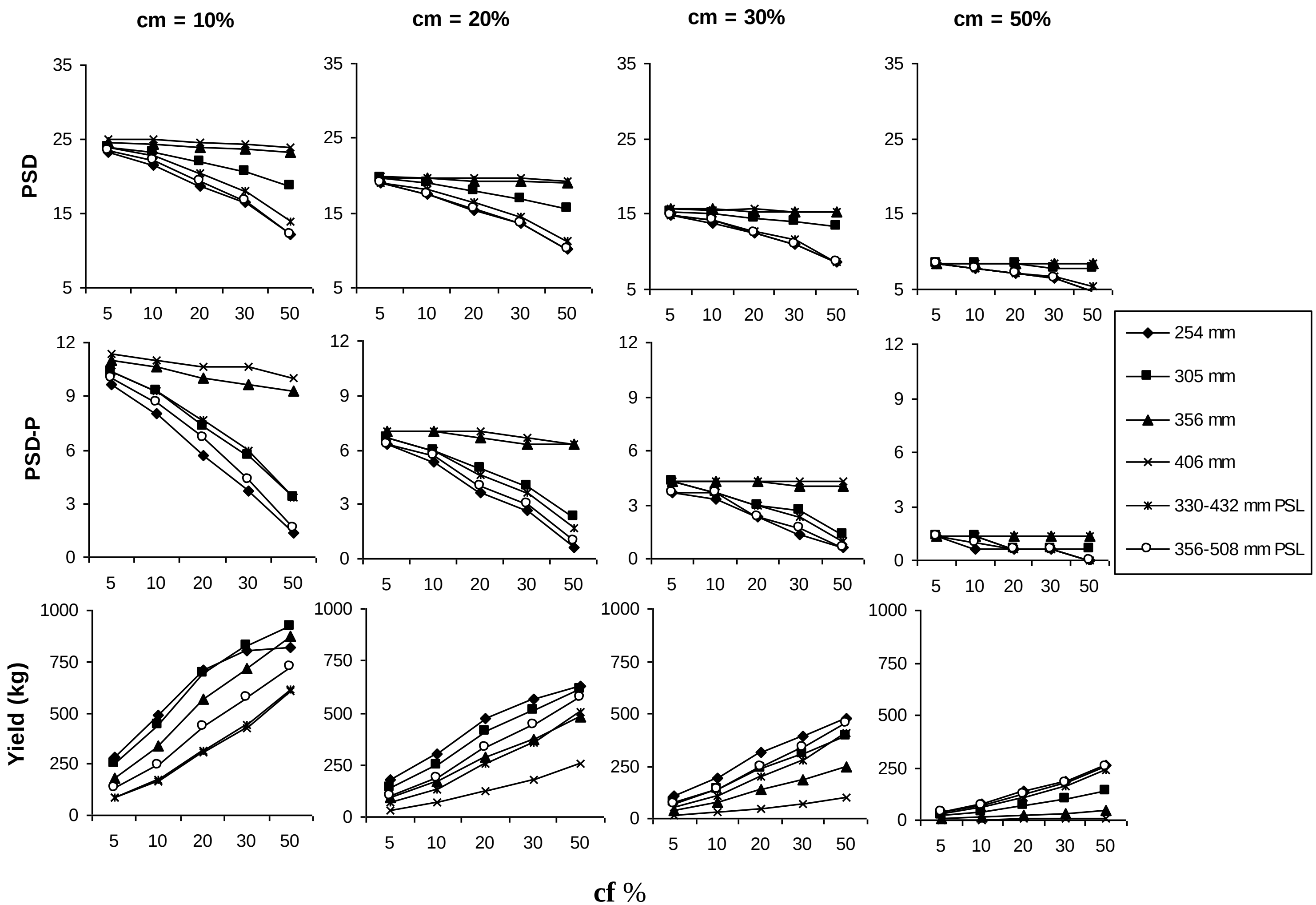

FIGURE 20.—Predicted proportional size distribution (PSD), PSD-preferred (PSD-P), and yield values for upper Dan River smallmouth bass at four levels of conditional natural mortality (*cm*), as a function of four minimum size limits (mm TL) and two protective slot limits (PSL; mm TL) over a range of conditional fishing mortality rates (*cf*).

