Spatial Ecology of Female Barbour's Map Turtles *(Graptemys barbouri)* in Ichawaynochaway Creek, Georgia

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Quantifying patterns of habitat use by riverine species is logistically challenging, yet instream habitat characteristics are likely important in explaining the distribution of species. We integrated radiotelemetry and sonar habitat mapping to quantify instream habitat use by female Barbour's Map Turtles *(Graptemys barbouri)* in Ichawaynochaway Creek, a tributary to the Flint River. We used logistic regression and a Bayesian information-theoretic approach to evaluate habitat use relative to habitat availability based on random locations. Over the two-year study period, turtles used an average of 839±199 m of creek length and exhibited site fidelity (mean 50% kernel density = 0.23±0.05 ha). Substrate was generally more predictive of habitat use of female *G. barbouri* compared to large woody debris and water depth. Turtles generally used deeper habitats close to rocky-boulder and rocky-fine substrate with greater amounts of large woody debris. Estimates of home range size and habitat use found in this study improve our understanding of the spatial ecology of *G. barbouri* and provide a baseline for their habitat use in a relatively undisturbed section of stream. It is imperative to understand the spatial ecology of species, such as map turtles, that are particularly vulnerable to indirect effects of habitat modifications caused by impoundments, sedimentation, pollution, and snagging.

THE spatial ecology of riverine organisms is influenced by heterogeneous instream habitat patches of varying quality, similar to that of animals residing in terrestrial landscapes (Wiens, 2002). Foraging mode and reproductive behavior are two factors that impact the amount of space needed by an animal (Huey and Pianka, 1981; Jackson et al., 2001). Additionally, efficiency in movements among patches can be especially important to reduce energy and time transport costs (Alerstam et al., 2003), especially in rivers, which can constrain movement. For riverine turtles, critical habitat includes areas for basking, nesting, foraging, and overwintering (Moll and Moll, 2004). The spatial configuration of these critical habitat features is known to impact the spatial ecology of river turtles (Moll and Moll, 2004; Ernst and Lovich, 2009); however, data on use of instream habitats by most turtle species is limited due to the paucity of information on the availability and distribution of instream habitats at a relevant scale to freshwater turtles.

Graptemys (map turtles) is a diverse genus of river turtles found throughout the southern and eastern U.S. In the southern part of their range, most species are drainage-specific river specialists that remain within the confines of aquatic habitat except when nesting (Ernst and Lovich, 2009). Map turtles exhibit extreme sexual dimorphism and the sexes have different diets; males consume insects and small mollusks and females develop a distinct head morphology allowing them to feed primarily on larger mollusks (Lindeman, 2013). Map turtles are of high conservation concern; all 14 recognized map turtle species are listed in CITES Appendix III (Lindeman, 2013). Like other imperiled river fauna (darters [Percidae] and mussels [Unionidae]), map turtles are particularly vulnerable to human alterations of streams such as impoundment, channelization, pollution, and agricultural land use (Buhlmann and Gibbons, 1997; Bodie, 2001; Sterrett et al., 2011; reviewed in Lindeman, 2013). Thus, to better manage and conserve map turtles, it is imperative to increase our knowledge of their spatial ecology, including movement patterns, home range, and instream habitat use associations (Moll, 1996).

Habitat features such as substrate type and water depth are commonly regarded as important to map turtles (Legler and Cann, 1980; Moll, 1980; Fuselier and Edds, 1994). Carriere and Blouin-Demers (2010) found depth to be an important factor for *G. geographica* at the home range scale with adult females selecting deeper areas than males, and Lindeman (1999) found a positive association between the amount of emergent large woody debris (LWD) and the abundance of five map turtle species in the Pearl and Pascagoula river drainages. Large woody debris tends to accumulate in the deepest part of streams and provides grazing substrate for turtles, protection from aquatic predators, and, if emergent, provides basking sites for thermoregulation (Chaney and Smith, 1950; Shively and Jackson, 1985; Jones, 1996; Lindeman, 1999). Barbour's Map Turtle (*Graptemys barbouri*) is endemic to streams in the Apalachicola-Chattahoochee-Flint River (ACF) Basin, which extends through southwestern Georgia, southeastern Alabama and the panhandle of Florida, although other populations have recently been discovered outside of this basin (Enge and Wallace, 2008). Stream geomorphology in the ACF basin is characterized by steep, sandy banks and Ocala limerock outcrops with alternating shallow, rocky shoals and deep, sandy pools. Juvenile and adult male *G. barbouri* are often associated with limerock shoals, while large adult females are more often associated with deep, sandy pools (Sanderson, 1974; Moulis, 2008). To our knowledge, only one study has examined home range size and movements of *G. barbouri* (Sanderson, 1974). This study was conducted in northern Florida and reported a linear home range of 364.5 m and 273.0 m of male and female *G. barbouri*, respectively.

