SMALLMOUTH BASS SURVIVAL, MOVEMENT, AND HABITAT USE IN RESPONSE TO SEASONALLY DISCONTINOUS SURFACE FLOW

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By

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Smallmouth Bass Survival, Movement, and Habitat Use in Response to Seasonally Discontinuous Surface Flow

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I, Andrew W. Hafs, agree that Arkansas Tech University shall make copies of this thesis available for scholarly purposes. Use of any material presented in this thesis shall result in due credit to the author and the University.

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LITERATURE REVIEW OF SMALLMOUTH BASS SUMMER HABITAT USE, SURVIVAL, AND MOVEMENT

This review summarizes the results and scope of the major research papers covering the topics of smallmouth bass summer habitat use, survival and, movement. Characteristics of habitat covered in this literature review were selected based on their relevance to a study of the Illinois Bayou, Arkansas, where temperature, substrate, depth, and velocity are the habitat characteristics most likely to influence smallmouth bass as water levels decline in summer. Consequently, these are the habitat characteristics that I covered in this literature review. It is possible that other characteristics, such as presence of woody debris, also affect smallmouth bass in the Illinois Bayou.

In this review and the chapters that follow, the term “preference” with respect to habitat has been limited to instances where both used and available habitat were measured sufficiently and the appropriate statistical methods were used to analyze the data. For studies that have not met this criteria smallmouth bass were either, using, captured at, frequented, or found most often over, but they did not show “preference” for specific habitat characteristics.

Temperature

The temperature tolerance of smallmouth bass is quite broad which is typical for warmwater fishes (Wrenn 1980). The normal range of summer temperatures that smallmouth bass are exposed to in their southern range is between 24 and 30°C (Bevelhimer 1996) while preferred temperatures have ranged between 26 and 31°C (Barans and Tubb 1973; Horning and Pearson 1973; Stauffer et al. 1976). Barans and Tubb (1973) reported that adult smallmouth bass selected temperatures between 30 and

31°C most frequently when placed in horizontal temperature gradient tanks based on the results of two fish that were observed multiple times after acclimation to about 23°C. Temperature preferences of 30-31°C were also reported by, Reynolds and Casterlin (1976), and Stauffer et al. (1976). In a laboratory experiment by Horning and Pearson (1973) 432 randomly selected juvenile smallmouth bass were subdivided into 12 different tanks and then acclimated to test temperatures at a rate no faster than 2°C/d. After 50-d, growth was greatest in the tanks with 26-29°C water, while smallmouth bass subjected to 35°C lost weight. Similarly, Peek (1965) reported that laboratory-reared fingerling growth rates were fastest between 28 and 29°C. Wrenn (1980) determined that positive growth occurred at temperatures as high as 32°C for 100 juvenile smallmouth bass evenly divided in four outdoor channels for 322-d. Reynolds and Casterlin (1976) reported that it was common for smallmouth bass to occupy 32°C in their test facility. An upper lethal temperature of 35°C was reported by Cherry et al. (1977) but it was only based on a single death during a 7-d exposure period. Wrenn (1980) observed no smallmouth bass mortalities directly related to elevated temperature despite temperatures that were near or above 35°C for 70-d and suggested that the upper lethal limit was probably as high as 37°C for smallmouth bass. The wide range of temperature preferences that have been reported may indicate that habitat choice is significantly influenced by the presence of cover and food as well as energetic considerations associated with water temperature (Bevelhimer 1996).

Substrate

Stream-dwelling smallmouth bass are generally found over substrates of gravel, cobble, and boulder (Coble 1975; Paragamian 1981). Cobble presence was a significant predictor of smallmouth bass presence in pool microhabitats of the Buffalo River, Arkansas, based on approximately 550 smallmouth bass observations while snorkeling during the summer of 1991 (Walters and Wilson 1996). Walters and Wilson (1996) concluded that the presence of cobble may be the most important factor contributing to the survival of age-0 smallmouth bass in this Ozark mountain stream. Bare (2005) found that adult smallmouth bass frequented stream reaches with gravel to cobble substrates and this varied little over seasons and streams in Bear Creek (a tributary) and the mainstem Buffalo River based on 408 relocations of 59 smallmouth bass tracked via radio telemetry. Variability in density and biomass was best associated with amounts of boulders and cobble in an electrofishing, mark-recapture study where 1,018 smallmouth bass were captured in the summers of 1982 and 1983 in another Ozark stream (McClendon and Rabeni 1987). In the Jacks Fork River, Missouri, 34 smallmouth bass that were monitored with radio-telemetry from July 1985 through January 1987, predominately used rootwads by day and boulders by night during warm seasons and boulders almost exclusively during the cooler seasons (Todd and Rabeni 1989). Density and biomass of smallmouth bass were positively correlated with proportions of exposed gravel and cobble based on electrofishing in the spring and fall seasons of 1977-1979 in the Maquoketa River, Iowa (Paragamian 1981). In summary, most researchers conclude that smallmouth bass are associated with substrates of gravel, cobble, and boulder.

Depth

Adult smallmouth bass tracked by radio-telemetry were found most commonly at depths ranging 1.4-1.8 m in the Buffalo River and 0.8-1.0 m in Bear Creek, Arkansas, across all seasons (Bare 2005). Walters and Wilson (1996) also studied smallmouth bass in the Buffalo River and reported that the age-1 and older smallmouth bass, observed in pools, were most often in depths ranging 0.7-1.0 m, which was slightly less than depths reported by Bare (2005). Fore et al. (2007) snorkeled Baron Fork Creek, Oklahoma, in July 2004 and reported that 65 smallmouth bass ≥ 100 mm occupied a mean depth of 0.82 m. Thirty-four adult smallmouth bass monitored with radio-telemetry from July 1985 through January 1987 in the Jacks Fork River, Missouri, were found most commonly in depths ranging 0.7-1.0 m at all times of the day and in all seasons (Todd and Rabeni 1989). Aadland (1993) sampled fish on six streams in Minnesota and reported that adult smallmouth bass were most frequently captured from a mean depth of 0.85 m, while juveniles were found most often at a mean depth of 0.57 m and age-0 at a mean depth of 0.34 m. In summary, adult smallmouth bass in streams are found most commonly in depths ranging between 0.7 and 1.8 m.

Velocity

Smallmouth bass can occur in lacustrine habitats; however, flowing water appears to be their natural habitat where they apparently prefer a sub-set of available velocities. Aadland (1993) reported that adult smallmouth bass in six different Minnesota streams were found at mean velocity of 0.24 m/s. Adult smallmouth bass monitored with radio-telemetry from July 1985 through January 1987 in the Jacks Fork River, Missouri, preferred velocities less than 0.20 m/s at all times of the day and in all seasons (Todd and Rabeni 1989). Fore et al. (2007) snorkeled Baron Fork Creek, Oklahoma, in July 2004 and observed that 66 smallmouth bass ≥ 100 mm used a mean velocity of 0.17 m/s. Various sized smallmouth bass observed from shore with binoculars in the Flat River, Michigan, typically used velocities less than 0.15 m/s (Rankin 1986). In experiments by

Sechnick et al. (1986), juvenile and adult smallmouth bass selected velocities of 0.10 m/s or less in laboratory stream tanks. In summary, previous studies report that smallmouth bass are found most commonly in velocities less than 0.25 m/s.

Survival

Annual survival of adults (age 2 and older) was estimated as 39% for smallmouth bass that were captured with electrofishing equipment from Glover Creek, Oklahoma, between November 1977 and September 1979 (Orth et al. 1983). In the Buffalo River, Arkansas, annual survival of 64% was estimated using the catch-curve method for age-1 and older smallmouth bass captured by electrofishing from January 1975 to February 1976 (Kilambi et al. 1977). Bare (2005) reported survival estimates of 70-76% for the Buffalo River and 78-84% for Bear Creek, Arkansas, based on telemetry data from 49 adult smallmouth bass. Bare (2005) also reported that survival rates in Bear Creek were higher from September to March than for other times of the year, but he did not explain these results. Annual survival was 84% in an unexploited population of smallmouth bass ages 3-7 captured by angling in a Missouri Ozark stream (Reed and Rabeni 1989). Since there was no fishing mortality in the study by Reed and Rabeni (1989), the estimate of natural mortality is 16%. Reed and Rabeni (1989) reviewed 15 different studies and reported that annual survival ranged 84-89% in streams with light to no fishing pressure, whereas, annual survival ranged 44-58% in streams with heavy fishing pressure. In summary, smallmouth bass populations subjected to light fishing pressure normally have approximately 80% annual survival; whereas, populations subjected to heavy fishing pressure often have annual survival closer to 50% or less. This leads to the conclusion that natural mortality generally is low, when compared to angling mortality, for smallmouth bass populations in lotic ecosystems.

Movement

Summer movement patterns of smallmouth bass have been extensively studied throughout their native distribution. Larimore (1952) removed a limited number of smallmouth bass (< 25) from their home pool and relocated them 1-1.3 km either upstream or downstream. He suggested that adult smallmouth bass display strong homing behavior and have a tendency to remain in home pools. After analyzing 109 reports of tagged fish caught by anglers, Funk (1957) considered smallmouth bass to be a sedentary species with a greater tendency to move upstream within the major stream systems of Missouri. He further suggested that intermediate ages were more likely to move than either younger or older fish. Fajen (1962) sampled multiple times for smallmouth bass that were greater than 127 mm in two small Ozark streams by treating the water with cresol. After accumulating 433 recaptures on 180 different fish, he concluded that smallmouth bass normally restricted their movements to one distinct pool. Bare (2005) tracked 59 smallmouth bass during the summer of 2004 with radio-telemetry equipment. Median 95% kernel home ranges for Bear Creek residents, Buffalo River residents, and for those using both streams during the summer was 0.3, 0.7, 3.2 km, respectively. Lyons and Kanehl (2002) reviewed available literature and concluded that during the summer, smallmouth bass generally remained in localized areas with net movements totaling less than 1 km. They also tracked five adult smallmouth bass by radio-telemetry during the summer of 1993 in Otter Creek and the Pecatonica River in Wisconsin, and found that all fish remained within a small area never moving more than

200 m upstream or downstream from original locations. Munther (1970) conducted a mark-recapture study of smallmouth bass ranging 122-480 mm in the Snake River, on the border of Idaho and Oregon, between June 1965 and November 1966. Ninety-nine (76%) of the recaptured fish were found in the same pool, 22 of 31 fish recovered outside the pool had moved less than 1.2 km, three fish had moved 1.6-2.8 km, and six fish had moved greater than 2.8 km upstream or downstream. Smallmouth bass, 200 mm and longer, exhibited few long range (> 2.5 km) movements, based on 168 recaptures of marked fish that were caught by electrofishing, during the summer in the Wolf and Embarrass Rivers of Wisconsin (Langhurst and Schoenike 1990). VanArnum et al. (2004) used radio-telemetry to track 39 adult smallmouth bass in 2000 and 15 in 2001 in Elkhorn Creek and the Kentucky River, Kentucky. In 2000, 20 of the fish had moved less than 2 km, 13 of the fish had moved 4-10 km, and 6 had moved greater than 15 km. In 2001, smallmouth bass moved less than in 2000 with 12 of the fish moving less than 1 km and all 15 fish moving less than 4 km.

The major topics of this literature review set the stage for the chapters that follow where smallmouth bass habitat use, survival, and movement will be presented in detail. This thesis differs from other smallmouth bass studies because it focuses on a stream system that exhibits seasonally discontinuous surface flow. The pattern, which is common in the Boston Mountains, is characterized by limited water movement through the hyporheic zone between more perennial, but otherwise disconnected pools. The effect of this phenomenon on smallmouth bass habitat use, survival, and movement was studied by comparing available habitat in reference sections to habitat at fish locations during the summer (see Appendix A for GPS coordinates of study reaches).

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CHAPTER 1

SMALLMOUTH BASS SUMMER HABITAT USE IN RESPONSE TO SEASONALLY DISCONTINOUS SURFACE FLOW

*Abstract.–*Toward the southwestern edge of the smallmouth bass (*Micropterus dolomieu*) natural range, the Boston Mountains Ecoregion of Arkansas contains streams which are prone to drying during the summer due especially to hydrogeologic conditions and high evapotranspiration rates. Associated changes in habitat throughout the summer have the potential to negatively affect smallmouth bass. The objectives of this study were to characterize smallmouth bass summer habitat use and characterize changes in the extent of available habitat (velocity, depth, temperature, and substrate) throughout this potentially critical time. Study streams included the North, Middle, and East Forks of the Illinois Bayou in the Ozark National Forest. Sixty radio-transmitters (20 per stream) were surgically implanted into smallmouth bass during May and fish were tracked until October 2006. Habitat characteristics were measured three times from June-September, except substrate (assessed only once). As summer progressed, most riffle and run habitat dried completely resulting in a series of disconnected, remnant pools. Losses in wetted area of some study sections exceeded 55% of the total stream area. Smallmouth bass, in all streams and months, were consistently found at a median depth of 0.80 m. When boulder habitat was available, it was preferred; however, cobble, gravel, and bedrock substrates were also utilized. In June, smallmouth bass were found in velocities near 0.01 m/s; however, by July they were confined to remnant pools where velocity was below detection levels and water temperature occasionally exceeded 30˚C. Thus,

seasonally discontinuous surface flow greatly restricts the areal extent of preferred smallmouth bass habitat which likely constitutes a major limiting factor in the Boston Mountain Ecoregion of the Interior Highlands. Land-use practices that further reduce availability of surface water in these streams seem likely to directly impact this top carnivore and popular gamefish.

INTRODUCTION

Smallmouth bass (*Micropterus dolomieu)* are an important top-predator and sportfish in streams throughout the central part of the United States (Funk and Pflieger 1975; Lyons and Kanehl 2002). Smallmouth bass appear to be sensitive to elevated turbidity, high water temperatures, and environmental disturbances, thus it constitutes an excellent indicator species of the health of an aquatic ecosystem (AGFC 1995). Their popularity as a sportfish, pivotal role in the ecosystem, and value as an indicator species make the smallmouth bass a worthwhile study species.

Southern parts of the smallmouth bass range, such as the Boston Mountain Ecoregion of northwest Arkansas, contain streams which tend to dry (Hines 1975) especially during the summer when evapotranspiration rates are high. During this time, riffle and run habitats become rare (Homan et al. 2005). Surviving fish in these systems apparently congregate in remnant pools where they may be more susceptible to predators (Lowe-McConnell 1975; Harvey and Stewart 1991; Gagen et al. 1998) while competing for available resources or move from the drying stream reaches entirely. Smallmouth bass populations located in streams prone to dryness within the Interior Highlands of Arkansas appear to have lower production rates relative to populations in streams with more continuous surface flow (Homan 2005). Thus, the quantity and juxtaposition of suitable smallmouth bass habitat in the Interior Highlands of Arkansas during low flow periods may constitute an important limiting factor.

Preferred habitat characteristics of smallmouth bass have been extensively studied. Smallmouth bass stream habitat has been generally classified as cool, clear water with a moderate velocity and gradient, over a rocky or gravel substrate (Coble 1975; Funk and Pflieger 1975; Todd and Rabeni 1989).

It appears that the temperature tolerance of smallmouth bass is quite broad which is typical of a warmwater species (Wrenn 1980). The normal temperature range that smallmouth bass are exposed to in their southern range is between 24 and 30°C (Bevelhimer 1996). Barans and Tubb (1973) reported that adult smallmouth bass selected temperatures between 30 and 31°C most frequently when placed in horizontal temperature gradient. Peek (1965) reported that laboratory-reared fingerling growth rates were fastest between 28 and 29°C.

Stream-dwelling smallmouth bass are generally found over substrates of gravel, cobble, and boulder (Coble 1975; Paragamian 1981). Cobble presence was a significant predictor of smallmouth bass presence in pool microhabitats of the Buffalo River, Arkansas, based on approximately 550 smallmouth bass observations while snorkeling during the summer of 1991 (Walters and Wilson 1996). In another Ozark stream, variability in density and biomass was best associated with amounts of boulders and cobble in an electrofishing, mark-recapture study where 1,018 smallmouth bass were captured in the summers of 1982 and 1983 (McClendon and Rabeni 1987).

Adult smallmouth bass tracked by radio-telemetry were found most commonly at depths ranging 1.4-1.8 m in the Buffalo River and 0.8-1.0 m in Bear Creek, Arkansas, across all seasons (Bare 2005). The adult smallmouth bass that were monitored with radio telemetry equipment from July 1985 through January 1987 in the Jacks Fork River, Missouri, were found most commonly at depths ranging 0.7-1.0 m at all times of the day and in all seasons (Todd and Rabeni 1989). Aadland (1993) sampled fish on six streams in Minnesota and reported that the mean water depth was 0.85 m at capture locations of adult smallmouth bass.

Smallmouth bass can occur in lacustrine habitats; however, flowing water appears to be their natural habitat where they apparently prefer a sub-set of available velocities. Aadland (1993) reported that adult smallmouth bass in six different Minnesota streams were found at mean velocity of 0.24 m/s. Adult smallmouth bass in the Jacks Fork River, Missouri, preferred velocities less than 0.20 m/s at all times of the day and in all seasons (Todd and Rabeni 1989). In experiments using laboratory stream tanks, conducted by Sechnick et al. (1986), juvenile and adult smallmouth bass selected velocities of 0.10 m/s or less.

Because smallmouth bass tend to be selective in the types of habitat they prefer, optimal habitat is frequently limited. Associated limitations on production has management implications and the potential to alter ecosystem function, especially in harsh or severe conditions which further limit availability of smallmouth bass habitat. The objectives of this study were to characterize smallmouth bass summer habitat use and characterize changes in the extent of available habitat (velocity, depth, temperature, and substrate) throughout the summer in a stream system prone to seasonal dryness.

METHODS

Study site

This study was on the North Fork, Middle Fork, and East Fork, of the Illinois Bayou which drains a portion of the Boston Mountain ecoregion in Arkansas (Figure 1.1). The Illinois Bayou contains pool riffle sequences dominated by bedrock, boulder, and cobble with reduced flow in the summer resulting in a series of isolated pools during late summer, which is typical of the Boston Mountains. The watershed areas for the three study streams were matched at 148 km^2 (± 1 km^2). Maximum bankfull width within the study sections was 33.7 m. All study reaches included study sites from previous studies of smallmouth bass production (Rambo 1998; Homan 2005).

Field methods

Smallmouth bass were captured between 17 May and 7 June 2006 via hook and line sampling presumably after the majority of spawning activity had occurred. Fish were also captured on 26 June 07 in the East Fork to reinsert transmitters that had apparently been expelled from fish within the first month (two from the East Fork and one from the Middle Fork). The entire study area of each stream was sampled in an effort to distribute the radio transmitters (Models F1580 and F1570, Advanced Telemetry Systems, Inc., Isanti, Minnesota) as evenly as possible (Figure 1.2). Immediately upon capture an easting and northing was recorded using a Magellan handheld GPS unit (3 m accuracy), fish were then anesthetized in clove oil at a concentration of 60 mg/L following the methods outlined by Peake (1998). To ensure that the transmitter weight never exceeded 3% of the fish's body weight (Winter 1996; Brown et al. 1999), two sizes of radio-transmitters with trailing-wire antenna were used. A 3.6 g transmitter with an estimated battery life of 200-d was used for fish weighing more than 120 g and a 3.1 g transmitter with an estimated battery life of 146-d was used for fish weighing more than 103 g. A total of 60 transmitters (20 per stream) were deployed with 45 of them 3.6 g and 15 at 3.1 g with both sizes evenly distributed among the three streams.

After the fish were anesthetized, the radio-transmitters were surgically implanted into peritoneal cavities. A 12-15 mm incision was made with a scalpel on the ventral side of the fish starting posterior to the pelvic fins. A small puncture was made 5-10 mm posterior to the incision. The transmitter was then placed in the peritoneal cavity with the antenna exiting through the small puncture. The incision was closed with 2-3 stitches using 2-0 sutures and duramycin was applied to the wounds externally. Stream water was flushed through the gills of the fish throughout the surgical procedure which lasted less than 7 minutes. Telemetry-fish were also marked with t-bar anchor tags (Appendix B). Fish were allowed to recover in the stream within wire baskets until swimming ability returned. After the recovery period, which was typically three minutes, fish were released at their original capture location.

Smallmouth bass summer habitat use was determined by locating fish with radio-telemetry monthly May through October 2006. Study reaches were traveled via kayak with a hand-held receiver (Communications Specialists, Inc.) attached to a Yagi-Uda antenna to scan for transmitter fish. Due to the low turbidity levels in the North, Middle, and East Forks of the Illinois Bayou, visual confirmation of the transmitter fish was achieved at 52% of fish locations. When a visual conformation of a fish was not possible because it was moving, in deep water, or hiding under a rock, I selected the spot that the fish moved through most often for the location of habitat measurements. After locating a fish with telemetry equipment, the easting and northing was recorded, water column depth was measured to the nearest centimeter with a leveling rod, and velocity was measured (Model 2000, Flo-Mate, Marsh-McBirney, Inc.). Temperature was measured to the nearest tenth °C by lowering a thermometer on a string to the fish's location. Primary and secondary substrates were estimated using a grade scale defined by

Wentworth (1922). These visual estimates of substrate composition were considered sufficiently accurate for this fisheries application based on Wang et al. (1996).

Available habitat was measured in June, July and September within three (upstream, midstream, and downstream) 1 km reference sections per stream (Appendix A). Available habitat was also measured in the midstream reference section of the North Fork on 11 May 2007 to provide estimates of habitat at a time of the year without stream dryness. Wetted area was also measured monthly in 1 km reaches extending from reference sections for a grand total of 6 km per stream. Habitat transects were set every 50 m along a hip-chain throughout each section. Easting and northing was recorded from the midpoint of each transect and the wetted width was measured with a laser range finder (Sokkia HL3D Handlaser, Lasercraft Inc.). The wetted width was then separated into quadrants and depth and velocity were measured from the midpoint of each quadrant. Substrate was measured at the same locations but relative to bankfull width rather than wetted width. Substrate was individually measured by two different people to provide an estimate of precision. The readers had an 86% agreement on the primary substrate at 648 locations in which both people measured substrate. Substrate was measured only in September because no major channel-altering velocity was expected during the study period. Available temperature was measured using six temperature loggers (Model DS1921G-F5, Maxim Dallas Semiconductor and StowAway Tidbit, Onset Computer Corporation) placed at the upstream and downstream ends of the study areas.

Data Analysis

The wetted area of each reference section was mapped in ArcGIS using the wetted widths, GPS waypoints, and hip-chain measurements. Depth maps were created using the Kriging ordinary interpolation method in ArcGIS Spatial Analyst. The spherical semivariogram model was selected with an output cell size of 0.5 m. The search radius was variable with the number of points set to 12 and a maximum search distance of 75 m. Brenden et al. (2006) determined that bathymetric maps created using similar methods were accurate within 0.25 m. Substrate maps were created in the same manner by giving substrate categories numeric values (bedrock = 5, boulder = 4, cobble = 3, gravel = 2, sand = 1) and calculating a weighted value based on the primary and secondary substrates for each location that substrate was estimated. For example, if I had estimated the substrate at a specific location to be 50% boulder, 40% cobble, and 10% gravel, I would have calculated the weighted substrate value as 3.2 = 0.50*4 + 0.40*3 where any value > 4.5 = bedrock, 4.5-3.5 = boulder, 3.5-2.5 = cobble, 2.5-1.5 = gravel < 1.5 = sand.

To determine if the depth or temperature where telemetry fish were found was significantly different by stream, tracking period, or position, the Kruskal-Wallis test was used at a 0.05 level of significance. Position was determined by separating the length of each stream within the study area into thirds in ArcGIS. If a Kruskal-Wallis test was significant, then a Dunn-Sidak analysis was used to determine which groups accounted for the effect. To determine if the substrate over which telemetry fish were found was significantly different by stream, tracking period, or position, the chi-square along with a Fisher's exact test was used at a 0.05 level of significance. If a Fisher's exact test was significant, then a chi-square along with a Fisher's exact was used comparing only two groups at a time to determine which groups were accountable for the effect. The Bonferroni test was then applied to resulting *P*-values. Only gravel, cobble, boulder, and bedrock substrates were used in this analysis due to the very low frequency of fish occurrence over sand and silt substrates.

To determine if depths used by telemetry fish were significantly different than the depths measured in the reference sections, the mean depth at each individual fish location, for fish that were located at least once (n = 57), was tested against 57 reference depths that were randomly selected out of the pool of all reference depths measured in June. Reference depths were weighted by wetted width to ensure that reference depths in transects with wider wetted widths were more likely to be selected. Ten different random samples of reference depths were analyzed with a Wilcoxon-Mann-Whitney analysis. This process was repeated for fish that had been located at least two times (n = 49) and at least three times (n = 39) for a total of thirty tests for June. This entire process was then repeated using reference depths from July and September instead of June for a grand total of 90 Wilcoxon-Mann-Whitney tests.

To determine if substrate used by telemetry fish was significantly different than the substrate measured in the reference sections, the frequency of substrates used by telemetry fish in an individual stream was tested against an equal number of reference substrates that were randomly selected out of the collection of all reference substrates measured in that particular stream. Reference substrates in the group were weighted by bankfull width to ensure that reference substrates in transects with wider bankfull widths were more likely to be selected. Ten different random samples of reference substrates were selected and the chi-square along with a Fisher's exact test was used ten times per stream. This process was repeated for all three streams. When testing the Middle Fork it was unclear if the average of the resulting *P*-values was significantly different than 0.05

so the number of tests was increased until the 95% confidence interval of the *P*-value for all Fisher's exact tests did not include 0.05. SAS version 9.1 was used for all statistical analyses (SAS Institute 1999).

RESULTS

Discharge throughout the summer of 2006 was below average, so losses in wetted area may be slightly greater than in a normal year (Figure 1.3). The North Fork had the greatest loss of wetted area (47%) relative to the upstream sections of the other streams. The midstream sections of all three streams had similar losses in wetted area ranging from 26% in the Middle Fork to 32% in the North Fork. However, the downstream sections ranged widely with respect to wetted areas throughout the summer. The downstream section of the North Fork had a 28% loss in the wetted area while the Middle Fork increased by 6%. The East Fork downstream section had the largest loss in wetted area throughout the summer (over 56%). Relative to average May flow conditions, the wetted area of the midstream section of the North Fork (measured in May 2007) was larger than any of the stream sections measured in June 2006. Graphical representation of wetted areas is shown in Figure 1.4 while detailed results are in Table 1.1.

Depth at telemetry fish locations (Figures 1.5 and 1.6) did not significantly differ between streams ($X^2 = 4.11$, df = 2, $P = 0.13$), period ($X^2 = 1.28$, df = 2, $P = 0.53$), or position ($X^2 = 1.93$, df = 2, $P = 0.38$). Results from all 90 different Wilcoxon-Mann-Whitney tests comparing reference and used depth all were significant ($P < 0.05$) providing evidence that smallmouth bass select specific depths within the study area during the summer (Figure 1.7). Detailed results from Wilcoxon-Mann-Whitney tests on used verses reference depth can be found in Table 1.2. Detailed depth maps for all reference sections can be seen in Figures 1.8-1.17. The lowest depth used by telemetry-fish throughout this study was 0.09 m (n =177). Mean area with depth greater than 0.09 m within the reference sections is shown in Table 1.3.

No measurable velocity was present at telemetry fish locations between 28 June and 26 September. Out of 179 total velocity measurements at telemetry fish locations, only 26 were > 0 (Figure 1.18). Mean velocity was 0.02 m/s for the 26 telemetry fish locations where a measurable velocity was present.

