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A COMPARISON OF FIVE NORTHERN VIRGINIA WATERSHEDS IN CONTRASTING LAND USE PATTERNS

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ABSTRACT

A study of the benthic macroinvertebrate community composition was conducted at five sites in Northern Virginia with contrasting land use patterns to determine the relative impact of the degree of urbanization on the biological condition of those watersheds. The biological diversity and productivity of the receiving streams was assessed through the collection and subsequent analysis of benthic invertebrates and periphyton in accordance with scientifically established procedures. Various physical and chemical parameters were also addressed in order to establish their relationship to the biological diversity and productivity of the streams. These parameters were water flow, pH, alkalinity, chlorophyll level, and suspended solids. The biological diversity of the benthic organisms and periphyton was found to be greater in those watersheds with a lower degree of urbanization. There were twenty or more taxa in the least developed areas and as few as eight in the most developed areas. The more urbanized area streams also had a substantially greater percentage of pollution-tolerant algal species and the chlorophyll-a values were greater as well. Furthermore, the quantity of suspended solids increased along with the degree of urbanization, in accordance with similar studies of this phenomenon, displaying increased erosion associated with reduced ground cover, especially during storm events.

The role of biological evaluation of polluted streams has long been recognized. Kolkwitz and Marsson published articles in 1908 and 1909 that delineated the responses of aquatic plant and animal species to sewage in slow- and even-flowing rivers [1, 2]. Ellis wrote in 1937 about the detection and measurement of stream pollution and effects of various waste on stream environments with fish as the biotic indicator [3]. Patrick noted in 1949 that a healthy stream reach was one in which the biodynamic cycle is such that conditions are maintained that are capable of supporting a great variety of organisms [4].

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Mackenthun suggested in 1968 that the total living aquatic community must be considered in any analysis of the effects of pollution [5]. Fish, bottom dwelling macroinvertebrates, plankton and attached algae are all important segments of the total community of stream organisms. A study of any of these organism groups can be projected through the aquatic food chain to predict effects on higher aquatic organisms and other species that feed upon them.

As an area becomes more urbanized the pollutant load in the watershed runoff of that area tends to increase. Several researchers have demonstrated some relationship between the degree of urbanization and the effect of urban land use practices on the quality of aquatic ecosystems [6-12].

In a study on non-point source (NPS) urban runoff, Porcella and Sorenson noted that because the control of non-point source runoff is expensive, it is important to determine its specific impacts on stream communities [9]. However, as Porcella determined through a review of the literature on the ecological effects of urban runoff on stream communities, there appears to be a dearth of principles for evaluating the impact of urban runoff on streams [10]. Porcella noted that there is a serious lack of studies that determine urban runoff impacts on communities of stream ecosystems. Increasing emphasis, however, has been placed on the pollution contributions from non-point sources such as runoff from agricultural lands and forestry management practices [13] and urban storm runoff [12; 14-17].

In his review of several case studies on urban runoff impact, Porcella [10] determined that the most effective indicators for monitoring impulse impacts on streams were macroinvertebrates and periphyton. However, there are limitations associated with the use of such indicators. When diversity and biomass are used for analysis of monitoring data, they are not always sufficiently sensitive to support or refute the hypotheses set out at the beginning of a study. Consequently, stream flow and the interactions of the watershed, hydrologic and transport characteristics should be examined to determine stream quality [9]. That is, the degree of stream quality impairment will be determined largely by the characteristics of the watershed of its origin. Klein [7] found a direct correlation between the degree of impairment and the degree of urbanization in adjacent watersheds in his study of the effects of urbanization on stream quality.

In a study on water quality and the biological effects of urban runoff in Coyote Creek near San Jose, Pitt and Bozeman [11] identified a clear relationship between the amount of sediment suspended in urban runoff and the quality of the aquatic community in associated streams. Much more silt was found in urban samples, signifying a greater discharge of finer sediments from the urban area. In their examination of the fish and benthic macroinvertebrate populations, Pitt and Bozeman found that the populations in the urbanized portion of the stream lacked the diversity of the non-urbanized section. The urbanized portion of the stream was dominated by pollution-tolerant-fish and -benthic invertebrates.