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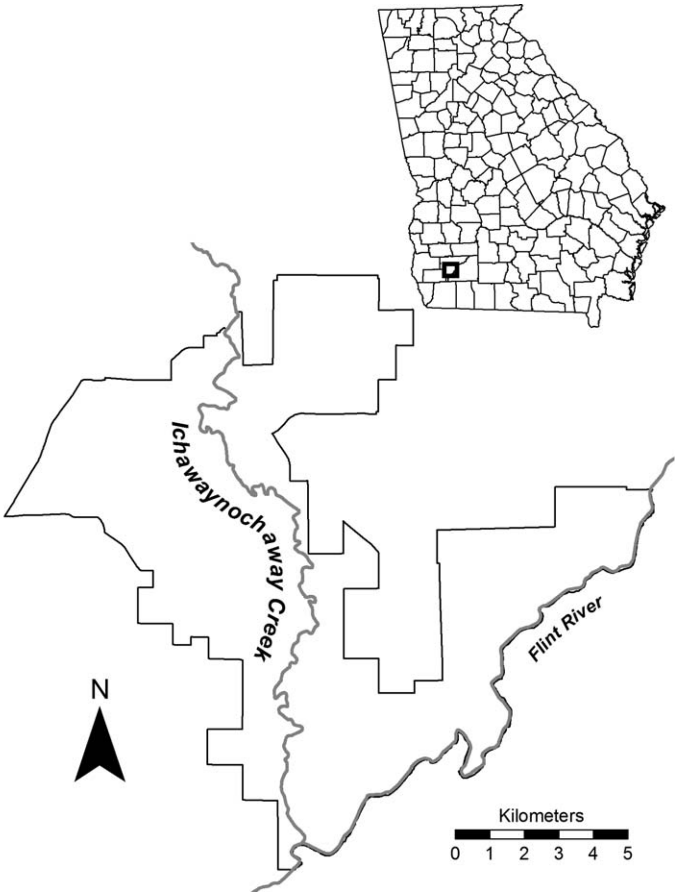

Fig. 1. Ichauway reserve, located in Baker County, Georgia. Ichawaynochaway Creek flows through the center of Ichauway reserve and into the Flint River along the eastern border.

The limited information on the spatial ecology of *G. barbouri* led us to focus our study on this imperiled species (Lindeman, 2013). Many southeastern U.S. streams can be turbid and non-wadeable during certain times of year, and traditional approaches for measuring habitat features, such as underwater point sampling and extrapolation to estimate available habitat, are typically not feasible. In this study, we assessed the spatial ecology of *G. barbouri* by quantifying habitat use and habitat availability using side-scanning sonar (Kaeser and Litts, 2008), a recently developed method for mapping instream habitats in non-wadeable streams. This method of habitat mapping, along with radio-telemetry of turtles, allowed us to quantitatively evaluate preferred habitats within a habitat use-availability framework (Manly et al., 2002; Johnson et al., 2006). The specific objective of this study was to estimate the home range of female *G. barbouri* and to evaluate the importance of instream habitat features in a relatively undisturbed stream in southwest Georgia.

MATERIALS AND METHODS

Study site.—This study was conducted on a lower reach of Ichawaynochaway Creek in Baker County, Georgia. Ichawaynochaway Creek flows through Ichauway, a 12,000 ha private reserve that is the research site of the Joseph W. Jones Ecological Research Center (Fig. 1). Ichawaynochaway Creek, a tributary of the lower Flint River, is largely fed by the Upper Floridan Aquifer during baseflow conditions (Golladay et al., 2007). The 24 km study reach has an intact, forested riparian zone. A 1920s-era concrete dam is located at the upstream end of the study reach that effectively blocks boat navigation, but a breach in the dam allows water to pass freely through the structure.

Radiotelemetry.—Female *G. barbouri* were hand captured by snorkeling in summer 2007 ($n = 7$) and 2008 ($n = 14$). Turtles were transported to a laboratory where they were measured (straight-line carapace and plastron length), weighed, and given unique identification marks by drilling the marginal scutes (Cagle, 1939). Transmitters were attached to the rear marginal scutes of the carapace following methods of Jones (1996). Turtles fitted with radio-transmitters varied in size but all were considered to be subadult (<210 mm CL; $n = 5$) or adult females (≥210 mm CL; $n = 16$; Cagle, 1952). Transmitter packages weighed approximately 35 g (Models SI-2F and AI-2F, Holohil Systems, Inc.) and represented <10% (mean±SE; 2.47±0.53) of the turtle's mass. All turtles were returned to their capture location within 48 hours of initial capture and followed until transmitter removal or failure.

