Herpetological Conservation and Biology 9(3):475−483.
Submitted: 10 March 2014; Accepted: 16 July 2014; Published: 31December 2014.

DESCRIPTION AND COMPARISON OF TURTLE ASSEMBLAGES AND POPULATIONS LOCATED WITHIN A SPRING-FED RIVER

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Abstract.—**Turtle populations and assemblages are influenced by and may vary with abiotic factors. Rivers are inherently spatially variable and river turtle assemblages may differ among abiotically distinct sections of the same river. The North Fork of White River (NFWR), Ozark County, Missouri, is characterized by a distinct, spring-generated thermal gradient and has been subjected to varying degrees of human impact along its course. We provide baseline data of a turtle assemblage located within a section of the NFWR that flows through Mark Twain National Forest (MTNF). The turtle assemblage, population size of the predominant species, and habitat within MTNF were compared with those observed in and previously reported for a section of the same river that is typified by a differing thermal regime and located outside of MTNF. In both turtle assemblages, the Northern Map Turtle (*Graptemys geographica*) was the predominant species, but the turtle assemblages varied in composition, species richness, and heterogeneity despite being separated by only 16 river km. The river section located within MTNF was less degraded than the river section adjacent to less-forested areas, suggesting the importance of intact forests and public lands for maintaining water quality and river turtle habitat, populations, and assemblages.**

Key Words.—*Graptemys geographica*; habitat; Northern Map Turtle; population; river turtle assemblage

INTRODUCTION

Turtles are influenced by a suite of abiotic (e.g., temperature) and biotic factors (e.g., prey availability, competitors; Ernst et al. 1994; Bodie and Semlitsch 2000; Bodie et al. 2000; Moll and Moll 2004). Changes in abiotic conditions can alter the biotic components of an ecosystem as organisms' physiological tolerance thresholds are met and species composition turnover occurs (Davis 1986; Cody 1996). The resultant fluctuations in identity and relative abundance of species can alter community composition and dynamics (e.g., predator-prey and/or competitive interactions; Cody 1996).

Rivers are the epitome of dynamic, variable systems (Pluto and Bellis 1988; Moll and Moll 2004; Schumm 2005) and most rivers have undergone massive alterations by humans (Benke 1990). Due to the inherent variability of rivers, organism populations, assemblages, and communities can change considerably along a river's length (Kinsolving and Bain 1993; Moll and Moll 2004). River turtle assemblages can differ among sections of a river (Anderson et al. 2002; Haramura et al. 2008) due to the specialized habitat requirements of many species (Ernst and Lovich 2009) and the heterogeneous habitat offered by rivers (Schumm 2005). River turtle populations and assemblages may be impacted by the integrity of the within-stream and riparian habitats as habitat degradation may result in a decline in the absolute and relative abundance of specialist species while generalist species become more prominent (Moll 1977; Sterrett et al. 2011).

The North Fork of White River (NFWR) in Missouri is an approximately 100 km-long river with a distinct temperature gradient created by the input from several major springs (Nickerson and Mays 1973; Bryant Watershed Project, Inc. 2008. Watersheds: North Fork Watershed. Available from http://www.watersheds.org/places/nf.htm [Accessed January 2008]). The NFWR watershed is characterized by grassland/cropland and forest/woodland, and approximately 13% of the watershed consists of Mark Twain National Forest (MTNF) lands (Bryant Watershed Project, Inc. 2008. *op. cit.*). Within Ozark County, the land bordering the NFWR upstream of the major springs is largely forested and within MTNF (Bryant Watershed Project, Inc. 2008. *op. cit.*). The land bordering the NFWR downstream of the major springs includes privately owned and state lands that comprise a matrix of forested and deforested areas of varying development intensity (Pitt and Nickerson 2012). The turtle assemblage in a 4.6 km section of the NFWR located downstream of the major springs has been periodically studied since 1968, with the most intensive studies occurring in 1969, 1980 (Nickerson and Pitt 2012), 2004 (Pitt and Nickerson

