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Land use effects on macrobenthic communities in southeastern United States tidal creeks

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Abstract Runoff from impervious land cover has a major impact on headwater tidal creek ecosystems resulting from ever increasing development along the coastline. Tidal creek habitats can serve as “early warning systems” for anthropogenic stressors due to their proximity to the uplands. In this study, the macrobenthic community was sampled along the longitudinal gradient of tidal creeks (i.e., first order, second order, and third order) in North Carolina, South Carolina, and Georgia which varied in their levels of watershed development (salt marsh, forested, suburban, and urban). This study was designed to assess the condition of macrobenthic communities in tidal creek ecosystems under varying levels of anthropogenic stressors and test whether the conclusions of a previous study in South Carolina (Holland et al., J Exp Mar Biol Ecol 298:151–178, 2004) could be generalized to the southeastern USA. Metrics of community-level and species-specific response within tidal creeks draining watersheds of varying degrees of impervious cover suggest the macrobenthic community may be a useful indicator of development in tidal creeks ecosystems. The differences observed when data from all three states were pooled was consistent with previous findings in South Carolina tidal creeks which illustrates that macrobenthic communities in tidal creeks may react to watershed development in similar patterns along the southeastern coast of the USA.

Keywords Tidal creek · Impervious cover · Macrobenthic · Development · Oligochaeta · Polychaeta

Introduction

Tidal creek and salt marsh systems are prominent features of the southeastern coastline of the USA. They serve as nursery areas, feeding grounds, and refuges for many fish, crustacean, and mollusk species (e.g., Hackney et al. 1976; Shenker and Dean 1979; Kneib 1997; Beck et al. 2001). They also serve as the primary linkage between upland and estuarine environments which makes them ideal for assessing impacts of upland development (Holland et al. 2004). They can serve as sentinel habitats, integrating the surrounding landscape condition, because of the flow of runoff from the

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surrounding watershed into the creeks (Holland 2000; Lerberg et al. 2000; Holland et al. 2004). This role is particularly important considering the increasing levels of development along the coast.

In order to maintain and protect the economic and ecological benefits of these headwater tidal creek ecosystems, we must be able to monitor for and detect the effects of anthropogenic impacts on these systems. One component of tidal creek habitats which can be used to assess anthropogenic effects is the macrobenthic community (Karr 1998; Bilkovic et al. 2006; Day et al. 2006). Macrobenthic communities are: (1) generally immobile and unable to escape pollution; (2) easy to sample; (3) well studied and their responses to stressors are known; and (4) associated with the sediments where contaminants accumulate (Chapman 2001; Macfarlane and Booth 2001, Delgado et al. 2003). These communities also serve as a food source for crabs, shrimp, and juvenile fish (e.g., Thorp and Bergey 1981; Kneib 1997; Chapman 2001) and affect sediment grain size, organic content, and oxygen demand (McCall and Fisher 1980; Rodriguez 1999; Seys et al. 1999).

Several previous studies have found annelids to be the dominant species in the macrobenthic communities of South Carolina tidal creeks (e.g., Lerberg et al. 2000; Filipowicz 2004; Holland et al. 2004). Oligochaetes have been found to be the dominant species in samples collected in South Carolina headwater or 1st-order tidal creeks (Filipowicz 2004; Gillett et al. 2007), while polychaetes have been found to be the dominant organisms in the deeper areas or 2nd/3rd orders of tidal creeks (e.g., Van Dolah et al. 2007). The dominance of these annelids is most likely due to their ability to survive in highly variable environments (e.g., Chapman 2001).

The objective of this study was to examine the responses of macrobenthic communities in tidal creeks to various levels of watershed development. These responses, such as changes in species abundances and diversity, were observed in tidal creeks throughout the southeastern US and down the length of the creek in each system. We hypothesized that macrobenthic responses would be similar throughout the region and would be most pronounced and easiest to assess within each creek furthest upstream or closest to upland development.

