Distribution of Freshwater Bivalves in the Canoochee River Drainage, Georgia

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Abstract: The Canoochee River originates in the Southern Coastal Plain of Georgia and flows through the Coastal Flatwoods to terminate at the Ogeechee River. The Canoochee Drainage is the largest tributary of the Ogeechee River and is a fifth-order woodland stream. Investigators surveyed 83 sites for freshwater bivalve presence, noting species and counting individuals. We analyzed water chemistry parameters including nitrate nitrogen, total inorganic nitrogen, total dissolved phosphate, and total dissolved copper. Multiple linear regression (MLR) analysis indicated mussel densities and catch per unit of effort to be positively correlated with nitrate nitrogen concentrations and pH even though mussel densities are low on the Canoochee River Drainage. We found highest densities of mussels in the Canoochee River as well as in Wolfe Creek.

Key Words: mussels, bivalves, coastal plain, blackwater, mollusks, unionid

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Over 75% of North America's freshwater mussel (Bivalvia: Unionidae) species are recognized as imperiled, primarily due to habitat degradation (Williams *et al.* 1993). Historically, the North American freshwater mussel fauna was the richest in the world, probably at one time exceeding 300 species (Williams *et al.* 1993). The southeastern United States has more species than any other region in North America totaling 80% of the mussel fauna (Burch 1975). Freshwater mussels were once a major part of the southeastern aquatic faunal diversity (Keferl 1993). Unfortunately, this fauna is in decline with 7% of the species considered extinct, 40% considered endangered or threatened, 24% of special concern, 24% stable, and about 5% undetermined (O'Brien and Williams 2002). Schilling and Williams (2002), as well as McCullagh *et al.* (2002) found that the decline of freshwater mussel species is due to habitat loss and degradation, sedimentation, increases of nutrients, contaminants, and creation of impoundments. Mussel communities in much of North America have been modified extensively by water quality and physical habitat degradation in the 20th century (Williams *et al.* 1993).

The Canoochee River is a blackwater, tannic acid river that originates in the Atlantic Coastal Plain Physiographic Province of Georgia. This system contains high concentrations of tannins derived from tree roots and decaying vegetation from adjacent riverine swamp areas. The Canoochee River is the largest tributary of the Ogeechee River, spans 164.5 km, and is a fifth-order woodland stream. This system drains low pH/alkalinity Pleistocene sands and clays of the Coastal Plain and is dominated by agriculture in its upper reaches. The Canoochee River meanders into forestland as it approaches and passes through the Coastal Flatwoods zone. The river flows through an ephemeral swamp forest and is described by Lewis and Turtora (1998) as having predominantly sand channel-bed substrates.

Stream environments are highly susceptible to human disturbances (Gillies *et al.* 2003), and habitat destruction is a primary reason for mussel species loss in many southeastern streams (Williams *et al.* 1993). In 2004, the Canoochee River drainage had 13 waters listed on the U.S. Environmental Protection Agency's 303D impaired waterways list. Impairments listed included: low dissolved oxygen, organic enrichment, fecal colliform, and fish contamination with heavy metals (*http://oaspub.epa.gov/pls/tmdl/huc_rept.control?p_huc=03060203&p_huc_desc=CANOOCHEE,* 2004), and these may have been affecting invertebrate occurrence throughout the drainage.

Although several freshwater mollusk surveys have targeted the Ogeechee River Basin, no inventories have been conducted of the Canoochee River Basin. Johnson (1970) published a summary of all the Unionidae in the entire southern Atlantic Slope region from Virginia to Florida. He summarized what was known about the distribution of mussels in the Ogeechee River system from museum records. Fuller (1973) reported the Atlantic pigtoe *(Fusconaia masoni)* from the Ogeechee River system, but did not report any other species. Alderman (1991) also surveyed a small part of the Ogeechee River for the Atlantic pigtoe. According to the historical records, 15 Unionid species have been reported from the Ogeechee River Drainage (Table 1).