2012), 2005, 2006, and 2007 (Pitt and Nickerson 2013). Substantial changes to the turtle assemblage and within-stream and adjacent terrestrial habitats have occurred since 1969 in association with turtle harvesting events and habitat degradation related to increased human activities (Nickerson and Pitt 2012; Pitt and Nickerson 2012, 2013). For example, the turtle assemblage shifted towards more generalist species, several areas of surrounding riparian and upland habitat were cleared, and higher levels of siltation and sedimentation were observed (Nickerson and Pitt 2012; Pitt and Nickerson 2012, 2013). Little is known about the turtle assemblage located in the section of the NFWR that flows through the MTNF, a section of river that is upstream of major springs and thus has a temperature regime that is more subject to air temperature fluctuations; and is surrounded by intact forest, suggesting a lesser degree of human impact compared to sections of the river located outside of MTNF. Our objectives were to describe and provide baseline data of the turtle assemblage located in a section of the NFWR within MTNF, generate population estimates for species with adequate sample sizes, and evaluate within-stream habitat parameters. We sought to compare the data with those collected by Pitt and Nickerson (2013) from the previously studied research section located downstream of the major springs in order to explore spatial variability in turtle assemblages, populations, and habitat in a river with a distinct thermal gradient and that has been subjected to varying degrees of human impact. We predicted that the turtle assemblage located in the section of the NFWR within MTNF would have a low relative abundance of generalist species as was observed in the research section located downstream of the major springs in 1969 prior to substantial habitat degradation.

Materials and Methods

We selected a 4.6 km section of the NFWR located within the MTNF, Ozark County, Missouri based on its physical similarities to the previously studied research section (Nickerson and Pitt 2012; Pitt and Nickerson 2012, 2013), upstream location relative to the major springs, and forested setting. The research section (herein referred to as the MTNF research section) is separated from the previously studied research section (herein referred to as the downstream research section) by approximately 16 river km. The only clearing and development adjacent to the MTNF research section is a U.S. Forest Service-operated campground and boat ramp located at the upstream end of the section. We divided the 4.6 km MTNF research section into fifty 92 m-long stations, following the protocols used in the downstream research section (Nickerson and Mays 1973; Nickerson and Pitt 2012; Pitt and Nickerson 2012, 2013).

In 2005, 2006, and 2007, the MTNF research section was surveyed for turtles every other day throughout the summer (15 June - 20 August) between 0900 and 1800, weather permitting, for a total of 351 person hours. We sought to compare the data collected in the MTNF research section with the data collected from the downstream section and reported in prior studies, therefore, we followed the same standardized protocols employed by Pitt and Nickerson (2013). Coordinated surveys in both research sections were conducted by the same research crew during the same time frame on alternating days in order to ensure comparability of data sets. Surveys were conducted primarily by snorkeling and hand-capturing turtles. We supplemented the snorkeling-based surveys by setting two 0.75 m and two 1.0 m diameter hoop nets baited with sardines in areas with high turtle concentrations once a week between 1800 and 0900 in 2005 and 2006. In both years, we abandoned the use of traps after several weeks as they proved ineffective and failed to capture any turtles, perhaps in part because the bait was quickly consumed by non-target species (e.g., crayfish).

We weighed, measured, marked, and released all captured turtles at their capture sites following the protocol of Pitt and Nickerson (2012). We visually determined the sex of turtles when possible based on secondary sexual characteristics (e.g., claw length, tail size) for each species as described by Ernst et al. (1994). We recorded capture location of each turtle relative to the nearest station marker in order to evaluate movement patterns. We calculated Hurlbert's Probability of