Methods

Sampling took place along the southeastern coast of the USA from New Hanover County, NC to Glynn County, GA in the summers (June–August) of 2005 and 2006. Twelve creek systems were sampled in SC during the summer of 2005. Four of these creek systems (Guerin, James Island, New Market, and Village) were sampled again in 2006. An additional seven creek systems were sampled in 2006: three in NC and four in GA (Fig. 1). Tidal creeks sampled were chosen to represent a range of watershed impervious cover levels (Sanger et al. 2008). To sample the entire creek length effectively, a tidal creek classification model was developed analogous to the freshwater stream model of Strahler (1957) with creeks being divided into 1st, 2nd, and 3rd orders (Sanger et al. 2008). A 2nd order was generally created by the merging of two 1st orders while a 3rd order was created by the merging of two 2nd orders. In general, 1st-order creeks were 350–2,200 m, 2nd-order creeks were 1,000–5,100 m, and 3rd-order creeks were 1,000–3,600 m in length. However, creek lengths did not necessarily determine runoff inputs and are not discussed further. Not every tidal creek system had all three orders and not every order in each tidal creek system could be sampled (Table 1). Creek orders were divided into three reaches, portions of an order with equal lengths, using ArcGIS 9 (ESRI, Redlands, CA).

Watershed delineation and impervious cover determination were performed using ArcGIS 9 following the method of Sanger et al. (2008). Watersheds were delineated by hand using United States Geological Survey (USGS) topographic maps and USGS Elevation Derivatives for National Applications (EDNA; http://edna.usgs.gov/). Corrected National Land Cover Database (NLCD) 2001 impervious cover data (D. White, pers. comm.) were used to classify each creek watershed as salt marsh, forested, suburban or urban based on established categories (Holland et al. 2004).

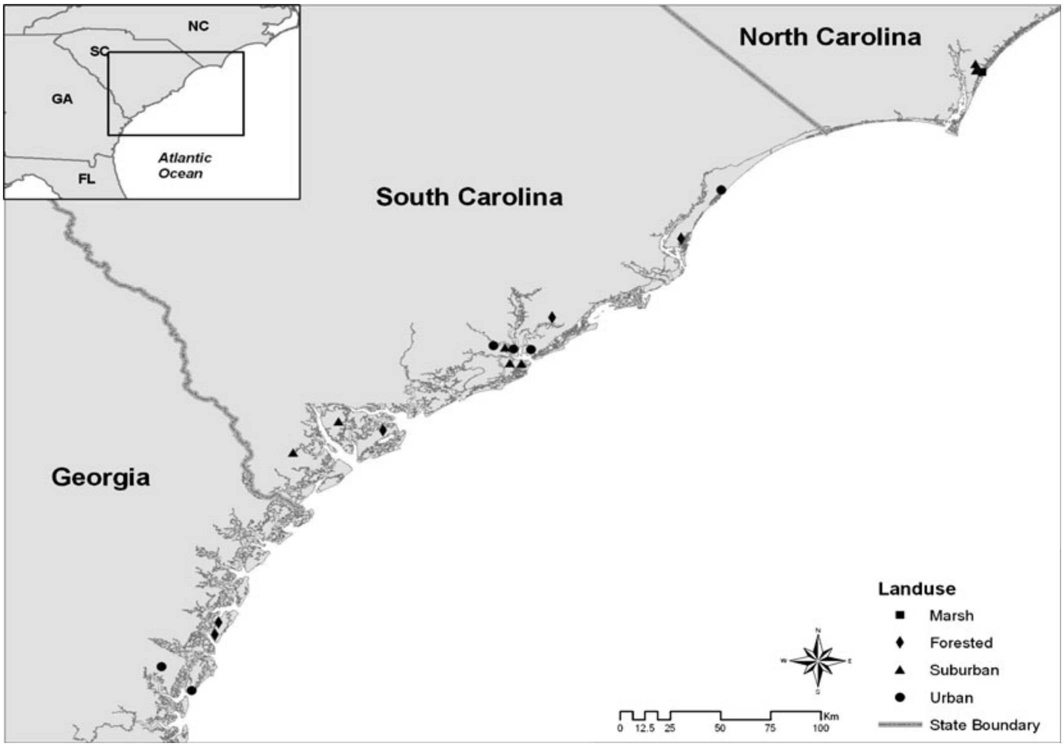

Fig. 1 Watershed locations of all creeks sampled in North Carolina, South Carolina, and Georgia in the summers of 2005 and 2006. Watersheds are labeled as *squares* for marsh, *diamonds* for forested, *triangles* for suburban, and *circles* for urban land use classes

Sampling took place approximately 1 h before low tide. Three stations were randomly located within each of the three equal reaches in the 1st order while one station was randomly located within each of the three reaches in the 2nd and 3rd orders. A macrobenthic sample was collected at each 1st order station in the intertidal area (nine samples per order at ~1–1.5 m below mean high tide) along the edge of the creek using a core with an area of 45.6 cm^2 pushed to a depth of 15 cm. In the 2nd and 3rd orders, a macrobenthic sample was collected at each station (three samples per order) in the subtidal channel of the creek using a Young grab with an area of 456 cm^2. Samples were collected subtidally in the 2nd/3rd order to sample similarly to the South Carolina Estuarine and Coastal Assessment Program (SCECAP; e.g., Van Dolah et al. 2007). Samples were sieved through a 500-µm screen and preserved in 10% formalin with rose bengal. Organisms were sorted and identified to the lowest taxonomic level with a 90% sorting and identification efficiency.