Between 2001 and 2002, Sukkestad *et al*. (in press) found 11 species of freshwater mussels on Fort Stewart Military Installation, seven of which are listed in the historical record (Table 1). In 2003, Savannah lilliput *Toxolasma pullus,* (Conrad, 1838) was added to the list of species found on Fort Stewart bringing the total to 12 native species (J. D. Williams, U.S. Geological Survey, pers. commun.). By 2004, 10 species of bivalves had been found outside of Fort Stewart boundaries. These species were: *Uniomerus carolinianus* (Bosc, 1801); *Elliptio congaraea* (I. Lea, 1831); *Elliptio icterina* (Conrad, 1834); *Elliptio lugubris* (I. Lea, 1834); *Elliptio complanata* form *conferta* (I. Lea, 1834); *Elliptio congaraea* form *corvus* (Lea, 1859); *Pisidium dubium* (Say, 1817); *Musculum partumeium* (Say, 1822); *Musculum lacustra* (Müller, 1774) and *Utterbackia imbecillis* Say, 1829.

Table 1. Listed below are the Unionidae species found in the Ogeechee River basin.

Species	Historical[a]	2001[b]	2002[b]	2003[c]
Subfamily Unioninae				
Fusconaia masoni (Conrad, 1834)	X			
Elliptio angustata (I. Lea, 1831)	X		X	
Elliptio complanata (Lightfoot, 1786)	X			
Elliptio complanata form *conferta* (I. Lea, 1834)			X	X
Elliptio congaraea (I. Lea, 1831)	X		X	X
Elliptio congaraea form *corvus* (I. Lea, 1859)			X	X
Elliptio folliculata (I. Lea, 1838)	X			
Elliptio icterina (Conrad, 1834)	X	X	X	X
Elliptio lugubris (I. Lea, 1834)		X	X	X
Elliptio producta (Conrad 1836)	X			
Uniomerus carolinianus (Bosc, 1801)	X	X	X	X
Subfamily Antodontinae				
Alasmidonta undulata (Say, 1817)	X			
Anodonta couperiana (I. Lea, 1840)		X	X	
Pyganodon cataracta (Say, 1817)	X	X	X	
Utterbackia imbecillis (Say, 1829)	X	X	X	X
Subfamily Lampsilinae				
Villosa delumbis (Conrad, 1834)	X	X	X	
Villosa vibex (Conrad, 1834)	X			
Lampsilis cariosa (Say, 1817)	X			
Lampsilis splendida (I. Lea, 1838)	X			
Toxolasma pullus (Conrad, 1838)				X[3]

a. Records modified from Johnson (1970) and Alderman (1991).

b. Records modified from Sukkestad *et al.* (in press).

c. Records modified from J. D. Williams (U.S. Geological Survey, pers. commun. 2004).

The Canoochee River upstream of Fort Stewart has not been surveyed systematically for unionids. The purpose of this study was to survey all swamps, creeks, streams, and rivers in the Canoochee Drainage for freshwater bivalves, and to assess water quality variables that may affect their distribution. We hypothesized that freshwater bivalve diversity as well as abundance would be low due to the tannic acid nature of the Canoochee Drainage. Also, we expected increased species richness in a downstream direction (Haag and Warren 1998), as well as absence of and/or decline in species richness and abundance where impacts from municipalities were evident (Strayer 1983).

Methods

Unionid Survey

During the summer season of 2003, we surveyed 83 sites in the Canoochee River Drainage including: Wolfe, Canoochee, Reedy, Hughes Prong, Flat and Cedar creeks. Also, we surveyed the North Prong Canoochee, South Prong Canoochee, and the Canoochee River upstream of Fort Stewart, Georgia (Fig. 1). Abundance and diversity of mussels were determined and compiled into the database for the entire Ogeechee River System. Because a drainage wide initiative was considered, we chose a two-stage sampling regime as suggested by Strayer and Smith (2003). The premise is based upon large-scale population estimates where population estimate is determined by how many sites are sampled rather than how many quadrats are sampled within a site. We surveyed habitats to include: swamps, ponding areas, small streams, and larger order river segments. We sampled approximately 300 m^2 transects both up and downstream of all bridge crossings beginning at the bridges. Sampling was variable among sites. Mussel density as number per $meter^2$ (N/m^2), and catch per unit effort (CPUE = N/h^1) were determined. Sampling effort was focused on all sites that were characterized by highly variable substrates, and we spent little time at ephemeral sites or those with hardpan clay substrate.

