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Distribution and Abundance of *Graptemys oculifera* (Ringed Sawback) and *Graptemys pearlensis* (Pearl Map Turtle) in the Pearl River System of Louisiana, USA

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Abstract.—**The Ringed Sawback (*Graptemys oculifera*) and the Pearl Map Turtle (*G. pearlensis*) are riverine turtles that are endemic to the Pearl River drainage of central Mississippi and southeastern Louisiana USA. *Graptemys oculifera* is listed as Threatened under the U.S. Endangered Species Act, and *G. pearlensis* was also recently proposed for Threatened status, yet most of the information on both species comes from the Mississippi portion of their range. During May/June 2020 and 2021, I assessed the status of both species in Louisiana using a combination of survey methods. Point count surveys detected both *Graptemys* primarily in the Bogue Chitto and Pearl rivers, with *G. oculifera* observations exceeding those of *G. pearlensis*. I documented *Graptemys oculifera* and *G. pearlensis* in 3 and 4 previously undocumented creeks, respectively. Basking density surveys at 22 sites were about 4.5× greater for *G. oculifera* (14/rkm) compared to *G. pearlensis* (3.1/rkm). Mark-resight population estimates at six sites for *G. oculifera* averaged 99/river km (rkm, range from 49–158/rkm), while *G. pearlensis* estimates at three sites averaged 10.6/rkm (range from 3–23/rkm). Lastly, trapping at six sites in 2020 and 2021 yielded a total of 111 *G. oculifera* and 14 *G. pearlensis*. In summary, *G. oculifera* appears secure in Louisiana, while *G. pearlensis* is rare and appears more sensitive to riverine modifications. Additional monitoring and enforcement efforts are needed in the future due to a myriad of threats for both species in the Pearl River system.**

Key Words.—basking density surveys; Bogue Chitto River; endangered species; gravel mining; population estimates; river turtle; West Pearl River Navigation Canal

Introduction

Two endemic *Graptemys* species occur sympatrically in the Pearl River system of central Mississippi and southeastern Louisiana, USA: the Ringed Sawback (*G. oculifera*; Baur 1890) and the Pearl Map Turtle (*G. pearlensis*; Ennen et al. 2010). *Graptemys oculifera* is listed as Threatened under the Endangered Species Act (USFWS 1986) and in Louisiana is considered State Threatened (S2) and a Tier 1 Species of Greatest Conservation Need (SGCN; Holcomb et al. 2015). It is also a Threatened species on the International Union for the Conservation of Nature (IUCN) Red List (van Dijk 2011a). *Graptemys pearlensis* is similarly imperiled as a Tier 1 SGCN species in Louisiana (Holcomb et al. 2015), and it has recently been proposed for listing under the Endangered Species Act (USFWS 2021). It is also currently assessed as Endangered on the IUCN Red List (van Dijk 2011b), and this higher threat-level assessment is associated with observed long-term population declines documented in Mississippi.

Many studies have been conducted on *G. oculifera* including population densities (Jones and Hartfield 1995; Lindeman 1998; Selman 2020), population structure (Jones and Hartfield 1995), reproductive ecology (Jones 2006), long-term trends in survivorship and population sizes (Selman and Jones 2017; Jones 2017), and population genetics (Gaillard et al. 2015). Most of this information was collected because *G. oculifera* was listed under the Endangered Species Act in 1986 (USFWS 1986) and subsequently, the *G. oculifera* recovery plan outlined specific research needs (Stewart 1988). There is very little information, however, available for *G. pearlensis*, with most data collected coincidental to *G. oculifera* visual population surveys (e.g., Lindeman 1998, Selman and Jones 2017). Nonetheless, most of the information collected thus far indicates that *G. pearlensis* is rarer than *G. oculifera*, and that *G. pearlensis* is declining, sometimes rapidly, in parts of its range (Selman and Jones 2017; Lindeman et al. 2020). Further, most of the ecological information available for both of these species originates from Mississippi, while only a few surveys have been completed for portions of Louisiana (Lindeman et al. 2020; Dena Dickerson and Kevin Reine, unpubl. report; Steve Shively, unpubl. report; Kurt Buhlmann and Whit Gibbons, unpubl. report; Keri Landry and Beau Gregory, unpubl. report). None of these studies, however, have thoroughly addressed the distribution and abundance of both species throughout their Louisiana ranges.

Along with the lack of intensive surveys in Louisiana, numerous threats exist to aquatic turtles in the Pearl and Bogue Chitto (a tributary of the Pearl) rivers in Louisiana and from upstream in Mississippi. First, the Pearl River has been hydrologically altered since the 1950s with the construction of the West Pearl River Navigation Canal (WPRNC) in southeastern Louisiana and the Ross Barnett Reservoir (RBR) north of Jackson, Mississippi. The former was completed in 1956 to facilitate barge traffic between the West Pearl River upstream to the town of Bogalusa, while the latter was completed in 1964 to secure a permanent drinking water source for Jackson and for recreation (Piller et al. 2004; Tipton et al. 2004). Second, the Pearl River around the city of Jackson has been historically altered via channelization, desnagging (i.e., removal of deadwood in the river channel), and riparian zone management. Third, along with these existing modifications, the Pearl River has also been historically subjected to water quality degradation via industrial and municipal effluent (Jack McCoy and Richard Vogt, unpubl. report), and this continues to the present day via excessive sewage overflows from the city of Jackson (U.S. District Court for the Southern District of Mississippi 2012; Selman 2020; https://www.wapt.com/article/jackson-sewage-overflows-into-pearl-river-federal-consent-decree/44005095#). Fourth, it is speculated that numerous *G. pearlensis* individuals, particularly reproductive females, have been collected from Louisiana for the pet trade over the last approximately 20–25 y (Will Selman and Carl Qualls, unpubl. report). Fifth, gravel mining was noted by Steve Shively (unpubl. report) as the largest threat to *G. oculifera* in the Bogue Chitto River because of channel filling impacts and the impacts of sand/gravel operation on the food base of *Graptemys*.

There are also additional looming threats to the Pearl River system including a proposed flood control project in central Mississippi, the One Lake Project. The One Lake Project proposes to impound a second section of the Pearl River downstream of the RBR to provide flood protection for the city of Jackson. This project would further alter hydrologic regimes downstream, however, and it could impact instream riverine habitat, adjacent nesting habitat, and directly impact a large population of *G. oculifera* as well as a small population of *G. pearlensis* (Selman 2020). Because of past, current, and potential future threats to both species and to habitats of the Pearl River, conservation efforts would benefit from collecting distribution and abundance data for both *Graptemys* species in the Pearl River drainage of Mississippi and Louisiana. Thus, the objective of my study was to determine the current distribution and abundance of both species at multiple localities in Louisiana to determine their population status in the state.