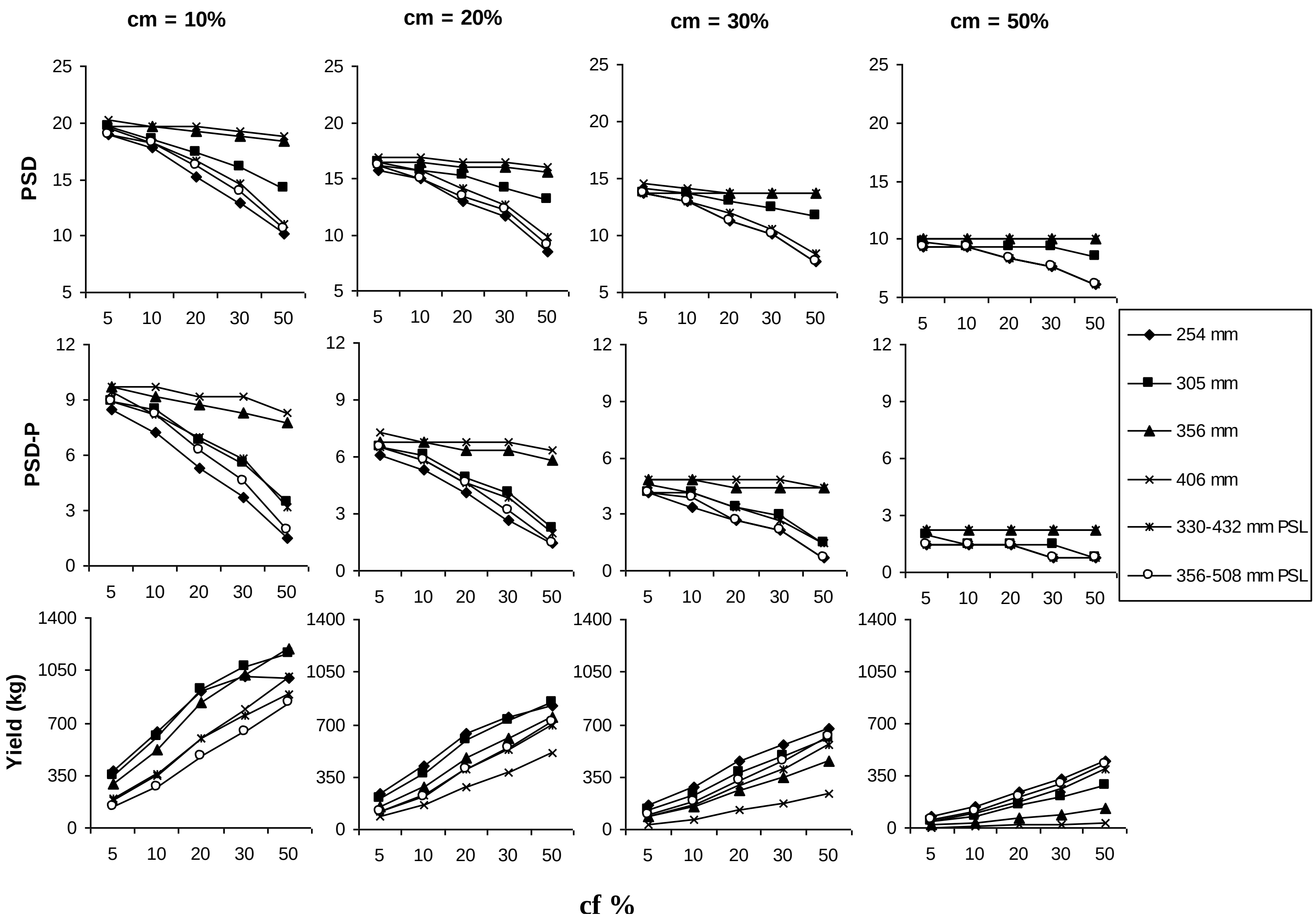

FIGURE 21.—Predicted proportional size distribution (PSD), PSD-preferred (PSD-P), and yield values for lower Yadkin River smallmouth bass at four levels of conditional natural mortality (*cm*), as a function of four minimum size limits (mm TL) and two protective slot limits (PSL; mm TL) over a range of conditional fishing mortality rates (*cf*).

