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Neosho Smallmouth Bass Movement, Spawning, and Associated Environmental Conditions in a Seasonally Discontinuous Stream: The Illinois Bayou, Arkansas

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NEOSHO SMALLMOUTH BASS MOVEMENT, SPAWNING, AND ASSOCIATED ENVIRONMENTAL CONDITIONS IN A SEASONALLY DISCONTINUOUS STREAM: THE ILLINOIS BAYOU, ARKANSAS

By

Jacob H. Martin

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Dedication

This thesis is dedicated to my loving parents and family who have helped shape me into the scientist and outdoorsman that I am today. My grandfather instilled in me a love for the outdoors and my mother fostered my love of fishing growing up. My uncle Mark taught me how to be an ethical sportsman by taking me on hunting and fishing trips. Finally, I'd like to thank my wife who has supported me in every step of my career. I've truly been blessed, thank you all for helping me succeed.

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Abstract

The Neosho Smallmouth Bass *Micropterus dolomieu velox* is a top predator and popular sportfish in Arkansas' Boston Mountain streams. In this ecoregion, Smallmouth Bass are common in headwater streams that are prone to drying during the summer months. My objectives were to characterize longitudinal movements of adult Smallmouth Bass and to determine the timing of spawning events along with associated environmental variables during the likely spawning months of June and July. Thirty Smallmouth Bass were captured and implanted with radio transmitters in March, and tracked weekly in the Middle Fork of Illinois Bayou until August 2016. Age-0 Smallmouth Bass were collected using electrofishing from May through August 2016, and otoliths were used to back-calculate spawn date. Stream discharge and water temperature were measured during the tracking period. The proportion of individuals that moved over 100 m per week was at its highest during April and May, when about 50% of individuals moved over 100 m per week, prior to the presumptive spawning peak and this proportion gradually declined to 13% through July and August. I attributed the reduced movement to reduced streamflow (e.g. < 400 L/s) which tended to restrict fish to remaining isolated pools. Net distances did not vary before, during, or after spawning (P>0.05). Cumulative movements were highest before spawning and decreased significantly once spawning began (F = 3.97, df = 2,271, $P \leq 0.01$). Minimum daily water temperature was inversely correlated to movement (P<0.01, R^2=0.61). Peak spawning in this system occurred during 17 days from May 25th to June 10th indicating that

individuals that successfully recruited to a catchable size (25 mm) were spawned over a short time-period. Age-0 Spotted Bass *M. punctulatus* spawned during the range of Smallmouth Bass spawning dates, and were collected incidentally along with age-0 Smallmouth Bass indicating a potential for introgression. The majority of Smallmouth Bass spawning occurred on the falling limbs of hydrographs and at temperatures between 17°C and 25°C. Median daily water temperature (R^2=0.51, P<0.01) was the best temperature variable and minimum $\log_{10}$ discharge (R^2=0.37, P<0.05) was the best discharge variable for predicting successful Smallmouth Bass spawning in the Illinois Bayou during the summer of 2016. The small movements observed in the pre-spawning period may have been fish searching for spawning sites and establishing dominance at optimal sites. Neosho Smallmouth Bass in this study had a short spawning duration compared to what is known about the northern sub-species. Global climate change, competition with Spotted Bass for spawning habitat, and introgression could lead to declines in Neosho Smallmouth Bass.

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Introduction

Neosho Smallmouth Bass *Micropterus dolomieu velox* are a popular sportfish and an indicator species in Arkansas. Neosho Smallmouth Bass have a small geographic range relative to the norther sub-species of Smallmouth Bass *Micropterus dolomieu dolomieu* and are found only in Arkansas, Missouri, Oklahoma, and Kansas (Brewer and Long 2015). Smallmouth Bass are most typically found in rivers and streams, but are also found in reservoirs. In Arkansas, at the southern extreme of their native range, they are most commonly found in cool, clear mountain streams with permanent flow (Robison and Buchanan 1984). However, in the Boston Mountain ecoregion, Neosho Smallmouth Bass are common in streams that are prone to drying and that have water temperatures that can exceed 30^{o} C (Homan 2005; Hafs et al. 2010). These streams typically have continuous surface flow through most of the year but tend to lose surface flow, due to decreased precipitation during the summer (Hines 1975). In these streams, Smallmouth Bass are typically the top predator (Lyons and Kanehl 2002), and likely play a key role in structuring fish and invertebrate assemblages (Williams and Taylor 2003).

Seasonally discontinuous streams present a challenging environment for fish living in them. Discontinuous surface flow limits fish movement and alters community structure (Girondo 2011). A variety of anthropogenic practices can reduce surface water availability, making this environment even more challenging for fish. During the summer, when surface flow becomes discontinuous, run and riffle habitats become particularly rare or non-existent for substantial portions of Interior Highland streams (Homan et al. 2005). This leads to isolation as fish are forced to take refuge in remaining pools that are deep enough to hold water through the summer.

The likely increased fish density in pools leads to higher mortality due to increased competition and predation (Gagen et al. 1998). Smallmouth Bass employ both a drift feeding and a cruise and chase strategy, are limited to a less effective cruise and chase feeding strategy when confronted with no measurable velocity (Paragamian and Wiley 1987) that is typical of isolated pools in the summer. Age-0 Smallmouth Bass in isolated pools could be subjected to higher levels of cannibalism by adult Smallmouth Bass, along with added stress as water temperatures rise during the summer months. While the lethal temperature range for Neosho Smallmouth Bass is not precisely known (Brewer and Long 2015), Wrenn (1980) predicted that it was 37°C for the northern sub-species. Water temperatures in the Boston Mountain ecoregion approach that lethal limit, rising above 30°C during the months of July and August (Hafs 2007).

Smallmouth Bass spawn during the spring and summer months from mid-April to mid-July (Robison and Buchanan 1984; Graham and Orth 1986; Etnier and Starnes 1993; Lukas and Orth 1995, Dauwalter and Fisher 2007). They prefer to spawn on a gravel substrate (Robison and Buchanan 1984; Etnier and Starnes 1993) but will utilize other substrates such as sand and boulders when gravel is not available (Robbins and MacCrimmon 1974). Spawning activity and nest building occur at water temperatures of 12-25°C (Winemiller and Taylor 1982; Wrenn 1984; Robison and Buchanan 1984; Graham and Orth 1986; Lukas and Orth 1995). Prior to spawning, male's fan-out circular nests in areas with low water velocity at depths less than 1 m near the margin of streams or lakes (Robison and Buchanan 1984; Etnier and Starnes 1993). Females then deposit eggs in nests and the male guards the nest until the eggs hatch and the fry disperse (Robison and Buchanan 1984; Etnier and Starnes 1993). After fertilization, eggs

incubate about 4-6 days before hatching, and the resulting fry occupy the nest area for 5-6 days (Neves 1975). Renesting may occur, especially when nests fail due to high flow and associated environmental conditions (Lukas and Orth 1995; Pflieger 1997).

Smallmouth Bass movements and behaviors have been extensively studied across their native range. Their behavior appears to vary widely in response to different environments. For example, some populations have been found to be highly sedentary, rarely moving from very limited home ranges their entire lives (Larimore 1952; Gerking 1953, 1959; Funk 1955; Todd and Rabeni 1989; Lyons and Kanehl 2002); whereas, other populations have been considered highly migratory (Langhurst and Schoenike 1990; Lyons and Kanehl 2002; Gunderson VanArnum et al. 2004). Certain populations seem to include subpopulations with both sedentary and migratory behavior (Funk 1955; Lyons and Kanehl 2002; Gunderson VanArnum et al. 2004). Several studies concluded that adults migrated upstream to headwaters or tributaries to spawn (Todd and Rabeni 1989; Langhurst and Schoenike 1990; Pezold et al. 1997; Lyons and Kanehl 2002). In addition, Smallmouth Bass have been documented using springs as thermal refugia when river water temperatures fall below groundwater temperatures and dispersing once river water temperature is warmer (Peterson and Rabeni 1996).

Although movements have been extensively studied, there have been few studies that focused on movements of Smallmouth Bass in seasonally discontinuous streams. Hafs et al. (2010) found that Neosho Smallmouth Bass were primarily sedentary in a seasonally discontinuous stream during the summer months. However, there is a lack of published data on spawning movements for Neosho Smallmouth Bass (Brewer and Long 2015). Homan (2005) found older fish were absent from his spring production study

reaches, but present in the fall and summer. Therefore, he hypothesized that older fish were moving out of his study reach to spawn.

Smallmouth Bass spawning is likely to be affected by instream environmental conditions (Graham and Orth 1986; Lukas and Orth 1995). Miller and Storck (1984) used otoliths from age-0 Largemouth Bass to back-calculate hatch dates and characterize water temperature at hatching. Otoliths from age-0 Smallmouth Bass can be used to estimate age at least 30 days after hatch (Hill and Bestgen 2014), as long as water temperatures exceed 10°C (Graham and Orth 1987; Hill and Bestgen 2014).

Hydrologic regime is a main driver affecting the structure of stream fish assemblages (Schlosser 1985; Poff and Allan 1995; Poff et al. 1997). Fluctuations in discharge also influence other environmental conditions such as water temperature and turbidity. The timing and intensity of stormflows can serve as important cues for spawning of stream fishes in general (Tetzlaff et al. 2005), and Smallmouth Bass spawning activity has been linked to fluctuations in streamflow (Surber 1943; Graham and Orth 1986; Lukas and Orth 1995). For example, high flow can disrupt spawning activity, may be among the greatest causes of nest failure, and spawning often occurs on the receding limb of hydrographs (Surber 1943; Graham and Orth 1986; Lukas and Orth 1995). Variation in flows during and immediately after spawning can reduce Smallmouth Bass recruitment (Smith et al. 2005). Lukas and Orth (1995) found that maximum discharge, change in discharge, mean discharge, and minimum discharge were all significant variables for predicting if a Smallmouth Bass nest would be successful or unsuccessful.

Water temperature is another important factor affecting fish movements and spawning activity. Stream temperature is often related to stream discharge. As discharge decreases, water temperature tends to approach ambient temperature. Graham and Orth (1986) found that mean daily water temperature was the single most important variable in predicting spawning dates for Smallmouth Bass. In addition, maximum and minimum temperature were also significant variables in determining if nests would be successful or unsuccessful. Water temperature can also trigger spawning movements in stream fishes (Langhurst and Schoenike 1990).

Smallmouth Bass and Spotted Bass, *Micropterus punctulatus*, have similar environmental requirements; however, Spotted Bass generally inhabit warmer waters and are more tolerant to disturbance, siltation, and increased turbidity (Pflieger and Fajen 1975). Hybridization between black basses can occur when there is limited spawning habitats available, altered environmental conditions, or when spawning between the two species occurs in close proximity (Hubbs 1955). Smallmouth Bass and Spotted Bass hybridization has been well documented (Hubbs 1955; Pflieger and Fajen 1975; Koppelman 1994; Pierce et al. 1997). Pierce et al. (1997) documented Smallmouth Bass and Spotted Bass F_1 and F_x hybrids, as well as back crosses with Smallmouth Bass in Alabama reservoirs. Pflieger and Fajen (1975) documented that a large proportion of eggs produced from F_1xF_1 and F_2xF_2 crosses were viable. Smallmouth Bass decline has been partly attributed to hybridization with Spotted Bass in portions of the Missouri Ozarks (Pflieger and Fajen 1975, Pflieger 1997).

The Smallmouth Bass decline in the Missouri Ozarks has also been attributed to increased sedimentation and increased tendency for streams to lose surface flow (Pflieger

1997). Smallmouth Bass have a low tolerance for high turbidity and are most commonly found in streams that maintain flow (Pflieger 1997). Increased turbidity associated with stormflow can cause nest failures. For example, Lukas and Orth (1995) found that males abandoned nests after substantial increases in stream velocity and turbidity.

The Arkansas Game and Fish Commission's Arkansas Smallmouth Bass Management Plan (Quinn et al. 2012) outlines a need to better understand the effects of stream flow on Smallmouth Bass spawning and recruitment dynamics in the Boston Mountain ecoregion. This study was conceived to address this need. Objectives included documenting adult Smallmouth Bass longitudinal movements to headwater reaches during the likely spawning months and assessing associated environmental conditions. I hypothesized that adult fish would move to headwater reaches in search of preferred spawning substrate, before or during the spawning months. Supporting objectives were to identify when spawning occurred and determine if stream discharge and water temperature were predictive of spawning. I hypothesized that spawning would coincide with the falling limbs of hydrographs as observed in previous studies (Surber 1943; Graham and Orth 1986; Lukas and Orth 1995).

While the effects of environmental conditions on Smallmouth Bass spawning have been previously studied (Surber 1943; Graham and Orth 1986, Lukas and Orth 1995), there have been few studies that have focused specifically on Neosho Smallmouth Bass, and no studies focused on high gradient streams with seasonally discontinuous flow. This information could be crucial to protecting instream flow in this Boston Mountain Smallmouth Bass fishery. Additionally, understanding Smallmouth Bass movements and the environmental conditions associated with spawning could aid in

management decisions regarding land use, supplemental stocking, and harvest regulations.

Methods

Study site selection

This study site is in the Boston Mountain ecoregion of north central Arkansas on the Middle Fork of the Illinois Bayou (Figure 1). This portion of river is characterized by high-gradient run, riffle, and boulder sequences (Hafs 2007). During stormflow this reach is considered class II and class III white water; however, during dry periods in the summer, loss of wetted area can exceed 26% (Hafs 2007).

Site selection was based on accessibility, proximity to the confluence of the Middle and East forks, proximity to a United States Geological Survey (USGS) gauging station #07257460, and the availability of relevant data from previous studies (Figure 2). The land on both sides of the river in this vicinity is mostly owned by the United States Department of Agriculture (USDA) Forest Service (Ozark-Saint Francis National Forest). In addition, a road parallels the study reach. The network of roads and trails along the Middle and East Forks facilitated land-based tracking when stormflow precluded safe canoeing, and allowed for easier access in general and additional canoe launching locations.

Fish movements

Adult Smallmouth Bass were captured by boat electrofishing (Figure 3) and hook and line sampling in March of 2016. Captured adult fish larger than 230 mm were immediately anesthetized in clove oil at 60 mg/L (Peake 1998), and an easting and northing for each fish was recorded with a handheld GPS (Garmin Montana® 600). Fish were then implanted with an RFID tag, intramuscularly injected with oxytetracycline, and

surgically implanted with a radio transmitter (Model F1580 Advanced Telemetry Systems, Incorporated, Isanti, Minnesota).

A tag injector was used to subcutaneously inject RFID tags into muscle tissue near the dorsal fin. The transmitters were inserted into a single incision, approximately 3 cm long and just anterior to the anus in the peritoneal cavity, and then closed with a surgical stapler (Visistat® Skin Stapler 5.9 mm). Transmitter weight was limited to 3% of the fish's body weight to minimize effects on behavior and movements (Brown et al. 1999, Hafs et al. 2010). Fish were placed into a wire fish basket after surgery to regain equilibrium in the stream before being released near the point of capture.

Starting in mid-April, fish were tracked weekly through mid-August. A Communications Specialist Inc. R-1000 telemetry receiver and a four element yagi antennae were used to track fish in combination with a four-wheel-drive truck, ATV, hiking, or canoe depending on stream conditions. The majority of tracking effort was confined to the study reach which was approximately 3.6-km long (Figure 2). On occasion fish were tracked upstream and downstream of the study reach by canoe in an attempt to find fish that were not found in the study reach (Figure 2). Fish locations were recorded as an easting and a northing by GPS.

Age-0 spawn date estimation

Age-0 Smallmouth Bass and Spotted Bass were collected from three locations within the study reach (Figure 4). Snorkeling surveys were used to determine when age-0 black bass were present in the stream and took place from May through early July, and were stopped once age-0 black bass *Micropterus* spp. were identified as present in the stream. Age-0 black bass were then sampled using a backpack electrofishing unit

(Smith-Root LR-20) and two netters. Electrofishing surveys began in early May and persisted into September; however, no age-0 black bass were collected until the July surveys.

Age-0 fish were sampled from three sites within the study reach on a weekly basis starting in July (Figure 4). Approximately 200 m of stream was electrofished at each site. The 200-m electrofishing reaches were sampled upstream in a zigzag pattern, with the person operating the backpack electrofisher in front, and the two netters following just behind on either side. Captured age-0 black bass were euthanized in ice chilled water 2-4°C and then frozen for later otolith extraction.

