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RELATIONSHIPS BETWEEN ABUNDANCE OF PHYSICALLY COMPLEX HABITAT AND BENTHIC MACROINVERTEBRATE COMMUNITY PARAMETERS IN THE JAMES RIVER, NELSON COUNTY, VA

by

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Abstract

Relationships between abundance of physically complex habitat and benthic macroinvertebrate community parameters in the James River, Nelson County, Virginia

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This study shows the importance of structurally complex habitat on abundance and diversity of organisms in a benthic macroinvertebrate community in the James River, Nelson County, Virginia. Structural complexity was manipulated by attaching stones to five concrete blocks (12.8 ± 0.97% coverage; mean ± SE) and comparing organism abundance on these blocks and blocks lacking stones (0% coverage). Concrete blocks were randomly placed at a site in the James River on November 14, 1999 and collected on December 12, 1999. Macroinvertebrates and particulate organic and inorganic matter on the blocks were collected. Total invertebrate abundance, abundance of eight individual taxa, taxonomic richness, and particulate organic and inorganic matter mass were greater in the low-coverage treatment then the control treatment. The increase in the particulate organic and inorganic matter in the low-coverage treatment likely provided the major resources for the invertebrates that positively responded. The slight increase in physical structure in the low-coverage treatment provided the organisms with refuge from predators and natural disturbances, as well as increased habitat variety. Physical structural complexity is an important habitat quality that is able to regulate organism distribution, abundance, and diversity.

This study could be an effective model to predict habitat changes and promote efficient management of a variety of natural resources in many ecosystems.

Acknowledgements

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Introduction

The importance of availability of structurally complex habitat in regulating the structure of biological communities has well been illustrated (e.g., Beck 1995, Angermeier and Winston 1998, Buford and Capen 1999). For example, abundance and diversity of organisms on coral reefs are regulated by levels of physical structure (Beck 1995). Similarly, structurally complex habitats in streams support greater densities and diversity of organisms, including benthic macroinvertebrates (Angermeier and Winston 1998, Schmude et al. 1998). It has previously been shown that with increasing substrate complexity, the numbers and diversity of the macroinvertebrates will increase (Schmude et al. 1998, Stewart et al. 1999). This was shown in a study comparing benthic invertebrate abundance and diversity on 2- and 3-dimensional substrates (Schmude et al. 1998). Here, increased substratum surface area and abundance of shelters formed by interstices between substratum particles (e.g., stones) were positively correlated with macroinvertebrate abundance and taxonomic richness.

Although positive relationships between physical structure abundance and community parameters have been frequently observed, the mathematical nature of relationships between physical structure abundance and measures of community structure are poorly understood. Certainly, increases in abundance of some taxa may be proportional to increases in physical structure. This linear response is most likely when organism abundance is limited only by habitat abundance. However, if organisms require refuges or shelters that physical structure can provide, a critical density of this habitat may be needed for organisms to benefit.

At low levels of physical structural complexity, large gaps affording little or no protection from predators, wave stress, and other disturbances would occur between adjacent areas of habitat structure (Beck 1995, Stewart et al. 1999). As abundance of physical structure increases, however, these gaps would decrease in size and abundance, and abundance of small interstices providing adequate shelter would increase rapidly. If organisms are under intense predation pressure or are particularly vulnerable to abiotic disturbances, abundance of these organisms would be expected to increase very little, if at all, before a critical threshold density of physical structure is reached where many high-quality refuges exist. Once this threshold is reached, organism abundance would increase very rapidly for every small increase in density of physical habitat (Quinn et al. 1998).

Thus, relationships between physical structure abundance and abundance of organisms requiring physically complex habitat are probably not linear but instead curvilinear in nature. I predict that as the density of physical structure in a landscape is increased, abundance of most organisms will increase only slowly until a critical density of physical structure is reached. After this threshold density of physical structure is reached, organism abundance would increase exponentially as density of physical structure continues to increase.