In June, 93% of the measured reference velocities were less than 0.1 m/s and in July, 98% were less than 0.1 m/s (Figure 1.19). No measurable velocity was present anywhere within the reference sections in September at the time of habitat mapping and velocities did not return until a rain event on 23 September 2006. On 11 May 2007, the discharge on the Illinois Bayou was at the median according to 60 years of previous data, (Figure 1.20); therefore velocity measurements from the middle reference section of the North Fork at that time are representative of the Illinois Bayou in May when measurable velocities are more common. On 11 May 2007, only 54% of the measured reference velocities were less than 0.1 m/s within the midstream reference section of the North Fork (Figure 1.19). Figure 1.21 shows discharge on the Illinois Bayou at the USGS reference gage in Scottsville for 2006. Discharge in 2006 during the study period is shown in Figure 1.3.

Temperature at transmitter fish locations (Figures 1.22 and 1.23) did not significantly differ between streams ($X^2 = 0.48$, df = 2, $P = 0.78$) or position ($X^2 = 0.44$, df = 2, $P = 0.80$). However, temperatures at telemetry fish locations were significantly different between tracking periods ($X^2 = 93.29$, df = 2, $P < 0.05$), furthermore, temperatures at telemetry fish locations in all three tracking periods were significantly different from each other ($P < 0.05$, Dunn-Sidak test). The majority of temperatures at telemetry fish locations were within the range of reference temperatures recorded by the temperature loggers. The exception to this was the tracking period in late July and early August (Figure 1.23). During this tracking period, telemetry fish were found in temperatures that were higher on average than the reference temperatures recorded. Out of 182 temperature measurements at transmitter fish locations only seven were measured greater than 30°C. Monthly average air temperatures, in Deer, Arkansas, which is within 40 km of the study area, were slightly higher than average from May-August of 2006 (Table 1.4).

Substrate at transmitter fish locations (Figure 1.24) did not significantly differ between period ($X^2 = 4.19$, df = 6, $P = 0.65$, Fisher's $P = 0.69$) or position ($X^2 = 1.53$, df = 6, $P = 0.96$, Fisher's $P = 0.96$). However, substrate at telemetry fish locations were significantly different between streams ($X^2 = 28.40$, df = 6, $P < 0.05$, Fisher's $P < 0.05$). Chi-square analyses (North*Middle, North*East, Middle*East) were all significant at a level of $P < 0.02$, which was set by the Bonferroni inequality, providing evidence that substrate types at telemetry fish locations were different among streams. Results from all 10 different Fisher's exact tests, comparing reference and used substrate on the North Fork, and East Fork, were significant ($P < 0.05$) providing evidence that smallmouth bass selected specific substrates within the study areas during the summer on the North and East Forks of the Illinois Bayou (Figure 1.25). A total of 45 random samples of reference substrates were analyzed for the Middle Fork before the 95% confidence interval (0.112 – 0.053) of the P value did not include 0.05. The 95% confidence interval was greater than

0.05 which provides evidence that smallmouth bass in the Middle Fork were not using the substrate at different proportions than what was measured in the reference sections. Detailed results from the Fisher's exact tests of substrate used verses reference for all three streams can be found in Table 1.5. Substrates measured within the reference sections were significantly different between streams (X^2 = 764.52, df = 6, P < 0.05). Chi-square analyses (North*Middle, North*East, Middle*East) were all significant at P = 0.02, the level set by the Bonferroni inequality, which provides evidence that reference substrate was different in all three streams. Comparisons of the substrate measured within the reference sections can be found Figure 1.26. Maps describing the dominant substrates for all reference sections can be found in Figures 1.27-1.29.

DISCUSSION

Within the study area of the Illinois Bayou, there was a significant decrease in the amount of habitat that was available to smallmouth bass throughout the summer. Homan and colleagues (2005) documented that during this time, riffle and run habitats become rare in Boston Mountain streams. It is likely that production rates within the Illinois Bayou are restricted by the significant loss of habitat that occurs during the summer. Surviving fish in these systems apparently congregate in remnant pools where they may be more susceptible to predators (Lowe-McConnell 1975; Harvey and Stewart 1991; Gagen et al. 1998). The loss of wetted area may also increase density dependent competition which could lead to the low abundances and low rates of production that have been documented in the Illinois Bayou (Rambo 1998; Homan 2005). There have also been reports of elevated water temperature affecting fish populations in shrinking stream pools (Matthews et al. 1982; Mundahl 1990).

Smallmouth bass did not appear to select specific temperatures; instead they utilized the range of temperatures available to them within the study area. The fact that fish were found at temperatures higher than those recorded by the temperature loggers implies that fish were seeking warm temperatures during the middle period of the study. However, I hypothesize that placement of temperature loggers in substantial pools, unlikely to dry, may have produced temperature records that were on average lower than what was actually available in the stream. This likelihood contributed to my hypothesis that smallmouth bass in the Illinois Bayou are not selecting specific temperatures; instead they are utilizing the range of temperatures available to them within the study area.

The range of temperatures that smallmouth bass utilized in this study (16-32^{o}C) approached the upper limit of what can be considered the normal range of temperatures for smallmouth bass at the southern edge of their distribution. Summer temperature preferences of 30-31°C were reported by Barans and Tubb (1973), Reynolds and Casterlin (1976), and Stauffer et al (1976). Although Wrenn (1980) reported that smallmouth bass grew at temperatures as high as 32°C, this is also within 3-5^{o}C of their lethal temperature (Cherry et al. 1977; Wrenn 1980). Water temperatures close to the smallmouth bass lethal temperature are likely to negatively affect smallmouth bass production. Horning and Pearson (1973) reported that juvenile smallmouth bass growth was greatest in the tanks with 26-29°C water, while smallmouth bass subjected to 35°C lost weight. Regier and Meisner (1990) suggested that changes in maximum and minimum water temperatures associated with anthropogenic climate change will affect the distribution of fishes. Smallmouth bass in the Illinois Bayou already were exposed to temperatures within 3-5^{o}C of their lethal temperature in a year when summer air temperatures were only slightly higher than average (NOAA 2007); therefore, long-term increases could potentially threaten these populations.

Apparently, it is natural for smallmouth bass to be forced into areas with no measurable velocity during the summer in the Illinois Bayou of Arkansas. Several studies have reported that smallmouth bass were found in low velocities (Rankin 1986; Todd and Rabeni 1989; Aadland 1993), but I have found none that report stream-dwelling smallmouth bass in situations without measurable velocity. Variable stream flows can have negative impact on smallmouth bass populations (Smith et al. 2005). The situation in the Illinois Bayou where no measurable velocity was present for much of the summer likely contributed to the low smallmouth bass production observed by Rambo (1998) and Homan (2005). In the absence of flowing water, fish are unable to drift feed which eliminates an important feeding tactic used by smallmouth bass (Paragamian and Wiley 1987). Fish become trapped in remnant pools where increased competition for food can be deleterious to smallmouth bass populations (Paragamian and Wiley 1987). Rimmer (1985) was able to decrease production of rainbow trout *Oncorhynchus mykiss* by artificially reducing stream discharge. Alterations to the already unstable hydrology of the Illinois Bayou should be closely monitored in the future to avoid any decreases in the already low smallmouth bass production.

Smallmouth bass within the study area of the Illinois Bayou appeared selective with respect to depth throughout the summer in all positions (upstream, midstream, and downstream) even while water levels decreased (median = 0.80 m). Results were very similar to numerous published reports (Todd and Rabeni 1989; Aadland 1993; Walters and Wilson 1996). The natural history advantage for smallmouth bass to utilize such a specific range of depths has not been documented but it likely results from a combination of factors. Smallmouth bass in the Illinois Bayou are commonly located at the interface between shallow and deeper habitats near upstream and downstream shoals of remnant pools. This area likely is deep enough to provide cover from predators, yet it is close to the edge of the shallow habitat where smaller prey species reside. Furthermore, pools with depths in this range appear less likely to experience severe stream dryness therefore increasing the chance of survival throughout the summer.

Smallmouth bass are generally associated with substrates of gravel, cobble, and boulder (Coble 1975; Paragamian 1981; McClendon and Rabeni 1987; Walters and Wilson 1996; Bare 2005). Results from this study were consistent with most previously published reports, but some new, and potentially important, aspects of habitat were identified that need to be considered. Although smallmouth bass were commonly found over cobble, it was also the most prevalent substrate within each of the three streams. Furthermore, cobble was used at much lower proportions than it was measured within the reference sections implying that if other substrates were available, such as boulder, then cobble may not be used as often. Boulder, on the other hand was used in much greater proportions than it was measured within the reference sections, thus, boulder substrate appears preferable when available. Bedrock does not normally come into consideration when discussing substrates and smallmouth bass, but in this study, fish were frequently found over bedrock substrate ranging from 10% of the time in the North Fork to 37% of the time in the East Fork. Bedrock substrate was most prevalent in the East and Middle Forks and those were also the two streams where smallmouth bass used bedrock most often. While smallmouth bass are not known to prefer bedrock substrate, bedrock pools in some streams may be the only places with ample water remaining in late summer. Thus, smallmouth bass can be forced to utilize this sub-optimal habitat which may further contribute to low smallmouth bass productivity.

The shallowest location that adult smallmouth bass used in this study was 0.09 m (n = 177). Thus, one can consider depths > 0.09 m tolerable for adult smallmouth bass. Within the midstream reference section of the North Fork in May 2007, a time of typical spring discharge, there was 18,100 m^2 of tolerable depth habitat available to smallmouth bass. However, during a typically dry September in 2006, the mean amount of tolerable depth habitat within the midstream reference sections was limited to 5,900 m^2. Todd and Rabeni (1989) reported that a third of the area within their study sites in the Jacks Fork River, Missouri, had preferred depths (> 0.66 m). Using a conservative depth of > 0.09 m, only a third of the May stream area is expected to have tolerable depths in September, within the major forks of the Illinois Bayou. Habitat quality within the North, Middle, and East Forks was further limited by low prevalence of boulders (on average only 16% of the substrate) and there was no measurable velocity in September. Todd and Rabeni (1989) suggested that a small amount of quality habitat can support a large biomass of adult fish; however it seems clear that in the major forks of the Illinois Bayou, the amount of quality habitat was limited to the extent that smallmouth bass production was negatively affected.

Although the Illinois Bayou appears to be a typical smallmouth bass stream throughout most of the year, I documented a major loss of habitat throughout the summer. The loss of favorable habitat forces resident smallmouth bass to survive in what likely constitutes a severe environment from July to September in normal years on the

Illinois Bayou and perhaps many Boston Mountain streams. Management actions need to ensure that the limited water volume and depth remaining during this time is protected. Water temperatures were near the upper thermal tolerance of smallmouth bass, so riparian zones must be protected to provide shade. Large proportions of bedrock characterize much of the stream system, thus activities such as in-stream gravel and rock mining, recreational ATV use, and agriculture must be monitored closely to avoid any further instability or reduction in suitable substrate. The Illinois Bayou and similar streams challenge the persistence of smallmouth bass which are an integral part of the Ozark Mountain ecosystem.

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Table 1.1.–Wetted areas of all reference sections in June, July, and September of 2006 as well as the midstream section of the North Fork in May 2007 for comparison to typical spring discharge on the Illinois Bayou, Arkansas.

	Wetted Area (m^2)				
Stream	Section	May 07	June 06	July 06	September 06
North	Upstream		20,000	18,600	10,600
	Midstream	33,900	21,900	19,300	14,900
	Downstream		28,600	26,000	20,600
Middle	Upstream		14,400	11,100	10,800
	Midstream		22,400	19,400	16,500
	Downstream		26,200	27,300	27,800
East	Upstream		13,300	9,000	8,800
	Midstream		23,600	20,900	16,600
	Downstream		24,800	19,200	10,800
Mean	Upstream		15,900	12,900	10,100
	Midstream		22,600	19,900	16,000
	Downstream		26,500	24,200	19,700

Table 1.2.–Wilcoxon-Mann-Whitney test details for comparisons between depths at telemetry-fish with at least one location, at least two locations, at least three locations and measured depths within reference sections in June, July, and September of 2006 on the Illinois Bayou, Arkansas.

		June		July		September	
	n	Z value (range)	*P* (range)	Z value (range)	*P* (range)	Z value (range)	*P* (range)
≥ 1 location	57	-3.78, -6.58	<0.0001	-3.82, -6.17	0.0001-<0.0001	-4.53, -6.08	<0.0001
≥ 2 locations	49	-3.42, -6.58	0.0006-<0.0001	-3.70, -6.01	0.0002-<0.0001	-4.24, -6.76	<0.0001
≥ 3 locations	39	-3.10, -6.05	0.0027-<0.0001	-3.37, -5.86	0.0007-<0.0001	-3.45, -5.69	0.0006-<0.0001

Table 1.3.–Mean area with depth > 0.09 m in the upstream, midstream, and downstream sections in June, July, and September of 2006 as well as the midstream section of the North Fork in May 2007 for comparison to typical spring discharge on the Illinois Bayou, Arkansas.

	Mean area (m^2) with depth > 0.09 m			
Reference Section	May	June	July	September
Upstream		5,600	3,900	2,600
Midstream	18,100	9,300	7,900	5,900
Downstream		13,800	11,900	9,000

Table 1.4.–Monthly average air temperatures for all years on record compared to 2006 average air temperatures for Deer, Arkansas, which is located within 40 km of the study area (NOAA 2007).

Month	Average (^oC)	2006 (^oC)
May	16	17
June	21	22
July	23	24
August	23	25
September	19	18
October	13	13

Table 1.5.–Chi-square and Fisher's exact test details for comparisons of dominant substrate at telemetry-fish locations verses dominant substrate within reference sections in the North, Middle, and East Forks of the Illinois Bayou, Arkansas.

Stream	n	# of tests	X^2 Value (range)	Critical Value	*P* (range)	Fisher's *P* (mean)	95% CI of Fisher's *P*
North	90	10	21.67-37.37	7.82	<0.0001	<0.0001	<0.0001
Middle	70	45	3.29-16.23	7.82	0.0010-0.35	0.083	0.053-0.11
East	78	10	19.25-40.60	7.82	<0.0001-0.0002	<0.0001	<0.0001

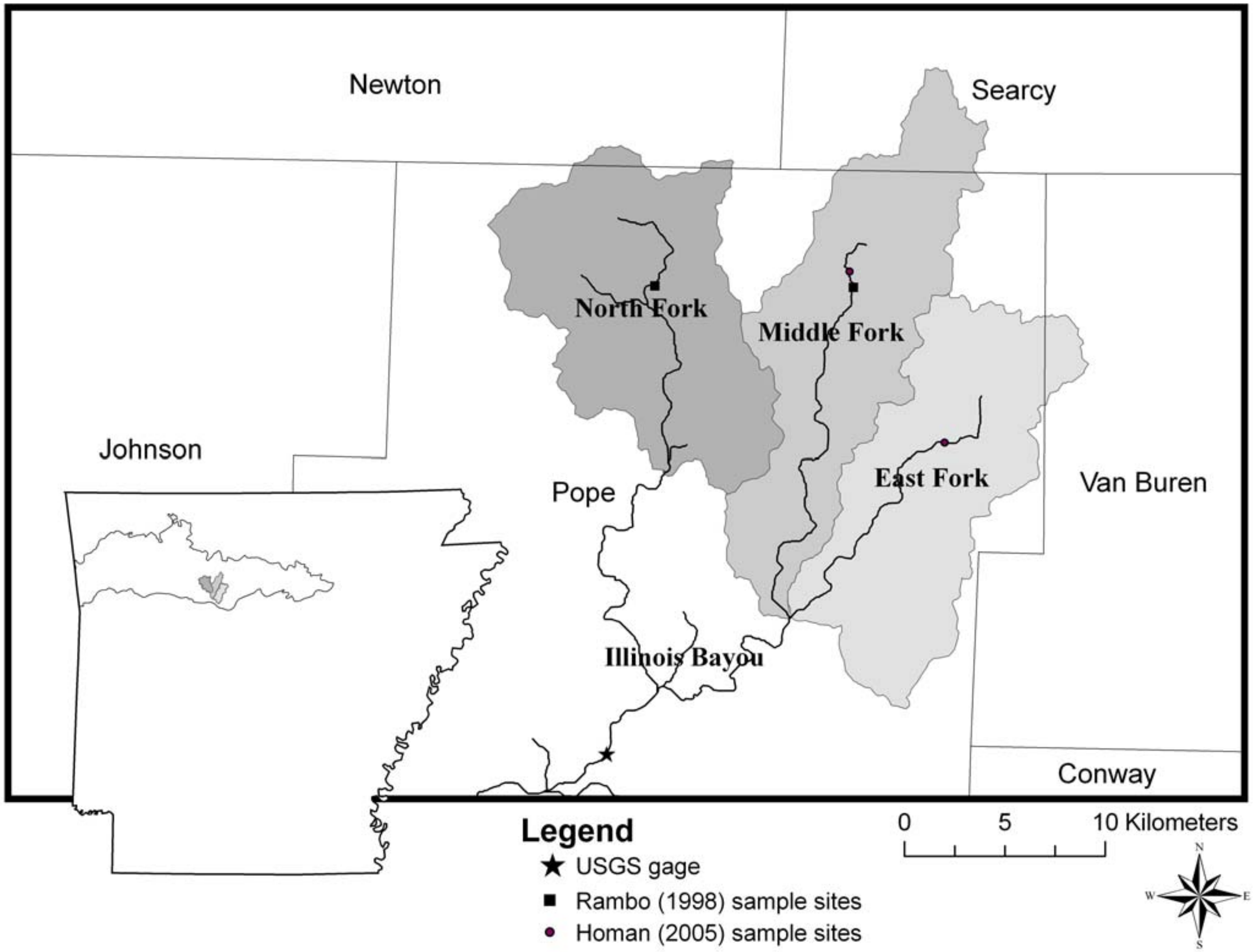


Figure 1.1.–Map of 2006 study watersheds (148 km^2) also showing counties, USGS gage location, and sites of previous smallmouth bass studies.

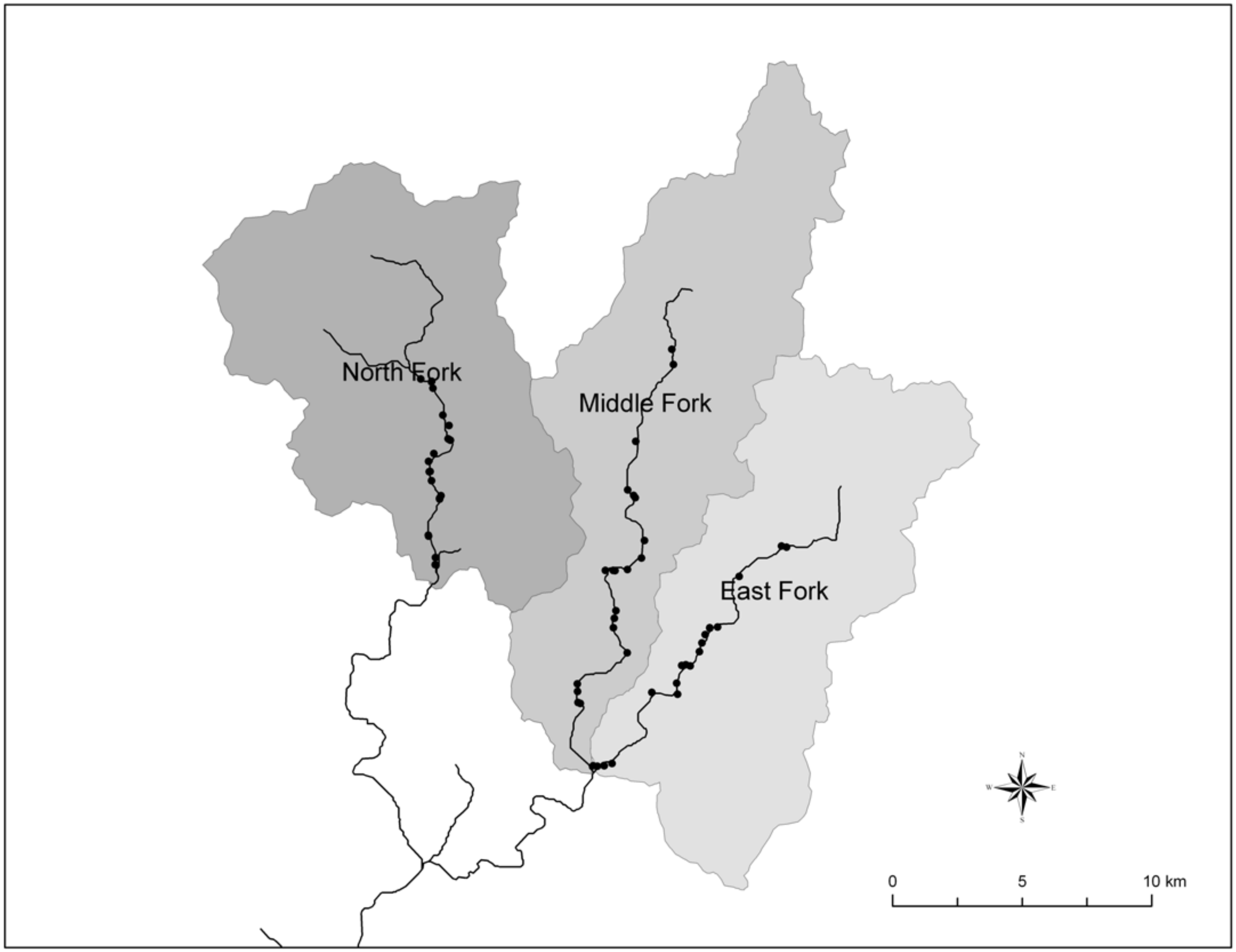


Figure 1.2.–Map of initial telemetry-fish locations shown as solid circles in the major forks of the Illinois Bayou drainage network.

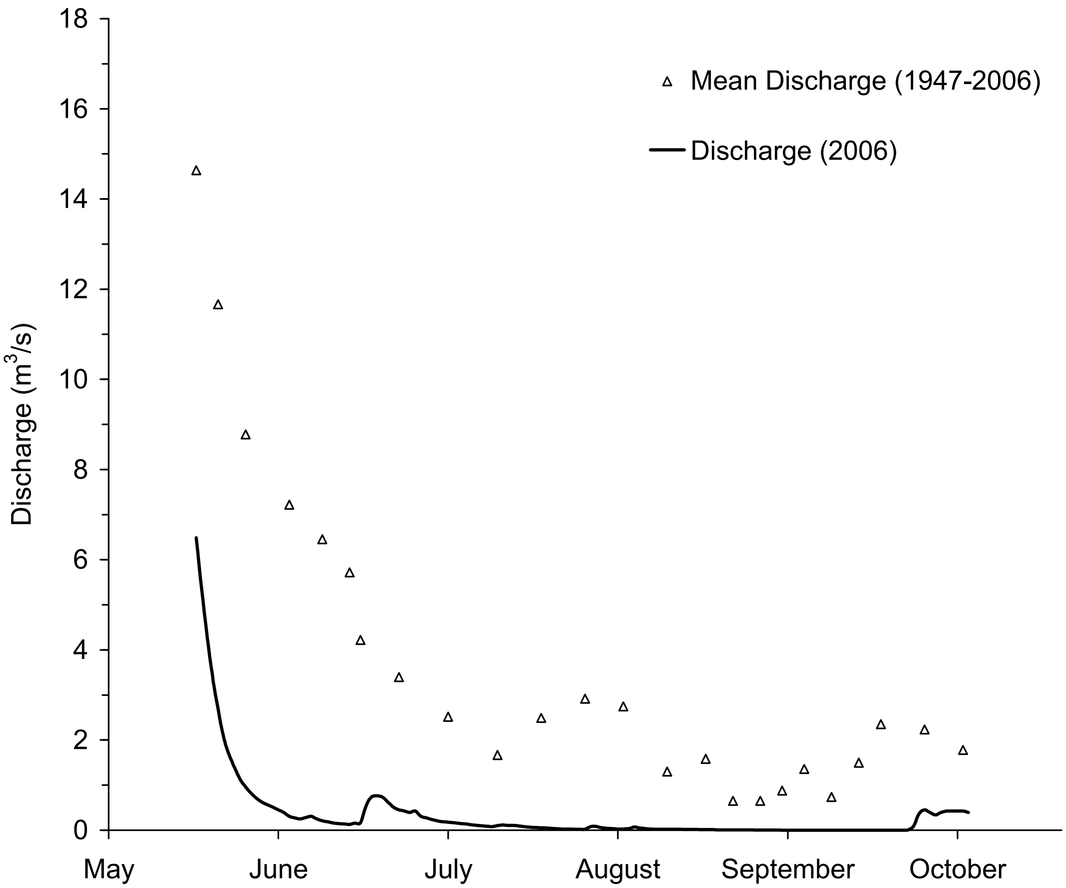


Figure 1.3.–Mean discharge (1947-2006) compared to 2006 discharge during the study period at the Scottsville USGS reference gage on the Illinois Bayou, Arkansas (USGS 2007).

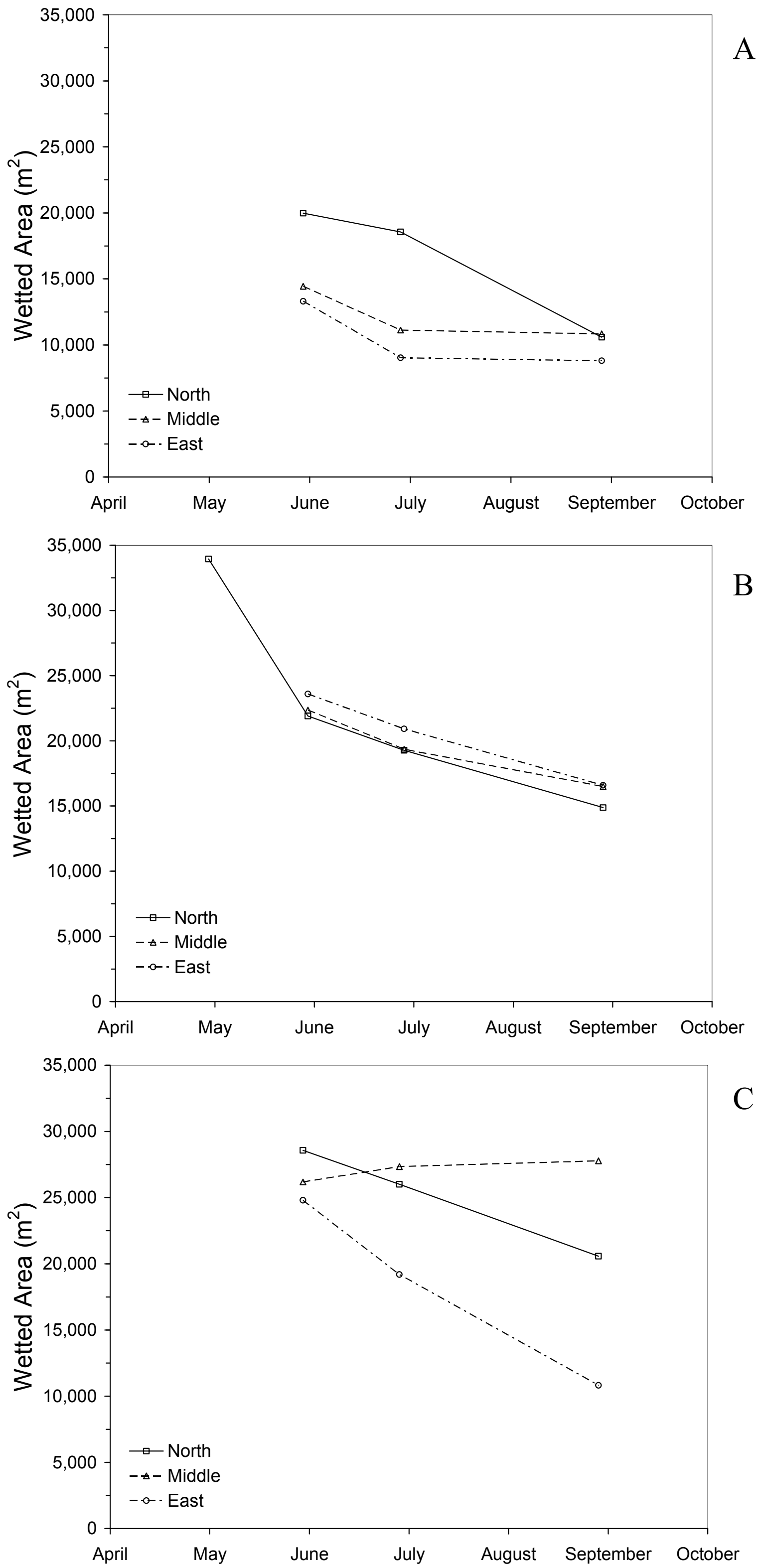


Figure 1.4.–Wetted areas in (A) upstream, (B) midstream, and (C) downstream reference sections in May 2007 and June, July, and September of 2006 within the major forks of the Illinois Bayou, Arkansas.

