Research Article

Diversity of Macroinvertebrate Communities Following Abnormal Spring Flooding of Denton Creek, Denton County, Texas

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CORPUS PUBLISHERS

Corpus International Journal of Oceanography and Aquatic Research (CIJOAR)

Volume 2 Issue 1, 2024

Article Information

Received date : November 01, 2024

Published date: November 13, 2024

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DOI: 10.54026/CIJOAR/1003

Keywords

Lotic systems; Macroinvertebrates; Flood Disturbances; Species Diversity; Simpson's Index

Abstract

Field sampling of aquatic macroinvertebrate communities was conducted to study the effects of sudden flood disturbances following a lull in abnormally persistent spring rainstorms. Despite this disturbance and low collection success, overall diversity was high (Simpson's index, $D_s = 0.87$), where pool zones exhibited the greatest diversity ($D_s = 0.93$) versus riffle zones ($D_s = 0.71$). Differences in diversity between riffles and pools were significant, suggesting floods disperse macroinvertebrates that occupy niches in the riffle zone. Measures of dominance showed Perlodidae (Plecoptera) was abundant in riffle zones, whereas pool zones were abundant with Chironomidae (Diptera), Baetidae and Heptageniidae (Ephemeroptera). Bottom-down trophic interactions show that flooding appears to have nearly wiped-out primary consumers in the riffle zones, leaving a top-heavy predator food chain. Pool zones were not directly affected by fast currents and exhibited a balanced, trophic pyramid.

Introduction

Streams, creeks and river systems (lotic habitats) are dominated by whole orders of the class, Insecta (e.g., Plecoptera, Ephemeroptera, Odonata, Tricoptera, Megaloptera, etc.). Unlike the zooplankton who dominate lentic and marine waters, insects (macroinvertebrates) have adapted well to the freshwater aquatic environment despite their terrestrial origin with the adaptation of their tracheal systems, flight abilities and waxy cuticles [1]. Macroinvertebrates play an important role in freshwater stream ecosystems, having long lifespans in the water, relatively small mobility and limited range (with the exception of biotic and abiotic ques to drift to a different site), easy to identify, and make good indicators of stream quality [2-4].

In order to compare the community structure of aquatic macroinvertebrates, numerous physical, chemical and biological factors need to be considered. Physical factors may be the regional and local climate, or the particular characteristics of the drainage basin in which the community resides; e.g., stream gradient, width, flood characteristics and substrate. Chemical characteristics can be both natural and anthropogenic, the latter possibly being a point source of toxic pollutants. Biological factors may include inter and intra-specific competition, predator-prey relationships, or allochthonous inputs from the watershed, such as leaf litter, which are a major source of nutrition for some of the feeding groups of aquatic macroinvertebrates.

Lotic systems contain different habitats where macroinvertebrates partition out special niches, such as pools and riffles. Physical examination of the substrate may reveal large cobbles, rocks, pebbles, sand, mud, or a combination of the above [5]. Above the substrate, there are macroinvertebrates that make their home among the aquatic plants, in the floating leaf packs, or live in the interface between the water's surface and the air. In riffle and pool habitats, macroinvertebrates have adapted to a particular lifestyle enabling them to live among the varying environmental conditions (Figure 1).

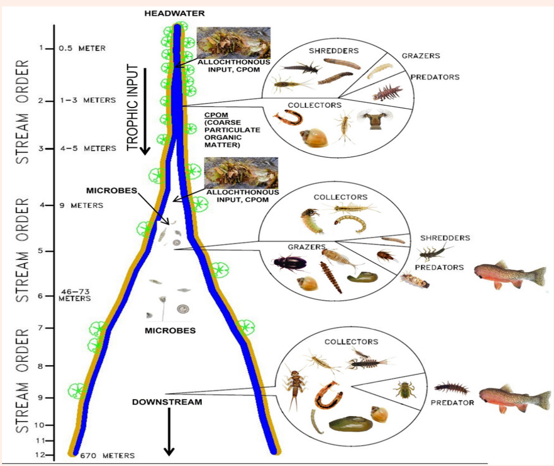

Figure 1: Author's rendering of the changes in macroinvertebrate functional feeding groups with the changing stream morphology and energy input [2].

