

FINAL REPORT

Distribution and Habitat of the Tennessee Bottlebrush Crayfish, *Barbicambarus simmonsii*

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Introduction

Crayfish are large aquatic invertebrates that have significant affects upon aquatic ecosystems and often comprise a large portion of an aquatic systems biomass (Taylor and Soucek 2010). Crayfish are good indicators of ecosystem health because they serve vital roles within aquatic systems, such as that of a primary consumer breaking down plants, woody debris and detritus into fine particulate organic matter (Parkyn and others 2001). In addition, crayfish can function as scavengers and predators of fish and invertebrates (Momot 1995; Taylor and Soucek 2010; Thomas and Taylor 2013). Finally, crayfish also have the capability to significantly alter their habitats via vegetation reduction and substrate disturbance (Momot 1995).

The genus *Barbicambarus* was comprised of one known species, *B. cornutus*, until 2010 when *B. simmonsi* (**Fig. 1**) was described (Taylor and Schuster 2010). The crayfish in this genus are characterized by having densely setose antennae, a larger than average body size, and a strongly dorsoventrally flattened carapace (Taylor and Schuster 2010). *B. cornutus* can be found within the Green River basin in Kentucky and Tennessee and occurs most commonly under large flat boulders along creek margins where there is current (Taylor and Schuster 2004). *B. simmonsi* is only known to occur in Shoal Creek, a Tennessee River tributary in southern Tennessee and

northern Alabama and is believed to also utilize large flat slab rocks within deeper portions of the stream (Taylor and Schuster 2010). At the time of its description, *B. simmonsi* was found at only two locations approximately 3 kilometers apart. Intensive sampling also yielded low numbers of individuals and suggested it was uncommon (Taylor and Schuster 2010). After the initial description, a third population was found at the Goose Shoals region of Shoal Creek near County Rd. 8 in extreme northern Alabama. At the start of this study little else was known about the natural history of this species. To properly manage for *B. simmonsi* and assess if there is a need for conservation activities, it is important to have an increased understanding of its natural history, including distribution and habitat use. To meet that end, the aim of our study is to thoroughly sample Shoal Creek in order to determine the distribution of *B. simmonsi*, describe its habitat use, and describe its population density.

Methods

Distribution and habitat use were determined by conducting sampling along the majority of Shoal Creek. The length of the Creek surveyed was traversed using a canoe, allowing previously inaccessible and unsampled sites to be reached. Satellite images of Shoal Creek, available with ACME Mapper 2.1, were used to find sites that appeared to have wadeable riffles and runs suitable for sampling. Coordinates for all possible sites were then recorded. The Creek was divided into sections, each consisting of 5 stream miles. Within each section, four of the previously identified sites were randomly selected using a randomization algorithm in Microsoft Excel. Sites were not permitted to be within one stream mile of each other. In total we selected and sampled 44 sites along Shoal Creek during the summer and fall of 2013.

Sites were sampled for presence/absence of *B. simmonsii* using standardized random sampling methods, which were to be used for occupancy analysis. Other studies have shown that this type of analysis can be successful in documenting the status of rare aquatic species (Albanese et al. 2007). Upon arrival at a site, a sampling reach length was determined by multiplying the stream width by 10. For the purpose of reducing sampling time, a maximum reach length was set at 100 meters. Each sampling reach was divided into 10 meter sections and 3 kick sets were conducted in each using a 1.5x3 meter mesh seine. Kick sets consist of disturbing the substrate within 1 square meter of the streambed while the seine is held immediately downstream to catch any disturbed organisms. Within each 10 meter section, locations sampled were randomized by performing one kick set in one of the downstream corners 1 meter out from the bank, one in the stream center, and one in the upstream opposite corner 1 meter out from the bank (**Fig. 2**). After each kick set was completed, the presence/absence of *B. simmonsii* was recorded as well as the presence/absence of other crayfish species. All crayfish captured were counted, identified at least to the genus level, and saved live in a 5 gal. bucket. Specific habitat covariates were recorded at each kick set site. These covariates included substrate type, depth, flow, distance from shore, and presence/absence of vegetation. Substrate was measured using a metal substrate cross, where a substrate reading is recorded for each point of the cross as well as the center point. Substrate types were recorded as; sand (S), gravel (G), pebble (P), cobble (C), boulder (B), silt (Si), or bedrock (Bed). Depth and flow were measured using a Global Water flow probe. Near the end of our study, the flow probe became inoperable due to an electrical malfunction. During this time we used the method of floating a lemon and timing it over a certain distance to gauge stream flow. The lemon was floated 3 times over a 10 meter distance. Those three measurements were then averaged to give a flow measurement for

that site. This method was used for 15 of 44 sites. Upon completion of the reach, the field team of 3 persons spent an additional 30 minutes (1.5 man hours) using a seine to sample microhabitats (usually boulders) missed by the randomized sampling in order to reduce the chance of recording a false absence for *B. simmonsi* at the site. All collected individuals of *B. simmonsi* were measured and gender was recorded before returning them to their site of collection. Specimens that were incidentally injured or killed during sampling were vouchered for the Illinois Natural History Survey Crayfish Collection. Other crayfish species were identified to genus and returned to the stream.

In addition to sampling wadable riffles and runs, 8 unwadable pools were also sampled for *B. simmonsi*. Pool locations were recorded during the first sampling period through Shoal Creek. The 8 pools sampled were randomly selected from those localities using the randomization algorithm in Microsoft Excel. Again, sites were not permitted to be within 1 mile of each other. Upon arrival at a site, pool length was measured and divided into 5 sections. The same habitat covariates measured for riffle/runs were also measured at the pools. Locations to record habitat data within each section were selected by tossing a rock over ones shoulder and taking measurements at the spot of impact. Depth was measured with a weighted measuring tape instead of the depth stick on our flow probe. Flow measurements for all 8 pool sites were recorded using the lemon method described previously.

Given their depth, unwadable pools did not allow for traditional sampling using seines, and preliminary trials showed that *B. simmonsi* was unresponsive to trapping. Instead, pools were sampled visually by using SCUBA equipment. Divers would descend to the stream bottom at a location randomly selected by tossing a rock over one's shoulder within each of the 5 sections. Once at the bottom, the diver visually surveyed for *B. simmonsi* within a 2 meter radius by

slowly turning over rocks. Any individuals collected were returned to the surface where they were sexed and measured.