Brown and Green [12] conducted a comparative study on stormwater impacts between urban and non-urban streams in different parts of the state of North Carolina. They monitored both physico-chemical (pH, temperature, dissolved oxygen, five-day BOD (biological oxygen demand), COD (chemical oxygen demand), fecal coliform, ammonia-nitrogen, total phosphorous, iron, solids, and various metals and biological parameters (aquatic benthic macroinvertebrates).

Brown and Green found all of the urban streams monitored to be extensively biologically degraded. Populations of the pollution-tolerant organisms Diptera and Oligachaeta comprised over 90 percent of the average standing crops of fauna. The intolerant groups were either reduced in numbers in the urban streams or they were absent entirely. In contrast, the mountain streams had a maximum of 15 percent pollution-tolerant organisms and the Piedmont streams had a maximum of 35 percent.

A methodological approach similar to the ones identified above was used to study the apparent impacts of urbanization on the biota in five different watersheds in Northern Virginia in the fall of 1982. The intent of the study was to display the effect of watershed urbanization on the taxonomic composition and diversity of periphyton and benthic invertebrates. Also examined were the effects of watershed urbanization on physical characteristics of streams and how those characteristics may account for differences in the biota between more and less urbanized watershed streams.

SAMPLING LOCATION DESCRIPTION

In order to minimize the effects of confounding variables, five streams of similar size, geology and geographical location whose watersheds differed in land use patterns were selected for the analysis. The sampling effort was intended to demonstrate the effects of the degree of urbanization on the biological community and selected physical-chemical characteristics of the streams.

Watershed Sites

North Quantico Creek Site – North Fork of the Quantico Creek which is a tributary of the Potomac River is located in Prince William County, Virginia forty-five miles south of Washington, D.C. The collection site was in the center of Prince William Forest National Park. The stream at the sampling site was 3.5 meters wide, approximately 14.5 centimeters deep, and had a substrate of sand, rubble, and bedrock. The stream had slow to moderate current and vegetation consisting of scattered rooted aquatic plants and filamentous algae. The shorelines were heavily wooded with substantial overhanging vegetation. Although this site was a National Park, portions of the park had been settled prior to dedication as a park, and using Antoine's [18] suggested categorization based on typical lot size the degree of urbanization of this area was approximately 15 percent.

Accotink Creek Site – Accotink Creek which is a tributary of Lake Accotink is located in Fairfax County, Virginia on the eastern side of Fairfax City twenty-five miles west of Washington, D.C. The sampling site was just south of Route 50. The streambed was sand, gravel, and rubble with some rooted plants and filamentous algae present. Overhanging vegetation consisting of tree, tree roots, and grasses was present along portions of the streambank. Stream depth at the site averaged 17.8 centimeters and the width was approximately 3 meters. Current was slow to moderate.

The sampling site was adjacent to a highly urbanized area with large asphalt-covered parking lots in the vicinity. Shortly upstream was a golf course on the boundary of one bank. Using Antoine's categorization the degree of urbanization would be 40-80 percent.

Pope's Head Creek Site – Pope's Head Creek which is a tributary to the Occoquan River is also in Fairfax County, Virginia. The collection site was adjacent to Fairfax Station Road. The stream at this site was about 2 meters wide and approximately 12.8 centimeters deep and had a substrate of sand, rubble, and bedrock. The stream had moderate to low flow. Scattered rooted aquatic plants and filamentous algae were present. The shorelines were wooded with substantial overhanging vegetation. The site had limited urbanization in the immediate area of sampling. Fairly low density suburban-type housing was scattered upstream of the sampling site. Using Antoine's scale [18] the degree of urbanization could be categorized as 25–40 percent.

Holmes Run – Holmes Run which is a tributary of the Potomac River is located in Fairfax County, Virginia about eighteen miles west of Washington, D.C. The collection site was adjacent to the Sleepy Hollow residential area.

The stream at the collection site was about 4 meters wide, approximately 14 centimeters deep and had a substrate of sand, rubble, and bedrock. The stream had moderate flow with little aquatic vegetation present. A review of the weather data revealed that a moderate-to-heavy storm event had occurred on the day before the sampling. This may have had some flushing effect on the benthos and periphyton. The stream was bordered with open lawns and occasional overhanging trees (although the overhang was sparse). The site was heavily urbanized with numerous homes and townhouses in the area. According to Antoine's categorization, the degree of urbanization was approximately 80 percent.