For example, fast-moving riffles require streamlined insects that have the ability to cling, hang, or suck onto the substrate, which may be large rocks or cobbles [1,6]. Here, they spend their larval lives hanging on while filter feeding and grazing. In the Hyporheic zone, there are specialized benthic macroinvertebrates living in the interstices of permeating water flow, consisting of sediments, sand and gravel [1]. Feeding groups of the benthic substrate consists of suspension and filter feeders, and grazers.

Leaf packs have been given considerable attention in the assessment of aquatic macroinvertebrate communities because they provide a major source of nutrition (carbon-nitrogen) and refuge [7]. Autumn is usually the time of major leaf input to riparian lotic systems; however, year-round inputs may come from natural events such as the natural death of the tree, beaver activity, wind storms and flooding [7]. Shredders are among the specialized feeding groups that make up this niche.

Seasonal variations impacting the community structure of aquatic macroinvertebrates are both natural and anthropogenic; particularly in hydrological alterations by changes in land use and from channelizing rivers and streams [8,9]. Depending on the region, seasonal floods can alter the stream characteristics and displace populations of macroinvertebrates far downstream [10,11]. Evolutionary changes of aquatic flora and fauna due to seasonal fluctuations in temperature and precipitation in order to adapt to the aquatic environment has been documented [12,13]. Abnormal spates (sudden flooding caused by heavy rains) are a major cause of disrupting community structure of biota in stream habitats [9], which may be attributed to more recent evidence of climate change [14-16]. Man-made disturbances such as stream alteration can have a devastating effect as well, to include increased siltation, choking out oxygen-rich habitats of sensitive fauna [17]. Wildfires of large magnitude have also had a major impact on the structure of faunal communities, impacting short-term effects resulting in increased erosion and sediment loading [10]. Disturbances of considerable magnitude have been known to cause dispersal of macroinvertebrates by way of drift, swimming, crawling or flight [10].

The objective of this study is to assess the diversity and community structure of aquatic macroinvertebrates following a sudden spate that affected a specific site on Denton Creek, a third-order stream in Denton County, Texas (Rosen [18]), often used by the University of North Texas Department of Biological Sciences. Denton Creek has recently experienced unseasonable spring flooding, and the results of this study may show how flooding impacts aquatic communities.

Methods

Study Site

Sampling took place on 10 April 1997 at a site on Denton Creek (Figure 2 – 33º03'03.69"N, 097º15'01.08"W, elevation 172 m) below the east side of the Interstate Highway-35W overpass in Denton County, Texas ca. 15 km south of the City of Denton. The creek is located along a riparian corridor running from northwest to southeast to the Elm Fork of the Trinity River.

Both sides of the creek are lined with steep-sloped eroding banks bearing signs of scour from recent high-water floods brought on by persistent, spring rainstorms. Predominant trees are elm, hackberry, cottonwood and willow. Riffle substrate consisted of cobbles and pebbles and the pool substrate was a combination of cobbles, pebbles, sand, and silty mud. Sampling was done in a pool and riffle on the northeast bank near the location of the study site (Figure 2).

Riffle sampling was done using a 1-by-6-meter bag seine (1 cm mesh) at three replicate sample locations in close proximity. Seine pulls were difficult due to the swift current, which resulted in only ≈5 m upstream pulls with a partially opened seine (≈4 m). Pool sampling was done using a 500µm Tri Net (0.3 m triangular opening) with a 1-meter-long wood handle and pushed along the bottom for ≈5 m while kicking up the substrate in front of it.