Surface sediment samples were collected at each of the benthic sampling locations to determine grain size. The percentages of sand and silt/clay were determined using a modified pipette method from Plumb (1981). Water quality was measured using a YSI 6600EDS Datasonde placed 15 cm above the creek bottom in the second reach of each creek order. The datasonde measured temperature, dissolved oxygen, conductivity, turbidity, chlorophyll, and depth for two full tidal cycles (~25 h). All data collected were entered into a PostgreSQL database and manipulated using a Microsoft Access frontend.

Due to the difference in sample size caused by the use of different sampling gear between the 1st and 2nd/3rd orders, analyses on dominant species were performed on densities (number of individuals per square meter). Data collected from South Carolina creeks sampled in both 2005 and 2006 (4 total) were averaged to provide a single value for data analysis. Samples collected within an order were then averaged. Data were

Table 1 Tidal creeks sampled in the summers of 2005 and 2006

Land use class	Watershed	Order 1 area (ha)	Impervious cover order 1 (%)	Order 2/3 area (ha)	Impervious cover order 2/3 (%)
South Carolina					
Suburban	Albergottie	558	8.1	2,096	23.9
Urban	Bulls	369	40.5	510	38.4
Forested	Guerin	219	3.0	3,427	3.0
Salt marsh	Guerin	25	0.0	342	0.0
Suburban	James Island-N	296	30.0	773	29.1
Suburban	James Island-S	144	41.3	2,820	29.5
Urban	Murrell's inlet	n/a	n/a	1,297	40.3
Urban	New market	199	70.4	n/a	n/a
Forested	North inlet	184	2.9	1,860	2.9
Salt Marsh	North inlet	55	0	102	0
Salt Marsh	Orangegrove	18	0	59	0
Suburban	Orangegrove	61	39.2	322	37.3
Salt Marsh	Parrot	28	0	n/a	n/a
Suburban	Parrot	52	21.2	501	17.7
Suburban	Okatee	2,415	17.9	5,501	13.3
Urban	Shem	456	49.4	1,269	47.7
Forested	Village	630	3.6	2,016	4.0
North Carolina					
Suburban	Hewlitts-S	614	40.9	n/a	n/a
Suburban	Hewlitts-N	459	34.5	2,782	33.4
Salt marsh	Masonboro	29	2.9	n/a	n/a
Suburban	Whiskey	482	34.7	712	32.4
Georgia					
Urban	Burnett	2,425	11.2	2,589	11.8
Forested	Duplin	385	3.0	1,480	3.0
Forested	Oakdale	286	3.1	n/a	n/a
Urban	Postell	218	39.8	n/a	n/a

Land use class, watershed, watershed area, and impervious cover are given

n/a not available

then averaged across the 2nd and 3rd orders to represent the larger subtidally dominated habitat. Analysis of variance (ANOVA) comparing many parameters between the 2nd and 3rd orders found few differences.

Species richness was obtained using the EstimatesWin800 software, and species diversity was measured as H′. However, to calculate diversity and richness, samples were summed in the 1st order while averaged in the 2nd/3rd order because the nine 1st order samples comprised approximately the same area as one 2nd/3rd-order sample. Higher taxonomic groupings at the phylum (i.e., Molluska), class (i.e., Polychaeta, Oligochaeta, Amphipoda and Decapoda), and family (i.e., Spionidae, Capitellidae and Tubificidae) were also analyzed. Community metrics were examined including the Carolinian Province benthic index of biological integrity (CP-IBI) (Van Dolah et al. 1999; EPA 2000) for 2nd/3rd-order creeks and indices for SC tidal creeks developed by Lerberg et al. (2000) involving the percent of the community comprised of pollution sensitive and indicator species for 1st order creeks.