Difficult Run – Difficult Run which is a tributary of the Potomac River is also in Fairfax County. The collection site was adjacent to the intersection of Waples Mill Road and Fox Mill Road between Fairfax City and Reston.

At the collection site, the stream was approximately 1-2 meters across and about 14 centimeters in depth. The streambed consisted of sand, rubble, and small rocks. Vegetation in the form of overhanging grasses and trees was present with occasional rooted aquatic plants. A large open, grassy field was adjacent to one bank. Flow was moderate with moderate-to-fast currents. A review of the weather data revealed that a moderate-to-heavy storm event occurred on the previous day which may have caused some flushing of organisms. The collection site was characterized by little immediate urbanization and those houses present were of relatively recent origin. Using Antoine's categorization, the degree of urbanization was approximately 25 percent.

SAMPLING METHODS

Biological Samples

Macrobenthic organisms were collected with a Surber mesh net square foot sampler according to standard methods recommended by Weber [19]. The samples were taken in riffles ecologically similar as to bottom type and flow characteristics. Samples were fixed in the field in 10 percent formalin solution and transferred to the laboratory where the organisms were handpicked from among the gravel and detritus and then preserved in pre-labeled jars filled with a 70 percent ethanol solution. With the aid of a dissecting microscope, the specimens were sorted and identified to the genus level, and where possible, to species, using keys such as Pennak [20] and Ward and Whipple [21]. The Shannon and Weaver [22] diversity index was selected for use in evaluating the species' diversity at each site.

Periphyton samples were collected in accordance with standard methods similar to those recommended by the American Public Health Association [23]. A proper transect of the stream was selected and fist-sized rocks were collected at five equal intervals across the stream. This was done in both a shady and a sunny section of the stream. The periphyton were scrubbed from the rocks with a stiff brush and specific volumes of the suspension containing the periphyton were filtered through glass filters. The samples were put on ice in the field and were transported back to the laboratory where they were analyzed by means of procedures recommended by APHA [23] for determination of Chlorophyll-a in the presence of Pheophytin-a. The materials collected on the filters were extracted with acetone and spectrophotometric measurements were made to determine the amount of Chlorophyll present in the algal cells of the water sample. A small glass jar was also filled with an aliquot of the periphyton and fixed in Lugol's iodine for later examination in the laboratory with a light transmission microscope. Specimens were identified to the genus level using Prescott's system of classification. The air and water temperature and dissolved oxygen concentration were determined electronically with a YSI (Yellow Springs Instruments) Oxygen Meter and the conductivity of the water samples was measured with a YSI-33 Conductivity Meter.

Physical-Chemical Sampling

The alkalinity, pH and hardness of the stream water were determined in the field using chemical analysis procedures recommended by the American Public Health Association [23]. The alkalinity was determined by means of the bromcresol green-methyl red indicator method. The hardness was determined through a Hach colorimetric method though an electrometric method may be preferred since the colors in the testing device can fade over time. The amount of suspended solids in the stream water was determined by filtering through glass filters and the filtrate was taken to the laboratory where it was weighed, baked and reweighed to determine dry weight.

RESULTS

The results of this study are in general agreement with the previously mentioned research on the subject of the effect on urbanization on water quality. A definite relationship was found between the degree of urbanization and the quality of the water as reflected in the biotic population and selected physical-chemical characteristics. Of the five sites where benthic invertebrate samples were collected, the three less-urbanized sites had the greatest diversity. The less-urbanized sites were in the good to excellent range on the Wilhm–Dorris diversity index scale [24] while the more-urbanized areas fell into the fair range.

The potential analysis of the diversity of algal species was constrained due to poor data recording procedures. Consequently, there was little that could be identified as a general trend in algal diversity. However, of the samples from the five sites those from the most-urbanized areas tended to have more pollution-tolerant algae present and more algal biomass than those taken from the less-urbanized sites.

The data from the study are summarized in Tables 1 through 8 and are discussed in the following sections.