Macroinvertebrate Sampling Method

Pool samples consisted of three replicate samples in close proximity. Contents of each replicate sample were hauled to the shore and sorted in a white porcelain pan, placed in labeled 250 ml bottles and preserved with 70% ethanol. Prior to sampling, water temperature was taken at each replicate site with a mercury thermometer. Depth was measured with a metric rod, and riffle current was measured by timing a small piece of paper released on the water surface, observing it flow the length of a measured transect, and dividing transect distance by the elapsed time.

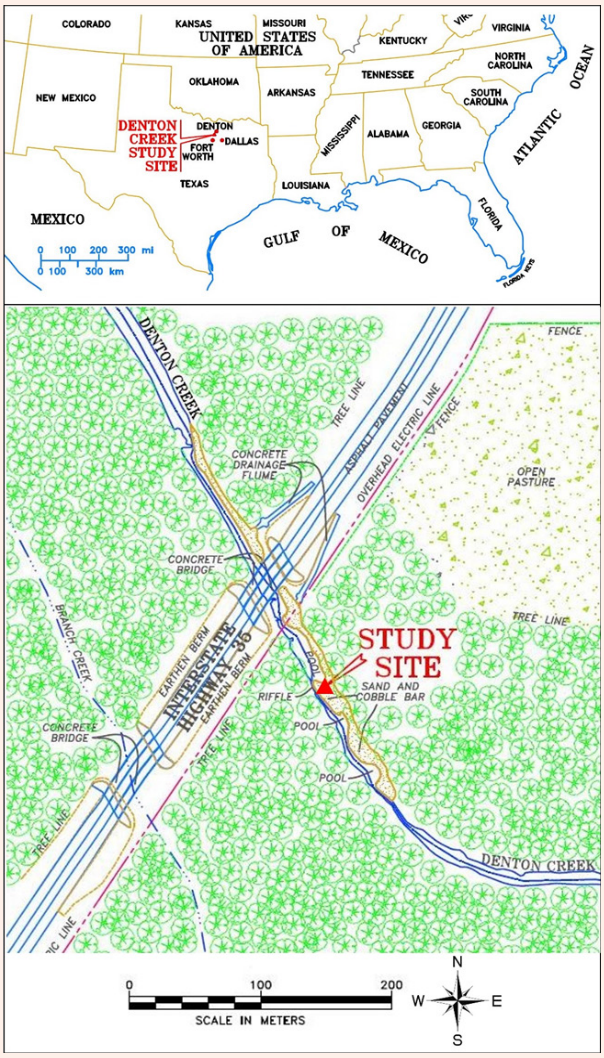

Figure 2: Map of Denton Creek Study Site (33º03'03.69"N, 097º15'01.08"W, elevation 172 m) below the east side of the Interstate Highway-35W overpass in Denton County, Texas, 15 km south of the City of Denton.

Laboratory Analysis

Replicate samples were sorted and counted by stream habitat under a dissecting microscope using the key by [19]. Organisms were identified down to family level or below.

Quantification of Community Structure

Frequency of occurrence was done for both riffle and pool habitats. Species dominance (*l*) and Simpson's Diversity indices (D_s) were calculated for both separate and combined habitats [20]:

$$n_i = \frac{\sum n_i(n-1)}{N(N-1)} \quad (1)$$

$$D_s = 1 - l \quad (2)$$

Where n_i is the number of individuals in a species (family and species are used interchangeably) and N is the sum total of organisms sampled. Diversity indices were compared by taking the variance (s^2) of D_s from each habitat and running a two-sample t-test [20]:

$$t = \frac{(D_s)1-(D_s)2}{\sqrt{s_1^2-s_2^2}} \quad (3)$$

Taxa were placed into trophic levels and categorized by the following functional feeding groups [1]: predators, shredders, grazers, filter-feeders and detritivores. Trophic levels were considered as primary, secondary and tertiary consumers and detritivores.

Results

Physical Characteristics

Recent rainstorms caused stream flooding throughout Denton County. Denton Creek had experienced bank full conditions during the spate; but at the time of sampling, the water level was well below the scour line left by the floods. Riffle velocity averaged 1.2 m . s^{-1}. Pool velocity was not measured and was considered negligible.