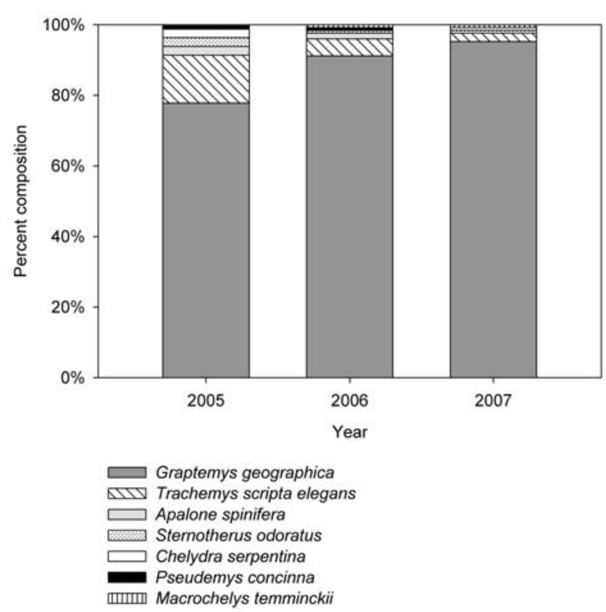

Figure 1. Turtle assemblage structure in a 4.6 km section of the North Fork of White River located in the Mark Twain National Forest, Ozark County, Missouri.

Interspecific Encounter (PIE; Hurlbert 1971) to assess heterogeneity, which accounts for species richness and evenness (Krebs 1989). In 2007, we regularly observed a group of Spiny Softshell Turtles (*Apalone spinifera*) basking together on a log in the MTNF research section, but failed to capture any due to their wary nature and fast swimming speed. The maximum number of *A. spinifera* observed basking together at any given time was five. Therefore, we calculated a corrected Hurlbert's PIE value for 2007 that included five *A. spinifera*. We used EcoSim version 7.72 (Gotelli and Entsminger 2011) to calculate Hurlbert's PIE values. Model parameters were set at 1000 iterations with a random number seed of zero.

Species-specific statistical analyses of turtle data were limited to the Northern Map Turtle (*Graptemys geographica*) due to larger sample sizes associated with their numerical dominance in the MTNF research section. We calculated population estimates with 95% confidence intervals for *G. geographica* using the Schumacher-Eschmeyer method (Krebs 1989) with each sampling day representing a partitioned sample unit. The population estimates were compared using the Chapman and Overton method (as described in Seber 1982) to identify significant differences between consecutive sampling years. We calculated standardized density estimates using the Schumacher-Eschmeyer estimated population sizes and the area calculated from the product of the mean stream width and research section length. Nonparametric Kruskal-Wallis tests were used to evaluate whether the mean plastron length of the *G. geographica* populations, partitioned by sex, varied among sampling years as assumptions of normality and equal variance were not met. Binomial tests were used to determine whether sex ratios differed from 1:1 (male:female) in a given year. We used chi-squared (χ^2) tests of independence to identify if sex ratios varied within the same site among sampling years.

To identify differences between the *G. geographica* populations in the MTNF and downstream research sections, we used the Chapman and Overton method (as described by Seber 1982) to compare the population estimates of the *G. geographica* population in the MTNF research section with those in the downstream research section generated by Pitt and Nickerson (2013). We used independent sample *t*-tests or Mann-Whitney U tests, depending on whether assumptions of normality and equal variance were met, to determine whether the mean plastron length of the *G. geographica* populations, partitioned by sex, varied among sampling years. We tested assumptions of normality and equal variance using the Kolmogorov-Smirnov and Levene analyses, respectively.

TABLE 1. Schumacher-Eschmeyer population size and corresponding density estimates of *Graptemys geographica* in 2005, 2006, and 2007 in a 4.6 km section of the North Fork of White River located in the Mark Twain National Forest, Ozark County, Missouri. Density estimates were based on area calculated from mean stream width and total length of the research section.

