WOODY DEBRIS AND MACROINVERTEBRATE

COMMUNITY STRUCTURE OF LOW-ORDER

STREAMS IN COLVILLE NATIONAL

FOREST, WASHINGTON

By

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Abstract

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Buffer strips of riparian vegetation are frequently used to protect aquatic resources. With the suppression of natural fire events, however, riparian areas are often comprised of even-aged, small diameter trees. Such conditions produce dense stands which have the potential to contribute large amounts of wood to headwater streams. Thus far, little research has been conducted on how dense, even-aged, small-diameter riparian vegetation may affect aquatic resources.

Benthic macroinvertebrate communities from forested headwater streams of Colville National Forest in northeastern Washington were used as indicators to determine the effects of large amounts of wood. Large amounts of wood could create wood jams that retain sediments that might interfere with macroinvertebrate biological processes such as respiration and egg-laying. Therefore, lower abundance, richness, evenness and diversity of the macroinvertebrate community were hypothesized for sites with more wood.

The numbers of wood pieces were counted to classify sites as "more wood" and "less wood" in each of three pairs on low-order streams. Physical parameters, such as width/depth ratio, slope, and substrate, were also analyzed to minimize potential differences that could influence the macroinvertebrate communities. Using three Surber samples from riffles at each site, the macroinvertebrate communities at "more wood" versus "less wood" sites were compared.

Significant differences in the physical parameters were not detected between "more wood" and "less wood" sites. Average and total macroinvertebrate abundances and family richness were not significantly different, although total abundance for "more wood" sites was half that for "less wood" sites. Averages for Shannon-Wiener diversity index values and Pielou's evenness metric were not significantly different; but overall average values for these metrics were slightly higher for "more wood" sites. A strong, significant difference existed in the functional feeding group composition at "more wood" versus "less wood" sites. Therefore, the differences in macroinvertebrate communities, the abundances and functional feeding group compositions in particular, suggest large amounts of wood may alter stream ecology in low-order streams of Colville National Forest.

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CHAPTER ONE

INTRODUCTION

In Colville National Forest, like many other of our nation's forests, decades of fire suppression has altered the composition of the forest. Prior to human intervention, natural fire events regularly occurred to maintain a forest of diverse tree species at various stages of growth. However in the 1920's, large wildfires burned large portions of the Colville National Forest coupled with fire suppression since then, has resulted in dense stands (up to 400 trees per acre) of small diameter trees (4 to 7 inches) in many areas (DePuit and Quigley 2002). These trees contribute limbs and logs to the forest floor, accumulating high fuel loads and increasing the risk of catastrophic wildfires (DePuit and Quigley 2002). Management plans, such as selective thinning, have been suggested in an effort to reduce fire risk and intensity while protecting property and timber. However, management plans often prohibit any actions in riparian areas to prevent disturbance to water quality, fish habitat, and other aquatic resources. Dense stands of small diameter trees, therefore, remain in large tracts of watersheds and riparian areas and contribute large amounts of woody debris to streams. The resultant increased supply of woody debris to small streams may be causing unanticipated alterations to the ecology of headwater streams.

Little is known about the effects of large amounts of woody debris on small, low-order streams. It has been suggested that excessive amounts of large woody debris could alter the balance of natural processes (Rosgen 1996). On the other hand, the effects of large amounts of wood on stream ecology have not been studied (Dolloff and Webster 2000). Dense, over-crowded riparian stands do not necessarily provide the habitat values for terrestrial components

of forest systems, and management options to improve these stands have been proposed. Such proposals may be at odds with mandated riparian "no-access" zones, yet over-crowded stands may not provide stream water quality and habitat protection either. Research is needed to determine how an increased supply of woody debris influences stream structure and function.

Aquatic invertebrate communities are sensitive to a variety of environmental perturbations; therefore, surveys of aquatic invertebrate communities are often used in assessing the aquatic environment (e.g., Rosenburg and Resh 1993). The mostly sedentary nature and fairly long life cycles of macroinvertebrates allow their community composition to reflect spatial and temporal disturbances (e.g., Rosenburg and Resh 1993, Merritt and Cummins 1996). Large amounts of wood alter the physical environment and influence macroinvertebrate abundance and richness by disrupting processes such as laying eggs and refuge-seeking. Large amounts of wood may create specialized environments suitable for only certain adaptable organisms. Low species richness, low abundance, reduced taxa richness, and less diversity are indicative of altered environments (Richards and Minshall 1992, Merritt and Cummins 1996). Therefore, it was hypothesized that macroinvertebrate communities of low-order streams containing large amounts of wood would have a lower abundance, richness, evenness and diversity than the macroinvertebrate communities of physically similar sites with less wood.