The streams directly to the east and west of Shoal Creek were sampled in an effort to record new locations for *B. simmonsii*. The streams sampled were Cypress Creek and Little Cypress Creek to the west and Bluewater Creek to the east. We sampled 4 sites along Little Cypress Creek, 5 sites within Cypress Creek, and 5 sites along Bluewater Creek during spring of 2014. All sites were selected for ease of access. Sites were sampled purely for presence/absence of *B. simmonsii* using 1.5x3 meter kick seines for 3 man hours.

Results

Our field efforts assessed 57 sites across Shoal Creek, Cypress Creek, Little Cypress Creek, and Bluewater Creek in southern Lawrence County Tennessee and northern Lauderdale County Alabama (**Fig. 3**). Stream sites consisted of both the three historical localities for *B. simmonsii* and potentially new locations.

Shoal Creek – *B. simmonsii* occurred at 14 of 44 sites, 3 of which were historical (**Table 1**). The species was consistently found under large flat boulders within a site, at depths between 0.2-0.6 meters and in flow ranging from no flow to 0.9m/s (**Table 2**). There were cases, especially in the upstream half of the creek, where suitable habitat was abundant but *B. simmonsii* was not found. *B. simmonsii* was also found to occur in 2 of the 8 pool sites sampled, a habitat not previously sampled for the species. Coordinates for positive sites are included below in **Table 1**. *B. simmonsii* typically occurred in low numbers where no more than 1-5 individuals were found at a site after extensive sampling (**Table 1**).

Cypress Creek and Little Cypress Creek- *B. simmonsii* did not occur at any of the 9 road-stream crossings sampled (**Fig. 3**).

Bluewater Creek- *B. simmonsii* did not occur at any of the 5 road-stream crossings sampled (**Fig. 3**).

B. simmonsii appears to prefer stream sites with large flat boulders (**Fig. 4**) at depths ranging between 0.2-0.6 meters (**Table 2**). The substrate around these flat boulders did not appear to be important as some individuals were found under boulders resting on top of or near gravel, pebbles, or cobble; while others were found under boulders resting only on bedrock. The flow at which individuals were found varied between sites and between individuals within a site and ranged from no flow to 0.9m/s (**Table 2**). The average stream width of our sites ranged from 10.9 – 64 meters and *B. simmonsii* was found within sites that were between 14.9 - 41 meters in average width. Stream width is represented as an average from 11 width measurements taken at each site. *B. simmonsii* is not restricted to just riffles and runs as we also documented it at 1-2 meter depths within 2 pools of Shoal Creek (**Table 2**). Habitat covariates for kick sets that did not yield *B. simmonsii* within reaches where it was present are recorded in **Appendix 1**.

Population density of *B. simmonsii* within a site was estimated using the data collected from our standardized random sampling. Using these methods, we found a total of 11 *B. simmonsii* from 8 sites. We estimated population density at a site by dividing the number of *B. simmonsii* found at a site by the total area sampled by the randomly selected kick set methods. Population densities ranged from .02 individuals/m² to .06 individuals/m² (**Table 3**). An additional 14 crayfish were found from these 8 sites during nonrandomized sampling. However,

we cannot quantify this data into population density because it was a timed effort and sampling areas were not standardized.

Discussion

The current survey presents evidence that *B. simmonsi* has a larger distribution than was previously recorded within Shoal Creek; although they still appear to be confined to a limited portion of the Shoal Creek stream system. New populations were encountered at multiple locations during the survey period with the majority of sites being in the middle and lower regions of Shoal Creek (**Fig. 3**). The range of *B. simmonsi* in Shoal Creek extends from near the mouth of the Poplar Branch in southwestern Lawrence County Tennessee down to the county road 8 stream crossing in Lauderdale County Alabama. While we did see favorable habitat in the upper region of the Creek, we did not find *B. simmonsi*. This could warrant a future study to assess any differences in water quality, or other stream related factors between the upstream and downstream portions of the Creek. It is also possible that the dam near Lawrenceburg, TN acts as a barrier to further upstream dispersal. Based on our sampling methods, *B. simmonsi* does not appear to occur in the adjacent streams along the Tennessee/Alabama border region. While the number of sites we sampled on those streams is small, we rigorously sampled habitat known to harbor the species in Shoal Creek. This fact, in addition to the lack of collections for the species in historical samples made by aquatic biologists over the past 100 years, argues for its absence in those streams.

B. simmonsi occurred almost exclusively under large flat boulders approximately 1.0 meters long and 0.6 meters wide (**Fig. 4**). Flow, depth, and width at sites of collection were variable. This is likely due to the dynamic nature of Shoal Creek. While we were there we

witnessed large and rapid fluctuations in flow and depth during rain events. As such, flow and depth may not play an important role in determining habitat. This is further supported by the fact that we found *B. simmonsi* in unswadable pools which have greater depths than the riffles and runs and low flow rates of 0.2 – 0.4 m/s. However, in pools they were found utilizing the same type of cover. The upper half of our sampling sites had an overall average width of 20.13 meters, whereas the lower half of our sites had an average width of 27.45 meters. We only found *B. simmonsi* consistently in the lower half of samplings indicating that wider average stream widths may be preferred by the species.

B. simmonsi appears to be a rare species. While we found multiple new locations for the species, it typically occurred at low population densities of 0.2-0.6 individuals per square meter (**Table 3**). This could potentially be explained by a few factors. One, it is possible that the crayfish are simply rare and naturally occur in low densities. Second, the preferred flat boulder habitat of *B. simmonsi* does not seem to occur in abundance within a site. Larger boulders are less common than smaller rocks that shelter other crayfish species. Third, we may not be accounting for total population sizes due to sampling error. Due to their habitat utilization, this species is often difficult to collect. It is possible that at some sites they are utilizing boulders that are too large or too deep for a three man field crew to effectively sample.

Within its narrow range, we do not believe that *B. simmonsi* is under any immediate threat due to development or habitat loss, but it should be considered as uncommon and rare. Most of the land along Shoal Creek's banks remains undeveloped, which aids in the stability of Shoal Creek's ecosystem. In addition, while habitat may not be abundant within a given 100 meter sampling reach, there is no shortage of large flat boulders throughout Shoal Creek. The species should be carefully managed as it can easily be affected by any future threats, such as an

invasive crayfish species or a disease outbreak, due to its narrow range and low population densities.

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Table 1: Sites, coordinates, dates sampled, site type, and number of individuals for all sites where *B. simmonsii* was located.

