FINAL REPORT

South Carolina State Wildlife Grant F21AF03593-02

South Carolina Department of Natural Resources
Grant Active Period: 1/1/2022 – 6/30/2024
Reporting Period: 1/1/2022 – 6/30/2024

Project Title: Occupancy and Distribution of SWAP Listed Freshwater Mussel Species

Summary: Freshwater mussels from the order Unionida are unique organisms that live discreetly in the substrate of rivers and lakes yet hold both historical and ecological significance for the freshwater ecosystems of the world. Serving as a crucial trophic link between the water column and the benthos, they help support the ecosystems in our rivers and lakes (Vaughn and Hakenkamp, 2001). Unfortunately, mussel populations throughout North America have been declining across the country in the last century. The causes for this decline are complex, but anthropogenic at their source. Pollution, channel modifications, and invasive species introductions are a few of the factors responsible for the deterioration of mussel populations (Williams et al., 1993). In 2022, South Carolina was home to 26 SWAP listed mussel species, 13 of which were highest priority SGCN, marked with an * below.

Alewife Floater (*Anodonta implicate*)
Altamaha Archmussel (*Alasmidonta arcula*)
Atlantic Pigtoe (*Fusconaia masoni*)*
Atlantic Spike (*Elliptio producta*)
Barrel Floater (*Anodonta couperiana*)*
Brook Floater (*Alasmidonta varicosa*)*
Brother Spike (*Elliptio fraterna*)*
Carolina Creekshell (*Villosa vaughaniana*)*
Carolina Elephantear (*Elliptio congaraea*)
Carolina Heelsplitter (*Lasmigona decorata*)*
Carolina Lance (*Elliptio angustata*)
Creeper (*Strophitus undulatus*)*
Eastern Creekshell (*Villosa delumbis*)
Eastern Elliptio (*Elliptio complanata* complex)
Eastern Lampmussel (*Lampsilis radiata*) / Rayed Pink Fatmucket (*Lampsilis splendida*)
Eastern Pondmussel (*Ligumia nasuta*)
Eastern Rainbow (*Villosa modioliformis*)*
Northern Lance (*Elliptio fisheriana*)
Notched Rainbow (*Villosa constricta*)*
Pod Lance (*Elliptio folliculata*)
Roanoke Slabshell (*Elliptio roanokensis*)
Savannah Lilliput (*Toxolasma pullus*)*
Tidewater Mucket (*Leptodea ochracea*)
Triangle Floater (*Alasmidonta undulata*)*
Variable Spike (*Elliptio icterina complex*)
Waccamaw Spike (*Elliptio waccamawensis*)*
Yellow Lampmussel (*Lampsilis cariosa*)*

Since the 2015 SWAP was written, several unionid mussel name changes were recognized by the Freshwater Mollusk Conservation Society (FMCS) due to published research on genetics, morphology, locality, etc. Moving forward the following mussels will be referred to as their most recently recognized names:

Alewife Floater (*Utterbackiana implicata)*
Barrel Floater (*Utterbackiana couperiana*)
Carolina Creekshell (*Sagittunio vaughanianus*)
Eastern Pondmussel (*Sagittunio nasuta*)
Eastern Rainbow (*Villosa vibex*)
Notched Rainbow (*Venustaconcha constricta*)
Tidewater Mucket (*Atlanticoncha ochracea*)
Waccamaw Spike (*Elliptio congaraea*); this species (*E. waccamawensis* in 2015) was synonymized with *E. congaraea*. Elliptio congaraea was a moderate priority SGCN, the synonymy of *E. waccamawensis* results in the species being a moderate conservation priority SGCN.

There is a need for the South Carolina Department of Natural Resources to effectively manage and conserve Freshwater Mussel populations to continue to meet the expectations of the public as well as maintain the viability of the freshwater mussels within the State. Many freshwater species, including freshwater mussels, lack distribution and survey information for baseline data. An update on the occupancy and distribution of the SWAP listed mussel species is needed for South Carolina to help conserve the freshwater mussels of the State and develop management plans for species recovery efforts.

The purpose of this project was to provide updated distribution data on SWAP listed species to update the Natural Heritage Database and inform management decisions. This project was accomplished, in part, by completing 45 catch per unit effort (CPUE) field survey sites for freshwater mussels. Catch per unit effort was calculated for all species at all sites using the following equation:

$$CPUE = \frac{\#\ of\ individuals\ of\ a\ single\ species}{(surveying\ hours * surveyors)}$$

Sites covered a minimum 100m of stream length. General habitat data was collected at all sites and most sites had observational data recorded (but see significant deviation 1 for more information). Individual mussels were collected through visual and tactile searches. Once collected, target individuals were held in a mesh collection bag until sampling was completed. All highest priority individuals were measured (mm), tagged, and photographed. All data was recorded and submitted to the Natural Heritage Database for statewide management.

Objective A: Conduct 40 investigations of SWAP listed mussel species by 2023 – Fish and Wildlife Species Data Acquisition and Analysis

Specific investigation: Provide distribution data on SWAP listed species through Catch Per Unit Effort surveys and collect genetic swabs of Highest Priority Species for archival storage.

Accomplishments: Site selection, landowner outreach, and freshwater mussel CPUE surveys were completed for a total of 45 field sites across the state of South Carolina. Field sites were selected based on historical occupancy of highest priority SWAP species with priority given to sites in HUC 10 watersheds with no records or records more than 20 years old and sites that were surveyed for native fishes during the 2006-2011 South Carolina Stream Assessment. Table 11 lists all field sites that were

surveyed during the life of the grant, the justification of the selection process, the coordinates of the sites, and comments associated with the site visited. All live animals were collected, entered into the freshwater unionid mussel CPUE database with pictures and shell condition information when needed, and placed back into suitable habitat. All data from field survey sites, including general habitat data of the site, were uploaded to the Natural Heritage Preserve database.

Results

In summary, surveying efforts across 45 field sites yielded a total of 5,667 individual mussels representing 15 different species across 8 different basins (Tables 2-9). Only 10 individuals of SWAP species of highest priority were collected, with 8 being collected from the Savannah River Basin sites. A total of 22 sites had 0 mussels found with most sites being in the Broad River Basin. There were 17 genetic swabs collected during surveys (Table 10).