Appendix 1: North Toe River angler diary.

TABLE A1.1.—Angler diary catch statistics for North Toe River smallmouth bass collected during March–October, 2008. Minimum (Min.), Maximum (Max.), and Mean fish total lengths (TL) corresponding with angler participants are shown. Standard errors for mean values are listed in parentheses.

Angler	Effort (hours)	N	Min. TL (mm)	Max. TL (mm)	Mean TL (mm)
1	128	61	178	533	333 (0.3)
2	165	184	152	470	312 (0.2)
3	169	198	127	508	295 (0.2)

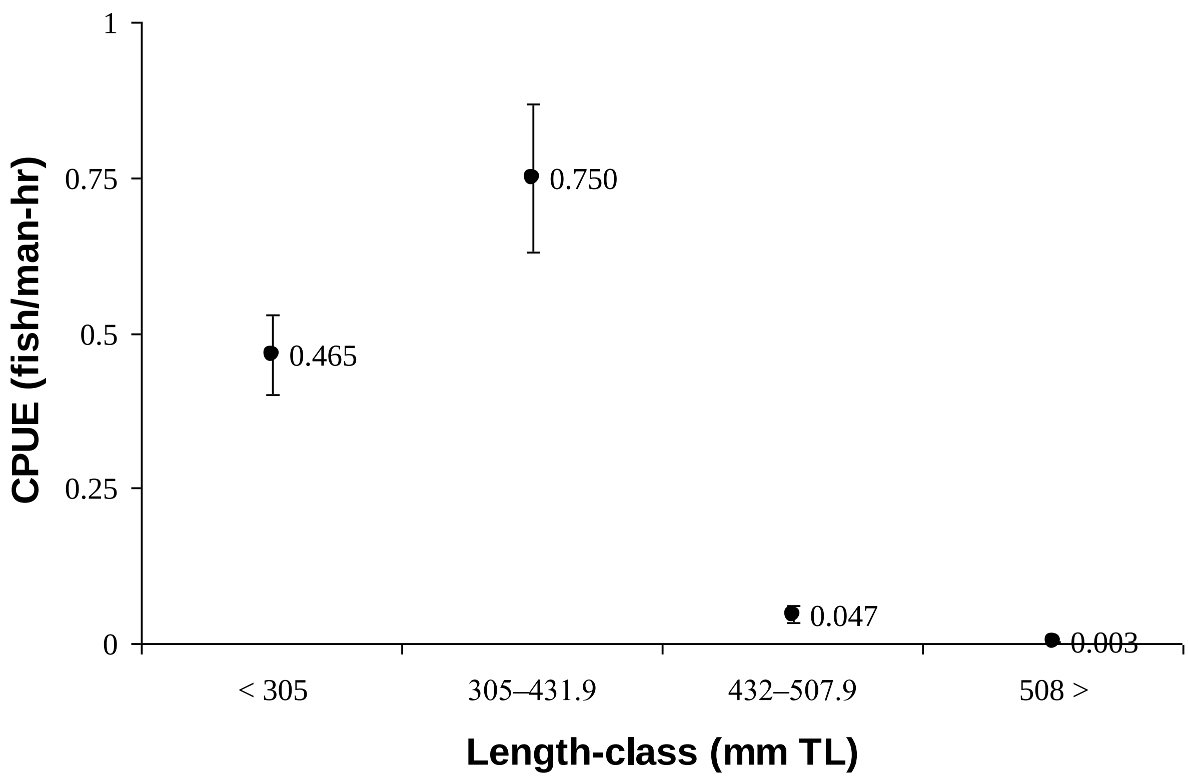

FIGURE A1.1.—Mean angler catch-per-unit effort (CPUE) values for North Toe River smallmouth bass calculated using angler diary information collected March–October, 2008. Standard error bars associated with mean values are shown. Unfixed asymptotic length estimate using the von Bertalanffy growth model for North Toe River smallmouth bass was 438 mm TL.