Smallmouth Bass and Spotted Bass were later identified to species in the lab where length (mm) and weight (g) were recorded for each individual. Otoliths were then extracted for daily increment analysis following Secor et al. (1992). Under a dissecting microscope (Olympus SZ61), fine forceps were used to pull away the gill arches and tissue was removed with forceps to expose the bulla. Fine forceps were then used to crack or pierce the bulla and grasp the sagittal otoliths. Sagittal otoliths were removed and placed into water to remove any otolithic membrane. Cleaned otoliths were stored in 15 x 45 mm 1 dram glass vials for age determination.

Otoliths were placed concave side up on a microscope slide and viewed under 400x magnification with a compound microscope (ZEISS Primo Star), and daily growth rings were counted by two independent readers. Otoliths with daily growth rings that were not easily counted were mounted on slides, concave side up, in cyanoacrylate (Super Glue). Mounted otoliths were then polished by wet sanding on 2400 grit sandpaper until daily growth rings were clearly visible under 400x magnification.

Glycerin was used to enhance the visibility of daily growth rings. Any otoliths that were not in agreement by the two readers were then reread until a consensus on age was reached. In cases where no consensus was reached, those otoliths were not included in analyses. Spawn date was calculated as:

$$S = A - D - 5$$

where,

S = Spawn date.

A = Daily growth ring count.

D = Capture date (Julian days).

5 = Estimated number of days for egg to hatch after spawning (Neves 1975).

Statistical analyses

Movement distance for each fish was calculated as the difference in meters between the current and previous week's location. Week one distances were the distance from the original tagging location. Cumulative distance for each telemetry fish was calculated as the sum of the absolute value of weekly distances. Total cumulative distance for each telemetry fish was calculated as the sum of the cumulative distances moved for all of the tracking weeks. Net distance for each fish was calculated as the distance moved between each week. Upstream distances were given a positive value and downstream distances were given a negative value. Total net distance for each fish was calculated as sum of the net distances for all of the tracking weeks. Stream location for each fish was calculated as the distance from the center of the reach, the USGS gaging station, fish located downstream of the gauge were given negative values and fish upstream of the gauge were given positive values. Range was calculated as the distance

between the most upstream location and the most downstream location for each fish. An experimental error rate of α =0.05 was used to determine significance unless otherwise noted.

Movement for each week was considered as the percent of telemetry fish that moved > 100 m, this was done to create predictive models with discharge and temperature. Movement >100 m was considered biologically relevant movement since fish would likely pass over at least two different habitat or substrate types based on figure 1.28 in Hafs (2007). Week one distances were not included in this analysis because elapsed time between tagging and week one tracked locations varied across individual telemetry fish. Linear regression was used to predict movements from environmental variables, separately for temperature and discharge. Multiple regression was then used to determine the best predictive models explaining movements of Smallmouth Bass using combinations of the best single temperature and discharge variables. Environmental variables that were used in these analyses included mean temperature, median temperature, maximum temperature, minimum temperature, mean discharge (L/s), median discharge, maximum discharge, and minimum discharge. Discharge was $\log_{10}$ transformed for all analyses. Akaike's information criterion (AIC) was used to select the best models. Low AIC values were considered best and when two values were close to each other ($\pm$ 5) an ANOVA was used to determine significant differences between the models (i.e., if one model had more explanatory value than the other). In cases where AIC values were not significantly different, the simplest model was chosen.

A repeated-measures ANOVA was used to determine if net weekly movements and cumulative weekly movements were influenced by spawning period. Fish that were

not located every week were not included in the analyses (n = 9). Cumulative and net movements for week 1 were not included in analyses because elapsed time between tagging and week one tracked locations varied across individual telemetry fish. Weeks were then categorized as before, during, or after spawning (pre-spawn, spawn, and post-spawn). Spawning dates were estimated from age-0 otoliths. Weeks 2 through 6 were classified as pre-spawn (April 4th – May 25th 2016), weeks 7 through 9 were classified as spawn (May 25th – June 14th 2016), and weeks 10 through 15 were classified as post-spawn (June 14th – July 26th 2016). Tukey's HSD post-hoc analysis was used to compare the mean cumulative movements for the three periods.

Regression analysis was used to model the relationship between the proportion of individuals spawned and environmental variables for both Smallmouth Bass and Spotted Bass. The number of individuals spawned on a particular day were converted from counts to the proportion of individuals spawned on that day. Environmental variables that were used in analyses were mean temperature, median temperature, maximum temperature, minimum temperature, mean discharge (L/s), median discharge, maximum discharge, and minimum discharge. Discharge data for June 3rd and 4th were predicted from a downstream USGS gage at Scottsville, AR (https://waterdata.usgs.gov/ar/nwis/uv?07257500) using a regression equation (R^2>0.60, n >15). Values were predicted by using regression to calculate a regression equation. Discharge was $\log_{10}$ transformed for all analyses. Akaike's information criterion (AIC) was used to select the best models. Low AIC values were considered best and when two values were close to each other ($\pm$ 5) an ANOVA was used to determine significant differences between the models (i.e., if one model had more explanatory value than the

other). In cases where AIC values were not significantly different, the simplest model was chosen. A Kolmogorov-Smirnov test was used to evaluate potential differences in Smallmouth Bass spawn date distributions for the three locations, upstream, midstream, and downstream. To maintain an experimental error rate of α =0.05, the significance level for each comparison was set at *P*=0.017 (0.05/3). A Kolmogorov-Smirnov test was also used to test for potential differences in Smallmouth Bass and Spotted Bass spawn date distributions (α =0.05).

Results

Fish movements

Smallmouth Bass weekly movements were relatively short and did not appear to be directional. Movement of adult Smallmouth Bass during the spring and summer months varied across individuals (Table 1). Telemetry fish were located 381 times over 15 weeks of tracking from April to July 2016. Movement was highest in April with 41% of individuals moving greater than 100 m, and it steadily declined to 10% in July (Figure 5). One fish, MD01, was moved by an angler over 7 km downstream and was not included in any further analyses. Eleven of 30 (37%) individuals exhibited net movements greater than 1,000 m over the study duration. The largest net upstream movement was approximately 5.6 km and the largest net downstream movement was 3 km (Figure 6). Each fish appeared to base their movements around a central location and 21 of 30 (70%) individuals were within 500 m of their original capture location at the end of the study, with a median net movement of 261 m from their original capture location (Table1; Figure 7). Most fish were present in the upstream portion of the study reach, but there were individuals found downstream as well (Figure 8).

Movement was inversely related to water temperature. Akaike's information criterion revealed that minimum weekly temperature (*AIC* = -25.96) was the best predictor of movement (Table 2). Minimum weekly temperature and movement were negatively related (R^2=0.61, F=18.57, df=1,12, P<0.01; Figure 9). Models with Log_{10} transformed discharge as the predictor for movement were not significant ($P \geq 0.05$, Table 2, Figure 10). A model with maximum temperature + $\log_{10}$ discharge as predictors was also found to be significant (P<0.01, Table 2).

Mean net distances moved fluctuated from positive (upstream) to negative (downstream) through the duration of the study (Figure 11). Mean net distance moved for the time categories: pre-spawn, spawn, and post-spawn were -12 m, -4 m, and -5 m respectively and did not differ significantly ($P>0.05$; Figure 12). Mean cumulative distance movement was highest in the spring and appeared to drop considerably during the first week that spawning occurred (Figure 13). Mean cumulative distance moved for the time categories: pre-spawn, spawn, and post-spawn were 178 m, 75 m, and 96 m, respectively (Figure 14). Cumulative movements differed significantly among spawning periods (F = 3.97, df = 2,271, P=0.01; Figure 14). Pre-spawn movements were higher than post-spawn movements ($P<0.05$), spawning movements were lower than pre-spawn ($P<0.04$), and there was no significant difference between spawn and post-spawn movements (P=0.87, Table 3). More than 60% of fish moved upstream during the pre-spawn period, more than 60% moved downstream during the spawn period, and there was no noticeable difference in direction during the post-spawn period (Figure 15).

Age-0 spawn date estimation

Age-0 Smallmouth Bass (n=91) were collected between July and September 2016. Six of the 91 (6%) otoliths were either unreadable or age could not be agreed upon by independent readers. The remaining 85 otoliths had a mean otolith age of 44 days and ranged from 26 to 97 days. The majority otoliths, 82 of 85 (96%), were determined to be $\leq$ 60 days. The back-calculated spawn dates showed that spawning occurred over 17 days from May 25 to June 10 2016 (Figure 16). Furthermore, 75 of 85 (88%) age-0 Smallmouth Bass were spawned over 10 days from May 31 to June 9 2016. Smallmouth Bass spawn date frequency distributions for the upstream, midstream, and downstream

sampling reaches overlapped and appeared to be similar to one another (Figure 17). Spawn date distributions for the three locations did not vary significantly from one another ($P > 0.1$; Table 4, Figure 17).

All age-0 Smallmouth Bass were spawned when mean daily temperatures were between 17 and 25°C (Figure 18). Spawning occurred immediately following a stormflow event, 84,400 L/s, and spawning continued for 17 days with another smaller stormflow event, estimated to be 13,000 L/s, occurring on the eleventh day. Regression equations ($R^2 > 0.60$, $n > 15$) were used to predict missing discharge values for June 2-3 2016 from a downstream gage located in Scottsville, AR (https://waterdata.usgs.gov/ar/nwis/uv? 07257500).

The best model for predicting the proportion of individuals spawned was a second order polynomial of median daily water temperature (AIC=-62.2, Table 5). Proportion of individuals spawned was significantly related to median daily water temperature (R^2= 0.51, F=7.39, df=2,14, P<0.01, Figure 19). Second order polynomial models using mean, maximum, and minimum daily temperatures were also significant (Table 5, Figure 19). The best model using discharge as a predictor was a second order polynomial of $\log_{10}$ minimum discharge (AIC=-57.73, Table 5). This relationship was marginally significant (R^2=0.37, F=4.07, df=2,14, P=0.04, Figure 20). The best model with multiple predictors was median ºC + (median ºC)^2 + $\log_{10}$ (min L/s) + ($\log_{10}$ (min L/s)^2). This model was significant (R^2=0.53, F=5.98, df=4, 12, P<0.01, Table 6), but did not add much explanatory value when compared to the best temperature model.

Age-0 Spotted Bass (n=17) were collected while age-0 Smallmouth Bass were sampled, and ages of all 17 otoliths were agreed upon by readers. Mean Spotted Bass age

was 53 days and ranged from 33 to 96 days and Spotted Bass on average had a smaller length to weight ratio (Figure 21). The majority of otoliths, 14 of 17 (82%), were estimated to be ≤ 60 days. Spotted Bass were spawned over 9 days from May 29 through June 5 2016 (Figure 22) when mean daily temperatures were between 18 and 21°C. Spotted Bass appeared to be more abundant at the downstream site; 14 of the 17 (82%) were from the downstream site, 1 of the 17 (6%) was from the midstream site, and 2 of the 17 (12%) were from the upstream site. Spawn date distributions for Smallmouth Bass and Spotted Bass differed significantly (D=0.53, P=0.02, Figure 22). The range of temperature and discharge in which Spotted Bass spawned was narrow. There was no relationship between proportion of Spotted Bass spawned and either discharge (P>0.1) or temperature (P>0.2).

Discussion

I hypothesized that adult Neosho Smallmouth Bass would move upstream to spawn before returning to their original capture location in this system based on Homan's (2005) observation. He found that adult fish were missing from his spring samples, but present in his fall and summer samples in his stream study reach, and as observed in previous studies (Todd and Rabeni 1989; Langhurst and Schoenike 1990; Lyons and Kanehl 2002). However, in this study, spawning migrations were not observed, which was contrary to Todd and Rabeni's (1989) findings that 75% of their tagged Smallmouth Bass left their home pool to spawn. It is possible that movement patterns and behavior were altered from the surgeries. However, I think this is unlikely due to the length of time between transmitter implantation and spawning; transmitters were implanted in March and spawning did not occur until June. Fish that left the tracking reach (i.e., fish that made long distance movements) were difficult to consistently locate which led to an underestimation of movement. As far as I am aware, this study is the first to document movement patterns for Neosho Smallmouth Bass associated with spawning so future research is needed to confirm this finding.

Movement was greatest in April and as time progressed into the summer months', fish appeared to move around a centralized location. Todd and Rabeni (1989) observed similar behavior in a perennial Missouri river where adult Smallmouth Bass remained in restricted home ranges for most of the year, but tended to leave home pools during the spring. I hypothesized that long-distance movements observed at the start of this study were a result of telemetry fish being captured on overwintering springs, and as water temperatures increased adult Smallmouth Bass dispersed. Increased Smallmouth Bass

biomass and abundance has been documented in springs when river water temperature is cooler than that of the groundwater (Peterson and Rabeni 1996).

Smallmouth Bass movement was negatively correlated with water temperature in contrast to what Todd and Rabeni (1989) reported for hourly movements, which were positively correlated with water temperature in the Missouri Ozarks. This is likely due to their measuring movements on a finer scale and throughout the year in a stream where water temperatures did not exceed 30°C; whereas, I measured weekly movements restricted to the spring and early summer months in a warmer stream. The decreased summer movement I observed was most likely associated with discontinuous flow characteristic of the runoff flashy flow regime, as described by Leasure et al. (2016), that is typical of streams in this ecoregion. Hafs (2007) documented a 26% loss of wetted area in the Middle Fork, and as much as 47% in upstream portions of the North Fork in the Illinois Bayou during the summer of 2006. Although there was no statistical relationship, Smallmouth Bass in this stream likely moved in response to discharge, but without fine scale measurements (i.e., daily or hourly) that relationship may have been obscured.

Spawning occurred over a relatively short time period of 17 days in this system compared to findings by Dauwalter and Fisher (2007), who found that Neosho Smallmouth Bass spawned from late April through mid-June in Baron Fork Creek, Oklahoma. Numerous studies on the northern sub-species have also noted a prolonged spawning duration of at least three months (Robison and Buchanan 1984; Graham and Orth 1986; Etnier and Starnes 1993; Lukas and Orth 1995). The short spawning period I observed could be a product of the runoff flashy flow regime, high gradients, and larger

substrates (cobble, boulder, and bedrock) characteristic of the study reach. Dauwalter and Fisher's (2007) study reaches were characterized as low-gradient, with wide floodplains, and the streambeds were mostly gravel. It is possible that spawning occurred earlier or later than what I observed, but age-0 fish may have not survived long enough to be included in samples or nests and eggs were destroyed by high flows. I think this is unlikely because environmental conditions such as water temperature and discharge did not exceed ranges observed in other studies where spawning occurred and age-0 fish recruited to sampling gear (Graham and Orth 1986; Lukas and Orth 1995). In addition, I observed age-0 fish of other species through the spring and early summer thus, it seems unlikely that age-0 Smallmouth Bass could not survive if they had been spawned at other times. If this diminished spawning period is characteristic of the Illinois Bayou year-after-year, extreme environmental conditions such as prolonged drought, extreme stormflows, and unusual temperatures could constitute a threat to recruitment.

Mean daily water temperature was an important variable associated with spawning which is consistent with findings by Graham and Orth (1986). My results also confirmed previous observations that Smallmouth Bass spawn during receding water levels immediately following stormflow events (Surber 1943; Graham and Orth 1986; Lukas and Orth 1995). Neosho Smallmouth Bass in this ecoregion are exposed to higher temperatures than typical for populations of the northern sub-species. During the summer of 2016 water temperature exceeded 31°C within the study reach, and it did not fall below 14°C, similar to Hafs et al. (2010). Spawning in this system occurred over similar temperature ranges reported by others, 12.5 to 23.5°C (Graham and Orth 1986; Lukas and Orth 1995). However, the range of spawning temperatures I documented, 17.4

to 25°C, was slightly higher than previous studies. Dauwalter and Fisher (2007) observed nesting activity in Neosho Smallmouth Bass at temperatures of 14 to 18°C in Baron Fork Creek. Few studies have focused on seasonally discontinuous streams and the subspecies of Smallmouth Bass that inhabits this region, future research is needed to better understand spawning dynamics in the Boston Mountains.

