Interannual Variability in Spatial and Temporal Spawning Distributions of White Bass in the Arkansas River

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Abstract: There is a limited understanding of the spatial and temporal variability of tributary use for riverine populations of white bass (*Morone chrysops*) during the spawning season. We sampled white bass in 10 tributaries of Arkansas River Pool 4 during their spawning season in 2010 and 2011. Each tributary was sampled using boat-mounted electrofishing every third week during the spawning season to assess spatial variability of white bass spawning. One tributary (Caney Bayou) known to be occupied by white bass during the spawning season was sampled weekly to document temporal variability of the spawn. Average (SE) CPUE was 5.5 (0.9) fish h^{-1} across Pool 4, with CPUE in Caney Bayou averaging 7.5 (1.4) fish h^{-1}. Although Caney Bayou was used during the spawning season both years, at least four other tributaries were also used both years. Spawning was unimodal in 2010, but bimodal in 2011. Water temperature appeared to influence white bass tributary use. When water temperatures reached 13° C, white bass CPUE in and near tributaries increased. Stream current velocities was significantly related to white bass CPUE only when the highest velocities were removed from the dataset because of the possible influence of current velocity on electrofishing catch rates. Understanding the relative importance of different spawning locations, the interannual variability in tributary use, and the factors influencing spawning in tributaries will help managers ensure fishery sustainability.

Key words: Morone, reproduction, lotic, recruitment

Journal of the Southeastern Association of Fish and Wildlife Agencies 7: 49–57

White bass (*Morone chrysops*) inhabit lakes, reservoirs, deep pools in streams, and moderate to large rivers throughout the United States (Robison and Buchanan 1988). This vast range is possible because white bass demonstrate a high adaptability to diverse habitats. Historically, white bass were only abundant along the Mississippi River and its primary tributaries, but introduction of white bass into other drainages through time has expanded its distribution significantly from the southern Great Lakes along the western Appalachians and Atlantic slope rivers towards northwest Florida and west to the Rio Grande and South Dakota (Etnier and Starnes 1993).

Understanding the elements of habitat that affect recruitment is essential to the management of any fish population (Maceina 1997, McMullin and Pert 2010). For example, some coastal striped bass (*Morone saxatilis*) populations are anadromous and return from the ocean to natal freshwater tributaries to spawn (McLaren et al. 1981, Ng et al. 2007). Reservoir striped bass populations have exhibited similar site fidelity behavior during spawning (Jackson and Hightower 2001). Likewise, many reservoir white bass populations occupy tributaries during the spring for reproduction (Guy et al. 2002) but the extent of site fidelity is unknown.

Previous studies have indicated that white bass recruitment is highly variable (Pope et al. 1997, Schultz et al. 2002), demonstrating cyclic patterns of abundance and reproductive success similar to crappies (*Pomoxis* spp.; Houser and Bryant 1970, Priegel 1970, Kawatski and Schmulbach 1971, Nordhaus et al. 1998). This variability produces highly unpredictable fishing seasons and is problematic for managing white bass populations (Lovell and Maceina 2002). White bass recruitment variability has been linked to food availability of larval fish (Bauer 2002, Guy et al. 2002, Shultz et al. 2002) and flow patterns, with higher spring flows often resulting in stronger year classes (Sammons and Bettoli 2000, DiCenzo and Duval 2002, Shultz et al. 2002).

White bass is a relatively popular sport fish throughout its range (Betsill and Pitman 2002, Schultz et al. 2002, Willis et al. 2002). However, white bass fisheries do not resemble trophy-type fisheries such as striped bass fisheries or, in many cases, largemouth bass (*Micropterus salmoides*) fisheries (Muoneke 1994). Management of white bass varies from liberal with no regulations (MDWFP 2018) to conservative with both creel and length limits (TPWD 2018). In Arkansas, white bass are managed statewide with a 25 fish per day creel limit (AGFC 2019). White bass are especially targeted by anglers during their spring spawning runs because their catchability and harvest potential are both high. Many Arkansas anglers view the white bass spawning run as opening day of spring fishing (Zellers 2019).

Management of white bass without knowledge of the species' flexibility in choosing among possible spawning habitats fails to account for the risk inherent in heavy fishing pressure on a sole spawning location. Hence, managers of white bass fisheries could better manage their fisheries if they knew the temporal and spatial distributions of spawning and how those distributions vary between years, especially given the high harvest rates experienced by this species during the spawning season. Thus, the objectives of this study were to: 1) quantify the spatial and temporal variability in tributary use by a population of white bass, 2) determine temporal variability in age and sex composition of fish using a tributary, and 3) examine the relationship between tributary use and two environmental variables, water temperature and current velocity, during two spawning seasons in an Arkansas River reservoir system.