Benthic Macroinvertebrates

There appears to be a definite relationship between the quality of the biological communities in a stream and the degree of urbanization. Analysis of the quality of the macroinvertebrate populations was accomplished through computation of diversity values by means of the Shannon–Weaver Diversity Index [22]. These values are found in Table 1.

The streams with the least amount of urbanization had the greatest diversity of macroinvertebrate species. The North Fork of Quantico Creek site which was situated in a primitive forested woodland had the greatest species diversity value, 3.312. This value falls into the excellent range on the Wilhm–Dorris Index [24] used to assess biological parameters for water quality. In contrast, the Holmes Run site which was a densely-populated residential area had the lowest diversity value, 1.469, which falls into the fair range on the Wilhm–Dorris Index.

Table 1. Diversity Analysis of Benthic Macroinvertebrate Species by Sampling Location

	H'	$\bar{H}'$	*Number Taxa*	*Number Organisms*
North Quantico Creek	3.312	3.343	20	348
Accotink Creek	1.779	1.774	12	409
Pope's Head	2.606	2.660	25	517
Holmes Run	1.469	1.464	8	94
Difficult Run	3.094	3.067	20	348

H' = Shannon-Weaver Diversity Index based on total numbers of organisms.
$\bar{H}'$ = Shannon-Weaver Diversity Index based on means of averages.

These diversity values can be better appreciated when they are correlated with the apparent degrees of urbanization of the sampling sites. Using an assessment approach similar to that suggested by Antoine [18] the collection sites could be ranked in the following manner: 1) Holmes Run (most urbanized); 2) Accotink Creek; 3) Pope's Head Creek; 4) Difficult Run; and, 5) North Quantico Creek (least urbanized).

When this ranking of degree of urbanization is compared with the ranking of the species diversity values there appears to be a direct correlation. Without implying any causal relationship, it appears that as the degree of urbanization increases there is a corresponding decrease in benthic macroinvertebrate species diversity (Table 2).

In her study on the effects of light and temperature on the structure of diatom communities, Patrick [4] found that in an ordinary diverse habitat many species occur in small numbers, but none is very abundant. She also concluded that in a severe habitat there tends to be few rare species while a few species are present in large numbers. Similar patterns were found in the data on macroinvertebrates in this study. At the more-urbanized sites (those with greater environmental stress), there were a large number of individuals in one species with a low number or none in many of the species examined. Conversely, there was a much more even spread in the number of individuals across several species at the less-urbanized sites with the best spread in the number of species at the North Fork Quantico Creek site (Table 3).

Like other aquatic organisms benthic macroinvertebrate species differ in their ability to tolerate pollution and as such become good water quality indicators. Cairns and Dickson [25], Mason, et al. [26], and Hynes [27], have identified Plecoptera (stoneflies), Trichoptera (caddisflies), Ephemeroptera (mayflies), and Coleoptera (beetles) as particularly pollution-sensitive or intolerant organisms. More specifically, Woodiwiss, using an extended Trent Biotic Index, found that these species tend to disappear in the following order as the degree of pollution

Table 2. Rank Order of Degree of Urbanization and Species Diversity by Sampling Location

Location	*Degree Urbanization (Percent)*	*Rank*	*Species Diversity*	*Rank*
North Quantico Creek	15	1	3.312	1
Difficult Run	25	2	3.094	2
Pope's Head Creek	25-40	3	2.606	3
Accotink Creek	40-80	4	1.774	4
Holmes Run	80	5	1.469	5

Table 3. Number of Benthic Macroinvertebrate Species Summed by Order by Sampling Location

	Quantico Creek	*Accotink Creek*	*Pope's Head Creek*	*Holmes Run*	*Difficult Run*
Trichoptera	51	264	245	68	138
Ephemeroptera	50	14	47	5	96
Plecoptera	13	1	0	0	0
Diptera	32	17	130	4	58
Coleoptera	7	0	56	4	11
Odonata	0	0	4	0	1
Mollusks	1	34	1	0	5
Annelids	4	63	33	12	20
Nematoda	4	16	0	1	8
Neuoptera	17	0	0	0	9
Crustaceans	1	0	1	0	2
Salamander	1	0	0	0	0
Total	181	409	517	94	348

increases: First, Plecoptera disappears; Second, Ephemeroptera; Third, Trichoptera (or *Baetis rhodani*) [28].