My study was part of a larger project designed to quantify the direction, strength, and mathematical nature (e.g., linear or nonlinear) of relationships between abundance of physical structure and benthic macroinvertebrate (i.e., bottom-dwelling invertebrates retained in a 500-micron mesh) community parameters at a site in the James River, Nelson County, Virginia. The experimental design of this larger study consisted of five treatments, and five replicates were used per treatment. The first treatment consisted of a control, which was a concrete block (42.5 X 4.2 X 22.8 cm) simulating bare rock. Twenty stones of similar size that covered 12.8 ± 0.97% (mean ± SE) of the upper surface of blocks were attached to blocks in the low coverage treatment. Remaining treatments included the intermediate-coverage (40% of block surface covered by stones), high-coverage (80% coverage), and very high-coverage (95% coverage) treatments. Locations for attaching stones to blocks were determined by dividing each upper block surface into 78 numbered cells (3 cm X 3 cm), generating random numbers from a computer, then attaching stones to cell numbers corresponding to these random numbers. All stones were attached to blocks using a dime-sized amount of silicone aquarium sealant. This method was effective in attaching and holding zebra mussel (*Dreissena polymorpha*) shells to unglazed ceramic tiles in a previous study (Stewart et al. 1998a).

For my thesis, I focused on comparing invertebrate community parameters in the control and low-coverage treatments. I hypothesized that with an increase in physical structure from the control block to the low-coverage block, there would be a notable increase in macroinvertebrate abundance and diversity. This increase would be numerically small but statistically significant due to the increase in habitat variety and refuges made available to the organisms.

Methods

Study Site

The study site was in the James River, near Wingina, Nelson County, Virginia (latitude = 37°38'01"N, longitude = 78°43'00"W). The James River is formed in west central Virginia by the confluence of the Cowpasture and Jackson Rivers (Department of Conservation Recreation 2000). The James River meanders eastward through the Blue Ridge Mountains and enters the Chesapeake Bay through the wide estuary of Hampton Roads. Two main tributaries are the Appomattox and the Chickahominy Rivers and the entire river resides in the state of Virginia. The selection of the study site was chosen for the historical connection to the state of Virginia, the excellent abundance of fish, and the rocky benthic bottom needed to do the study. Historically, the area around the study site had been used for agriculture but seems to have not been cultivated in many years. The vegetation around the banks of the river is one of mixed-deciduous forest and the width of the river at the site was around 750 meters. The benthic substrata at this site were typical of the rest of the upper James River, and consisted of gravel, cobble, and boulders overlying bedrock (Garman and Smock 1999).

Deployment of Substrata

Blocks were placed in the James River on November 14, 1999. Blocks were arranged in a Latin-square design (Zar 1999), with blocks placed in five rows of five substrates, and one replicate of each treatment randomly placed in each row. All blocks were separated from each other by a distance of 1 meter to ensure statistical independence. Measurements taken on November 19, 1999 indicated that locations of individual block placement did not differ in depth (range = 62-74 cm total depth; independent t-test, $t = -.376$, $df = 7$, $p = .718$), near-bed current velocity (2-3 m/sec total flow; $t = .882$, $df = 7$, $p = .407$), dissolved oxygen (10.4-10.8 mg/L total; $t = .344$, $df = 7$, $p = .741$), pH (7.0), and temperature (13.2-13.8 °C ; $t = -.572$, $df = 7$, $p = .585$).

Sample Collection

Each block was collected on December 12, 1999 by transferring it to a plastic tub held at the water surface, and then transporting to the shoreline for processing. Comparisons of block surfaces with photographs taken before the experiment revealed no loss of stones during the 28-day study period. Stones were then removed from blocks and placed in the tub.

Stones and blocks were rinsed with filtered water and lightly scrubbed with a soft-bristled brush to remove invertebrates and other particulate matter. Stones were placed in numbered polyethylene bags corresponding to numbers on the blocks from which they were removed. Remaining bucket contents were sieved through a 45-µm mesh, and retained material was transferred to a jar where it was preserved in 5% buffered formalin. The 5% buffered formalin was used to fix the invertebrates in their exact state of being. The formalin was replaced with 70% ethanol within 24 hours to preserve the specimens.