Turtles were located by homing from a kayak approximately weekly in summer (1 June–31 August) of 2007 and 2008, and at least once a month in fall, winter, and spring (1 September–31 May) of 2007 through 2009. Turtle locations were identified using Communications Specialist, Inc. R-1000 (Orange, CA) telemetry receiver with a Yagi 3-element antenna and recorded with a Trimble Geo3 Explorer (Trimble Navigations, LTD., Sunnyvale, CA) GPS with differential correction post-processing (accuracy 1–5 m). During high flow periods, turtle locations were determined using biangulation from the stream bank. When possible, visual observations of turtle behavior and position were noted. All locations were incorporated into a GIS using Environmental Systems Research Institute (ESRI) ArcGIS 9.3 software.

Sonar habitat mapping.—On 8 April 2008, we conducted a sonar survey of the 24 km study reach on Ichawaynochaway Creek using a Humminbird 981c Side Imaging system (i.e., side scan sonar). During the survey, we captured images and associated geographic coordinates, and recorded depth at three-second intervals along Ichawaynochaway Creek. Sonar images were georeferenced, rectified, and interpreted to create a spatially continuous, instream habitat map of the study reach as described in Kaeser and Litts (2008, 2010). The habitat map included classified substrate type, mid-channel water depth, stream bank boundaries, and large woody debris (defined as any piece of wood ≥10 cm diameter and ≥1.5 m in length; Fig. 2). Substrate class descriptions and details of field-assessed map accuracy are provided in Kaeser and Litts (2008, 2010).

Habitat use and availability.—Turtle locations obtained with telemetry were used to characterize habitat use. We used a distance-based approach (Conner and Plowman, 2001) because it is robust to spatial error associated with GPS-based animal locations and habitat map position (Conner et al., 2003; Kaeser and Litts, 2010). To account for positional uncertainty, a 15 m buffer was generated around each turtle location to represent the area in use. To minimize possible bias in estimates of habitat use, we generated a random location for each observed turtle use location ($n = 462$;