Table 3 indicates that the most sensitive species, Plecoptera, was virtually absent from all sites except the heavily forested North Quantico Creek area. Although it may not be desirable to make a classification on the basis of a single group, it is noteworthy that the two more urbanized sites (Holmes Run and Accotink Creek) have very low populations of the second most sensitive group as well. However, in line with standard ecological principles, there is a heavy loading on the third most sensitive species (Trichoptera) for Holmes Run and Accotink Creek. The Trichoptera population apparently increased in order to fill the void created by the absence of Plecoptera and the low incidence of Ephemeroptera. It should also be noted that the Trichoptera represented the greatest number of species for all sites.

Algae

Although certain limitations exist in the manner in which the algal data were reported in this study, certain gross trends in the types of algae present still provide helpful information. The algal samples are interpreted through the apparent diversity of species and through an assessment of the chlorophyll-a biomass. This approach was taken in order to determine whether effects similar to those found by Staub, Appling, Hogstetter and Haas were present in this study [29]. In a study on the effects of industrial wastes they found that less populated and less industrialized areas supported higher diversities among planktonic river diatoms than collection sites in heavily populated locations.

The algae gathered at the collection sites is categorized into two groups in Tables 4 and 5: 1) polluted water algae, and 2) clean water algae according to the categorization established by the noted authority on freshwater algae, C. M. Palmer [30]. No apparent trend or pattern can be determined from this categorization, alone, given the nature of the data. However, Palmer [31] developed an index in the form of a composite rating of algae that tolerate organic pollution. Using this approach, as in Table 5, the available data seem to indicate a pattern similar to that found by Staub, et al. [29]. The more-urbanized sites had a substantially greater percentage of total species that are pollution tolerant (53-68%) versus the least-urbanized sites (29-32%).

Although all of the streams sampled in this study were of the same order, it is noteworthy that Seyfer and Wilhm [32] found in a study on the effect of stream order on species composition, diversity, biomass, and chlorophyll of periphyton that an increasing number of pollution-tolerant algae were present as the stream order increased and that chlorophyll-a and ash-free weight values decreased with increased order. The increase in the number of pollution-tolerant

Table 4. Number and Percent of Pollution Tolerant Algae by Genera by Sampling Location

	Total Number of Genera	*Number of Pollution Tolerant Genera*	*Percent*
North Quantico Creek	19	6	32
Accotink Creek	16	11	68
Pope's Head Creek	NA	NA	NA
Holmes Run	19	10	53
Difficult Run	28	8	29

NA = Not available (due to reporting error).

Table 5. Algae Classification by Sampling Location

	Polluted Water Algae (Number)	*Clean Water Algae (Number)*
North Quantico Creek	*Chlamydomonas* (rare)	*Meridion* (rare) *Cyclotella* (occasional) *Ulothrix* (occasional) *Micrasterias* (rare)
Accotink Creek	*Chlorella* (frequent) *Gomphonema* (frequent)	*Ulothrix* (occasional) *Rhizoclonium* (occasional) *Ankistrodesmus* (rare) *Cocconeis* (frequent) *Cyclotella* (occasional) *Microcoleus* (rare) *Ulothrix* (rare)
Pope's Head Creek	*Lyngbya* (occasional) *Chlorella* (occasional) *Gomphonema* (occasional)	*Cyclotella* (frequent) *Ulothrix* (occasional) *Rhizoclonium* (occasional) *Ankistrodesmus* (rare) *Cocconeis* (frequent)
Holmes Run	*Nitzschia* (frequent) *Stigeclonium* (rare) *Spyrogyra* (rare) *Oscillatoria* (rare)	*Cocconeis* (frequent) *Meridion* (rare) *Ulothrix* (frequent)
Difficult Run	*Nitzschia* (occasional) *Stigeoclonium* (rare) *Oscillatoria* (rare)	*Cocconeis* (rare) *Meridion* (occasional) *Ulothrix* (frequent) *Microcleus* (rare)

Note: Categorized according to C. Mervin Palmer [30].

algae found in higher order and, therefore, probably more-urbanized streams is somewhat substantiated. With the exception of North Quantico Creek, the data in Table 4 indicate greater chlorophyll-a weight values for the more-urbanized streams and lower weight values for the less-urbanized areas.