Water depth and substrate are shown in Table 1. Mean riffle and pool depths were 0.40 m and 0.28 m, respectively. Although not used in data analysis for this study, riffle and pool temperatures were 17 °C and 18 °C, respectively. Riffle substrate was primarily cobble whereas pool substrate was a combination of cobbles, pebbles and mud.

Table 1: Stream habitat, physical characteristics and composition of aquatic macroinvertebrates and other fauna taken from Denton Creek, 10 April 1997.

Habitat	Riffle			Pool		
Replicate #	1	2	3	1	2	3
Substrate	Cobble	Cobble	Cobble/ Pebble	Cobble	Muddy/ Pebble	Muddy/ Pebble
Depth (m)	0.47	0.2	0.54	0.17	0.33	0.33
Velocity ($m.s^{-1}$)	1.2	1.2	1.2	n/a	n/a	n/a
TAXON						
Cypriniformes (Cyprinidae) *Cyprinella venusta*	9					3
Ephemeroptera Leptophlebiidae Siphlonuridae Baetidae Ephemerellidae Heptageniidae			3		2 3 1	1
Plecoptera Perlodidae		16				1 exuvium
Diptera Syrphidae Chironomidae Simuliidae	1			1 winged adult 1	4 1	
Odonata				1 early instar		
Hemiptera Corixidae				1		
Orthoptera Tridactylidae				1		
Class Bivalva Veneroida Corbiculidae *Corbiculus sp.*		6	various shells		1	
Gastropoda			1			
Oligochaeta					1	

Stream Taxonomy

Stoneflies (Perlodidae: Plecoptera) dominated the riffle habitats followed by the Blacktail shiner, *Cyprinella venusta*, and the freshwater clam, *Corbiculus sp.* (Table 1). There were very few mayflies (one Leptophlibiidae and one Siphlonuridae: Ephemeroptera). One Dipteran (Syrphidae) and one Gastropod were collected. Mayflies dominated the pool habitats, which consisted of Leptophlibiidae, Baetidae, Ephemerellidae and Heptageniidae. The next most abundant taxa in descending dominance were dipterans (Chironomidae and Simuliidae), *C. venusta*, Corixidae (Hemiptera), Odonata (one early instar), Tridactylidae (Orthoptera), Corbiculidae, and one oligochaete (Table 1). Tridactylidae was included because of its affinity to aquatic ecosystems [19].

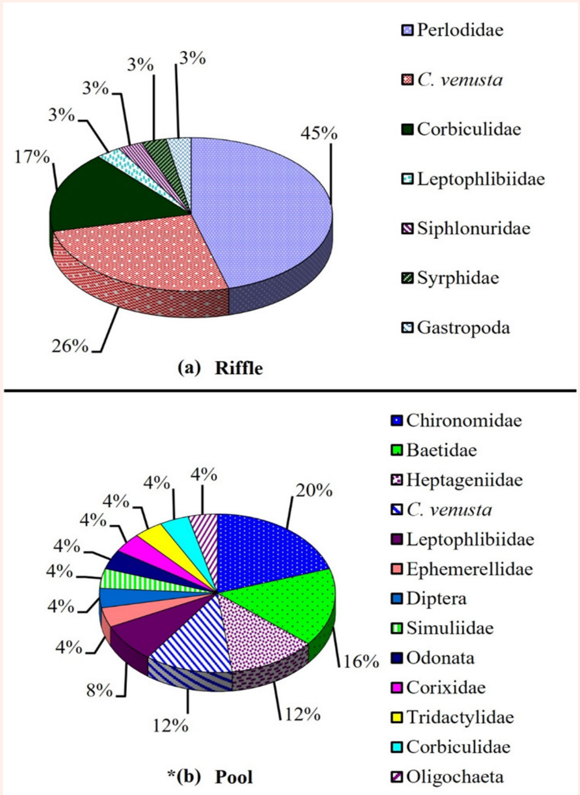

Figure 3: Percent family composition of taxa taken at Denton Creek 10 April 1997. Figure 3 (a) = Riffle, Figure 3 (b) = Pool. *(One exuvium of Plecoptera found).