Methods

Study Area

This research focused on Pool 4 of the lower Arkansas River, located in the proximity of Pine Bluff, Arkansas (Figure 1). Pool 4 encompasses 32 km of river channel between dams 4 and 5 and has a surface area of approximately 2300 ha. The reservoir is part of a network of run-of-the-river impoundments within the McClellan-Kerr Arkansas River Navigation System (MKARNS). The MKARNS begins in Oklahoma and crosses Arkansas until it joins the Mississippi River near Arkansas City, Arkansas. Main channel habitat averages 66% (range 52%–82%) of the total aquatic habitat in these navigation pools (Schramm et al. 2008) and the navigation channel is maintained at a minimum of 2.7 m. Pool 4 has 12 notable tributaries and backwaters connected to the main river channel. The tributaries are all relatively shallow with mean depths 2 m or less. Caney Bayou is one of the largest tributaries in Pool 4 and it flows into Lake Langhofer (Figure 1). Anecdotally, the Lake Langhofer region of the pool contains the majority of the angling effort (Fontaine 2009). Primary substrates consist of a heterogeneous mixture of silt and clay, sand, and gravel. Additionally, submersed macrophytes and woody debris are present in littoral zones along tributaries and backwaters (Schramm et al. 2008).

Fish Collections

We sampled white bass during their spawning season in every major tributary of this run-of-the-river impoundment on the lower Arkansas River for two years to determine spatial and interannual variability of tributary use. We also intensively sampled one tributary (Caney Bayou), known to be consistently used by white bass during the spawning season, to determine the temporal variability of use of that tributary. By intensively sampling Caney Bayou, we were also able to determine the relationship between tributary use and both water temperature and stream current velocity during the spawning season. We considered CPUE in tributaries to be a relative indication of spawning activity since white bass populations use tributaries for spawning (Robison and Buchanan 1988) but are seldom found there at other times (Lincoln et al. 2016).

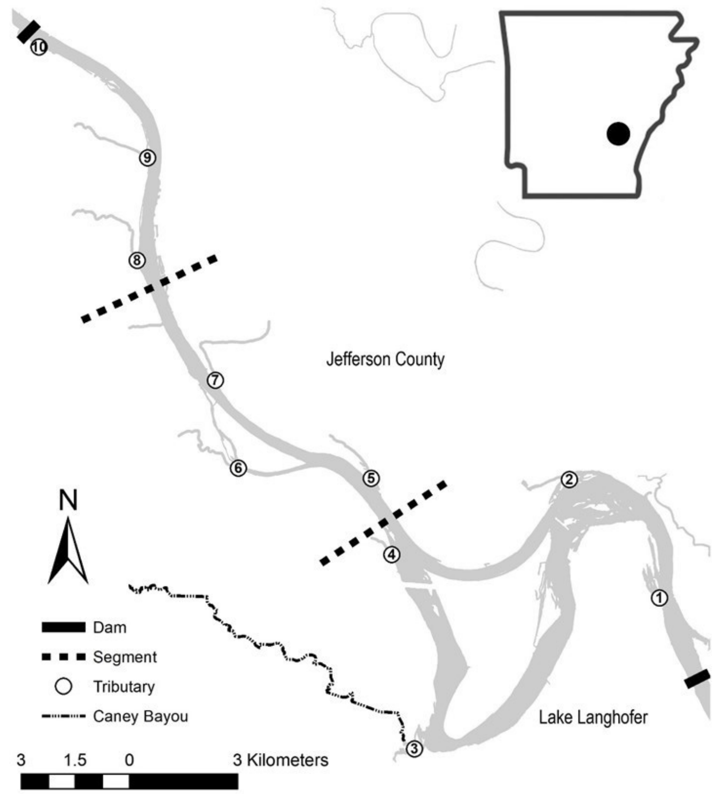

Figure 1. Pool 4 Arkansas River separated into three segments (upper, middle, and lower pool) and the 10 tributaries where white bass were collected. Solid bars represent dams while the segmented bars separate the three segments. Tributaries are numbered 1–10. Location of Pool 4 on the Arkansas River within the state of Arkansas.

White bass were collected with pulsed DC during the spawning season in 2010 and 2011 defined as beginning the last week of February 2010 and the last week of February 2011 and continuing until no eggs could be found in females collected from two consecutive sampling trips. Sampling was conducted using a boom-mounted boat electrofishing unit (model 7.5 GPP, Smith-Root Inc., Vancouver, Washington) and a 5000-W generator. Electrofishing settings were standardized depending on water temperature and conductivity to achieve a power output of approximately 3000 W, which equated to approximately 7–10 A of pulsed-DC current (Burkhardt and Gutreuter 1995).