The data in Table 6 also appear to corroborate the findings of Odum [33], where he notes that when photosynthesis exceeds respiration in an aquatic community the chlorophylls predominate and that the carotenoids tend to increase as the community respiration increases. When the amount of chlorophyll-a is placed in rank order, by collection site, the pattern is quite distinct: ranks 1-4 were sunny sites and ranks 5-8 were shady sites.

Physical-Chemical Patterns

The effects of the degree of urbanization on the physical and chemical composition of water in associated watersheds varies significantly. In this section, the impacts of the degree of urbanization on selected physical-chemical

Table 6. Comparison of Chlorophyll-a Biomass Content and Pheopigment Between Sunny and Shady Sites by Sampling Location

	Sunny Site ($\mu g/cm^2$)	*Shady Site ($\mu g/cm^2$)*
Chlorophyll-a		
North Quantico Creek	NA	4.82 (NA)
Accotink Creek	4.24 (2)	.48 (8)
Pope's Head Creek	3.48 (3)	2.57 (5)
Holmes Run	5.39 (1)	1.86 (7)
Difficult Run	2.76 (4)	2.42 (6)
Pheopigment		
North Quantico Creek	NA	2.51 (NA)
Accotink Creek	1.28 (4)	.19 (8)
Pope's Head Creek	.65 (7)	1.33 (3)
Holmes Run	1.47 (1)	.86 (6)
Difficult Run	1.34 (2)	.93 (5)

Note: NA = not available; numbers in parentheses = rank.

parameters is discussed with some attention given to the consequences of those impacts on biota living in the streams.

Temperature

As an area becomes more urbanized, perhaps the most striking feature is that the amount of vegetative cover is reduced significantly. The consequences of this reduction in vegetation are often reflected by altered physical-chemical characteristics in streams draining the area. In a study on the effect of urbanization on water temperature, Pluhowski determined that urban streams tend to be 10 degrees to 15 degrees Fahrenheit above those in an nonurbanized area [17]. Greater direct exposure to solar radiation and indirect consequences from solar-heated runoff appear to be the principal sources of the noted change.

However, as the data in Table 7 indicate there is virtually no appreciable difference in temperatures between the more- and less-urbanized streams in this study. There is only a slight increase in temperature for the urbanized areas (.5° on the first day and .2° on the second day). It is possible that since there were several hours between measurements and the more urbanized areas were measured first, the degree of difference may have been offset partially by solar radiation.

The biological consequence of slight increases in temperature according to Patrick [4] is that larger populations of the species that are present occur and thus the total biomass of the community increases with possible reductions in

Table 7. Physical-Chemical Characteristics by Sampling Location

Variable	*North Quantico Creek*	*Accotink Creek*	*Pope's Head Creek*	*Holmes Run*	*Difficult Run*
Temperature (Water—Co)	20	17	16.5	13	12.8
Temperature (Air—Co)	—	18	19.5	12	13
pH	7.0	7.0	7.0	7.5	7.0
Alkalinity (mg/1 as $CaCO_3$)	22	47	33.5	40	40
Dissolved Oxygen (mg/1)	10	6.9	8.9	9.65	11.3
Hardness (mg/1 as $CaCO_3$)	34	100	65.5	113	80
Conductivity (μmho)	45	150	100	188	79
Suspended Solids	.5[a]	7.7	7.4	5.15[a]	3.0[a]
Flow Discharge (cms)	NA	588.7	282.2	1969.9	600.7

[a] Average when more than one reading taken.
NA = not available.

dissolved oxygen. Furthermore, Anderson and Faust conclude that over a fourteen-year period there was a reduction in dissolved oxygen content in the Passaic River at Little Falls, New Jersey from 78 percent to 62 percent saturation [34]. They attributed this change to the increase in population and, hence, degree of urbanization over the test period.