The SAS 9.1 program (SAS Institute Inc., Cary, NC) was used to analyze these data. Two-way analyses of covariance (ANCOVA) were performed on all parameters with the main effects being land use class and order while two-way ANOVAs were performed on several environmental parameters used as covariates. If an interaction term or covariate was not significant at $\alpha = 0.10$ then it was removed. Other analyses were considered significant at $\alpha = 0.05$. No covariates were significant in any models examining higher taxonomic groupings, and two-way ANOVAs were performed on these data instead.

There was an unbalanced sampling design caused by the disproportionate amount of creeks sampled in South Carolina and which were in a suburban watershed. Type III sums of squares and least square means were used for comparisons between land use classes and orders to account for this imbalance. Parameters were transformed to meet assumptions of ANCOVA/ANOVA.

Dominant taxa analyzed included the oligochaete species: *Monopylephorus rubroniveus*, *Tubificoides heterochaetus*, *Tubificoides brownae*, and *Tubificoides wasselli*; the polychaete species/genera: *Laeonereis culveri*, *Streblospio benedicti*, *Capitella capitata*, *Heteromastus filiformis*, *Nereis succinea*, *Mediomastus* sp., *Polycirrus* sp., and *Cirriformia* sp.; and the phylum Nemertea. These taxa comprised over 78% of the organisms collected. The percent of the community comprised of higher taxonomic groupings (phylum and class) as well as the CP-IBI and pollution indicator/sensitive indices were also analyzed. In addition, one-way ANOVAs were performed with land use class as the treatment on pollution indicator and pollution sensitive data (Lerberg et al. 2000) for the 1st orders. Finally, the percent of pollution indicator/sensitive taxa were regressed against the percent impervious cover in each watershed.

Community composition was examined by performing non-metric multi-dimensional scaling (nMDS) analyses using the primer statistical package (Clark and Gorley 2006). Because of the different sample sizes between orders, the nine samples collected in each 1st-order creek (24 total) were summed to get one sample, and each 2nd/3rd-order sample (87 total with nine creeks which have a 2nd order lacking a 3rd order) was analyzed separately. Only the 50 most abundant species were used in the nMDS analysis. Many environmental and chemical parameters were also used to explain benthic distributions and examine gradients among sites. The environmental model which best explained differences among sites used the following parameters: total pore-water amine nitrogen, % mud, average DO, average temperature, minimum salinity, and DO range (max–min). Finally, analyses of similarity (ANOSIM) were used to test whether there were differences in the benthic community and environmental model listed above between orders and individual land use class pairs. The ANOSIM operates on a resemblance matrix similar to standard univariate 1- and 2-way ANOVAs and tests for differences between 1 or 2 factors (land use and order in the present analysis) with groups chosen a priori (Clark and Gorley 2006).

Results and discussion

Salinity concentrations and ranges (Shirley and Loden 1982; Seys et al. 1999; Gillett et al. 2007), dissolved oxygen concentrations and ranges (Lerberg et al. 2000; reviewed by Giere 2006; Gillett et al. 2007), and sediment composition (i.e., % mud) (Seys et al. 1999; Verdonschot 2001) have been found to influence macrobenthic communities in coastal areas. These parameters were examined to understand and explain the natural variability in these tidal creek systems before examining the anthropogenic effects on benthic distributions. The two-way ANOVA model for average salinity levels measured over ~25 h (i.e., two tidal cycles) with land use class and order as treatments was not significant. The model for salinity range was significant with higher ranges found in the 1st orders (14 ± 2.1 ppt) compared to the 2nd/3rd orders (8.4 ± 1.2 ppt) and higher ranges in the urban and suburban systems compared to the forested or salt marsh systems.

Dissolved oxygen concentrations were generally higher in the 2nd/3rd order but were not significantly different spatially down the length of the creek or among land use classes. The model for the range of DO concentrations was significant with larger ranges in the 1st order (6.9 ± 0.6 mg/L) compared to the 2nd/3rd order (4.1 ± 0.3 mg/L). In general, DO ranges were lower in salt marsh and forested creeks but were not statistically different among land use classes. The model for mud content (% silt/clay) was not significant, but mud content was found to vary spatially down the length of the creek being significantly higher in the 1st order (50 ± 5%) compared to the 2nd/3rd order (33 ± 6%). Mud content did not significantly vary among land use classes; however, it tended to be highest in salt marsh systems (58 ± 12%). After averaging 2005 and 2006 data, a total of 18,296 organisms were collected in 303 samples representing 279 taxa. Annelids comprised nearly 95% of the macrobenthos sampled with oligochaetes comprising 60% and polychaetes comprising 34%. The remainder of the benthic community was composed of crustaceans (3%), mollusks (1%) and other taxa (1%). In the 1st order, oligochaetes were the most abundant taxon. Oligochaetes reached their highest densities in suburban and urban creeks (Fig. 2). In the 2nd/3rd order, polychaetes were the dominant organisms reaching their highest densities in forested systems. After accounting for polychaetes and oligochaetes, other taxa were more equally represented in the 2nd/3rd orders than in first orders (Fig. 2).