Site	County, State	Date	Lat/Long	Type	No. <i>B. simmonsii</i>	Notes	Historic Site
Shoal Creek	Lauderdale, AL	3-Jun-13	34.95339, -87.59387	Riffle/Run	7	All Day Sample	*
Shoal Creek	Lauderdale, AL	17-Aug-13	34.95339, -87.59387	Riffle/Run	6	Resample	*
Shoal Creek	Lawrence, TN	4-Jun-13	35.1203, -87.5089	Riffle/Run	14	All Day Sample	*
Shoal Creek	Lawrence, TN	27-Mar-14	35.1203, -87.5089	Riffle/Run	2	Resample	*
Shoal Creek	Lawrence, TN	31-Jul-13	35.13384, -87.44829	Riffle/Run	1		
Shoal Creek	Lawrence, TN	1-Aug-13	35.1066, -87.50932	Riffle/Run	2		
Shoal Creek	Lawrence, TN	1-Aug-13	35.10046, -87.52119	Riffle/Run	1		
Shoal Creek	Lawrence, TN	1-Aug-13	35.08008, -87.54720	Riffle/Run	4		
Shoal Creek	Lawrence, TN	15-Aug-13	35.05922, -87.56850	Riffle/Run	2		
Shoal Creek	Lawrence, TN	15-Aug-13	35.05085, -87.56524	Riffle/Run	6		
Shoal Creek	Lawrence, TN	15-Aug-13	35.03847, -87.56725	Riffle/Run	4		
Shoal Creek	Lawrence, TN	15-Aug-13	35.03237, -87.57729	Riffle/Run	1		
Shoal Creek	Lauderdale, AL	16-Aug-13	35.00348, -87.57726	Riffle/Run	1		
Shoal Creek	Lawrence, TN	25-Sep-13	35.04272, -87.56043	Pool	5		
Shoal Creek	Lawrence, TN	25-Sep-13	35.01212, -87.57323	Pool	1		
Factory Creek (Shoal Creek Trib)	Lawrence, TN	26-Sep-13	35.10119, -87.53975	Riffle/Run	4		*

Table 2: Habitat covariates at each kick set location where *B. simmonsii* were collected. Substrate measurements were recorded at each point of a substrate cross giving 5 readings. B=Boulder, C=Cobble, P=Pebble, G=Gravel, S=Sand, Si=Silt, and Bed=Bedrock. Lat/Longs are unique to the sampling reach, not the kick set location.

Site	Lat/Long	Substrate	Depth (meters)	Flow (m/s)	Site Type
Shoal Creek	34.95339, -87.59387	B,B,B,B,B	0.48	0.2	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.47	0.2	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.45	0.3	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.49	0.2	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.43	0.3	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.445	0.4	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.29	0.5	Riffle/Run
Shoal Creek	35.1203, -87.5089	B,B,G,G,S	0.56	0.1	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.325	0.2	Riffle/Run
Shoal Creek	"	B,B,G,G,G	0.385	0.3	Riffle/Run
Shoal Creek	"	B,B,G,G,G	0.385	0.3	Riffle/Run
Shoal Creek	"	B,B,G,G,G	0.385	0.3	Riffle/Run
Shoal Creek	"	B,B,B,G,G	0.3	0.2	Riffle/Run
Shoal Creek	"	B,B,G,G,G	0.29	0.2	Riffle/Run
Shoal Creek	"	B,B,B,B,G	0.5	0.1	Riffle/Run
Shoal Creek	"	B,B,G,G,G	0.495	0.4	Riffle/Run
Shoal Creek	"	B,B,G,G,G	0.495	0.4	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.495	0.4	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.33	0.2	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.33	0.2	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.33	0.2	Riffle/Run
Shoal Creek	35.13384, -87.44829	B,B,B,P,P	0.21	0.1	Riffle/Run
Shoal Creek	35.1066, -87.50932	B,B,B,G,Bed	0.395	0.5	Riffle/Run
Shoal Creek	"	B,B,Bed,Bed,Bed	0.615	0.9	Riffle/Run
Shoal Creek	35.10046, -87.52119	B,B,B,B,B	0.36	0.8	Riffle/Run
Shoal Creek	35.08008, -87.54720	B,B,B,B,B	0.27	0.9	Riffle/Run
Shoal Creek	"	B,B,B,C,G	0.39	0.9	Riffle/Run
Shoal Creek	"	B,B,C,G,G	0.395	0.8	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.37	0.9	Riffle/Run
Shoal Creek	35.05922, -87.56850	B,B,B,B,B	0.295	0.2	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.385	0.4	Riffle/Run
Shoal Creek	35.05085, -87.56524	B,B,C,C,P	0.29	0	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.445	0.8	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.21	0.3	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.195	0.2	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.26	0.2	Riffle/Run
Shoal Creek	"	B,B,B,G,Bed	0.515	0.3	Riffle/Run
Shoal Creek	35.03847, -87.56725	B,B,B,B,G	0.45	0.8	Riffle/Run
Shoal Creek	"	B,B,B,Bed,Bed	0.37	0.6	Riffle/Run
Shoal Creek	"	B,B,Bed,Bed,Bed	0.595	0.6	Riffle/Run
Shoal Creek	"	B,B,B,B,Bed	0.45	0.7	Riffle/Run
Shoal Creek	35.03237, -87.57729	B,B,B,P,G	0.64	0.9	Riffle/Run
Shoal Creek	35.00348, -87.57726	B,B,G,G,G	0.575	0.4	Riffle/Run
Shoal Creek	34.95339, -87.59387	B,B,G,G,Bed	0.285	0.4	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.405	0.5	Riffle/Run
Shoal Creek	"	B,B,B,B,B	0.42	0.5	Riffle/Run
Shoal Creek	"	B,B,B,Bed,Bed	0.325	0.4	Riffle/Run
Shoal Creek	"	B,B,B,G,G	0.27	0.3	Riffle/Run
Shoal Creek	"	B,B,B,G,Bed	0.2	0.4	Riffle/Run
Shoal Creek	35.04272, -87.56043	B,B,B,C,C	0.95	0.2	Pool
Shoal Creek	"	B,B,B,C,C	1.27	0.2	Pool
Shoal Creek	"	B,B,B,C,P	1.2	0.2	Pool
Shoal Creek	"	B,B,B,C,C	1.43	0.2	Pool
Shoal Creek	"	B,B,B,B,B	1.87	0.2	Pool
Shoal Creek	35.01212, -87.57323	B,B,C,C,C	1	0.4	Pool
Shoal Creek	35.10119, -87.53975	B,C,P,P,G	0.3	0.7	Riffle/Run
Shoal Creek	"	B,B,B,P,G	0.29	0.9	Riffle/Run
Shoal Creek	"	B,B,B,P,P	0.49	0.6	Riffle/Run
Shoal Creek	"	dead: in the open	-	-	Riffle/Run
Shoal Creek	35.1203, -87.5089	In the open	0.305	0.3	Riffle/Run
Shoal Creek	"	B,B,B,P,G	0.305	0.3	Riffle/Run