Sampling year	Estimated population size (95% confidence interval)	Estimated density
2005	115 (92–154)	1 turtle/ 1136 m^2
2006	304 (189–779)	1 turtle/ 430 m^2
2007	578 (317–3231)	1 turtle/ 226 m^2

We collected habitat data for both the MTNF and downstream research sections to provide context for the comparisons of the turtle assemblages and populations. To quantify the physical differences between the MTNF and downstream research sections, we recorded stream width, water depth, substrate composition, and the presence or absence of aquatic vegetation for each of the two research sections in 2005. We measured stream width as the distance between banks at each station marker. We measured water depth, substrate composition, and vegetation at midstream and 1 m from each bank at each station marker. We compared stream widths and depths using independent sample *t*-tests to determine if mean values were significantly different between the two research sections. We summarized and compared substrate composition and vegetation presence using χ^2 tests of homogeneity. Water temperature was measured prior to each turtle survey day. We compared water temperatures of the two research sections using an independent sample *t*-test to determine whether they were significantly different. As a relatively inexpensive indicator of human impact on water quality, we analyzed water samples collected in 2007 from within each research section and the local springs for total coliform bacteria and *Escherichia coli* content using the Coliplate™ test (Bluewater Bioscience, Inc. Mississauga, Ontario, Canada). We sampled four sites within the main channel of the MTNF research section, five sites within the main channel of the downstream research section, and five spring outlets (Blue Springs, Rainbow Spring Outlet 1, Rainbow Spring Outlet 2, Spring Creek, Althea Spring). We conducted five water quality sampling rounds: two in June, two in July, and one in August. We did not collect samples at each site during each sampling round due to processing constraints. We used SPSS version 11.5 (SPSS Inc., Chicago, Illinois, USA) with α = 0.05 to perform statistical analyses unless otherwise specified.

RESULTS

We captured seven river turtle species in the MTNF research section in 2005–2007: *G. geographica*, Red-eared Sliders (*Trachemys scripta elegans*), Eastern Musk Turtles (*Sternotherus odoratus*), River Cooters

TABLE 2. Mean plastron lengths (PL) of *Graptemys geographica* in 2005, 2006, and 2007 in a 4.6 km section of the North Fork of White River located in the Mark Twain National Forest, Ozark County, Missouri. *n* represents the sample size. SD represents the standard deviation.

Sampling year	Sex	n	Mean PL ± SD (cm)	Range (cm)
2005	Male	24	7.8 ± 1.3	5.1–10.2
	Female	20	11.2 ± 4.8	5.6–19.5
2006	Male	39	7.5 ± 0.9	6.0–10.2
	Female	38	13.3 ± 5.5	5.1–20.2
2007	Male	32	7.2 ± 1.0	5.4–9.2
	Female	29	12.6 ± 5.1	4.3–20.5

(*Pseudemys concinna*), Snapping Turtles (*Chelydra serpentina*), *A. spinifera*, and Alligator Snapping Turtles (*Macrochelys temminckii*), though we did not capture more than six species in a given sampling year (Fig. 1). *Graptemys geographica* was the most abundant turtle species in the MTNF research section in all study years (Fig. 1). We also captured *Trachemys scripta elegans* and *S. odoratus* in the MTNF research section in all years (Fig. 1). We consistently observed a small number (≤ 5) of *A. spinifera* basking in the MTNF research section during all sampling years, but sampling methods were not conducive to their capture, thus their presence is not accurately described by Figure 1. *Chelydra serpentina*, *P. concinna*, and *M. temminckii* represent uncommon, transient, and/or cryptic species in the MTNF research section and we did not observe them in every sampling year (Fig. 1). Hurlbert's PIE values for 2005 (0.379), 2006 (0.167), and 2007 (0.094; corrected: 0.161) suggested low community heterogeneity within the MTNF research section.