We detected mussels by visually searching in shallow water for mussel siphons, collecting shells, and hand picking or "noodling" for mussels in the organic and bank side habitats of waters <1 m deep. In deeper waters, modified clam and garden rakes were used to examine the substrate for mussels. Because most mussels were found in unconsolidated sediments in protected areas near banks, our efforts were focused in these locations. We counted and identified all mussels using the keys of Davis and Mulvey (1993), Burch (1975), and Watters (2001). Also, mussels were identified using Turgeon *et al.* (1998). We obtained latitude and longitude data using a hand-held Garmin E-Trex GPS.

Water Quality Analysis

We measured alkalinity by using the bromcresol indicator / 1.8N sulfuric acid titration procedure provided in the HACH FF2–Fish Farming Kit at each site. Ambient water temperature, specific conductance, dissolved oxygen, total dissolved solids, pH, and turbidity were measured at each site using a Hydrolab Quanta. This unit was calibrated monthly. Total dissolved phosphorous (TDP), total inorganic nitrogen, nitrate nitrogen (NO_3-N), and copper (Cu) metal concentrations of grab samples taken at field sites were measured using the HACH DR4000 spectrophotometer. We used water quality data to construct a multiple linear regression model where mussel density was regressed against the water quality variables at $\alpha = 0.05$ significance level (Zar 1999, Daniel and Terrell 1995). We selected water quality variables based upon what was logistically feasible for our field analysis. Also, we wanted to investigate how municipal water treatment and agricultural practices might affect mussel abundance and species richness through out the drainage. These variables are traditional indicators of eutrophication and pollution in freshwater systems (Reynolds and Guillaume 1998, McKinney *et al.* 2001).