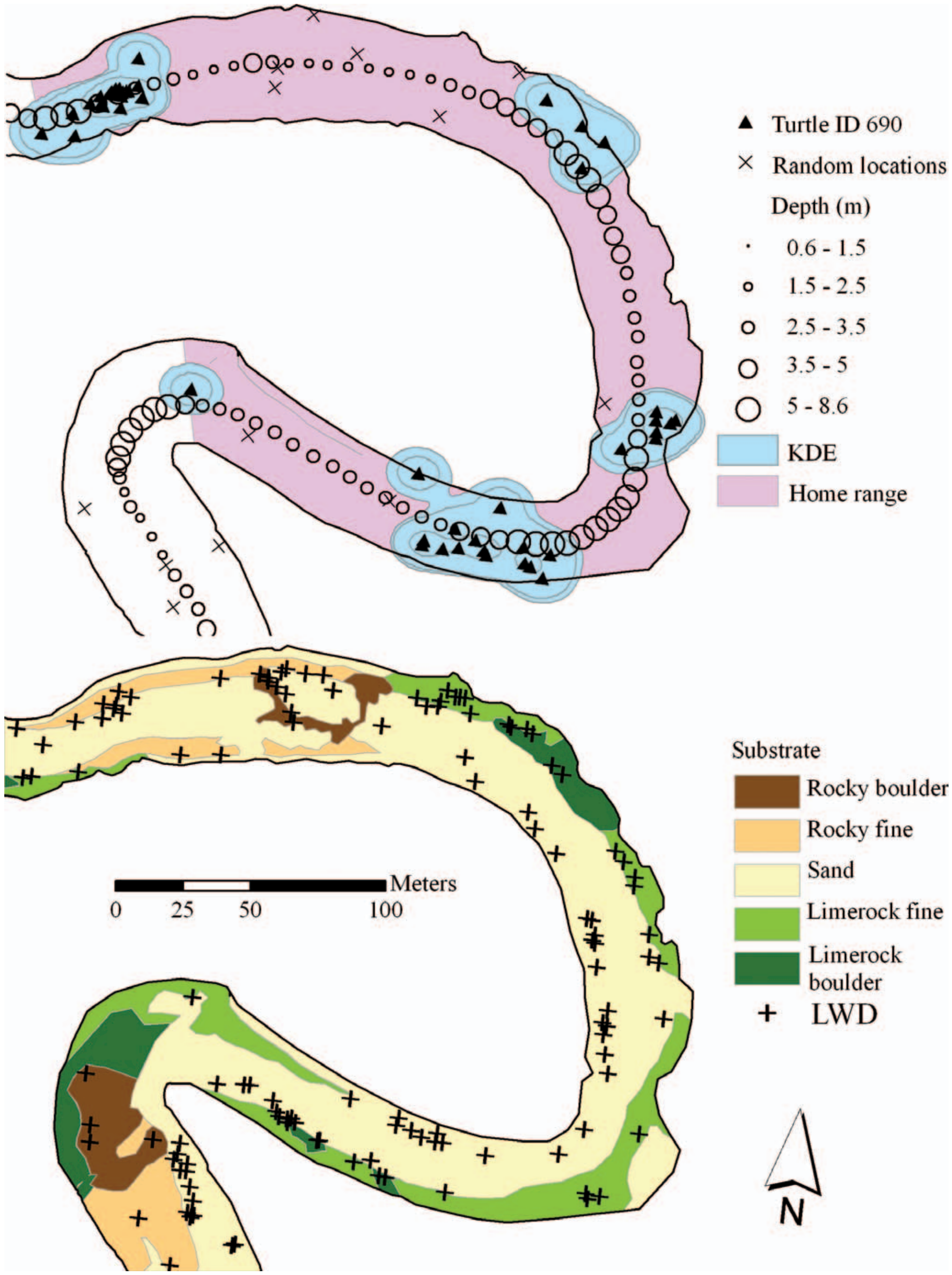

Fig. 2. Example of an individual (ID 690) female *G. barbouri* home range, kernel density estimated home range (KDE), actual and random turtle locations, and mid-channel depth along a reach of Ichawaynochaway Creek (upper panel). Size of open circles represents mid-channel depth classes. Substrate and large woody debris (LWD) mapped within the same area (lower panel). Substrate classes are represented by unique color shade or pattern, and LWD as black "+".

Northrup et al., 2013) that represented habitat available within the study area (from 50 m below the dam to the confluence between Ichawaynochaway Creek and the Flint River, approximately 24 km) using the random point generator in Hawth's tools (Beyer, 2004). We assumed all random availability locations were independently distributed. We defined available habitat as habitat within a turtle's potential home range (i.e., third order selection; Johnson, 1980) and assumed that habitat measured at the 24 km scale was proportionally similar to habitat available at the home range scale (i.e., 1 km). To prevent overlap of used and random locations, buffered areas around used locations were excluded from the area available for random location assignment. All biangulated locations (n = 29) and all locations within 50 m of the dam were excluded from the habitat analysis due to lack of precision in habitat use or availability data.

To extract relevant habitat variables from the sonar map for model development, we calculated the linear distances from each used and random location to the edge of the nearest representative of each of the following substrate classes: rocky boulder, rocky fine, limerock boulder, limerock fine, and sand (Kaeser and Litts, 2010) using ArcGIS 9.3 (ArcInfo level). Unsure rocky and island substrate classes were excluded from this analysis because of their rarity in the sonar map. We incorporated the class originally designated as unsure sandy into the sand class following the recommendations by Kaeser and Litts (2010). To assess local woody debris abundance, total counts of LWD were summarized within a 15 m buffer of all locations. To extract relevant water depth data, all used and random locations were snapped to the mid-channel line that represented the sonar survey track. At the snapped position, a 15 m buffer was generated around each location, and all depth measurements within the buffer ($n \geq 4$) were used to yield a measurement of average local depth and depth variability (standard deviation of depths) for each location.

Data analysis.—We used ArcGIS 9.3 to calculate the total length of creek used and the home range size of each turtle (e.g., the minimum convex polygon (MCP); Mohr, 1947). Because of concerns about precision, locations obtained via biangulation were placed in the center of the stream channel for home range analysis. The creek area home range of each radio-tagged turtle was estimated using the surface creek area developed by the sonar-based habitat map. Kernel density estimates (KDE) were analyzed with Home Range Tools Extension (HRT; version 1.1; Rodgers et al., 2007) to get 50% (core areas; Donaldson and Echternacht, 2005) and 95% adaptive kernel estimates. As the most objective option, we used least squares cross validation as the determinant of the KDE bandwidth selection (h; Seaman and Powell, 1996; Gitzen et al., 2006). Row and Blouin-Demers (2006) suggested that KDE are not appropriate for estimating the home range of herpetofauna due to autocorrelation issues. However, there is a lack of consensus on the best method to report home range size; therefore, we report both MCP and KDE (50, 95%) per recommendations of Laver and Kelly (2006) to illustrate areas of higher use. All statistical analyses were considered significant at $\alpha = 0.05$ level.