Table 3: Population Densities of *B. simmonsi* within sites according to standardized random sampling methods

Site	Lat/Long	Type	Pop. Density (individuals/m ²)
Shoal Creek	35.10660, -87.50932	Riffle/Run	0.03
Shoal Creek	35.08008, -87.54720	Riffle/Run	0.03
Shoal Creek	35.05085, -87.56524	Riffle/Run	0.03
Shoal Creek	35.03847, -87.56725	Riffle/Run	0.03
Shoal Creek	35.00348, -87.57726	Riffle/Run	0.03
Shoal Creek	35.04272, -87.56043	Pool	0.05
Shoal Creek	35.01212, -87.57323	Pool	0.02
Factory Creek	35.10119, -87.53975	Riffle/Run	0.06



Figure 1: The Tennessee bottlebrush crayfish (*Barbicambarus simmonsii*)

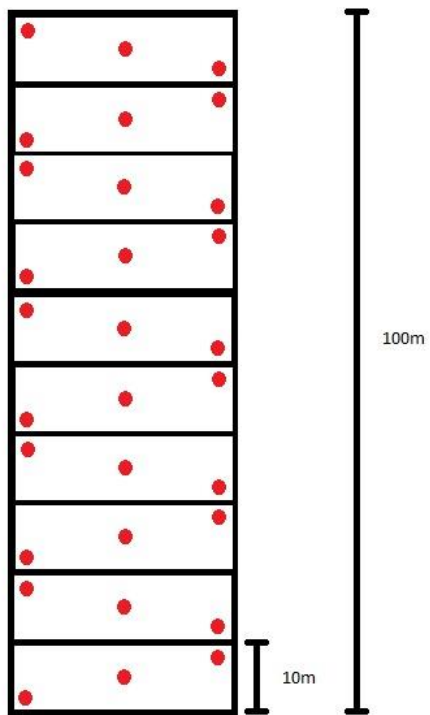


Figure 2: Schematic of crayfish occupancy sampling protocol within a 100m stream reach. Each red dot represents a kick set location.

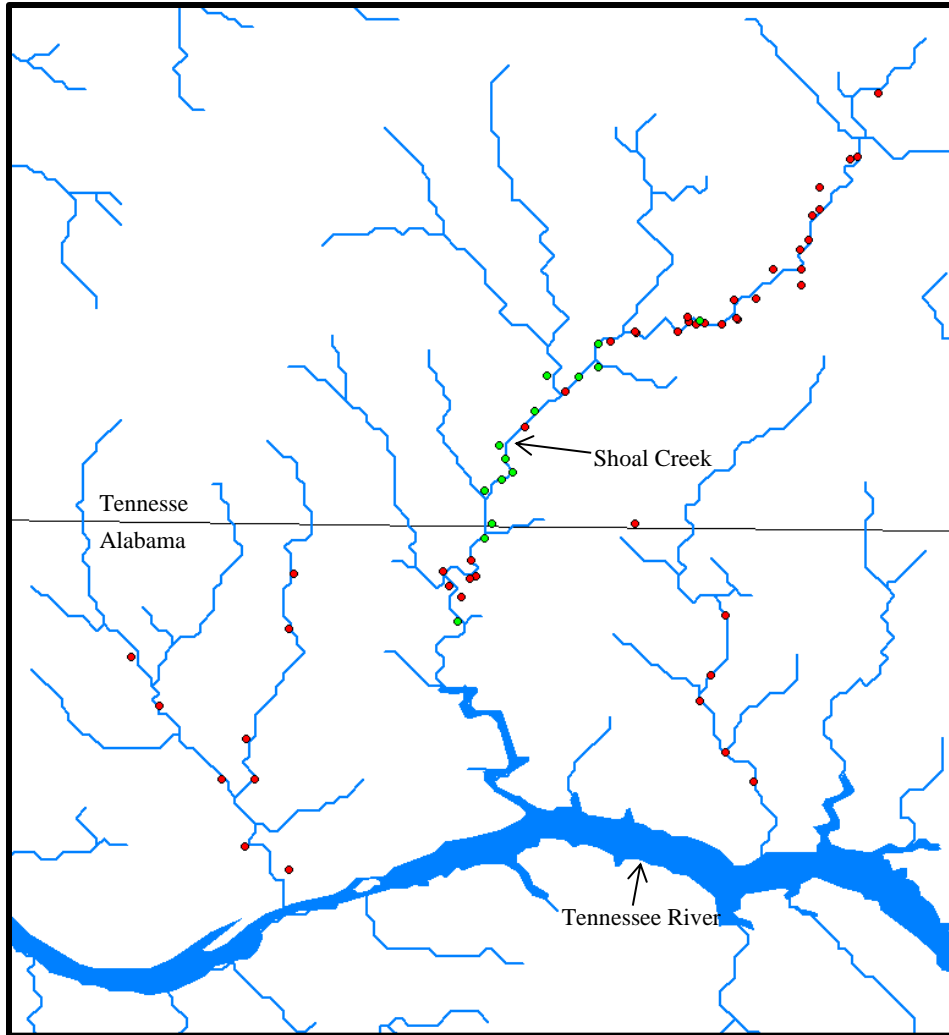


Figure 3: Map of sites sampled during 2013 and 2014 in the Tennessee River drainage of southern Tennessee and northern Alabama. Green dots indicate positive detection sites for *B. simmonsii*. Red dots indicate negative detection sites.



Figure 4A and 4B: Flat boulder substrate utilized by *B. simmonsii*

Appendix 1: Habitat covariates at each kick set location where *B. simmonsii* was not collected, at sampling reaches where *B. simmonsii* was present. Substrate measurements were recorded at each point of a substrate cross giving 5 readings. B=Boulder, C=Cobble, P=Pebble, G=Gravel, S=Sand, Si=Silt, and Bed=Bedrock. Lat/longs are unique to the site not the kick set.

