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Systematic Ichthyofaunal Surveys in Urban and Non-Urban Watersheds

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ABSTRACT

Objectives were to model fish species richness relative to natural and anthropogenic variables in Quantico Creek, a forested undisturbed stream environment, and Cameron Run, a highly disturbed urban stream environment in the lower Piedmont-Fall Line region of the Potomac River watershed. Species richness in all stream orders (e.g. avg. range=2.5-9.65 in 1st-3rd orders) of Quantico Creek were significantly higher than those (e.g. avg. range=2.1-7.6 in 1st-4th orders) of Cameron Run. Fish species richness in Quantico Creek watershed can be modeled by eight factors: season, stream order, elevation, river km, stream width and depth, watershed size, and percent of undeveloped land cover; and that in Cameron Run can be modeled with four factors: stream gradient, stream flow, water temperature, and percent undeveloped land cover. Therefore, it cannot be assumed that a model composed of one set of variables that represents species richness for a given watershed can be applied to a nearby watershed. Based on potential impacts of increased population growth and climate change in the area, coupled with a paucity of information on the extent of the use of the lower reaches of Quantico Creek as a spawning area for anadromous fishes, we propose that the national park, Prince William Forest Park, should be included as a freshwater protection area for the Quantico Creek watershed as proposed by the National Park Service for 50 other national parks in the country. Data and models generated in our study can serve as baselines in future comparative studies of mid-Atlantic streams relative to changes in system parameters (e.g. human population,

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corresponding anthropogenic effects and climatic change predicted for the mid-Atlantic region).

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INTRODUCTION

Many lotic systems in the mid-Atlantic's Piedmont Region have been altered by human activities (e.g. agricultural, industrial and urban development), and few natural systems representing non-impacted conditions now exist. As such, discerning the effects of change in lotic systems is challenging due to the scarcity of baseline sites. However, a few mid-Atlantic Piedmont lotic systems have been preserved over the course of the past 50 to 100 years and as such provide a close approximation to baseline stream conditions. For example, the drainage basin of Quantico Creek is wholly within a national park (Prince William Forest Park) and a marine corps base (Quantico Marine Corp Base) where virtually no agricultural and urban development has occurred within the past 80 years. As such, Quantico Creek has been used as a benchmark control site for short-term environmental and ecological studies of watersheds in the mid-Atlantic's Piedmont region (2008 personal communication P. Petersen, Acting Chief Resource Manager, Prince William Forest Park).

Studies of fishes in freshwater streams have identified and quantified changes in fish distributions and species richness and diversity relative to natural changes in physical stream condition (e.g. elevation, gradient, and stream order) as well as anthropogenic perturbations (e.g. damming) (Azaele et al. 2009; Lotrich 1973; Maurakis and Grimes 2004; Maurakis et al. 1987; Mundy and Boschung 1981; Paller 1994). Accuracy of stream system modeling based on the accumulated data of historical studies has allowed more recent researchers (Argent et al. 2003) to use landscape-level physical variables in Geographical Information Systems to predict freshwater fish distributions in river drainages.

With 116 fish species, of which 86 are considered native (including one endemic, *Cottus cognatus*) and 30 as introduced, the Potomac River watershed has one of the richest ichthyofaunas in Chesapeake Bay drainage (Cummins 2006; Jenkins and Burkhead 1993). Historically, distributions of freshwater fishes in the Potomac River drainage have been presented for the entire drainage and used in biogeographic and aquatic impact studies. However, information on changes that may occur in species richness within discrete stretches (i.e., within the confines of a sub-watershed) relative to either natural or human induced changes in the environment in the Potomac River drainage is exiguous. Studies at the sub-watershed level have been typically focused on physical environmental variables and less on the modeling of the community structure of aquatic biota as a function of those variables. Studies of note for this research include Kelso et al. (2001), who investigated Quantico Creek's water and habitat quality relative to other sites in northern Virginia; Dawson (2010) who examined the ecological values and ecosystem services of Prince William Forest Park in northern Virginia; and Starnes et al. (2011) who examined fish occurrences in the vicinity of Plummers Island in the lower reaches of the Potomac River in vicinity of

Washington, DC. However, there have been no long-term monitoring studies conducted of fish populations at the sub-watershed level in the mid-Atlantic lower Piedmont and upper Coastal Plain regions to create a basis for understanding changes in community structure relative to natural and anthropogenic factors in the environment.