The % compositions of the higher taxonomic groupings were analyzed using ANOVA models with order being significant and explaining the majority of variability for all higher taxonomic groupings. The proportion of oligochaetes was significantly higher in the 1st order while all other groupings were signifycantly higher in the 2nd/3rd order. None of the groupings had a significant land use class effect; however, pairwise differences were observed for oligochaetes with higher compositions in urban creeks relative to forested creeks. Species richness was examined using Mao-Tau, and diversity was examined using H′ in two-way ANOVAs. Richness and diversity were significantly different between orders and among land use classes. The 1st-order richness and diversity were two to three times lower than the 2nd/3rd order. Richness and diversity were also significantly higher in forested creeks compared to suburban and/or urban creeks (Table 2). The densities of sixteen taxa were analyzed using two-way ANCOVAs, and eleven of these had significant models ($p < 0.05$). The five taxa which did not have significant models were: *Cirriformia* sp., *T. brownae*, *T. wasselli*, *N. succinea*, and *Polycirrus* sp. (Table 2). Average salinity was a significant covariate for the majority of taxa. Mud content was only significant for *C. capitata*. Average DO concentration was not significant for any taxon while DO and

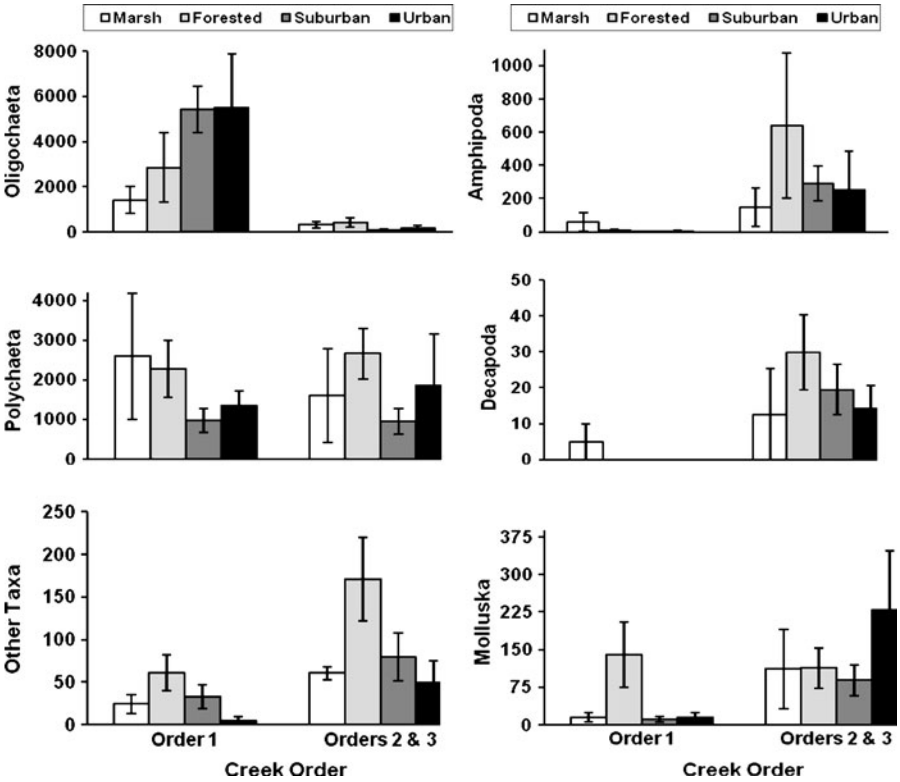

Fig. 2 The average densities of the groupings of organisms collected in the summers of 2005 and 2006. *Error bars* represent one standard error