Spotted Bass spawned within the same range of dates as Smallmouth Bass and age-0 individuals were collected in the same sections of river. This contrasts with the generally accepted knowledge that Smallmouth Bass tend to spawn earlier in the spring than Spotted Bass (Pflieger 1997). Spotted Bass tolerate warmer waters and more disturbances (stormflows and associated high turbidity) than Smallmouth Bass (Pflieger and Fajen 1975). The range of temperatures in which Spotted Bass were spawned was narrower than that of Smallmouth Bass but conforms to known ranges, 18 to 22°C (McMahon et al. 1984). Spotted Bass may outcompete Smallmouth Bass for spawning habitat in streams with altered flow and temperature regimes (Quinn et al. 2012).

Introgression between Smallmouth Bass and Spotted Bass has been partly attributed to declines in Smallmouth Bass where Spotted Bass have been introduced (Pflieger and Fajen 1975; Pflieger 1997). Hybridization between black basses can occur when there is limited spawning habitat available, altered environmental conditions, and when both species spawn in close proximity (Hubbs 1955). Although Smallmouth Bass and Spotted Bass are native to the Illinois Bayou, they appear to be spawning in the same sections of river at the same time thus, introgression seems possible. Koppelman (1995) found high rates of hybridization that resulted in Smallmouth Bass decline in his study reach. He also noted that this was likely due to habitat being more suitable for Spotted

Bass. Future research is needed to determine if concerns regarding black bass introgression in Boston Mountain streams are warranted.

Exploitation of telemetry fish was low, compared to Hafs (2007), with no noticeable mortality from harvest. This may be because high exploitation rates were observed by Hafs (2007) from July to September; whereas, I stopped tracking fish in July. In late summer, adult Smallmouth Bass confined within isolated remnant pools are likely more vulnerable to fishing mortality (Hafs 2007). Reaches with high fishing pressure may not be replenished quickly by immigrating individuals due to the low productivity (Homan 2005), and the observed sedentary behavior of Smallmouth Bass in this reach. Portions of the Middle Fork of the Illinois Bayou are likely blue-ribbon quality (Rambo 1998). Current regulations allow four Smallmouth Bass of 25.4 cm (10 inches) or larger to be harvested per day. High exploitation rates as observed by Hafs (2007) combined with low movement and productivity may indicate a need to limit harvest in the summer when flows are low.

Melillo et al. (2014) stated that increased temperatures, extreme storms, and increased drought between storms are likely in Arkansas as a consequence of global climate change. These changes along with increased water temperatures will likely lead to declines in cool water species such as Smallmouth Bass (Eaton and Sheller 1996) and could potentially alter Boston Mountain streams in favor of Spotted Bass. In general, climate change seems likely to negatively influence Smallmouth Bass in the Boston Mountain ecoregion. Future studies in this ecoregion will be crucial to develop strategies that mitigate these effects.

Table 1. Net movement, cumulative movement, and range for each Smallmouth Bass from the original tagging location to the last known location in the Middle Fork of the Illinois Bayou, Arkansas 2016.

Fish ID	Net Movement (m)	Cumulative Movement (m)	Range (m)
MD01 ***	-7797	7797	7797
MD02 ***	5593	5593	5593
MD03	-2625	3444	2645
MD04	131	478	244
MD05	265	915	265
MD06	146	645	183
MD07	68	350	139
MD08	-72	2123	750
MD09	30	2684	551
MD10	239	675	277
MD11	110	957	377
MD12	372	2530	1137
MD13 *	241	7779	2185
MD14	207	3174	673
MD15	258	5874	2443
MD16 *	-21	2394	1048
MD17	-26	1723	571
MD18	-37	507	139
MD19	-269	1643	668
MD20	-520	1026	550
MD21 **	643	6306	2737
MD22 **	138	5400	2456
MD23 **	-3796	4987	-3796
MD24	-1540	2365	1827
MD25	558	2617	692
MD26 ***	3672	3791	3672
MD27	-407	4094	1632
MD28	-275	2198	485
MD29 **	368	1399	825
MD30 *	-115	2082	483
Mean	-149	2918	1557
Median	89	2380	721
SD	2122	2164	1766
SE	387	395	322
95% CI	±609.82	± 3692.53	±2188.98

*** Located < 5 times, ** located < 10 times, * located < 15 times.

Table 2. Linear and polynomial models used to predict Smallmouth Bass movement with discharge (L/S) and temperature (°C) variables as predictors in the Middle Fork of the Illinois Bayou 2016. Adjusted R^2 is reported for models with multiple predictors.

Model	R^2	AIC	p-value
Mean ºC + Mean ºC^2	0.57	-22.91	0.008
Maximum ºC	0.55	-24.14	0.002
Minimum ºC + Minimum ºC^2	0.67	-26.47	0.002
Minimum ºC	0.61	-25.96	0.001
Log_{10}(mean L/s)	0.25	-16.92	0.067
Log_{10}(maximum L/s)	0.29	-17.69	0.050
Log_{10}(minimum L/s) + Log_{10}(minimum L/s)^2	0.02	-11.22	0.868
Log_{10}(median L/s) + Log_{10}(median L/s)^2	0.13	-12.89	0.450
Minimum ºC + Log_{10}(maximum L/s)	0.54	-24.02	0.005

Table 3. Results from Tukey's HSD post-hoc analysis for a repeated measures ANOVA with cumulative Smallmouth Bass movement as the response variable and spawning season as the treatment for the Middle Fork of the Illinois Bayou, Arkansas 2016.

Comparison	Difference	SE	z-value	p-value
Pre-spawn – post-spawn	81.82	34.61	2.36	0.047
Spawn – post-spawn	-20.05	40.41	-0.49	0.872
Spawn – pre-spawn	-101.87	41.74	-2.44	0.038

Table 4. Results for comparisons of Smallmouth Bass spawn date frequency distributions among the three sites using pairwise Kolmogorov-Smirnov two-sample tests for the Middle Fork of the Illinois Bayou 2016.

Sites	D	p-value
Upstream, downstream	0.352	0.24
Upstream, midstream	0.411	0.11
Midstream, downstream	0.294	0.45

Table 5. Models predicting proportion of Smallmouth Bass spawned per day with environmental variables as predictors for the Middle Fork of the Illinois Bayou 2016. Adjusted R^2 is reported for models with multiple predictors.

Model	R^2	AIC	p-value
Maximum ºC + maximum $ºC^2$	0.44	59.93	0.016
Minimum ºC + minimum $ºC^2$	0.50	-61.93	0.007
Mean ºC + mean $ºC^2$	0.49	-61.55	0.008
Median ºC + median $ºC^2$	0.51	-62.20	0.006
Log_{10}(maximum L/s) + log_{10}(maximum L/s)^2	0.30	-56.03	0.081
Log_{10}(minimum L/s) + log_{10}(minimum L/s)^2	0.37	-57.91	0.037
Log_{10}(median L/s) + log_{10}(median L/s)^2	0.34	-56.92	0.056
Log_{10}(mean L/s) + log_{10}(mean L/s)^2	0.33	-56.78	0.059
Median ºC + median $ºC^2$ + log_{10}(minimum L/s) + Log_{10}(minimum L/s)^2	0.55	-64.48	0.007

Table 6. Summary of multiple regression analyses for variables predicting the proportion of Smallmouth Bass spawned per day (R^2=0.61, F=7.45, df=4, 12, P<0.01) for the Middle Fork of the Illinois Bayou 2016.

	Estimate	SE	t value	p-value
(Intercept)	-3.35	1.12	-2.96	0.011
Median ºC	0.77	0.25	3.00	0.011
Median ºC^2	-0.01	0.01	-3.05	0.010
Log_{10}(Minimum L/s)	-2.16	1.05	-2.05	0.063
Log_{10}(Minimum L/s)^2	0.28	0.14	1.99	0.069

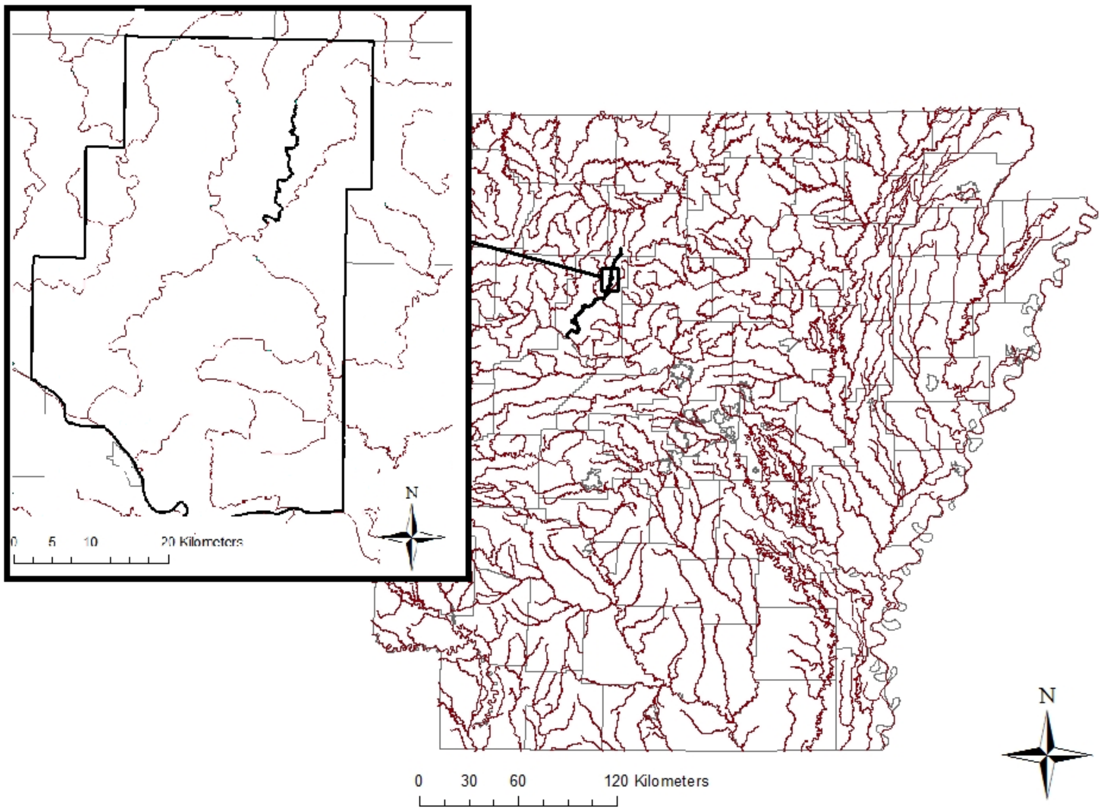

Figure 1. Map of Pope County showing the upper portion of the Middle Fork of the Illinois Bayou (bold line), where the study reach is located.

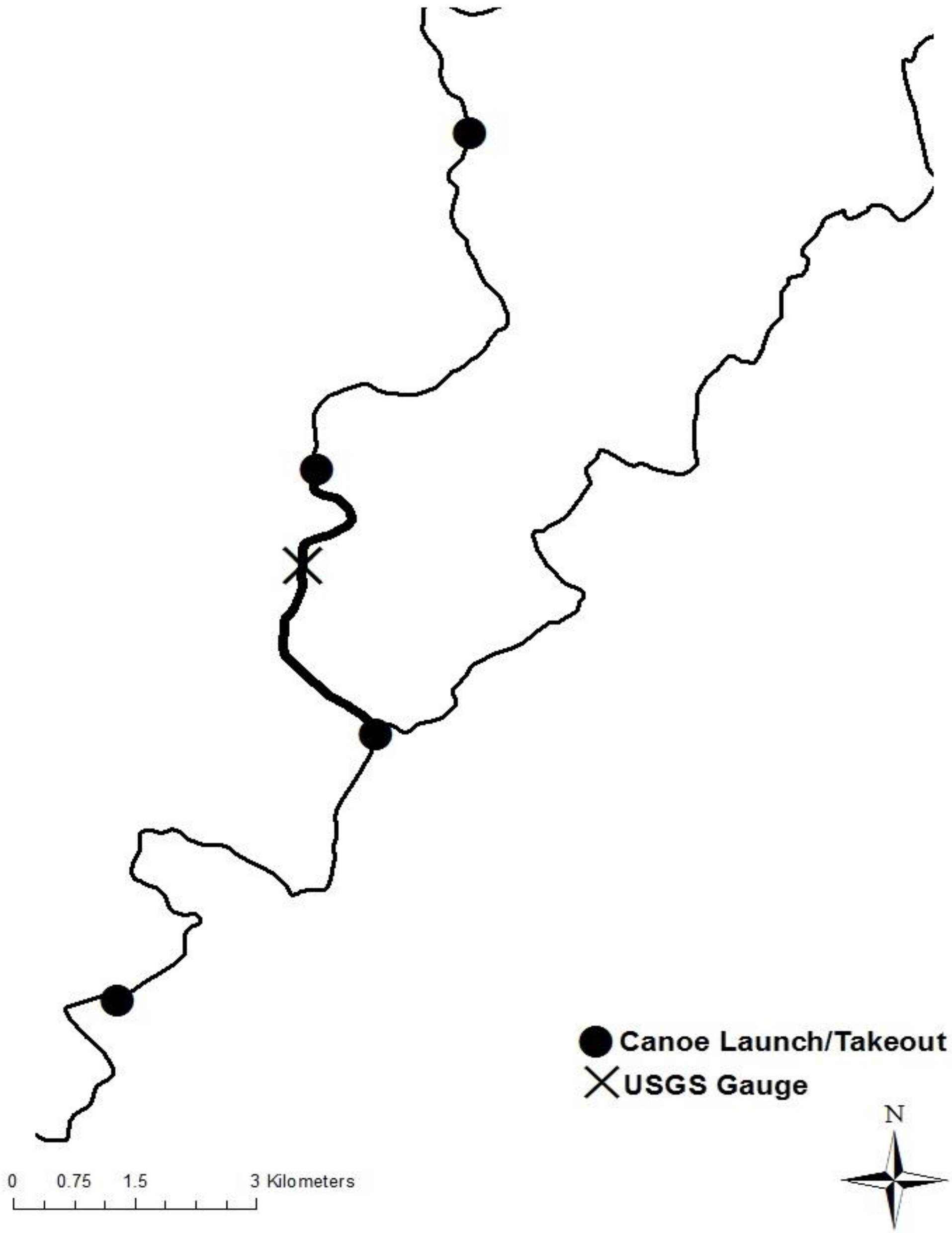

Figure 2. Map of the study reach located in the Middle Fork of the Illinois Bayou showing canoe access points, location of water quality monitoring and discharge gages, and principle 3.6-km study reach (bold line). These access points were used during tracking events.