Materials and Methods

Basking surveys.—I used two methods to determine the distribution of basking *Graptemys* in southeastern Louisiana, USA. For the first method, I identified bridge crossings or river access points from which to survey on the Pearl River (including East and West Pearl), WPRNC, Bogue Chitto River, and minor tributaries (surveys are hereafter called point counts; Fig. 1). I visited each point count locality (n = 62) at least once during May/June 2020 and 2021 between 0900–1700, and I resurveyed seven sites twice and one site three times. For the resurveyed sites, I recorded the maximum number of individuals of each species observed during all surveys for that locality. I identified basking turtles with a 20–60× spotting scope (Vortex, Barneveld, Wisconsin, USA) with tripod (Manfrotto, Cassola, Italy) or 12×36 Canon Image Stabilized Binoculars (Canon, Melville, New York, USA). I also photographed individuals for locality vouchers with a Nikon Coolpix P900 digital camera (Melville, New York, USA). I recorded the number of each species at each survey point, and I distinguished basking turtle species using a combination of body size, carapace shape, head size, and head/carapace markings and color patterns. Additionally, I identified and counted other species of basking turtles, and if turtles could not be recorded to species, they were recorded to the lowest possible taxonomic grouping (e.g., unknown *Graptemys*, unknown emydid). I deposited photographic vouchers for both *Graptemys* species at the Florida Museum of Natural History Herpetology Collection (UF).

For the second method, I completed basking density surveys by boat or canoe along 22 river and creek stretches of variable length (recorded to 0.1 km) within the Pearl River system of Louisiana to

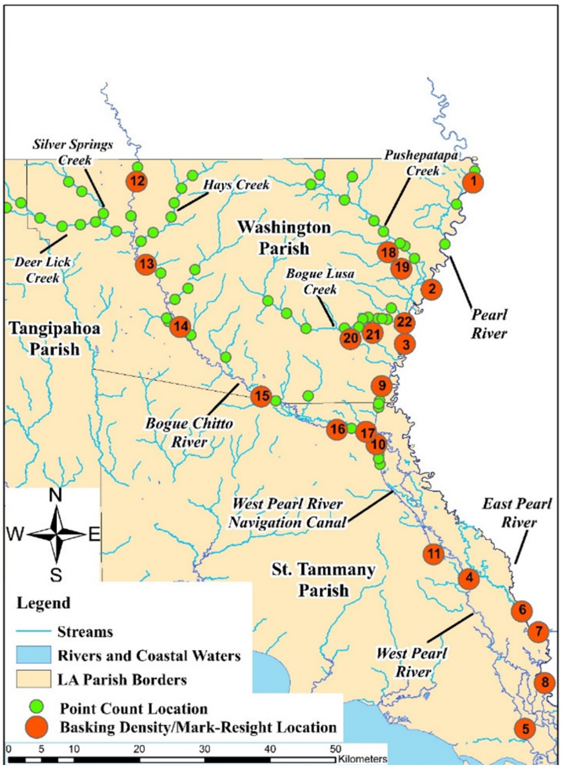

Figure 1. Sampling locations for point counts (green circles) and basking density or mark-resight locations (orange circles) of turtles in southeastern Louisiana, USA, 2020–2021. The numbers in the circles correspond with the sites in Tables 1 and 2.

determine species presence, as well as their densities (Fig. 1). I completed replicate surveys at most of these locations to provide higher confidence in observed basking densities and to account for natural basking variability associated with different environmental factors. During these surveys, I located basking turtles with 12 × 36 image stabilizing binoculars from the motorboat or canoe if sandbars were not present. If sandbars were present, I walked them and used a 20–60× spotting scope with tripod to identify and count basking turtles. I identified basking turtles to species similar to point counts, and basking densities are reported in number of turtles observed per river kilometer (rkm).

Because basking density survey data were non-normal in distribution, I used separate nonparametric Kruskal-Wallis tests to determine if *G. oculifera* and *G. pearlensis* densities (turtles/rkm) were equal across four drainage units with all survey data pooled by drainage (Pearl, Bogue Chitto, WPRNC, and small tributaries). If I found significant differences, I used Wilcoxon nonparametric multiple comparisons *post hoc* analyses to determine differences among drainage units. For all statistical analyses, I used the software JMP 12.2.0 (SAS Institute, Cary, North Carolina, USA), with $\alpha = 0.05$.

Trapping and mark-resight population estimates.—I trapped turtles at six sites in southeastern Louisiana in May/June 2020 and 2021, and four sites were on the mainstem or distributaries of the Pearl River (sites 2, 3, 4, 7) and two were located on the WPRNC (sites 9 and 11; Fig. 1). I captured turtles by submerging basking traps (made of 1.9 cm PVC coated crawfish wire) from observed turtle basking structures (Selman et al. 2012). I left traps slightly submerged, and they varied in size from 61 × 40 × 40 cm to 137 × 30 × 61 cm. I affixed traps to logs or branches known to be *Graptemys* basking sites using nails and cotton twine. I used trap days (i.e., number of days on the river trapping) as a measure of effort rather than per trap effort, because the number of basking traps I used to capture *Graptemys* varied from 10–14 traps per day. The number of traps varied by day because I often had to move traps when turtles exhibited avoidance behavior of the trap log or when river levels changed. I also opportunistically captured turtles by dip net while turtles were basking on emergent deadwood.

Following capture, I permanently marked individuals using a combination of drill holes in the marginal scutes (Cagle 1939) using a cordless drill, and I determined the sex each individual based on secondary sex characteristics for the species (i.e., males were smaller, had longer foreclaws, and longer pre-cloacal tail lengths compared to females). I paint-marked *Graptemys* on the 2nd and 3rd vertebral scutes with non-toxic, tree-marking spray paint (Aervoe Professional Choice Tree Marking Spray Paint, Gardnerville, Nevada, USA) to facilitate mark-resight population surveys. I released all marked turtles at their point of capture after the paint-mark dried.