Broad

The Broad River basin resulted in only 18 individuals of the Eastern Creekshell (*Villosa delumbis*), a moderate priority SGCN, being collected (Table 2). Of the 9 sites visited, 5 were selected from the SC Stream Assessment survey points and 4 were selected because of historical observations of highest priority SGCN species. No surveys conducted at chosen survey sites resulted in the targeted species being collected. No genetic swabs were collected but 1 vouchered *V. delumbis* male was collected and stored. Five of the sites were dominated by sand substrate; the site where animals were found was dominated by coarse gravel and cobble. Many sites visited had similar habitat degradation concerns as those sites in the Catawba (see below for more information).

Table 2. Number of individuals and calculated CPUE for each unionid mussel species found at each survey site within the Broad River basin. Table shows highest priority SWAP listed species that occupy small streams (notated with an *) and unionid mussel species found at other field sites.

		A. varicosa*	E. angustata	E. complanata	E. congaraea	E. folliculata	E. icterina	E. producta	E. roanokensis	L. cariosa*	L. decorata*	P. cataracta	S. undulatus*	S. vaughnianus*	T. pullus*	U. carolinianus	U. couperiana*	U. imbecillis	V. constricta*	V. delumbis	V. vibex*
BRO001	# ind																				
	CPUE																				
BRO002	# ind																				
	CPUE																				
BRO003	# ind																				
	CPUE																				
BRO005	# ind																				
	CPUE																				
BRO006	# ind																				
	CPUE																				
BRO007	# ind																				
	CPUE																				
BRO008	# ind																				
	CPUE																				

BRO041	**# ind**																		18	
	CPUE																		4.46	
BRO042	**# ind**																			
	CPUE																			

Catawba

A total of 7 sites were surveyed in the Catawba River Basin and 254 mussels representing 4 different species were collected. There were 3 sites that resulted in no unionid mussels being collected. One site was selected from the SC Stream Assessment survey points and 6 were selected because of historical occupancy of highest priority SGCN. Only 1 site with historical occupancy of a SGCN resulted in that species being collected again (CAT031), and this was the only highest priority SGCN individual collected throughout the Catawba River Basin survey sites. Sites CAT031 and CAT044 had the highest species diversity with 3 species represented during sampling. Four genetic swabs were collected from the Catawba basin survey sites and stored for future use (Table 10). Observations at sites in the Catawba River Basin show habitat degradation due to urbanization across the watershed but especially in York and Chester Counties. Streams in these areas are dominated by sand, incised, and have steep banks. Normal rain events in these areas result in extreme flow, leaving debris trapped in trees 8-12ft above base flow conditions (Figure 1a). Several streams were noted as having no riparian buffer and allowing livestock to enter streams (Figure 1b). One *S. vaughanianus* was swabbed for genetic analysis at site CAT031. A total of 3 more *S. vaughanianus* swabs were collected from the Catawba River Basin but were collected at sites associated with a different study (Table 10). In January 2023 all *S. vaughanianus* genetic swabs collected from the Catawba River Basin were transferred to the North Carolina Wildlife Resource Commission for use in a genetic analysis. Results are not yet available.

Figure 1. Habitat degradation noticed by a) debris trapped roughly 10 ft above base flow after a normal precipitation event and b) clearcut pasture with no riparian buffer and livestock entering stream.

Table 3. Number of individuals and calculated CPUE for each unionid mussel species found at each survey site within the Catawba River basin. Table shows highest priority SWAP listed species that occupy small streams (notated with an *) and unionid mussel species found at other field sites.

		A. varicosa*	E. angustata	E. complanata	E. congaraea	E. folliculata	E. icterina	E. producta	E. roanokensis	L. cariosa*	L. decorata*	P. cataracta	S. undulatus*	S. vaughnianus*	T. pullus*	U. carolinianus	U. couperiana*	U. imbecillis	V. constricta*	V. delumbis	V. vibex*
CAT031	# ind			8	1									1							
	CPUE			3.2	0.4									0.4							
CAT033	# ind																				
	CPUE																				
CAT034	# ind																				
	CPUE																				
CAT039	# ind			24																	
	CPUE			5.1																	
CAT043	# ind			201																	
	CPUE			38.5																	
CAT044	# ind			12	1															6	
	CPUE			3.2	0.3															1.6	
CAT099	# ind																				
	CPUE																				

Edisto

There was one field site visited in the Edisto River Basin. The site was selected from the SC Stream Assessment survey points. The stream was narrow and swampy before feeding into a mill pond. No freshwater unionid mussels were found (Table 4). This may be due to the small size which may dry during periods of drought. It could also prove unsuitable for host fish, minimizing mussel distribution instream.

Table 4. Number of individuals and calculated CPUE for each unionid mussel species found at each survey site within the Edisto River basin. Table shows highest priority SWAP listed species that occupy small streams (notated with an *) and unionid mussel species found at other field sites.

		A. varicosa*	E. angustata	E. complanata	E. congaraea	E. folliculata	E. icterina	E. producta	E. roanokensis	L. cariosa*	L. decorata*	P. cataracta	S. undulatus*	S. vaughnianus*	T. pullus*	U. carolinianus	U. couperiana*	U. imbecillis	V. constricta*	V. delumbis	V. vibex*
EDI001	# ind																				
	CPUE																				

Pee Dee

The Pee Dee River basin survey sites resulted in the most individuals of freshwater mussels observed with a total of 2,043 animals collected across 13 field sites (Table 5). Six sites were selected based on the SC Stream Assessment survey points and 7 were selected because of historical observations of highest priority SGCN. No surveys conducted at chosen historical sites resulted in the targeted species being collected. There were 7 field sites that did not result in any freshwater mussels being collected. Four of the sites that did not have any unionid mussels found had historical observations of freshwater mussel species. No highest priority SGCN were collected at the Pee Dee River Basin survey sites. Sites where no unionid mussels were found varied and some (e.g. PEE050, PEE054) seemed as though mussels should be there based on physical habitat observed at the date of sampling. Site PEE010 had the most diversity and abundance of freshwater mussels compared to any other site sampled during the grant. A total of 1,585 animals were collected during the survey and 6 species were represented (Table 5). The site was heavily connected to the floodplain and had mixed silt, clay, and sand substrate which provided mussels with stable, unshifting substrate. Site PEE061 was close to PEE010 and exhibited the same habitat conditions but had a deeper midchannel and presumably swifter current. Not many unionid mussels were found in the midchannel of PEE061. Both PEE061 and PEE010 had an abundance of fishes noted.