To test this hypothesis, three pairs of study sites on low-order streams in Colville National Forest were identified (Figure 1). Each pair consisted of a high wood, or "more wood" site, and a low wood, or "less wood" site. The physical environments of the sites were also analyzed for differences other than wood that might impact the macroinvertebrate communities. In particular, width/depth ratio, slope, and substrate were compared between sites. Average macroinvertebrate abundance, mean family richness, Pielou's J' evenness metric and average

Shannon-Wiener diversity index values were calculated between "more wood" and "less wood" sites. Additionally, the feeding guilds, or functional feeding group composition (such as the percentage of shredders, scrapers, gatherers, or predators at a site), were compared between pairs.

Figure 1: Photograph looking downstream on Clinton Creek, a "more wood" site in Colville National Forest in northeastern Washington.

CHAPTER TWO

LITERATURE REVIEW

There are many publications on the value of riparian vegetation protecting streams and on the impacts of terrestrial inputs such as woody debris and other litter (e.g., leaves, needles, bark) on stream ecology. In some cases, streams have been manipulated through the removal or reduction of wood debris (e.g. Bilby and Likens 1980, Trotter 1990). However, published research regarding the effects of increased amounts of wood on small streams is scarce (Dolloff and Webster 2000). Nevertheless, introducing woody debris may alter stream processes with possible negative results (Rosgen 1996).

Low-order streams are dramatically affected by terrestrial inputs such as woody debris because of the high ratio of shoreline to stream bottom (Vannote et al. 1980). In streams, wood becomes a resource for nutrients and habitat and retains sediments and debris flowing downstream. Wood decomposes more slowly in water than on land because oxygen cannot easily penetrate submerged wood (Maser and Sedell 1994). This allows wood to build up in stream systems, with larger pieces having the potential to affect the stream for a longer time period than smaller pieces.

When wood remains in headwaters streams, it can influence the physical and biological environment, which, in turn influences habitat for aquatic invertebrates. For example, wood can alter water velocity by creating steps or pools, retain organic matter in log jams, and offer protection from predators.

The River Continuum Concept

The River Continuum Concept (RCC) is the foremost stream ecosystem theory. The RCC proposes a relationship between stream size, increasing longitudinally downstream, and a progressive shift in structural and functional attributes of the biological community (Vannote et al. 1980). The RCC links terrestrial materials (allochthonous inputs) and/or materials of aquatic origin (autochthonous inputs) with invertebrate community structure, primarily functional feeding group distribution, along the stream continuum.

According to the RCC, headwater streams (first- through third-order) are heavily forested with a high degree of canopy cover. The RCC predicts that invertebrate communities of low-order streams will be dominated by shredders because of the relative abundance of leaves, needles, bark, and other allochthonous inputs (Hawkins and Sedell 1981). However, the presence of shredders is not only caused by increased inputs of coarse particulate organic matter (CPOM), but by the physical retentiveness (log and debris jams and coarse substrate) of low-order streams (Bilby and Likens 1980). Shredders in headwater streams break down terrestrial materials and CPOM into smaller particles that can be transported downstream.

In high-order streams, shredders are scarce or limited to the shoreline. High-order streams depend on upstream resources for particulate matter. Filterers collect the fine particulate organic matter flowing from upstream sources as a result of shredder activity. These communities grade into one another thus exhibiting a continuum of habitats. Wider streams have less canopy cover to restrict photosynthesis and algal growth and the resulting autochthonous resources required by scrapers.

Many studies have attempted to find exceptions to this theory. Not all headwater streams are forested; many exist or begin above the treeline on mountains. First order streams that are not

forested may not depend on allochthonous inputs; therefore, the macroinvertebrate communities of these streams are not dominated by shredders. Large rivers of mid- and high-orders in steep-sided canyons may have a limited amount of sunlight reaching the streambed, thereby limiting autochthonous inputs and scrapers. However, the existence of a continuum from upper tributaries to lower elevation rivers as an important concept in stream ecology cannot be ignored. The RCC provides an overview of the physical parameters and biological communities that may exist along a stream network. Nevertheless, it is imperative to view study streams in context of local and regional characteristics specific to the area that may result in the study sites deviating from predictions made in the RCC.

Sources of Litter

Litter, such as wood, leaves, and needles, enters streams from the canopy above, laterally from the adjacent riparian area, or from upstream reaches. These routes may vary considerably in the composition and quality of allochthonous materials delivered to the stream. The quantity of material delivered to the stream varies seasonally, especially if the source area includes deciduous trees. The RCC predicts the aquatic biota, like shredders and gatherers, depend on these allochthonous inputs as food in headwater streams.