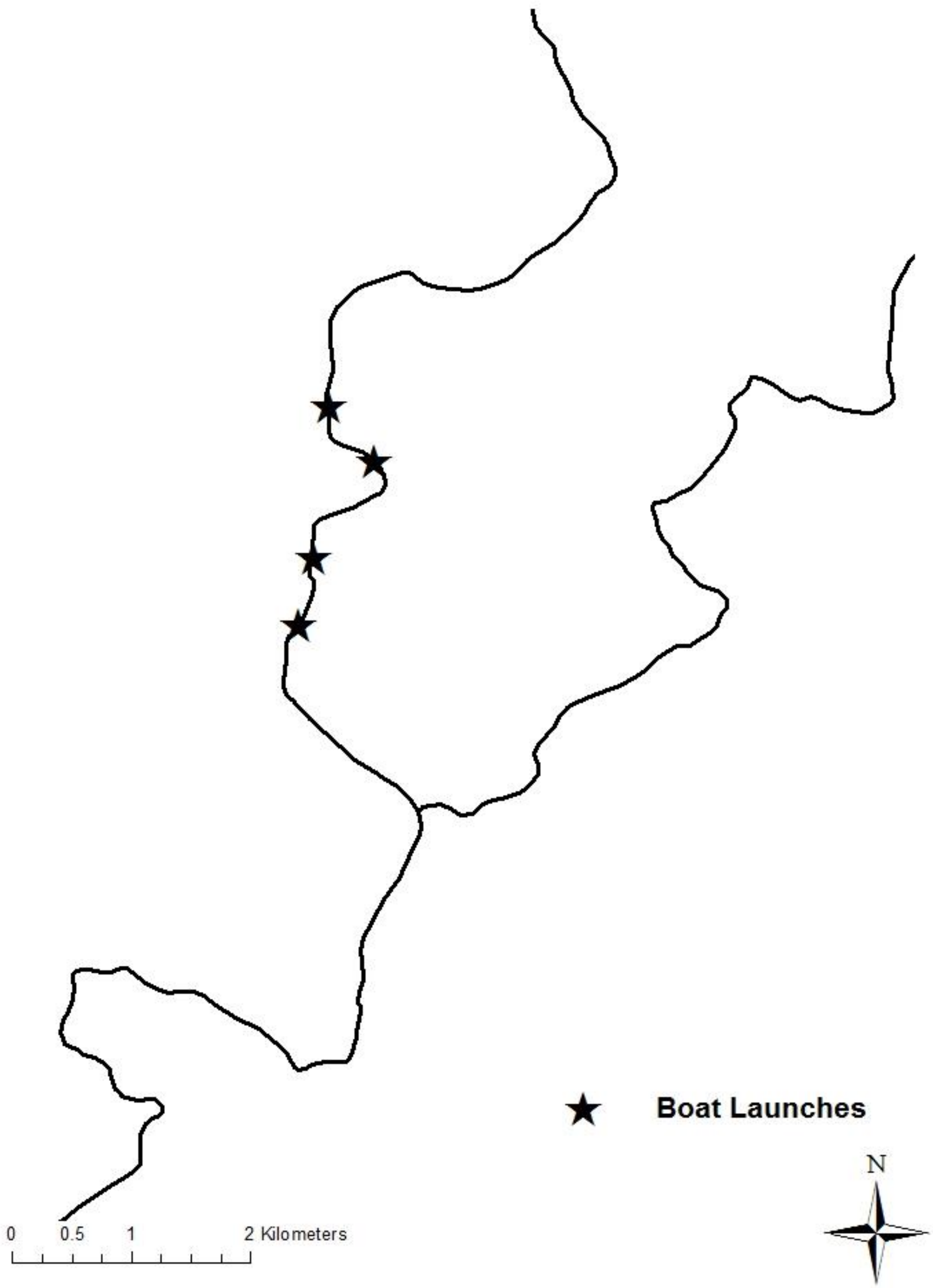

Figure 3. Map of the study reach located in the Middle Fork of the Illinois Bayou showing the locations of four electrofishing boat launches. These unimproved launches were used while tagging adult Smallmouth Bass in March 2016.

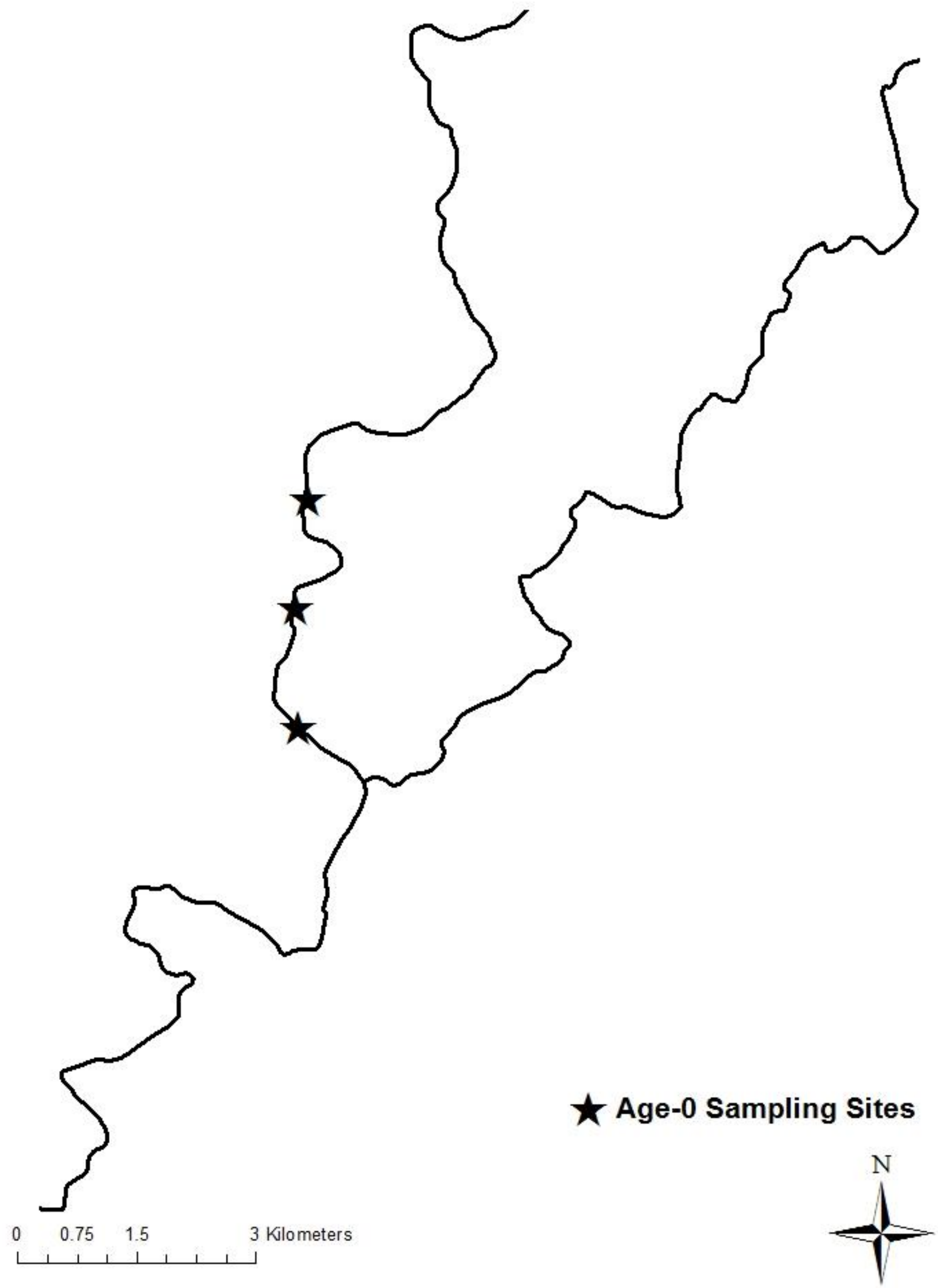

Figure 4. Map of the study reach located in the Middle Fork of the Illinois Bayou showing the three sites where age-0 black bass were sampled during June, July, and August 2016.

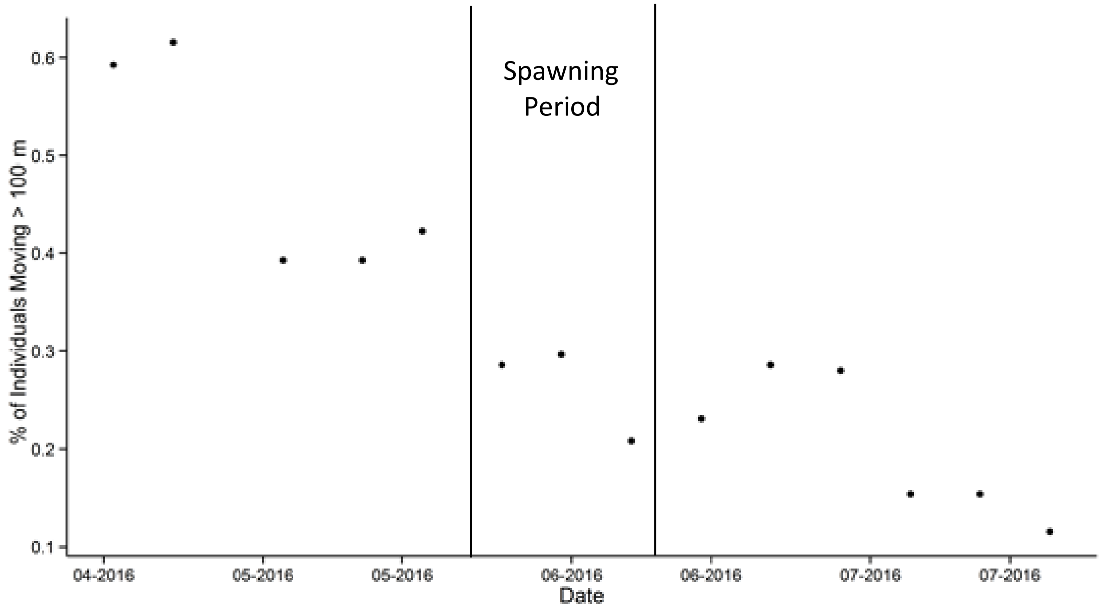

Figure 5. Percent of tagged adult Smallmouth Bass that moved over 100 m in the Middle Fork of the Illinois Bayou for each tracking week from April through July 2016.

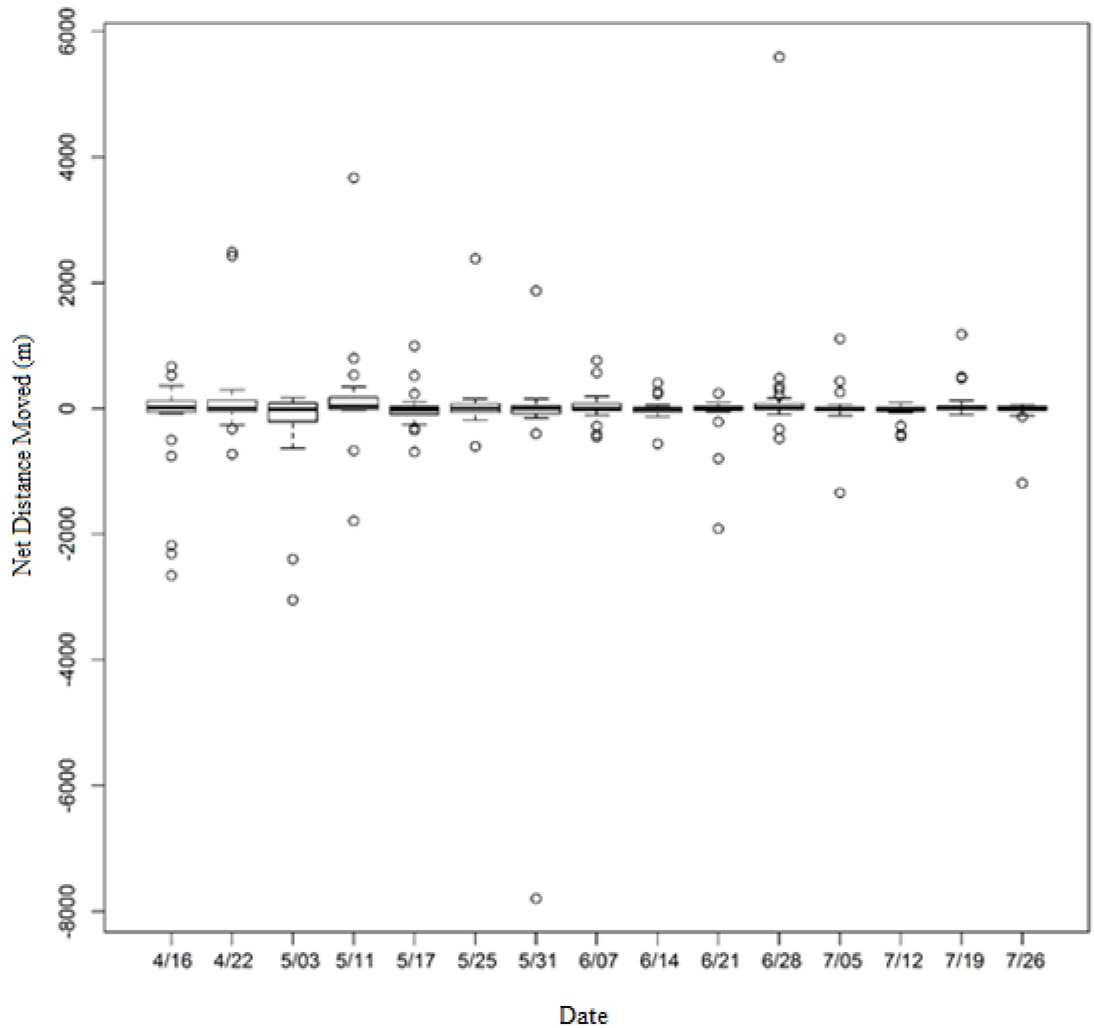

Figure 6. Weekly net movements of adult Smallmouth Bass in the Middle Fork of the Illinois Bayou for each telemetry tracking week from April through July 2016.

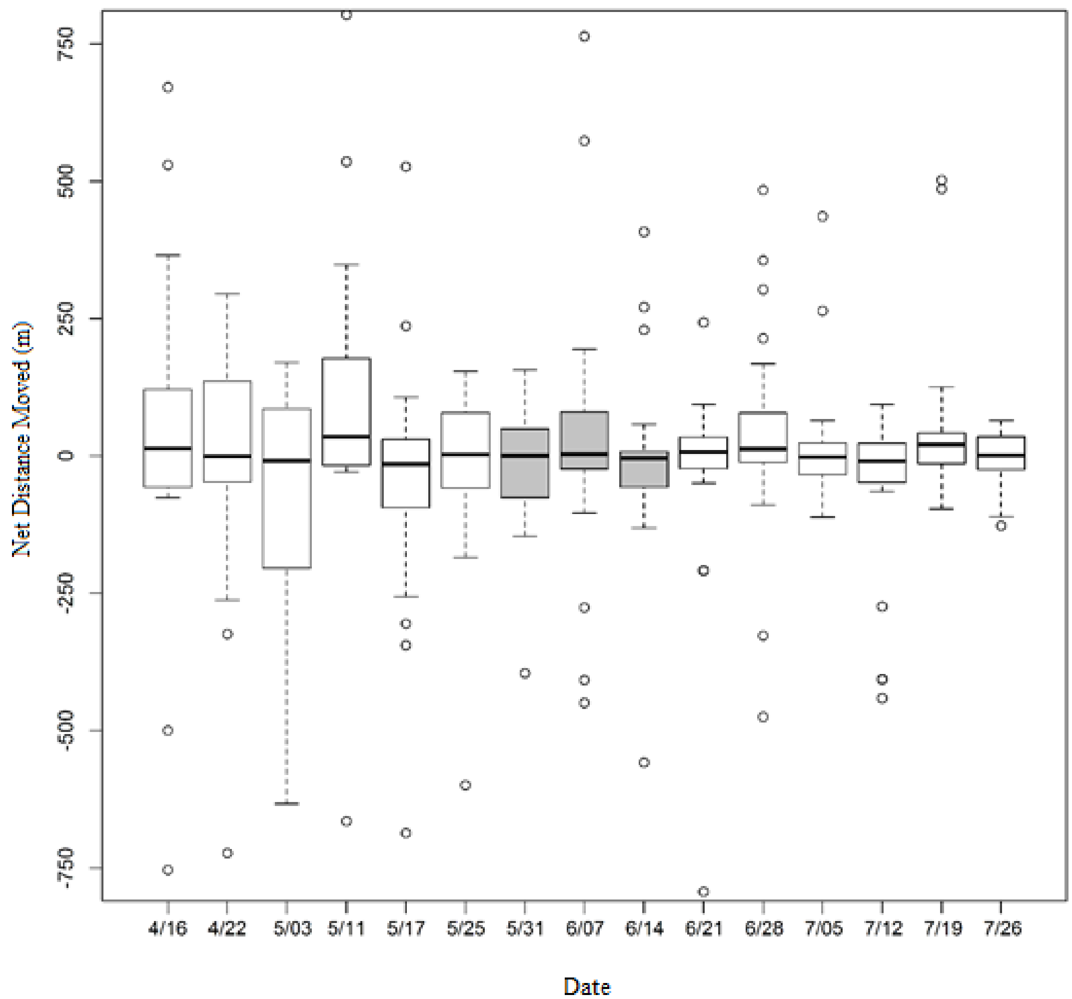

Figure 7. Weekly net movements on a finer scale (omitting outliers > 750 m and <-750 m) of adult Smallmouth Bass in the Middle Fork of the Illinois Bayou for each telemetry tracking week from April through July 2016. Gray shading represents spawning period.