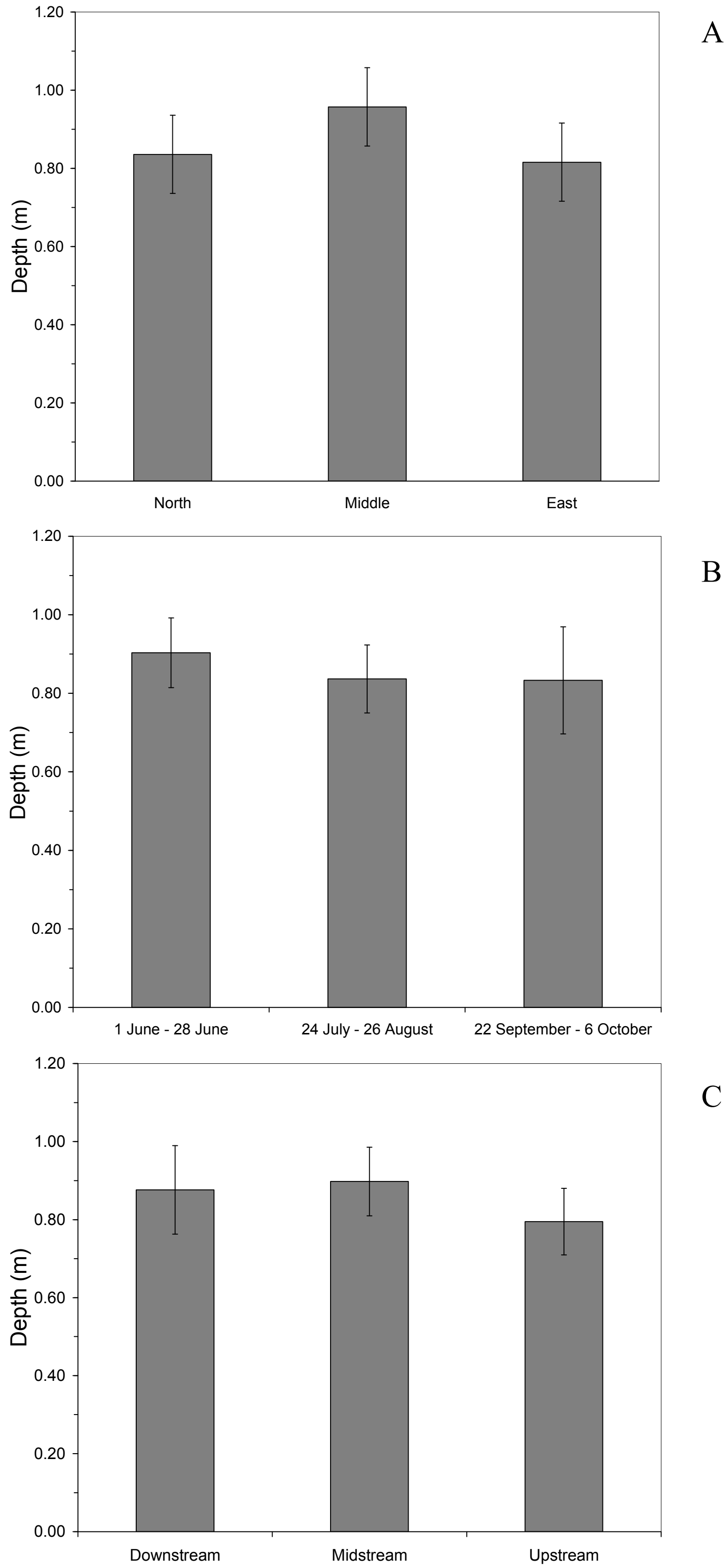


Figure 1.5.–Mean depths (± 2 SE) at telemetry-fish locations in the major forks of the Illinois Bayou, Arkansas, based on (A) stream, (B) tracking period, and (C) position (n = 177).

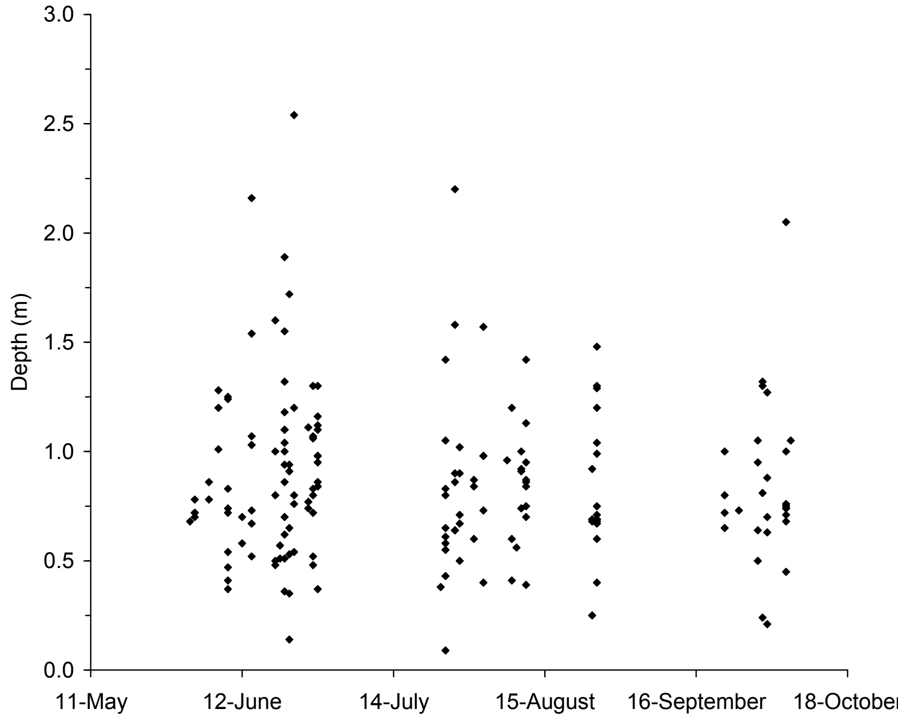


Figure 1.6.–Scatter plot of depths at telemetry-fish locations in major forks of the Illinois Bayou, Arkansas, from 1 June 2006 to 6 October 2006.

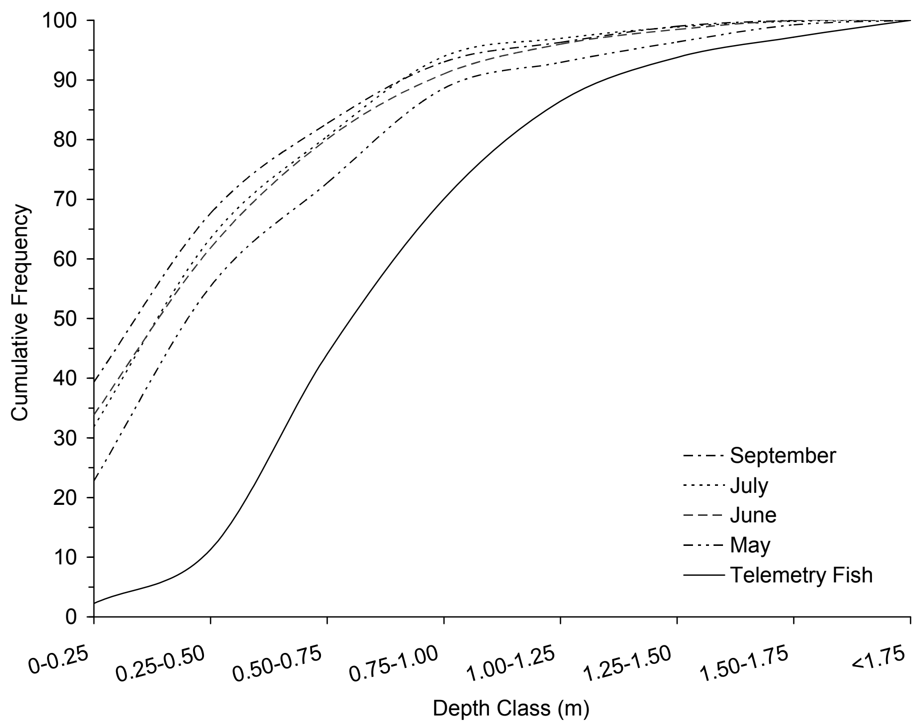


Figure 1.7.–Comparison between cumulative frequency curves for depth at telemetry-fish locations (n = 177) from 1 June to 6 October 2006 and measured depths within reference sites on the Illinois Bayou, Arkansas, in May 2007, June, July, and September of 2006.

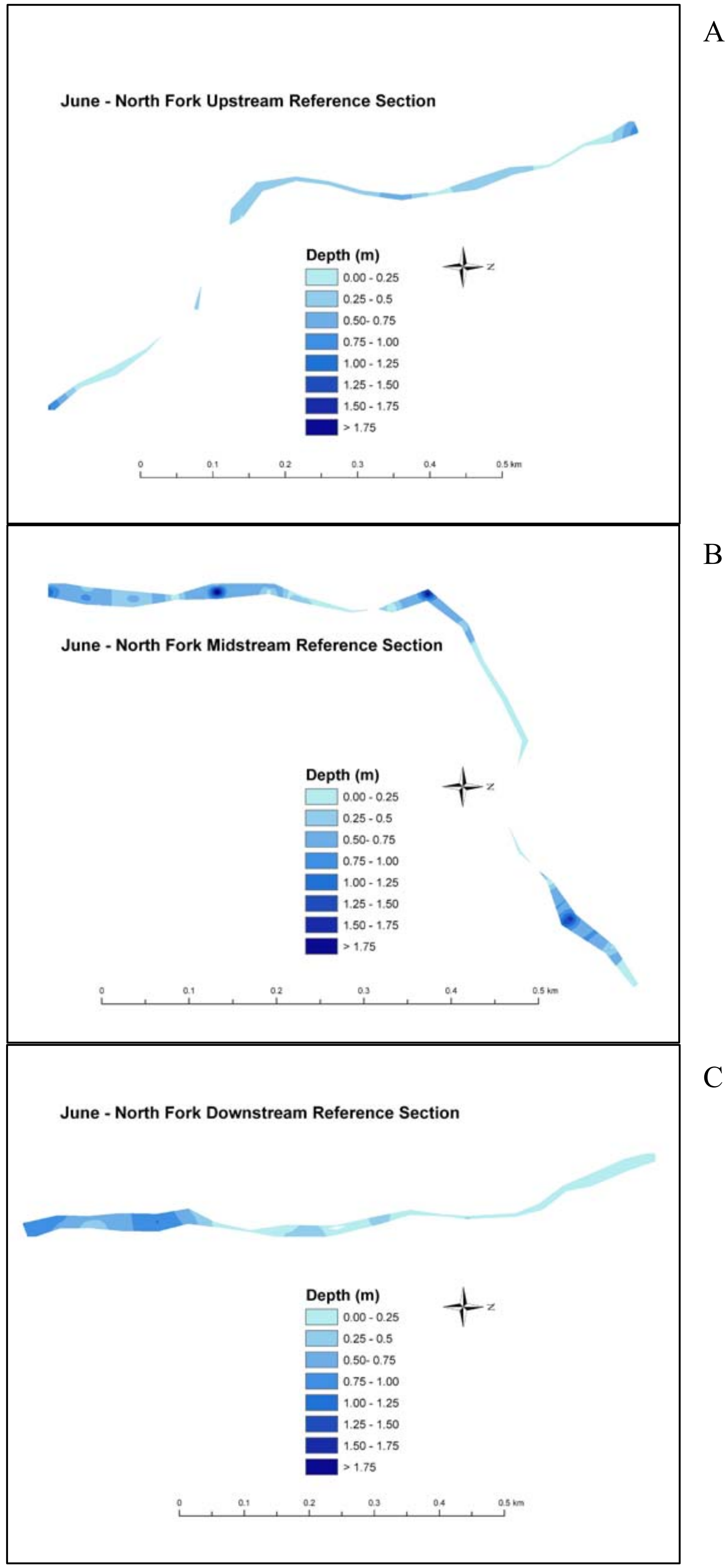


Figure 1.8.–Depth maps for the (A) upstream, (B) midstream, and (C) downstream reference sections on the North Fork of the Illinois Bayou, Arkansas, in June 2006.

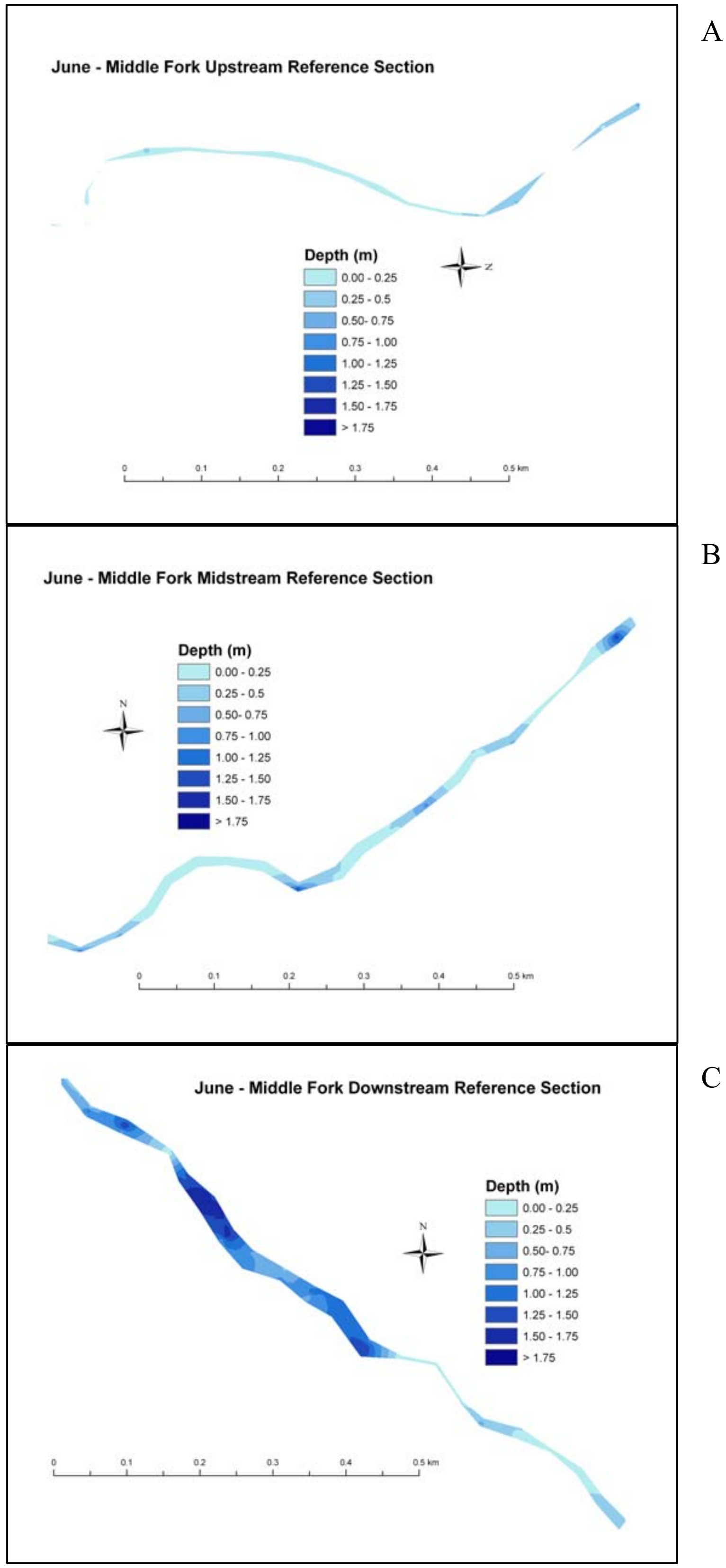


Figure 1.9.–Depth maps for the (A) upstream, (B) midstream, and (C) downstream reference sections on the Middle Fork of the Illinois Bayou, Arkansas, in June 2006.

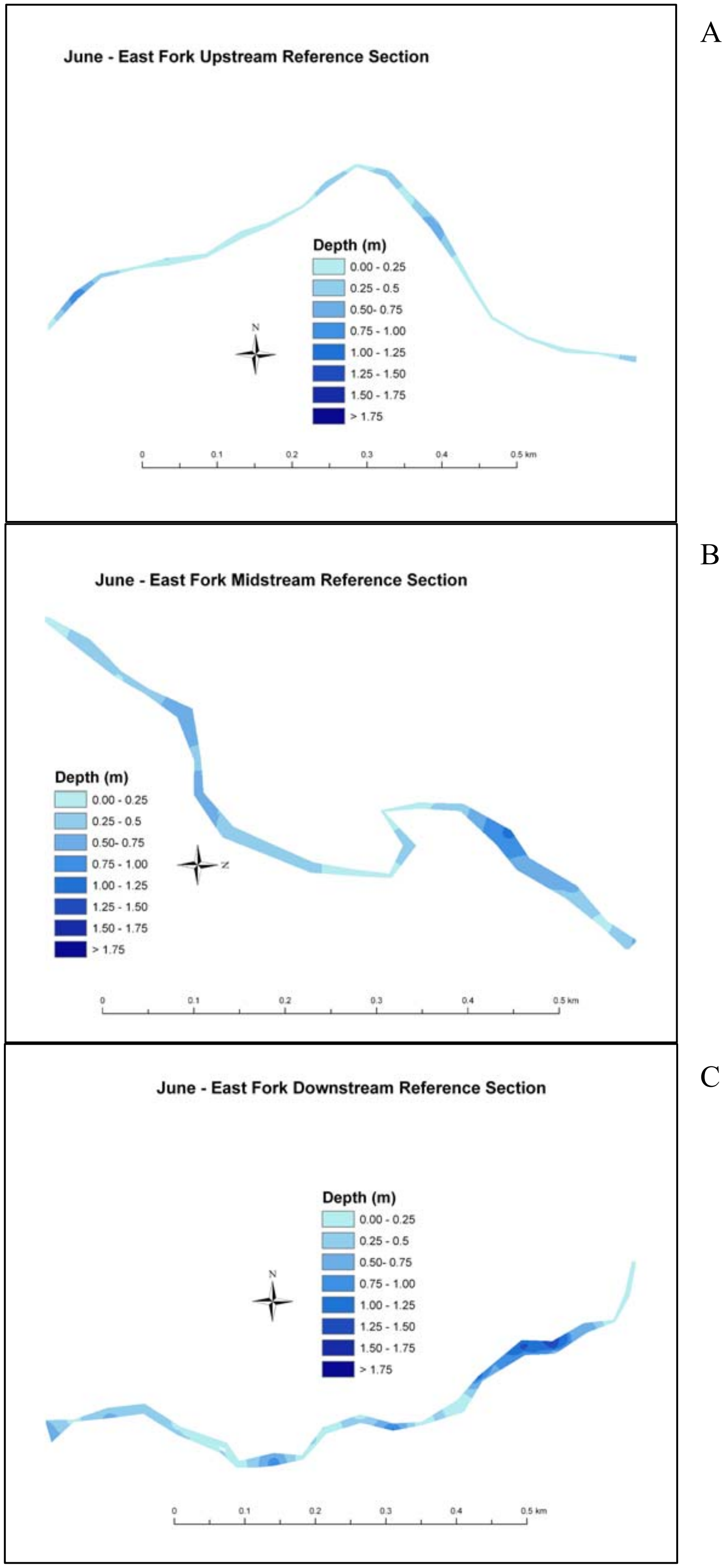
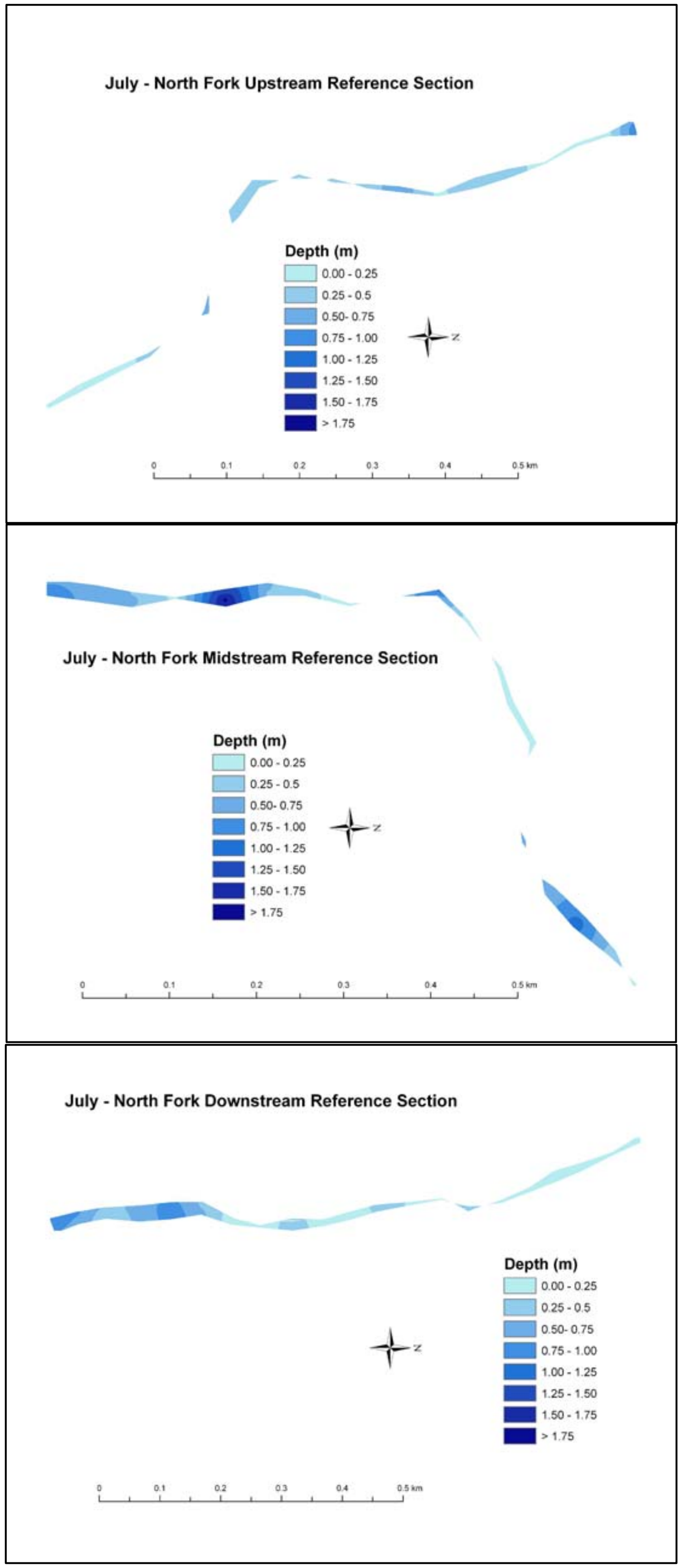


Figure 1.10.–Depth maps for the (A) upstream, (B) midstream, and (C) downstream reference sections on the East Fork of the Illinois Bayou, Arkansas, in June 2006.



A

B

C

Figure 1.11.–Depth maps for the (A) upstream, (B) midstream, and (C) downstream reference sections on the North Fork of the Illinois Bayou, Arkansas, in July 2006.

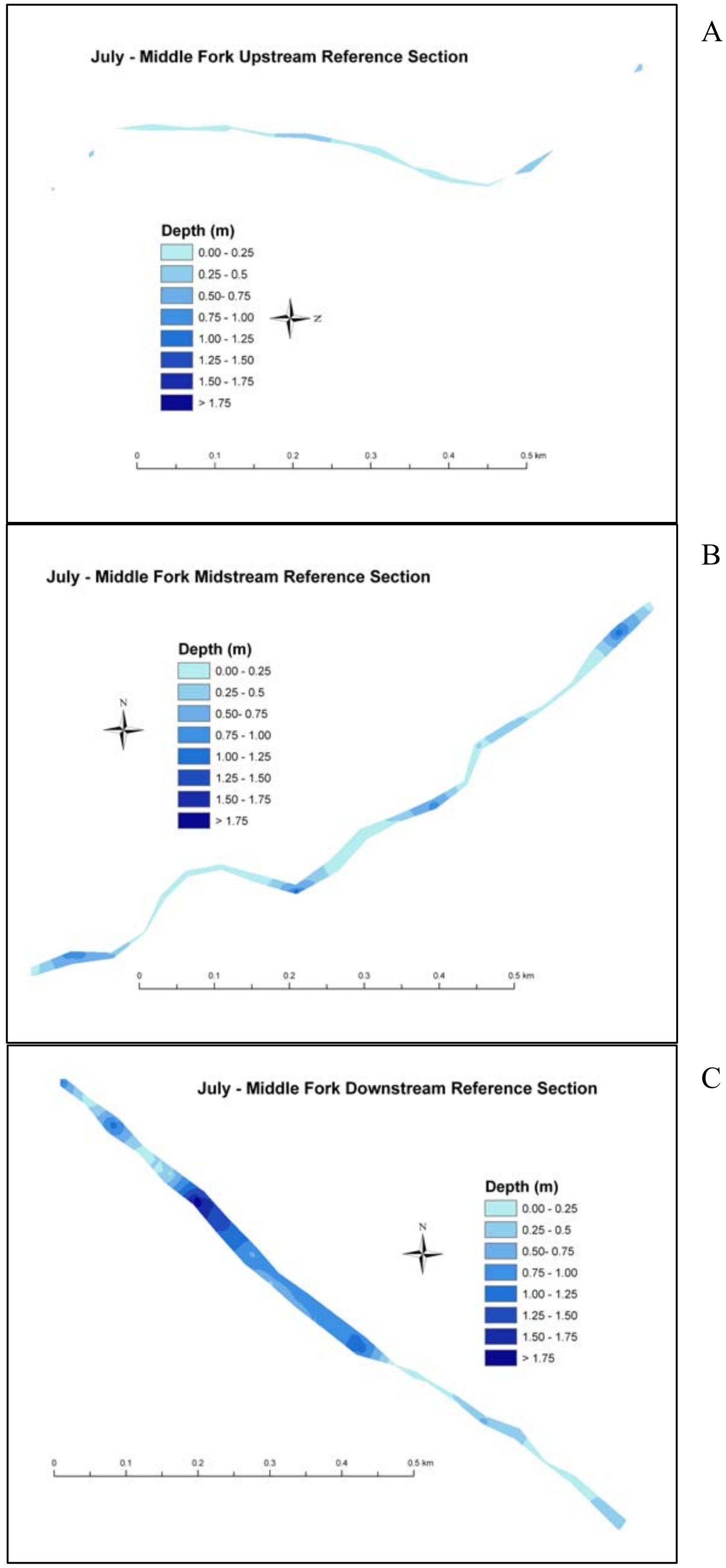
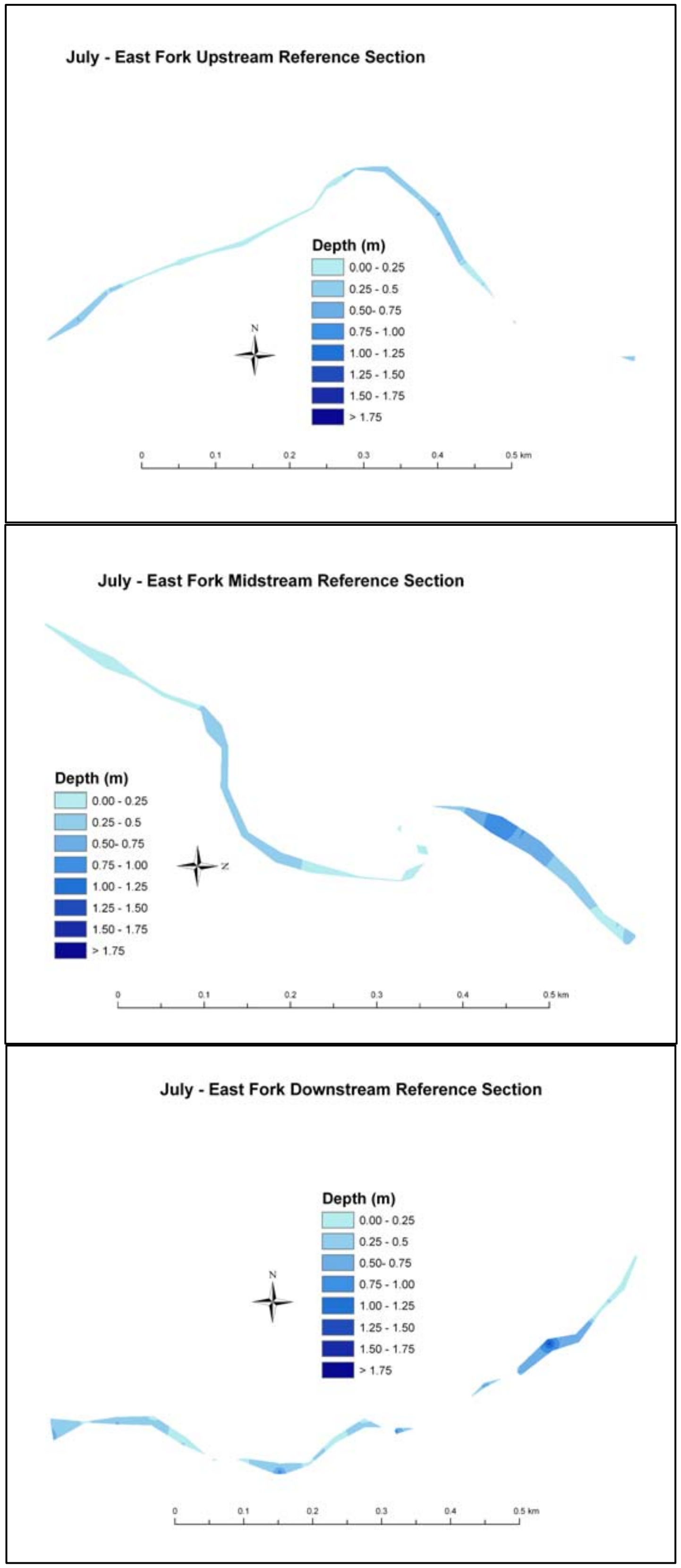


Figure 1.12.–Depth maps for the (A) upstream, (B) midstream, and (C) downstream reference sections on the Middle Fork of the Illinois Bayou, Arkansas, in July 2006.