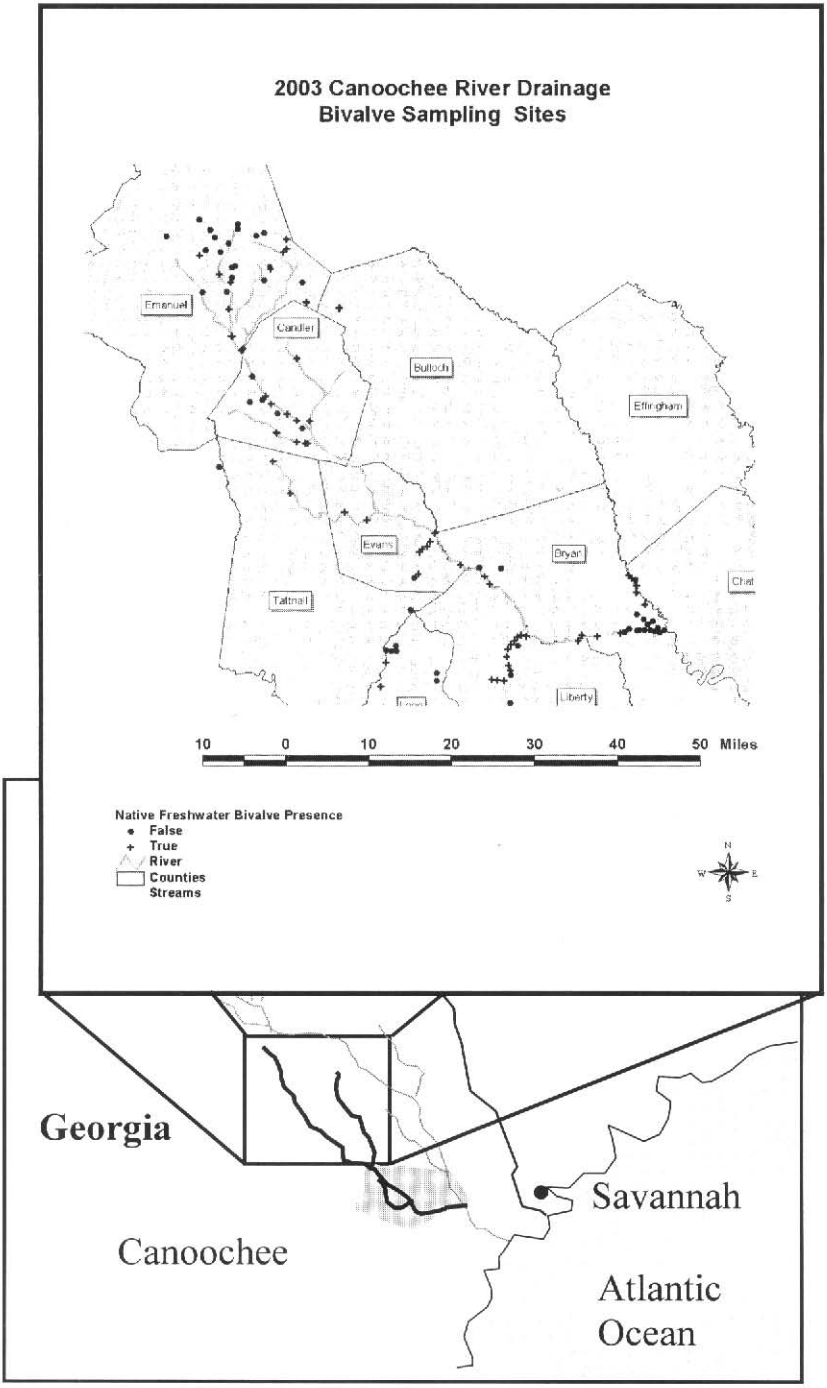

Figure 1. Sites for the Canoochee Drainage Inventory, 2003. Dots indicate sites where no bivalves were found while crosses indicate presence of bivalves.

Results

Unionid Survey

Mollusk diversity in the Canoochee River is relatively low compared to other southeastern drainages. To date, we have surveyed over 50% of the Canoochee River Drainage including 83 sites. Mussels were found at 30 of the 83 sites. *Corbicula fluminea* (Müller, 1774) was not observed at any of the sites, even though it is present in the main stem of the Canoochee River on Fort Stewart, Georgia. Mean mussel density among the sites surveyed was 0.028 N/m^2. Mussel density variance among surveyed sites was low (*var* = 0.001).

Mussels were most abundant in the Canoochee River site south of Metter, Georgia, downstream of Highway 121 (Cobbtown Road) Bridge. CPUE for this site was 68.42 N/h^1, and three species were collected (Table 2). The site southeast of Stillmore, Georgia down stream from the Highway 46 Bridge, had the second highest CPUE of 52.4 N/h^1. We collected four species at the Highway 46 Bridge site.

U. carolinianus was the dominant species thus far upstream of Fort Stewart, followed by *P. dubium* (Table 2). These two species are typically found in small, ephemeral creeks and characteristic of the headwaters of the Canoochee River. *U. carolinianus* were found at 23 sites, whereas *P. dubium* has been found in 21 sites. *U. carolinianus* was found primarily in the stream bed channel in root mats. However, in the four sites that had the highest CPUE, *E. congaraea* was the dominant species, followed by *E. lugubris* (Table 2). *E. congaraea* and *E. lugubris* were found in only nine sites in the drainage, while *E. icterina* were found in only three sites. *E. congaraea* form *corvus,* and *E. complanata* form *conferta,* were found in one site southeast of Stillmore, Georgia, downstream of the Highway 46 Bridge. *E. icterina* along with *E. congaraea, E. lugubris, E. congaraea* form *corvus,* and *E. complanata* form *conferta* can be found in beds along the bank line in stable silt-sand mud underneath leaf litter. *E. congaraea* was uncommon in this region.

Table 2. Species abundance from timed searches and CPUE for the Canoochee Basin, 2003

	Location			
Species	Canoochee River Downstream Hwy 46 Bridge	Canoochee River Upstream Stillmore Hwy Bridge	Cedar Creek Upstream Hwy 169 spur	Canoochee River Downstream Cobbtown Rd. Bridge
E. conferta	8 (14.81%)	0	0	0
E. lugubris	17 (31.48%)	14 (48.28%)	0	12 (35.29%)
U. carolinianus	2 (3.70%)	1 (3.45%)	13 (65.00%)	2 (5.88%)
E. congaraea	27 (50.00%)	12 (41.38%)	0	20 (58.82%)
E. icterina	0	2 (6.90%)	0	0
P. dubium	0	0	7 (35.00%)	0
CPUE	52.40	28.20	21.51	68.42

Table 3. Final summary output for the model at $P < 0.05$ where independent water quality variables were regressed upon mussel density and then regressed again in forward, backward and stepwise model building procedures.