Dissolved Oxygen

Decreased dissolved oxygen levels can adversely affect aquatic insect larvae and nymphs and other animals on which fish feed [35, 36]. The recommended minimum concentration of dissolved oxygen (D.O.) is 5.0 mg/l (U.S. Environmental Protection Agency [37]) in order to support a well-rounded population of fish as suggested by Ellis [3] to be an indicator of clean water. The data in Table 7 indicate that all of the sampling sites had dissolved oxygen concentrations greater than 5.0 mg/l. The range of 6.9-11.3 mg/l would indicate that dissolved oxygen was probably not a limiting factor on the aquatic community at these selected sites.

The fact that there was more dissolved oxygen in the water measured at each of the less urbanized sites when compared individually with the more urbanized sites measured on the same day, may be attributed to the degree of urbanization. But, the additional fact that each of these latter measurements were conducted later in the day may mean that the photosynthetic process may have contributed to the difference. Also, those streams examined on the second day may have had higher readings partially as a result of the previous day's storm event.

Alkalinity

The degree of alkalinity of water is important for aquatic organisms in freshwater systems because it buffers pH changes that occur as a result of photosynthetic activity of green plants in the water [37]. The National Technical Advisory Committee on Water Quality recommends a minimum alkalinity of 20 mg/l to maintain the quality of the water [38]. Consequently, since the range of alkalinity readings from the samples taken in this study had a range of 22–47 mg/l, alkalinity was probably not a limiting factor to the aquatic community. In all instances, however, the alkalinity values in the streams in the more urbanized areas (Holmes Run and Accotink Creek) were greater to or equal to those in the less urbanized areas.

The U.S. Environmental Protection Agency indicates that since the degree of dissociation of weak acids or bases is affected by changes in pH it is an important factor in the chemical and biological systems of natural waters [37]. Furthermore, the toxicity of chemicals can be altered by changes in pH. Delfino and Lee found that the solubility of metal compounds located in bottom sediments or suspended matter is affected by pH [39]. The data in Table 7 point out that there was virtually no change in pH values across the sites with the exception of the most urbanized area, Holmes Run which had a pH value .5 higher than the other sites. Given the exponential nature of pH values, this represents a significant difference. The higher value may be attributed to the runoff containing fertilizers from local lawns. However, since the U.S. Environmental Protection Agency suggests that a pH range of 6.5 to 9.0 is necessary to provide adequate protection for the life cycles of freshwater fish and benthic organisms and the lowest pH value recorded was 7.0, pH was not likely a limiting factor [37].

Hardness and Conductivity

Since health-related effects have not been proven in association with hardness concentrations solely and the effects of hardness on freshwater aquatic life appear to be more related to the ions causing the hardness, hardness and conductivity should be considered together. The data in Table 7 indicate that there is a direct positive slope demonstrating a positive relationship between the degree of urbanization and the values for hardness and conductivity. Specifically, the conductivity value is important for aquatic communities since it affects the rate of exchange of ions and, therefore, can affect the rate of uptake of nutrients in the water column by organisms. The low numbers of macroinvertebrate species in Holmes Run and Accotink Creek, then, are probably related to the combination of high hardness values (113 and 100 mg/l) and high conductivity values (188 and 150 μmho) in those streams.

Suspended Solids

Burton, et al. found that one of the most dramatic effects of urbanization observed in their study was the large increase in the concentration of suspended solids in urban streams [40]. They found concentrations of suspended solids from urban runoff to be 24.3 times greater than runoff from forested-agricultural lands. The amount of sediment in urban runoff can be directly associated with the amount of suspended solids in the water of receiving streams. In fact, Leopold found that there was a direct correlation between the sediment yield of a particular area and the degree of urbanization [8]. Furthermore, sediment has a considerable impact on aquatic populations: bottom habitat is smothered; the food supply is reduced due to limited light penetration, and; the physiological functions of benthic organisms can be impaired.

Given this information, one would expect a similar correlation between the degree of urbanization and the presence of suspended solids in the water samples collected in these Northern Virginia sites. However, there does not appear to be any direct correlation evident between the level of urbanization and the amount of suspended solids in samples from the various collection sites. The data in Table 7 indicate that Holmes Run, the most urbanized area, has the third highest amount of suspended solids. A more general pattern, however, may be determined in that the two least urbanized collection sites exhibited substantially lower measures of suspended solids than the other three sites. It should be noted that it is difficult to interpret data on suspended solids from data collected during periods of low flow and none of the data was collected during a high flow period.