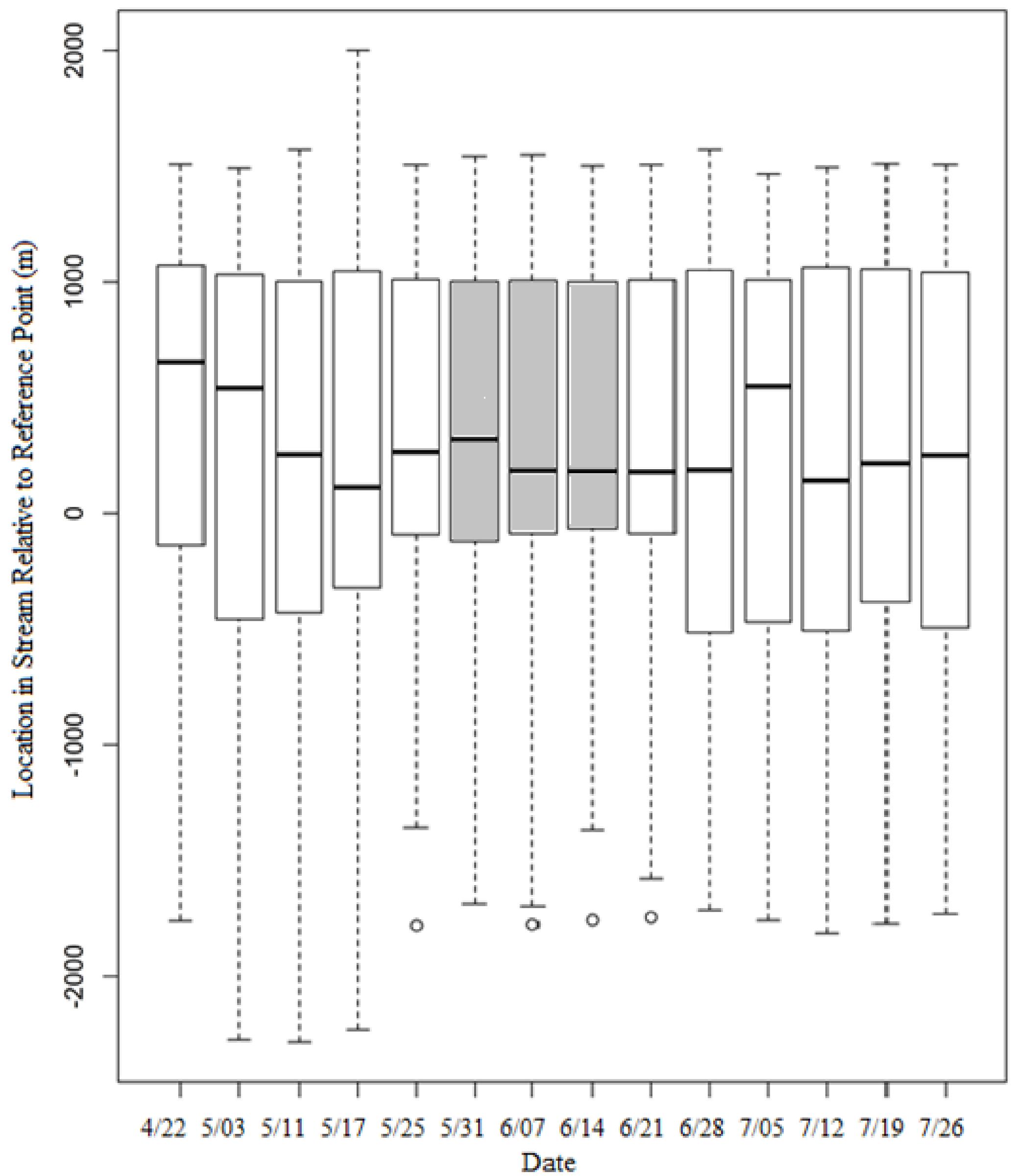

Figure 8. Smallmouth Bass locations relative to the USGS gaging station on the Middle Fork of the Illinois Bayou (n=21) in 2016. Gray shading represents weeks that had spawning.

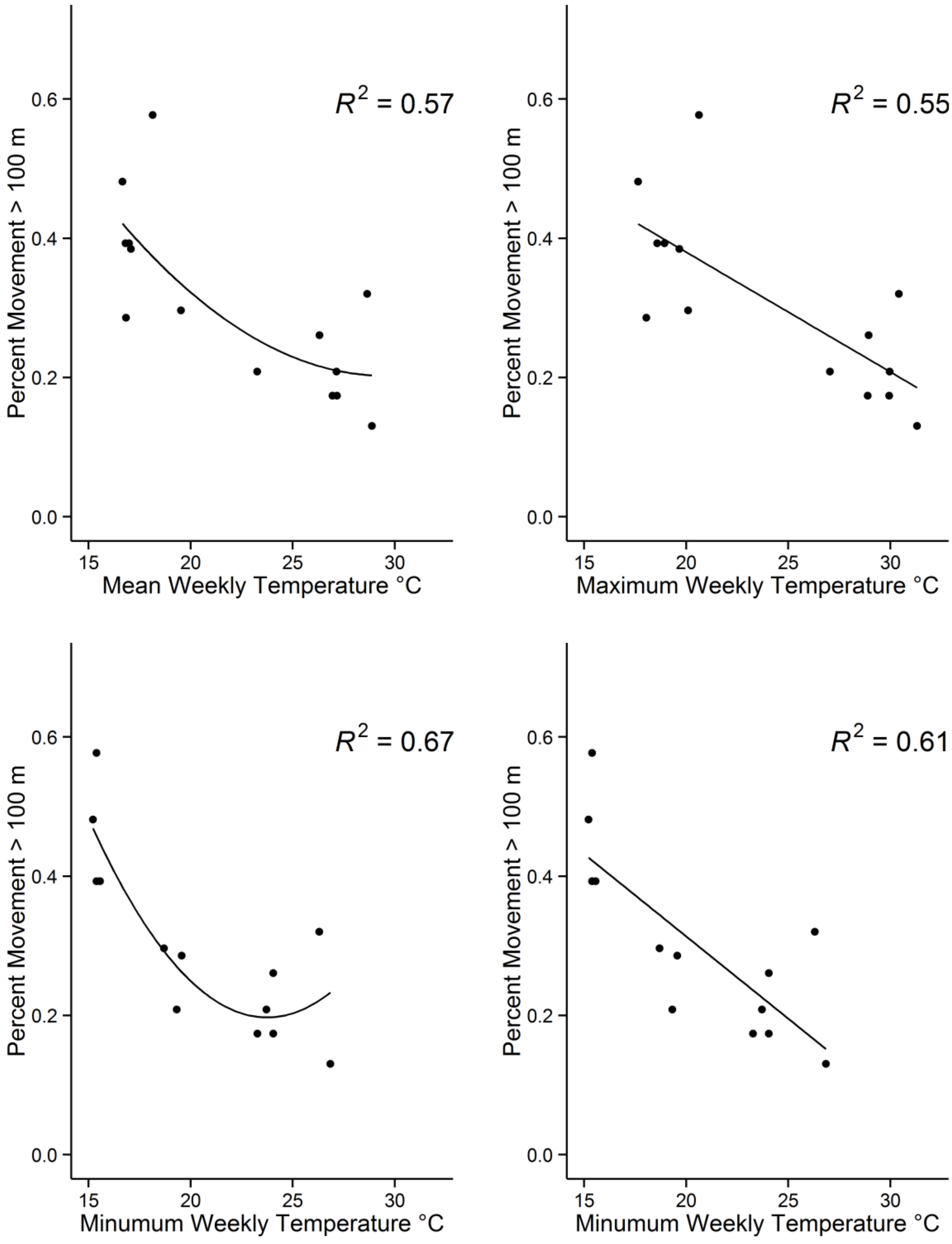

Figure 9. Models predicting percent of adult Smallmouth Bass moving over 100 m/week using variants of weekly temperature as predictor variables ($P<0.05$) for the Middle Fork of the Illinois Bayou.

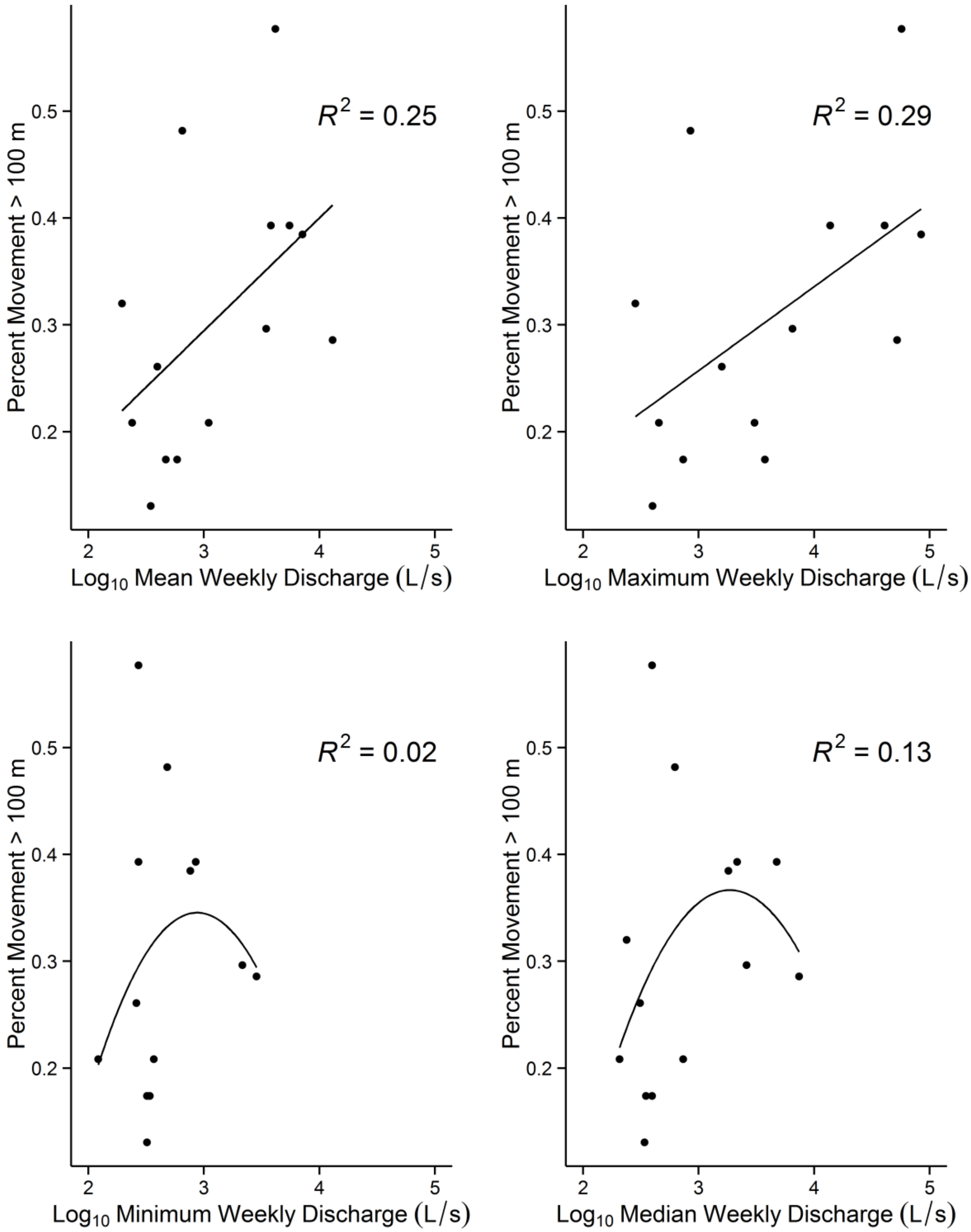

Figure 10. Models predicting percent of adult fish moving over 100 m/week using variants of weekly discharge as predictor variables (*P*>0.1) for the Middle Fork of the Illinois Bayou.

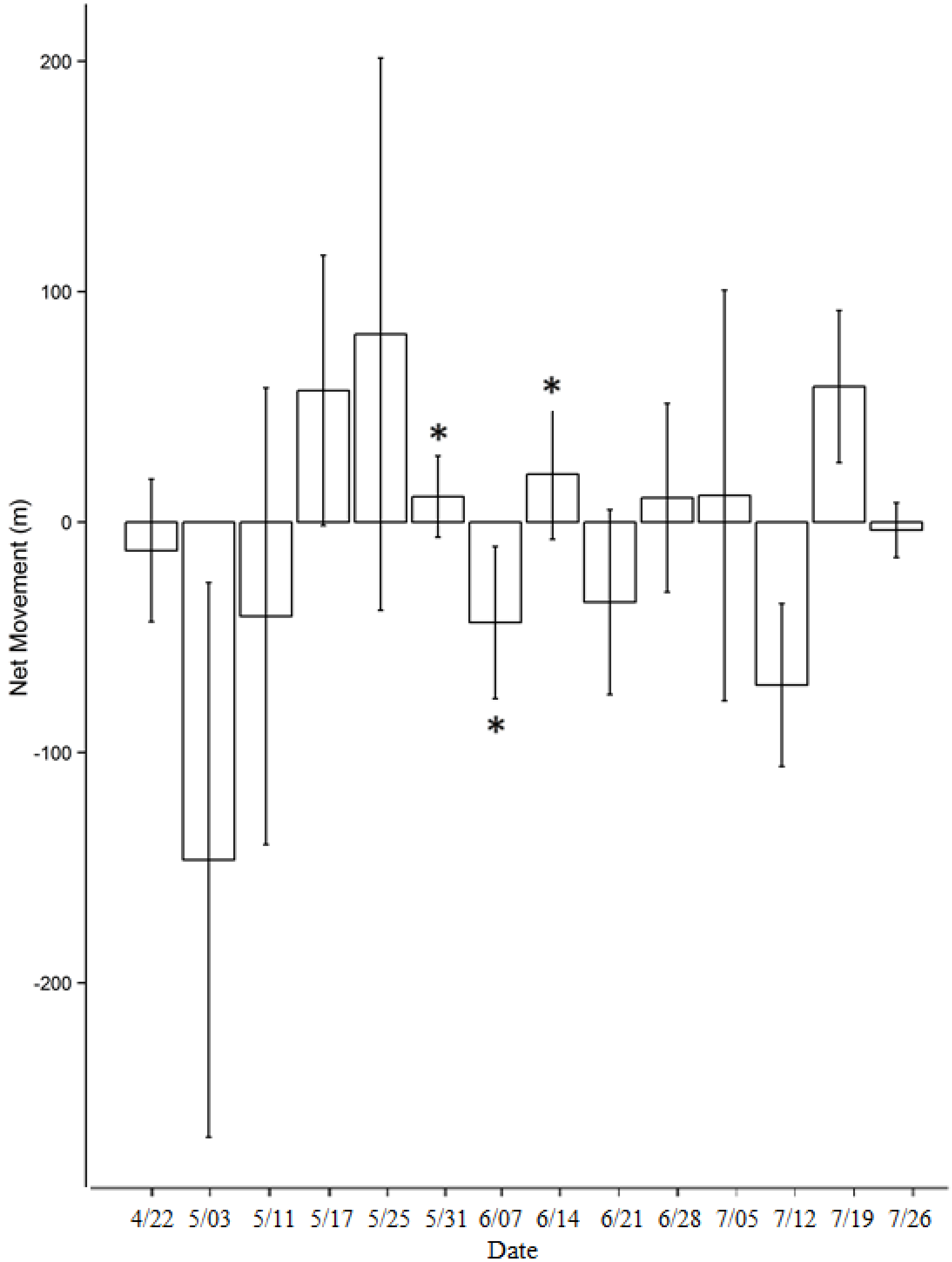

Figure 11. Mean net movement relative to capture locations (±1 SE) for Smallmouth Bass that were located 15 times in the Middle Fork of the Illinois Bayou (n=21) in 2016. Asterisks represent weeks that had spawning.