Percent family composition of taxa at both riffle and pool habitats is shown in Figure 3. In the riffles, 45% were Perlodidae, 26% were Cyprinellidae, and 17% were Corbiculidae, followed by equal percentages of Ephemeroptra, Diptera and Gastropoda. Pool habitats yielded twice as many families as riffle habitats. Chironomidae (20%) dominated the pools followed by Baetidae (16%), Heptageniidae (12%), *C. venusta* and Leptophlibiidae (8%). The remaining 32% consisted of equal percentages of Ephemerillidae, Simuliidae, Odonata, Corixidae, Tridactylidae, Corbiculidae and Oligochaeta.

Table 2: Species dominance (l) and Simpson's Diversity Index (D_s) of aquatic macroinvertebrates and other aquatic fauna taken from Denton Creek on 10 April 1997.

Taxa	Abundance (n_i)	Relative Abundance	$n_i(n_i - 1)$
Cypriniformes (Cyprinidae) *Cyprinella venusta*	12	0.2	132
Ephemeroptera Leptophlebiidae Siphlonuridae Baetidae Ephemerellidae Heptageniidae	3 1 4 1 3	0.05 0.02 0.07 0.02 0.05	6 0 12 0 6
Plecoptera Perlodidae	1 16	0.02 0.26	0 240
Diptera Syrphidae Chironomidae Simuliidae	1 1 5 1	0.02 0.02 0.08 0.02	0 0 20 0
Odonata	1	0.02	0
Hemiptera Corixidae	1	0.02	0
Orthoptera Tridactylidae	1	0.02	0
Bivalva Corbiculidae	7	0.11	42
Gastropoda	1	0.02	0
Oligochaeta	1	0.02	0
$\sum s = 18$	N=61	$\sum n_i(n_i-1) =$ $l =$ $D_s =$	458 0.13 0.87

Table 3: Species dominance (l) and Simpson's Diversity Index (D_s) for riffle and pool habitats.

Taxa	Abundance (n_i)	$n_i(n_i - 1)$
Riffle		
Perlodidae	16	240
C. venusta	9	72
Corbiculidae	6	30
Leptophlibiidae	1	0
Siphlonuridae	1	0
Syrphidae	1	0
Gastropoda	1	0
	$s = 7$ $N = 35$	$\sum n_i(n_i-1)$=347 l=0.29 D_s=0.71
Pool		
Chironomidae	5	20
Baetidae	4	12
Heptageniidae	3	6
C. venusta	3	6
Leptophlibiidae	2	2
Ephemerellidae	1	0
Diptera	1	0
Simuliidae	1	0
Odonata	1	0
Corixidae	1	0
Tridactylidae	1	0
Corbiculidae	1	0
Oligochaeta	1	0
Plecoptera	1	0
	$s = 14$ $N = 26$	$\sum n_i(n_i-1)$ $\sum n_i(n_i-1)$=46 l=0.07 D_s=0.93

Family Dominance and Diversity

Overall, family dominance was low (0.13, Table 2), giving both riffle and pool habitats a combined Simpson's Diversity index of 0.87 (Table 2). Considering that this study was done following the spring flood, this agrees with the species richness by Hortle and Lake (1982) when they compared their results between channelized and unchanneled stream habitat sites. Perlodid stoneflies had the highest relative dominance (0.26) followed by *Cyprinella venusta* (0.20). When looked at separately, riffle habitats (Table 3) had higher dominance (0.29) and lowered diversity (0.71). Pool habitats had very low dominance (0.07) and very high diversity (0.93). Comparing diversity indices showed a highly significant difference (Table 4)) between the riffle and pool habitats ($t_{0.05(2)\,\infty}$ = 13.964; $p << 0.001$).