Objectives of this study were to model fish species richness relative to natural and anthropogenic physical variables in Quantico Creek, a forested undisturbed stream environment, and Cameron Run, a highly disturbed urban stream environment in the lower Piedmont-Fall Line region of the Potomac River watershed.

Study Area

The Quantico Creek watershed (approximately 4,778 ha) is 56 km S of Washington, DC. Its headwater tributaries and main stem above the fall line are entirely within Prince William Forest National Park and the Quantico Marine Corps Base. The watershed is predominantly piedmont forest that has had a minimal level of development since the close of World War II. Approximately 81 percent of the watershed is currently undeveloped land cover, and impervious cover in the watershed totals about 611 ha (12.8 %) (Maurakis et al. 2010). The population of approximately 3,500 people is concentrated in a small number of communities, the largest being located at or below the fall line. These watershed characteristics provided a low impact control site, which has been used in earlier studies in the region (Kelso et al. 2001).

The portion of the Cameron Run watershed included in this study is approximately 15 km South of Washington, DC, and did not include the area that drains into Lake Barcroft. The watershed area that was sampled is approximately 4,808 ha and lies within a highly developed urban and industrial environment with about 60 percent impervious cover. Undeveloped land cover is approximately 42 ha and the population is about 62.8 times greater (220,000) than that of the Quantico Creek study area (Maurakis et al. 2010).

MATERIALS AND METHODS

Fifteen sampling locations, representing stream orders 1, 2 and 3 were established in the Quantico Creek watershed and sampled monthly or bimonthly from November, 2008 through June, 2010. Seven sampling locations, representing stream orders 1, 2, 3, and 4 were sampled in the Cameron Run watershed during the same time period. Fishes were collected with a 12 or 24 Volt Smith-Root backpack electroshocker and dip-nets. Fishes were identified, counted and then returned to the stream except the invasive species *Channa argus* (Snakehead fish), which was saved and given to the VA Department of Game and Inland Fisheries.

Latitude, longitude, stream order, elevation (m), stream width and depth (m), gradient (m/km), river kilometer (distance from the mouth of the river to a collection point (km), water temperature (C), water velocity (m/sec), water flow (m^3/sec), and pH were recorded at each sampling station. The Horton method (1945) was used to assign stream order with the exception that intermittent streams were not classified as first order. Stream order was determined by tracing drainages on USGS Topographic maps (1:250000 scale) and verified through a GIS hydrology analysis. Map contours were used to determine gradients (m/km) for each collecting location. Elevation (m) was determined from a Garman Oregon 550t GPS receiver, and USGS topographic maps (1:125,000). Stream width (m) and stream depth (m) were measured with a meter stick, and water temperature (Cº) with a hand held thermometer. River kilometer (km) was determined using USGS topographic maps (scale) and tracing the distance between a collecting location in a stream and the mouth of its parent river with a planimeter. Watershed and sub-watershed populations were determined from US census data, and watershed development (percents of impervious cover and vegetated land cover) was determined from GIS analysis of digital land cover maps from the University of Maryland's RESAC project.

Fish species richness was calculated using the raw number of species collected at each location. The Jaccard Coefficient of Similarity was used to determine taxa similarity between stream orders.

Detailed methods for GIS analyses are presented in Maurakis et al. (2010). Base maps were developed on 1:24k topographic maps of the study area (USGS 2006, 2010a-c). Collection stations for the study area were imported to the base map as x, y data using latitudes and longitudes collected in the field using a Garmin Oregon 550t GPS receiver. Polygons of the Quantico Creek and Cameron Run study area watersheds were was developed for use in sub-watershed analyses. The Cameron Run study area watershed did not include the portion of the watershed above the Lake Barcroft dam as it was assumed the lake would attenuate flows from that portion of the watershed. Sub-watersheds associated with each collection station were developed through a hydrology analysis of 30 m gridded Digital Elevation Models (ESRI 2008, 2010; USGS 2006, 2010a-c) using a flow accumulation weight of 400. Total population denisty, percent impervious surface and percent vegetated land cover were determined for each sub-watershed using the 2000 U.S. Census Block Group numbers and the 2000 RESAC land cover data (USDC 2009; RESAC 2000 CBW Impervious Surface Product – Version 1.3, CBW Land Cover – Version 1.5).