	Model containing NO^3-N and pH		
Variables[a]	Coefficients	*t* Stat	*P*-value
Intercept	–0.04671652	–2.02121	0.047317
pH	0.008463757	2.10207	0.039367
[NO^3-N]	0.00050552	7.709653	8.76E-11
R^2	0.478		
Adj. R^2	0.462		

a. Does not include all variables.

The highest mussel densities were recorded on the Canoochee River, and Wolfe, Cedar, Fifteen Mile, and Canoochee creeks. The Canoochee River had the highest average mussel density of 0.044 N/m^2 followed by Wolfe Creek which had an average mussel density of 0.032 N/m^2. Fifteen Mile Creek had an average mussel density of 0.027 N/m^2, and Canoochee and Cedar Creeks had average mussel densities of 0.025 and 0.021 N/m^2 respectively.

Water Quality Analysis

The initial test for significance of regression indicated a linear relationship between mussel density and at least one of the regressor variables ($F = 8.55$; $R^2 = .533$). Using a combination of forward, backward, and stepwise selection model building techniques along with type III sums of squares analysis it was determined that both nitrate nitrogen (NO_3-N mg L^{-1}) with $P < 0.0001$, and pH with $P < 0.01$ were the only statistically significant predictors of mussel density from the original model (Table 3). The reduced model strongly reaffirmed the linear relationship among nitrogen levels, pH and mussel density ($F = 30.21$; $R^2 = 0.478$). In addition, when making adjustments for over fitting, the model accounted for over 46% of the variation (Adj. $R^2 = 0.462$) when using nitrate nitrogen and pH as predictor variables. All analyses were evaluated at significance level $\alpha = 0.05$.

Discussion

Mussel species diversity and abundance is low on the Canoochee River. However, 80% of all mussel species reported in the Ogeechee River Drainage were detected in our survey (Johnson 1970, Alderman 1991, J. D. Williams, U.S. Geological Survey, pers. commun., Sukkestad *et al.* in press). Based on their studies of museum voucher specimens and fieldwork, Johnson (1970) and Alderman (1991), identified 15 species that should exist in the Coastal Plain of Georgia. In our study, unionid species found upstream of Fort Stewart made up 47% of the total identified species throughout the drainage. Possible factors attributing to the absence of previously-inventoried species could be due to loss of species due to habitat degradation via anthropogenic effects, or prior misidentification of species, the former scenario being more probable.

Mussel CPUE and species richness were greatest in downstream reaches. Strayer (1983) along with Haag and Warren (1998) found that stream size was the most consistent predictor of mussel assemblage structure. They also hypothesized that assemblage variability may be related to stochastic processes in headwater reaches. We found no bivalves at first order sites. At second order sites, *P. dubium, M. partumeium, M. lacustra* and *U. carolinianus* were numerically dominant and appeared tolerant of a wider range of flows and habitat types than other freshwater bivalves. We found *E. icterina* and *E. congaraea* in second order tributaries of the Canoochee River. Also, we observed *E. congaraea* at all third order stream sampling sites, and this species was dominant in 80% of these sites. *E. congaraea,* form *corvus,* and *E. complanata,* form *conferta* were restricted to the Canoochee River and were absent from second order stream sites. In 2004, *E. congaraea* was being tracked as a species of special concern by the Georgia Natural Heritage program, and its conservation status is currently under review (B. Albanese, pers. commun.). The Canoochee River is one of the few un-impounded rivers along the South Atlantic Slope and is a critical refuge for *E. congaraea.*

Water quality impacts to mussel densities were evident; however, the results were unexpected. Mussel densities were highest at sites with high NO_3-N concentrations expected mussel densities were expected to be reduced or nonexistent. Direct discharge pollution inputs include the Twin City Water Pollution Control Plant (WPCP), the Collins WPCP, the Fort Stewart WPCP, and the Statesboro WPCP. Non-discharge pollution inputs as permitted by the Georgia Environmental Protection Division include the Pembroke WPCP, the Metter WPCP, the Claxton WPCP, and the Claxton Poultry Plant. Upstream land use is classified as agricultural with little urban development (Lewis and Turtora 1998). Sites where density and species richness are higher in the Canoochee River are in part, due to nutrient input (NO_3-N) from point and non-point sources (Fig. 2). Nutrient input may promote mussel growth by providing enrichment to the food web base. Coastal Plain blackwater streams are naturally low nutrient and pH systems (Winger 1981).