Sampling locations were placed in 10 tributaries throughout

Pool 4 that were identified using aerial photographs in conjunction with field observations (Figure 1). All of these tributaries were considered potential spawning locations for white bass based on known biology and life-history characteristics of the species (Colvin 1993). The pool was divided into upper, middle, and lower river segments (i.e., upper, middle, lower) that were each approximately 12 km in length and contained either three or four tributaries (Figure 1). Tributaries in each river segment were sampled once every three weeks, with tributaries from the lower segment sampled the first week of the rotation and the tributaries in the middle and upper segments sampled during the second and third weeks, respectively. This rotation continued for the duration of the white bass spawning season.

Field collections entailed sampling three 600-sec electrofishing transects per tributary. Two transects began at the tributary mouth and proceeded either upstream or downstream along the Arkansas River shoreline. The other transect began at the tributary mouth and proceeded upstream into the tributary. All sampling was conducted during daylight hours starting at approximately sunrise. All white bass from each transect were bagged separately, labeled, and placed on ice until the samples could be stored in a laboratory freezer. Information recorded in the field included global positioning system (GPS) coordinates for each tributary, as well as transect, date, and time that the tributary was sampled. Water temperature (°C) and stream current velocity (m sec^{-1}) were recorded on both sides of the tributary mouth from the stern of the boat with the bow on shore each time the tributary was sampled. The two measurements were averaged to obtain a mean water temperature and mean stream current velocity for each sampling date. Water temperature was measured using a YSI Model 85 meter (YSI Inc., Yellow Springs, Ohio), and stream current velocity was measured with a Marsh-McBirney FLO-MATE 2000 flow meter (Marsh–McBirney Inc., Frederick, Maryland). This sampling scheme allowed for spatial coverage of all possible white bass spawning tributaries during both years of the study.

In the laboratory, sagittal otoliths were removed and placed in an envelope marked with date, tributary, and fish identification code. Whole-view and cross-sectioned otoliths were examined under a dissecting microscope and double-blind read by two independent readers (Lovell and Maceina 2002). If the readers disagreed on the annulus count, a third reader examined the otolith, or the second sagittal otolith was cross-sectioned and re-examined. Gender of fish was determined, when possible, from gonad inspection. Gender ratios (M:F) were calculated for the whole study and by year. The proportion of females by week of the year (WOY) were determined for Caney Bayou during both years.

Spatial Variability

Spatial variability of spawning was examined by determining the magnitude of use for each tributary during each year of the study. Magnitude of use was estimated as the mean CPUE (fish h^{-1}) for a tributary for the entire spawning season. We examined the effects of year, tributary, and their interaction on mean CPUE using a mixed model repeated measures ANOVA (SAS 2004) with transect as the subject. If the interaction term was not significant, a reduced model was run without the interaction term to test only the main effects. The CPUE data were rank transformed to meet assumptions of normality. An alpha level of 0.05 was used for all statistical tests as the threshold for determining statistical significance.

Temporal Variability

One tributary in the lower section of the impoundment (Caney Bayou) was sampled weekly during both years of the study to examine the temporal distribution of white bass spawning. Nine to 12 600-sec electrofishing transects were conducted each week using the same gear as described above. Four transects were sampled along the Arkansas River shoreline near Caney Bayou, two each upstream and downstream of the tributary mouth. The other transects continued sequentially upstream into the tributary. These data were evaluated independently from other electrofishing data described previously to examine the temporal distribution of spawning. Sampling dates were categorized by WOY, which allowed for comparison of temporal spawning distributions between years. The CPUE data were also rank transformed to meet assumptions of normality. The effects of year, WOY, and their interaction on CPUE were examined using a mixed model repeated measures ANOVA (SAS 2004) with transect as the subject. Again, if the interaction term was not significant, a reduced model was run without the interaction term to test the main effects.