Table 5. Number of individuals and calculated CPUE for each unionid mussel species found at each survey site within the Pee Dee River basin. Table shows highest priority SWAP listed species that occupy small streams (notated with an *) and unionid mussel species found at other field sites.

		A. varicosa*	E. angustata	E. complanata	E. congaraea	E. folliculata	E. icterina	E. producta	E. roanokensis	L. cariosa*	L. decorata*	P. cataracta	S. undulatus*	S. vaughnianus*	T. pullus*	U. carolinianus	U. couperiana*	U. imbecillis	V. constricta*	V. delumbis	V. vibex*
PEE009	# ind															1					
	CPUE															0.2					
PEE010	# ind		24	1451	74	2	14	20													
	CPUE		3.2	196.1	10.0	0.3	1.9	2.7													
PEE011	# ind																				
	CPUE																				
PEE013	# ind																				
	CPUE																				
PEE014	# ind			96			7									2					
	CPUE			36.1			2.6									0.8					
PEE047	# ind																				
	CPUE																				
PEE050	# ind																				
	CPUE																				
PEE051	# ind																				
	CPUE																				
PEE053	# ind			3																	
	CPUE			0.7																	

PEE054	**# ind**																				
	CPUE																				
PEE055	**# ind**																				
	CPUE																				
PEE057	**# ind**			1																	
	CPUE			0.6																	
PEE061	**# ind**			132	5	11	174									26					
	CPUE			8.5	0.32	0.71	11.23									1.68					

Salkehatchie

There were 2 field sites visited in the Salkehatchie River basin; one was chosen for historical occupancy of *Utterbackiana couperiana* (SAK003) and the other was chosen from the SC Stream Assessment survey points (SAK004). Site SAK003 had higher diversity and abundance of freshwater mussels but both sites had dense, active populations of freshwater mussels (Table 6) with numerous age classes being found. Both sites were heavily connected to the floodplains and were more swamp-like in habitat. The substrate was a mix of fines and sand which resulted in stable, unshifting substrates. An abundance of unionid mussel shells were collected at both sites. Shells were transported to the North Carolina Museum of Natural Sciences for species verification, and this proved difficult. Some animals did not fit a singular species profile. For instance, individuals collected that externally looked like *Elliptio angustata* did not have the internal psuedocardinal and lateral teeth of *E. angustata*. This could be an adaptation to the soft substrate and stagnant flow conditions, or these shells could represent a species that has not yet been recognized in South Carolina. Sites in swamp-like habitats have been largely under-sampled in South Carolina due to hazardous conditions, and it is likely that some species have not been observed until now. No highest priority SGCN were collected at either survey site. It was noted that the *Villosa delumbis* that were collected at SAK004 appeared to all be males which causes skepticism in their identification, and these could be a more common species such as *Elliptio icterina*. The external shell coloring did not offer assistance as waters were tannic and almost all shells were black in color regardless of species. At both sites, the banks were low and the surrounding floodplains were intact with mature trees. An abundance of macroinvertebrates, fishes, turtles, snakes, and birds were seen at these sites.

Table 6. Number of individuals and calculated CPUE for each unionid mussel species found at each survey site within the Salkehatchie River basin. Table shows highest priority SWAP listed species that occupy small streams (notated with an *) and unionid mussel species found at other field sites.

		A. varicosa*	**E. angustata**	**E. complanata**	**E. congaraea**	**E. folliculata**	**E. icterina**	**E. producta**	**E. roanokensis**	**L. cariosa***	**L. decorata***	**P. cataracta**	**S. undulatus***	**S. vaughnianus***	**T. pullus***	**U. carolinianus**	**U. couperiana***	**U. imbecillis**	**V. constricta***	**V. delumbis**	**V. vibex***
SAK 003	**# ind**		135	430	340		60									8		6			
	CPUE		13.99	44.56	35.23		6.22									0.83		0.62			
SAK 004	**# ind**			571			30									1				19	
	CPUE			50.98			2.68									0.09				1.7	

Saluda

Four sites in the Saluda River Basin were surveyed for freshwater mussels and 3 of the 4 resulted in collections. A total of 262 mussels were collected representing 6 different species (Table 7). All survey sites within the Saluda were chosen based on historical occupancy of highest priority SGCN species; however, no targeted species were collected during surveys. Site SAL013 had the most diversity and abundance of freshwater mussels. The site was downstream of a pond and managed by the SC Forestry Commission. The site had many dense mussel beds that formed in complex sand and cobble substrates near both banks. Mussels were found in the midchannel of this site in stable substrates often between large boulders. Site SAL015 had no mussels found in the survey area and was dominated by sand. There was a singular, old, *Elliptio complanata* mussel found upstream of the survey site. Although two mussels were found at SAL041, it was noted that based on the habitat conditions during the time of the survey, more mussels were expected.

Table 7. Number of individuals and calculated CPUE for each unionid mussel species found at each survey site within the Saluda River basin. Table shows highest priority SWAP listed species that occupy small streams (notated with an *) and unionid mussel species found at other field sites.