A

B

C

Figure 1.13.–Depth maps for the (A) upstream, (B) midstream, and (C) downstream reference sections on the East Fork of the Illinois Bayou, Arkansas, in July 2006.

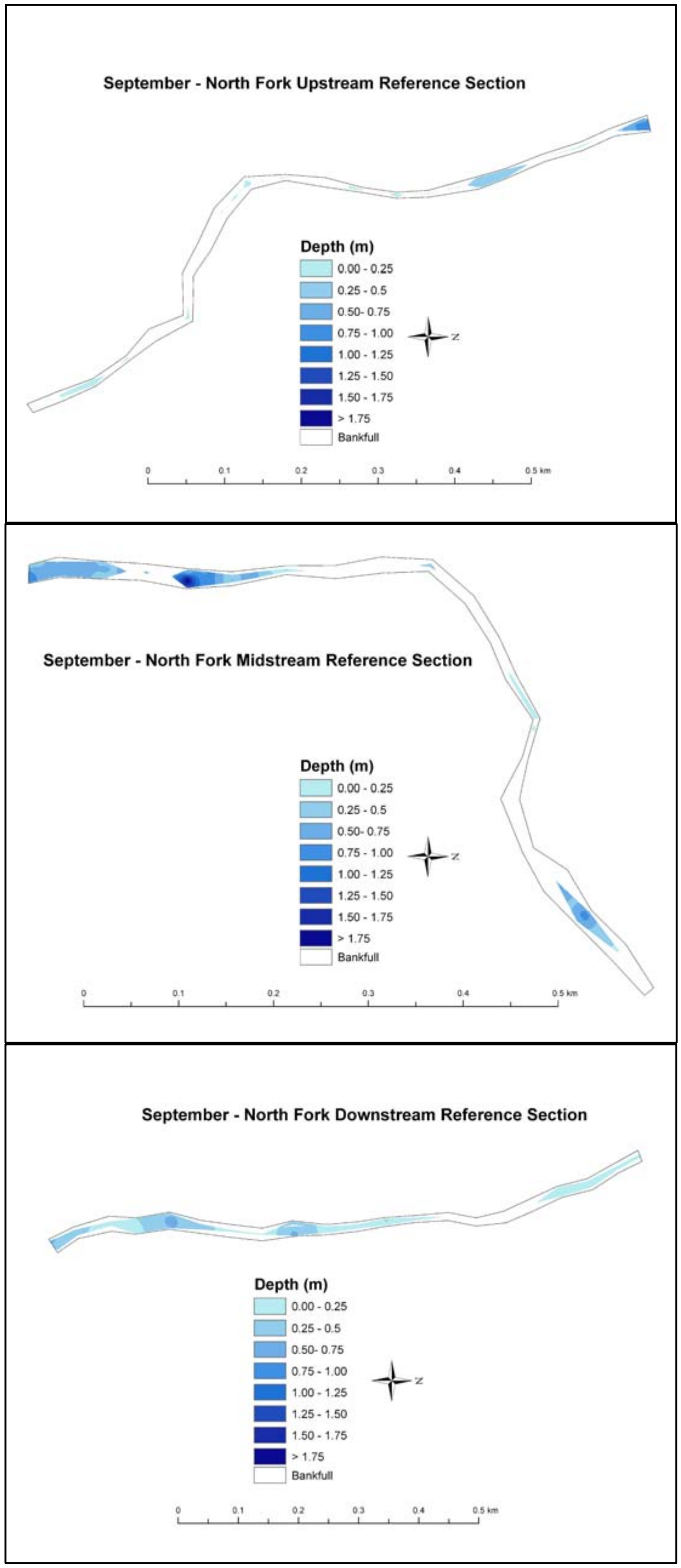


Figure 1.14.–Depth maps for the (A) upstream, (B) midstream, and (C) downstream reference sections on the North Fork of the Illinois Bayou, Arkansas, in September 2006.

A

B

C

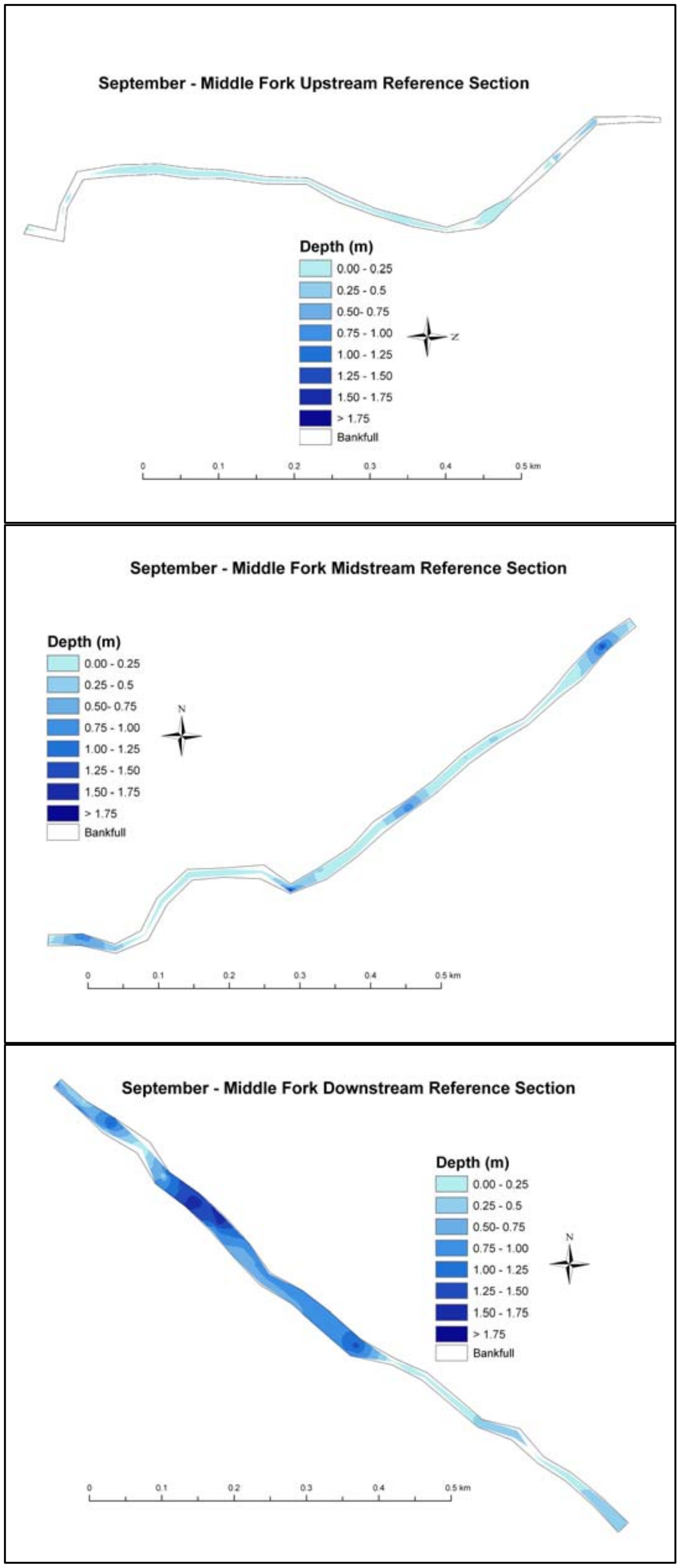


Figure 1.15.–Depth maps for the (A) upstream, (B) midstream, and (C) downstream reference sections on the Middle Fork of the Illinois Bayou, Arkansas, in September 2006.

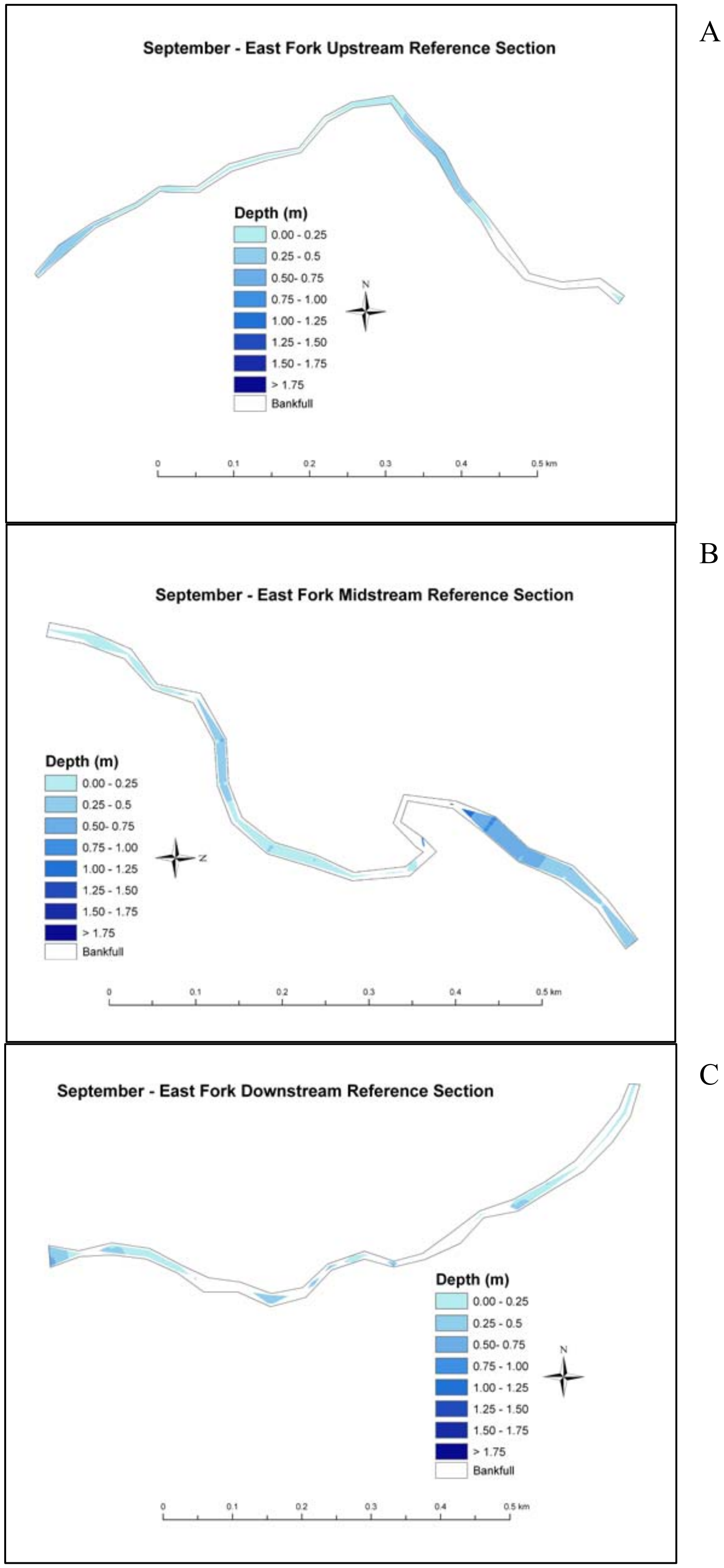


Figure 1.16.–Depth maps for the (A) upstream, (B) midstream, and (C) downstream reference sections on the East Fork of the Illinois Bayou, Arkansas, in September 2006.

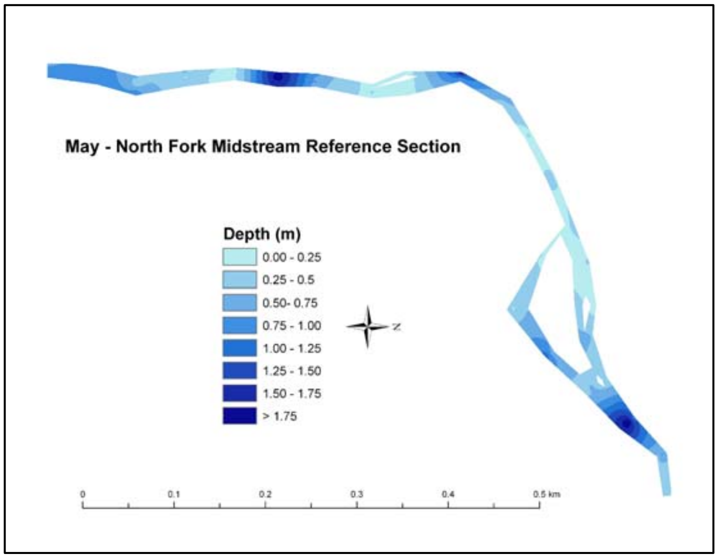


Figure 1.17.–Depth map for the midstream reference section on the North Fork of the Illinois Bayou, Arkansas, during a period of typical spring discharge in May 2007.

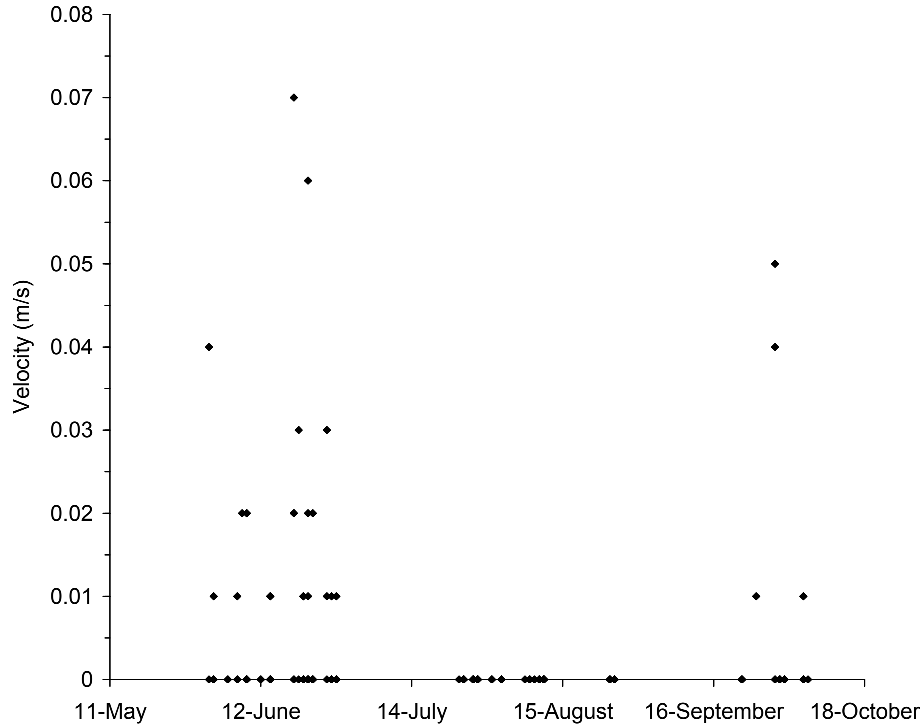


Figure 1.18.–Velocities at telemetry-fish locations in major forks of the Illinois Bayou, Arkansas, from 1 June 2006 to 6 October 2006.

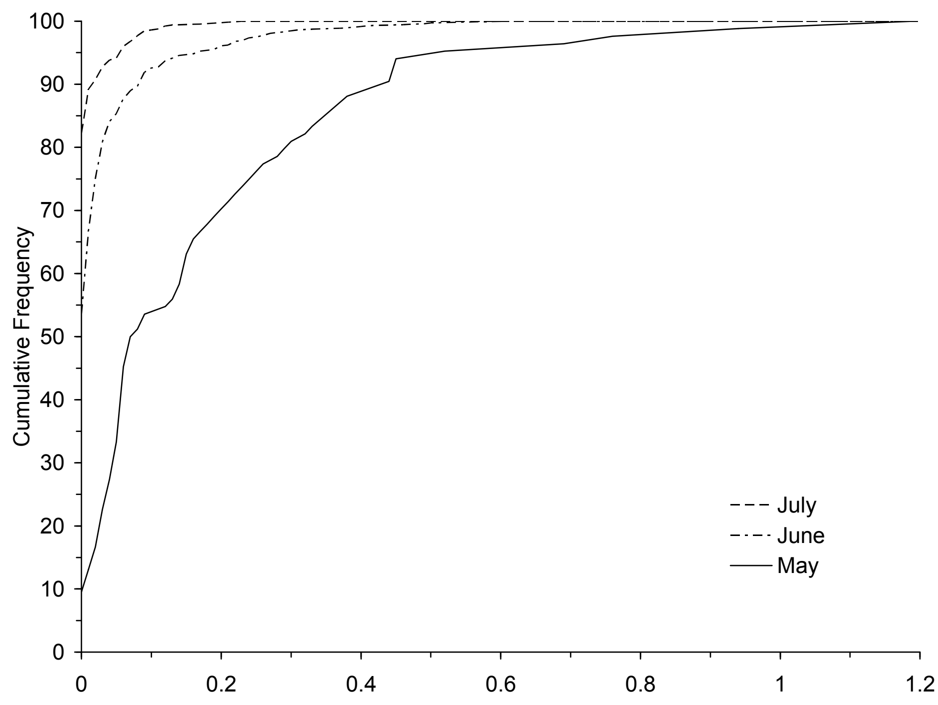


Figure 1.19.–Cumulative frequency curves for measured velocities within reference sections on the Illinois Bayou, Arkansas, in May 2007, and June and July of 2006.

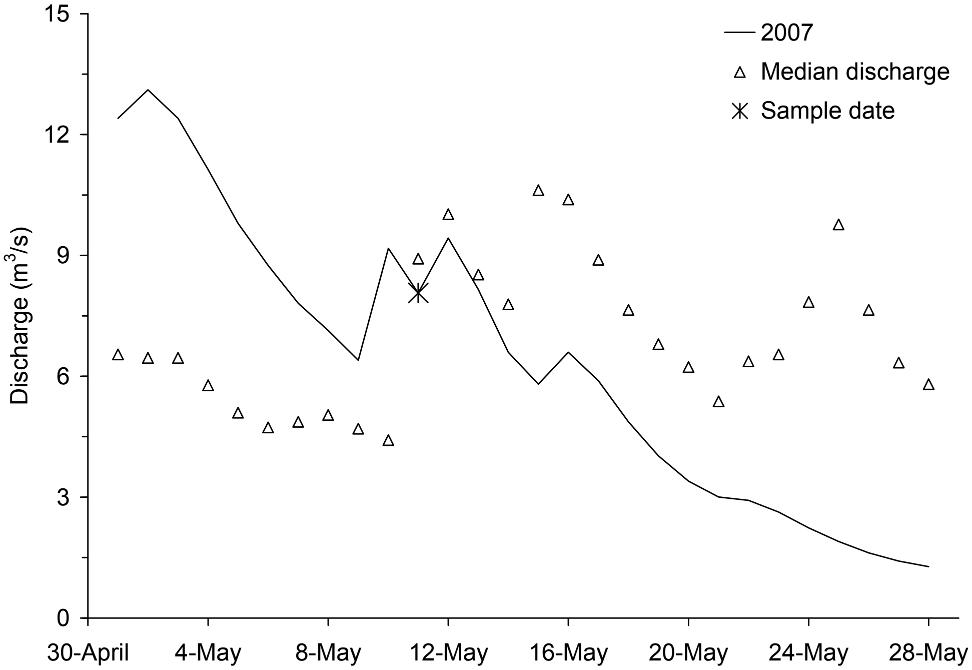


Figure 1.20.–Median discharge (1976-2006) compared to discharge during May 2007 at the Scottsville USGS reference gage on the Illinois Bayou, Arkansas (USGS 2007).

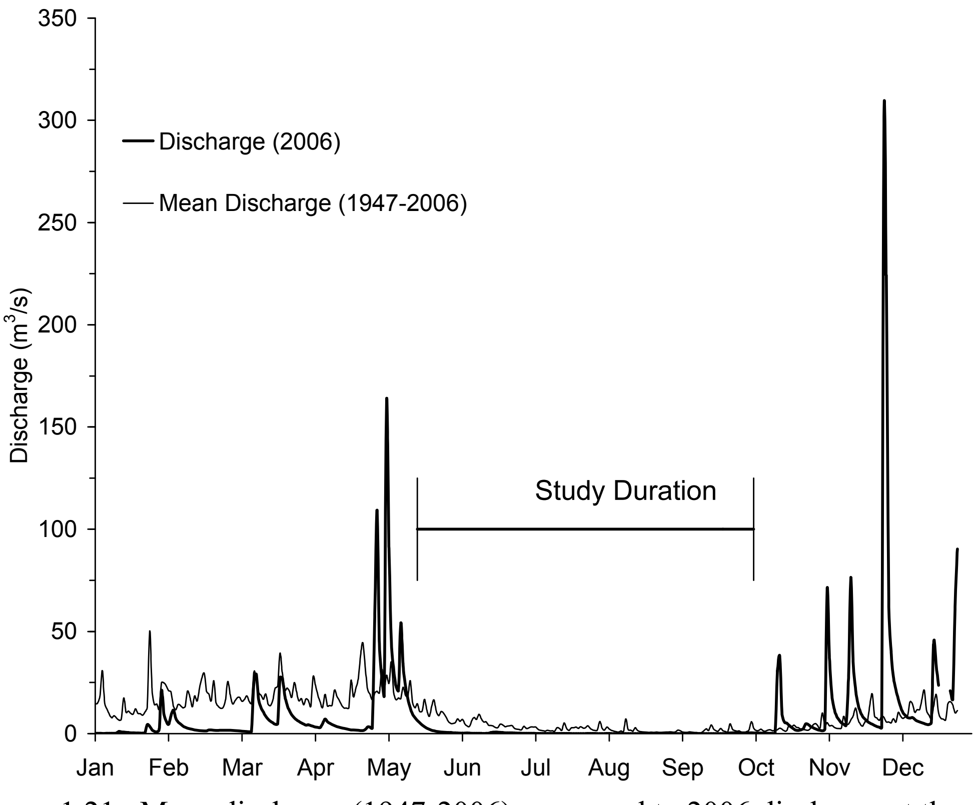


Figure 1.21.–Mean discharge (1947-2006) compared to 2006 discharge at the Scottsville USGS reference gage on the Illinois Bayou, Arkansas (USGS 2007).

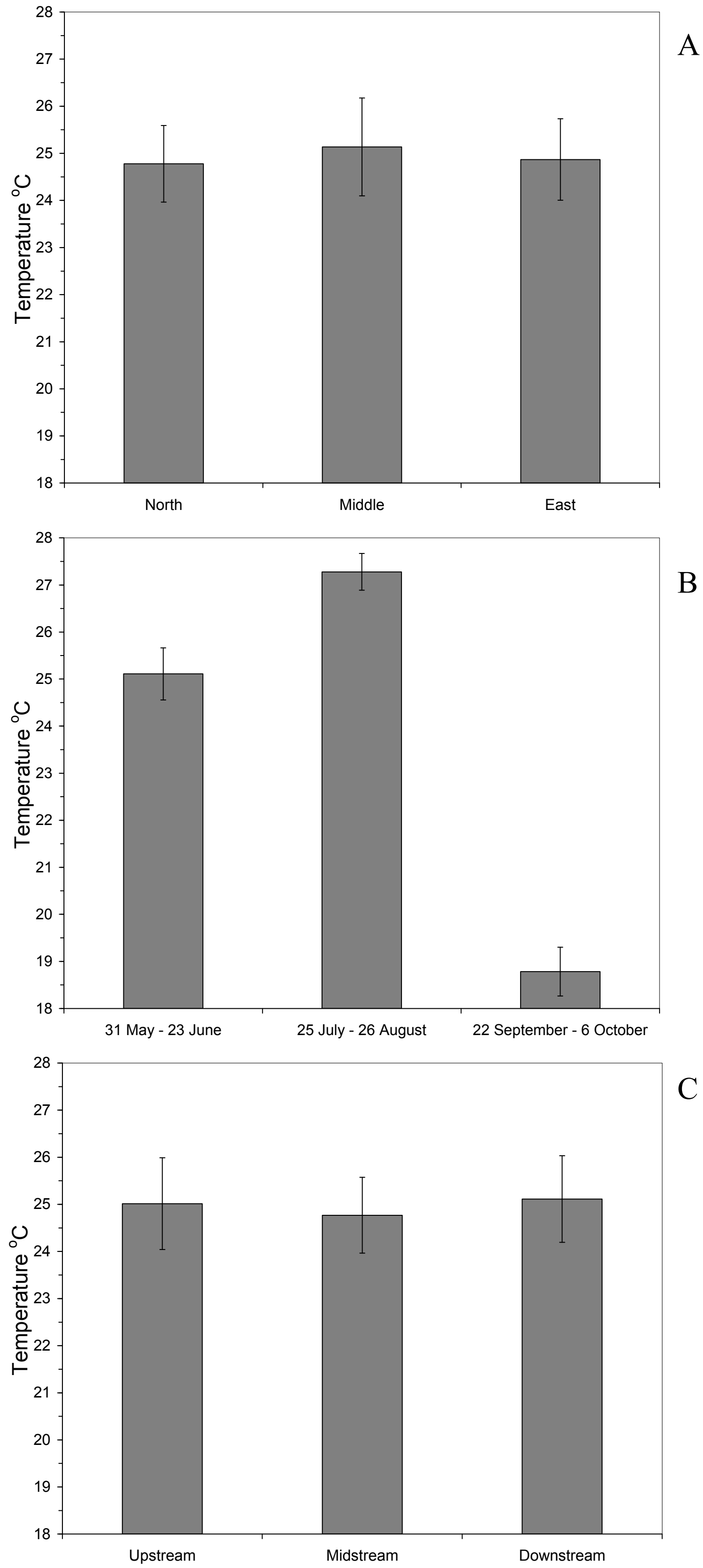


Figure 1.22.–Mean water temperature (± 2 SE) at telemetry-fish locations in the major forks of the Illinois Bayou, Arkansas, based on (A) stream, (B) tracking period, and (C) position (n = 182).