The annual *G. geographica* population estimates for the MTNF research section were significantly higher each subsequent sampling year (2005 vs. 2006: Z = 2.324, P = 0.020; 2006 vs. 2007: Z = 2.145, P = 0.032; Table 1). No significant differences in mean plastron length, partitioned by sex, were observed among sampling years for the *G. geographica* population located in the MTNF research section (males: χ^2 = 3.030, df = 2, P = 0.220; females: χ^2 = 2.428, df = 2, P = 0.297; Fig. 2, Table 2). Sex ratios of *G. geographica* for which sex was distinguishable did not differ significantly from 1:1 in any sampling year in the MTNF research section (male:female$_{2005}$ = 1.00:0.83, n = 44, P = 0.652; male:female$_{2006}$ = 1.00:0.97, n = 77, P = 1.000; male:female$_{2007}$ = 1.00:0.91, n = 61, P = 0.798). Sex ratios of *G. geographica* for which sex was distinguishable in the MTNF section were not significantly different among sampling years (χ^2 = 0.173, df = 2, P = 0.917). Movement data from recapture histories in the MTNF research section suggest that 76% of the recaptured *G. geographica* moved ≤ 184 m and only 11% of recaptures had moved ≥ 460 m during the course of the study. The maximum distance moved by a *G. geographica* in the MTNF research section was by a female turtle that moved 3,703 m

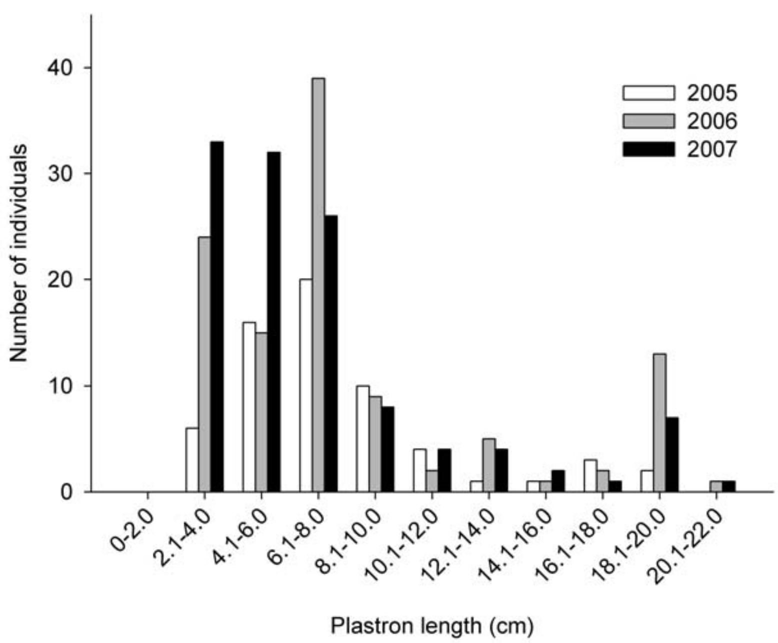

FIGURE 2. Size distribution of *Graptemys geographica* in a 4.6 km section of the North Fork of White River located in the Mark Twain National Forest, Ozark County, Missouri (n_{2005} = 63; n_{2006} = 111; n_{2007} = 118). Individuals with plastron length > 12.0 cm were all females.

downstream between 2005 and 2006.

The *G. geographica* population estimates for the MTNF (Table 1) and downstream (Pitt and Nickerson 2013) research sections were not significantly different in 2005 ($Z = 0.121$, $P = 0.903$), 2006 ($Z = 0.431$, $P = 0.666$), or 2007 ($Z = 1.190$, $P = 0.234$). The mean plastron lengths, separated by sex, of the *G. geographica* population located in the MTNF research section were not significantly different from those observed for the population located in the downstream research section in any sampling year (males$_{2005}$: $t = -0.068$, df = 36, $P = 0.946$; males$_{2006}$: $Z = -0.328$, $P = 0.743$; males$_{2007}$: $t = 1.337$, df = 78, $P = 0.185$; females$_{2005}$: $Z = -0.877$, $P = 0.380$; females$_{2006}$: $Z = -0.905$, $P = 0.365$; females$_{2007}$: $Z = -1.160$, $P = 0.246$).