		A. varicosa*	E. angustata	E. complanata	E. congaraea	E. folliculata	E. icterina	E. producta	E. roanokensis	L. cariosa*	L. decorata*	P. cataracta	S. undulatus*	S. vaughnianus*	T. pullus*	U. carolinianus	U. couperiana*	U. imbecillis	V. constricta*	V. delumbis	V. vibex*
SAL013	# ind		7	200	8		7									4					
	CPUE		0.71	20.24	0.81		0.71									0.40					
SAL015	# ind																				
	CPUE																				
SAL041	# ind			1																1	
	CPUE			0.29																0.29	
SAL051	# ind		1	27			4									2					
	CPUE		0.48	13.0			1.93									0.97					

Santee

Two sites were surveyed within the Santee River Basin and a total of 354 mussels representing 5 different species were collected (Table 8). Site SAN001 was selected from the SC Stream Assessment survey points and site SAN003 was selected because of historical observations of *Villosa vibex*. No highest priority SGCN were collected during surveying efforts. Both sites were dominated by sand and silt particles which provided stable substrates. Both sites had low to moderate banks that were connected to the floodplain and swamp-like in nature. At site SAN003, there were many individuals that did not fit a singular species description and were *Villosa*-like in shape but did not have the other *Villosa* characteristics, likely making them *Elliptio icterina*. Three genetic swabs of presumed *Villosa delumbis* and 2 genetic swabs of presumed *Elliptio icterina* were collected from SAN003 (Table 10). In January 2023, all *V. delumbis* genetic swabs collected from the Santee Basin were transferred to the North Carolina Wildlife Resource Commission for use in a genetic analysis. Results are not yet available. The *E. icterina* swabs are in storage for future analysis.

Table 8. Number of individuals and calculated CPUE for each unionid mussel species found at each survey site within the Santee River basin. Table shows highest priority SWAP listed species that occupy small streams (notated with an *) and unionid mussel species found at other field sites.

		A. varicosa*	E. angustata	E. complanata	E. congaraea	E. folliculata	E. icterina	E. producta	E. roanokensis	L. cariosa*	L. decorata*	P. cataracta	S. undulatus*	S. vaughnianus*	T. pullus*	U. carolinianus	U. couperiana*	U. imbecillis	V. constricta*	V. delumbis	V. vibex*
SAN001	# ind			2	7											58					
	CPUE			0.39	1.38											11.43					
SAN003	# ind			187	34		59													7	
	CPUE			39.0	7.1		12.3													1.5	

Savannah

The Savannah River Basin was the most diverse having 14 species collected across 7 sites; 2 sites had no unionid mussels collected (Table 9). Two field sites were selected based on historical occupancy of SGCN species and 5 sites were selected from the SC Stream Assessment survey points. A total of 8 highest priority SGCN individuals were collected from the Savannah field sites and 1 site, SAV040, resulted in a range expansion for the Brook Floater mussel (*Alasmidonta varicosa*). Site SAV040 is the southern-most point of collection to date for the Brook Floater mussel which has a distribution from South Carolina to Nova Scotia, Canada. Site SAV040 was also the most diverse site visited within the basin and was approximately 500m downstream of a low head dam. Through communication with the landowner, the dam has been maintained by the family for generations and they maintain a base flow downstream, even during periods of drought. Animals at this site were found throughout the stream from bank to bank, and the substrate was a heterogenous mix of fine particles, cobble, and gravel which provided animals with stability. The two sites where no mussels were collected were dominated by sand and coarse gravel (SAV010) and bedrock (SAV016) (see Table 11). A total of 7 genetic swabs were collected in the Savannah River Basin and stored for future use (Table 10). The Savannah Basin showed the highest diversity of SGCN collected, and a large portion of the watershed land is state or federally protected (Figure 3).

Table 9. Number of individuals and calculated CPUE for each unionid mussel species found at each survey site within the Savannah River basin. Table shows highest priority SWAP listed species that occupy small streams (notated with an *) and unionid mussel species found at other field sites.

		A. varicosa*	E. angustata	E. complanata	E. congaraea	E. folliculata	E. icterina	E. producta	E. roanokensis	L. cariosa*	L. decorata*	P. cataracta	S. undulatus*	S. vaughnianus*	T. pullus*	U. carolinianus	U. couperiana*	U. imbecillis	V. constricta*	V. delumbis	V. vibex*
SAV 010	# ind																				
	CPUE																				
SAV	# ind			57							1	4								2	2

012	**CPUE**			6.79							0.12	0.48							0.24	0.24
SAV 014	**# ind**			16	1						1		1						4	
	CPUE			0.31	0.3						0.02		0.02						0.04	
SAV 015	**# ind**			472				6								40			8	
	CPUE			43.42				0.55								3.68			0.74	
SAV 016	**# ind**																			
	CPUE																			
SAV 023	**# ind**			2															1	
	CPUE			0.38															0.19	
SAV 040	**# ind**	2	1	953					7	2						4			5	
	CPUE	0.17	0.09	81.04					0.60	0.17						0.34			0.43	

Discussion

Completion of this project allowed researchers to visit 25 historical occupancy survey sites and 20 survey sites that were selected from the SC Stream Assessment project across the State of South Carolina. Although only 10 individuals of highest priority SGCN were collected, we were able to collect updated general habitat condition parameters and occupancy data that can be used to aid in conservation and management efforts of freshwater mussel across the State. Observational data at sites where no mussels were found suggest that habitat degradation is of concern. Many sites where no mussels were found were surrounded by increasing urbanization or clearcut pastures, and most of them did not have adequate riparian buffers. A riparian buffer is the section of trees, woody plants, bushes, shrubs, grasses, and even downed vegetation adjacent to a waterbody that partially protects it from impacts from surrounding land use. Sites with no mussels were dominated by loose sand substrate which is not stable, especially during periods of increase flow. Banks were often steep, and evidence of extreme high flow was noted. Sites where an abundance of mussels were found had stable substrates and were often heavily connected to the surrounding floodplains or had adequate riparian buffers of old growth trees.

Freshwater mussels are an indicator species and are often the first taxa to be affected when pollutants are present in streams, and this may be why sites which seemed to have adequate habitat conditions did not result in the collection of mussels. Freshwater mussels and snails represent the most sensitive taxa in the EPA's 2013 criteria for ammonia, which resulted in a reduction of the acute criterion for total ammonia nitrogen being listed (USEPA 2013). Unionid mussels represented the top 7 most sensitive species to ammonia compared to other species tested which included species of freshwater fishes, other freshwater mollusks, freshwater amphibians, and other freshwater invertebrates (USEPA 2013). Although among the most sensitive taxa, tolerances vary across species and in 2013, only 17 species of freshwater mussels had ammonia toxicity testing. Ammonia in freshwater systems is naturally occurring; however, it is a common toxicant introduced at elevated concentrations through effluent discharge and agricultural, industrial, and urban runoff.