Correlation analyses (SAS 2009) were performed to determine significant relationships among biotic and physical parameters for each watershed. A General Linear Model followed by Duncan's Multiple Range Test (SAS 2009) was used to determine significant differences for each parameter. Multiple stepwise regression ($p=0.15$, SAS 2009) was used to determine factors accounting for significant variation in species richness in each watershed.

RESULTS

A total of 210 collections of fishes and physio-chemical parameters were made at 15 locations (stream orders, 1, 2, and 3) in Quantico Creek watershed; and 98 collections at seven locations (stream orders 1, 2, 3, and 4) in Cameron Run watershed from November, 2008 to June, 2010. Data and analyses are available upon request. Results are presented within watersheds and then between watersheds.

Quantico Creek watershed: A total of 29 fish species (representing 10 families) were collected in Quantico Creek (Table 1). The most frequently collected species were

TABLE 1. Presence (1) and absence (blank) of fish species collected in Quantico Creek and Cameron Run, VA from November, 2008-June, 2010.

	Quantico Creek Stream Order			Cameron Run Stream Order			
Species	1	2	3	1	2	3	4
Lampetra aepyptera			1				
Petromyzon marinus			1				
Anguilla rostrata	1	1	1			1	1
Esox niger		1	1				
Cyprinidae		1					
Clinostomus funduloides	1	1	1		1	1	1
Semotilus atromaculatus	1	1	1	1	1		1
Rhinichthys atratulus	1	1	1	1	1	1	1
Luxilus cornutus	1	1	1				
Exoglossum maxillingua	1	1	1				
Notropis procne		1	1			1	1
Semotilus corporalis		1	1				
Cyprinella analostana			1			1	1
Notropis hudsonius			1				1
Notemigonus crysoleucas		1	1				
Hybognathus regius			1				
Pimephales notatus						1	1
Catostomus commersoni		1	1	1	1	1	1
Erimyzon oblongus	1	1	1		1		1
Noturus insignis		1	1			1	
Ameiurus natalis			1		1	1	1
Ameiurus nebulosus			1		1		1
Fundulus diaphanus			1			1	1
Fundulus heteroclitus						1	1
Lepomis auritus	1	1	1			1	1
Lepomis gibbosus	1	1	1			1	1
Lepomis cyanellus	1	1	1		1		
Lepomis microlophus		1	1				
Lepomis macrochirus	1	1	1	1	1	1	1
Micropterus salmoides			1		1		1
Etheostoma olmstedi	1	1	1		1	1	1
Channa argus			1				
Total	12	20	29	4	11	15	19

Rhinichthys atratulus (12.3%), *Etheostoma olmstedi* (9.1%), *Lepomis auritus* (9.0%), *Clinostomus funduloides* (7.2%), *Semotilus atromaculatus* (6.1%), *Exoglossum maxillingua* (5.7%), *Semotilus corporalis* (5.6%), *Catostomus commersoni* (5.6%), *Lepomis cyanellus* (5.6%), *Notropis procne* (5.5%), *Noturus insignis* (5.5%) and *Erimyzon oblongus* (5.0%), which accounted for 82.2 % of occurrences of all fishes during the study period (Table 1). Six species (i.e., *N. procne*, *S. corporalis*, *Notemigonus crysoleucas*, *N. insignis*, *L. microlophus*, and *Esox niger*) were common in 2nd and 3rd order streams but not present in 1st order streams. Ten species (i.e., *Cyprinella analostana*, *Notropis hudsonius*, *Hybognathus regius*, *Ameiurus natalis*, *Ameiurus nebulosus*, *Fundulus diaphanus*, *Micropterus salmoides*, *Channa argus*, *Lampetra aepyptera*, and *Petromyzon marinus*) occurred in 3rd order streams only (Table 1).

Total species richness (12, 19, and 29 species) increased with increasing stream order from 1st, 2nd and 3rd order streams, respectively in Quantico Creek (Table 1). Average species richness (9.6) in stream order 3 was significantly greater than those (6.3 and 2.5 species) in stream orders 2 and 1, respectively (Table 2). Similarity of species composition between 1st and 2nd order streams was 60 percent (12 species in common); that between 2nd and 3rd order streams was 63 percent (19 species in common) (Table 3).