Sample Processing

In the laboratory, macroinvertebrates and coarse particulate matter were separated from fine particulate matter and smaller organisms by sieving sample jar contents through a 500-µm mesh overlying a 45-µm mesh. Macroinvertebrates were separated from other coarse material by scanning material retained in the 500-µm sieve under a stereomicroscope (10X power). Macroinvertebrates were separated into coarse taxonomic groups. Densities (= abundance) of each macroinvertebrate taxon were then determined (number of individuals/block). Course and fine particulate matter were dried at 60°C for 24 hours, then ashed at 500°C for 24 hours to quantify particulate inorganic and organic matter mass (APHA 1989).

Data Analysis

Means and Standard Errors were determined for total macroinvertebrate abundance, taxonomic richness (total number of macroinvertebrate taxa present on each block; Brower and Zar 1977), and particulate inorganic and organic matter. Differences in total macroinvertebrate abundance, taxonomic richness, and particulate inorganic and organic matter mass in control and low-coverage treatments were determined by independent t-tests. Prior to conducting statistical analysis, data were transformed using logarithmic transformation [log(x+1)] to satisfy linearity and normality assumptions (Zar 1999). Macroinvertebrate sampling counts are varied and can have many zero counts. To correct for the nonnormality, data can be changed or transformed from the original form to a different form that will have a valid application of a parametric analysis. All statistical analyses were conducted using SPSS 9.0, and the effects were considered statistically significant at $p < 0.05$ (Zar 1999). To correct for the increased likelihood of Type I errors (erroneously rejecting the null hypothesis) when conducting several univariate tests on the same data set simultaneously, Bonferroni corrections ($p = 0.05$/number of dependent variables) were used to adjust the critical value for rejecting null hypotheses of no differences in abundance of individual macroinvertebrate taxa between treatments (Scheiner 1993, Stewart et al. 1998b).

Results

Total Invertebrate Abundance

Physical structure positively affected benthic macroinvertebrate abundance. Mean total macroinvertebrate abundance was 3 times greater ($p = 0.035$; Table 1) in the low-coverage treatment relative to the control.

Individual Taxa Abundance

Effects on 28 macroinvertebrate taxa were analyzed and the critical *p*-value was very low after the Bonferroni adjustment ($p = .002$). Although, there was still an effect of physical structure on one taxonomic group, the oligochaetes (segmented worms). Without the use of the Bonferroni adjustment, there were many organisms that responded positively to physical structure. The increase in structural complexity in the low-coverage treatment caused a significant increase in turbellarians (flatworms), *Chaetogaster* (segmented worm), unidentified oligochaetes (other segmented worms), *Corbicula fluminea* (a bivalve), Ephemeroptera (mayflies), Hydroptilidae (microcaddisflies), Hydropsychidae (net-spinning caddisflies), and Simuliidae (blackflies; Table 1).

Taxonomic Richness

Along with the increase in total abundance of macroinvertebrates, there was an increase in taxonomic richness in the low-coverage treatment ($p = .006$; Table 1). Mean taxonomic richness was more than 2 times greater.

Particulate Matter

Particulate organic matter and inorganic matter increased significantly from the control to the low-coverage treatment (Table 2).

Table 1. Macroinvertebrate abundance (mean number of individuals/block with 1 SE in parentheses) in the 2 treatments. *P*-values are presented from independent t-tests and statistically significant differences exclusive of Bonferroni adjustment of *p*-values are highlighted ($p \leq 0.05$). * = statistically significant differences at the 95% confidence level after Bonferroni adjustment of critical values (critical *p*-value/28).

Taxon	Treatment		
	Control	Low-coverage	*p*-value
Phylum Platyhelminthes			
Class Turbellaria (flatworms)	**0.50(0.50)**	**2.00(0.45)**	**.036**
Phylum Nematoda (simple worms)	0.50(0.29)	3.80(2.46)	.416
Phylum Annelida			
Class Oligochaeta (segmented worms)	**1.25(1.25)**	**220.00(118.36)**	**.002***
***Chaetogaster sp* (segmented worms)**	**1.00(1.00)**	**9.60(2.75)**	**.007**
Phylum Mollusca			
Class Bivalvia (clams)			
Corbicula fluminea	**0.25(0.25)**	**2.00(0.55)**	**.010**
Class Gastropoda (snails)			
Subclass Prosobranchia	1.75(1.18)	5.00(1.34)	.068
Subclass Pulmonata	0.00(0.00)	0.20(0.20)	.407
Phylum Arthropoda			
Class Arachnoidea			
Order Acarina (mites)	2.75(0.95)	5.60(1.69)	.192
Class Crustacea			
Order Copepoda (copepods)	0.00(0.00)	0.40(0.24)	.193
Order Amphipoda (amphipods)	0.00(0.00)	0.80(0.58)	.227
Class Insecta			
Order Odonata			
Suborder Anisoptera (dragonflies)	0.00(0.00)	0.60(0.40)	.210
Suborder Zygoptera (damselflies)	0.75(0.25)	0.60(0.40)	.614
Order Ephemeroptera (mayflies)	**10.75(3.28)**	**117.40(63.24)**	**.014**
Order Trichoptera (caddisflies)			