Table 4: Two sample t-test comparison of diversity indices between riffle and pool habitats.

Riffle		
N	pi^2	pi^3
35	0.013061	0.000373
	0.007347	0.00021
	0.004898	0.00014
	0.000816	2.33E-05
	0.000816	2.33E-05
	0.000816	2.33E-05
	0.000816	2.33E-05
	S p_i^2	S p_i^3
	0.028571	0.000816
s^2 =0.0000700		
Pool		
N	pi^2	pi^3
26	0.007396	0.000284
	0.005917	0.000228
	0.004438	0.000171
	0.004438	0.000171
	0.002959	0.000114
	0.001479	5.69E-05
	0.001479	5.69E-05
	0.001479	5.69E-05
	0.001479	5.69E-05
	0.001479	5.69E-05
	0.001479	5.69E-05
	0.001479	5.69E-05
	0.001479	5.69E-05
	0.001479	5.69E-05
	S p_i^2	S p_i^3
	0.038462	0.001479
s^2 =0.0001707		
	t 0.05(2), ∞	Probability
	13.964	p << 0.001

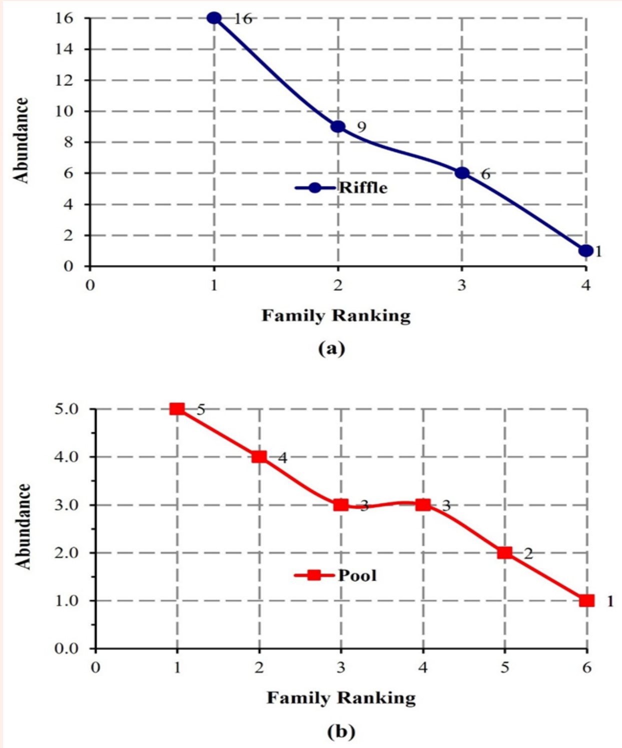

Figure 4: Species importance curve for taxa collected at Denton Creek, 10 April 1997, comparing riffle Figure 4 (a) and pool Figure 4 (b) habitats. Note the differences in the x and y axes.

Ranked species-importance curves for taxa collected are shown in Figure 4, comparing (a) riffle and (b) pool habitats. In the riffle habitats, the number of individuals found in the stonefly family Perlodidae was 16, with a ranking of 1. In the pool habitats, five midge larvae (Chironomidae) were found to be most abundant; however, pools had the most diverse aquatic fauna (midges, mayflies, top minnows, Dipterans, Hemipterans, Orthopterans, clams, aquatic annelids and stoneflies).

Functional Feeding Groups and Trophic Levels

Trophic levels ranged from detritus up to tertiary consumers (Table 5 & Figure 5). Detritivores included Corbiculidae, which are filter-feeders. Primary consumers consisted of shredders, grazers and filter-feeders. Gastropoda were considered to be scrapers. Secondary consumers were predators. Tertiary consumers were entirely *C. venusta* and considered to be a predator-grazer. Bottom-down trophic interactions of riffle habitats were 25.7% tertiary, 48.6% secondary, 8.6% primary, and 17.1% detrivores. Bottom-down trophic interactions of pool habitats were 12.0% tertiary, 32.0% secondary, 48.0% primary, and 8.0% detritivores. *Cyprinella venusta*, a predator-grazer, is treated as a tertiary consumer for this study.