The periods of greatest concentration of suspended solids in the water column are normally associated with high flows during a storm event and it would have been preferable to have collected samples during a high flow period. Consequently, the range of suspended solid values of .3 to 7.7 mg/l may not be particularly indicative of the effect of the degree of urbanization. In fact, all of these values fall between the good to excellent range on the Department of the Army's [41] environmental quality scale for suspended solids.

Water Flow

Leopold [8] has demonstrated that the amount of water runoff from urbanized areas tends to be significantly greater than from nonurbanized areas. With the reduced vegetative cover in urbanized areas, the water travels faster and

Table 8. Degree of Urbanization Related to Flow Discharge by Sampling Location

	Degree of Urbanization[a] (Percent)	*Flow Discharge (m^3/sec)*	*Suspended Solids (mg/l)*
North Quantico Creek	25	29.98	.5[b]
Accotink Creek	40-80	58.87	7.7
Pope's Head Creek	25-40	28.23	7.4
Holmes Run	80	197.02	5.15[b]
Difficult Run	25	60.09	3.0[b]

[a] Value estimated using Antoine's suggested categorization based on typical lot size [18].
[b] Averaged value.

erodes streambanks which, in turn contribute further to the sediment load. The data in Table 8 tend to support Leopold's findings when the respective more urbanized and less urbanized watersheds measured on the same day are compared. The Accotink Creek discharge rate was more than double (2.09) the flow in Pope's Head Creek which had a considerably less urbanized watershed area. Similarly, Holmes Run, the most urbanized area, had more than triple (3.28 times) the discharge rate of Difficult Run.

The increased discharge rate contributes to the channelization of urban streams directly, but this may lead indirectly to an increase in the overall stream temperature. As the stream channel becomes wider, the amount of shade is reduced and the stream becomes more shallow which adds to the degree of heat loss and gain [7]. For example, Holmes Run which had the widest channel in the study and was fairly shallow had a slightly higher temperature than its less urbanized counterpart on the day of data collection.

DISCUSSION OF THE RESULTS

Most of the indicators examined throughout this study tended to demonstrate the negative implications of increased levels of urbanization on stream water quality and attendant biological communities. The diversity of the macroinvertebrate benthic population was reduced directly with the amount of urbanization. The reduction in diversity in benthic fauna was particularly striking between the most urbanized watershed of Holmes Run and the forested control site of North Quantico Creek. Furthermore, the two more urbanized sites had a benthic community composed primarily of the more pollution-tolerant midge larvae [27, 37] while the less urbanized sites were characterized by pollution intolerant species such as Plecoptera, Ephemeroptera, Trichoptera, and Coleoptera. Plecoptera and Coleoptera were virtually absent from the most urbanized watersheds sampled.

Also, the more urbanized watershed samples were characterized by substantially more pollution-tolerant algal species. Out of the total number of genera the number of pollution-tolerant genera in Holmes Run and Accotink were substantially higher (53-68%) than in the less urbanized watersheds (29-32%). Similarly, the samples from the more urbanized areas had more algal biomass (measured by chlorophyll-a content). This is partially a result of the fact that the more urbanized areas had less shade over the streams partially due to the increased channelization effects. In fact, the flow discharge rates were significantly greater in the more urbanized watersheds. And, the higher discharge rates may have contributed to the reduced benthic populations in these more urbanized areas due to the smothering effect of siltation.

CONCLUSIONS

The quality of the water in a stream is highly dependent upon the type and quality of the runoff which feeds into the stream. The data obtained through this study of benthic organisms, algae, and selected water quality parameters in five Northern Virginia watersheds support the contention that the degree of urbanization of a watershed appears to be a fairly good indicator of the quality of the water in the stream into which its runoff goes. If the land use pattern is highly urbanized, a stream's water quality and the associated biological communities are likely to be significantly lower than a stream with a rural, forested watershed. Specifically, the results of this study demonstrated a one-to-one correlation between the degree of urbanization and the diversity of benthic species in the streams examined.

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