Table 2 Two-way ANOVA results performed on abundant taxa and community measures

Parameter	R^2	Transformation	Land Use *p* value	Order *p* value	Creek lsmeans	Order	
Species							
Monopylephorus rubroniveus	0.84	ln	ns	<0.0001	ns	3^a	1^b
Streblospio benedicti	0.32	ln	ns	ns	ns	ns	
Tubificoides heterochaetus	0.61	rank	0.1084	0.0119	SM^a F^{ab} S^{ab} U^b	3^a	1^b
Laeonereis culveri	0.61	rank	0.0067	<0.0001	SM^a F^{ab} S^{bc} U^c	3^a	1^b
Capitella capitata	0.65	ln	0.0175	<0.0001	SM^a S^a U^{ab} F^b	3^a	1^b
Heteromastus filiformis	0.37	root	0.2081	ns	S^a U^{ab} F^{ab} SM^b	ns	
Mediomastus sp.	0.54	ln	ns	<0.0001	ns	1^a	3^b
Family/Phylum							
Tubificidae	0.62	ln	ns	<0.0001	ns	3^a	1^b
Spionidae	0.38	ln	ns	ns	ns	ns	
Capitellidae	0.30	ln	ns	0.0120	ns	3^a	1^b
Nemertea	0.44	root	0.0016	0.0010	U^a S^a SM^a F^b	1^a	3^b
Community							
Mao-tao	0.50	ln	0.0060	<0.0001	S^a U^{ab} SM^{bc}F^c	1^a	3^b
H’	0.56	none	0.0890	<0.0001	S^a U^a SM^{ab} F^b	1^a	3^b
CP-IBI	0.47	none	0.0310	<0.0001	S^a U^{ab} SM^b F^b	1^a	3^b
Pollution Indicator taxa	0.39	none	0.0190	n/a	SM^a F^a S^b U^b	n/a	
Pollution Sensitive taxa	0.24	none	ns	n/a	ns	n/a	

The two parameters tested were land use class which included SM, F, S, and U systems and order which included 1st and 2nd/3rd orders. Only parameters with significant model *p* values were included. Least squared mean results are ordered from low to high with statistical differences represented by different superscript letters

SM salt marsh, *F* forested, *S* suburban, *U* urban system, *ns* not significant

salinity ranges were not tested. Eight taxa showed significant spatial variation down the length of the creek, and three taxa showed significant variation among land use classes. *Mediomastus* sp. and Nemertea were found in significantly higher densities in the 2nd/3rd order while the remaining taxa were significantly higher in the 1st order. Densities of *C. capitata* and Nemertea were significantly higher in the forested creeks relative to suburban and/or urban creeks. *L. culveri* had significantly higher densities in the urban creeks relative to the forested and salt marsh creeks (Table 2).

The two-way ANOVA model examining the CP-IBI found significant differences between orders and among land use classes with forested and salt marsh creeks having higher scores than suburban creeks (Table 2). CP-IBI values were also higher in the 2nd/3rd order (2.84) compared to the 1st order (1.76), but the CP-IBI was developed for deeper systems so the lower values obtained for 1st orders may represent habitat differences rather than degradation. Therefore, communities in 1st order systems were analyzed using indices developed by Lerberg et al. (2000) to assess community degradation. The one-way ANOVA model for pollution indicator taxa was significant with a higher percentage found in suburban and urban systems compared to forested and salt marsh systems while the model for pollution sensitive taxa was not (Table 2). Regression analyses found the proportion of pollution sensitive taxa to decrease with impervious cover ($R^2 = 0.27$, $p = 0.02$) while the opposite was true for the proportion of pollution indicator species ($R^2 = 0.31$, $p = 0.01$; Fig. 3). Salt marsh creeks were not included in the regressions because they were widely variable systems with roughly equal

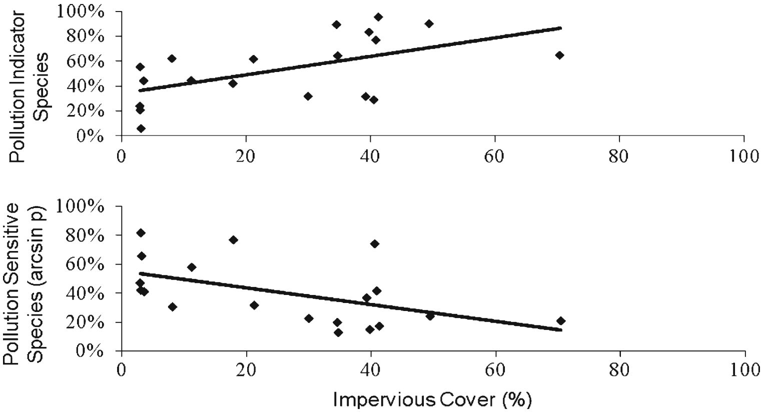

Fig. 3 The percent of the 1^{st}-order community in each creek composed of pollution indicator (*top*) (*M. rubroniveus*, *L. culveri*, and *T. brownae*) and pollution sensitive taxa (*bottom*) (*T. heterochaetus*, *S. benedicti*, *Tharyx acutus*, *H. filiformis*, and *Nemertea*) regressed against the amount of impervious cover in each watershed. Salt marsh creeks were not included due to their wide variability and equal impervious cover (~0%)