Stream width of the MTNF research section was significantly narrower than that of the downstream research section ($\bar{x} \pm SD = 28.4 \pm 10.5$ m and 43.4 ± 9.1 m, respectively; $t = 7.438$, df = 93, $P < 0.001$). Midstream water depth was significantly shallower in the MTNF research section than in the downstream research section ($\bar{x} \pm SD = 60.9 \pm 28.3$ cm and 76.4 ± 40.5 cm, respectively; $t = 2.195$, df = 96, $P = 0.031$). A similar significant pattern was detected for water depths taken 1 m from the east bank ($\bar{x}_{MTNF} \pm SD = 25.1 \pm 19.4$ cm, $\bar{x}_{downstream} \pm SD = 38.7 \pm 20.4$ cm; $t = 3.369$, df = 96, $P = 0.001$). There was no significant difference in depth between values measured 1 m from the west bank ($\bar{x}_{MTNF} \pm SD = 35.0 \pm 22.3$ cm, $\bar{x}_{downstream} \pm SD = 35.1 \pm 19.1$ cm; $t = 0.005$, df = 96, $P = 0.996$). The stream substrate composition in both research sections did not differ from the historical description of the downstream research section offered by Nickerson and Mays (1973) with the exception of silt and sediment deposits (but see Pitt and Nickerson 2012 for differences in substrate distribution in the downstream research section). Substantial silt and sediment deposits were not observed in studies prior to 2004 (Nickerson and Mays 1973; Pitt and Nickerson 2012), but were apparent in both research sections in similar proportions ($\chi^2 = 0.256$, df = 1, $P = 0.613$) in 2005. Floating algal masses, submerged filamentous algal growths, and emergent vegetation stands were apparent in both research sections in similar proportions ($\chi^2 = 0.794$, df = 1, $P = 0.373$). Total coliform levels exceeded the values deemed safe for full body contact by the Missouri Department of Natural Resources (MDNR 2005) in 34 of the 46 individual water samples collected from the research sections and springs (Fig. 3A). Fourteen of the 46 water samples also surpassed safe levels of *E. coli* content for full body contact (MDNR 2005; Fig. 3B). Seven water samples from the MTNF research section and 14 water samples from the downstream research section exceeded the threshold level of total coliform content deemed safe for full body contact. One water sample from the MTNF research section and seven water samples from the downstream research section exceeded the threshold level of *E. coli* content deemed safe for full body contact. Water temperatures were significantly warmer in the MTNF research section than in the downstream research section ($\bar{x} = 23.7 \pm 1.4°$ C and $18.7 \pm 1.2°$ C, respectively; $t = -16.901$, df = 74, $P < 0.001$).

DISCUSSION

Graptemys geographica was the most abundant species in the MTNF research section in all sampling years, a result consistent with patterns observed for the downstream research section (Nickerson and Pitt 2012; Pitt and Nickerson 2012, 2013) and in other lotic systems where river turtle fauna is dominated by *Graptemys* species (Bury 1979; Moll and Moll 2004). Seven species were observed in the MTNF section, although the identity of species observed each year varied, and no more than six species were observed in a given sampling year. The failure to observe all seven species in all years may be a result of species being cryptic, transient, and/or uncommon resulting in a low probability of observation. In comparison, only six turtle species were observed in the downstream research section in 2005–2007 with no more than five turtle species observed in any given sampling year (Pitt and Nickerson 2013).

Low Hurlbert's PIE values suggested low heterogeneity within the MTNF research section in 2005–2007. The low heterogeneity was reflective of the low species evenness. Similar patterns of low species evenness and heterogeneity were observed for the downstream research section in 1969, prior to extensive habitat degradation, but heterogeneity and species evenness increased in the downstream research section in conjunction with habitat degradation (Nickerson and Pitt 2012; Pitt and Nickerson 2012, 2013). Moll (1977) demonstrated that river turtle assemblage composition changes from an assemblage typified by more specialist species to one with more generalist species following habitat degradation. Based on our results and previously documented trends for other turtle assemblages (Moll 1977; Nickerson and Pitt 2012; Pitt and Nickerson 2012, 2013), we hypothesize that the low heterogeneity and species evenness and the high relative proportion of *G. geographica*, a species with specialized habitat and dietary requirements (White and Moll 1992; Ernst and Lovich 2009), observed in the MTNF research section may be indicative of a less degraded habitat.