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	35.13384, -87.44829	GCPPP	0.14	0.2	Riffle/Run
Shoal Creek	"	CPGGG	0.16	0.9	Riffle/Run
Shoal Creek	"	PPGGC	0.505	0.8	Riffle/Run
Shoal Creek	"	PPPCC	0.5	0.7	Riffle/Run
Shoal Creek	"	PPGGC	0.2	1.1	Riffle/Run
Shoal Creek	"	CCCPG	0.26	0.9	Riffle/Run
Shoal Creek	"	CCPPG	0.32	1	Riffle/Run
Shoal Creek	"	CPPGG	0.24	1	Riffle/Run
Shoal Creek	"	PGGGG	0.26	0.5	Riffle/Run
Shoal Creek	"	PGGGG	0.185	0.7	Riffle/Run
Shoal Creek	"	CCPGG	0.25	1	Riffle/Run
Shoal Creek	"	CCPPP	0.39	0.7	Riffle/Run
Shoal Creek	"	CCPPG	0.425	0.4	Riffle/Run
Shoal Creek	"	CPPPG	0.475	0.7	Riffle/Run
Shoal Creek	"	CGGGG	0.08	0	Riffle/Run
Shoal Creek	"	CCGGG	0.08	0	Riffle/Run
Shoal Creek	"	CPPGG	0.635	0.8	Riffle/Run
Shoal Creek	"	CPGGS	0.08	0	Riffle/Run
Shoal Creek	"	BBPPG	0.08	0	Riffle/Run
Shoal Creek	"	CCPPG	0.37	1.5	Riffle/Run
Shoal Creek	"	PPSSS	0.08	0.2	Riffle/Run
Shoal Creek	"	PPPGS	0.08	0.2	Riffle/Run
Shoal Creek	"	CPPPP	0.255	1.4	Riffle/Run

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	GGGGBed	0.16	0.7	Riffle/Run
Shoal Creek	"	GGGGS	0.23	0.7	Riffle/Run
Shoal Creek	"	CCCPP	0.61	0.6	Riffle/Run
Shoal Creek	"	PSSSS	0.2	0.2	Riffle/Run
Shoal Creek	"	GGGGG	0.16	0.3	Riffle/Run
Shoal Creek	"	GGGGG	0.23	0.7	Riffle/Run
Shoal Creek	"	BBCCC	0.21	0.1	Riffle/Run
Shoal Creek	35.1066, -87.50932	BPPGG	0.365	0.7	Riffle/Run
Shoal Creek	"	Bedx5	0.525	1	Riffle/Run
Shoal Creek	"	BBGGG	0.01	0.1	Riffle/Run
Shoal Creek	"	SSBedx3	0.57	0.1	Riffle/Run
Shoal Creek	"	CCPPP	0.255	0	Riffle/Run
Shoal Creek	"	CPPPG	0.2	0	Riffle/Run
Shoal Creek	"	BCBedx3	0.59	1.1	Riffle/Run
Shoal Creek	"	PGGGG	0.59	0.2	Riffle/Run
Shoal Creek	"	SiSiSiSiBed	0.62	0.2	Riffle/Run
Shoal Creek	"	CPPPP	0.13	0.1	Riffle/Run
Shoal Creek	"	PGGGG	0.32	0	Riffle/Run
Shoal Creek	"	PPGGG	0.335	0	Riffle/Run
Shoal Creek	"	PPPPP	0.82	1	Riffle/Run
Shoal Creek	"	PPPPP	0.125	0	Riffle/Run
Shoal Creek	"	PGGGG	0.255	0.4	Riffle/Run
Shoal Creek	"	CPPPP	0.175	1.5	Riffle/Run
Shoal Creek	"	PPGGG	0.08	0.5	Riffle/Run
Shoal Creek	"	CCPPP	0.08	0.7	Riffle/Run
Shoal Creek	"	CCPPP	0.195	1	Riffle/Run
Shoal Creek	"	PPPGG	0.32	0.9	Riffle/Run

Appendix 1 cont'd

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	BBBBG	0.25	0.9	Riffle/Run
Shoal Creek	"	CCPPP	0.45	0.9	Riffle/Run
Shoal Creek	"	PPPPP	0.08	0	Riffle/Run
Shoal Creek	"	PPPPP	0.08	0	Riffle/Run
Shoal Creek	"	PPPGG	0.555	0.6	Riffle/Run
Shoal Creek	"	GGGGG	0.35	0	Riffle/Run
Shoal Creek	"	GGSSS	0.495	0	Riffle/Run
Shoal Creek	"	CPGGG	0.62	0.7	Riffle/Run
Shoal Creek	"	PPGGG	0.08	0.1	Riffle/Run
Shoal Creek	35.10046, -87.52119	CPPGG	0.125	0.3	Riffle/Run
Shoal Creek	"	GGGBP	0.43	1.3	Riffle/Run
Shoal Creek	"	BBBPG	0.32	0.9	Riffle/Run
Shoal Creek	"	BBCCP	0.3	0.1	Riffle/Run
Shoal Creek	"	CCCCC	0.31	0.4	Riffle/Run
Shoal Creek	"	CCPGG	0.135	0.5	Riffle/Run
Shoal Creek	"	PPGSS	0.195	0.4	Riffle/Run
Shoal Creek	"	PPPPG	0.21	0.7	Riffle/Run
Shoal Creek	"	PPPPC	0.8	0.2	Riffle/Run
Shoal Creek	"	PPPPG	0.8	0.4	Riffle/Run
Shoal Creek	"	CPGGG	0.155	0.7	Riffle/Run
Shoal Creek	"	BBGGG	0.535	1.2	Riffle/Run
Shoal Creek	"	CCPGG	0.17	0.5	Riffle/Run
Shoal Creek	"	GGGGW	0.19	0.4	Riffle/Run
Shoal Creek	"	Bedx5	0.79	0.6	Riffle/Run
Shoal Creek	"	PPGGG	0.36	0.4	Riffle/Run
Shoal Creek	"	PPGGG	0.395	0.5	Riffle/Run
Shoal Creek	"	BGGGBed	0.69	0.6	Riffle/Run