Trees from the riparian area often fall into and across the stream channel, contributing wood logs and branches. Streamside litter traps often collect more leaves and wood than forest traps, but both may receive 13-18% of the total input as needles (Conners and Naiman 1984). Therefore, laterally transported litter may be a minor component for stream systems; less than 10% of the total litter input to a stream may be attributed to lateral transport (Campbell et al.

1992). However, lateral inputs may differ significantly from canopy-derived material as a nutritional resource, having already experienced some decomposition on land.

In the stream itself, large pieces of wood require high, fast flows to move them downstream, and smaller pieces are often retained, limiting the distance detritus travels downstream. Less than 50% of the detritus that enters low-order streams is actually transported downstream (Anderson and Sedell 1979), because material is retained by wood, debris jams, and substrate, to be used by aquatic biota. Invertebrate communities themselves influence the breakdown and utilization of materials that are transported downstream (Wallace et al. 1982). Changes to upstream resources may alter the quantity and quality of materials transported to downstream macroinvertebrate communities.

The rate at which the vegetation is subject to bacterial decay and is processed by shredders and consumed by gatherers depends on the vegetation type. The quantity of processed material delivered downstream was found to be related to the type of vegetation, with less litterfall where herbaceous species (nonwoody litter) dominate and than where deciduous woody species dominate (Delong and Brusven 1994). Furthermore, deciduous and coniferous trees make different contributions to the stream system. Streams with young alder have been found to export more detritus than young conifer streams (Piccolo and Wipfli 2002).

The riparian vegetation composition leads to another consideration: the temporal component of litterfall. No measurable litterfall during months other than August through November was determined to correspond with neighboring deciduous trees (Delong and Brusven 1994). Streams with alders export more detritus annually than stream with conifers because of the seasonal litterfall associated with the deciduous alder (Piccolo and Wipfli 2002).

Macroinvertebrate communities have evolved to take advantage of these seasonal fluctuations in the quantity and quality of litter inputs.

Physical Effects of Wood

After wood enters the stream, it begins to influence the physical structure and function of the system. Wood is presumably more resistant to being dislodged during flooding than leaves (Hax and Golladay 1993), offering an element of stability to maintain the channel. However, wood can alter channel morphology and energy dynamics (Beschta and Platts 1986, Gregory et al. 1991).

Wood is a critical component of stability in small streams (Anderson and Sedell 1979). Wood logs and large branches can shield banks from the erosive nature of flowing water. Within the stream, wood is able to anchor into the streambed, thus protecting substrate from being swept downstream during high, fast flows. By retaining sediments, wood contributes to channel stability (Bragg and Kershner 1999).

Woody debris influences stream hydraulics by forming steps (Maser and Sedell 1994, Gomi et al. 2001). As water cascades over the edge of the step, the stream's energy is dissipated (Bilby and Likens 1980, Rosgen 1996). The formation of steps also alters the slope of the streambed, with increased water velocities over steep gradients (Rosgen 1996).

A third contribution of wood to stream structure and function is the formation of debris jams. Greater proportions of wood pieces in low-order streams with steep slopes are found in debris jams than as individual pieces. Wood and wood jams can create microhabitats for invertebrates, resulting in a patchy distribution of invertebrates throughout the stream. In addition, accumulations of coarse woody debris can divert the flow of water (Tabacchi et al.

2000, Trotter 1990) and, therefore, control organic matter and sediment transport (Gregory et al. 1991) and storage (Rosgen 1996). Wood also helps remove dissolved and particulate material from the water column as it is being transported downstream. Suspended sediments settle out upstream from jams where water velocity is slowed and are retained until flows are at a capacity to flush them out (Bilby and Likens 1980). However, when wood jams retain sediment, it can influence the biological community, such as suffocating insect larva (Gordon et al. 1992).

Biological Effects of Wood

Many of the physical effects of wood can alter the biological community. If wood retains sediment in the stream channel, silt and sand may fill interstices, which are important habitats for many aquatic organisms (Chutter 1969, Beschta and Platts 1986) and cover food producing substrates (Waters 1995) as well as suffocate larva (Gordon et al. 1992). Deposited sediments may also interfere with the egg stage, respiration, and/or the attachment of invertebrates (Chutter 1969).