Temporal Variability in Age and Sexual Composition

Temporal variability in age and gender composition of fish in Caney Bayou were examined. Weekly frequency of ages was plotted for each WOY to examine temporal variation in age. Weekly proportions of female fish were plotted for each WOY to examine temporal variation of the sexes. The absence of fish some weeks precluded the ability to calculate mean age or proportion of females during such weeks. Hence, the previous approach of examining the main effects (year and WOY) and interaction term using a mixed model repeated measures ANOVA was not possible. Instead, mixed model repeated measures ANOVAs examining only main effects (year and WOY) on average age and proportion of females, with transect as the subject, were conducted. The pro-

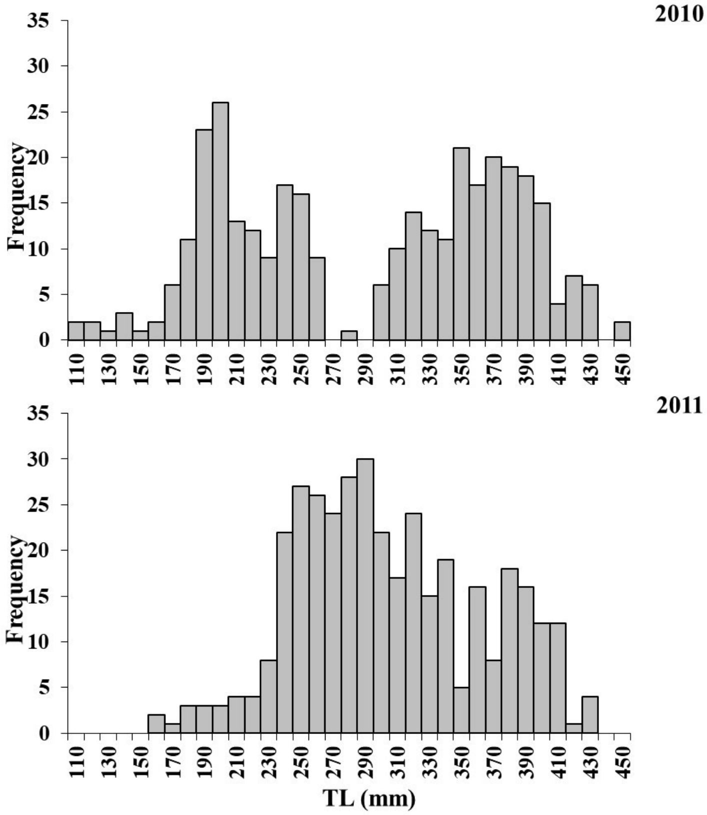

Figure 2. Length-frequency histogram for white bass sampled in Pool 4 of the Arkansas River during 2010 and 2011.

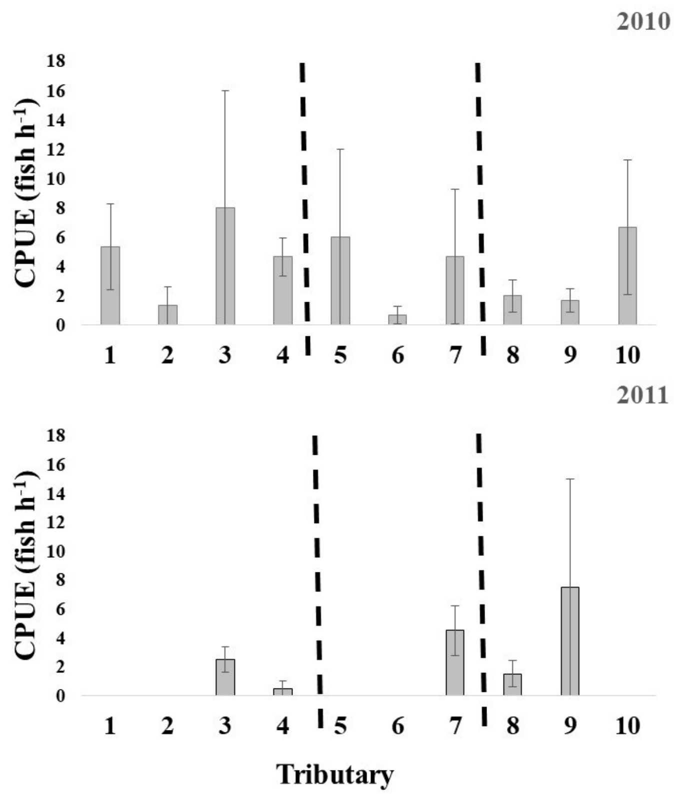

Figure 3. White bass mean CPUE during the 2010 and 2011 spawning season from 10 tributaries in Pool 4 of the Arkansas River. Error bars represent ±1 SE. Segmented bars separate tributaries in Pool 4 Arkansas River into three segments (upper, middle, and lower pool).

portion of females was transformed using the arcsin square root transformation to meet the assumption of normality (Zar 1999). In addition, simple linear regressions were used to examine the relation between average age or proportion of females and WOY.

Tributary Use and Environmental Variables

The CPUEs and environmental measurements from Caney Bayou were used to examine the relationships between CPUE and water temperature, as well as CPUE and stream current velocity. Weekly CPUEs were plotted with current velocity. Periods when temperatures exceeded 12° C were indicated on the graphs. Furthermore, simple linear regression analyses of CPUE on temperature or current velocity were conducted (SAS Institute 2004).