Fish species richness was positively correlated with stream order, stream width, depth, and current, stream flow, watershed size, human population, impervious cover, undeveloped land cover and water temperature, and negatively correlated to stream gradient (Table 4). Stream order was positively correlated with stream width, stream depth, stream current, watershed size, human population, impervious cover, undeveloped land, and stream flow; and negatively correlated with elevation, river km, and stream gradient. Percent undeveloped land cover was inversely correlated with human population ($r=-0.3071$; $p<0.0001$) and impervious cover ($r=-0.2454$; $p=0.0006$). The fish species richness model for Quantico Creek is composed of eight variables (Tables 5):

Fish species richness = 0.51449+(0.43460*Season) + (1.73006*Stream Order) + (0.04152*Elevation) + (0.25609*River km) + (0.23222*Stream Width) + (2.00873*Stream Depth) + (0.00081546*Sub-Watershed Size) + (-0.08121*Percent Undeveloped Land Cover)

Cameron Run watershed: A total of 21 species (representing seven families of fishes) were collected in the Cameron Run watershed (Table 1). The most frequently collected species were *R. atratulus* (17.8%), *S. atromaculatus* (10.8%), *C. commersoni* (10.4%), *C. analostana* (7.0%), *A. natalis* (7.6%), *E. olmstedi* (7.6%), *N. procne* (6.7%), and *L. auritus* (6.5%), which accounted for 74.4 % of all occurrences of species during the study period (Table 1). Three species (i.e., *R. atratulus*, *C. commersoni*, and *Lepomis macrochirus*) occurred in all four stream orders. Three species (i.e., *C. funduloides*, *A. natalis*, and *E. olmstedi* occurred only in stream orders 2, 3, and 4. Eight species (i.e., *N. procne*, *C. analostana*, *P. notatus*, *A. rostrata*, *Fundulus heteroclitus*, *F. diaphanus*, *L. auritus*, and *Lepomis gibbosus*) were collected only in stream orders 3 and 4. *Notropis hudsonius* occurred only in stream order 4. Similarity of species composition was low (36 and 30%) between 1st and 2nd order streams and

TABLE 2. Results of Duncan's Multiple Range test (SAS, 2009) of mean values of species richness by stream order in Quantico Creek and Cameron Run watersheds, VA from November, 2008 – June, 2010. Underscored means do not differ significantly at p=0.05.

Quantico Creek Stream Order	1	2	3	
Mean F = 107.1, p>F = <.0001	2.53	6.30	9.65	
Cameron Run Stream Order	1	2	4	3
Mean F = 42.6, p>F = <.0001	2.11	5.32	<u>7.59</u>	<u>8.08</u>

between 2nd and 3rd order streams, respectively; and 70 percent between 3rd and 4th order streams (Table 3).

Total species richness increased with increasing stream order (i.e., 1st order=3 species; 2nd order=11 species; 3rd order=15 species; and 4th order=19 species) in Cameron Run (Table 1). Average species richness values (avg. range=7.6-8.1) in 4th and 3rd stream orders, respectively, were significantly higher than those (avg. range=2.1-5.3) in 1st and 2nd stream orders, respectively (Table 2).

Fish species richness was positively correlated with stream order, stream width, stream current, stream flow, water temperature, watershed size, human population, impervious cover, and undeveloped land cover; and negatively correlated with elevation and river km (Table 4). Stream order was positively correlated with stream width, current, flow, and water temperature; sub-watershed size, human population, impervious cover, and undeveloped land cover; and negatively correlated with elevation, river km, and gradient (Table 4). Sub-watershed size and human population were correlated with impervious cover (r=0.999; p<0.0001 and r=0.984; p<0.0001, respectively), undeveloped land cover (r=0.993; p<0.0001 and r=0.966; p<0.0001, respectively), and stream flow (r=0.354; p=0.0004 and r=0.414; p<0.0001, respectively). The fish species richness model for Cameron Run is composed of four variables (Table 5):

Fish species richness = 10.10139 + (-0.62161*Gradient) + (0.11283*Water Temperature) + (0.18116*Stream Flow) + (-0.03953*Percent Undeveloped Land Cover)

TABLE 3. Number of species per stream order, species in common and unique in stream orders, and Jaccard Coefficient of Similarity of Species in Quantico Creek and Cameron Run watersheds, VA from November, 2008 – June, 2010.