Table 5: Functional feeding groups and trophic status of taxa taken at Denton Creek 10 April 1997.

Taxa	Number/Taxon	Feeding Group	Trophic Status
Cypriniformes (Cyprinidae) *Cyprinella venusta*	12	Predator-Grazer	Tertiary Consumer
Ephemeroptera			
Leptophlebiidae	3	Filter Feeder	Primary Consumer
Siphlonuridae	1	Predator	Secondary Consumer
Baetidae	4	Grazer	Primary Consumer
Ephemerellidae	1	Grazer	Primary Consumer
Heptageniidae	3	Grazer	Primary Consumer
Plecoptera Perlodidae	16	Predator	Secondary Consumer
Diptera	1Winged Adult	Predator	Secondary Consumer
Syrphidae	1	Grazer	Primary Consumer
Chironomidae	5	Predator	Secondary Consumer
Simuliidae	1	Filter Feeder	Primary Consumer
Odonata	1	Predator	Secondary Consumer
Hemiptera Corixidae	1	Predator	Secondary Consumer
Orthoptera Tridactylidae	1	Shredder	Primary Consumer
Bivalva Corbiculidae	7	Filter Feeder	Detritivore
Gastropoda	1	Scraper	Primary Consumer
Oligochaeta	1	Detritivore	Detritivore

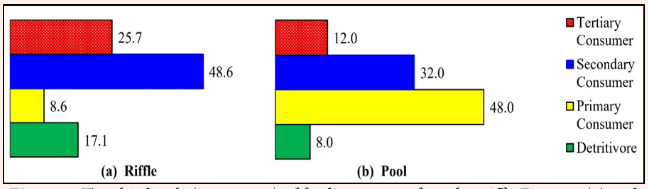

Figure 5: Trophic levels (in percent) of feeding groups found at riffle Figure 5 (a) and pool Figure 5 (b) sites.

Discussion

Abundance of macroinvertebrates at Denton Creek was low compared to previous spring and summer sampling trips (personal observation). Abnormally persistent rainstorms this spring caused streams in north Texas to rise well beyond bank full capacity, dispersing residents downstream, making it difficult to colonize [11]. There was little to find in the form of leaf packs, due to the swift current washing everything downstream, where some species of macroinvertebrates would be found. For example, shredders and scrapers were scarce, possibly due to the scarcity of leaf packs [7]. However, macroinvertebrate communities tend to recover once there is a cessation of disturbance events of the surrounding landscape [10]. There were some insects present who are adapted to fast-flowing currents, such as the mayfly family Heptageniidae, that have specialized gills which form a "suction-cup" enabling them to cling to the substrate in swift currents [19].

Diversity among the taxa collected was still high in spite of the recent stream disturbances. Presence of Plecoptera, Ephemeroptera, and Tricoptera are indicators of heathy streams [3,4,21], which are sensitive to pollution and toxic sediments in freshwater streams [22], and rising salinity (Ephemeroptera, Coleoptera, Heteroptera (Hemiptera), Piscart et al. [23], and are usually used as environmental pollution indicator species [3]. Macroinvertebrates-notably-are resilient and capable of recovering from spates and drought [8]. Combined and separate analysis of families in each habitat showed low dominance, which is a good measure of diversity [20]. Species abundance in both habitats tended to be near-linear and "stepped" downward (Figure 5); i.e., the most abundant species has twice the number of the next most abundant species, and so forth, indicating high diversity [20].