APPENDIX 1: Continued.

NORTH CAROLINA
WILDLIFE RESOURCES COMMISSION

ANGLER DIARY PARTICIPANT

Name: __________

FIGURE A1.2.—Cover of angler diary booklet used to obtain smallmouth bass data at North Toe River during March–October, 2008.

APPENDIX 1: Continued.

Instructions

1. Fill out a different sheet each time you go fishing. It is important that you fill out a sheet even on days when **no** fish were caught.

2. Fill in your name and date of the fishing trip.

3. Record the body of water where you fished (N. Toe, Nolichucky, etc.) and information about put-in and take-out points (list times and locations for each).

4. Record the number of people fishing.

5. Record the total number of hours (to the nearest ¼ hour) that were fished for either smallmouth bass / muskellunge. SMB = Smallmouth bass and MK = Muskellunge, so please place hours with the appropriate species. For example: if you (or your party) fished for 10.5 hr on the Nolichucky, with 7.5 hr for SMB and 3 for MK; you would enter: Hours Fished _7.5_ / _3_.

6. Please fill in the appropriate data within the table for **all** fish caught (enter length to the nearest ¼ inch). **If no fish were caught, enter 0 in the table for each species that was not caught.**

7. Use the Fish Notes column to note disease, deformities, etc. The Additional Notes section is a place for information of interest to you or the biologist. In addition, use this section to record the number of fish caught on days when the catch is high and it is not feasible to measure each individual fish.

8. If more than one diary keeper are fishing together, each of you fill out a sheet as if you were fishing alone (enter "1" for number fishing and record only the fish that you caught). Do not record the same fish in more than one diary.

FIGURE A1.3.—Instruction page, angler diary used to obtain smallmouth bass data at North Toe River during March–October, 2008.

APPENDIX 1: Continued.

Fishing Trip Summary

Name ________________________ Date ___________________

Body of Water ____

Put-In: When ___________ Where _______________________

Take-Out: When ___________ Where _______________________

Number of People Fishing _________ Hours Fished (SMB / MK) _____ / _____

Species (SMB/MK)	Length	Weight (optional)	Check One Released	Kept	Fish Notes (optional)

Additional Notes: (Weather conditions, water temperature, tackle, etc.)

____

FIGURE A1.4.—Example of trip data entry page, angler diary used to obtain smallmouth bass data at North Toe River during March–October, 2008.

Appendix 2: Mean length at age of smallmouth bass collected May 2007–September 2009.

TABLE A.2.1.—Observed mean total length (TL, mm) at mean age (years) values for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Top values indicate mean TL estimates with associated standard errors (SE) in parentheses, and bottom values indicate mean age estimates calculated using a standardized 1 June birth date. Stream reaches where age-11+ individuals were observed are marked with an asterisk. Mean TL estimates without SE values represent one individual.