Watershed	Stream order	Total # species	Stream order comparison	# species in common	Species unique to lower order	Species unique to higher order	Jaccard Coefficient of Similarity x 100
Quantico	1	12	1 and 2	12	0	8	60
	2	20	2 and 3	19	1	10	63
	3	28					
Cameron	1	4	1 and 2	4	0	7	36
	2	11	2 and 3	6	5	9	30
	3	15	3 and 4	14	1	5	70
	4	19					

TABLE 4. Relevant significant (>0.05) correlation results of fish species richness and physiochemical parameters in Quantico Creek and Cameron Run watersheds from November, 2008-June, 2010. Blanks indicate non-significant correlations.

	Quantico Creek		Cameron Run	
	Richness	Order	Richness	Order
Order	0.743		0.716	
Width	0.544	0.756	0.640	0.690
Depth	0.364	0.330		
Water current	0.149	0.272	0.346	0.368
Stream flow	0.254	0.265	0.372	0.409
Sub Watershed size	0.541	0.776	0.562	0.874
Human population	0.483	0.581	0.656	0.894
Impervious cover	0.339	0.384	0.565	0.871
Undeveloped land cover	0.543	0.788	0.561	0.902
Water Temp	0.165		0.438	0.203
Gradient	-0.448	-0.519		-0.831
Elevation		-0.309	-0.831	-0.916
River km		-0.160	-0.574	-0.734

Interdrainage comparisons

GIS Parameters: Human population (103,728) in the 4th order Cameron Run sub-watershed was significantly greater than those (avg. range=0-44,811) in all Cameron Run and Quantico Creek sub-watersheds (Table 6). Impervious cover (3,428.4 ha) in the 3rd and 4th order sub-watersheds of Cameron Run were significantly greater than those (avg. range=12.4-1,412.2 ha) in all other sub-watersheds of both Cameron Run and Quantico Creek (Table 6). Percentage (avg. range=83.35-94.39) of hectares of undeveloped land cover in 1st, 2nd, and 3rd sub-watersheds of Quantico Creek were significantly greater than those (avg. range=26.67-48.22) in 1st, 2nd, 3rd, and 4th order sub-watersheds of Cameron Run (Table 6).

TABLE 5. Results of stepwise multiple regression for fish species richness in Quantico Creek and Cameron Run watersheds, VA from November, 2008 – June, 2010.

Quantico Creek Variable	Parameter Estimate	F Value	Pr > F
Intercept	0.51449	0.11	0.7361
Season	0.4346	12.7	0.0005
Stream order	1.73006	16.97	<.0001
Elevation (m)	0.04152	21.85	<.0001
River Km	0.25609	31.75	<.0001
Stream width (m)	0.23222	3.32	0.0703
Stream depth (m)	2.00873	3.5	0.0633
Watershed size (ha)	0.00081546	8.74	0.0036
% Undeveloped land cover	-0.08121	31.89	<.0001

Cameron Run Variable	Parameter Estimate	F Value	Pr > F
Intercept	10.10139	117.04	<.0001
Stream gradient (m/km)	-0.62161	145.77	<.0001
Stream flow (m3/sec)	0.18116	4.12	0.0463
Water Temperature (C)	0.11283	23.98	<.0001
% Undeveloped land cover	-0.03953	6.99	0.0102

Fish species richness and composition: Overall, nine species (i.e., *L. cornutus*, *E. maxillingua*, *S. corporalis*, *N. crysoleucas*, *Hybognathus regius*, *Lepomis microlophus*, *Channa argus*, *Lampetra aepyptera*, and *Petromyzon marinus*) present in Quantico Creek were not collected in Cameron Run watershed (Table 1). Nine species (i.e., *C. funduloides*, *L. cornutus*, *E. maxillingua*, *E. oblongus*, *A. rostrata*, *L. auritus*, *L. gibbosus*, *L. cyanellus*, and *E. olmstedi*) were present in 1st order streams of Quantico

TABLE 6. Results of Duncan's Multiple Range Test (SAS, 2009) among watershed size (ha), human population, impervious cover (ha), undeveloped land cover (ha), and % undeveloped land cover in Quantico Creek and Cameron Run watersheds, VA. Underscored means do not differ at p=0.05.