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	Bedx5	0.87	0.8	Riffle/Run
Shoal Creek	"	Bedx5	0.87	0.7	Riffle/Run
Shoal Creek	"	BGGGG	0.88	0.9	Riffle/Run
Shoal Creek	"	GGGGG	0.175	0.2	Riffle/Run
Shoal Creek	"	PPGGG	0.2	0.2	Riffle/Run
Shoal Creek	"	CPPPG	0.41	0.3	Riffle/Run
Shoal Creek	"	GGGGG	0.51	0.5	Riffle/Run
Shoal Creek	"	GGGGG	0.45	0.5	Riffle/Run
Shoal Creek	"	GGGGG	0.54	1.4	Riffle/Run
Shoal Creek	"	PPGGG	0.375	0.9	Riffle/Run
Shoal Creek	"	BBGGG	0.33	0.9	Riffle/Run
Shoal Creek	"	BGGGG	0.59	0.9	Riffle/Run
Shoal Creek	35.08008, -87.54720	GGGGG	0.295	0.1	Riffle/Run
Shoal Creek	"	CCCCC	0.44	0.4	Riffle/Run
Shoal Creek	"	Bedx5	0.56	1	Riffle/Run
Shoal Creek	"	Bedx5	0.54	1	Riffle/Run
Shoal Creek	"	Bedx5	0.95	0.5	Riffle/Run
Shoal Creek	"	GGGGG	0.555	0.1	Riffle/Run
Shoal Creek	"	PPGSS	0.635	0.3	Riffle/Run
Shoal Creek	"	Bedx5	0.885	0.9	Riffle/Run
Shoal Creek	"	BBBedx3	0.38	0.5	Riffle/Run
Shoal Creek	"	Bedx5	0.45	0.7	Riffle/Run
Shoal Creek	"	PPPPG	0.65	0.1	Riffle/Run
Shoal Creek	"	GGGGG	0.395	0	Riffle/Run
Shoal Creek	"	CCPPP	0.38	0	Riffle/Run
Shoal Creek	"	GGGGG	0.68	0.9	Riffle/Run
Shoal Creek	"	BGBedx3	0.45	0.9	Riffle/Run

Appendix 1 cont'd

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	BPPPP	0.6	1.2	Riffle/Run
Shoal Creek	"	SiSiSiSiSi	0.205	0.5	Riffle/Run
Shoal Creek	"	PPPPP	0.235	1.2	Riffle/Run
Shoal Creek	"	CGGGG	0.42	1.1	Riffle/Run
Shoal Creek	"	BBCCG	0.44	1.3	Riffle/Run
Shoal Creek	"	BBBedx3	0.56	1.1	Riffle/Run
Shoal Creek	"	BBBBP	0.34	0.4	Riffle/Run
Shoal Creek	"	GGGGG	0.08	0.3	Riffle/Run
Shoal Creek	"	GGGGG	0.12	0.3	Riffle/Run
Shoal Creek	"	BBBGG	0.365	0.7	Riffle/Run
Shoal Creek	"	BPBedx3	0.36	0.5	Riffle/Run
Shoal Creek	"	BBBedx3	0.345	0.8	Riffle/Run
Shoal Creek	"	BBBGG	0.35	0.8	Riffle/Run
Shoal Creek	"	GGGGG	0.16	0.1	Riffle/Run
Shoal Creek	35.05922, -87.56850	PPGGG	0.29	0	Riffle/Run
Shoal Creek	"	PPPPP	0.47	0.3	Riffle/Run
Shoal Creek	"	CSSSS	0.545	0.6	Riffle/Run
Shoal Creek	"	CPGSS	0.375	0.6	Riffle/Run
Shoal Creek	"	BBBGG	0.235	0.4	Riffle/Run
Shoal Creek	"	PPPGG	0.14	0.1	Riffle/Run
Shoal Creek	"	PPGGG	0.16	0.1	Riffle/Run
Shoal Creek	"	BBBPG	0.465	0.5	Riffle/Run
Shoal Creek	"	CGGGG	0.205	0.4	Riffle/Run
Shoal Creek	"	BCGGG	0.27	0.2	Riffle/Run
Shoal Creek	"	GGGGG	0.45	0	Riffle/Run
Shoal Creek	"	BBBBB	0.7	0	Riffle/Run
Shoal Creek	35.05085, -87.56524	BBBGG	0.27	0.2	Riffle/Run

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	Bedx5	0.525	0.4	Riffle/Run
Shoal Creek	"	CCPGG	0.41	0.3	Riffle/Run
Shoal Creek	"	CPPPG	0.405	0.3	Riffle/Run
Shoal Creek	"	Bedx5	0.53	0.8	Riffle/Run
Shoal Creek	"	Bedx5	0.175	0.2	Riffle/Run
Shoal Creek	"	Bedx5	0.21	0.1	Riffle/Run
Shoal Creek	"	BBCGBed	0.43	0.6	Riffle/Run
Shoal Creek	"	BCGGG	0.38	0.5	Riffle/Run
Shoal Creek	"	GGGGG	0.33	0.5	Riffle/Run
Shoal Creek	"	Bedx5	0.535	0.4	Riffle/Run
Shoal Creek	"	BBedx4	0.12	0.1	Riffle/Run
Shoal Creek	"	Bedx5	0.155	0.1	Riffle/Run
Shoal Creek	"	BBedx4	0.435	0.4	Riffle/Run
Shoal Creek	"	GGGBedx2	0.47	0.3	Riffle/Run
Shoal Creek	"	GGGBed	0.48	0.3	Riffle/Run
Shoal Creek	"	Bedx5	0.46	0.4	Riffle/Run
Shoal Creek	"	BBedx4	0.085	0.2	Riffle/Run
Shoal Creek	"	Bedx5	0.07	0.2	Riffle/Run
Shoal Creek	"	GGGBedx2	0.37	0.4	Riffle/Run
Shoal Creek	"	PPPPP	0.19	0.1	Riffle/Run
Shoal Creek	"	PPGGG	0.2	0.1	Riffle/Run
Shoal Creek	"	GGGGG	0.545	0.3	Riffle/Run
Shoal Creek	"	Bedx5	0.245	0	Riffle/Run
Shoal Creek	"	Bedx5	0.2	0	Riffle/Run
Shoal Creek	"	Bedx5	0.68	0.3	Riffle/Run
Shoal Creek	"	GGGGG	0.34	0	Riffle/Run
Shoal Creek	"	PPGGG	0.4	0	Riffle/Run