Results

During spring 2010 and 2011, 693 white bass were collected during all sampling in Arkansas River Pool 4. The total catches during 2010 and 2011 were 327 and 366 white bass, respectively. The 2009 cohort dominated the white bass population both years. In 2010, this cohort (i.e., age-1) comprised fish from 110–260 mm TL, and in 2011, comprised fish from 210–340 mm TL (Figure 2). These fish represented 45% of all fish collected in 2010, and 66% of the total catch in 2011. The oldest white bass sampled was age 7, with one age-7 individual being collected each year.

Spatial Variability

Considerable annual spatial variation was observed for white bass in Pool 4 during the two spawning seasons. In 2010, white bass were collected from all 10 tributaries, and mean CPUE (SE) was 8.25 (1.12) fish h^{-1} (Figure 3). Conversely, white bass were collected at only 5 of the 10 tributaries in 2011, and mean CPUE was 2.93 (0.98) fish h^{-1}. There was a high incidence of transects with zero catches in 2011 (Figure 3). The interaction between year and tributary was not significant ($F=1.47$, df = 9, 20; $P=0.227$), so the model was re-run without the interaction term. Mean CPUE was higher in 2010 than in 2011($F=7.91$, df = 1, 29; $P=0.009$) but the tributary effect was not significant ($F=1.34$, df = 9, 20; $P=0.277$).

Temporal Variability

Duration of the spawning season varied between years in Caney Bayou. In 2010, white bass spawned from the middle of March to the end of April (~28 days). Spawning in 2011 began at the end of February and extended to the end of May (~77 days). In terms of spawning effort, 2010 contained a single peak around week 13. By contrast, spawning effort was bimodal in 2011, with peaks in activity occurring in weeks 16 and 18 (Figure 4). The interaction term in the general linear model was not significant ($F = 1.65$, df = 6, 4; $P = 0.326$). Mean CPUE was similar between 2010 and 2011 ($F = 3.08$, df = 1, 11; $P = 0.107$). However, weeks in the middle and latter portions of the purported spawning season had higher CPUE than weeks early in the spawning season in both years (Figure 4; $F = 3.08$, df = 12, 49; $P = 0.003$).

Temporal Variability in Age and Sexual Composition

In 2010, early weeks of spawning were dominated by older fish that entered the tributary before peak spawning. The age structure of spawning fish transitioned to younger ages as the spawning season progressed (Figure 5). Only age-1 and age-2 fish were collected in Caney Bayou two weeks following the peak of the 2010 spawning season, which occurred between 11 April and 18 May. In contrast, there were two major spawning events during 2011 (Figure 5). Spawning fish were represented by several age groups up through the second spawning peak in early May, with only age-1 fish present at the end of the spawning season in mid–May (Figure 4). Average age of fish was older in 2011 than 2010 ($F = 9.82$, df = 1, 11; $P = 0.010$), but mean age did not vary among weeks in either year ($F = 1.78$, df = 12, 42; $P = 0.083$). However, mean age was negatively related to WOY in 2010 ($r^2 = 0.24$, $P = 0.004$), but not in 2011 ($r^2 = 0.01$, $P = 0.431$).

In 2010, females comprised half or more of samples in the first two weeks, but the proportion of females declined to less than one third in subsequent weeks (Figure 6; $r^2 = 0.23$, $P = 0.005$). In 2011, no weekly trend was found in proportion of females ($r^2 < 0.01$, $P = 0.768$), but the average sex ratio over the samples was close to 50:50. Neither the effect of year ($F = 1.38$, df = 1, 11; $P = 0.265$) or the effect of WOY ($F = 1.82$, df = 12, 41; $P = 0.076$) were significant.

Tributary Use and Environmental Variables

Once water temperature reached 13° C, white bass CPUE increased noticeably both years (Figure 4). White bass were never collected in tributaries when water temperatures were below 11° C. The CPUE peaked both years when water temperatures reached about 20° C. Females were spent once water temperature reached 21° C in 2010 and 27° C in 2011. White bass CPUE was positively related to water temperature ($r^2 = 0.45$, $P < 0.001$) but not to stream