Watershed size							
Habitat	Quantico-1	Cameron-1	Quantico-2	Cameron-2	Cameron-3	Quantico-3	Cameron-4
Mean	71	152	581	605	2011	3371	4808
F = 7.17, p>F = 0.0009							
Human population							
Habitat	Quantico-1	Quantico-2	Quantico-3	Cameron-1	Cameron-2	Cameron-3	Cameron-4
Mean	0	240	1250	2342	10957	44811	103728
F = 69.12, p>F = <.0001							
Impervious cover							
Habitat	Quantico-1	Quantico-2	Cameron-1	Quantico-3	Cameron-2	Cameron-3	Cameron-4
Mean	12.4	41.0	91.3	188.8	287.8	1412.2	3428.4
F = 16.19, p>F = <.0001							
Undeveloped land cover							
Habitat	Cameron-1	Quantico-1	Cameron-2	Quantico-2	Cameron-3	Cameron-4	Quantico-3
Mean	59.0	67.8	291.2	550.3	809.5	1599.5	3059.5
F = 7.40, p>F = 0.0008							
% Undeveloped land cover							
Habitat	Cameron-1	Cameron-4	Cameron-3	Cameron-2	Quantico-2	Quantico-3	Quantico-1
Mean	26.7	33.3	41.6	48.22	83.4	93.0	94.4
F = 12.90, p>F = <.0001							

Creek but not collected from 1st order streams of Cameron Run. In a comparison of 2nd order streams, *L. cornutus*, *E. maxillingua*, *N. procne*, *S. corporalis*, *N. chrysoleucas*, *N. insignis*, *A. rostrata*, *F. diaphanus*, *L. auritus*, *L. gibbosus*, and *L. microlophus* were present in Quantico Creek 2nd order streams but not in those of Cameron Run. A total of 14 species (i.e., *L. cornutus*, *E. maxillingua*, *S. corporalis*, *N. hudsonius*, *N. chrysoleucas*, *H. regius*, *E. oblongus*, *A. nebulosus*, *L. cyanellus*, *L. microlophus*, *M. salmoides*, *C. argus*, *L. aepyptera*, and *P. marinus*) occurred in 3rd order streams of Quantico Creek but were absent from 3rd order streams of Cameron Run (Table 1). In contrast, only two species (i.e., *Pimephales notatus* and *Fundulus heteroclitus*) occurred in both 3rd and 4th order streams of Cameron Run but not in any stream orders of Quantico Creek (Table 1).

Species richness (avg.=9.65) in 3rd order Quantico Creek was significantly higher than those (avg. range=7.6-8.1) in 3rd and 4th orders in Cameron Run (Table 7). Species composition similarity in Quantico Creek 1st and 2nd order streams (60 %) and that between 2nd and 3rd order streams (63 %) were about twice those in Cameron Run 1st-2nd order (36 %) and Cameron Run 2nd-3rd order (30 %). Cameron Run species composition similarity (70 %) between 3rd and 4th order streams was comparable to that (63 %) for Quantico Creek 2nd-3rd order (Table 3).

DISCUSSION

Long-term studies of discrete stream segments or stream orders are crucial to understand and predict changes in fish communities that may result from changes in system parameters. The present investigation resulted in establishing a broad scope of baseline data for fish communities, and creating models for fish species richness in two mid-Atlantic stream systems, lower Piedmont forest (Quantico Creek) and urban (Cameron Run) watersheds. The current study's baseline data and models are requisite for future comparative studies of these mid-Atlantic streams relative to changes in system parameters (e.g. human population, corresponding anthropogenic effects, and climatic changes that have been modeled for the mid-Atlantic region). For example, the population in the Cameron Run watershed has been projected to increase by 100 percent or more by 2050 (CARA 2006). The high human population and impervious cover in the Cameron Run watershed were significant factors accounting for reduced species richness compared to that in Quantico Creek watershed (Table 6). These results suggest that the forecasted population growth has the potential to significantly impact fish communities in the Cameron Run watershed. Our study's predictive model captures this relationship, which can be applied in determining alterations in fish communities relative to these and other forecasted changes in this urban watershed. The use of this predictive model in the land planning process can facilitate the environmental impact avoidance and minimization analysis of proposed development plans in a watershed that is already significantly impacted relative to the nearby forested Quantico Creek watershed. Studies of plant species richness by Tilman (2001) and Tilman et al. (1997, 2006) and those of aquatic food webs by Steiner et al. (2005) have demonstrated that more species diverse communities are more resilient to environmental changes than those with fewer species. Higher degrees of biodiversity

TABLE 7. Results of Duncan's Multiple Range Test (SAS, 2009) of fish species richness by stream order in Quantico Creek (QC) and Cameron Run CR) watersheds, VA from November, 2008 – June, 2010. Underscored means do not differ at p=0.05.