Densities of invertebrates are often found to be greater on wood and leaves than mineral substrate (Hax and Golladay 1993) supporting the idea that wood serves two major functions: habitat and nutrient resource. Woody debris influences invertebrates by changing the structure and abundance of habitat (Gomi et al. 2001). Particularly in low-order streams, wood and wood-created habitats may comprise half of the stream (Anderson and Sedell 1979). The wood itself is a habitat providing protection from the stream's current, suspended sediments, and predation, to invertebrates living in the grooves and crevices of wood or under the bark (Maser and Sedell 1994). Wood offers various light, oxygen, and current conditions for macroinvertebrates, after softening and being broken down by physical forces (Hax and Golladay 1993). However, the

hardness and condition of the wood, not its texture, determines its suitability for use by macroinvertebrates (Magoulick 1998).

In addition, many invertebrates use wood as habitat in other ways. Some case-building caddisflies use wood, bark, twigs, and leaves, to build cases for protection (Merritt and Cummins 1996). Net-spinning caddisflies will often anchor their nets to wood to direct the flow of water, and food, into their nets (Maser and Sedell 1994).

Although wood provides a variety of opportunities for habitat, a diverse consumer community is prevented from developing because wood is often unpalatable (Naiman and Decamps 1997). Some species of caddisflies, stoneflies, craneflies, midges, and beetles, however, have been reported as feeding on wood (Anderson and Sedell 1979, Gomi et al. 2001). Wood jams benefit shredders, by retaining leaves, and gatherers, by creating pools where slow water allows particulate organic matter to settle out. Indirectly, wood serves as a foundation for bacteria, biofilm, and algae to grow, which are then consumed by scrapers (Magoulick 1998). In addition, wood can enhance prey variety and availability for predators. Therefore, wood may lead to a diverse assemblage of functional feeding groups.

CHAPTER THREE

STUDY AREA AND METHODS

This study was conducted in Colville National Forest in northeastern Washington, specifically the South Fork of Deep Creek watershed, an area encompassing about 50,000 acres (over 20,000 hectares). Established in 1906, the Colville National Forest is located on over one million acres (or just less than 445,000 hectares) in the northeastern quarter of Washington. The geology of this region consists of metasedimentary rocks and granitics (Bisson 2002). This area of the state experiences cold winters, averaging -2.2 °C (28 °F), and warm summers, averaging 18.3 °C (65 °F) (Bisson 2002). Average annual snowfall, taken from the local airport, is 10 cm (47 in) and average rainfall is 46 cm (18 in) (Bisson 2002).

In the early 1900's, lightning strikes started fires that burned many acres of the forest. More than half of the timberlands that are now a part of the Colville National Forest were burned between 1920 and 1934 (Holstine 1987). In the South Fork of Deep Creek watershed, wildfires in 1926 and 1929 burned many acres of land surrounding the study sites. After decades of fire suppression, large sections of the forest are now composed of dense (more than 400 trees per acre), even-aged (60-80 year age class), small (10 to 18 cm, or 4 to 7 in) diameter stands (DePuit and Quigley 2002).

Site Selection

Several criteria were used to select study sites. First, all sites were situated on Forest Service land in close proximity to each other to minimize differences in geology and climate. Second, the sites needed to be accessible by roads. Five of the six study sites were adjacent to

Forest Service roads (within 61 m or 200 ft) with the sixth site (Clinton Creek – Site Z_2) about 186 m (or 610 ft) from the road. Third, low-order streams where there would be the greatest influence of wood on streams were selected. The focus on low-order streams also minimized variations in the macroinvertebrate communities between sites. Small, low-order, headwater streams are directly influenced by allochthonous inputs from the canopy above and neighboring riparian area, allowing shredders to thrive (Hawkins and Sedell 1981, Vannote et al. 1980).

Six study sites, in three pairs, were chosen on low-order streams from 1:24,000 United States Geological Survey (USGS) quadrangle maps (Figure 2). Sites were given a letter (X, Y, Z) to identify pairs and a corresponding subscripted number. The lower number (1) designated the "less wood" site in the pair, with the higher number (2) for the "more wood" site. Two pairs of sites on four different first-order streams were selected: an unnamed tributary to upper Rocky Creek (site X_1) was paired with an upper reach in the headwaters of Rocky Creek (site X_2), and the South Fork of Rogers Creek (site Z_1) was paired with Clinton Creek (site Z_2). An additional pair was located on Rocky Creek with one site on a second-order segment (site Y_1) and one site downstream on a third-order segment (site Y_2). In situ observations allowed for the selection of reaches representative of the stream and with fairly uniform flow.