Copper is another toxicant that is naturally occurring in freshwater systems in trace amounts (0.2-30µg/L; Bowen et al. 1985); however, it becomes toxic to some organisms at elevated levels. Like ammonia, copper is introduced to freshwater systems through anthropogenic and industrial inputs and likely enters South Carolina systems from herbicide and algicide use (McKnight et al. 1983; Patterson et al. 1998). Copper toxicity testing using glochidia of 9 freshwater mussel species found that most 24-hour median effective concentrations (EC50s) for survival were <45µg Cu/L (Wang et al. 2007)

although more research is needed to determine acute and chronic lethal concentrations of copper, and other pollutants, to different species of unionid mussels.

Additional studies find mussels more sensitive than commonly tested fish and aquatic invertebrates to metals such as zinc, copper, chromium, nickel, cadmium, and mercury (Keller and Zam, Beckvar et al. 2000), acidification (Fuller 1974), and alachlor, chloride, potassium, and sulfate (Wang et al. 2017). Although it is undeniable that freshwater unionid mussels are sensitive to common pollutants, toxicity testing is still needed to determine species specific acute and chronic endpoints and behavioral and physiological effects from toxicant exposures.

Most pollutants enter freshwater systems due to anthropogenic and agricultural sources and this is exacerbated by increased runoff due to impervious surfaces (roads, buildings, parking lots, etc.), clearcutting of land that reduces contact time of runoff with vegetation, and disjunct or missing riparian buffers. Clearing riparian vegetation also destabilizes stream and riverbanks, allowing excessive siltation and destruction of instream mussel habitat.

Siltation is the accumulation of fine particles in water bodies which historically results from clearing land for agriculture and development, mining operations, and dam construction. In South Carolina, observational data suggests that siltation is largely attributed to clearcutting land for pasture and housing developments and mining operations. Like pollutants, the effects of siltation are exacerbated when impervious surfaces increase, cattle are allowed to enter streams, and sufficient riparian buffers are not maintained. Clearcutting in a substantial part of a watershed can also contribute to siltation, even if a riparian buffer is maintained due to exposed sediment and increased runoff. The use of motor vehicles and allowing livestock (e.g. cows) in streams and along banks can also degrade the stability of banks, stir up benthic sediments, and increase siltation. Factors that contribute to siltation can also change the topography of the stream or river by changing the slope of the bank and eliminating heterogeneity in the channel. Eliminating structural heterogeneity may also slow the flow of water and reduce its oxygen content, therefore harming species that require highly oxygenated water.

While this project allowed for updated distribution data and site habitat conditions, more work is needed to determine what may be the driving forces behind the noticeable decline of species diversity and SGCN across the State.

Significant deviations: The 2022 field season was abbreviated due to staffing turnover in the technician position in September 2022. In December of 2022 a new technician was onboarded and in January 2023 a new biologist joined the mussel program both of which began training on South Carolina mussel ID. We were able to complete the 40 field sites during the 2023 field season, but after visiting all 40 sites, many sites resulted in no SWAP listed species being found. We requested a six-month, no cost extension in December of 2023 to add 5 additional historic sites for S1 SWAP listed species in hopes of collecting updated occupancy data. In April 2024, the original project PI left the program, and the grant and project were taken over by the new SCDNR freshwater mussel program coordinator. Some anecdotal and observation data was lost during this transition (e.g., site conditions, mussel habitat preferences, specific comments on individual mussels, etc.).

Objective B: Develop 1 new research tool for Freshwater Mussels by 2023 – Conservation Techniques Development

Specific investigation: Use information from the first objective and existing data to develop a conservation planning map for prioritizing restoration efforts that will benefit SWAP listed mussel species.

Accomplishments: We were able to provide updated occupancy data to the Natural Heritage Program database which is used during environmental reviews for conservation and restoration priority planning. Figure 2 illustrates all survey sites visited during the life of the grant. Figure 3 shows the total number of unionid mussels collected at each field site, the number of SCGN species collected at the sites, and state and federally protected lands.

Significant deviations: This objective could not be completed until all field sites were surveyed; completion of field site surveys required the previously mentioned six month, no-cost extension.

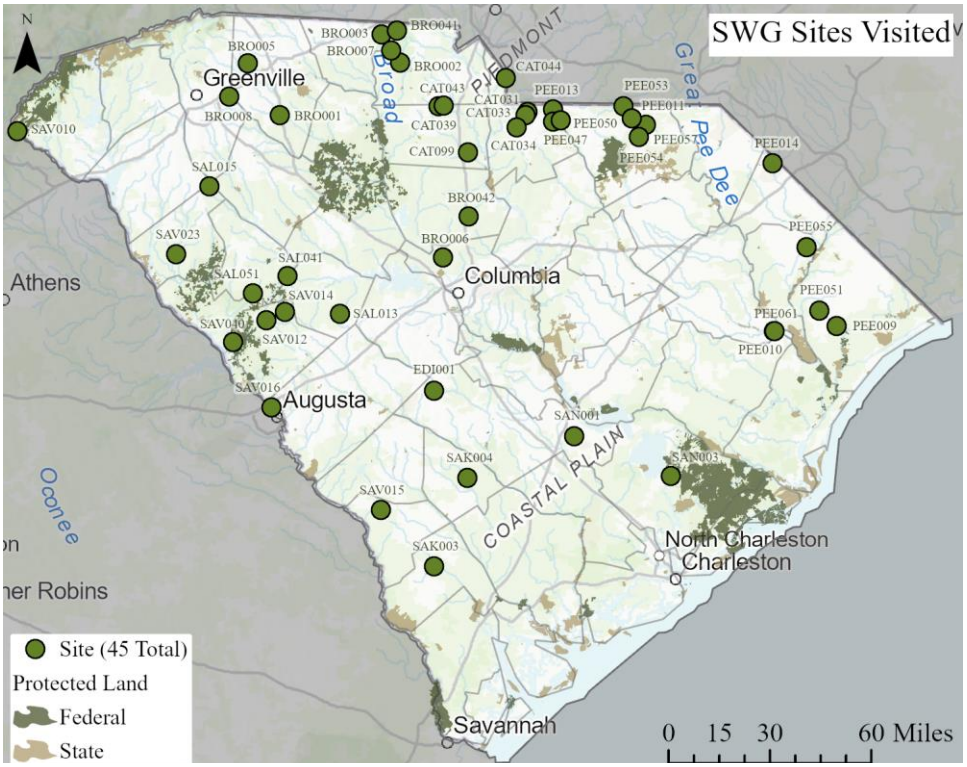

Figure 2. Map showing field sites visited during the life of the grant and state and federally protected lands.