The significant increase in population size of *G. geographica* within the MTNF during 2005–2007 appeared to be a result of higher recruitment in 2006 and 2007. The *G. geographica* populations within the MTNF and downstream research sections were similar in size. The similarity in *G. geographica* population size and the higher number of species observed in the MTNF

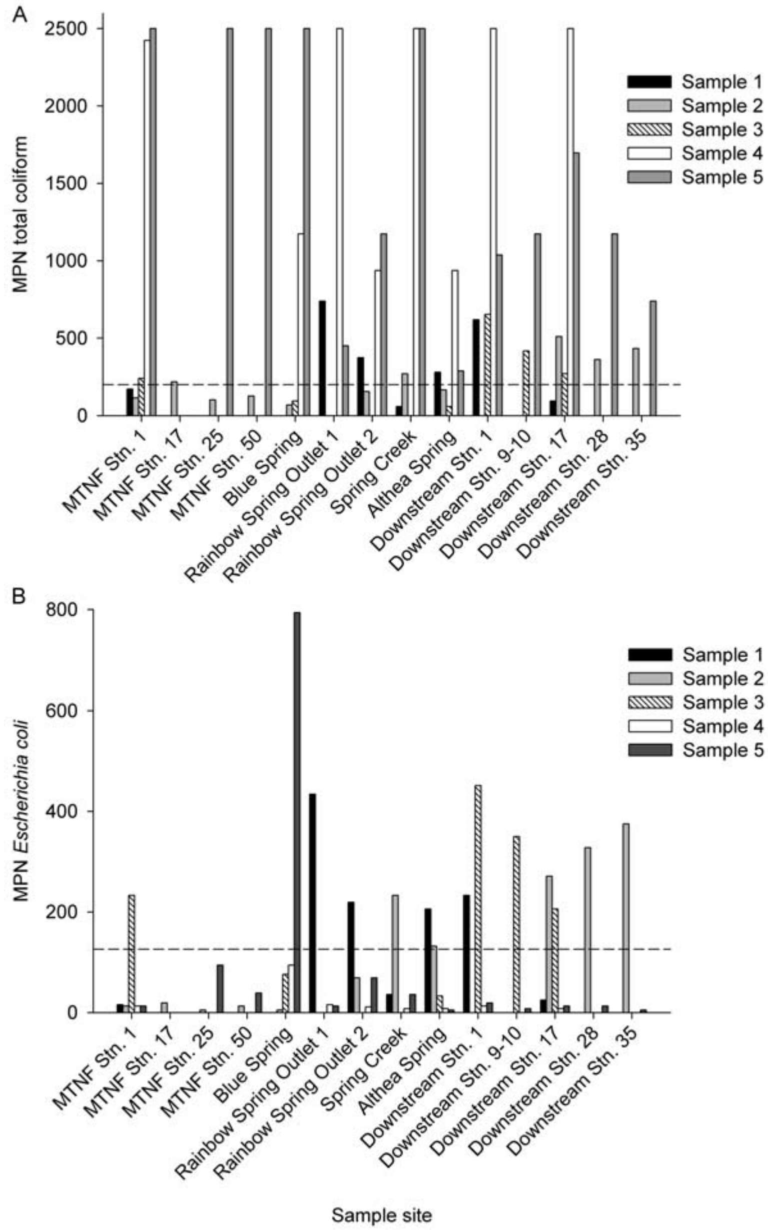

FIGURE 3. (A) Total coliform bacteria and (B) *Escherichia coli* content observed in the North Fork of White River, Ozark County, Missouri. MTNF indicates the research section located within the Mark Twain National Forest. Downstream indicates the research section located downstream of the MTNF and major spring effluents. Samples 1, 2, 3, 4, and 5 were collected during the third and fourth week of June, first and last week of July, and first week of August 2007, respectively. Samples were not collected at each site during each sampling period due to processing constraints; sites for which no data were available lack values. MPN represents the most probable number of colony-forming units per 100 mL of water. The dashed lines indicate the threshold (A) total coliform bacteria (200 MPN) and (B) *E. coli* (126 MPN) concentrations deemed safe for full body contact by the Missouri Department of Natural Resources (2005). Values depicted equal to 1 and 2500 MPN represent values < 3 and > 2424 MPN, respectively.