Habitat	CR-1	QC-1	CR-2	QC-2	CR-4	CR-3	QC-3
Mean F=61.51, p>F=<.001	2.11	2.53	5.32	6.30	7.59	8.08	9.65

in a community or in an ecosystem give the systems stability (Tilman 1997). A worthwhile research project in the future will be to determine if the already compromised fish communities in each of the stream orders of Cameron Run will be able to sustain themselves relative to the projections of increased human population and concomitant impacts (e.g. additional stream pollutants, habitat alteration, and potential decreases in remaining forest cover), and hydrologic changes that may be associate with climate change modeled for the area. In a report on the effects of climate change in the Champlain Basin, Stager and Thill (2010) indicated that rising temperatures may also exacerbate late-summer low flows by increasing evapotranspiration through vegetation and evaporation from land and water surfaces, warmer and less oxygenated tributaries in summer, changes in the timing of spawning, increased erosion and siltation, and physical disruption of streambeds.

The variability in terrestrial and aquatic features that defines discrete segments in watersheds is crucial to take into account when making comparisons between ichthyofaunas in different watersheds. Of particular note is the trenchant difference between the parameters that comprise the mathematical models for the forested Quantico Creek watershed and the urbanized Cameron Run watershed. Fish species richness in Quantico Creek watershed currently can be modeled by eight factors: season, stream order, elevation, river km, stream width and depth, watershed size and percent of undeveloped land cover (Table 5). That in Cameron Run can be modeled with three different factors (stream gradient, stream flow, and water temperature), and one (percent undeveloped land cover) also used in the Quantico Creek model (Table 5). Therefore, it cannot be assumed that a model composed of one set of variables that represents species richness for a given watershed can be applied to a nearby watershed. As a result, researchers should evaluate species richness by discrete segments within a given watershed as the abiotic and biotic features defining these segments cannot be assumed to be comparable within or between watersheds. We caution that direct applications of our two species richness models to other watersheds are limited because they are unique to watersheds we studied.

Anthropogenic effects have been demonstrated to impact species richness independently of stream order as was observed in Cameron Run. For example, Schlosser (1987) stated that species richness tended to increase from modified to natural upstream areas. Based on the differences in species richness models between Quantico Creek and Cameron Run watersheds, we propose that stream order and its other correlated factors used to model species richness in forested watersheds where human disturbance is minimal, are not appropriate for streams in highly modified urban environments such as those in the Cameron Run watershed. For example, total species richness (4 and 11) in 1st and 2nd order streams of Cameron Run were lower than those (12 and 20) in 1st and 2nd order streams of Quantico Creek, respectively, and those (range=15-22 in 1st order; range=17-33 in 2nd order streams) in the lower Piedmont and upper Coastal Plain provinces of the Rappahannock River drainage reported by Maurakis et al. (1987). The low species richness in 1st and 2nd order streams in the urbanized Cameron Run is not unlike those of harsh environments (e.g. streams in desert and boreal environments) summarized by Hutchinson (1993). Likewise, species richness in 2nd and 3rd order streams in Quantico Creek watershed were significantly higher than those in 2nd, 3rd, and 4th order streams in the Cameron Run watershed (Table 1), which reflects the differences in habitat characteristics (stream widths and depths, water temperature, human population, impervious cover, and percent undeveloped land cover between the forested Quantico Creek and urbanized Cameron Run watersheds (Table 6).

Lawrence et al. (2011) assessed the representation of freshwater fish diversity provided by the National Park Service (NPS) and the potential for parks to serve as freshwater protected areas (FPA) in the United States. They identified 50 national parks that could serve as a comprehensive system of freshwater protected areas in the country as 62 % of native fishes reside in national parks. Prince William Forest Park, however, was not designated as a FPA in the assessment by Lawrence et al. (2011). However, the potential impacts of increased population growth and climate change in the area, coupled with a paucity of information on the extent of the use of the lower reaches of Quantico Creek as a spawning area for anadromous fishes, we propose that the national park, Prince William Forest Park, should be included as a freshwater protection area for the Quantico Creek watershed, now wholly contained within the Prince William Forest Park, and the upper undisturbed areas in the US Quantico Creek Marine Base.

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