I completed three Visual Mark-resight Surveys at each site during optimal basking times (0900–1700; Selman and Qualls 2011) within two weeks of marking the first paint-marked individual to meet the assumption of a closed population. Similar to basking density surveys, when sandbars were present (sites 2, 3, and 4), I walked the banks/sandbars and used a 20–60× spotting scope with a tripod to locate unmarked as well as marked individuals along the outer cutbank and inner sandbars. At three sites where sandbars were not present (sites 7, 9, and 11), I completed surveys by idling downstream in a motorboat and spotted turtles with 12 × 36 image-

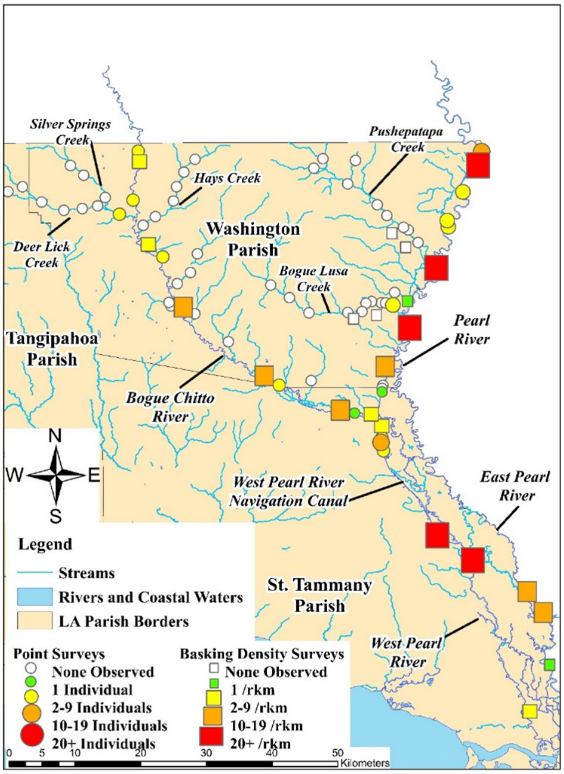

Figure 2. Point count and basking density survey results for Ringed Sawbacks (*Graptemys oculifera*) in the Pearl River system, Louisiana, USA, 2020–2021.

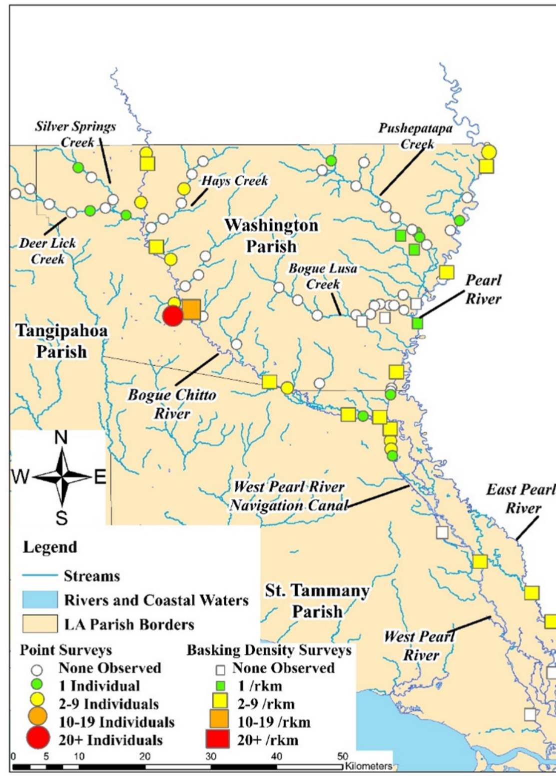

Figure 3. Point count and basking density survey results for Pearl Map Turtles (*Graptemys pearlensis*) in the Pearl River system, Louisiana, USA, 2020–2021.

stabilizing binoculars. I identified and distinguished basking turtle species similar to the basking density surveys.

Prior to mark-resight surveys, I attempted to have a minimum of 10 turtles paint-marked in the sampled river stretch to improve the confidence of each population estimate. I was able to complete this for *G. oculifera* at all sites and surveys except the first mark-resight survey at site 3 where I could capture and paint-mark only nine individuals prior to that survey. This standard could not be met for *G. pearlensis* at any sites or surveys due to the inability to capture more than six individuals at any site. Therefore, I report population estimates for *G. pearlensis* at four sites (sites 2, 3, 4 and 7). Also, I did not capture or observe any *G. pearlensis* individuals at site 11, and no marked individuals were resighted at site 9, so estimates could not be generated at these sites.

I calculated all population estimates, minimum alive estimates, and the corresponding 95% confidence intervals (CI) using the program NOREMARK (White 1996) using the joint hypergeometric maximum-likelihood estimator (Bartmann et al. 1987). I used this estimator because paint-marked turtles were not uniquely marked and were resighted and not recaptured. NOREMARK can also account for additional marked individuals added to the population between resight survey intervals. The assumptions for NOREMARK were that each individual in the population has an equal and random chance of being resighted, that paint marking of one individual does not affect another individual from being resighted, that no paint marks are lost via emigration and mortality (i.e., a closed population), and that marking does not affect the chance of emigration or mortality of an individual (White 1996).

Results

Basking point count surveys.—I made 298 observations of eight turtle species at 62 point count locations in Washington, Tangipahoa, and St. Tammany parishes of Louisiana. The two dominant species I observed were the River Cooter (*Pseudemys concinna*; 92 individuals at 29 sites; 30.9% of total observations) and *G. oculifera* (88 at 15 sites, 29.5%). Other species I observed in order of abundance included *G. pearlensis* (67 at 20 sites with 30 individuals at one site; 22.4%), Slider Turtle

(*Trachemys scripta*; 29 at 17 sites, 9.7%), Smooth Softshell Turtle (*Apalone mutica*; eight individuals at one site, 2.7%), Razorback Musk Turtle (*Sternotherus carinatus*; two individuals at two sites, < 1%), Stinkpot (*Sternotherus odoratus*; one individual, < 1%), and Alligator Snapping Turtle (*Macrochelys temminckii*; one individual, < 1%).

I documented *G. oculifera* consistently throughout

Table 1. Results of basking density surveys for turtles at 22 sites in southeastern Louisiana, USA. Species abbreviations are Go = Ringed Sawback (*Graptemys oculifera*), Gp = Pearl Map Turtle (*Graptemys pearlensis*), Am = Smooth Softshell Turtle (*Apalone mutica*), As = Spiny Softshell Turtle (*Apalone spinifera*), Dr = Chicken Turtle (*Deirochelys reticularia*), Pc = River Cooter (*Pseudemys concinna*), Sc = Razorback Musk Turtle (*Sternotherus carinatus*), and Ts = Slider Turtle (*Trachemys scripta*). Other abbreviations are WPRNC = West Pearl River Navigation Canal, rkm = river kilometer, SD = standard deviation. Superscript letters indicate significant differences of nonparametric multiple comparisons post hoc tests as described in text for *G. oculifera*/rkm (Go/rkm) and *G. pearlensis*/rkm (Gp/rkm).