impervious cover (0%) and very different than all upland systems sampled which drained maritime forest.

Community composition and environmental gradients were examined between orders and among land use classes using nMDS analyses. The 1st-order systems were all clumped and confined to the left center of the graph, while the 2nd/3rd-order systems were spread across the rest of the graph. No discernable pattern was observed for land use class (data not shown). The ANOSIM found significant differences between orders ($p = 0.007$), forested systems and all other land use classes ($p < 0.02$) and urban and suburban creeks ($p = 0.02$). The ANOSIM comparing the environmental model among land use classes, with parameters listed earlier, found similar pairwise differences.

Studies of river and stream ecology have shown that environmental gradients occur along the length of a channel. In freshwater systems, the River Continuum Concept was developed to explain differences along this longitudinal network (Frissell et al. 1986; Cushing 1994; Mykra et al. 2004). A longitudinal gradient has also been observed in tidal creek systems. In this study, the macrobenthic communities were found to differ from small headwater (1st order) to deeper, larger (2nd/3rd order) creeks in species diversity, species richness, taxa densities, and compositions. Seys et al. (1999) found similar patterns to this study with densities increasing with exposure to air. Ysebaert et al. (2000) also found results similar to this study with species richness greater in the subtidal zone of the Schelde Estuary in Belgium while densities were greater in the intertidal zones.

The spatial distributions of polychaetes and oligochaetes were found to vary down the length of the creek in a pattern similar to previous studies with oligochaetes comprising more of the community in shallow systems and polychaetes comprising more in deeper systems (Martin et al. 1999; Seys et al. 1999). This was most likely due to the highly variable and more stressful conditions present in the 1st order relative to the 2nd/3rd order including higher mud content, lower salinity, lower DO values, and the proximity to anthropogenic pressures which have been found in previous studies of tidal creeks (e.g., Lerberg et al. 2000; Holland et al. 2004; Gillett et al. 2007). Other factors such as predation and potential food sources most likely play a role in these distributions as well (Mallin et al. 2000).

Increased watershed development, measured by impervious cover, results in increased runoff, increased variability in water quality, and increased pollutant loadings (reviewed by Klein 1979; Lerberg et al. 2000; reviewed by Mallin et al. 2000; Holland et al. 2004). The higher salinity range found in suburban and urban creeks in this study corroborates previous hydrological studies in these creek systems (Sanger et al. 2008).

Other studies have found ranges of environmental variables to increase with impervious cover (Lerberg et al. 2000; Holland et al. 2004).

The significantly higher abundances of several taxa considered tolerant to environmental and anthropogenic stressors in the 1st order also suggests these habitats are more heavily impacted by nutrients and pollutants from anthropogenic sources. *M. rubroniveus*, *L. culveri*, and *C. capitata* were all found to be much more abundant in the 1st order. The densities of tubificid oligochaetes and the % of oligochaetes comprising the communities were also higher in 1st orders, and several studies have shown oligochaetes to dominate in polluted areas (e.g., Finogenova 1996; Ysebaert et al. 2000; Gillett et al. 2007).

In the creeks sampled in this study, Sanger et al. (1999a, b), DiDonato et al. (2008), and Sanger et al. (2008) found significantly higher concentrations of nitrate plus nitrite, pathogen indicators (i.e., enterococci, fecal coliforms and coliphages), total PAHs, and total PCBs in the suburban and/or urban systems. Although samples were collected in different locations across the creek channel in the 1st and 2nd/3rd order, previous research comparing macrobenthic communities between intertidal and subtidal microhabitats found few differences between these habitats (Filipowicz 2004).