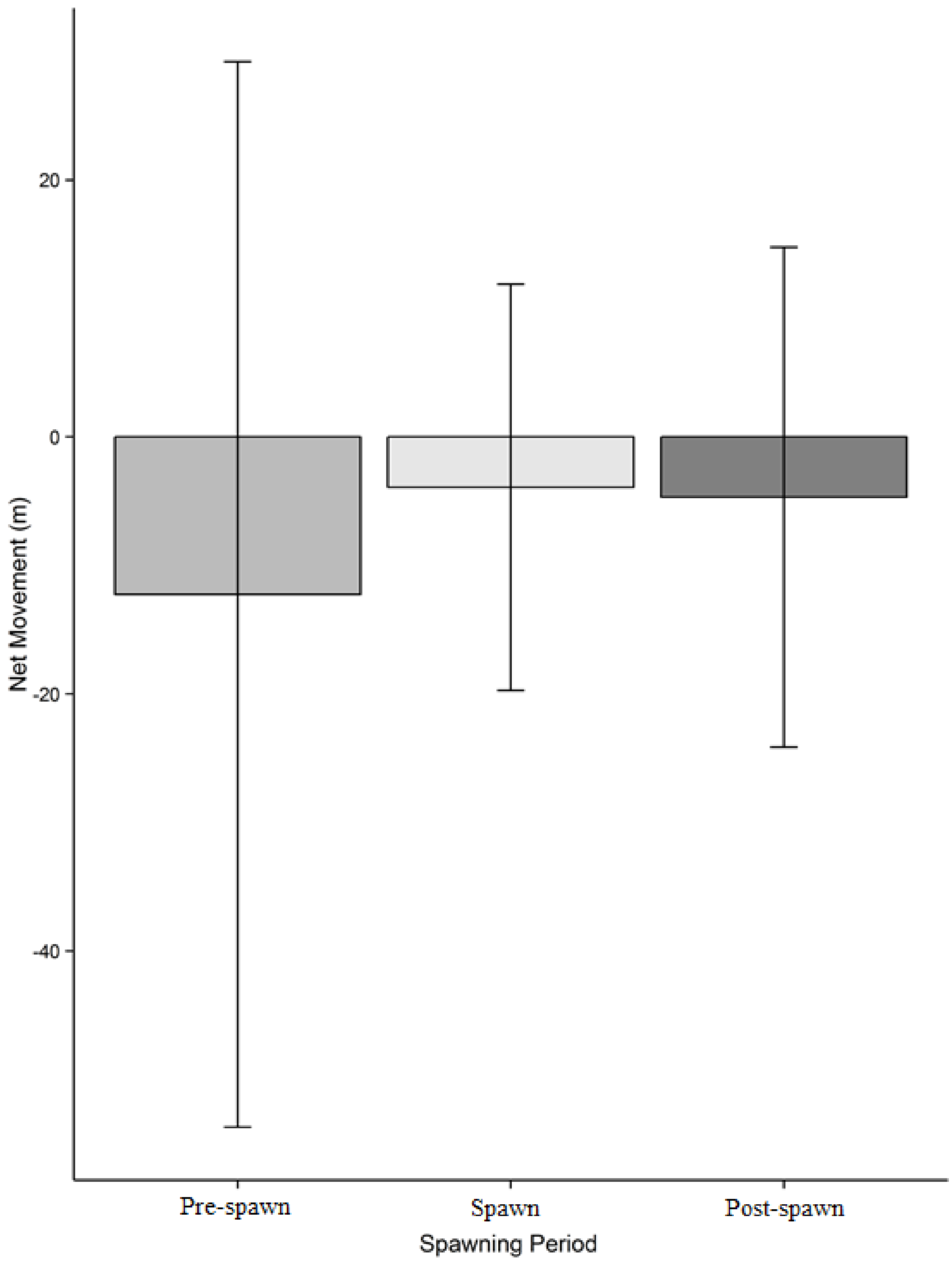

Figure 12. Mean net movement relative to capture locations (±1 SE) for 3 time categories: pre-spawn, spawn, and post-spawn for the Middle Fork of the Illinois Bayou in 2016.

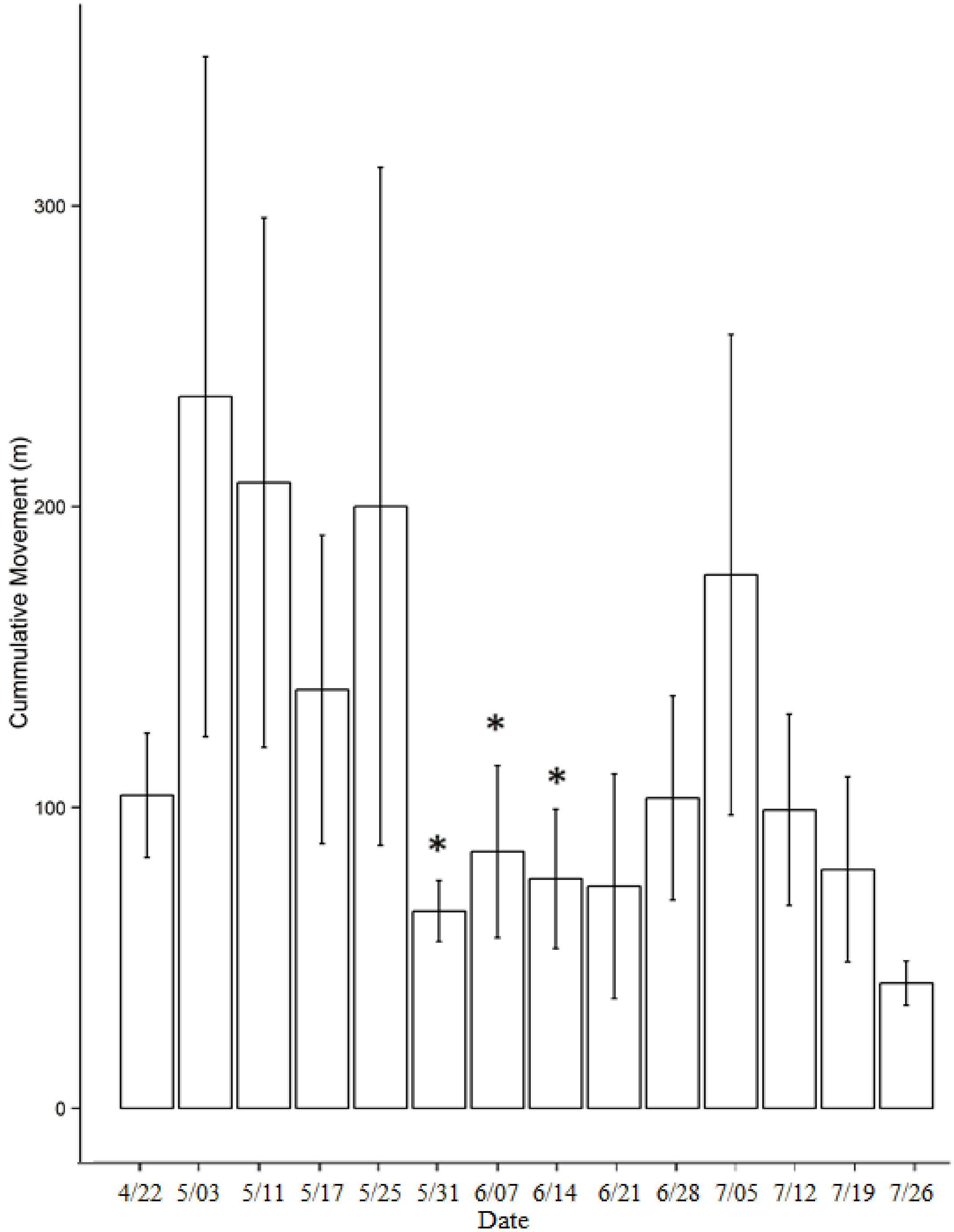

Figure 13. Mean cumulative movement (±1 SE) for Smallmouth Bass that were located using telemetry 15 times in the Middle Fork of the Illinois Bayou (n=21) in 2016. Asterisks represent weeks that had spawning.

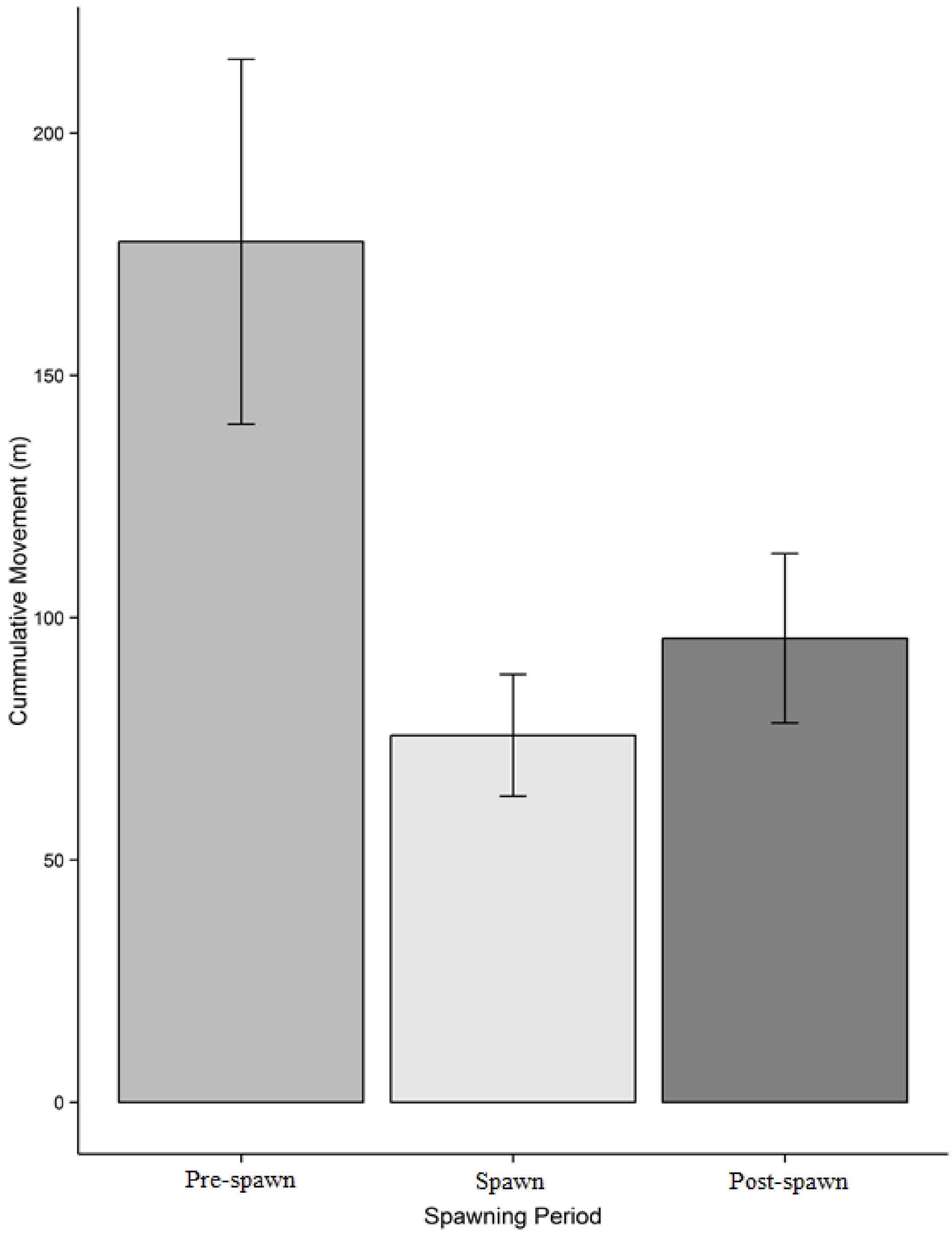

Figure 14. Mean cumulative movement (±1 SE) of Smallmouth Bass for three time categories: pre-spawn, spawn, and post-spawn for the Middle Fork of the Illinois Bayou in 2016.

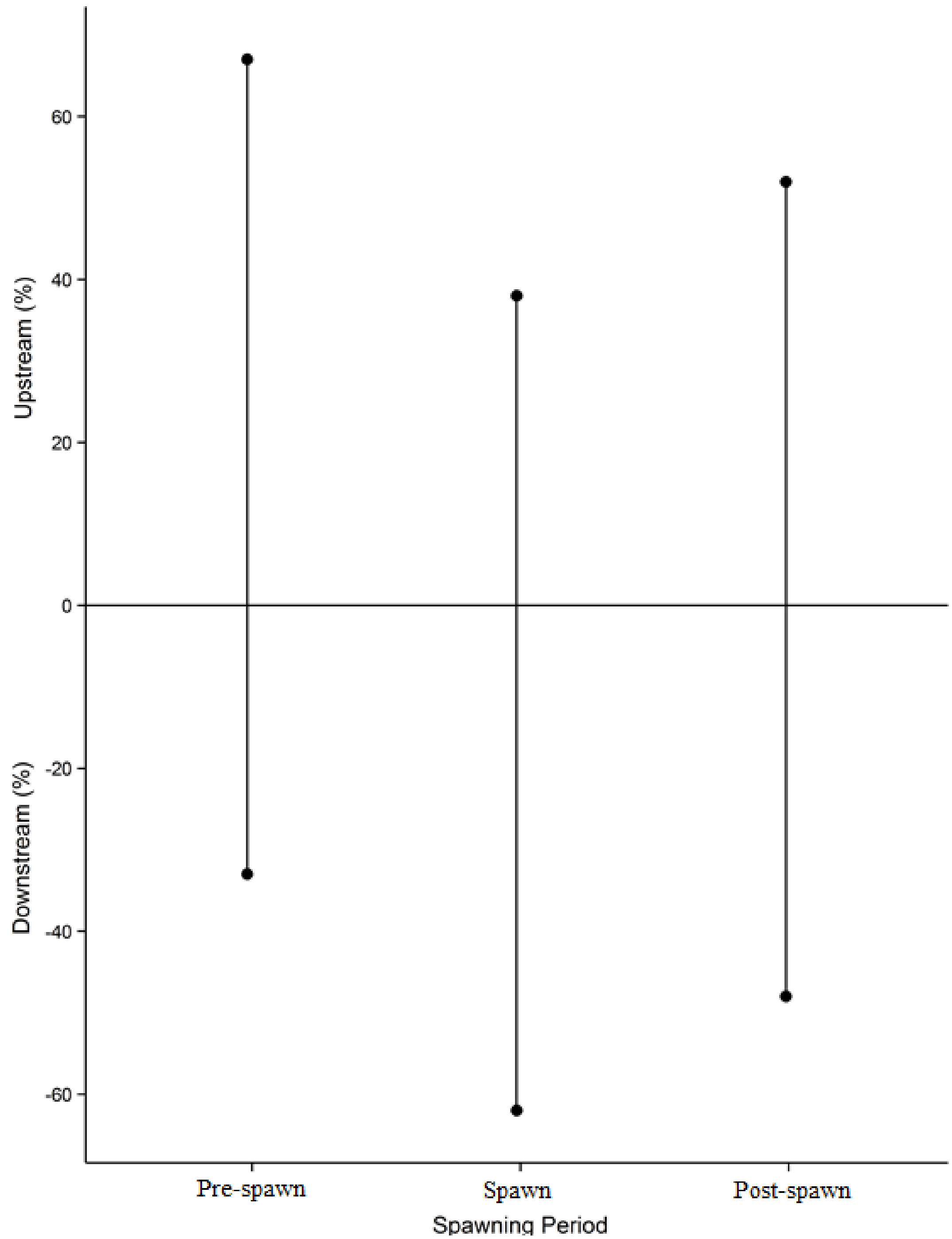

Figure 15. Percent of Smallmouth Bass moving upstream and downstream for three time categories: pre-spawn, spawn, and post-spawn for the Middle Fork of the Illinois Bayou in 2016.