research section compared to the downstream research section may be somewhat surprising as the MTNF research section encompasses a significantly smaller aquatic area and volume than the downstream research section. Typically, a larger area contains more species and perhaps larger populations than a smaller area (Groom 2006). Additionally, larger areas often contain a higher diversity of microhabitats than do smaller areas (Pluto and Bellis 1988; Dunning et al. 2006). Based on the premise that larger areas can support more species and perhaps more individuals than smaller areas, we would expect that more species and individuals would be observed in the downstream section as it had a larger aquatic area and volume. However, the opposite pattern was observed in terms of the number of species and no difference was observed for the *G. geographica* population size estimates. When viewed in the light of the habitat differences between the two research sections, the results may not be counterintuitive. Water temperatures were significantly different between the two research sections. Because turtles are ectothermic, water temperature can strongly influence body temperature (Boyer 1965; Schuett and Gatten 1980; Brown et al. 1994). Turtles may move to and among areas of favorable temperatures within their aquatic habitats (Schuett and Gatten 1980; Moll and Moll 2004; Picard et al. 2011). As a result, some species may select habitats with higher water temperatures, as were recorded for the MTNF research section, and avoid cooler thermal regimes, such as those that typified the downstream research section.

If turtles prefer less impacted habitats, the assemblage and population patterns observed are expected as the MTNF research section was less degraded than the downstream research section. Only the first station within the MTNF research section had *E. coli* levels that exceeded concentrations deemed safe for full body contact by MDNR (2005). In contrast, all areas sampled within the downstream research section had *E. coli* levels that exceeded concentrations deemed safe for full body contact in at least one sampling event during the summer. The MTNF research section was surrounded by mostly forested, undeveloped land and intact riparian zones with the exception of the one clearing associated with the national forest campground and boat ramp located at the upstream boundary of the research section. In contrast, there were seven cleared areas along portions of the downstream section in 2004 (Pitt and Nickerson 2012) and an additional clearing was added by a private land owner during the 2005–2007 study period. Intact forest and riparian zones, such as those characterizing the MTNF research section, are known to prevent excess sediment runoff during rain events (Gilliam 1994) and may influence river turtle populations and assemblages (Sterrett et al. 2011).

The NFWR supports a diverse turtle assemblage predominated by *G. geographica*. Turtle assemblages in NFWR varied in composition, species richness, and heterogeneity in areas with varying thermal regimes and degrees of degradation. Sections of the NFWR located within the heavily forested MTNF were less degraded than river sections adjacent to non-forested areas, suggesting the importance of intact forests and public lands for maintaining water quality and river turtle habitat, populations, and assemblages. The human population is increasing rapidly (Cohen 1995) and most rivers have undergone massive alterations due to the resource demands of humans (Benke 1990). As many turtle populations have declined (Moll and Moll 2004; Ernst and Lovich 2009), it is imperative to establish assemblage, population, and habitat baselines for comparison with future studies so that we may document trends and establish effective management and conservation strategies.

Acknowledgments.—We thank the Saint Louis Zoological Park and Reptile & Amphibian Conservation Corps for providing funding, Joseph J. Tavano for his indispensable field assistance, Sunburst Canoe Ranch for providing a campsite and use of its facilities, and the Wild Branch Fly Shop for providing a boat. We thank Don L. Moll, J. Perran Ross, Mel E. Sunquist, and Kent A. Vliet for guidance and comments on various versions of this manuscript. Research was conducted with the approval of the Missouri Department of Conservation (Wildlife Collector's Permits: 12394, 12401, 12783, 12859, 13330) and the University of Florida's Institutional Animal Care & Use Committee (Protocol: D712).

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