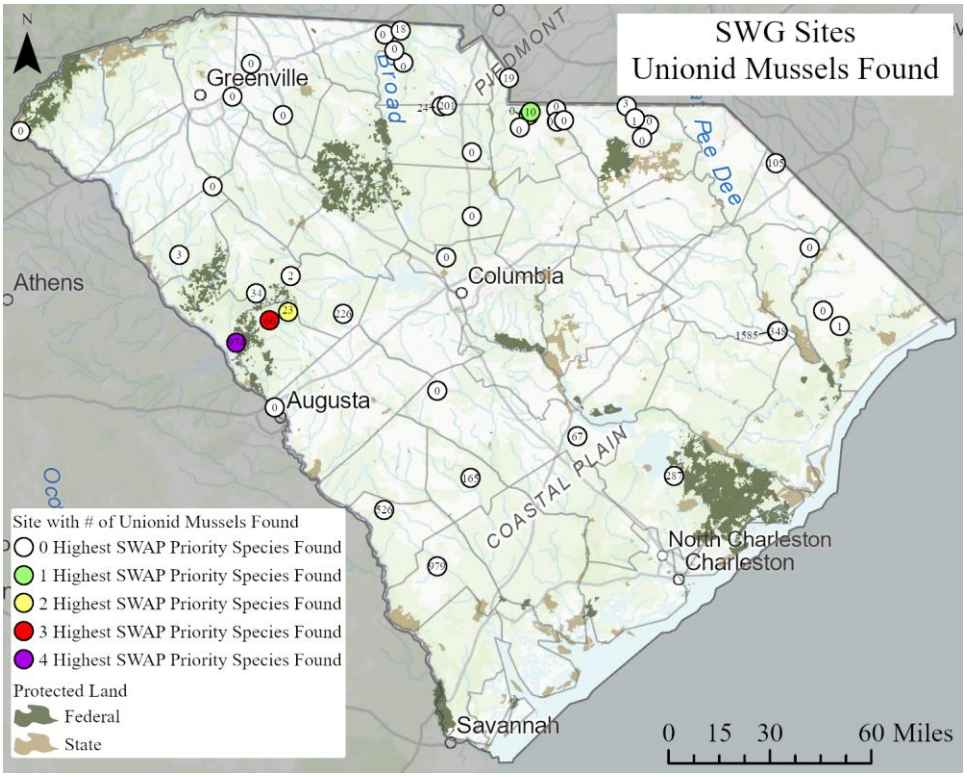

Figure 3. Map showing total unionid mussels collected at each field site, total number of SGCN collected at each site, and state and federally protected lands.

Literature Cited:

Beckvar, N., Salazar, S., Salazar, M., & Finkelstein, K. (2000). An in situ assessment of mercury contamination in the Sudbury River, Massachusetts, using transplanted freshwater mussels (Elliptio complanata). *Canadian Journal of Fisheries and Aquatic Sciences*, *57*(5), 1103- 1112.

Bowen, H. J. M., Frevert, T., Grant, W. D., Kratz, G., Long, P. E., & Kratz, G. (1985). Modelling the global carbon cycle. *The Natural Environment and the Biogeochemical Cycles*, 29-81.

Keller, A. E., & Zam, S. G. (1991). The acute toxicity of selected metals to the freshwater mussel, Anodonta imbecilis. *Environmental Toxicology and Chemistry: an International Journal*, *10*(4), 539-546.

McKnight, D. M., Feder, G. L., Thurman, E. M., Wershaw, R. L., & Westall, J. C. (1983). Complexation of copper by aquatic humic substances from different environments. *Science of the Total Environment*, *28*(1-3), 65-76.

Patterson, J. W., Minear, R. A., Gasca, E., & Petropoulou, C. (1998). Industrial discharges of metals to water. *Metals in surface waters*, 37-66.

South Carolina Department of Natural Resources (SCDNR). 2015. South Carolina State Wildlife Action Plan and Supplemental Volume. Columbia, South Carolina. <http://www.dnr.sc.gov/swap/>. Accessed 10/10/2024.

USEPA. (2013). Update if Ambient Water Quality Criteria for Ammonia. United States Environmental Protection Agency.

Vaughn, Caryn & Hakenkamp, Christine. (2001). The Functional Role of Burrowing Bivalves in Freshwater Ecosystems. Freshwater Biology. 46. 1431-1446. 10.1046/j.1365-2427.2001.00771.x.

Wang, N., Ingersoll, C. G., Hardesty, D. K., Ivey, C. D., Kunz, J. L., May, T. W., ... & Barnhart, M. C. (2007). Acute toxicity of copper, ammonia, and chlorine to glochidia and juveniles of freshwater mussels (Unionidae). Environmental Toxicology and Chemistry: An International Journal, 26(10), 2036-2047.

Wang, N., Ivey, C. D., Ingersoll, C. G., Brumbaugh, W. G., Alvarez, D., Hammer, E. J., ... & Barnhart, M. C. (2017). Acute sensitivity of a broad range of freshwater mussels to chemicals with different modes of toxic action. *Environmental toxicology and chemistry*, *36*(3), 786-796.

Estimated Federal Cost: $63,357.96 (January 1, 2022 – June 30, 2024)

Recommendations: Close the grant.

Prepared By: Ericah Beason, PI

APPENDIX…

Table 10. Genetic swabs collected from individuals during the grant. Note swabs taken at CHS study sites.