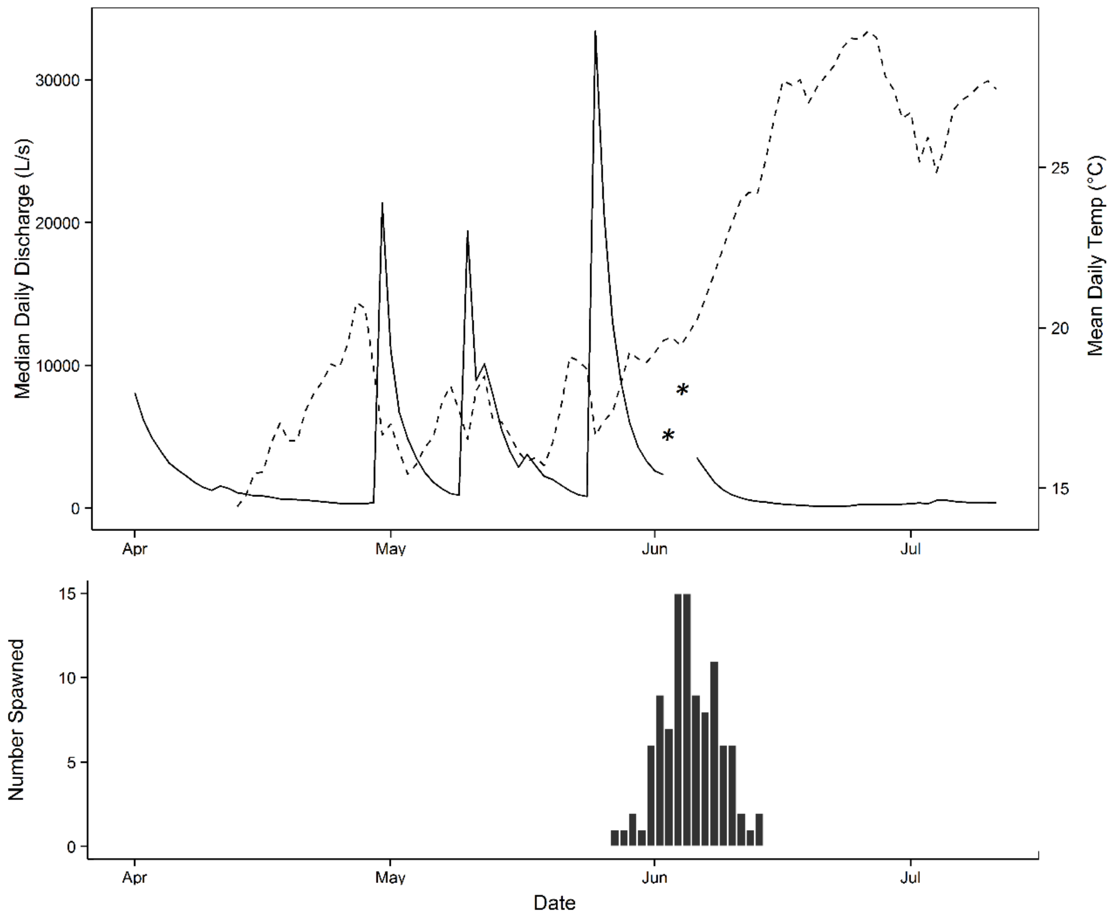

Figure 16. Median daily discharge (solid line), predicted median daily discharge (asterisks), and mean daily temperature (dashed line) for the Middle Fork of the Illinois Bayou from April through July 2016. The bottom graph shows a histogram representing the number of fish spawned for each day.

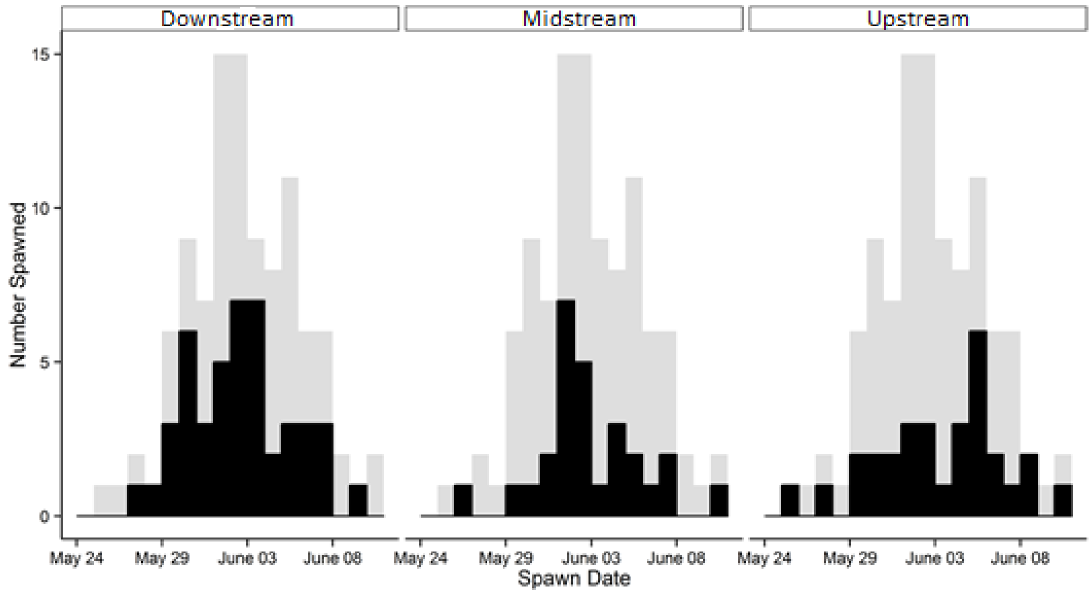

Figure 17. Histograms showing spawn dates determined from daily otoliths of Neosho Smallmouth Bass frequency distributions in the Middle Fork of the Illinois Bayou during 2016, for downstream, midstream, and upstream sites. The gray histogram set behind each site histogram represents a combined spawn frequency distribution all sites.

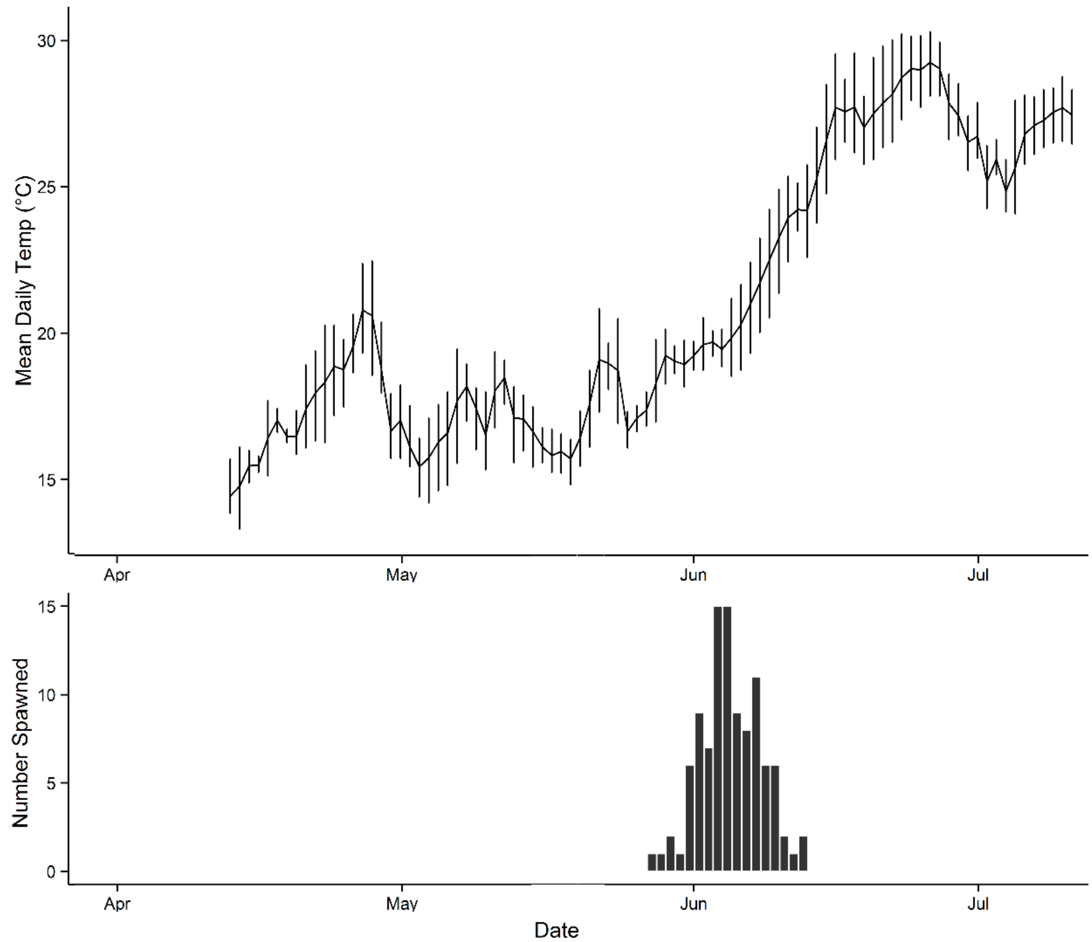

Figure 18. Mean daily temperature, error bars are maximum and minimum temperatures, (top) and number of Smallmouth Bass spawned per day (bottom) for the Middle Fork of the Illinois Bayou from April through July 2016.

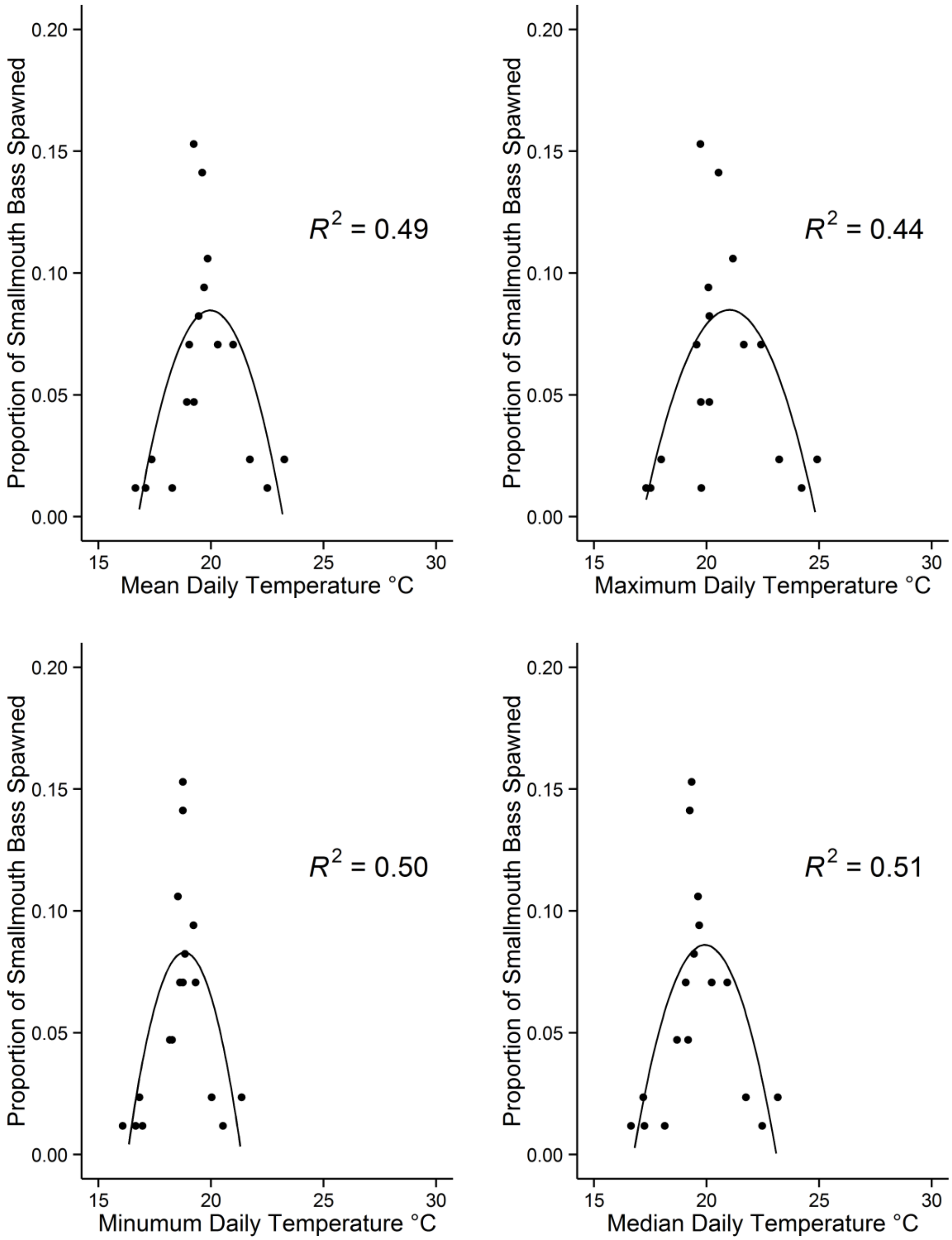

Figure 19. Second-order polynomial models for variants of temperature predicting the proportion of Smallmouth Bass spawned per day (P<0.05) in the Middle Fork of the Illinois Bayou.

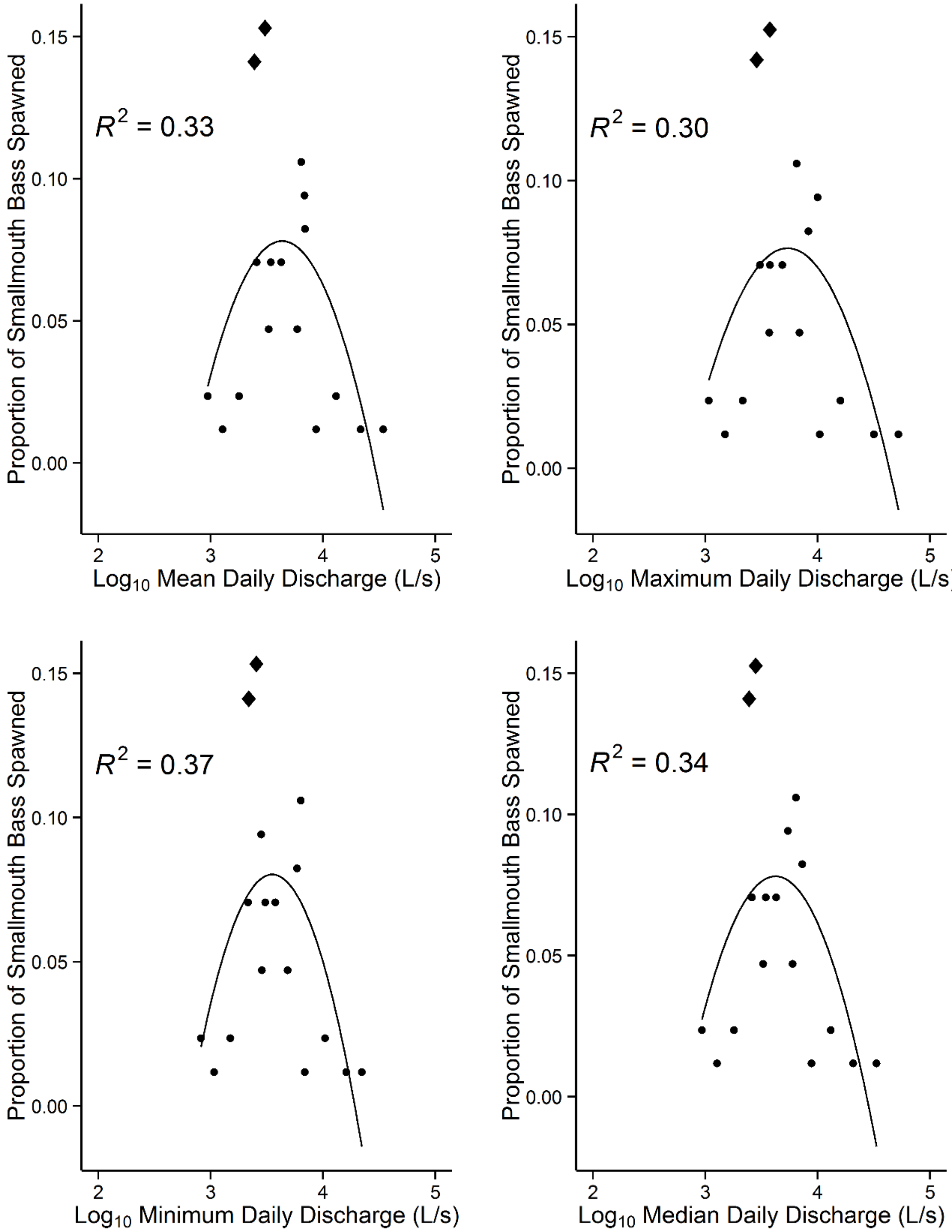

Figure 20. Second-order polynomial models for variants of discharge predicting the proportion of Smallmouth Bass spawned per day in the Middle Fork of the Illinois Bayou. Diamonds represent estimated values.