	TL (SE) at Age										
River Basin/Stream Reach	**0+**	**1+**	**2+**	**3+**	**4+**	**5+**	**6+**	**7+**	**8+**	**9+**	**10+**
Broad River Basin											
Broad River (Lower)	116 (5.2) 0.55	209 (3.2) 1.22	259 (5.0) 2.21	298 (10.5) 3.19	383 (18.9) 4.36	420 5.17	437 6.25	-	-	-	-
Broad River (Upper)	-	195 (7.3) 1.25	245 (3.0) 2.25	292 (21.5) 3.25	-	-	348 6.25	-	-	-	-
Cove Creek	72 (2.8) 0.08	170 (12.0) 1.08	-	-	-	299 (5.0) 5.08	344 7.08	-	-	-	-
Catawba River Basin											
Catawba River	78 (6.2) 0.08	154 (4.6) 1.10	222 (5.5) 2.12	263 (8.1) 3.13	-	315 (14.1) 5.08	343 (29.5) 6.08	300 7.08	-	442 9.17	-
Henry Fork River	70 (6.9) 0.43	122 (10.3) 1.08	163 (14.5) 2.08	220 (2.5) 3.25	211 4.92	290 5.08	341 6.08	-	319 8.92	-	-
Jacob Fork River	77 (13.3) 0.08	130 (3.8) 1.08	177 (14.5) 2.08	-	-	275 (5.0) 5.08	-	-	-	-	-
Johns River	81 (9.6) 0.15	142 (6.4) 1.08	194 (7.0) 2.08	232 (22.0) 3.04	-	286 (6.8) 5.06	336 6.08	380 7.08	-	-	-
Linville River	73 (13.5) 0.08	127 (8.8) 1.09	177 (9.5) 2.09	226 (4.1) 3.08	293 (13.0) 4.08	270 (20.5) 5.08	287 6.08	312 7.08	-	358 (5.5) 9.08	-
Mulberry Creek	130 0.08	129 (5.8) 1.08	223 2.08	232 3.08	-	271 (8.2) 5.08	-	351 7.08	-	-	-
North Fork Catawba River	120 0.08	141 (4.3) 1.08	188 (6.5) 2.01	260 (7.3) 3.05	286 (11.9) 4.0	315 (0.5) 5.08	327 (7.0) 6.03	342 (10.9) 7.0	344 8.0		
Upper Creek/Warrior Fork	83 (2.9) 0.08	116 (6.2) 1.08	-	237 (11.6) 3.08	230 4.08	317 (11.4) 5.08	-	-	-	-	-
Wilson Creek	72 (14.9) 0.08	144 (8.1) 1.08	189 (15.3) 2.08	243 (4.5) 3.08	-	305 (27.5) 5.08	299 (6.8) 6.08	-	345 (64.5) 8.08	-	-

Appendix 2: Continued.

TABLE A.2.1.—Continued. Observed mean total length (TL, mm) at mean age (years) values for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Top values indicate mean TL estimates with associated standard errors (SE) in parentheses, and bottom values indicate mean age estimates calculated using a standardized 1 June birth date. Stream reaches where age-11+ individuals were observed are marked with an asterisk. Mean TL estimates without SE values represent one individual.

	TL (SE) at Age										
River Basin/Stream Reach	**0+**	**1+**	**2+**	**3+**	**4+**	**5+**	**6+**	**7+**	**8+**	**9+**	**10+**
French Broad River Basin											
Cane River	82 (30.0) 0.17	143 (4.3) 1.17	211 (3.8) 2.25	240 (6.6) 3.21	289 (11.8) 4.24	264 (6.6) 5.17	332 (8.3) 6.24	331 (14.2) 7.18	347 (14.4) 8.22	430 (25.0) 9.21	387 (8.7) 10.2
French Broad River (Lower)*	108 (4.9) 0.26	151 (5.2) 1.40	216 (3.0) 2.22	273 (5.2) 3.19	302 (6.5) 4.59	330 (20.7) 5.46	336 (22.5) 6.59	-	-	-	-
French Broad River (Upper)	163 (22.5) 0.08	161 (3.2) 1.13	199 (7.8) 2.09	274 (4.8) 3.12	313 4.17	298 (3.9) 5.23	320 (9.5) 6.11	330 7.08	339 (21.0) 8.13	317 9.17	-
North Toe River*	85 (2.8) 0.17	179 (8.5) 1.17	211 (2.7) 2.17	247 (2.9) 3.17	272 (6.6) 4.17	314 (5.0) 5.17	308 (7.6) 6.17	328 (8.8) 7.17	349 (12.9) 8.17	359 (13.6) 9.17	375 (12.4) 10.17
Pigeon River	82 (2.6) 0.17	153 (1.8) 1.11	181 (6.8) 2.14	265 (5.5) 3.08	255 (6.5) 4.15	283 (5.0) 5.13	310 (21.9) 6.13	238 7.17	252 8.17	-	-
Pigeon River (By-Pass)	64 (6.5) 0.17	134 (4.0) 1.16	188 (3.5) 2.14	235 (7.3) 3.13	264 (4.5) 4.17	288 (6.7) 5.17	324 6.17	-	-	-	-
South Toe River*	-	188 (1.0) 1.17	208 (6.5) 2.17	-	254 (14.1) 4.17	243 5.17	270 (22.0) 6.17	299 (30.9) 7.17	-	-	-
Hiwassee River Basin											
Hiwassee River	-	-	201 (8.0) 2.17	240 3.17	-	263 (20.6) 5.17	-	-	-	310 9.17	-
Little Tennessee River Basin											
Little Tennessee River	-	148 (4.5) 1.16	202 (4.6) 2.12	181 (34.4) 3.17	281 (31.0) 4.13	297 5.17	269 (10.5) 6.13	335 7.08	370 8.08	-	-
Tuckaseegee River	84 (6.4) 0.31	142 (7.6) 1.29	208 (7.1) 2.31	221 (12.5) 3.31	317 (15.6) 4.28	-	301 (23.0) 6.25	327 (24.5) 7.17	318 8.33	-	350 10.33
Roanoke River Basin											
Dan River (Lower)	-	203 (8.6) 1.25	280 (7.6) 2.25	349 3.25	-	-	-	-	-	-	-
Dan River (Upper)	100 (6.6) 0.25	202 (2.1) 1.40	223 (2.5) 2.16	256 (5.9) 3.12	362 4.17	343 (6.6) 5.38	360 (6.8) 6.21	395 (6.9) 7.36	382 8.25	381 9.92	-