We used logistic regression (Hosmer and Lemeshow, 2000) and a Bayesian information-theoretic approach (Speigelhalter et al., 2002) to evaluate alternative models of instream habitat features that best predict turtle habitat use given the habitat available measured by random locations (Gillies et al., 2006; Beyer et al., 2010). We developed a set of seven *a priori* candidate models that included combinations of distance to each substrate category, depth, depth variability, and quantity of LWD, and a global model that included all predictor variables. All variable combinations were considered in candidate model development because variables were not strongly correlated ($r^2 < 0.49$), with the exception of depth and depth variability ($r^2 = 0.57$). We included an individual random effect to account for non-independence among repeat observations of habitat used by the same turtle. The random effect was centered on zero with a large variance in each candidate model, which allowed for robust population-level inference in habitat use (Gillies et al., 2006). We used all random locations ($n = 462$) to represent habitat available to each individual and assumed that actual habitat availability (i.e., within each turtle's home range) was proportional to habitat available along the entire creek length.

We identified the best-approximating model using deviance information criteria (DIC), which is a measure of model fit or adequacy, with smaller DIC values indicating a better approximating model (Spiegelhalter et al., 2002). We based inferences of the importance of habitat characteristics on variables included in top approximating models and the precision of each parameter estimate using 95% credibility intervals. We calculated scaled odds ratios for each predictor in top approximating models to facilitate interpretation of habitat variables (Hosmer and Lemeshow, 2000). All models used Markov chain Monte Carlo sampling implemented in JAGS (version 3.2.0) using the Rjags package in R (version 3.0.0), and were fit using 2000 iterations, a 500 burn-in, a thinning rate of 5 to reduce autocorrelation among samples, 3 chains, and diffuse priors. Model convergence was assessed using visual inspection of chains and Gelman-Rubin's convergence diagnostic (R-hat $<$1.1; Gelman and Rubin, 1992). We evaluated model fit of the global model using a posterior predictive check and a Bayesian p-value based on sums of squares discrepancy metric, with a p-value near 0.5 indicating adequate model fit (Gelman and Hill, 2007).

RESULTS

Twenty-one female *G. barbouri* (mean weight$\pm$standard deviation; 2242$\pm$11 g; range 282–3131 g) were affixed with radio-transmitters. We used 14 turtles that were relocated an average of 32$\pm$11 times over 303$\pm$42 days from 5 July 2007–23 February 2009 to estimate home range because low recaptures (i.e., $<$20) can bias estimates of kernel densities (Seaman et al., 1999). All turtles ($n = 21$; relocated 1–57 times) were used in habitat use-availability logistic regression analysis. Three of 21 radio-tagged *G. barbouri* were found dead during the study: one following a high flow period associated with Tropical Storm Faye and two depredated by mammals (Sterrett, 2009). Four individuals were lost following initial release. Turtles were observed visually during 9% of radio-tracking events.

Graptemys barbouri used an average of 839$\pm$199 m (mean$\pm$standard error) of creek length and 3.13$\pm$2.74 ha of creek area. Mean 50% kernel area was 0.23$\pm$0.05 ha and mean 95% kernel area was 1.68$\pm$0.39 ha. The kernel estimates of two turtles were deemed inappropriate due to overestimation along the linear creek channel, and were not reported. Long-distance movements were observed for female *G. barbouri*, primarily from June through August with the longest movement being 6.4 km within 21 days.

Habitat use variables measured for use-availability analysis varied within and among individuals; however, frequently relocated individuals had similar ranges in habitat use variables compared to individuals observed less often, suggesting limited influence of unequal recaptures on observed habitat use. On average, turtles used habitats with greater water depths and slightly higher quantities of LWD (Table 1). Turtles also occurred closer to rocky-fine and rocky-boulder substrates, whereas distance to limerock fine and limerock boulder were similar among turtle use locations and random locations (Table 1).

The best-approximating model of turtle habitat use included substrate variables and contained all model support (Table 2). The second and third best-approximating models were substantially less supported and included the model with LWD and the global model containing all variables, respectively (Table 2). Parameter estimates of the best-approximating model indicated that distance to rocky boulder, rocky fine, and sand substantially influenced turtle habitat use given measured habitat availability captured by random locations within the 24 km lower reach of Ichawaynochaway Creek (Table 3). Scaled odds ratios suggested that female *G. barbouri* were, on average, 2, 3, and 11 times less likely to associate with areas with every 10 m

Table 1. Mean and standard error (SE) of variables quantified at capture locations ($n = 462$) of female *G. barbouri* and random locations ($n = 462$) throughout the Ichawaynochaway Creek study area.