Date	Site ID	Genus	Species	Notes
9/16/2021	CAT030	Sagittunio	vaughanianus	Collected at CHS site
9/16/2021	CAT030	Sagittunio	vaughanianus	Collected at CHS site
9/16/2021	CAT030	Sagittunio	vaughanianus	Collected at CHS site
5/3/2022	CAT031	Sagittunio	vaughanianus	
6/2/2022	SAV012	Lasmigona	decorata	
8/31/2022	SAV014	Strophitus	undulatus	Collected at CHS site
9/21/2022	SAN003	Villosa	delumbis	
9/21/2022	SAN003	Villosa	delumbis	
9/21/2022	SAN003	Villosa	delumbis	
9/21/2022	SAN003	Elliptio	icterina	
9/21/2022	SAN003	Elliptio	icterina	
2/7/2023	Mountain Creek	Elliptio	complanata	Collected at CHS site
6/8/2023	SAV022	Villosa	delumbis	Collected at CHS site
6/8/2023	SAV022	Villosa	delumbis	Collected at CHS site
6/8/2023	SAV022	Villosa	vibex	Collected at CHS site
8/29/2023	SAV040	Alasmidonta	varicosa	
9/6/2023	SAV015	Villosa	delumbis	

Table 11. All mussel survey sites visited for the grant and associated site conditions.

Date	Site	Purpose	X	Y	Site Conditions
4/21/2022	BRO001	Stream Team Empty HUC10: Site 50560	34.7675663	-81.9652632	Water gauges close to base flow, chalky upstream of bridge, sandy bottom, murky water. Shifting sand. No life seen in stream.
4/5/2023	BRO002	Stream Team Random Site 19268	34.9966	-81.3405	Two V. delumbis shell found on hike. Mosquito fish, stone roller, salamander, crayfish, darters bluehead chub, dace. Corbicula, toads, and frogs.
6/7/2022	BRO003	Stream Team Empty HUC10: Site 5308	35.117192	-81.4383612	Corbicula, dragon fly. Bluegill, madtom, darter. Crayfish. Higher bed rock less in gravel.
7/26/2022	BRO005	Stream Team Random Site 19708; Empty HUC10	34.9881	-82.1351	Lots of sand with bedrock underneath, creek chub and bluegill, abundant corbicula.
8/3/2022	BRO006	S1 Historic; Intentional: S. undulatus	34.1625	-81.1145	Bream, darters, other fish. Many Corbicula and snails. Intermittent sandbar in wet width 3. Started above riffle just after bridge. Low embeddedness. Lots of fish darters shiner chub. Crayfish, snail collected.

4/5/2022	BRO007	Historic Intentional: vaughaniana	35.0484314	-81.3863306	9-foot banks, mixed cobble sand, some areas of shifting sand, some beaver dams, some exposed bedrock, looks flashy. Gravel Elima, crayfish, darters.
7/13/2023	BRO008	SWG: Stream Team	34.84634	-82.22975	Catfish, chubs, shiners, crawdads present. High banks and two riffles.
5/2/2024	BRO041	SWG: S1 Historic, S. vaughanianus	35.134104	-81.356	Fairly shallow. Lots of larger rocks and bedrock but with fine sediments throughout. Mussels typically found in slightly deeper locations with finer mixed sediments. Banks either undercut or bedrock. Delumbis had minimal rays.
5/8/2024	BRO042	SWG: S1 Historic, S. vaughanianus	34.339034	-80.981894	Lots of Hardpan clay and sand. Some corbicula. Visited after rain event. Very muddy. Hard clay. Lots of pockets.
5/3/2022	CAT031	SWG: S1 Historic; Intentional: vaughaniana	34.7846004	-80.6753962	Upstream from bridge site, shallow water, narrow stream, moderate banks, Walked downstream towards culvert, moderate undercut bank. V. vaughaniana found.
5/17/2022	CAT033	SWG: S1 Historic; Intentional: vaughaniana	34.7726305	-80.687917	Small creek. Some portions may run dry. Corbicula shells, crayfish, mosquito fish. Consolidated substrate. Looked like mussels should be here. Location at end of survey.
5/19/2022	CAT034	Intentional: vaughaniana	34.719708	-80.732291	Hannah's creek, intermittent sand bars and pools, upstream of old dixie road bridge.
5/25/2023	CAT039	Stream Team Random Site 42905; Possible S. vaughanianus	34.8114	-81.1391	Found freshwater shrimp, crayfish, darters, salamander larvae, tadpoles, small brim, turtle. Hole with many E. comp. 34.8140970, -81.1325536. V. delumbis shell.
4/26/2023	CAT043	S1 Historic; Intentional: S. vaughanianus	34.8135	-81.1136	Mostly sand on River Right. Last 2/3 of survey right side was consolidated clay with pit marks. Mussels were found packed in holes. Otter, crayfish, campeloma, pickerel. Mud turtle, water scorpion, gomphidae.
9/7/2023	CAT044	SWG: S1 Historic, S. vaughanianus	34.931186	-80.789867	Smelled like treated sewage water. Ericah has pics of site. Surveyed above natural dam. Brim, darters, crayfish, spotted gar. Most mussels found on river left.
5/30/2024	CAT099	SWG: S1 Historic, S. vaughanianus	34.612416	-80.984691	Very sandy. Deep in the middle. Clay sporting targets. Very loose sand. Incised banks. Corbicula and gravel elimia? Darters, crayfish, mason, burrowing dragonflies, tadpoles.