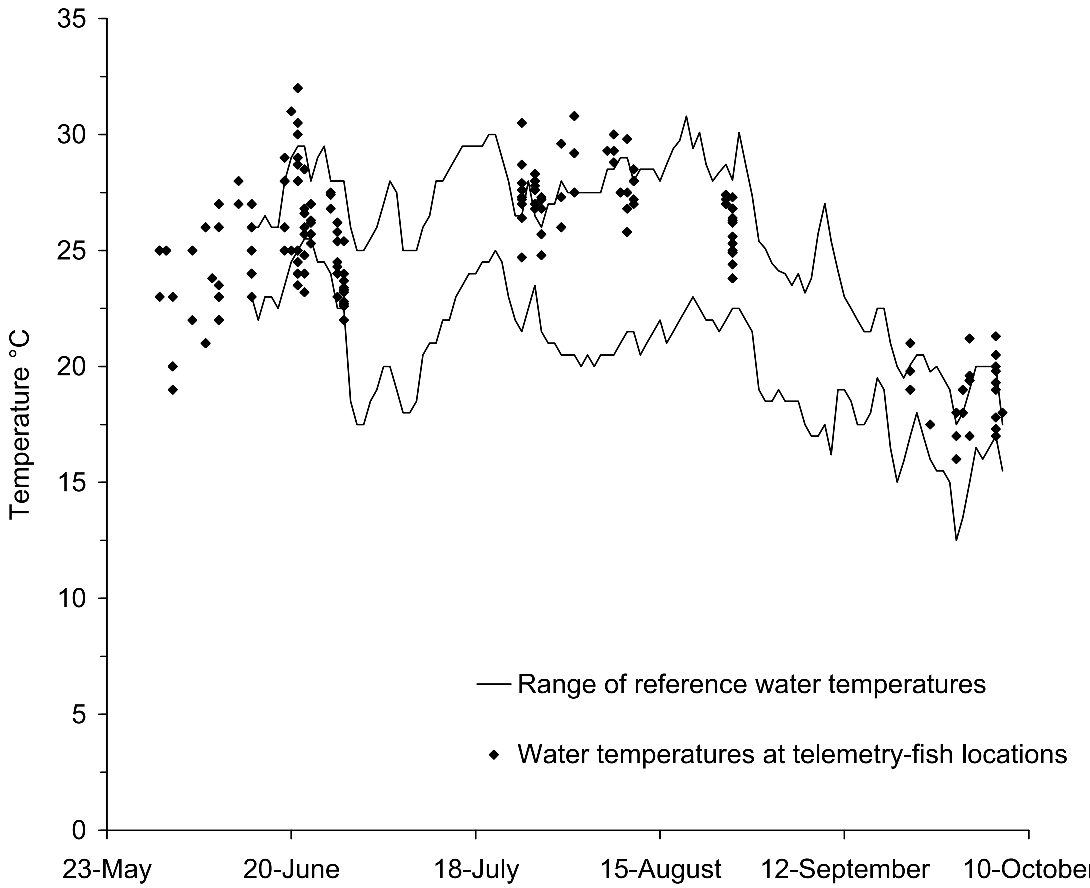


Figure 1.23.–Scatter plot of water temperature at telemetry-fish locations (n = 182) compared to maximum and minimum water temperatures recorded by temperature loggers at upstream and downstream reference locations in the major forks of the Illinois Bayou, Arkansas.

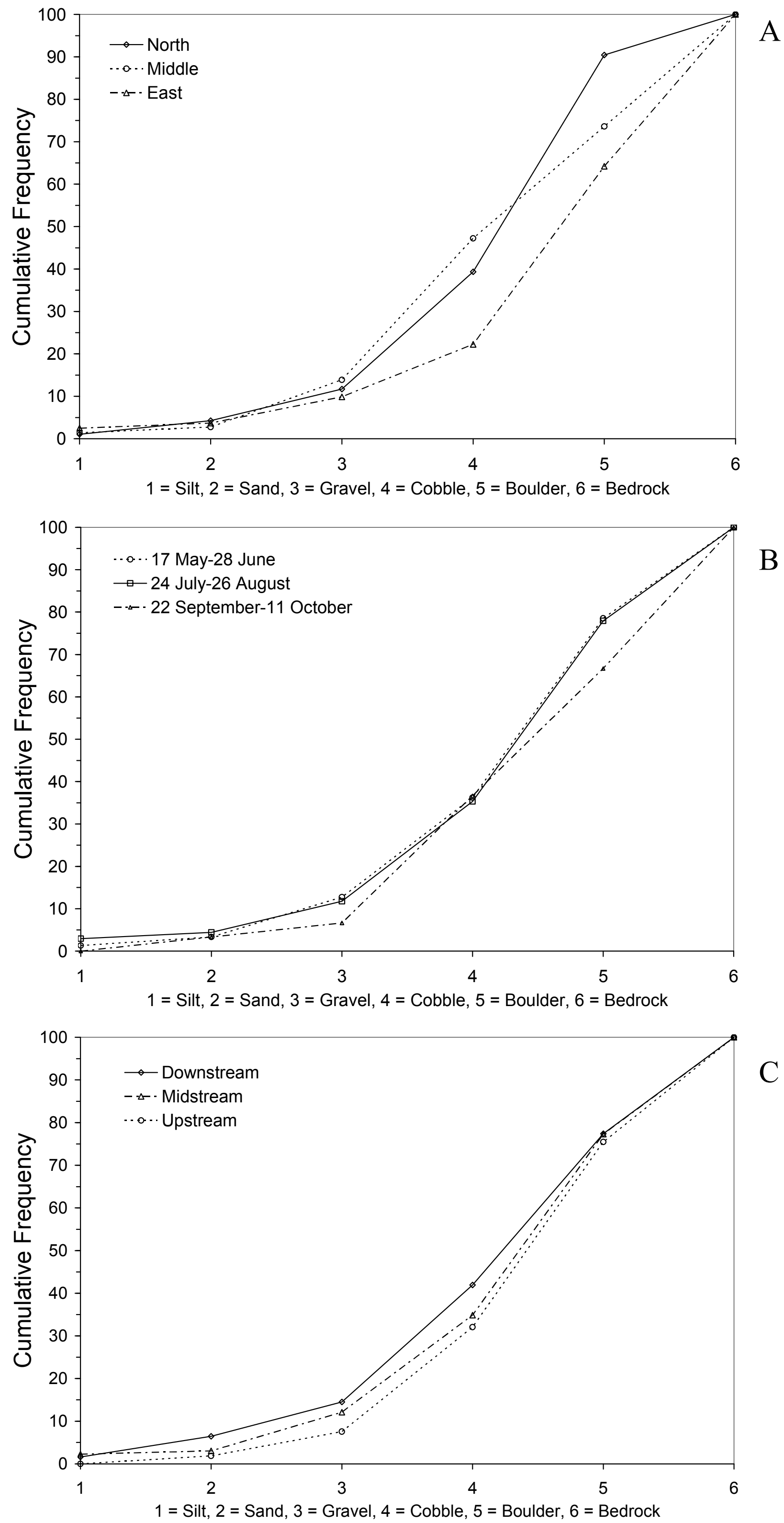


Figure 1.24.–Cumulative frequencies for substrate at telemetry-fish locations within the major forks of the Illinois Bayou, Arkansas, based on (A) stream, (B) tracking period, and (C) position (n = 238).

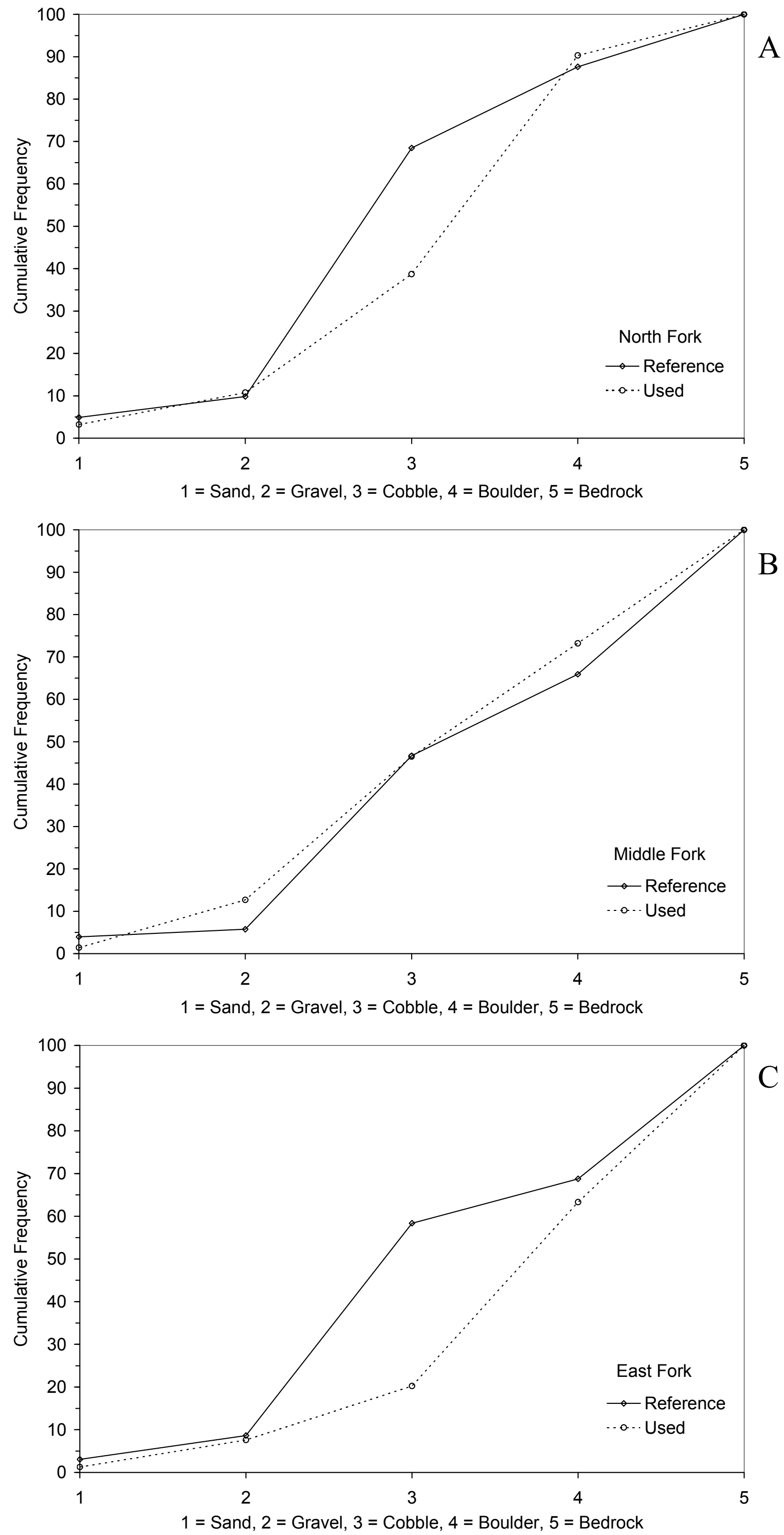


Figure 1.25.–Cumulative frequencies for dominant substrates at telemetry-fish locations relative to substrate within reference sections, on the (A) North, (B) Middle, and (C) East Forks of the Illinois Bayou.

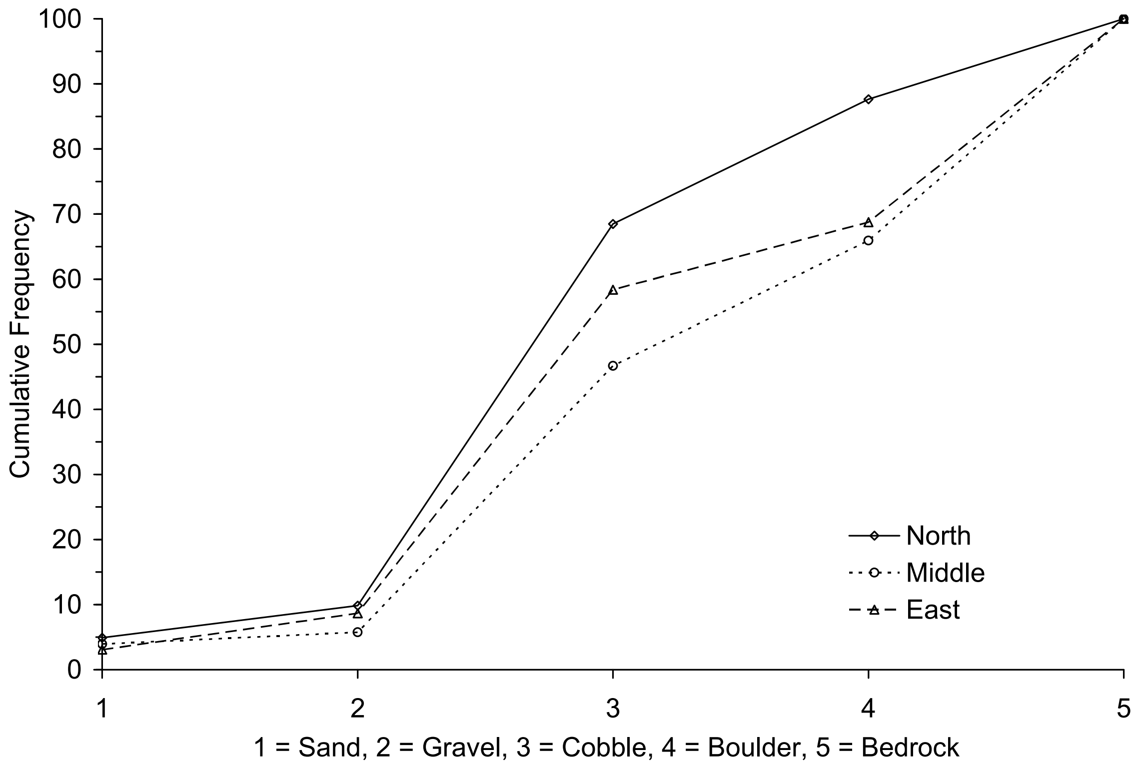


Figure 1.26.–Cumulative frequencies for substrate measured within reference sections on the North, Middle, and East Forks of the Illinois Bayou.

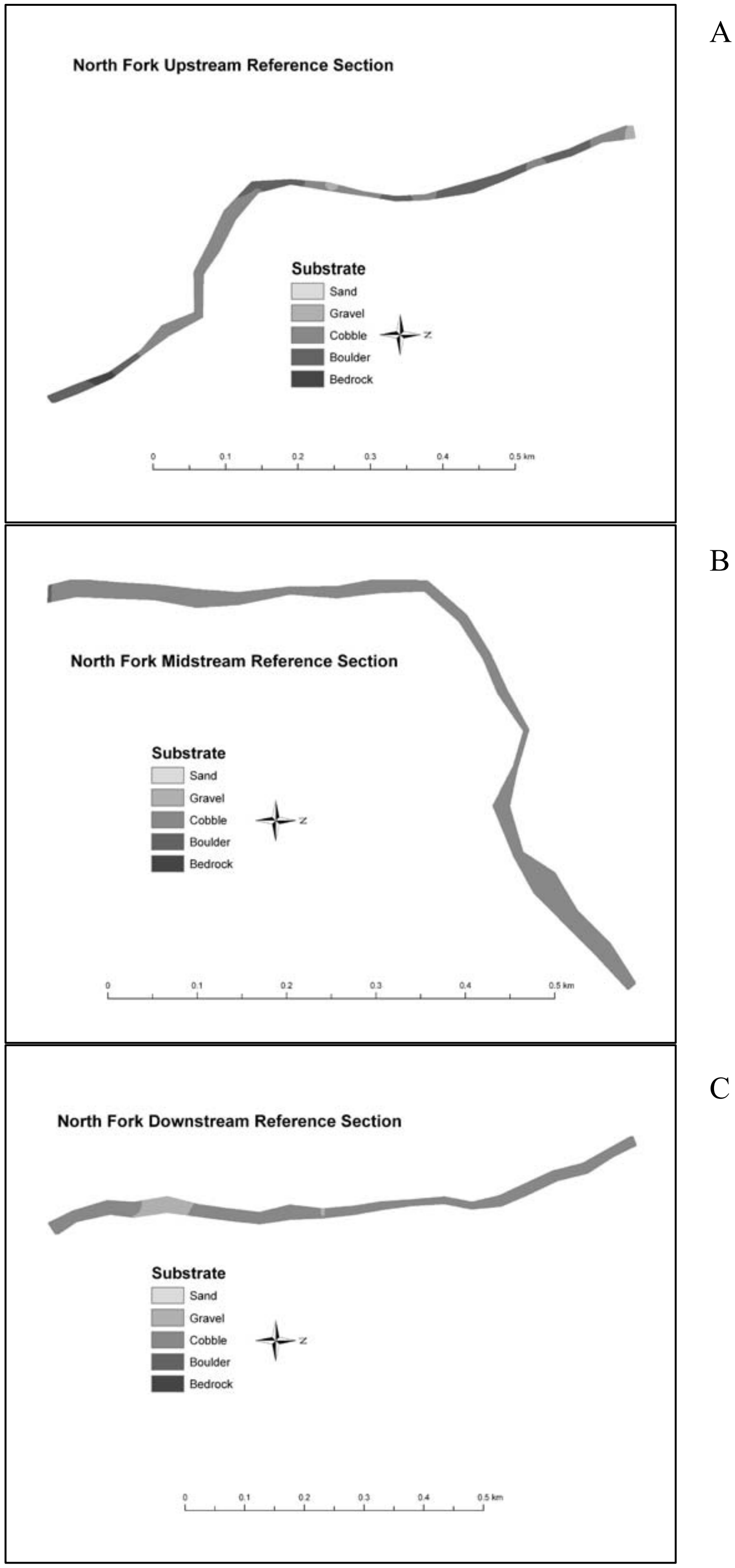


Figure 1.27.–Dominant substrates for the (A) upstream, (B) midstream, and (C) downstream reference sections on the North Fork of the Illinois Bayou, Arkansas, in September 2006.

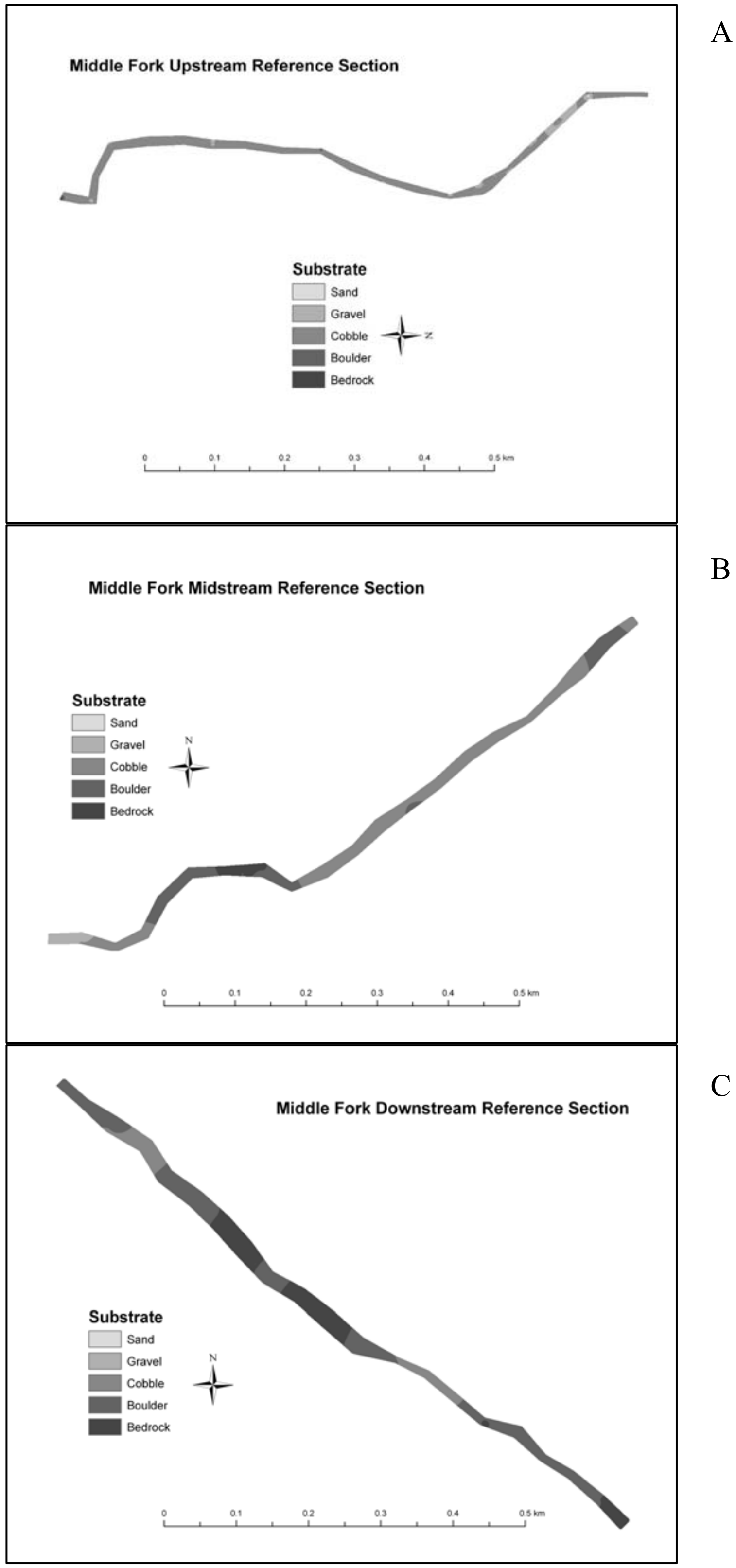
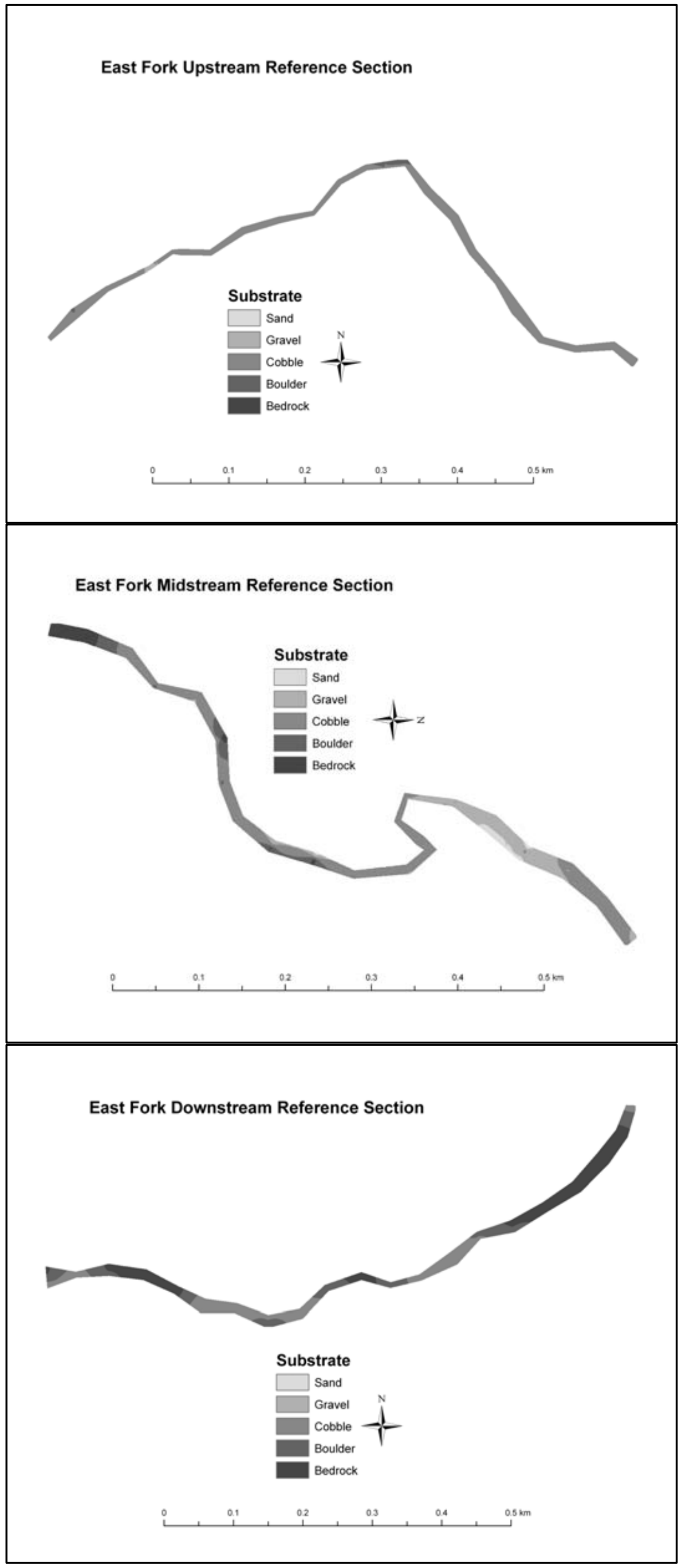


Figure 1.28.–Dominant substrates for the (A) upstream, (B) midstream, and (C) downstream reference sections on the Middle Fork of the Illinois Bayou, Arkansas, in September 2006.



A

B

C

Figure 1.29.–Dominant substrates for the (A) upstream, (B) midstream, and (C) downstream reference sections on the East Fork of the Illinois Bayou, Arkansas, in September 2006.

CHAPTER 2

SMALLMOUTH BASS SURVIVAL AND MOVEMENT IN RESPONSE TO SEASONALLY DISCONTINOUS SURFACE FLOW

Abstract.–Toward the southwestern edge of the smallmouth bass (*Micropterus dolomieu*) natural range, the Boston Mountains Ecoregion of Arkansas contains streams prone to drying during summer due especially to hydrogeologic conditions and high evapotranspiration rates. Fish in drying stream sections can either move avoiding dryness or die. Objectives of this study included estimating smallmouth bass survival and characterizing movement patterns during this potentially critical time. Study streams included the North, Middle, and East Forks of the Illinois Bayou in the Ozark National Forest. Sixty radio-transmitters (20 per stream) were surgically implanted into adult smallmouth bass during May and fish were tracked until October 2006. As summer progressed, most riffle and run habitat dried completely resulting in a series of disconnected, remnant pools. Decreases in wetted area exceeded 55% in some sections. Average net movements were 458, 212, and 429 m in the North, Middle, and East Forks, respectively. Six of 58 (10%) telemetry fish had a net movement of > 1,000 m and only one of those fish was in the Middle Fork. Average movement was greater and more variable in streams with greater losses of wetted area. Movement direction was influenced by the location of stream drying with fish tending to move away from those areas. Although all streams experienced significant loss in wetted areas, the North Fork, which was more accessible to anglers, had the lowest survival rate. The North Fork was also the only stream to have fish mortalities directly related to stream dryness. Middle

and East Forks were less accessible to anglers. Survival rates were lower than those reported for streams with continuous flow throughout the summer and limited angling pressure indicating the likelihood of dryness contributing to mortality. When managing easily accessible streams with hydrologic patterns similar to the Illinois Bayou, resource protection may require limiting angling pressure from late July to early September when stream dryness is most severe.