	Capture locations		Random locations	
Variable	Mean	SE	Mean	SE
LWD[a]	3.0	0.2	2.7	0.2
Depth[b]	3.8	0.06	3.0	0.06
SD of depth	0.5	0.02	0.4	0.02
Limerock boulder[b]	140.2	6.2	148.0	7.6
Limerock fine[b]	57.5	3.6	56.3	3.6
Rocky boulder[b]	44.1	2.1	55.6	3.9
Rocky fine[b]	30.4	2.4	41.4	3.1
Sand[b]	5.7	0.5	7.5	0.6

[a] LWD units are number of pieces within a 15 m buffer around location.
[b] Mean units are in meters; substrate class measurements are distances between locations and the nearest representative of a particular substrate class.

increased distance away from rocky-boulder, rocky-fine, and sand substrates, respectively (Table 3). In other words, proximity to rocky-boulder, rocky-fine, and sand substrate was associated with greater habitat use of female *G. barbouri* compared to their relative availability in the creek. Estimates of habitat use in relation to limestone-boulder and limestone-fine habitats were generally less precise (e.g., 95% credible intervals crossed zero). Although less supported, the global model parameter estimates of LWD and depth showed a positive association with habitat use of *G. barbouri* (Table 3). Higher counts of LWD and increased average water depth were also associated with greater turtle use (Table 1). Bayesian p-values indicated that the global model adequately fit the observed data ($P = 0.50$).

DISCUSSION

Although home range size and linear distance used varied among individuals, our findings for *G. barbouri* were generally comparable to those reported for other riverine species of *Graptemys* (Craig, 1992; Jones, 1996; Bodie and Semlitsch, 2000; Carriere et al., 2009). Our study increased home range estimates for this poorly studied species. Sanderson (1974) used a two-year mark–recapture study of female *G. barbouri* on the Chipola River to estimate a linear home range of 273±48 m, which is 67% less than our home range estimates of turtles in Ichawaynochaway Creek.

Our larger home range size reflects increased movement among habitats during the study period. Like other species of *Graptemys*, long distance movements by female *G. barbouri* in spring and summer are likely attributable to movement to suitable nesting habitat (Jones, 1996; Bodie and Semlitsch, 2000). Although Ichawaynochaway Creek has numerous sandy beaches accessible to nesting turtles, these patches are widely dispersed and separated by long and deeply entrenched reaches of creek with steep sandy banks or limerock outcrops (Golladay et al., 2006). But river turtles are known to make extensive movements to find optimal nesting habitat patches (Moll and Moll, 2004). We suggest that some adult female turtles monitored in this study nested far from their shelter and foraging areas, and suspect that the reported variation in home range size was due to the dispersed nature of optimal nesting beaches along Ichawaynochaway Creek. While *G. barbouri* will occasionally traverse terrestrial riparian habitat in search of a suitable nesting location (Sterrett, 2009), it is rare to find nests of *G. barbouri* more than 100 m from a stream (Ewert et al., 2006).

A substantial drought during the study period resulted in a 50% decline in average annual streamflow (average annual discharge in 2007 = 9.9 $m^3 s^{-1}$ and 2008 = 14.6 $m^3 s^{-1}$) in Ichawaynochaway Creek compared to the long-term 72 yr annual average (20.8 $m^3 s^{-1}$; USGS stream gage no. 02353500; U.S. Geological Survey, 2013), and a tropical storm-induced a substantive flood in August 2008 (Georgia Automated Environmental Monitoring Network, 2008, http://www.griffin.uga.edu/aemn/). Despite both extreme low and high flow conditions, *G. barbouri* exhibited relatively high site affinity within their home ranges. Locations obtained for individuals before and after the tropical storm, which significantly increased discharge, indicate that turtles were not displaced as a result of the flood event. Likewise, Sanderson (1974) found no movements in *G. barbouri* on the Chipola River before or after a hurricane-induced flood. While we did not examine site fidelity *per se*, most turtles were found repeatedly at the same few locations throughout the year or returned to a previously visited location after a large movement event. This strong site fidelity was manifested in small 50% and 95% kernel estimates. We interpret site fidelity as evidence that specific habitat requirements were met in the immediate vicinity of these locations (e.g., shelter, foraging; Arvisais et al., 2002; Fig. 2). In our study, female *G. barbouri* often occupied deep pools with limerock outcrops along the outside bends of the creek in the vicinity of submerged LWD (i.e., specifically large logs; Fig. 2). Pool habitats occupied by the turtles were also relatively close to shallow, rocky areas of Ichawaynochaway Creek.