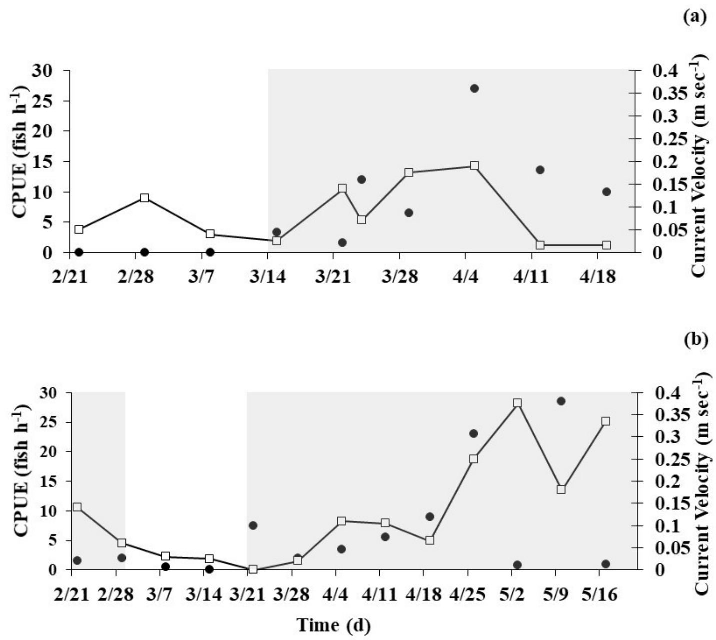

Figure 4. White bass CPUE (solid circles) in Caney Bayou and the associated stream current velocity (open squares) for each sample date in 2010 (a) and 2011 (b). The shaded area corresponds to sample dates when the water temperature was above 12° C.

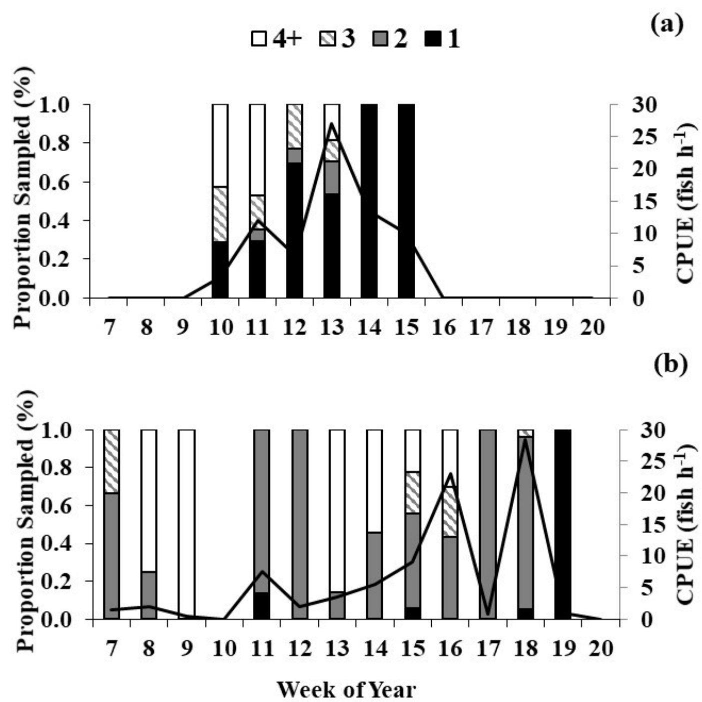

Figure 5. Relative age distribution by percent of catch of white bass in Caney Bayou for sampling dates during the 2010 (a) and 2011(b) spawning seasons. Darker colors represent younger fish. The solid line corresponds to the mean CPUE for each sampling date.