Site	Total rkm	No. of Surveys	Go	Go/rkm (± SD)	Gp	Gp/rkm (± SD)	Am	As	Dr	Pc	Sc	Ts
Pearl River												
1	4.2	3	177	42.1 ± 32.7	24	5.7 ± 3.8	43			5		1
2	9.5	3	414	43.8 ± 8.8	36	3.8 ± 1.7	486	1		31	1	4
3	5.7	3	116	20.4 ± 0.8	6	1.1 ± 0.5	156	1		19		15
4	7.8	3	229	29.4 ± 6.2	45	5.8 ± 0.4	181	2		25		
5	4.0	1	25	6.3	-	-	1			18		2
6	2.2	1	25	11.4	6	2.7				2		
7	9.0	3	106	11.8 ± 2.5	19	2.1 ± 0.8				56		1
8	6.8	1	2	0.3	-	-				22		
Subtotal	49.2	18	1094	25.6 ± 19.0^{A}	136	3.6 ± 2.6^{B}	867	4		178	1	23
WPRNC												
9	14.6	4	240	16.0 ± 4.5	15	1.1 ± 1.1		4		57	9	12
10	3.1	1	26	8.4	6	1.9				5		5
11	8.7	3	194	22.3 ± 3.2	-	-				69	10	19
Subtotal	26.4	8	460	17.4 ± 5.9^{A}	21	0.8 ± 1.0^{C}	0	4		131	19	36
Bogue Chitto River												
12	4.5	3	31	6.7 ± 4.4	15	3.3 ± 1.7				60		
13	10.4	2	55	5.2 ± 1.3	28	2.6 ± 1.1				12	2	
14	4.5	3	71	15.8 ± 5.4	47	10.4 ± 3.4	10	1		29		
15	12.6	3	129	10.2 ± 3.6	98	7.8 ± 4.9	23			50	2	1
16	5.3	3	22	12.4 ± 1.2	31	5.8 ± 1.2	2			9		
17	5.8	1	48	8.28	22	3.8	12			13		1
Subtotal	43.1	15	356	8.7 ± 5.2^{B}	241	6.1 ± 3.8^{A}	47	1		173	4	2
Pushepatapa Creek												
18	13.4	4	-	-	19	1.4 ± 0.3	1		1	17	1	
19	1.4	1	-	-	1	0.7						
Bogue Lusa Creek												
20	2.2	1	-	-	-	-				3		
21	4.4	4	-	-	-	-		3		77	2	17
Coburn Creek												
22	1.3	1	1	0.8	-	-				12		2
Subtotal	22.7	11	1	0.07 ± 0.2^{C}	20	0.6 ± 0.7^{C}	1	3	1	109	3	19
Total	141.4	52	1911	14.0 ± 15.2	418	3.1 ± 3.3	915	12	1	591	27	80

Table 2. Captures of Ringed Sawbacks (*Graptemys oculifera*) and Pearl Map Turtles (*Graptemys pearlensis*) by site, species, life stage, and mark-resight population estimates at six sites in Louisiana, USA, May-June 2020 and 2021. The abbreviations CPUE = catch per unit effort, Pop. = population, and CI = 95% confidence interval. An asterisk (*) indicates a population estimate that was not estimable because zero individuals were resighted and the symbol -- means no turtles were observed.

Site	Species	# Male	# Female	# Juveniles	Total	Trap Days	CPUE	Pop. Estimate/ rkm (CI)	Minimum Alive
2	*G. oculifera*	8	10	2	20	2.5	8.0	140 (97–220)	173
	G. pearlensis	1		1	2	2.5	0.8	23 (8–353)	18
3	*G. oculifera*	6	3	2	11	2.5	4.4	158 (76–480)	49
	G. pearlensis		1		1	2.5	0.4	3.2 (2–41)	4
4	*G. oculifera*	13	7		20	1.5	13.3	108 (77–171)	105
	G. pearlensis	1	3	2	6	1.5	4.0	86.1 (22.7–1449)	21
7	*G. oculifera*	11	5	7	23	3.0	7.7	49 (33–84)	54
	G. pearlensis	2		2	4	3.0	1.3	5.7 (3.7–15)	10
9	*G. oculifera*	9	7		16	1.5	10.7	67 (45–112)	86
	G. pearlensis	1			1	1.5	0.7	*	4
11	*G. oculifera*	4	15	2	21	2.0	10.5	74 (54–113)	89
	G. pearlensis				0	2.0	0.0	--	--
Total	*G. oculifera*	51	47	13	111	13	8.5		
	G. pearlensis	5	4	5	14	13	1.1		

the Pearl River (including East/West Pearl), Bogue Chitto River, and WPRNC (Fig. 2). I also observed them in three previously undocumented drainages, including two tributaries of the Pearl River (Bogue Lusa Creek, UF 193427, and lower Coburn Creek [no photo voucher]) and one tributary of the Bogue Chitto River (Silver Springs Creek, UF 193428, 193445). For new drainage records, these add about 8.4 additional rkm occupied for the species in the state based on the nearest known localities.

I documented *G. pearlensis* in the Pearl and Bogue Chitto rivers, as well as in the northern and central WPRNC sites (Fig. 3). I observed *G. pearlensis* in four previously undocumented drainages, all tributaries of the Bogue Chitto River (Bonner, UF 193431; Deer Lick, UF 193432; Hays, UF 193433; and Silver Springs, UF 193434 creeks). I also documented a major range extension (i.e., an observation of an individual upstream/downstream of known localities) of *G. pearlensis* when I observed a male in Pushepatapa Creek near the Mississippi state line (UF 193435); this is about 26 rkm upstream of the record reported by Carr and Messinger (2002) near Varnado, Louisiana (Washington Parish). Including new drainage records and range extensions, this equates to about 65.7 additional rkm occupied for the species in the state based on the nearest known localities.