Table 2. Candidate models with mean deviance, effective number of parameters (pD), deviance information criterion (DIC), the difference between the best model and each subsequent model (ΔDIC), model weight (w_i), and the standard deviation of the individual random effects (RE SD) for habitat selection of female *G. barbouri* in Ichawaynochaway Creek in Georgia, 2007–2009.

Model	Deviance	pD	DIC	ΔDIC	w_i	RE SD
Substrate	3551.4	6816.5	9589.1	0.0	1.0	0.66
LWD	3574.3	6090.2	9664.5	75.3	0.0	0.65
Depth, depth variability, substrate, LWD	3299.2	6871.2	10170.4	581.2	0.0	0.64
Depth, depth variability	3374.0	6799.5	10173.5	584.3	0.0	0.67
Depth	3373.6	6816.5	10190.1	600.9	0.0	0.68
LWD, depth	3365.1	7135.0	10500.1	911.0	0.0	0.62
Depth, substrate	3303.9	7501.6	10805.5	1216.4	0.0	0.61

Table 3. Mean and standard error (SE) of parameter estimates, unit scalar, mean scaled odds ratio, and upper and lower 95% Bayesian credible intervals (CI) of scaled odds ratios from the top three best-approximating habitat-use availability logistic regression models of habitat use of female *G. barbouri* in Ichawaynochaway Creek in Georgia, 2007–2009. Scaled odds ratios represent the number of times more likely that a turtle would use a particular habitat per unit increase in each habitat variable (i.e., two times less likely to be associated with habitat with every ten meter increase away from rocky boulder habitat). Parameters in bold indicate significant estimates.

Model	Parameter	Estimate	SE	Unit scalar	Scaled odds ratio	Lower 95% CI	Upper 95% CI
Substrate	Limerock boulder	−0.0658	0.0492	10 m	0.9956	0.9892	1.0018
	Limerock fine	−0.0276	0.0528	10 m	0.9964	0.9829	1.0094
	Rocky boulder	**−0.1254**	**0.0522**	**10 m**	**0.9815**	**0.9661**	**0.9963**
	Rocky fine	**−0.1823**	**0.0667**	**10 m**	**0.9700**	**0.9487**	**0.9913**
	Sand	**−0.1417**	**0.0592**	**10 m**	**0.8932**	**0.8153**	**0.9753**
LWD	LWD	0.0724	0.0435	1 count	1.0199	0.9953	1.2452
Global	Limerock boulder	0.0105	0.0471	10 m	1.0007	0.9949	1.0069
	Limerock fine	0.0079	0.0575	10 m	1.0010	0.9847	1.0147
	Rocky boulder	**−0.2079**	**0.0643**	**10 m**	**0.9696**	**0.9507**	**0.9880**
	Rocky fine	**−0.3370**	**0.0734**	**10 m**	**0.9453**	**0.9247**	**0.9698**
	Sand	0.1409	0.0514	10 m	1.1188	1.0279	1.2086
	LWD	**0.1043**	**0.0438**	**1 count**	**1.0287**	**1.0039**	**1.0524**
	Depth	**0.8699**	**0.0780**	**1 m**	**2.0314**	**1.8287**	**2.2536**
	Depth variability	−0.0146	0.0560	1 SD	0.9650	0.7335	1.2609

Our models indicated that proximity to rocky-boulder and rocky-fine bed sediments (i.e., shoals) and sandy substrates were the most important criteria for habitat use by female *G. barbouri*. Reaches of the creek containing these substrates were typically shallower and had higher flows than pool habitats. Although we rarely observed radio-tagged turtles inhabiting shoals, study animals appeared to select areas closer to shoals more than would be expected given the availability of shoals within the creek. In general, shoals are physically heterogeneous and offer sandy and rocky substrates for gastropods and invasive Asian clams (*Corbicula fluminea*; Karatayev et al., 2005), which are the primary diet items of female *G. barbouri* in Ichawaynochaway Creek (S. Sterrett, unpubl. data). Selection of areas near shoals may be associated with increased food availability within and around shoals.

Greater water depth was also positively associated with habitat use of female *G. barbouri*; female turtles were typically found in locations with >3.0 m water depth during April 2008 when the sonar survey was done. Sanderson (1974) described similar observations with larger females frequently found in holes 2–4 m deep and near the channel thalweg. Both Jones (1996) and Pluto and Bellis (1986) reported positive associations between body size of *Graptemys*, depth, and surface current velocity. Carriere and Blouin-Demers (2010) found adult female *G. geographica* selected deeper areas, when compared to males and juvenile adults, at the home range scale. Deep pools may provide refuge from terrestrial predators, reduced current velocities near the bottom for resting, and access to preferred food items such as freshwater bivalves. A diet shift from native mussels to Asian Clams (*Corbicula* spp.) has been well documented in map turtles (Moll, 1980; Shively and Vidrine, 1984; Lindeman, 2006, 2013). The Asian Clam, *Corbicula fluminea*, a more recent, but common component of the diet of female *G. barbouri* (S. Sterrett, pers. obs.) has been found in stream habitats up to 8 m deep (Abbott, 1979).