6/21/2022	EDI001	Stream Team Random: Site 284551	33.5901121	-81.1607936	Small. Walked downstream. Turns into swamp before mill pond.
7/18/2023	PEE009	SWG: Stream Team Site	33.852325	-79.089579	Invasive herbaceous vegetation. Lots of corbiculae, crawfish, small fish. Campeloma snail. One mussel found. Stream looks like it is regularly cut and mowed. Culverts present roughly every 50 yards. Site is disturbed and constantly dredged.
9/26/2023	PEE010	SWG: S1 Historic, S. vaughanianus	33.8345427	-79.4133811	Drove upstream of river and parked. Trek through muddy bog to river. Snakes. Big mosquitoes. Lots of mussels. Mussels found throughout. Hogchoker fish. Weird mussels.
7/14/2022	PEE011	S1 Historic; Intentional: V. constricta, S. undulatus	34.7268	-80.0616	River Right Bank was clay and rough bedrock. Somewhat turbid.
6/14/2022	PEE013	Intentional vaughaniana	34.7970574	-80.5420386	Crayfish, shiners sunfish. Corbicula shell. Near bridge almost dry. Deeper further upstream. Tannic water.
7/12/2022	PEE014	Stream Team Random Site 91717	34.5566	-79.4061	Small creek downstream of dam. Runs dry according to landowner.
5/9/2023	PEE047	S1 Historic; Intentional: V. constricta	34.7437	-80.5418	Started above riffle just after bridge. Low embeddedness. Lots of fish darters shiner chub. Crayfish, snail collected.
6/29/2023	PEE050	S1 Historic; Intentional: V. constricta	34.7498	-80.502	Darters, salamanders, chub, shiners, crayfish, snails, shrimp, madtom, shallow, no shells, corbicula, bedrock under sand.
5/11/2023	PEE051	Stream Team Random site 219819	33.9195	-79.1745	One U. carolinianus shell. Many mosquito fish, possible pickerel, crayfish, and frogs. Ditched swamp. Dug out over winter 2022 for bridge replacement. Small berms possibly manmade created 30m pools. Upstream of bridge.
8/2/2023	PEE053	SWG: Stream Team	34.8078259	-80.1753097	Darters mosquitofish crayfish. Banks tall, hardpan clay midchannel bars. Uniomerus downstream of bridge
5/24/2023	PEE054	Stream Team Random Site 69005	34.674	-80.0985	Crawfish, sunfish, mating scorpions, half eaten catfish, ton of beetles, water striders. Lots of larval fish (shiners or chub likely). No unionid. No Corbicula. Cottonmouth on bank.

5/17/2023	PEE055	Stream Team Random Site 163545	34.1918	-79.2367	Crayfish, leech, studfish, turtle present, braided channel, small creek, back of woods, low elevation. Did not sample River Left of braid or deep parts, straight system.
4/20/2023	PEE057	S1 Historic; Intentional: V. constricta	34.756	-80.1335	Darters, crayfish. Corbicula. Young comp found wedged in bedrock. Clear cut on River Left. Additional 2 E. comp and possible U. carol on walk back to bridge. Mostly sand until survey site, small patch of mixed cobble. A couple of large log jams.
6/13/2024	PEE061	SWG: S1 Historic, S. vaughanianus	33.835209	-79.408048	Lots of mussels on banks. Could not sample first 40 meters of river right bank - too mucky. Lots of Corbicula in middle stream. More complanata in 2nd portion of survey. Took vouchers. Very connected to floodplain
7/25/2023	SAK003	Historic: U. couperiana	32.8371911	-81.1606291	Eel. Softshell turtle, gar, tons of corbiculae and snails. At parts of survey shells made up part of the substrate. Mosquitofish, sunfish. Lots of bugs.
7/26/2023	SAK003	Historic: U. couperiana	32.8371911	-81.1606291	Finished the rest of the 100m survey. Snails (collected campeloma) , mosquitofish, lots of corbiculae. Tannic water. Cottonmouth (water moccasin). Braided channel surrounded by swamp. Low banks. Found more mussels at this site than other site even and was not entirely covered.
8/22/2023	SAK004	SWG: Stream Team	33.21517	-80.98949	All presumed delumbis were male (may be comp). Smooth, sloping banks that connect to floodplain. Mussels evenly distributed through survey, but large amounts found a meter and in from the bank.
6/6/2023	SAL013	S1 Historic; Intentional: T. pullus	33.9188	-81.6471	Baby bream present. Molluscivorous activity. Dragonflies and sunfish present. Mussel beds in complex sand gravel and crevices between large boulders.
8/1/2023	SAL015	SWG: S1 Historic	34.45953	-82.3278	Broad Mouth Creek, SWG, Abbeville. 1.3km hike in. Property with road on side and pump station.
5/16/2024	SAL041	SWG: S1 Historic, S. vaughanianus	34.079817	-81.918155	Nice site. One side of bank undercut. Would expect more mussels. Some shells present. Corbicula, crayfish, darters, salamanders. Water chem probe not working. Bedrock substrate near bridge. Looks flashy.
4/19/2024	SAL051	SWG: S1	34.00344	-82.094034	Muddy by bridge, mussels near banks.

		Historic, L. decorata			
5/18/2022	SAN001	Stream Team Random: Site 315425	33.3926297	-80.4433057	Shallow, little current, sandy and silty bottom, moderate banks, narrow. Initial view bucket, changed to hand grubbing, crayfish, many types of snails, some snail shells were collected.
9/21/2022	SAN003	S1 Historic; Intentional: V. vibex	33.2209	-79.9502	Braided channel chose the right channel facing upstream and surveyed past the first beaver dam. Villosa esqe animals and alasmidonta esqe animals but could all be complanata. Tagged animals placed on banks.
6/9/2022	SAV010	Stream Team Random: Site 61059	34.6820178	-83.3279123	Upstream of confluence of Brasstown Creek and Tugaloo River. Surveying Brasstown Creek. Some shifting sand. Some trees crossing stream.
6/2/2022	SAV012	Intentional: Alasmidonta undulata, S. undulatus	33.8894711	-82.023506	Downstream of 25 bridge, end of survey at least 50m downstream of affluent culvert.
8/31/2022	SAV014	Stream Team site 220793	33.925	-81.9308	Upstream of Meeting Street bridge.
9/6/2023	SAV015	SWG: Stream Team	33.07914	-81.43117	Miller Creek. David contact, "visit whenever".
6/28/2023	SAV016	Stream Team Random Site 295697; Intentional: close to F. masoni	33.5145	-81.9944	Catfish, smallmouth bass, and other species were present. Shiners, chubs. High gradient, shifting sand near confluence. No evidence of mussels.
8/17/2023	SAV023	SWG: Stream Team	34.1651869	-82.495765	All mussels found in bank grubbing. Complanata were confirmed to be less than half long as they were high. Sunfish, Shiners, darters, tadpoles. Asian clam.
8/24/2023	SAV040	SWAP E. producta	33.79191	-82.193923	Most mussels found in middle of stream, there was a five-meter section that was too deep to survey. Half of Bri's lane grubbed. Small sunfish and darters. Delumbis were found in muddy banks. Turtle.
8/29/2023	SAV040	SWAP E. producta	33.79191	-82.193923	Finished the last 53 m of 8/24/23 survey.