Basking density surveys.—I completed 141 rkm of basking density surveys at 22 stream and river sites; this includes the six mark-resight survey sites and 16 additional survey locations. At all locations and for all survey counts summed, I made 4,080 turtle observations (Table 1). The most abundant species observed during these surveys in rank order were *G. oculifera* (46.8%; 1,911 observations), followed by *A. mutica* (22.4%; 915), *P. concinna* (14.4%; 591), *G. pearlensis* (10.2%; 418), *T. scripta* (2.0%; 80), *S. carinatus* (0.7%; 27), Spiny Softshell Turtle (*Apalone spinifera*; 0.3%; 12), and Chicken Turtle (*Deirochelys reticularia*; one in Pushepatapa Creek; < 0.1%). I could not identify to species the turtles in the other 125 turtle observations (3.1%), which consisted of unknown *Graptemys* (0.7%; 27), unknown emydids (1.5%; 63), unknown *Apalone* (< 0.1%; 3), and unknown turtles (0.8%; 32).

For *G. oculifera*, the mean basking density for all 52 surveys at 22 sites was 14/rkm (range from 0–79/rkm; Table 1). Excluding four sites where they did not occur (sites 18–21), mean basking density was 17/rkm (range from 0.7–79/rkm). In the Pearl River, densities were high (> 40/rkm) in the northern portions of Washington Parish and decreased to moderate levels in middle sections (12–30/rkm), and I found low densities (< 12/rkm) in the lower Pearl River (Table 1). The southern range limit of *G. oculifera* was extended in both the East and West

Pearl rivers. In the West Pearl, I observed individuals south of U.S. 90 on the West Pearl (UF 193430), and this is about 10.7 rkm south of previously reported individuals observed near Interstate 10 (Jack McCoy and Richard Vogt, unpubl. report). In the East Pearl, I observed individuals south of Interstate 10 (UF 193429), and this is about 7.3 rkm south of previously reported individuals near Napoleon, Mississippi (Jones and Selman 2009).

Compared to *G. oculifera* densities in the Bogue Chitto River, densities of *G. oculifera* in the Pearl River were greater, and densities also changed along the length of the Bogue Chitto River; densities were low in the upstream segments, moderate in the middle segments, and decreased to low densities again in the downstream segments nearer the confluence with the Pearl River (Table 1). In the WPRNC, I consistently observed moderate densities of *G. oculifera*, but they were about 20–25% lower than neighboring, unmodified sections of the Pearl/West Pearl rivers. Densities of *G. oculifera* were different among the four drainage units compared ($\chi2$ = 34.2, df = 3, $P < 0.001$; Table 1). Wilcoxon nonparametric multiple comparisons *post-hoc* analyses indicate that densities of *G. oculifera* were highest in the Pearl River and WPRNC, and these densities were higher than densities observed in the Bogue Chitto and minor tributaries; densities in the Bogue Chitto were higher than in minor tributaries.

For *G. pearlensis*, basking density counts at the same 22 sites averaged 3.1/rkm (range from 0–13/rkm; Table 1). Excluding six sites where *G. pearlensis* did not occur, basking densities were 4.0/rkm (range from 0.5–13/rkm; Table 1). *Graptemys pearlensis* densities did not exceed *G. oculifera* densities at any site except the two Pushepatapa Creek sites where *G. oculifera* was absent. Densities of *G. pearlensis* were low throughout the mainstem Pearl and East/West Pearl, and the highest densities never exceeded 5.8/rkm at any Pearl River site. Further, *G. pearlensis* densities were approximately 8× lower than densities of *G. oculifera* at the same locations (sites 1–8). Their downstream distribution on the East Pearl was found to be near Napoleon (Hancock County, MS) and similar to the previously reported downstream limit (Selman 2016). The downstream limits in the West Pearl appear to be near Porter River, also similar to the previously reported downstream limit (Lindeman 2013).

Densities of *G. pearlensis* in the Bogue Chitto were low in the upstream segments, were at moderate densities in the middle segments, and decreased to low densities again in the downstream segments. Overall, densities of *G. pearlensis* were the highest in Louisiana at the Bogue Chitto River sites, and their densities more closely matched *G. oculifera* densities at these sites (Table 1). I found very low densities of *G. pearlensis* at two sites of the WPRNC, and they were absent from a third WPRNC site. Densities were about 80% lower in canal sections than neighboring sections of the Pearl and West Pearl rivers. Densities of *G. pearlensis* were different among the four drainage units compared ($\chi2 = 26.7$, df = 3, $P < 0.001$). Wilcoxon nonparametric multiple comparisons *post-hoc* analyses indicated that densities of *G. pearlensis* were higher in the Bogue Chitto River compared to the Pearl, WPRNC, and minor tributaries; densities were greater in the Pearl compared to the WPRNC and minor tributaries, but there was no difference between the latter two groups.

Trapping and mark-resight population estimates.—I trapped 111 *G. oculifera* at six sites over 13 trap days, and I captured males, females, and juveniles at almost all sites. The trapping results varied by site (Mean Capture Per Unit Effort [CPUE]: 8.5/trap day; site range from 4.4–13.3/trap day; Table 2). The highest CPUE was at a site in the West Pearl River, but the CPUE at two WPRNC sites was also high (Table 2). The lowest CPUE was on the Pearl River in Washington Parish downstream of the town of Bogalusa.

Similar to basking density surveys and trapping efforts, mark-resight population estimates for *G. oculifera* also varied across the six study sites (mean estimate: 89/rkm; range from 49–158/rkm; Table 1). The highest population estimates were for the two northernmost sites in the Pearl River (northern Washington Parish), while the lowest population estimate was in the lower East Pearl River (southeastern St. Tammany Parish; Table 2). Lower estimates were also found for both WPRNC sites (Table 2). Based on the length of the WPRNC (30 rkm) and the two similar population estimates I derived from two locations on the WPRNC (67 and 74/rkm), I extrapolated that approximately 2,100 *G. oculifera* (CI: 1,350–3,390) occur in the WPRNC. One incongruence I observed was the moderately high estimate observed at site 3, a site with the lowest minimum alive estimate of the six sites (Table 2), lowest CPUE, and a site with moderate basking densities (Table 1). This site also had the largest confidence interval of any of the six mark-resight locations.