Numerous studies have focused on the importance of LWD as basking structures (Moll, 1980; Pluto and Bellis, 1986; Jones, 1996; Lindeman, 1999), yet few have considered LWD as critical underwater habitat for freshwater turtles (Chaney and Smith, 1950). Although weakly supported, we found a positive association of *G. barbouri* and submerged LWD. Aquatic turtles are rarely found in open water or on sandy bottoms that lack other substrate (Legler and Winokur, 1979), with the exception of *Apalone* spp. (Ernst and Lovich, 2009). The occurrence of LWD in pools likely enhances the attractiveness of these habitats to *G. barbouri* by providing cover to avoid aquatic predators such as American Alligator (*Alligator mississippiensis*) and River Otter (*Lutra canadensis*), which are present in Ichawaynochaway Creek (Smith et al., 2006). Submerged wood also serves as habitat for prey such as benthic macroinvertebrates (Wallace and Benke, 1984). Large woody debris in Ichawaynochaway Creek comes from both natural and anthropogenic sources (Kaeser and Litts, 2008). Distributed throughout the study area are numerous pre-cut, submerged logs, also referred to as deadhead logs (DHLs). These massive DHLs are sometimes found resting on the bottom of pools in such a way that a small refuge is present beneath the log. In 2006, during turtle snorkeling surveys conducted in association with this study, we captured 11 females from beneath two DHLs submerged in a deep (~3 m) sandy pool. Four of these female turtles were recaptured under the same two DHLs within the following year. Although we did not make any attempts to discriminate between DHLs (~10.2 m^2) and other large woody debris (~2.97 m^2; Kaeser and Litts, 2008) with respect to used and random locations, in retrospect, these data may have provided valuable insight into the biological value of deadhead logs in this river system.

Given the affinity of female *G. barbouri* to deep pools containing limerock substrate (Sanderson, 1974; Enge and Wallace, 2008), we expected to find a stronger association between proximity to limerock and habitat use. The large confidence intervals associated with the parameter estimates of both limerock boulder and limerock fine indicated these variables were not robust predictors of used versus random locations. We attribute this result to the fact that 77% of the deep areas (i.e., areas with at least two consecutive, mid-channel depth observations $\geq$ 3.66 m, n = 82) found throughout the Ichawaynochaway Creek study reach contained limerock substrate (boulder, fine, or both). Given the widespread nature of limerock substrate, randomly placed locations were equally likely to be near this substrate than locations occupied by turtles, thus our results do not rule out the possibility that limerock substrate is an important component of female *G. barbouri* habitat. In other words, if we had examined habitat use in a stream or in reaches where limerock substrate was more limited, we might have identified proximity to this substrate type as important to habitat use of female *G. barbouri* (Beyer et al., 2010).

Snagging, or the removal of LWD, is a practice that can potentially fragment populations, reduce local abundance of turtles, alter prey availability, and alter stream morphology (Bodie, 2001; Ewert et al., 2006). In particular, removal of deadhead logs could pose a threat to *G. barbouri*. Large female *G. barbouri* have been observed to be associated with deadhead logs in Ichawaynochaway Creek, which suggest these habitat elements are important refuge areas (Sterrett, 2009). We recommend that future studies discriminate between use of DHLs and other LWD by *G. barbouri*, and consider investigating the ecological relationships between these habitat elements and stream fauna.

This study used novel telemetry methods to investigate movements of female *G. barbouri*, and successfully integrated radio telemetry and low-cost, sonar habitat mapping to measure habitat use of and habitat available to an aquatic organism. The highly detailed and complete geographic census of instream habitat enabled us to sufficiently characterize habitat availability within the study reach. We recommend the use of low-cost, side scan sonar habitat mapping to estimate habitat availability of other aquatic organisms because it can generate relatively large data sets and capture details of habitat features at differing spatial scales, which is essential for testing alternative hypotheses of habitat selection (Beyer et al., 2010). The method worked particularly well in conjunction with radio-telemetry of turtles to estimate habitat use. Given the exclusive focus on female *G. barbouri* in this study, the spatial ecology and movement of male and juvenile *G. barbouri* was not addressed, and remains an important area of future investigation.

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