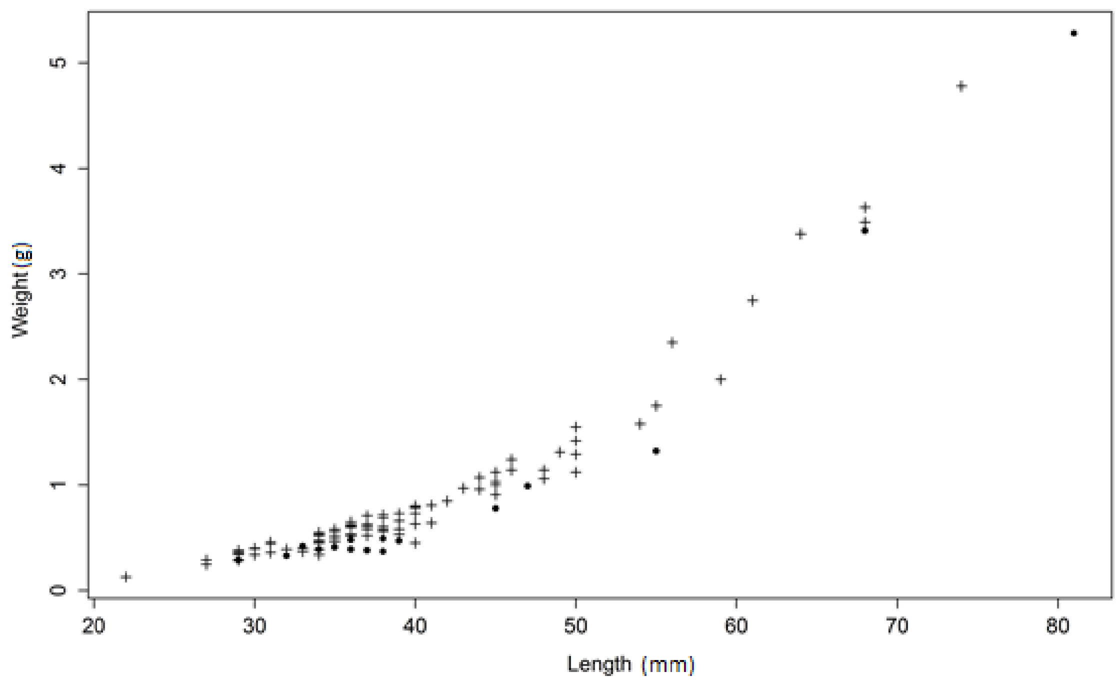

Figure 21. Length and weight relationship for Age-0 black bass in the Middle Fork of the Illinois Bayou during the summer of 2016. Plus signs represent Smallmouth Bass and circles represent Spotted Bass.

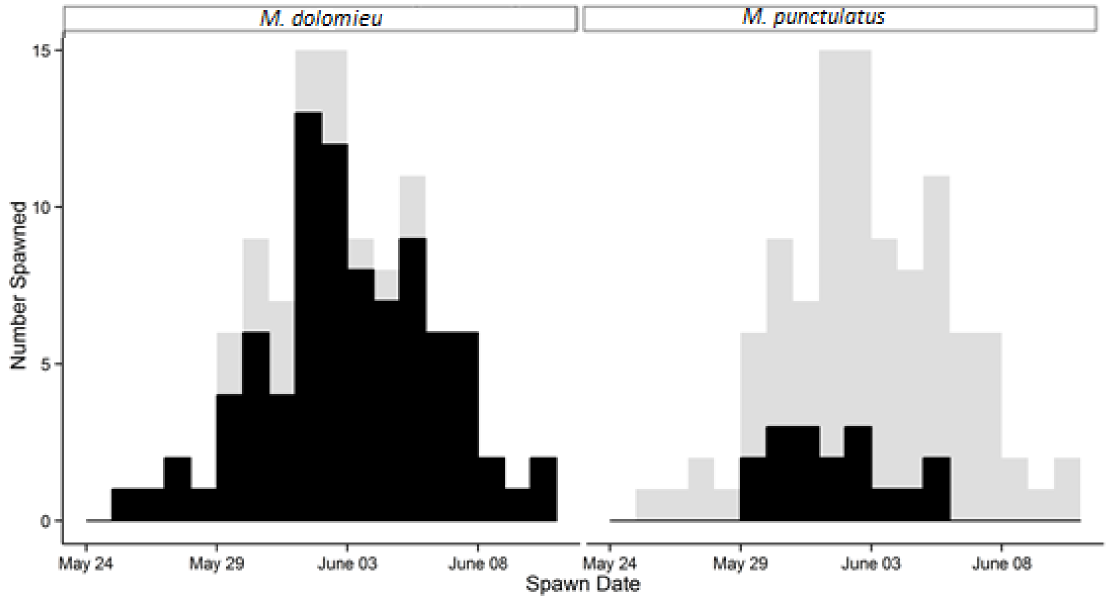

Figure 22. Histograms of 2016 spawn frequency distributions for Smallmouth Bass and Spotted Bass in the Middle Fork of the Illinois Bayou. The gray histogram set behind each individual species histogram represents a combined spawn frequency distribution for both species.

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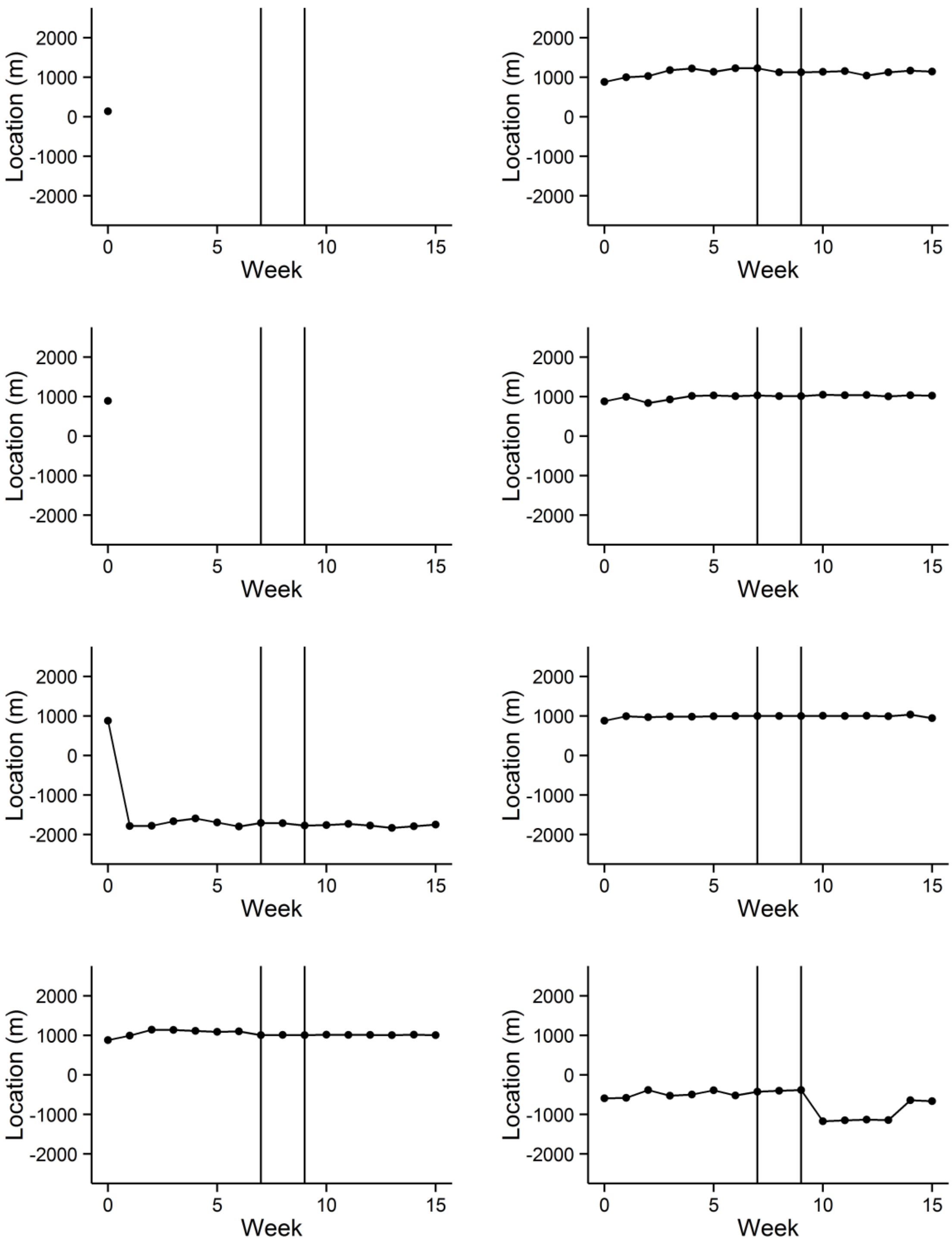
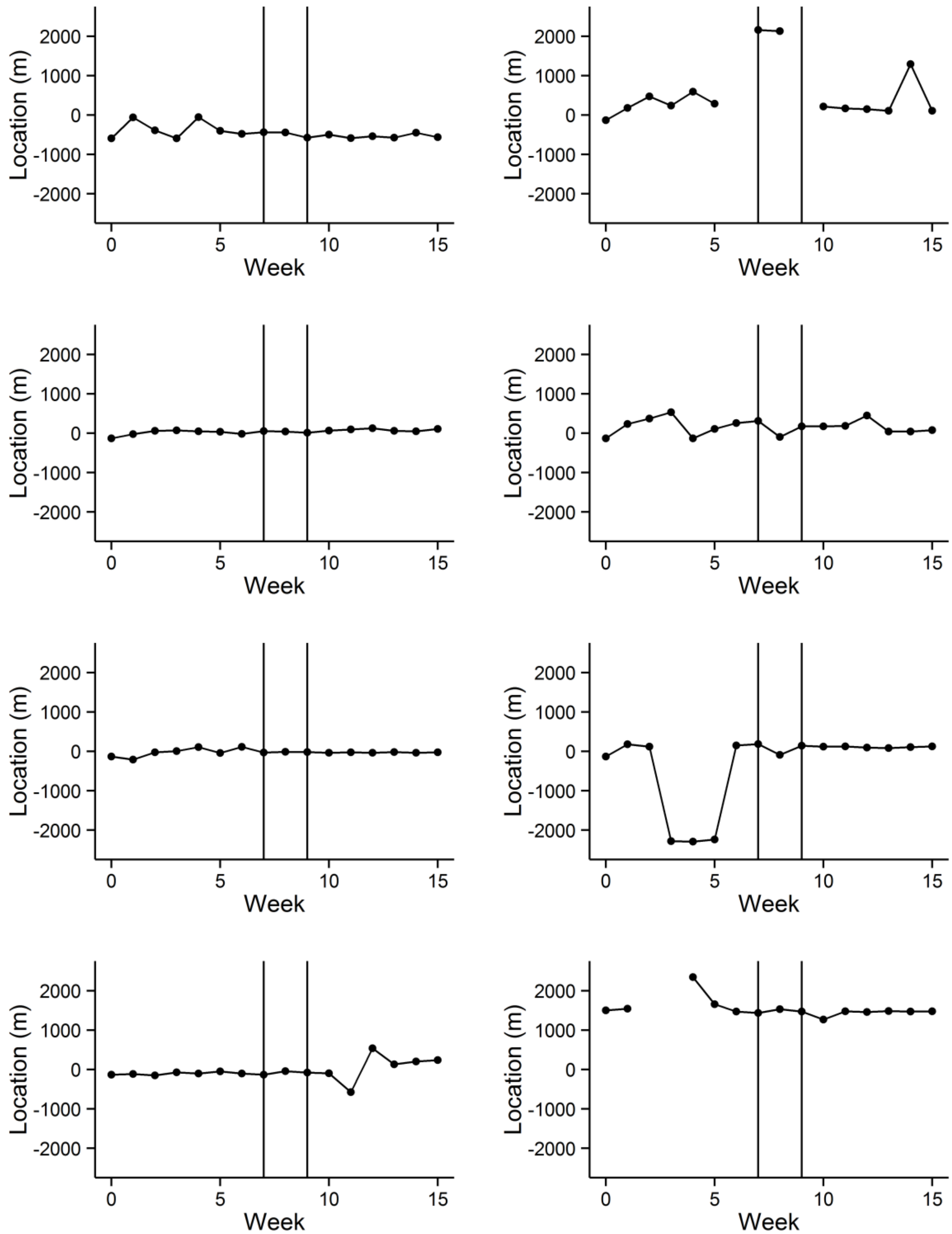
Appendix A

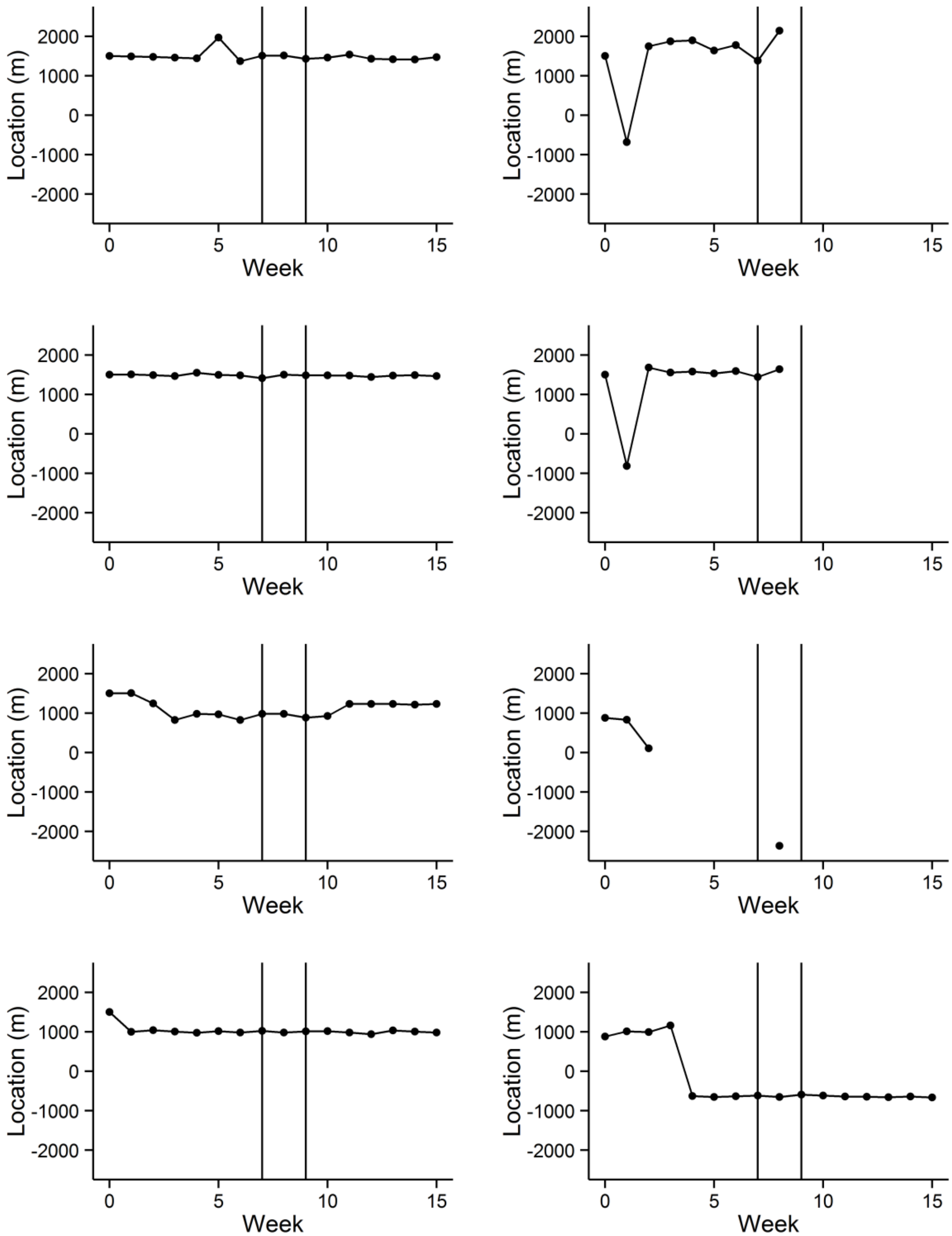
Individual graphs showing each telemetry fish's location relative to the USGS gauge #07257460 for each tracking week in the Middle Fork of the Illinois Bayou for spring and summer of 2016. Week 0 is initial tagging location and range between vertical lines represents when spawning occurred.



Appendix A (continued). Individual graphs showing each telemetry fish's location relative to the USGS gauge #07257460 for each tracking week in the Middle Fork of the Illinois Bayou for spring and summer of 2016. Week 0 is initial tagging location and range between vertical lines represents when spawning occurred.



Appendix A (continued). Individual graphs showing each telemetry fish's location relative to the USGS gauge #07257460 for each tracking week in the Middle Fork of the Illinois Bayou for spring and summer of 2016. Week 0 is initial tagging location and range between vertical lines represents when spawning occurred.



Appendix A (continued). Individual graphs showing each telemetry fish's location relative to the USGS gauge #07257460 for each tracking week in the Middle Fork of the Illinois Bayou for spring and summer of 2016. Week 0 is initial tagging location and range between vertical lines represents when spawning occurred.