I captured only 14 *G. pearlensis* in 13 d of trapping (mean CPUE: 1.1/trap day; range from 0–1.3/trap day; Table 2). Males, females, and juveniles were represented at only one of the six sites, and CPUE was low to very low at all sites. Collectively, CPUE was 8× lower than that of *G. oculifera*. The highest CPUE was at a site in the West Pearl River (4.0/trap day). At the low end of the spectrum, in the WPRNC, I trapped only a single individual at one site and no *G. pearlensis* were captured or seen during basking surveys at another site (Table 2). Because I captured and paint marked so few turtles, and few of those individuals were resighted, there is less confidence in the population estimates for *G. pearlensis* compared to the *G. oculifera* estimates (Table 2). Two reliable estimates (i.e., with relatively narrow confidence limits) were made for sites 3 (1.1/rkm) and 7 (5.7/rkm). Estimates from two additional sites (2 and 4) were higher, but the confidence intervals were broader (Table 2). Minimum alive estimates ranged from 4–21 for *G. pearlensis*, much lower than the 49–173 for *G. oculifera* at the same sites.

Discussion

***Current status of* Graptemys oculifera**.—Combining results of point count and basking density surveys, *G. oculifera* populations occurred at moderate to high densities throughout the main stem of the Pearl River and most of the Bogue Chitto River. I also found the species in three tributaries of the Pearl River where it previously had not been reported, and farther south in the Pearl River than previously reported. The range extensions were small and densities were low in these stretches (e.g., southern range extensions in the East and West Pearl rivers), and these additions to the range add little to the population status of the species in Louisiana or in its overall distribution. Compared to prior studies in the range, basking densities of *G. oculifera* in the Pearl River of northern Washington Parish (42–44/rkm) were similar to the second largest population sampled in Mississippi by Jones (2017; Lakeland, 49/rkm) and similar to sites upstream and downstream of Jackson, Mississippi (Selman 2020; 45–52/rkm). Five of six downstream sites in the lower Pearl River and the WPRNC (Table 1) were similar to the two lowest density populations sampled in Mississippi by Jones (2017; e.g., Carthage, 16/rkm; Columbia, 14/rkm), as well as two urban sections of the Pearl River adjacent to the city of Jackson (Selman 2020; 11.7–20.6/rkm).

At the WPRNC sites, I found higher *G. oculifera* densities than previously reported by Dena Dickerson and Kevin Reine (unpubl. report; Bogue Chitto Sill site: 3.2–15.7/rkm), but WPRNC densities were lower than the middle and upper Pearl River sites in Louisiana. It is unknown if the higher densities I observed compared to observations by Dena Dickerson and Kevin Reine (unpubl. report) within the WPRNC represent real population increases or if the differences are associated with survey methodology (i.e., slightly different methods or different surveyor experience level). It seems possible that my values may represent a real increase given the high number of juveniles observed at one site on the WPRNC (pers. obs.). Because sandbars are lacking along the WPRNC, this suggests that females are using alternative nesting sites at these locations.

In the Bogue Chitto River, *G. oculifera* basking densities observed at all six sites (mean: 8.7/rkm; range: 2–22/rkm) were almost double those described by Keri Landry and Beau Gregory (unpubl. report; mean: 4.7/rkm; range: 1.5–8.6/rkm). They are nearly identical to what was observed >20 y ago by Steve Shively (unpubl. report; mean: 8.7/rkm; range from 4–17/rkm). It is unknown if the densities I observed represent a population rebound to former densities or a difference in survey techniques and/or experience among the three surveyors. Nonetheless, one consistent similarity to both studies (Steve Shively, unpubl. report; Keri Landry and Beau Gregory, unpubl. report) was that I also observed lower densities in the Bogue Chitto River in the upper sections compared to middle and lower sections. Considering the continued gravel mining in the region, *G. oculifera* populations should be monitored into the future using similar replicate surveys as used in this study. Alternatively, while difficult due to limited boat navigability, mark-resight surveys of populations in the Bogue Chitto would be valuable to control for potential biases by surveyors or by environmental differences that are also known to influence basking densities (Waters 1974; Shealy 1976; Selman and Qualls 2011).

Mark-resight population estimates for this study were similar to or less than previous estimates reported for *G. oculifera* in the Mississippi portion of their range. The largest estimated population in Louisiana (site 2: 138/rkm) was similar to mark-resight population estimates described for *G. oculifera* about 93 rkm upstream in Columbia, Mississippi (146–151/rkm; Selman and Jones 2017); however, the highest Louisiana estimate was considerably lower than described for two sites in Mississippi (Carthage: 245/rkm; Ratliff Ferry: about 1,170/rkm; Jones and Hartfield 1995). The estimates for three sites, one on the East Pearl River and two on the WPRNC, were lower than any site in Mississippi described by mark-resight estimation to date. Uncertainty in one of the site estimates (site 3) is evidenced in the large confidence intervals. This population estimate was less certain than the other five mark-resight locations due to the lower number of resighted individuals during surveys and the relatively low number of individuals I could capture and mark at this location. Along with the lower capture success, I also observed low basking densities at this site. Even though the two WPRNC sites had lower population estimates than other Pearl River sites (with the exception of the East Pearl River), these populations should not be considered insignificant as the extrapolation of population estimates indicate that at least 1,350 individuals could occur in the WPRNC. Because the WPRNC is an artificially constructed habitat (i.e., subsidized habitat), the additional individuals occupying it improves the overall *G. oculifera* population in Louisiana. Therefore, the high CPUEs at these sites are misleading, and do not appear to be due to high densities. Rather it was likely due to the small number of basking logs and the subsequent concentration of basking turtles on the few logs available to them. A higher concentration on these logs made it easier to catch turtles in comparison to a location with high snag density and low concentration of basking turtles, a situation where turtles can easily avoid basking trap logs.

***Current status of* Graptemys pearlensis**.—Combining the results of point count and basking density surveys, *G. pearlensis* was found throughout the Pearl and Bogue Chitto Rivers, portions of the WPRNC, and a few smaller tributaries. In most of these drainages, however, *G. pearlensis* occurred in low to very low densities, and they occurred in much lower densities relative to *G. oculifera*. Within the Bogue Chitto River, the species achieved moderate densities (mean: 6.1/rkm; range from 1.3–13/rkm), and they are generally higher than those observed in the mainstem Pearl River system (Lindeman et al. 2020; this study). The densities I found suggest that the Bogue Chitto River appears to be the stronghold for the species in the state.

I also documented *G. pearlensis* in four additional tributaries of the Bogue Chitto River (about 65.7 rkm). Populations in these streams appeared to be present at very low densities (likely < 0.5/rkm), and therefore, they contribute little to the overall *G. pearlensis* population in Louisiana or the rangewide population estimate. Furthermore, small populations like those found in these tributaries are more vulnerable to extirpation due to random or stochastic events (demographic, environmental, genetic, or natural catastrophes; Shaffer 1981; Lacy 2000), especially if they are dependent upon source populations in the major rivers. Nonetheless, they do provide additional redundancy and a so-called safe harbor if catastrophic events occur in other parts of the river system.