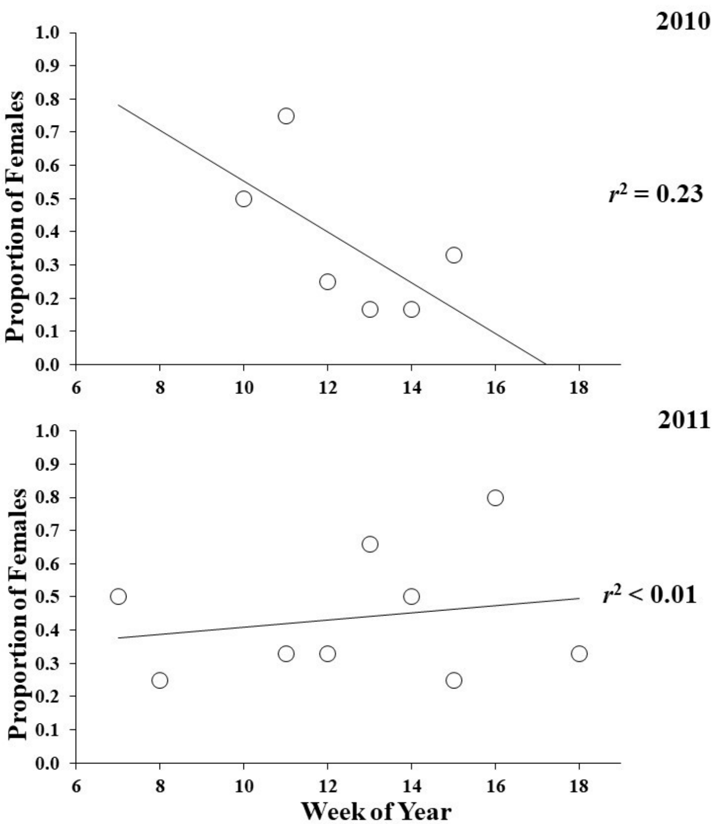

Figure 6. Proportion of white bass sampled in Caney Bayou that was female during the 2010 and 2011 spawning seasons.

current velocity ($r^2 = 0.03$, $P = 0.409$). In 2011, there were two sample periods when stream current velocity was extremely high, which could have affected electrofishing catch rates. The positive relationship between CPUE and stream current velocity was significant ($r^2 = 0.30$, $P = 0.011$) if these two points were removed from consideration.

Discussion

White bass exhibited interannual variation in spatial distribution of spawning. Our study found white bass at every tributary during the first year but at only half of the tributaries during the second year. Age-frequency data suggested that this population exhibited considerable annual recruitment variability from year to year (Baker and Lochmann 2012), which could be related to variable use of tributaries in the current study. Howell (1945) noted that the spawning locations of white bass in Wheeler Reservoir, Alabama, were unpredictable. Martin et al. (2009) quantified spring home ranges in two reservoirs along the Republican River, Nebraska. Fish were observed to move at three scales, ranging from small areas (<25% of the reservoir), moderate (25–75% of the reservoir), and large areas utilizing almost the entire reservoir. However, that study was unable to discern specific spring movement patterns for white bass. Studies in lakes and reservoirs have suggested that white bass spawn in tributaries where water is warm enough and flowing (Bonn 1952, Moen and Dewey 1980, Colvin 1993, DiCenzo and Duval 2002, Quist et al. 2002). Hayden et al. (2011) found 73% of mature white bass exhibited spawning-site fidelity behavior during spawning in the Sandusky River of Lake Erie using otolith microchemistry. However, given the high annual variation of temperature and flow, it is not surprising that white bass exhibit flexibility in their spawning locations. White bass likely select alternate spawning locations in years when environmental conditions are less suitable for spawning in preferred locations (Howell 1945, Bonn 1952, Wright and Hasler 1967).

Previous studies have shown that unfavorable environmental conditions alter white bass spawning behaviors (Quist et al. 2002). Wright and Hasler (1967) found that white bass in Lake Winnebago, Wisconsin, usually migrated up the Fox River to spawn. However, when water levels were low, spawning switched from the Fox River to mid-lake sites on rocky points. Similarly, white bass utilized two coves for spawning in Lake Mendota, Wisconsin, and did not spawn in a polluted tributary (Wright and Hasler 1967). Fish were observed in two consecutive years returning to Lake Texoma after the normal spawning season, where they continued to spawn on wind-swept points (Bonn 1952). White bass can spawn successfully in reservoirs without using tributaries (Howell 1945) provided that appropriate shallow habitat is available. Our study was not designed to assess white bass spawning outside of the tributaries in Arkansas River Pool 4, and white bass certainly spawned in more areas than the sampled tributaries.

White bass had at least two major spawning events in 2011. Multi-peak spawning seasons have been observed in other studies with white bass (Webb and Moss 1967, Yellayi and Kilambi 1975, Kindschi et al. 1979, Starnes et al. 1983, Quist et al. 2002). The two peak spawning events observed in our study in 2011 appeared to correspond to small fluctuations around a critical threshold temperature (approximately 13° C). Conversely, steady increases in temperatures throughout the 2010 spawning season may have resulted in one peak spawn which corresponded with water temperature that steadily increased throughout the spawning season until 21° C. When the water temperature decreased during the spawning period, fewer white bass were collected, possibly indicating a temporary abandonment of the spawning areas.

Proportion of females mostly ranged between 0.40 and 0.60, so one sex rarely dominated a sample. Horrall (1961) also found both sexes arrived at the spawning area at about the same time. However, most studies indicate that males stage at or near the mouth of a tributary several weeks before females (Riggs 1955, Webb and Moss 1967, Colvin 1993, Beck et al. 1999). We found no evidence of males staging near the mouth of Caney Bayou, or within the tributary, prior to spawning. In addition, we did not observe large groups of fish moving in to spawn, or remaining in the tributary after spawning. Males reportedly remain in the spawning area for the duration of the spawning season (Riggs 1955, Houser and Bryant 1970). Conversely, females are believed to leave and return to the spawning area multiple times within a season, if environmental conditions remain favorable (Horrall 1961). Webb and Moss (1967) sampled a higher proportion of females near the end of the spawning season. In the present study, a high proportion of females (>70%) was observed spawning near the beginning of the season in 2010 and near the end in 2011. White bass were observed at the mouth of the tributary and in the tributary when fish were believed to be spawning. A large congregation of both sexes was observed at the mouth of Caney Bayou following spawning when all females sampled were spent. During both years, the largest single congregation of white bass occurred at or near the mouth of Caney Bayou after the spawning season had ended.