INTRODUCTION

Smallmouth bass (*Micropterus dolomieu)* are an important top-predator and sportfish in streams throughout the central part of the United States (Funk and Pflieger 1975; Lyons and Kanehl 2002). Smallmouth bass appear to be sensitive to elevated turbidity, high water temperatures, and environmental disturbances, thus it constitutes an excellent indicator species of the health of an aquatic ecosystem (AGFC 1995). Their popularity as a sportfish, pivotal role in the ecosystem, and value as an indicator species make the smallmouth bass a worthwhile study species.

Southern parts of the smallmouth bass range, such as the Boston Mountain Ecoregion of northwest Arkansas, contain streams which tend to stream dry (Hines 1975) especially during the summer when evapotranspiration is high. During this time, riffle and run habitats become rare (Homan et al. 2005). Surviving fish in these systems apparently congregate in remnant pools where they may be more susceptible to predators (Lowe-McConnell 1975; Harvey and Stewart 1991; Gagen et al. 1998) while competing for available resources or move from the drying stream reaches entirely. Smallmouth bass populations located in streams prone to dryness within the Interior Highlands of Arkansas appear to have lower production rates relative to populations in streams with more continuous surface flow (Homan 2005). Thus, the extent and juxtaposition of dry reaches in the Interior Highlands of Arkansas during low flow periods may affect smallmouth bass movement patterns and survival rates.

Smallmouth bass have been described as a sedentary species (Funk 1957; Todd and Rabeni 1989) with strong homing behavior following movement (Larimore 1952). Fajen (1962) found that smallmouth bass, in two small Ozark streams, normally restricted their movements to one distinct pool. Lyons and Kanehl (2002) reviewed available literature and concluded that during the summer, smallmouth bass generally remained in localized areas with net movements totaling less than 1 km. In Otter Creek and the Pecatonica River, Wisconsin, movements were < 200 m (Lyons and Kanehl 2002). Smallmouth bass exhibited few long range (> 2.5 km) movements during the summer in the Wolf and Embarrass Rives of Wisconsin (Langhurst and Schoenike 1990). Although smallmouth bass movement patterns have been extensively studied, further research is needed in harsh or severe conditions which may disrupt normal summer movement patterns.

It is characteristic of smallmouth bass populations to have a total annual mortality rate of about 50% or greater (Coble 1975; Paragamian and Coble 1975). Fishing mortality is often a significant portion of the total annual mortality (Coble 1975). Reed and Rabeni (1989) reviewed 15 studies and found that annual mortality ranged 11-16% in streams with light to no fishing pressure; whereas, annual mortality ranged 42-66% in streams with heavy fishing pressure. Management implications of high fishing mortality rates combined with harsh or severe conditions, such as summer stream dryness, which may cause further morality need to be considered.

The objectives of this study were to estimate smallmouth bass summer survival rates and characterize summer movement patterns during this potentially critical time in the North, Middle, and East Forks of the Illinois Bayou, Arkansas.

METHODS

Study site

This study was on the North Fork, Middle Fork, and East Fork of the Illinois Bayou which drains a portion of the Boston Mountain ecoregion in Arkansas (Figure 2.1). The Illinois Bayou contains pool riffle sequences dominated by bedrock, boulder, and cobble with reduced flow in the summer resulting in a series of isolated pools during late summer, which is typical of the Boston Mountains. The watershed areas for the three study streams were matched at 148 km^2 (± 1 km^2). Maximum bankfull width within the study sections was 33.7 m. All study reaches included study sites from previous studies of smallmouth bass production (Rambo 1998; Homan 2005).

Field methods

Smallmouth bass were captured between 17 May and 7 June 2006 via hook and line sampling presumably after the majority of spawning activity had occurred. Fish were also captured on 26 June 06 in the East Fork to reinsert transmitters that had presumably been expelled from fish within the first month (two from the East Fork and one from the Middle Fork). The entire study area of each stream was sampled in an effort to distribute the radio transmitters (Models F1580 and F1570, Advanced Telemetry Systems, Inc., Isanti, Minnesota) as evenly as possible (Figure 2.2). Immediately upon capture an easting and northing was recorded using a Magellan handheld GPS unit (3 m accuracy), fish were then anesthetized in clove oil at a concentration of 60 mg/L following the methods outlined by Peake (1998). To ensure that the transmitter weight never exceeded 3% of the fish's body weight (Winter 1996; Brown et al. 1999), two sizes of radio-transmitters with trailing-wire antenna were used. A 3.6 g transmitter with an estimated battery life of 200-d was used for fish weighing more than 120 g and a 3.1 g transmitter with an estimated battery life of 146-d was used for fish weighing more than 103 g. A total of 60 transmitters (20 per stream) were deployed with 45 of them 3.6 g and 15 at 3.1 g with both sizes evenly distributed among the three streams.

After the fish were anesthetized, the radio-transmitters were surgically implanted into peritoneal cavities. A 12-15 mm incision was made with a scalpel on the ventral side of the fish starting posterior to the pelvic fins. A small puncture was made 5-10 mm posterior to the incision. The transmitter was then placed in the peritoneal cavity with the antenna exiting through the small puncture. The incision was closed with 2-3 stitches using 2-0 sutures and duramycin was applied to the wounds externally. Stream water was flushed through the gills of the fish throughout the surgical procedure which lasted less than 7 minutes. Telemetry-fish were also marked with t-bar anchor tags (Appendix B). Fish were allowed to recover in the stream within wire baskets until swimming ability had recovered. After the recovery period, which was typically three minutes, fish were released at their original capture location.

Smallmouth bass summer movement was determined by locating fish with radio-telemetry monthly May through October 2006. Study reaches were traveled via kayak with a hand-held receiver (Communications Specialists, Inc.) attached to a Yagi-Uda antenna to scan for transmitter fish. Due to the low turbidity levels in the North, Middle, and East Forks of the Illinois Bayou, visual confirmation of transmitter fish was achieved at 52% of fish locations. When a visual confirmation of a fish was not possible because it was moving, in deep water, or hiding under a rock, I selected the spot that the fish moved through most often for the location to record the easting and northing.

In the Middle and East Forks the upstream sections of the study area contained few smallmouth bass and it is unlikely that missing fish would have moved upstream out of the study area. In the North Fork, the upper extent of the study area coincided with a 1 m waterfall that would have presumably prevented upstream movement of missing telemetry fish out of the study area. Also, there were no major tributaries which fish could have moved into. Approximately 36 km of the Illinois Bayou immediately downstream of the study area was traveled in early September in an effort to locate missing telemetry fish.

Movement was estimated by plotting the GPS locations in ArcGIS. The track log which was created in the GPS while searching for transmitter fish throughout the summer was used as the stream layer for the Illinois Bayou. Cumulative and net movement was calculated for each individual transmitter fish. Cumulative movement was calculated by summing the distance moved every time a fish was located without regard for direction of movement. Net movement was described as the distance and direction between the fish's final and initial locations. Daily cumulative and net movement was calculated by dividing the cumulative and net movement for each individual fish by the number of days elapsed between determining that specific fish's locations.

Survival was estimated using the Kaplan-Meier staggered enter design (Pollock et al. 1989). Most conservative, least conservative and most reliable, summer survival rates were calculated for each study stream. For the most conservative estimate, transmitters that were found in the stream outside of fish during the first tracking period after surgeries were considered to have been either expelled or a fish death resulting from surgery. If a transmitter was recovered in this way after it had been in a fish for at least one tracking period, it was considered a mortality. All missing transmitters were censored in the most conservative survival estimate. Field notes on the condition of the fish and stream were taken into consideration to decide whether the fish had most likely lived or died for the most reliable estimate. All missing fish were considered to be dead for the least conservative survival estimate. Confidence intervals were calculated for all estimates of survival.

Wetted area was measured in June, July and September within three (upstream, midstream, and downstream) 2 km reference sections per stream (Appendix A). Wetted area was also measured in the midstream reference section of the North Fork on 11 May 2007 to provide an estimate of wetted area at a time of the year without stream dryness. When mapping wetted area, transects were established every 50 m along a hip-chain throughout each section. Easting and northing was recorded from the midpoint of each transect and the wetted width was measured with a laser range finder (Sokkia HL3D Handlaser, Lasercraft Inc.). The wetted area of each reference section was mapped in ArcGIS using the wetted widths, GPS waypoints, and hip-chain measurements.

RESULTS

The North Fork had the greatest loss of wetted area (47%) relative to the other upstream sections. The midstream sections of all three streams had similar losses in wetted area ranging from 26% in the Middle Fork to 32% in the North Fork. However, the downstream sections ranged widely with respect to wetted areas throughout the summer. The downstream section of the North Fork had a 28% loss in the wetted area while the Middle Fork increased by 6%. The East Fork downstream section had the largest loss in wetted area losing over 56% of the wetted area throughout the summer.

Relative to average May flow conditions, the wetted area of the midstream reference section of the North Fork (measured in May 2007) was larger than any of the stream sections measured in June 2006. Graphical representation of wetted areas is shown in Figure 2.3 while detailed results are in Table 2.1.

Smallmouth bass summer survival varied among the three forks of the Illinois Bayou. In the North Fork, summer survival was estimated to be 67.1% which was the lowest of the three streams. The Middle and East Forks had relatively similar rates of summer survival at 78.9 and 84.2%. Least conservative estimates of summer survival were considerably different between the three streams. The North Fork least conservative estimate was 27.3% which was much lower than the Middle and East Forks which had relatively similar estimates at 50.0 and 43.7%. Most conservative estimates of summer survival were similar between the three forks and ranged 78.9-89.4%. Graphical representation of summer survival estimates is shown in Figure 2.4 while detailed results with 95% confidence intervals are found in Tables 2.2-2.4.

Seven of 58 (12%) smallmouth bass had cumulative movements > 1,000 m throughout the duration of the study, 6 of 58 (10%) had a net movement of > 1,000 m. Fish 8.804 from the North Fork had the greatest cumulative and net movements totaling 5,480 and 3,860 m. Most fish (44 of 58) showed movements totaling less than 500 m. Average cumulative movements for the North, Middle, and East Forks were 645, 298, and 480 m, respectively, while mean net movements for the North, Middle, and East Forks were 458, 212, and 429 m (Figure 2.5). Average daily cumulative movements for the North, Middle, and East Forks were 7.4, 2.9, and 5.6 m, while mean daily net movements for the North, Middle, and East Forks were 5.6, 2.2, and 5.1 m (Figure 2.6).

Detailed movement results for individual fish in each of the forks are presented in Tables 2.5-2.10. Movement direction was very similar between the North and Middle Fork with 39.0 and 40.2% of the cumulative movement being in the upstream direction indicating that smallmouth bass in these two streams tended to move downstream more often (Table 2.11). Smallmouth bass in the East Fork tended to move upstream more often with 55.3% of the cumulative movements being in the upstream direction (Figure 2.7). Results for the direction of the net movements were very similar with only 34.7 and 36.1% of the net movements in the North and Middle Forks heading upstream, while net upstream movement in the East Fork accounted for 56.2% of the total (Figure 2.8). Graphical representation of net and cumulative movements for individual transmitter fish plotted against the length of time the fish's location was known is located in Figures 2.9 and 2.10.

DISCUSSION

Access by 2WD vehicles was very limited in the Middle and East Forks within the study areas (Appendix C), so fishing pressure was likely also low. Thus, mortality of fish in these two streams was probably dominated by natural mortality resulting from things such as stream dryness or predation. Bare (2005) estimated the survival of adult smallmouth bass to be approximately 84% in a similar Ozark stream for the period of September-March. By combining his dormant season estimates with the growing season survival estimates from this study (79-84%) in East and Middle Forks for the period of May-September an annual survival of 66-71% is estimated. Although most adult smallmouth bass positioned themselves in large pools that contained enough water for fish to survive the dry period of the summer, it appeared that the mortality rates of the adult smallmouth bass were slightly elevated in comparison to those reported for systems that have continuous flow throughout the summer and limited angling pressure. For example, annual survival was 84% in an unexploited population of adult smallmouth bass in a perennial Missouri Ozark stream (Reed and Rabeni 1989). In a review of 15 different studies, Reed and Rabeni (1989) found that annual survival ranged 84-89% in streams with light to no fishing pressure. Thus, it seems likely that the low abundances and production rates for these two streams reported by Homan (2005) can partially be explained by high mortality during the harsh summer conditions.

Although the harsh summer conditions appeared to be associated with elevated mortality rates, only two of the smallmouth bass tracked in this study had deaths that were clearly attributed to stream dryness and both of these fish were in the North Fork. The two pools that the fish were located in became isolated in late June consequently trapping the smallmouth bass. Smallmouth bass in the isolated pools remained alive into early July, but stream dryness became very severe in late July. On August 9, the transmitters of the two fish were recovered on the beds of the pools that had completely dried. The location of this stream reach on the North Fork is within the upper section where numerous primitive campsites were occupied frequently throughout the summer. Three additional fish, also in this stream section, could not be located in July after pools had become isolated. Fish congregating in shrinking remnant pools are more susceptible to predators (Lowe-McConnell 1975; Harvey and Stewart 1991; Gagen et al. 1998). These three missing transmitter fish were probably either killed by a predator or captured by an angler camping in the vicinity. Further evidence for this conclusion is that the only transmitter returned after harvest by an angler came from a campsite located just downstream of this section on the North Fork. Populations of smallmouth bass subjected to heavy fishing pressure often have annual survival less than 50% (Coble 1975; Reed and Rabeni 1989). By combining Bare's (2005) dormant season estimates with the North Fork growing season survival estimates from this study (67%), the annual survival of 56% is estimated, which is substantially lower than the Middle and East Fork estimates. The low survival estimate in the North Fork is likely the result of combining stream dryness and angler access.

The low number of deaths in this study that were clearly attributable to stream dryness could be the due to the tendency of adult smallmouth bass to remain in home pools throughout the summer. Larimore (1952) removed about two dozen smallmouth bass from their summer pools and relocated them to pools that were 1-1.3 km either upstream or downstream. Results from his study indicated that smallmouth bass ranging 180-380 mm display homing behavior with a strong tendency to remain in home pools. Fajen (1962) sampled multiple times for smallmouth bass that were greater than 127 mm in two small Ozark streams by treating the water with cresol. Based on 433 recaptures of 180 different fish, Fajen (1962) concluded that smallmouth bass normally restricted their movements to a single pool. Although the mortality of adult smallmouth bass in the Illinois Bayou does not completely account for the low abundance and production estimates previously reported for this system (Rambo 1998; Homan 2005), I hypothesize that high mortality of sub-adult smallmouth bass before home pools are established could be substantially elevated due to individuals being trapped in drying habitats. Furthermore, sub-adult smallmouth bass may be subjected to elevated cannibalism by larger fish in home pools.

Although the loss of wetted area throughout the summer does not seem to proportionately affect adult smallmouth bass mortality, the amount and location of stream dryness appears to affect adult smallmouth bass summer movement patterns. Smallmouth bass in the Middle Fork, on average, moved less and had showed little variation between individual fish in relation to fish in the North and East Forks. Loss of wetted area was much lower in the Middle Fork than the other two tributaries of the Illinois Bayou. Several fish in the North and East Forks had net movements greater than 2 km and effectively avoided areas that later experienced complete stream dryness; whereas, in the Middle Fork, with fewer long reaches of complete stream dryness, the largest net movement was 1.1 km. Systems with high loss of wetted area likely alter movement patterns by increasing both average net and cumulative movements and especially increase variability by causing a few individual fish to move long distances (> 1 km) to avoid areas of complete stream dryness. The potential influence of these induced movements on smallmouth bass bioenergetics may also be significant.

Stream sections with greater loss of wetted area appeared to affect the direction of adult smallmouth bass movement. Throughout the summer, stream dryness in the upper sections of the North and Middle Forks was more severe than in the downstream sections and in these two streams, the majority of fish movements were also downstream. However, stream dryness in the downstream section of the East Fork was more severe than in the midstream or upstream sections and in this stream, the majority of movement was upstream. Thus, adult smallmouth bass showed a tendency to move away from reaches most prone to dryness toward areas with more perennial water (though a replicated experimental study is needed to confirm this assertion). Other warmwater fishes are known to move from drying stream reaches to areas with more permanent flow (Ross et al. 1985). Albanese et al. (2004) reported that *Nocomis leptocephalus* was more likely to emigrate from intermittent reaches than perennial reaches based on mark-recapture data of 104 fish. Davey et al. (2006) found that *Gobiomorphus breviceps* tended to move to runs as riffles dewatered.

Although a few adult smallmouth bass in the North and East Forks emigrated from areas that lost surface flow, the majority of the fish in this study remained in home pools containing sufficient water for the fish to survive the summer. Consequently, these home pools constituted seasonal refuges (sensu Gagen et al. 1998) during the harsh summer conditions in the Illinois Bayou, and perhaps many streams with similar hydrologic patterns. Unlike most non-game fish (Gagen et al. 1998) the majority of these piscivorous adult fish seem likely to survive the summer even in years when water levels are below normal. However, fish in these pools appear quite vulnerable which may indicate a need to further limit angling harvest from late July to early September when stream dryness is most severe.

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Table 2.1.–Wetted areas of all reference sections in June, July, and September of 2006 as well as the midstream section of the North Fork in May 2007 for comparison to typical spring discharge on the Illinois Bayou, Arkansas.

		Wetted Area (m^2)			
Stream	Section	May 07	June 06	July 06	September 06
North	Upstream		20,000	18,600	10,600
	Midstream	33,900	21,900	19,300	14,900
	Downstream		28,600	26,000	20,600
Middle	Upstream		14,400	11,100	10,800
	Midstream		22,400	19,400	16,500
	Downstream		26,200	27,300	27,800
East	Upstream		13,300	9,000	8,800
	Midstream		23,600	20,900	16,600
	Downstream		24,800	19,200	10,800
Mean	Upstream		15,900	12,900	10,100
	Midstream		22,600	19,900	16,000
	Downstream		26,500	24,200	19,700

Table 2.2.–Most conservative, most reliable, and least conservative survival estimates with 95% upper and lower confidence intervals (UL, LL), for smallmouth bass in the North Fork of the Illinois Bayou, Arkansas, from 18 May to 29 September 2006.

North Fork					
Most Conservative					
Date	At Risk	Deaths	Censored	Added	% Survival estimate (UL, LL)
18-May	0	0	0	13	100 (100, 100)
31-May	13	0	0	7	100 (100, 100)
25-June	20	1	2	0	95.0 (100, 85.4)
10-August	17	2	3	0	83.8 (100, 67.0)
29-September	11	0	7	0	83.8 (100, 67.0)
Most Reliable					
Date	At Risk	Deaths	Censored	Added	% Survival estimate (UL, LL)
18-May	0	0	0	13	100 (100, 100)
31-May	13	0	0	7	100 (100, 100)
25-June	20	1	2	0	95.0 (100, 85.4)
10-August	17	5	0	0	67.1 (88.7, 45.4)
29-September	11	0	7	0	67.1 (88.7, 45.4)
Least Conservative					
Date	At Risk	Deaths	Censored	Added	% Survival estimate (UL, LL)
18-May	0	0	0	13	100 (100, 100)
31-May	13	0	0	7	100 (100, 100)
25-June	20	3	0	0	85.0 (100, 69.4)
10-August	17	5	0	0	60.0 (81.5, 38.5)
29-September	11	6	0	0	27.3 (47.4, 7.1)

Table 2.3.–Most conservative, most reliable, and least conservative survival estimates with 95% upper and lower confidence intervals (UL, LL), for smallmouth bass in the Middle Fork of the Illinois Bayou, Arkansas, from 25 May to 5 October 2006.

Middle Fork

Most Conservative

Date	At Risk	Deaths	Censored	Added	% Survival estimate (UL, LL)
25-May	0	0	0	20	100 (100, 100)
23-June	20	0	1	0	100 (100, 100)
31-July	19	1	0	0	94.7 (100, 84.7)
5-October	18	3	5	0	78.9 (97.3, 60.6)

Most Reliable

Date	At Risk	Deaths	Censored	Added	% Survival estimate (UL, LL)
25-May	0	0	0	20	100 (100, 100)
23-June	20	0	1	0	100 (100, 100)
31-July	19	1	0	0	94.7 (100, 84.7)
5-October	18	3	5	0	78.9 (97.3, 60.6)

Least Conservative

Date	At Risk	Deaths	Censored	Added	% Survival estimate (UL, LL)
25-May	0	0	0	20	100 (100, 100)
23-June	20	1	0	0	95.0 (100, 85.4)
31-July	19	1	0	0	90.0 (100, 76.9)
5-October	18	8	0	0	50.0 (71.9, 28.1)

Table 2.4.–Most conservative, most reliable, and least conservative survival estimates with 95% upper and lower confidence intervals (UL, LL), for smallmouth bass in the East Fork of the Illinois Bayou, Arkansas, from 23 May to 30 September 2006.

East Fork

Most Conservative

Date	At Risk	Deaths	Censored	Added	% Survival estimate (UL, LL)
23-May	0	0	0	17	100 (100, 100)
10-June	17	0	3	3	100 (100, 100)
1-July	17	0	1	3	100 (100, 100)
26-July	19	0	0	0	100 (100, 100)
30-September	19	2	7	0	89.5 (100, 75.7)

Most Reliable

Date	At Risk	Deaths	Censored	Added	% Survival estimate (UL, LL)
23-May	0	0	0	17	100 (100, 100)
10-June	17	0	3	3	100 (100, 100)
1-July	17	0	1	3	100 (100, 100)
26-July	19	0	0	0	100 (100, 100)
30-September	19	3	6	0	84.2 (100, 67.8)

Least Conservative

Date	At Risk	Deaths	Censored	Added	% Survival estimate (UL, LL)
23-May	0	0	0	17	100 (100, 100)
10-June	17	2	1	3	88.2 (100, 72.9)
1-July	17	1	0	3	83.0 (100, 65.6)
26-July	19	0	0	0	83.0 (100, 65.6)
30-September	19	9	0	0	43.7 (64.5, 22.9)

Table 2.5.–Detailed cumulative movements for individual telemetry-fish in the North Fork of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

North Fork			
Transmitter ID	Movement (m)	Transmitter Life (days)	Movement (m/day)
8.052	118	29	4
8.072	874	86	10
8.111	47	73	1
8.133	34	14	2
8.292	340	73	5
8.314	965	119	8
8.393	127	73	2
8.412	41	42	1
8.533	273	86	3
8.576	620	122	5
8.804	5,484	135	41
8.893	266	14	19
8.952	111	122	1
9.013	237	104	2
9.171	1,205	101	12
9.242	58	37	2
9.254	1,045	85	12
9.353	539	85	6
9.372	373	37	10
9.412	133	84	2
Sum =	12,890	1,521	148
Average =	645	76	7
Standard Dev. =	1,197	37	9
Standard Error =	268	8	2

Table 2.6.–Detailed cumulative movements for individual telemetry-fish in the Middle Fork of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

Middle Fork			
Transmitter ID	Movement (m)	Transmitter Life (days)	Movement (m/day)
8.024	385	135	3
8.091	603	127	5
8.172	19	70	0
8.234	465	126	4
8.332	96	124	1
8.371	569	133	4
8.433	345	133	3
8.452	483	133	4
8.472	55	64	1
8.511	135	126	1
8.682	57	66	1
8.743	99	69	1
8.862	248	133	2
8.982	27	68	0
9.052	80	126	1
9.092	42	126	0
9.133	1,087	96	11
9.332	174	61	3
9.451	691	69	10
Sum =	5,659	1,985	54
Average =	298	104	3
Standard Dev. =	291	31	3
Standard Error =	67	7	1

Table 2.7.–Detailed cumulative movements for individual telemetry-fish in the East Fork of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

East Fork			
Transmitter ID	Movement (m)	Transmitter Life (days)	Movement (m/day)
8.152	56	64	1
8.212	26	64	0
8.254	1,192	98	12
8.274	2,008	131	15
8.353	12	98	0
8.491	146	64	2
8.533	455	134	3
8.592	377	66	6
8.623	240	131	2
8.922	118	131	1
9.032	119	133	1
9.111	552	133	4
9.150	14	51	0
9.190	72	64	1
9.217	2,833	67	42
9.273	72	64	1
9.311	427	51	8
9.390	67	98	1
9.433	335	64	5
Sum =	9,122	1,706	107
Average =	480	90	6
Standard Dev. =	752	33	10
Standard Error =	172	7	2

Table 2.8.–Detailed net movements for individual telemetry-fish on the North Fork of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

North Fork			
Transmitter ID	Movement (m)	Movement (m/day)	Direction
8.052	118	4	Upstream
8.072	883	10	Upstream
8.111	4	0	Downstream
8.133	34	2	Upstream
8.292	38	1	Downstream
8.314	590	5	Upstream
8.393	100	1	Downstream
8.412	31	1	Upstream
8.533	65	1	Downstream
8.576	532	4	Upstream
8.804	3,857	29	Downstream
8.893	266	19	Downstream
8.952	111	1	Downstream
9.013	57	1	Upstream
9.171	542	5	Upstream
9.242	58	2	Upstream
9.254	1,009	12	Downstream
9.353	508	6	Downstream
9.372	333	9	Upstream
9.412	21	0	Downstream
Sum =	9,158	113	
Average =	458	6	
Standard Dev. =	855	7	
Standard Error =	191	2	

Table 2.9.–Detailed net movements for individual telemetry-fish in the Middle Fork of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

Middle Fork			
Transmitter ID	Movement (m)	Movement (m/day)	Direction
8.024	88	1	Upstream
8.091	561	4	Downstream
8.172	2	0	Upstream
8.234	228	2	Upstream
8.332	1	0	Downstream
8.371	297	2	Downstream
8.433	64	0	Upstream
8.452	437	3	Downstream
8.472	55	1	Upstream
8.511	14	0	Upstream
8.682	16	0	Downstream
8.743	99	1	Upstream
8.862	205	2	Upstream
8.982	3	0	Upstream
9.052	52	0	Downstream
9.092	11	0	Upstream
9.133	1,041	11	Downstream
9.332	166	3	Downstream
9.451	681	10	Upstream
Sum =	4,022	41	
Average =	212	2	
Standard Dev. =	283	3	
Standard Error =	65	1	

Table 2.10.–Detailed net movements for individual telemetry-fish in the East Fork of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

East Fork			
Transmitter ID	Movement (m)	Movement (m/day)	Direction
8.152	29	0	Upstream
8.212	6	0	Upstream
8.254	1,186	12	Upstream
8.274	2,007	15	Upstream
8.353	12	0	Upstream
8.491	64	1	Upstream
8.533	273	2	Upstream
8.592	353	5	Downstream
8.623	183	1	Upstream
8.922	14	0	Upstream
9.032	39	0	Downstream
9.111	291	2	Upstream
9.150	14	0	Upstream
9.190	65	1	Downstream
9.217	2,841	42	Downstream
9.273	70	1	Upstream
9.311	427	8	Upstream
9.390	57	1	Downstream
9.433	210	3	Downstream
Sum =	8,143	98	
Average =	429	5	
Standard Dev. =	767	10	
Standard Error =	176	2	

Table 2.11.–Comparison between movement direction by telemetry-fish and the loss of wetted areas of all reference sections from June to September of 2006, within the major forks of the Illinois Bayou, Arkansas.