Excessive discharge into the surrounding environment can, however, facilitate eutrophication and can degrade water quality leading to anoxia. TDP additions to alluvial systems can contribute to habitat degradation by altering water chemistry, enriching phytoplankton blooms, and facilitating a eutrophic environment (Reynolds and Guillaume 1998). Although we found a significant positive relationship between mussel density and NO_3-N, we observed a negative relationship between mussel density and TDP concentrations. Adding pH to our model further reduced its overall predictive power (Table 3). Freshwater mollusk high filtration rates lead to excessive accumulation of pollutants, which can inhibit filtration by elevated rates of closure of their siphons (Sloof *et al.* 1983). This may explain the negative relationship between TDP and mussel density, even though this relationship was not found to be signifi-

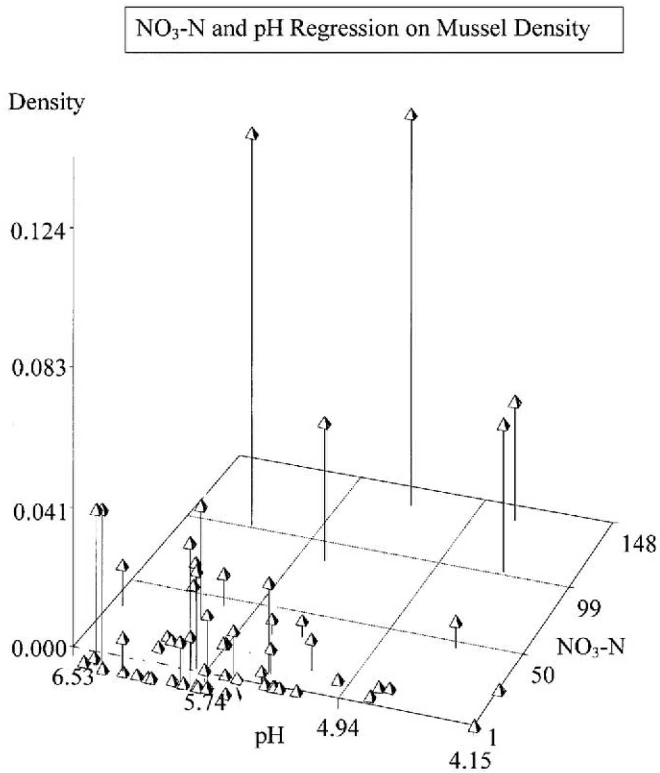

Figure 2. NO_3-N and pH regressed upon mussel density.

cant in our model ($P = 0.81$). Also, no significant relationship was found to exist between Cu metal concentrations within the water column and mussel density ($P = 0.99$). According to Markich *et al.* (2001), bioaccumulation in freshwater bivalves for each divalent metal is linearly and inversely related to its solubility as a hydrogen phosphate salt. Markich *et al.* also found that calcium intake is a significant predictor of divalent metal bioaccumulation for bivalves. Because calcium carbonate concentrations are low in Canoochee waters and Cu is readily transformed into a hydrogen phosphate salt, we hypothesize that little bioaccumulation of Cu is taking place within the bivalves in the Canoochee River Drainage, thus explaining the reason for little effect of Cu on mussel density within our model ($P = 0.99$) (Markich *et al.* 2001).

According to McKinney *et al.* (2002), nutrient enrichment in freshwater systems can be more effectively managed if models are used which link watershed land use to water quality. Assessment of nutrient input as it relates to mussel density can provide important information concerning regulation of nutrient enrichment. By establishing nutrient concentration versus mussel density models, nutrient discharges can be managed more effectively, and can provide insight into land use and water quality relationships. This information will be crucial to scientists and water regulators in developing water quality policy.

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