Within the Pearl River, *G. pearlensis* basking densities are generally at the lower end of densities reported to date (Lindeman 1998; Selman and Jones 2017; Lindeman et al. 2020; Selman 2020). At site 2 (about 4/rkm), *G. pearlensis* densities were similar to mainstem Pearl River sites in Mississippi and Louisiana described by Lindeman et al. (2020; 0.3–16.1/rkm), but they were greater densities in comparison to the urban population (Jackson, Mississippi) sampled by Selman (2020; 0.4–3.2/rkm). Sites in the middle and lower Pearl River in Louisiana are near the lower end of the density spectrum reported for the urban Mississippi sites reported by Selman (2020) and the Pearl and West Pearl river sites (0.6–2.6/rkm) reported by Lindeman et al. (2020). Furthermore, *G. pearlensis* densities at two WPRNC sites were similar to densities reported by Dena Dickerson and Kevin Reine (unpubl. report) for a site they surveyed (Bogue Chitto Sill site; 0–1.1/rkm), and the WPRNC is of lesser global importance to *G. pearlensis* populations compared to its importance for *G. oculifera*.

I do not know why *G. pearlensis* densities are low in the Pearl River (inclusive of East and West Pearl) and WPRNC compared to other parts of the drainage. It is possible that industrial/municipal effluents and/or high sedimentation from upstream have impacted *G. pearlensis* populations through their pollution-sensitive food base of mollusks and aquatic insects (Vučenović and Lindeman 2021). A recent freshwater mussel survey in Mississippi indicates that mussel diversity in the Pearl River has declined compared to historic collections (pre-1976), and that mussel densities in the Pearl River have declined dramatically over the last century; for the latter, Robbie Ellwanger et al. (unpubl. report) noted that mussel beds in the Pearl River previously supported a button industry in the early 1900s, but this would be impossible today. Urban Pearl River sites in central Mississippi described by Selman (2020) have historically and contemporaneously been contaminated by sewage and industrial effluent, and densities of *G. pearlensis* there were low to very low. Thus, water quality issues and loss of benthic mollusk species could be a potential explanation for Louisiana sites having similarly low *G. pearlensis* densities. Also, altered hydrologic regimes may be impacting *Graptemys* species due to the regulation of the Pearl River upstream at the RBR and the regulation by the WPRNC locks. Selman and Jones (2017) found that *G. pearlensis* populations downstream of the RBR were all declining over 27 y, with two downstream populations exhibiting significant declines (Lakeland and Columbia sites), while a site upstream of the RBR remained stable. Lastly, numerous *G. pearlensis* individuals, particularly reproductive females, were collected from Louisiana for the pet trade over the last 20–25 y (Will Selman and Carl Qualls, unpubl. report). Some collection restrictions exist in Mississippi, but no protection status extends to the species in the Louisiana portion of the Pearl River system (Selman and Jones 2017). Because the Pearl River is easily accessible to collectors working via boats, it is possible that the lower densities observed in the Pearl River may be a legacy effect of past or current collection pressures due to the slow population recovery in a long-lived turtle species (Congdon et al. 1993; Pitt and Nickerson 2013).

To date, there have been no mark-resight population estimates made for *G. pearlensis*, so there are no intrapopulational comparisons that can be made. The only similar estimate for a megacephalic *Graptemys* species is for *G. gibbonsi* (Pascagoula Map Turtle), the sister species and ecological analog to *G. pearlensis* from the Pascagoula River system (i.e., *G. gibbonsi* has similar life-history and behavioral characteristics). Selman and Qualls (2009) reported population estimates for *G. gibbonsi* to be 34–44/rkm at a site on the upper Leaf River, and this estimate is considerably higher than estimates for *G. pearlensis* reported herein (mean: about 8/rkm; 1–23/rkm). For an ecologically similar species from the Pascagoula River in Mississippi (Selman and Lindeman 2015), *G. gibbonsi* capture success and basking density observations were also higher than what I observed in this study, and all the data collectively seem to suggest smaller *G. pearlensis* densities compared to *G. gibbonsi* densities, and this confirms similar findings by Lindeman et al. (2020). Some of the *G. pearlensis* estimates calculated herein, however, should be viewed with some caution due to the inability to capture a large enough sample for resighting (i.e., a rare species that is difficult to capture) and the large confidence intervals observed around the estimates.

Threats, conservation, and management.—There are numerous conservation challenges with the Pearl River system of Louisiana. Gravel mining is a major industry in southeastern Louisiana, particularly along the length of the Bogue Chitto River in Washington and St. Tammany parishes (Steve Shively, unpubl. report). In the late 1990s, these mining operations were considered to be the biggest concern for *Graptemys* in the Bogue Chitto River (Steve Shively, unpubl. report). Based on my observations >20 y later, I agree that gravel mining is still the biggest threat to the riverine habitats of *Graptemys* in southeastern Louisiana. In several locations near the Bogue Chitto River, I observed high sediment loads in smaller streams near current and former gravel mining operations. High sediment loads are often associated with the declines or extirpation of mussel populations (Williams et al. 2008; Österling et al. 2010; Goldsmith et al. 2021), primary prey items of *Graptemys* species.

Along with active gravel mining, remnant gravel pit lakes (i.e., former active gravel pits) near stream channels are looming threats to the Bogue Chitto River system and several smaller creek systems. When gravel pits were originally constructed, they may have been far away (> 50 m) from a river or stream channel; however, because river channels meander over time, many of these gravel pit lakes eventually connect to the river (hereafter, bank breaks). Bank breaks can lead to massive destabilization of the river channel at certain points (as seen in Google Earth time lapse imagery northwestern Washington Parish; 30.94696°N, -90.20324°W), and it is unknown how bank break events may destabilize riverine processes including riverine sediment distribution, flow patterns, or aquatic food webs (i.e., the benthic organisms consumed by *Graptemys* species). It seems likely that the densities of generalist species may increase in gravel mining areas, while specialists may not be as adaptable to these altered settings. Indeed, several studies have found that generalists (e.g., Painted Turtle, *Chrysemys picta*, Snapping Turtle, *Chelydra serpentina*, and *T. scripta*) readily inhabit abandoned gravel pits, with densities in gravel pits sometimes exceeding natural habitats (Bernstein and Christiansen 2011; Hollender and Ligon 2021). Bernstein and Christiansen (2011), however, found that a habitat specialist for shallow water, the Yellow Mud Turtle (*Kinosternon flavescens*), was absent from gravel pit habitats and preferred natural wetlands in Iowa, USA. Therefore, future research should assess aquatic processes and benthic fish/invertebrates along the Bogue Chitto River in control and gravel mining impacted sections to determine the effects on both generalist and riverine-specialist turtle species.