Appendix 1 cont'd

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	SBedx4	0.64	0.5	Riffle/Run
Shoal Creek	35.03847, -87.56725	GGGGG	0.26	0.4	Riffle/Run
Shoal Creek	"	Bedx5	0.43	0.4	Riffle/Run
Shoal Creek	"	GGGGG	0.3	0.2	Riffle/Run
Shoal Creek	"	GGSSS	0.26	0.2	Riffle/Run
Shoal Creek	"	Bedx5	0.345	0.5	Riffle/Run
Shoal Creek	"	GSiSiSiSi	0.295	0.8	Riffle/Run
Shoal Creek	"	GGGGG	0.29	0.8	Riffle/Run
Shoal Creek	"	PGBedx3	0.435	0.5	Riffle/Run
Shoal Creek	"	Bedx5	0.455	0.6	Riffle/Run
Shoal Creek	"	Bedx5	0.515	0.6	Riffle/Run
Shoal Creek	"	GBedx4	0.535	0.2	Riffle/Run
Shoal Creek	"	GGGGG	0.57	0.2	Riffle/Run
Shoal Creek	"	Bedx5	0.59	0.9	Riffle/Run
Shoal Creek	"	BBCCP	0.22	0.1	Riffle/Run
Shoal Creek	"	BCPPG	0.1	0.1	Riffle/Run
Shoal Creek	"	Bedx5	0.56	0.5	Riffle/Run
Shoal Creek	"	SSSSS	0.2	0	Riffle/Run
Shoal Creek	"	SSSSS	0.225	0	Riffle/Run
Shoal Creek	"	SSSSBed	0.67	0.7	Riffle/Run
Shoal Creek	"	PGGGS	0.365	0	Riffle/Run
Shoal Creek	"	PPGSS	0.39	0	Riffle/Run
Shoal Creek	"	GGBedx3	0.635	0.6	Riffle/Run
Shoal Creek	"	CPPGG	0.255	0.3	Riffle/Run
Shoal Creek	"	PPPPP	0.32	0.3	Riffle/Run
Shoal Creek	"	GGGGG	0.67	0.4	Riffle/Run
Shoal Creek	"	Bedx5	0.53	0.1	Riffle/Run

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	Bedx5	0.53	0.1	Riffle/Run
Shoal Creek	"	GBedx4	0.545	0.5	Riffle/Run
Shoal Creek	"	PPPPP	0.39	0.2	Riffle/Run
Shoal Creek	35.03237, -87.57729	PPPPG	0.11	0.1	Riffle/Run
Shoal Creek	"	CPPPP	0.33	0.7	Riffle/Run
Shoal Creek	"	PPGGG	0.265	0.4	Riffle/Run
Shoal Creek	"	GGGGG	0.32	0.1	Riffle/Run
Shoal Creek	"	PPPPP	0.4	0.8	Riffle/Run
Shoal Creek	"	CPPGG	0.27	0.6	Riffle/Run
Shoal Creek	"	BPPPG	0.175	0.5	Riffle/Run
Shoal Creek	"	PPPGG	0.31	0.7	Riffle/Run
Shoal Creek	"	PPPPP	0.195	0.7	Riffle/Run
Shoal Creek	"	PPPPP	0.245	0.6	Riffle/Run
Shoal Creek	"	PPPGG	0.385	0.5	Riffle/Run
Shoal Creek	"	PPPPP	0.085	0.1	Riffle/Run
Shoal Creek	"	PPPPG	0.16	0.1	Riffle/Run
Shoal Creek	"	GGGGG	0.435	0.3	Riffle/Run
Shoal Creek	"	PPGGG	0.28	0.1	Riffle/Run
Shoal Creek	35.00348, -87.57726	CCPPP	0.26	0.7	Riffle/Run
Shoal Creek	"	GGGGG	0.43	0.8	Riffle/Run
Shoal Creek	"	PGGGBed	0.3	0.7	Riffle/Run
Shoal Creek	"	PPPPG	0.26	0.5	Riffle/Run
Shoal Creek	"	GGGGG	0.345	0.9	Riffle/Run
Shoal Creek	"	PPGGG	0.295	0.3	Riffle/Run
Shoal Creek	"	PPGGG	0.29	0.2	Riffle/Run
Shoal Creek	"	PPPPP	0.435	1.1	Riffle/Run
Shoal Creek	"	CCGGG	0.45	0.5	Riffle/Run

Appendix 1 cont'd

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	BBBGG	0.455	0.5	Riffle/Run
Shoal Creek	"	PPPPP	0.515	1.3	Riffle/Run
Shoal Creek	"	CPPPP	0.535	0.1	Riffle/Run
Shoal Creek	"	PGGGG	0.57	0.1	Riffle/Run
Shoal Creek	"	GGGGG	0.59	0.8	Riffle/Run
Shoal Creek	"	PPPPP	0.22	0.7	Riffle/Run
Shoal Creek	"	PPPPP	0.1	0.7	Riffle/Run
Shoal Creek	"	CPPPP	0.56	0.9	Riffle/Run
Shoal Creek	"	CPPPG	0.2	0.4	Riffle/Run
Shoal Creek	"	CCPPG	0.225	0.3	Riffle/Run
Shoal Creek	"	PPPPG	0.67	0.5	Riffle/Run
Shoal Creek	"	CPPPP	0.365	0.3	Riffle/Run
Shoal Creek	"	PPPGS	0.39	0.3	Riffle/Run
Shoal Creek	"	PGGGG	0.635	0.4	Riffle/Run
Shoal Creek	"	BGGGG	0.255	0.2	Riffle/Run
Shoal Creek	"	PPGGG	0.32	0.2	Riffle/Run
Shoal Creek	"	PPPPP	0.53	0.3	Riffle/Run
Shoal Creek	"	PPPGG	0.53	0.3	Riffle/Run
Shoal Creek	"	GGGGG	0.545	0.4	Riffle/Run
Shoal Creek	"	CGGGG	0.39	0.1	Riffle/Run
Shoal Creek	35.04272, -87.56043	Bedx5	1.9	0.6	Pool
Shoal Creek	"	Bedx5	1.7	0.5	Pool
Shoal Creek	35.01212, -87.57323	BBBBB	1.25	1	Pool
Shoal Creek	"	CGGGG	1.3	1.2	Pool
Shoal Creek	"	BBBGP	1.38	1.1	Pool
Shoal Creek	"	Bedx5	1	1.4	Pool
Shoal Creek	35.1203, -87.5089	PPPGG	0.165	0.4	Riffle/Run