Table 1. (continued)

Taxon	Treatment		
	Control	Low-coverage	*p*-value
Family Hydroptilidae (microcaddisflies)	**0.50(0.29)**	**8.40(2.93)**	**.003**
Family Hydropsychidae (net-spinning caddisflies)	**0.75(0.25)**	**4.20(1.24)**	**.007**
Family Leptoceridae	0.25(0.25)	0.40(0.24)	.685
Family Heliopsychidae	0.25(0.25)	0.80(0.37)	.298
Family Brachycentridae			
Brachycentrus	0.00(0.00)	0.20(0.20)	.407
Order Coleoptera (beetles)			
Family Elmidae (riffle beetles)	0.25(0.25)	2.80(1.24)	.071
Family Psephenidae (water pennies)	0.25(0.25)	0.00(0.00)	.292
Order Diptera (flies)			
Family Chironomidae (midges)	334.75(125.20)	690.40(141.14)	.084
Family Simuliidae (blackflies)	**0.00(0.00)**	**2.00(0.71)**	**.021**
Unidentified Diptera	0.00(0.00)	0.40(0.24)	.193
Order Lepidoptera (moths)	0.00(0.00)	0.60(0.40)	.210
Total abundance	**375.25(130.87)**	**1143.20(349.80)**	**.035**
Taxonomic richness	**8.75(1.49)**	**17.60(1.94)**	**.006**

Table 2. Particulate inorganic and organic matter (mean mass/block in grams with 1 SE in parentheses) in the two treatments. *P*-values are presented from independent t-test values.

Table 2. Particulate inorganic and organic matter (mean mass/block in grams with 1 SE in parentheses) in the two treatments. *P*-values are presented from independent t-test values.

Particulate matter (grams)	Treatment		
	Control	Low-coverage	*p*-value
Inorganic matter (ash mass)	1.59(0.39)	17.36(3.86)	.009
Organic matter (ash-free mass)	0.09(0.01)	2.19(0.70)	.034

Discussion

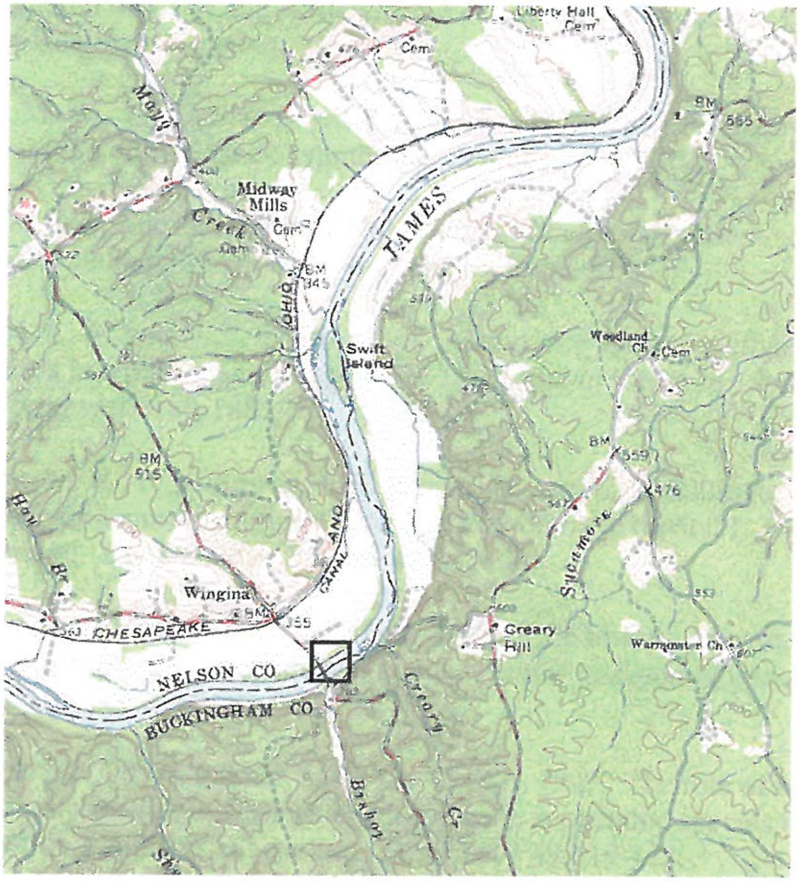
Clearly, physical structural complexity is an important habitat quality that regulates organism distribution, abundance, and diversity. I expected to observe an increase in species abundance and diversity with a more structurally complex habitat and my results support this hypothesis. The increase in physical structure between control and low-coverage treatments allowed for a significant increase in total macroinvertebrate abundance, abundance of several taxa, and taxonomic richness.