Along with gravel mining, two local inhabitants offered information to me about turtle harvesting that was occurring in local waterways. Based on these conversations, wild turtles are still being captured and collected in the Pearl River system of Louisiana for the pet trade, and at least one of them indicated collection methods that were consistent with capturing *Graptemys* species. Corroborating my anecdotal information, Easter et al. (2023) documented 54 illegal turtle trade cases, and four cases had starting locations in Louisiana and 5–6 cases had ending locations in Louisiana. Of the 54 cases, at least nine of these involved *Graptemys* species; there was no differentiation among *Graptemys* species with this study, likely due to the difficulty in determining species identification by law enforcement personnel. Many of the turtles collected are destined for China and possibly other southeastern Asian countries as part of a high-end market for pet turtles, a market that has rendered the turtle fauna of some countries commercially or ecologically extinct (Rhodin et al. 2018). Furthermore, the number and scale of illegal trade cases have increased over the last 20 y, with many cases including IUCN Threatened turtle species (Easter et al. 2023).

Because sandbars are important nesting areas for *Graptemys* in the Pearl River (Jones 2006), off-road vehicles (ORV) can be major sources of nest mortality of river turtle nests, sometimes even higher than natural forms of nest mortality (Godwin et al. 2021). In the Pearl River system of Louisiana, I commonly observed ORV tracks and other vehicle tracks along sandbars. I also observed people riding ORVs in the stream channel of Pushepatapa Creek, a Louisiana Scenic Stream, as well as ORV trails crossing entire stream channels. These types of activities negatively impact benthic invertebrates (Evans 2002), many of which are prey items consumed by both *Graptemys* species. It seems likely that ORV use will continue to grow in the Pearl River watershed into the future, and this increase will be associated with growing recreational demand by a growing human population that has increased 10–15% along the Interstate-10 corridor in southeastern Louisiana between 2010 and 2020 (https://www.census.gov/geographies/reference-files/time-series/geo/gazetteer-files.html).

The Pearl River also has been subjected to numerous municipal/industrial effluents over the last 100 y, and *Graptemys* populations in the Pearl River system may have been impacted from these events directly or indirectly (Selman 2020). Given the lower densities of both *Graptemys* species from downstream locations, it seems possible that the lower segment of the Pearl River has impaired water quality. Indeed, there have been at least three documented spills from the paper mill in Bogalusa that have occurred (https://www.nola.com/news/environment/article_fba9ebb2-7518-503c-a630-cb82a876fff3.html [accessed 6 July 2021]). A report from a 2011 spill indicated that *G. oculifera* were killed by the spill (https://www.enn.com/articles/43132-louisiana-paper-mill-spill-causes-massive-fish-kill [accessed 6 July 2021]). Along with direct mortality, paper mill effluent has been implicated in sex hormone disruption and lower reproductive viability of *Graptemys* species (Shelby et al. 2000; Shelby and Mendonça 2001, Horne et al. 2003). Many environmental contaminants also have been shown to be maternally transferred to offspring through contaminant deposition in egg yolk (Hopkins et al. 2013). I recommend that future studies investigate chemical loads in turtles from upstream and downstream populations with respect to the paper mill.

Along with the Pearl River, Bogue Lusa Creek, a tributary of the Pearl, may also be connected to this impacted area, as it is adjacent to the paper mill. Lindeman (2019) did not document *G. pearlensis* in this stream at two locations, and I also did not find the species in this stream at two basking density survey locations and 10 point count locations. Qualitatively, Bogue Lusa Creek, upstream of the town of Bogalusa, appears similar to several smaller streams that are occupied by *G. pearlensis*. Thus, the absence of *G. pearlensis* from Bogue Lusa Creek is an enigma. One explanation is that the Great Southern Lumber Company sawmill (founded in 1908 along the banks of Bogue Lusa Creek and later the location of the paper mill) may have caused spills into the creek from the early to mid-1900s that went unreported. Thus, Bogue Lusa Creek was likely impaired for decades prior to the Clean Water Act of 1972. Indeed, Goodyear (1950) indicated there was almost an inexhaustible supply of sand and gravel from the streambed of Bogue Lusa Creek that was suction dredged from the streambed for concrete construction. Additionally, there are two water-control structures (weirs) near the mill that may limit connectivity of *G. pearlensis* populations between the Pearl River and Bogue Lusa Creek. One or a combination of these effects may have impacted connectivity and metapopulation dynamics of *G. pearlensis*. Interestingly, I found *G. oculifera* individuals in Bogue Lusa Creek downstream of the paper mill, and this, along with their higher densities in the WPRNC, seems to suggest that *G. oculifera* appears more tolerant of environmental perturbations relative to *G. pearlensis*. Indeed, Selman (2020) also found more *G. oculifera* compared to *G. pearlensis* in urban stretches of the Pearl River near downtown Jackson, Mississippi.

Because this is the first study to assess the distribution and abundance of both species throughout the Pearl River system in Louisiana, future research should replicate mark-resight surveys to determine the long-term trends of both species. This effort would provide data similar to the long-term studies conducted by R.L. Jones in Mississippi (Jones 2017). Research should also focus on why densities are different along the length of the river, particularly how water quality/sediment loads throughout the Pearl River relate to *Graptemys* densities, how prey densities are different among river segments, and how gravel mining interacts with prey availability and turtle densities.

From a management perspective, if *G. pearlensis* is listed under the U.S. Endangered Species Act, the Bogue Chitto River should be considered critical habitat along with a second area identified by Lindeman et al. (2020) in the upper Pearl River of Mississippi (Leake County). Additional regulations should be considered on gravel mining operations that occur near rivers or tributaries, as well as their floodplains (e.g., larger streamside management zones near mining operations, no new mining pits within the floodplains of large waterways). Lastly, additional education/outreach and law enforcement efforts are needed to curb the take of turtles from the wild (both intentional and bycatch) and also to prevent excessive ORV use on nesting sandbars and in streambeds of southeastern Louisiana.

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