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	CCPGG	0.61	1.2	Riffle/Run
Shoal Creek	"	CCGGG	0.05	0.4	Riffle/Run
Shoal Creek	"	CPGGG	0.18	0	Riffle/Run
Shoal Creek	"	PPPGS	0.495	0.7	Riffle/Run
Shoal Creek	"	PPPPG	0.125	0.5	Riffle/Run
Shoal Creek	"	PPGGG	0.19	0.4	Riffle/Run
Shoal Creek	"	GGGGG	0.675	0.5	Riffle/Run
Shoal Creek	"	Bedx5	0.77	0	Riffle/Run
Shoal Creek	"	SiSiSiSiSi	0.72	0	Riffle/Run
Shoal Creek	"	CPPPG	0.275	0.6	Riffle/Run
Shoal Creek	"	GGGGG	0.27	0.3	Riffle/Run
Shoal Creek	"	PGGGG	0.335	0.2	Riffle/Run
Shoal Creek	"	PPPGG	0.34	0.6	Riffle/Run
Shoal Creek	"	SSSSS	0.32	0	Riffle/Run
Shoal Creek	"	SSSSS	0.245	0.1	Riffle/Run
Shoal Creek	"	PPGGG	0.385	0.4	Riffle/Run
Shoal Creek	"	GGGSiSi	0.36	0.1	Riffle/Run
Shoal Creek	"	GGGGSi	0.365	0.1	Riffle/Run
Shoal Creek	"	CPPGG	0.435	0.5	Riffle/Run
Shoal Creek	"	SiSiSiSiSi	0.321	0.1	Riffle/Run
Shoal Creek	"	SiSiSiSiSi	0.262	0.2	Riffle/Run
Shoal Creek	"	PPPPP	0.415	0.5	Riffle/Run
Shoal Creek	"	BBPPP	0.205	0.3	Riffle/Run
Shoal Creek	"	CGGGG	0.175	0.2	Riffle/Run
Shoal Creek	"	PPGGG	0.395	0.4	Riffle/Run
Shoal Creek	"	PGGSS	0.525	0.1	Riffle/Run
Shoal Creek	"	GGGSS	0.45	0.1	Riffle/Run

Appendix 1 cont'd

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	GGGGS	0.4	0.4	Riffle/Run
Shoal Creek	"	BBBGG	0.305	0.3	Riffle/Run
Shoal Creek	34.95339, -87.59387	CCCPP	0.28	0.5	Riffle/Run
Shoal Creek	"	Bedx5	0.18	0.6	Riffle/Run
Shoal Creek	"	Bedx5	0.26	0.2	Riffle/Run
Shoal Creek	"	Bedx5	0.095	0.2	Riffle/Run
Shoal Creek	"	CGGGBed	0.33	0.6	Riffle/Run
Shoal Creek	"	PPGG	0.42	0.8	Riffle/Run
Shoal Creek	"	CCPGG	0.335	0.8	Riffle/Run
Shoal Creek	"	GGBedx3	0.405	0.6	Riffle/Run
Shoal Creek	"	CCBedx3	0.29	0.1	Riffle/Run
Shoal Creek	"	Bedx5	0.25	0.1	Riffle/Run
Shoal Creek	"	BBGGP	0.44	0.4	Riffle/Run
Shoal Creek	"	BBCGG	0.275	0.4	Riffle/Run
Shoal Creek	"	BCGGG	0.27	0.4	Riffle/Run
Shoal Creek	"	CGGGG	0.36	0.3	Riffle/Run
Shoal Creek	"	Bedx5	0.1	0.1	Riffle/Run
Shoal Creek	"	GGGGBed	0.1	0.1	Riffle/Run
Shoal Creek	"	BBGGG	0.345	0.4	Riffle/Run
Shoal Creek	"	PGSSS	0.13	0.1	Riffle/Run
Shoal Creek	"	PGSBedx2	0.19	0.1	Riffle/Run
Shoal Creek	"	CCGGBed	0.24	0.5	Riffle/Run
Shoal Creek	"	Bedx5	0.14	0.1	Riffle/Run
Shoal Creek	"	Bedx5	0.11	0.1	Riffle/Run
Shoal Creek	"	BBedx4	0.3	0.5	Riffle/Run
Shoal Creek	"	Bedx5	0.205	0.1	Riffle/Run
Shoal Creek	"	CCBedx3	0.135	0.1	Riffle/Run

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Shoal Creek	"	BBBedx3	0.37	0.5	Riffle/Run
Shoal Creek	"	BBGGP	0.25	0.1	Riffle/Run
Shoal Creek	"	Bedx5	0.145	0.1	Riffle/Run
Shoal Creek	"	Bedx5	0.645	0.6	Riffle/Run
Shoal Creek	"	BGGGS	0.38	0	Riffle/Run
Factory Creek	35.10119, -87.53975	PPGG	0.15	0.3	Riffle/Run
Factory Creek	"	BBGBedx2	0.15	0.6	Riffle/Run
Factory Creek	"	SSSSS	0.26	0.6	Riffle/Run
Factory Creek	"	CCPSBed	0.45	0.8	Riffle/Run
Factory Creek	"	CPPPP	0.16	0.1	Riffle/Run
Factory Creek	"	PPPPP	0.18	0.1	Riffle/Run
Factory Creek	"	PPPGC	0.65	0.75	Riffle/Run
Factory Creek	"	SSSGG	0.27	0.4	Riffle/Run
Factory Creek	"	SSSSS	0.25	0.4	Riffle/Run
Factory Creek	"	BBBGG	0.26	0.6	Riffle/Run
Factory Creek	"	GGGPP	0.1	0.3	Riffle/Run
Factory Creek	"	GGPPP	0.12	0.3	Riffle/Run
Factory Creek	"	PPPPP	0.56	0.5	Riffle/Run
Factory Creek	"	SSSPC	0.21	0	Riffle/Run
Factory Creek	"	PPGGG	0.08	0.2	Riffle/Run
Factory Creek	"	BBBGG	0.46	0.6	Riffle/Run
Factory Creek	"	CGPPP	0.4	0.1	Riffle/Run
Factory Creek	"	PPPPG	0.3	0.1	Riffle/Run
Factory Creek	"	Bedx5	0.06	0.1	Riffle/Run

Appendix 1 cont'd

Site	Lat/Long	Substrate	Depth (m)	Flow (m/s)	Site Type
Factory Creek	"	Bedx5	0.05	0.1	Riffle/Run
Factory Creek	"	SSBedx3	0.53	0.5	Riffle/Run
Factory Creek	"	GGGGG	0.37	0.5	Riffle/Run
Factory Creek	"	GGGGS	0.34	0.5	Riffle/Run
Factory Creek	"	CCBedx3	0.46	0.6	Riffle/Run
Factory Creek	"	Bedx5	0.11	0	Riffle/Run
Factory Creek	"	Bedx5	0.12	0	Riffle/Run
Factory Creek	"	GGGPBed	0.51	0.5	Riffle/Run
Factory Creek	"	SSSSS	0.1	0	Riffle/Run