	Cumulative Movement Direction (%)		Net Movement Direction (%)		% Loss of Wetted Area June-September		
Stream	Upstream	Downstream	Upstream	Downstream	Upstream Section	Midstream Section	Downstream Section
North Fork	39.0	60.5	34.7	65.3	47.0	32.1	28.0
Middle Fork	40.2	58.8	36.1	63.9	24.9	26.2	6.1% increase
East Fork	55.3	44.0	56.2	43.8	33.9	29.7	56.4

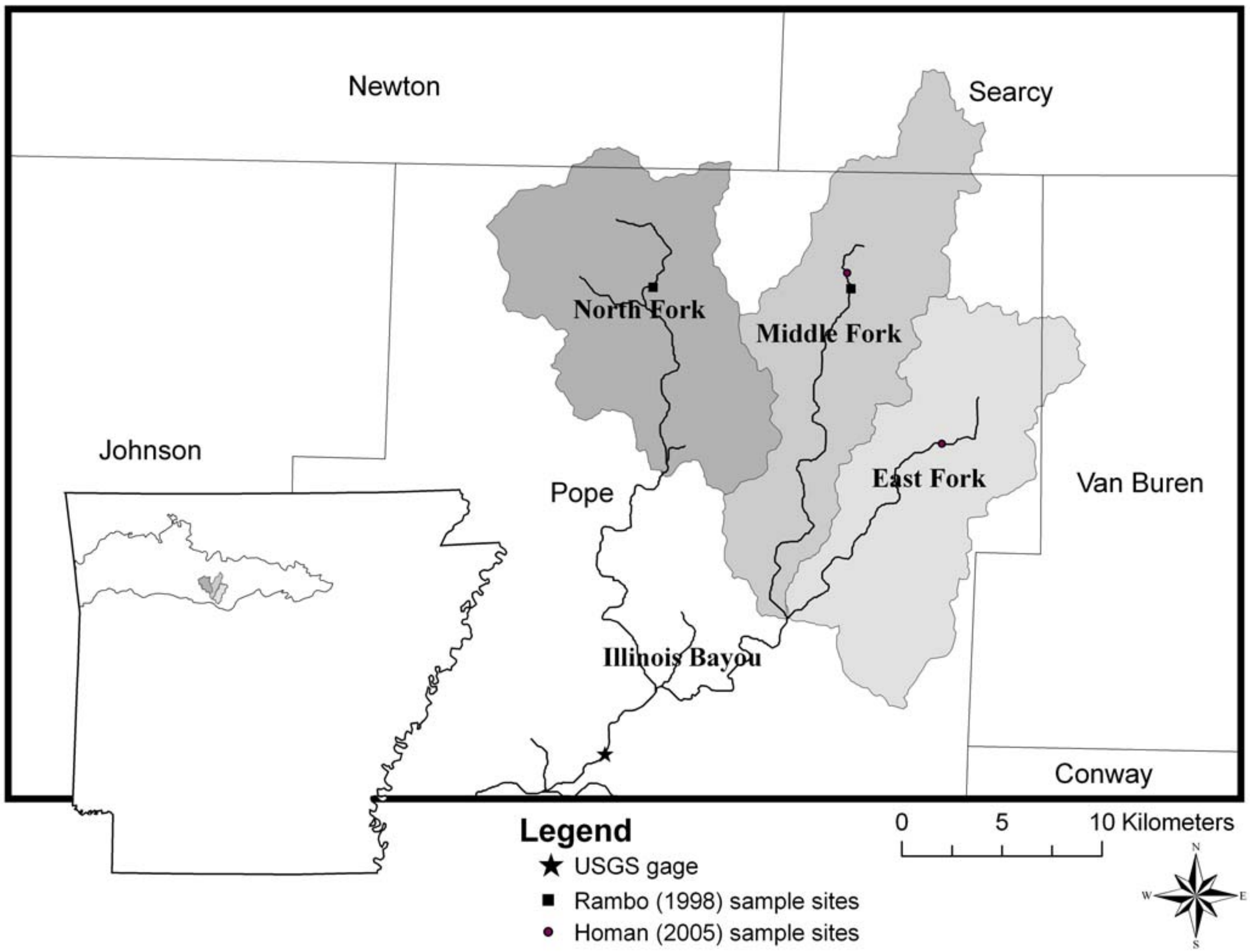


Figure 2.1.–Map of 2006 study watersheds (148 km^2) also showing counties, USGS gage location, and sites of previous smallmouth bass studies.

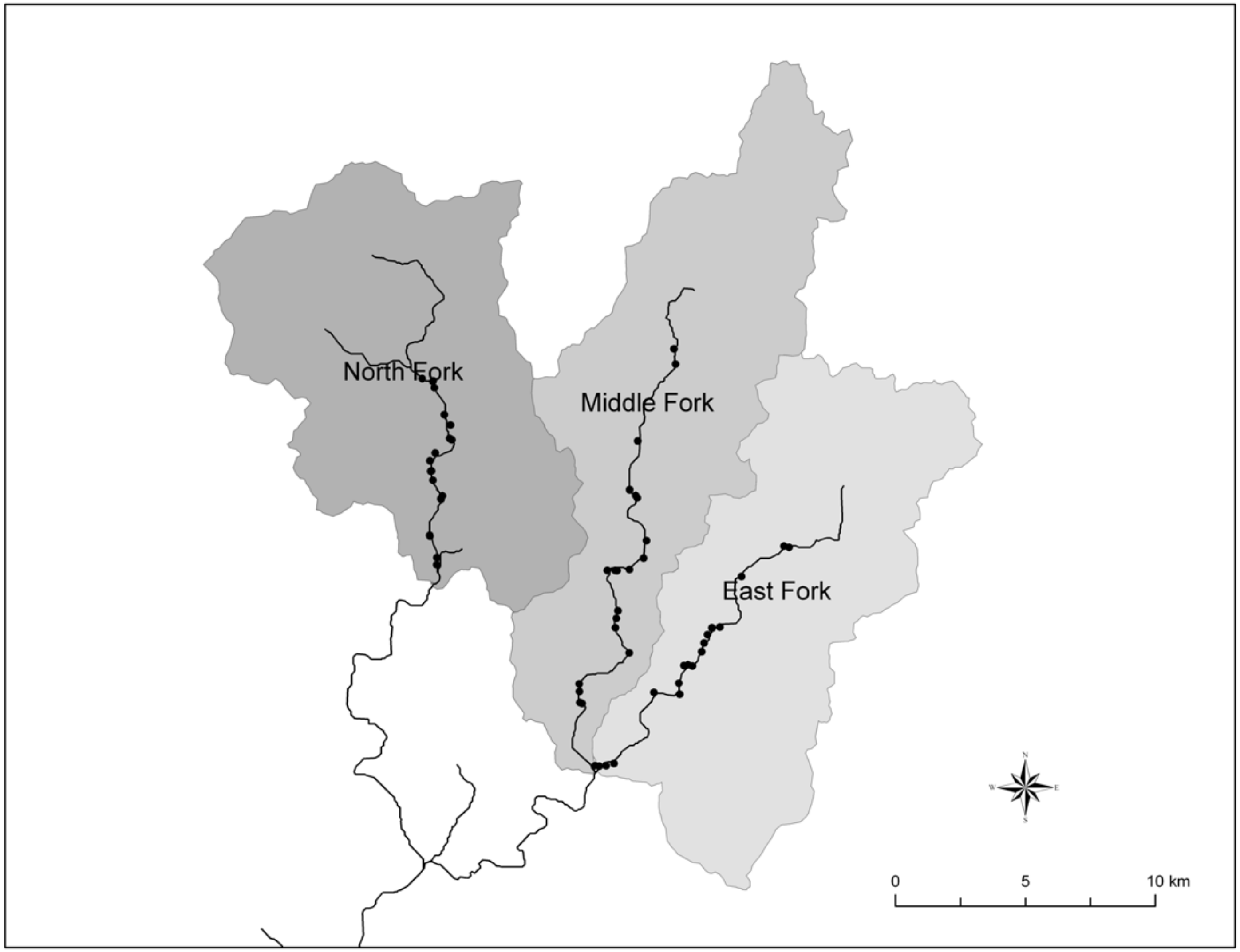


Figure 2.2.–Map of initial telemetry-fish locations shown as solid circles in the major forks of the Illinois Bayou drainage network.

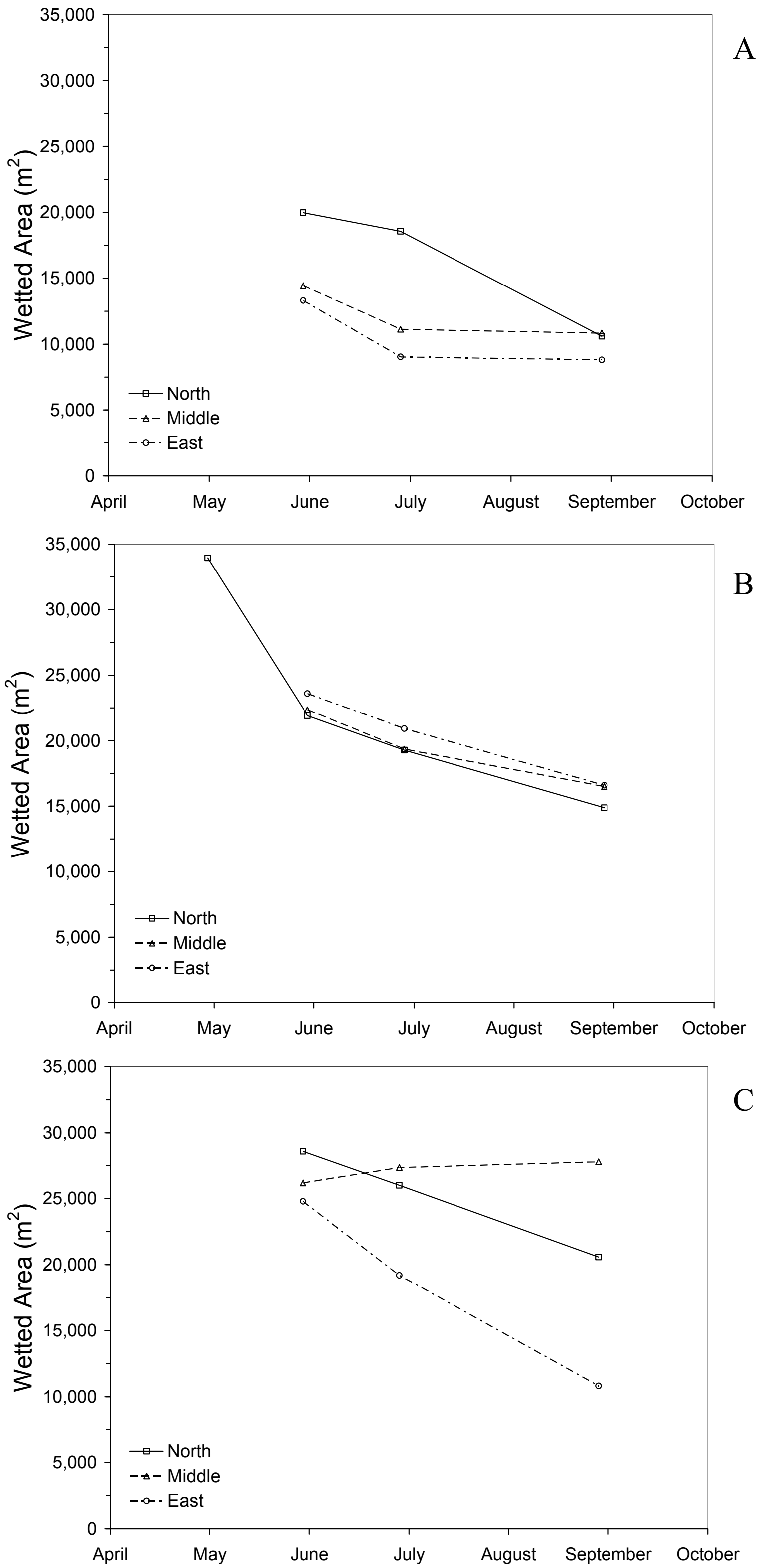


Figure 2.3.–Wetted areas in (A) upstream, (B) midstream, and (C) downstream reference sections in May 2007 and June, July, and September of 2006 within the major forks of the Illinois Bayou, Arkansas,

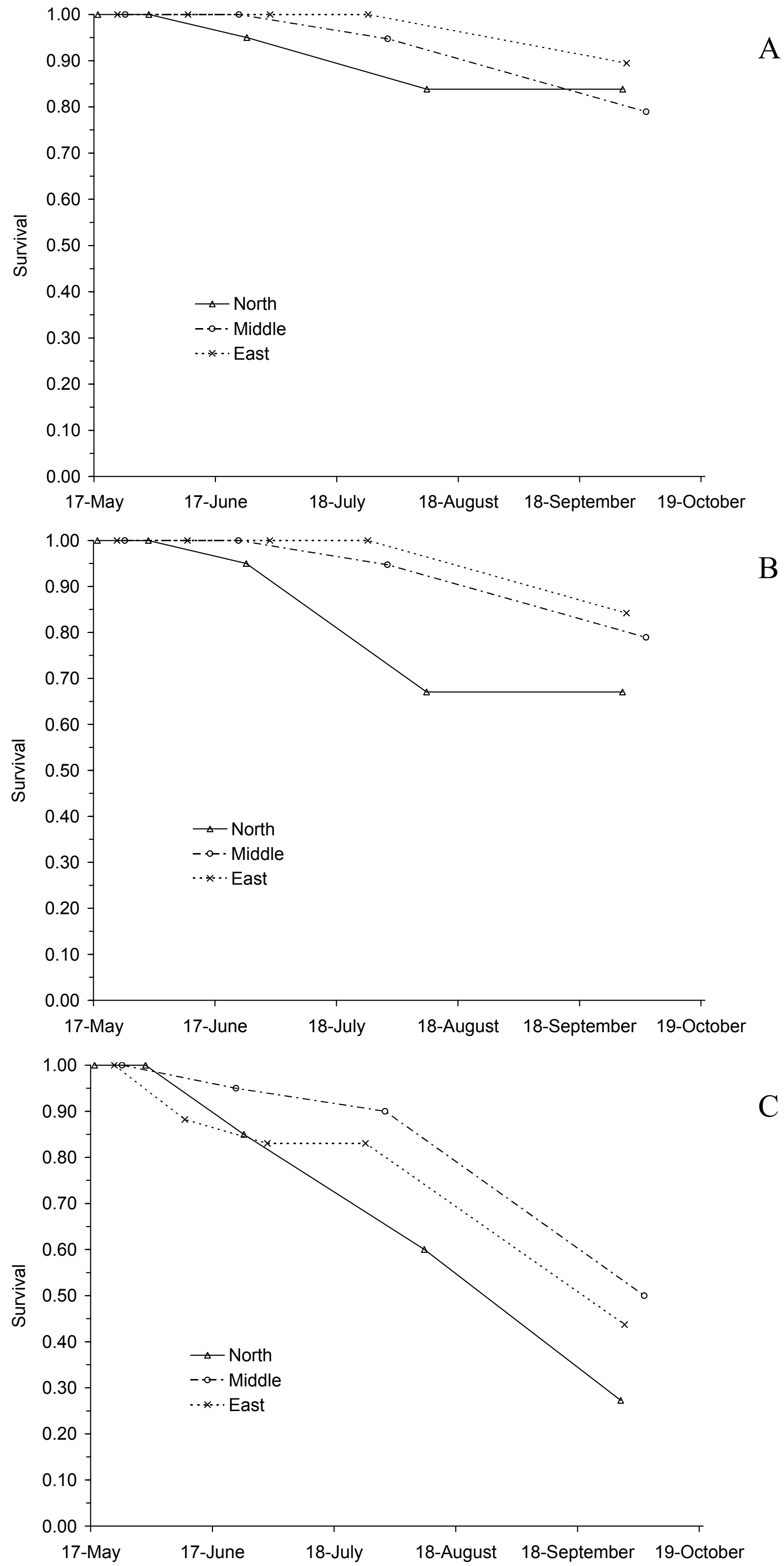


Figure 2.4.–Survival of smallmouth bass based on (A) most conservative, (B) most reliable, and (C) least conservative estimates in the North, Middle, and East Forks of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

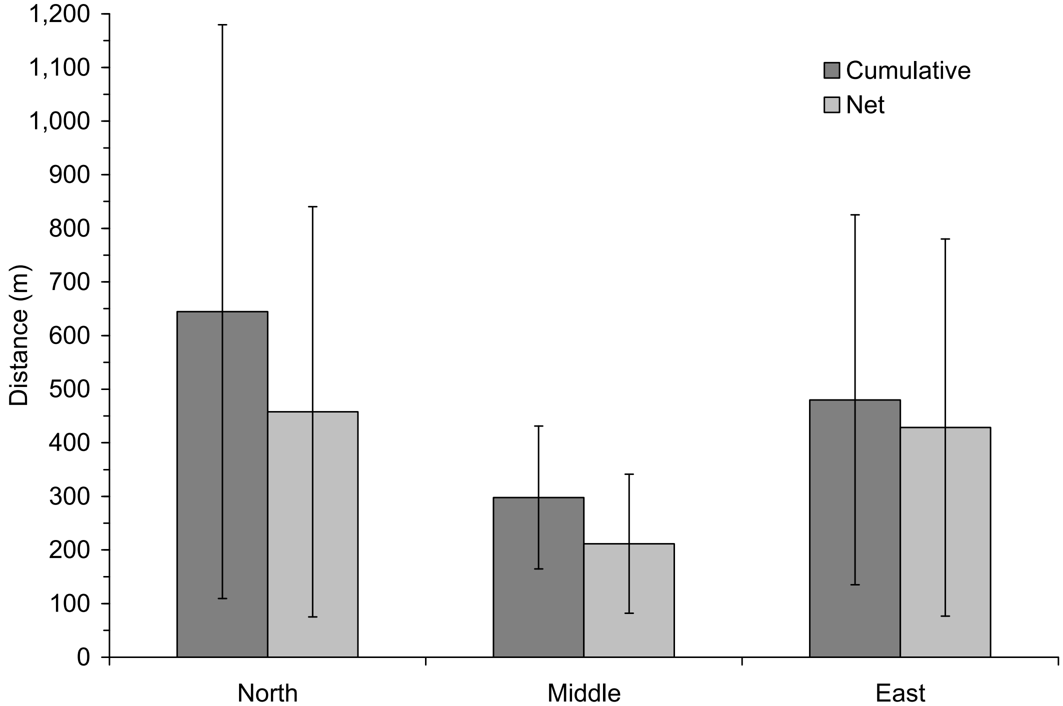


Figure 2.5.–Mean cumulative and net movement (± 2 SE) for telemetry-fish tracked within the North, Middle, and East Forks of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

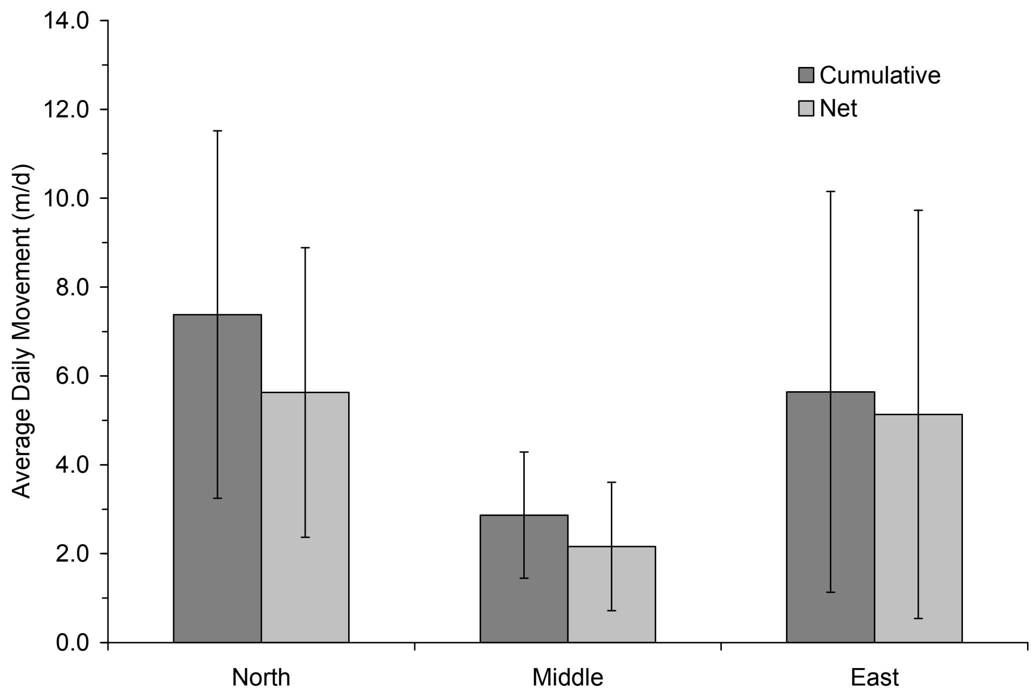


Figure 2.6.–Mean daily cumulative and net movement (± 2 SE) for telemetry-fish tracked within the North, Middle, and East Forks of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

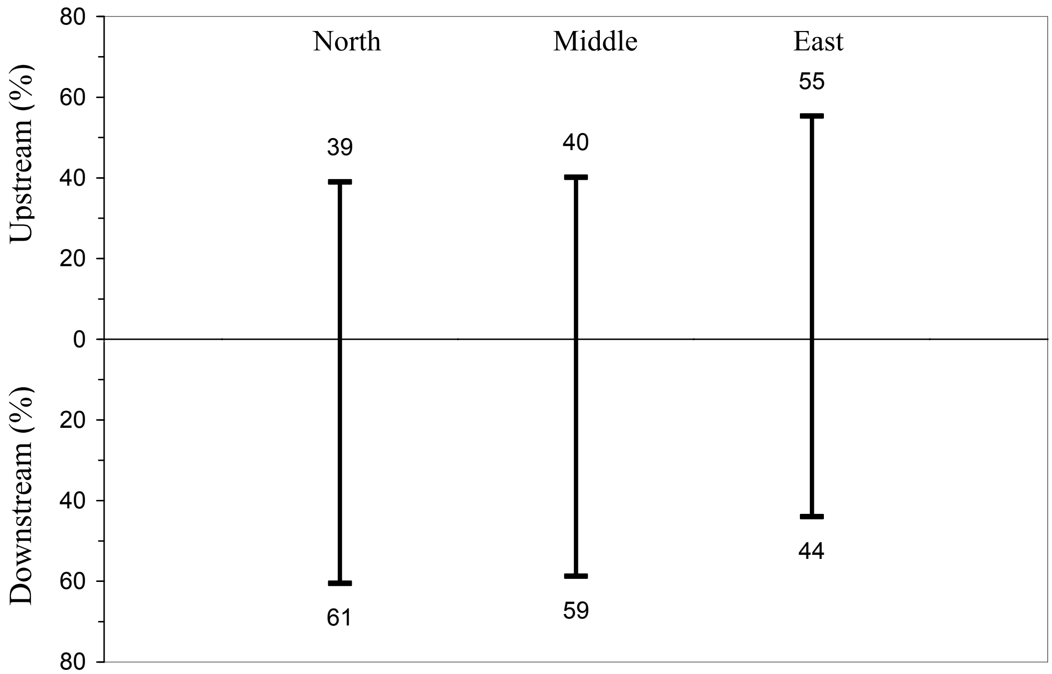


Figure 2.7.–Percent of cumulative upstream and downstream movements in the North, Middle, and East Forks of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

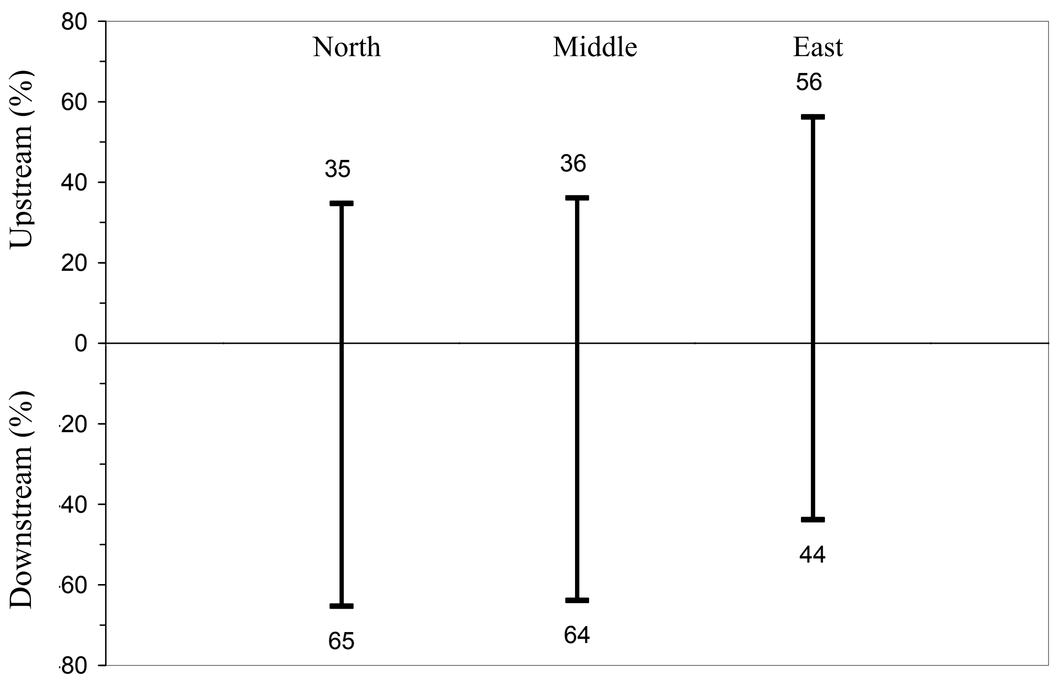


Figure 2.8.–Percent of net upstream and downstream movements in the North, Middle, and East Forks of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

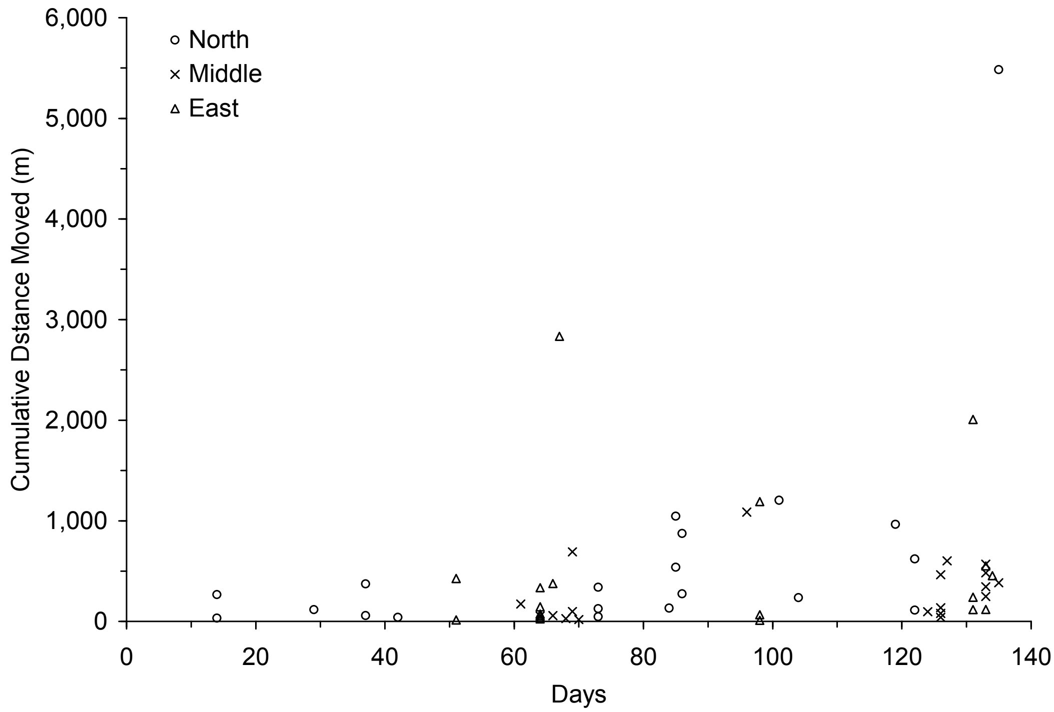


Figure 2.9.–Cumulative movements for individual telemetry-fish plotted against the length of time the fish's location was known in the North, Middle, and East Forks of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

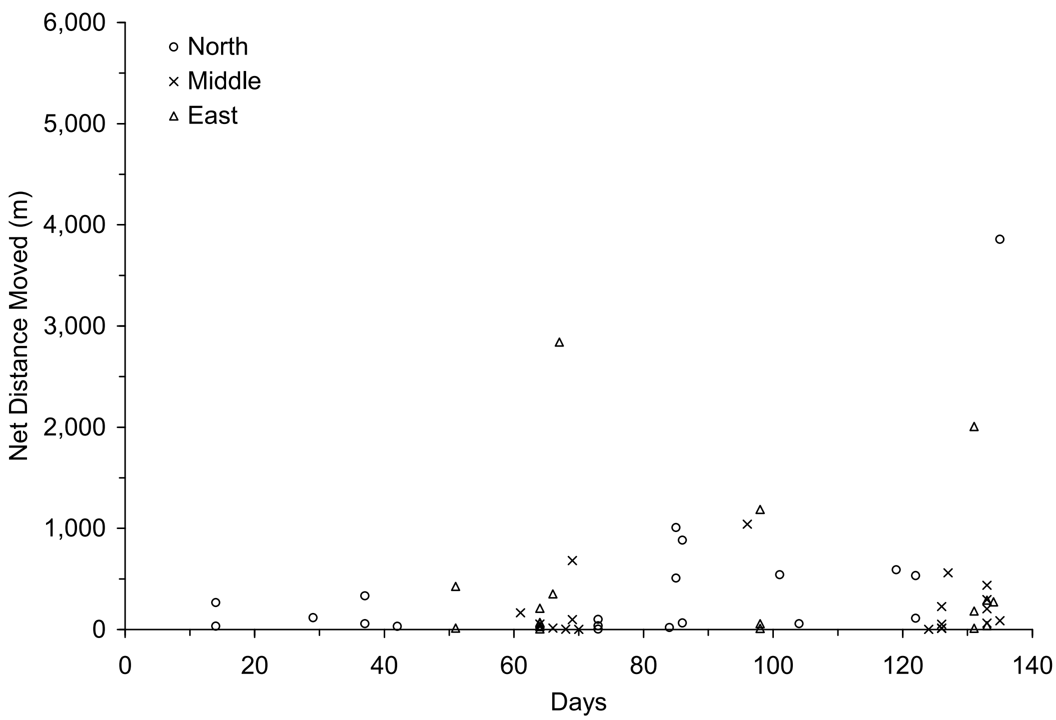


Figure 2.10.–Net movements for individual telemetry-fish plotted against the length of time the fish's location was known in the North, Middle, and East Forks of the Illinois Bayou, Arkansas, from 17 May to 6 October 2006.