The total abundance of macroinvertebrates increased with physical structure because of increased abundance of certain macroinvertebrate taxa. The increase in abundance of some macroinvertebrates may have been caused by the increase in particulate matter that collected between the stones (Stewart et al. 1998b, Covich et al. 1999). This increase in particulate organic and inorganic matter provides food and habitat for several taxa. For example, mayflies showed a significant increase with respect to structure. Mayfly larvae are collectors or scrapers and their diets consist of algae and detritus (Christman and Voshell 1992). Particulate organic matter increase may also have allowed for increases in oligochaetes (segmented worms) that are adapted to inhabiting pockets of sediment and feed on algae that becomes available (Harper et al. 1981). Another benthic macroinvertebrate that showed a positive response with the increase in structure was the bivalve, *Corbicula fluminea*. *C. fluminea* are moved by water currents over long distances and this dispersal is a possible reason for its presence on my substrata. Increases in *Corbicula* in the low-coverage treatments relative to the control may be due to corresponding increase in inorganic matter (sand and gravel) that is critical habitat for this organism (McMahon 1983). This filter feeder also consumes organic detritus and inhabits areas where it can consume food present in the sediment (McMahon 1983).

With the increase in organic and inorganic matter and the habitat variety available in the low-coverage treatment, there are additional resources available for macroinvertebrates. The increase in physical structure provides more interstitial spaces that serve as refuges for small invertebrates from strong currents and predation (Walters and Wethey 1996, Schmude et al. 1998, Stewart et al. 1999). By providing refuges, these spaces increase the likelihood of coexistence of predator and prey. Interstitial spaces also collect particulate matter and provide food and habitat important to many macroinvertebrates that inhabit the benthic habitats of rivers, streams, and lakes. Refuges, in combination with inorganic and organic matter, are potential causes for increased taxonomic richness in the low-coverage treatment relative to the control (Wellborn et al. 1996, Stewart et al. 1999). In addition, benthic macroinvertebrates have species-specific roles in processing organic matter with specialized mouthparts. One macroinvertebrate species may not be able to exist in an area without the other species that fall above or below them in the food web. Therefore, the absence of just one species could alter food availability for another species as well as the entire stream foodweb (Covich et al. 1999).

Quantitative descriptions of relationships between physical structure density and community parameters are critical for effective and efficient management of a variety of natural resources (e.g., endangered and game species) in a wide range of ecosystems (Burnett et al. 1998, Villard et al. 1999, Buford and Capen 1999). For effective management of endangered species, critical habitat requirements must first be determined before recovery of species can be possible. Habitat quality and quantity are important aspects for the management of all species, aquatic or terrestrial. For example, how large a forest needs to be or how dense the sedges in a field need to be are critical questions that must be addressed to establish and maintain a balanced ecosystem. Studies such as mine that focused on macroinvertebrates can enhance our ability to assess these critical habitat requirements.

Appendix I



Map 1. Study Site Location on James River near Wingina, Virginia.

Source: United States Department of the Interior Geological Survey, Buckingham Quadrangle Virginia, 15 minute Series.

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