Fish arriving during the first three weeks of spawning in both years were primarily older individuals, and younger individuals dominated the catch towards the end of the spawning season. This finding was consistent with Horrall (1961), who reported older fish spawning first and younger fish spawning later, possibly because older fish had ripe eggs before younger fish and were thus ready to spawn sooner. There are ecological advantages when older fish spawn first. Older females have larger ovaries and higher fecundities (Newton and Kilambi 1973, Guy et al. 2002). Because white bass are batch spawners (Yellayi and Kilambi 1975, Berlinsky et al. 1995), the chance to spawn multiple times during the spawning season increases the earlier an individual begins spawning.

Conversely, Webb and Moss (1967) observed younger fish spawning before older fish in a Tennessee reservoir, which has not been commonly reported. This may be a riskier and more unpredictable strategy. Given that younger females have smaller gonads (Guy et al. 2002), younger females spawning earlier could reduce the number of times a younger female would spawn during a season. If food is available, early-hatched larvae may have a head start at growing out of the critical stage which usually translates into increased survival for an early cohort (McCormick 1978). If a younger female releases its gametes during an early spawn, and the environment is not conducive to egg or larval survival, those progeny could be lost (Leggett and Deblois 1994, Michaletz 1997). Younger females might not have the capacity to spawn again later in the season when better conditions exist. Conversely, older females can risk spawning early because they likely have the capacity to spawn again. Thus, the early spawning life-history strategy of older females increases the chances of their progeny dominating the year-class.

Our data supported the notion that water temperature serves as a cue for white bass spawning in Arkansas River Pool 4. Water temperature has been reported in the literature numerous times as an important environmental cue for white bass spawning (Olmstead and Kilambi 1971, Horrall 1981, Starnes et al. 1983, Colvin 1993, Zale and Odornato 1996). White bass abundance in the tributaries of Pool 4 increased when water temperature exceeded 13° C, and studies have identified this as a critical water temperature for spawning activity of white bass (Horrall 1981, McInerny and Held 1995, Zale and Odornato 1996, Colvin 2002). Additionally, water temperature might also govern the duration and peaks during the spawning season (Horrall 1981, Zale and Odornato 1996). Quist et al. (2002) reported that white bass spawning stopped when water temperature exceeded 22° C, whereas another study reported that spawning ceased at 26° C (Horrall 1981). This type of pattern was not observed in the present study, as white bass catches did not abruptly decrease at any particular water temperature.

We wanted to determine the relative importance of the various possible spawning tributaries in this impoundment. Caney Bayou supports an active white bass fishery during the spawning season. Because of access difficulties, other tributaries in this impoundment do not receive high angler effort during the spawning season. A creel survey conducted on this impoundment in 2007 showed only one angler (of 348 interviews) targeted white bass (Fontaine 2009). However, the 2007 survey was conducted at boat ramps, and the fishery on Caney Bayou is almost exclusively composed of bank anglers. Betsill and Pitman (2002) pointed out that traditional creel surveys likely underestimate effort and harvest for white bass fisheries that focus on fish as they spawn in tributary streams. The current regulation on this white bass fishery is a 25 fish per day creel limit with no length limit, and the authors have frequently witnessed anglers harvesting more than 25 fish per day during the spawning season.

Although Caney Bayou was used during the spawning season both years, at least four other tributaries were also used both years. Because Caney Bayou does not represent the sole spawning location for white bass within this impoundment, the risk of heavy harvest in a single spawning tributary negatively impacting the white bass population in Pool 4 appears low. A study indicating the relative contribution of progeny produced in each of the respective tributaries to the year class would further support the preliminary conclusion that high harvest in a single tributary presents little risk in Pool 4.

Acknowledgments

This research was partially funded by the Southern Regional Aquaculture Center (SRAC). We thank the Aquaculture/Fisheries Center at the University of Arkansas Pine Bluff and many students for their assistance with collecting, processing, and ageing fish. We thank Michael Eggleton, Alf Haukenes, and Yushun Chen for providing helpful review comments.

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