CONCLUSION

Although the Illinois Bayou appears to be a typical smallmouth bass stream during most of the year, I documented extensive stream drying throughout the summer. The loss of habitat forced resident smallmouth bass to survive in what is not normally considered favorable smallmouth bass habitat (see Chapter 1). Loss of up to 50% of the wetted area, zero velocity throughout the stream, and the large amount of bedrock in remnant pools combined with the limited amount of depths ranging from 0.60-1.00 m, likely constitutes a severe environment from July to September in normal years on the Illinois Bayou and perhaps many other Boston Mountain streams.

The range of temperatures that smallmouth bass utilized in this study (16-32^{o}C) is within the normal range of temperatures for smallmouth bass at the southern edge of their distribution. Regier and Meisner (1990) suggested that changes in maximum and minimum water temperatures associated with anthropogenic climate change will affect the distribution of fishes. Smallmouth bass in the Illinois Bayou already are exposed to temperatures within 3-5^{o}C of their lethal temperature; therefore, anthropogenic-induced temperature increases should be avoided because they may threaten these populations. Oxygen levels in remnant pools were sufficient to support smallmouth bass, but low production was probably also related to low calcium content in these Boston Mountain streams (Appendix D).

Apparently, it is natural for smallmouth bass to be forced into areas with no measurable velocity during the summer in the Illinois Bayou of Arkansas. However, in the absence of flowing water, fish are unable to drift feed which eliminates an important feeding tactic used by smallmouth bass (Paragamian and Wiley 1987). Rimmer (1985) was able to decrease production of rainbow trout *Oncorhynchus mykiss* by artificially reducing stream discharge. Consequently, anthropogenic-induced reductions in flow should be avoided to prevent a decrease in the already low smallmouth bass production.

Although smallmouth bass were commonly found over cobble in the Illinois Bayou, cobble was used at much lower proportions than it was measured within the reference sections. This indicates that if other substrates are available, such as boulder, cobble may not be used as often. Fish were frequently found over bedrock substrate ranging from 10% of the time in the North Fork to 37% of the time in the East Fork. While smallmouth bass are not known to prefer bedrock substrate, bedrock pools in some streams may be the only places with ample water left in late summer. Thus, smallmouth bass may be forced to utilize this sub-optimal habitat which may further contribute to poor body condition at the end of summer (Appendix E) as well as low smallmouth bass productivity.

Smallmouth bass within the study area of the Illinois Bayou appeared selective with respect to depth occupied even while water levels decreased (median = 0.80 m). Smallmouth bass were commonly located at the interface between shallow and deeper habitats near upstream and downstream shoals of remnant pools. This depth probably provides cover from predators and proximity to the edge of shallow habitat where smaller prey species reside. Furthermore, pools with depths in this range appear less likely to experience severe stream dryness, therefore increasing the chance of survival throughout the summer.

Although most adult smallmouth bass in the Middle and East Forks positioned themselves in large pools that contained enough water for fish to survive the dry period of the summer, it appeared that the mortality rates of the adult smallmouth bass were slightly elevated in comparison to those reported for systems that have year-round continuous flow and limited angling pressure (see Chapter 2). The elevated mortality is likely the result of smallmouth bass being forced to occupy relatively unfavorable bass habitat throughout most of the summer. High mortality of telemetry-fish in the North Fork demonstrates the potential negative effects that angling can have on a smallmouth bass population while stream dryness is occurring. Research is needed to accurately assess the amount and cause of fishing mortality that is occurring in this system.

Systems with a high loss of wetted area likely alter movement patterns by increasing both average net and cumulative movements. Variance is increased because a few individual fish moved long distances (> 1 km) to avoid areas of complete stream dryness. Adult smallmouth bass showed a tendency to move away from reaches most prone to dryness toward areas with more perennial water. The potential influence of these induced movements on smallmouth bass bioenergetics may be significant and should be studied further.

Home pools constitute refuges during the harsh summer conditions in the Illinois Bayou, and perhaps other streams with similar hydrologic patterns. However, fish in these pools appear quite vulnerable to angling pressure indicating a need to consider limiting angling harvest from late July to early September when stream dryness is most severe. Management actions should ensure that the limited water remaining during this time is protected. Summer water temperatures are already near the upper thermal tolerance of smallmouth bass, so riparian zones should be protected to provide shade. Large proportions of bedrock characterize much of the stream system, thus activities such as rock mining, recreational ATV use, and agriculture should be monitored closely to avoid any further reduction in suitable substrate. By increasing our knowledge of these systems we will be better equipped to make decisions that will protect this resource for the use of future generations.

REFERENCES

Paragamian, V. L., and M. J. Wiley. 1987. Effects of variable streamflows on growth of smallmouth bass in the Maquoketa River, Iowa. North American Journal of Fisheries Management 7:357-362.

Regier, H. A., and J. D. Meisner. 1990. Anticipated effects of climate change on freshwater fishes and their habitat. Fisheries 15:10-15.

Rimmer, D. M. 1985. Effects of reduced discharge in production and distribution of age-0 rainbow trout in seminatural channels. Transactions of the American Fisheries Society 114:388-396.

APPENDIX A

GPS COORDINATES (UTM ZONE 15 NORTH) OF REFERENCE SECTIONS

		Reference Section					
		Upstream		Midstream		Downstream	
Stream	Section Boundary	Easting	Northing	Easting	Northing	Easting	Northing
North Fork	Upstream	498185	3947437	499475	3943614	498925	3941142
	Downstream	499203	3946114	499444	3942128	499282	3939187
Middle Fork	Upstream	508301	3948657	507156	3939602	504634	3933146
	Downstream	508365	3946870	505919	3938832	505313	3931640
East Fork	Upstream	514562	3940330	509799	3936866	506819	3932511
	Downstream	513025	3940156	508982	3935528	505330	3931628

APPENDIX B

TAGGING STUDY OF SMALLMOUTH BASS

Before surgeries were preformed on the telemetry-fish, a passive integrated transponder (PIT) tag (Biomark, Inc.) and T-bar anchor tag (Floy Tag, Inc.) were inserted into the muscular tissue near the dorsal fin in an attempt to estimate tag loss. Visual confirmation on the status of the Floy tag was achieved for 36 different smallmouth bass throughout the duration of the telemetry portion of the study.

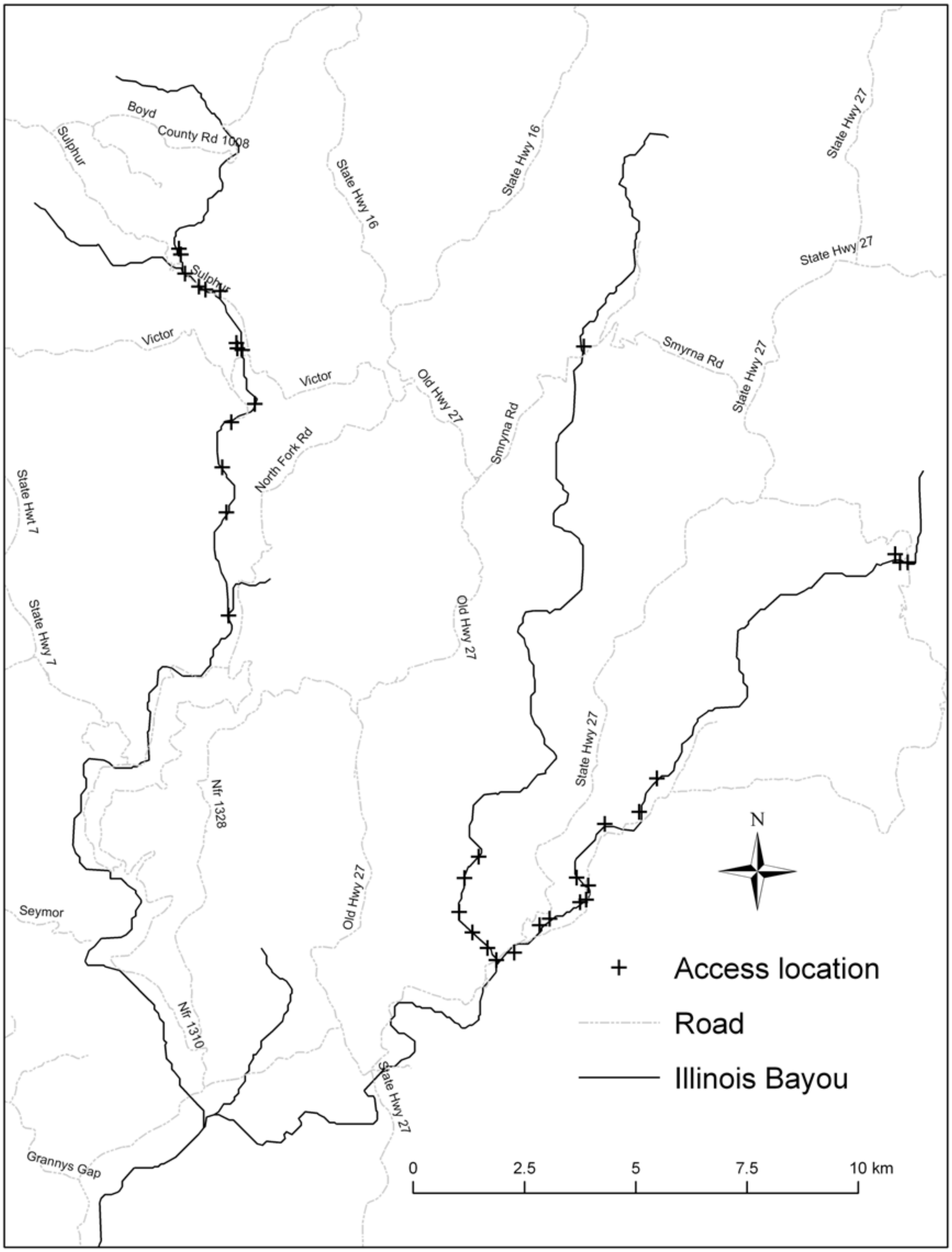
Day	17	20	27	28	29	30	31	32	36	37	42	57
Floy tag present	23	22	20	19	18	16	15	15	14	13	11	7
Floy tag absent	0	0	0	0	1	1	2	2	3	4	5	7
Status unknown	13	14	16	17	17	19	19	19	19	19	20	22
Status known	23	22	20	19	19	17	17	17	17	17	16	14
Lower limit tag loss (%)	0	0	0	0	3	3	6	6	8	11	14	19
Upper limit tag loss (%)	36	39	44	47	50	56	58	58	61	64	69	81

Day	61	64	66	68	69	71	74	87	101	124	125	129
Floy tag present	7	6	6	3	3	3	2	2	2	2	1	1
Floy tag absent	7	8	9	10	12	12	13	15	16	16	17	17
Status unknown	22	22	21	23	21	21	21	19	18	18	18	18
Status known	14	14	15	13	15	15	15	17	18	18	18	18
Lower limit tag loss (%)	19	22	25	28	33	33	36	42	44	44	47	47
Upper limit tag loss (%)	81	83	83	92	92	92	94	94	94	94	97	97

At 129 d, Floy tag loss was at least 47%, but I hypothesize that the actual rate is substantially closer to the worst case scenario of 97%. It is clear that Floy tags should not be used to mark smallmouth bass in the Illinois Bayou. The PIT tags, however, seem to have excellent retention rates based on recaptures of a limited number of double-marked fish and I suggest continuing deployment of PIT tags for marking smallmouth bass in the Illinois Bayou.

APPENDIX C

ACCESS LOCATIONS (2WD TRUCK)



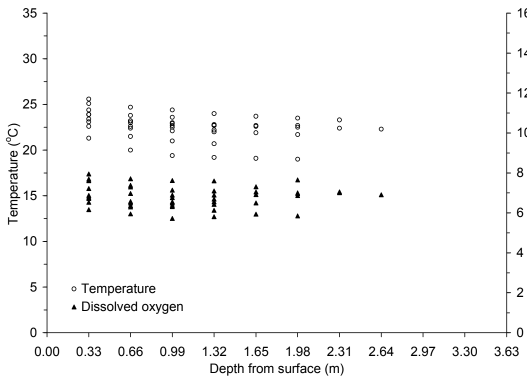
APPENDIX D

VARIATIONS IN WATER QUALITY

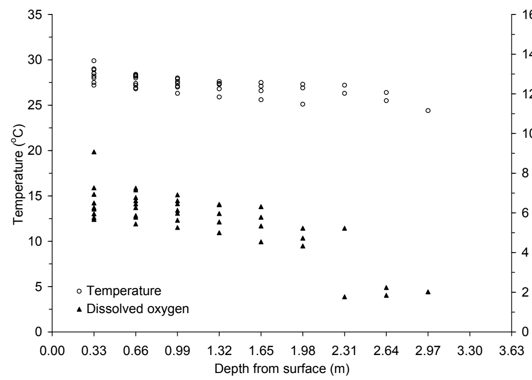
Temperature and dissolved oxygen were measured at 0.33 m intervals from the deepest location within three pools from the upstream, middle and downstream sections of each stream.

North Fork

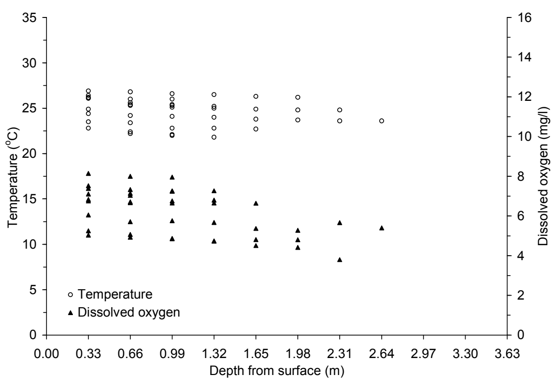
3-9 July 2006

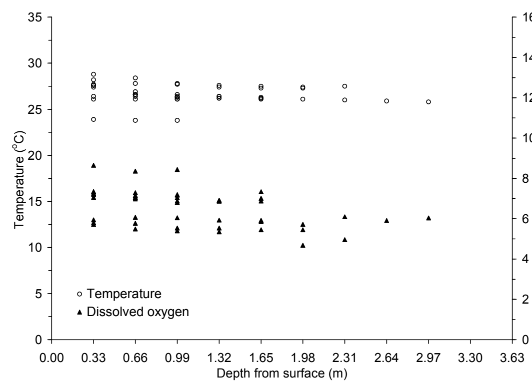


15-29 August 2006

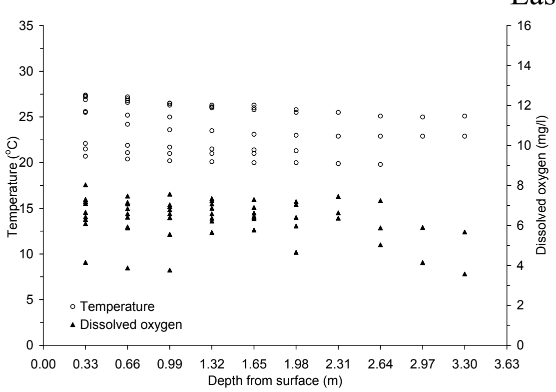


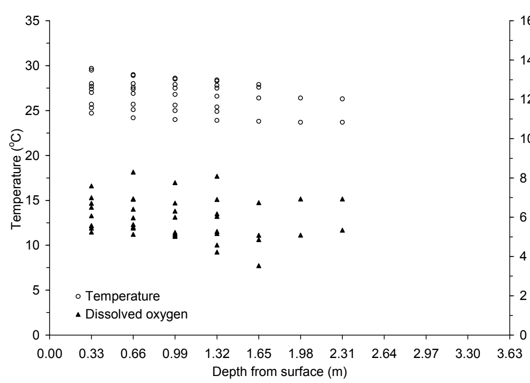
Middle Fork





East Fork



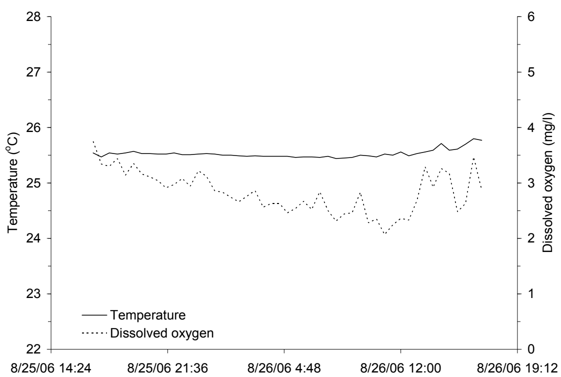


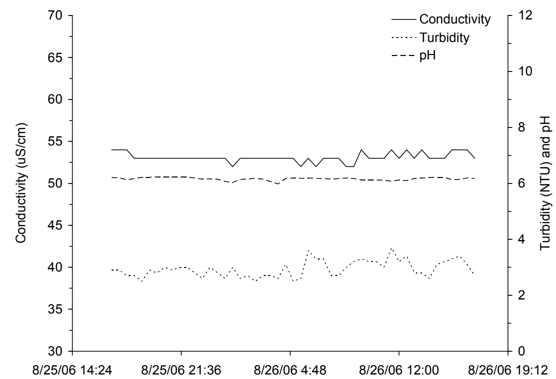
Water samples were collected 17 August 2006, refrigerated, and sent to the Arkansas Water Resources Center Water Quality Lab at the University of Arkansas, Fayetteville for analysis of alkalinity, conductivity, pH, and concentrations of calcium and nitrate.

Stream	Site	Easting	Northing	Alkalinity mg/l as CaCO3	Calcium mg/l	Conductivity uS/cm	Nitrate mg/l	pH
North Fork	Upstream	498760	3946529	22.0	5.82	56.7	0.000	7.1
	Midstream	499390	3943560	28.0	7.02	64.8	0.000	6.9
	Downstream	499280	3939177	22.0	5.30	52.1	0.011	7.1
Middle Fork	Upstream	508444	3947089	2.0	5.09	49.7	0.015	7.2
	Midstream	506166	3937309	22.0	6.46	55.3	0.000	6.6
	Downstream	504576	3933228	22.0	5.47	55.7	0.000	7.2
East Fork	Upstream	513844	3940417	22.0	5.52	50.1	0.018	6.9
	Midstream	509424	3936047	22.0	5.97	54.9	0.010	7.1
	Downstream	505823	3931627	24.0	6.06	61.4	0.000	6.8

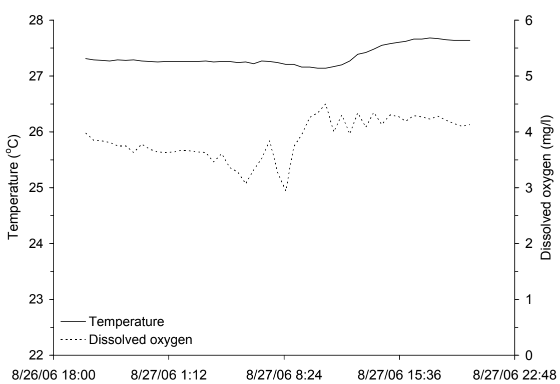
A Hydrolab DataSonde was placed in each stream for twenty-four hours, to measure temperature, pH, turbidity, and conductivity, as well as concentrations of dissolved oxygen. Measurements were recorded at half-hour intervals from a depth of 1.2-1.3 m, which was 0.33 m off the bottom.

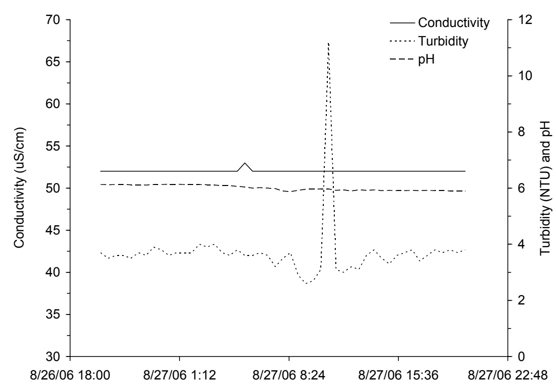
North Fork



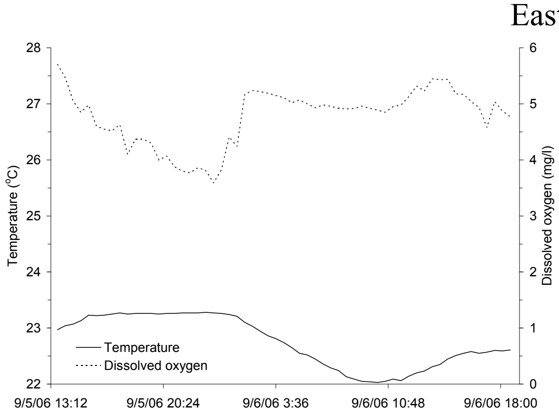


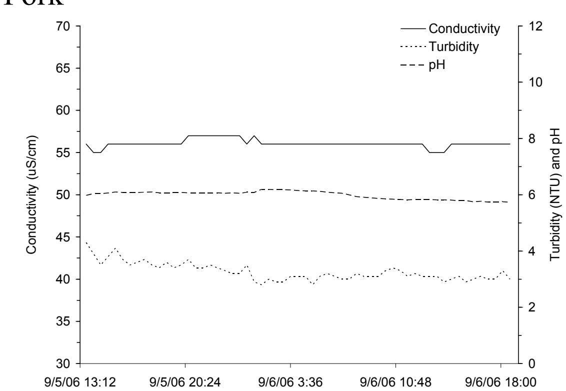
Middle Fork





East Fork



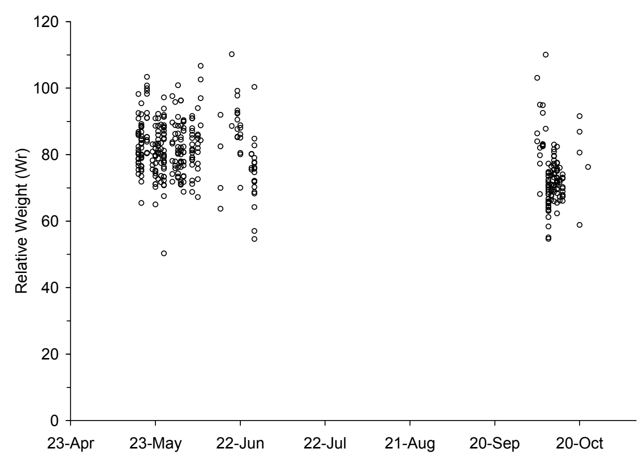


APPENDIX E

RELATIVE WEIGHT STUDY OF SMALLMOUTH BASS

In the process of capturing the fish that were used for the main focus of this study, lengths and weights were measured for a total of 266 different smallmouth bass. These fish were captured from 17 May to 27 June 2006. In an attempt to recover missing transmitter-fish study sections were also sampled from 5 October to 23 October 2006. During this time another 114 smallmouth bass were measured. To determine if the smallmouth bass within the study section were less healthy at the end of the summer, relative weights were calculated for every fish in which lengths and weights had been measured. A Wilcoxon-Mann-Whitney analysis was used to determine if the relative weights at the beginning of the study period were significantly different than the relative weights of the fish at the end of the study period.

A mean relative weight of 82 was calculated for fish that were captured at the beginning of summer and a mean relative weight of 73 was calculated for smallmouth bass that were captured at the end of the study period. Mean relative weight was 84-88 in the Jacks Fork River, Missouri, a stream that does not have a notable loss in habitat due to stream dryness (McClendon and Rabeni 1987).



The Wilcoxon-Mann-Whitney analysis determined that these means were significantly different (Z = -8.95, $P < 0.5$).

Shrinking wetted areas, the loss of all measurable velocity, and the large amount of bedrock in remnant pools, forced the smallmouth bass of the Illinois Bayou into sub-optimal habitat for most of the summer. These harsh conditions seem to have caused the overall condition of the smallmouth bass to be lower at the end of summer probably due to high metabolic demands (elevated water temperatures) and competition for limited food resources (e.g. I noticed that crawfish abundance diminished throughout the summer). I hypothesize that the low body condition of the smallmouth bass at the end of summer also adversely affects fecundity and recruitment. The effect of this phenomenon on the fecundity and recruitment of the smallmouth bass needs to be researched.

REFERENCE

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.