Macrobenthic communities tend to respond to the adverse changes in the physical and chemical environment associated with anthropogenic stressors, such as increased runoff due to increases in impervious surface, by either declines in overall diversity or higher abundances of selected species (reviewed by Klein 1979; Blumenshine et al. 1997; Lerberg et al. 2000; Holland et al. 2004; Day et al. 2006). This trend is similar to that observed in 1st-order systems in this study, which had the highest total densities and lowest diversities and richness in the more developed suburban and urban systems. In contrast to the patterns observed in the 1st order, few differences in the benthic community were found among land use classes in the 2nd/3rd orders. This was most likely due to the fact that this habitat is farther away from the direct source of development (i.e., nonpoint source pollution) and has additional buffering capacity to dilute pollutants. Day et al. (2006) found nutrient concentrations to be high near effluent discharge but to decrease by 80–90% as water flowed down the wetland.

The relative composition of polychaetes and oligochaetes were also found to vary across 1st-order creeks with different levels of impervious cover. Oligochaetes comprised over 80% of the community in suburban and urban systems while comprising 35–55% of the community in salt marsh and forested systems, respectively. Polychaetes comprised only 15–20% of the community in suburban and urban systems while comprising 40–65% of the community in forested and salt marsh systems, respectively. Oligochaetes are generally thought of as very tolerant to anthropogenic stress (Finogenova 1996; Lerberg et al. 2000; Ysebaert et al. 2000; Gillett et al. 2005, 2007). For example, Day et al. (2006) found naidids to dominate areas near effluent discharge. Individual species have also been found to be indicative of pollution including the oligochaetes *M. rubroniveus* and *T. brownae* as well as the polychaete *L. culveri* (Lerberg et al. 2000). In this study, the individual densities of these three species increased with increasing impervious cover in the 1st order. Lerberg et al. (2000) and Holland et al. (2004) found similar results when examining 1st orders in South Carolina.

Some taxa are considered to be relatively intolerant to environmental and anthropogenic stressors in tidal creek habitats. The few crustaceans and mollusks found in the 1st orders were confined to salt marsh and forested systems. Previous studies have shown densities of crustaceans such as amphipods and decapods to decrease with increased contaminant loadings (EPA 2000; Day et al. 2006). Individual species which were found to be pollution sensitive in a previous study of tidal creek ecosystems (Lerberg et al. 2000) include *T. heterochaetus*, *S. benedicti*, *Nemertea*, *H. filiformis*, and *Tharyx cf. acutus* (Lerberg et al. 2000). The densities of all of these taxa except *T. heterochaetus* decreased in the 1st order with increased impervious cover. Some of these species have been found to be pollution tolerant in other studies (e.g., *S. benedicti*) but appear to be more sensitive to these stressors in the already environmentally stressful environments of tidal creek habitats.

In addition to examining individual taxa, community changes were examined (Van Dolah et al. 1999; EPA 2000; Lerberg et al. 2000). Such analyses showed that richness, diversity, and the CP-IBI scores were all greater in the forested and salt marsh systems compared to suburban and/or urban systems. Diversity, richness, and B-IBIs have been found to decrease with increased development in other studies (reviewed by Klein 1979; Van Dolah et al. 1999; EPA 2000). In the 1st order, the proportion of the community composed of pollution sensitive and pollution indicator taxa, as defined by Lerberg et al. (2000), were found to decrease and increase, respectively, with increased impervious cover. The analysis of similarity examining community structure found the forested, suburban, and urban systems all to be significantly different from one another, further corroborating the differences in macrobenthic communities among land use classes.

Conclusions

Macrobenthic communities exhibited several responses to increased levels of watershed development. This study found higher proportions of pollution indicator taxa and higher total abundances in the suburban and urban systems while higher proportions of pollution sensitive taxa and higher overall diversity were found in the forested and salt marsh systems. Differences have generally been observed between forested/salt marsh systems (<10% impervious cover) and suburban/urban systems (>20% impervious cover) in previous studies in South Carolina tidal creeks (e.g., Lerberg et al. 2000; Holland et al. 2004).

Differences among land use classes were primarily found in the 1st-order creeks with few differences being found in the 2nd/3rd orders. Also, trends found across land use classes in previous studies (e.g., Lerberg et al. 2000; Holland et al. 2004) examining macrobenthic communities in South Carolina tidal creeks were observed in this study suggesting that macrobenthic responses to development are similar throughout the southeastern USA. Thus macrobenthic communities appear to be a reliable early indicator of anthropogenic stressors in southeastern US tidal creeks, with impaired benthic condition being most pronounced in the shallow headwater areas closest to sources of upland development.

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