Trophic levels in riffles were somewhat skewed towards secondary consumers (Figure 5a), probably due to disturbances brought on by intense rainfall, leaving a dearth of leaf pack shredders and grazers such as ephemerellid and baetid mayflies. Normally, the trophic levels take on a pyramid shape, which is similar to what was found in the pool habitats (Figure 5b), with the greatest biomass going to primary producers (e.g., benthic algae), followed by primary consumers, secondary consumers; until reaching the top of the food chain (≈ 1% total biomass) where tertiary consumers are found [20]. These macroinvertebrates play an important role in accelerating decomposition of substrate detritus material, which is critical in the ecosystem's nutrient cycle and trophic interaction [3]. It would be interesting to have measured primary producer biomass in this study and test the hypothesis that local disturbances affect their standing crop of biomass [10], and then relate that to presence of primary consumers.

As has been demonstrated, the riffle and pool sites sampled at Denton Creek show a high amount of diversity among macroinvertebrate taxa, in spite of the persistent local flood disturbances it experienced during the spring of 1997. Understanding the effects of local stream disturbances on stream habitat diversity at this pilot study site will require a more detailed, experimental design approach with multiple transects.

Acknowledgment

This paper is dedicated to Dr. James Kennedy, Regents Professor, Department of Biological Sciences, University of North Texas. Dr. Kennedy is the quintessential entomologist working in Texas and drives his pickup truck with a butterfly net placed on a gun rack in the rear window, something that made quite an impression on me in a gun culture state. I would like to thank Dr. Jessica Franks for allowing me to use her laboratory and microscope in the keying and identification of aquatic macroinvertebrates. Many thanks to Ben Johnson and Sylvia Zuber, who volunteered to assist me in the field collection during this study. Their efforts contributed to the successful completion of this project.

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Appendix I: Taxonomy of invertebrates of the world.

PHYLUM ONYCOPHORA, ARTHROPODA	
and HIGHER PHYLA	
Phylum Onycophora	**Phylum Bryozoa** (lophophorates)
Peripatus sp.	*Bugula sp.* (moss animal)
Phylum Arthropoda	**Phylum Brachiopoda** (lamp shells)
Subphylum Trilobita trilobites	*Lingula sp.*
Subphylum Chelicerata	**Phylum Echinodermata**
Class Merostomata	Subphylum Echinozoa
Limulus polyphemus (horseshoe crab)	**Class Echinoidea** (sand dollars, urchins)
Class Insecta	**Class Holothuroidea**
Order Orthoptera (grasshoppers, crickets)	*Cucumcaria sp.* (sea cucumber)
Order Lepidoptera (moths, butterflies)	Subphylum Asterozoa
Order Diptera (flies, midges, mosquitos)	**Class Stelleroidea**
Order Plecoptera (stoneflies)	Subclass Asteroidea
Order Ephemeroptera (mayflies)	*Asterias sp.* (starfish)
Order Trichoptera (caddis flies)	Subphylum Crinozoa (sea lilies)
Order Odonata (dragonflies, damselflies)	
Order Hemiptera (true bugs)	**Phylum Chordata**
Order Coleoptera (beetles)	Subphylum Urochordata (tunicates, sea squirts)
Class Arachnidia	Subphylum Cephalochordata
Order Opilones (daddy longlegs)	*Amphioxus lancelet*
Order Araneae (spiders, tarantulas)	
Order Acari (ticks, mites)	
Order Scorpions	
Order Uropygi (whip scorpions)	
Subphylum Uniramia	
Class Cilliopoda (centipedes)	
Class Diplopoda (millipedes)	
Subphylum Crustacea	
Class Cirripedia (barnacles)	
Class Ostracoda (bivalved seed shrimp)	
Class Copepoda (copepods)	
Class Branchiopoda	
Order Cladocera (water fleas; daphnia)	
Order Notostraca	
Triops sp. (tadpole shrimp)	
Order Anostraca (fairy shrimp)	
Class Malacostraca	
Order Isopoda	
Armadillium sp. (pill bugs)	
Order Amphipoda	
Gammarus sp. (scuds)	
Order Stomatopodia	
Squilla sp. (mantis shrimp)	
Order Decopoda (shrimp, crabs, lobsters)	
Callinectes sp. (blue crab)	
Homarus sp. (lobster)	
Cambarus sp. (crayfish)	