Appendix 2: Continued.

TABLE A.2.1.—Continued. Observed mean total length (TL, mm) at mean age (years) values for smallmouth bass collected during NCWRC surveys, May 2007–September 2009. Top values indicate mean TL estimates with associated standard errors (SE) in parentheses, and bottom values indicate mean age estimates calculated using a standardized 1 June birth date. Stream reaches where age-11+ individuals were observed are marked with an asterisk. Mean TL estimates without SE values represent one individual.

	TL (SE) at Age										
River Basin/Stream Reach	**0+**	**1+**	**2+**	**3+**	**4+**	**5+**	**6+**	**7+**	**8+**	**9+**	**10+**
Watauga River Basin											
Watauga River*	-	-	158 (3.8) 2.25	199 (4.6) 3.16	249 (7.5) 4.21	269 5.25	-	-	-	368 9.08	-
Yadkin River Basin											
Elk Creek	-	-	171 (6.5) 2.08	249 (7.6) 3.08	275 4.08	336 (7.0) 5.08	-	362 7.08	347 8.08	-	-
Fisher River	-	-	221 (2.9) 2.19	266 (11.0) 3.20	331 (6.0) 4.19	363 (10.0) 5.17	-	400 (42.0) 7.21	-	374 9.17	423 10.17
Hunting Creek	88 (10.3) 0.17	194 (6.2) 1.17	248 (5.0) 2.17	-	-	-	-	-	-	-	-
Yadkin River Basin											
Mitchell River	-	165 (7.6) 1.19	226 (2.9) 2.10	265 (10.4) 3.0	342 (3.7) 4.0	-	318 (5.6) 6.0	344 (15.2) 7.0	323 (18.0) 8.0	-	-
Mulberry Creek	-	132 (6.5) 1.0	209 (4.2) 2.0	-	296 (15.2) 4.0	-	315 (21.8) 6.0	364 7.0	385 (9.5) 8.0	410 9.0	-
Reddies River	74 (2.4) 0.19	153 (3.0) 1.19	199 (6.5) 2.05	248 (7.1) 3.07	-	287 (128) 5.23	324 6.25	-	-	-	-
Roaring River	-	142 (22.2) 1.08	204 (9.3) 2.08	252 (4.6) 3.08	277 (6.5) 4.08	-	339 6.08	-	380 8.08	-	-
Stony Fork	79 (21.5) 0.08	129 (5.7) 1.08	182 (9.6) 2.08	216 (14.2) 3.08	243 4.08	264 (2.3) 5.08	316 (41.0) 6.08	316 7.08	-	-	-
Yadkin River (Lower)	136 (9.0) 0.22	198 (3.1) 1.97	229 (3.5) 2.20	303 (6.6) 3.21	382 (9.5) 4.21	376 (17.7) 5.24	390 (9.4) 6.17	381 7.25	456 (19.9) 8.19	462 9.17	419 (20.5) 10.29
Yadkin River (Upper)	-	156 (12.6) 1.08	229 (4.6) 2.08	-	289 (14.0) 4.08	-	-	-	-	-	-