Figure 2: Map of study sites in the South Fork of Deep Creek watershed in Colville National Forest in northeastern Washington. All sites are located along low-order streams on forest service land.
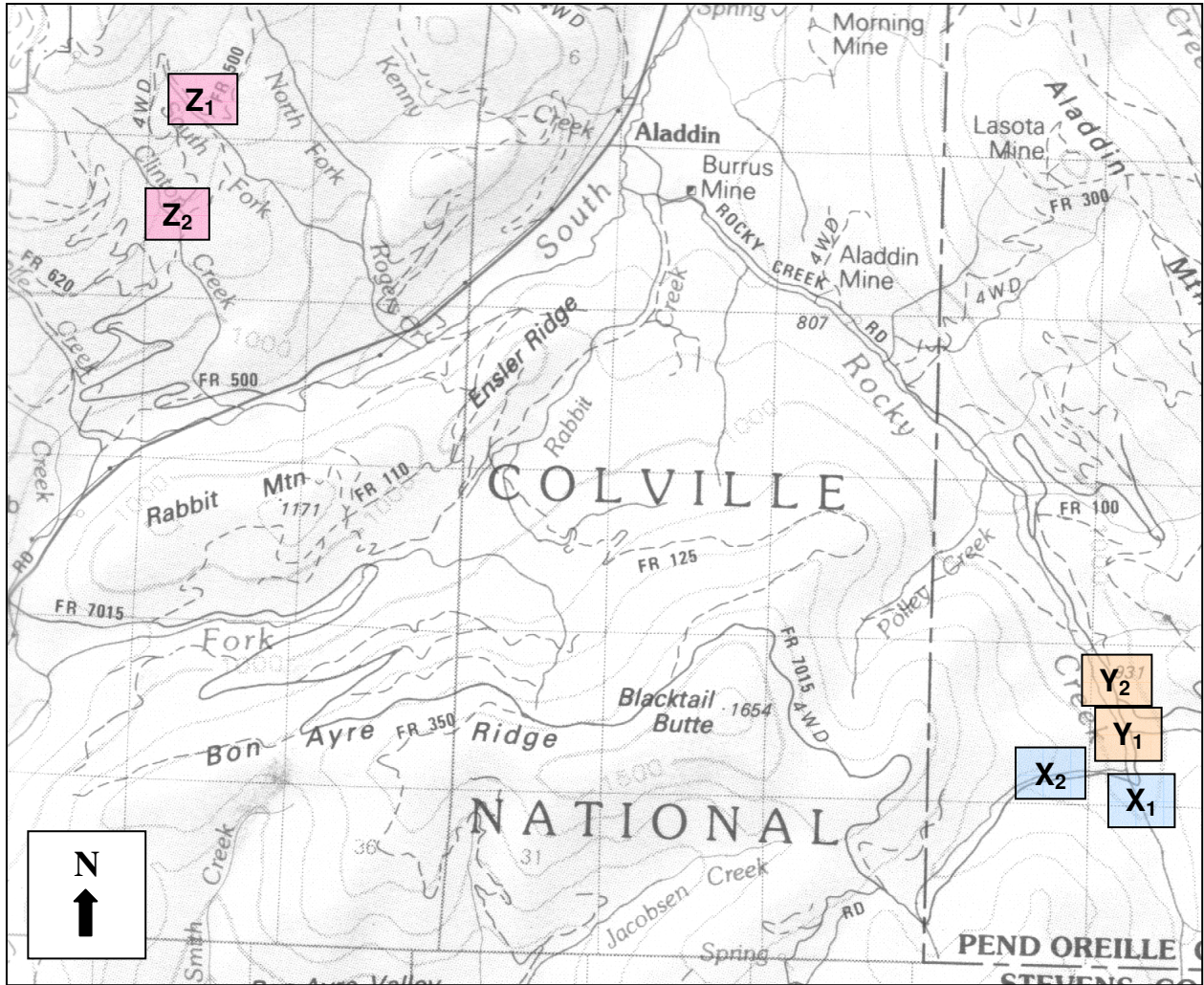
Site Descriptions

Terrain Navigator (MapTech 2002), Washington region, program determined the watershed area for each study site. Delineation of the area of land contributing runoff to each study site developed from the pattern of the contour intervals on digitized USGS maps (Figure 3). Photographs of the canopy above the study reach one time during the sampling season, with the use of a grid, aided in the estimation of average percent canopy cover for each site. Canopy cover over the study sites ranged from 51-77%, with one outlier at 23% (Table 1). In addition, a Swoffer velocity meter measured the water flow through riffles at each site. Identification of riparian vegetation composition occurred at 0.3 m intervals along a 9 m (30 ft) transect on each bank (Table 2). The distance of 9 m was selected because at some sites the road was within 12 m (40 ft) of the stream.

Figure 3: Watershed delineation for Clinton Creek sites Z_2 (red) and South Fork of Rogers Creek site Z_1 (purple) using Terrain Navigator (MapTech 2002).
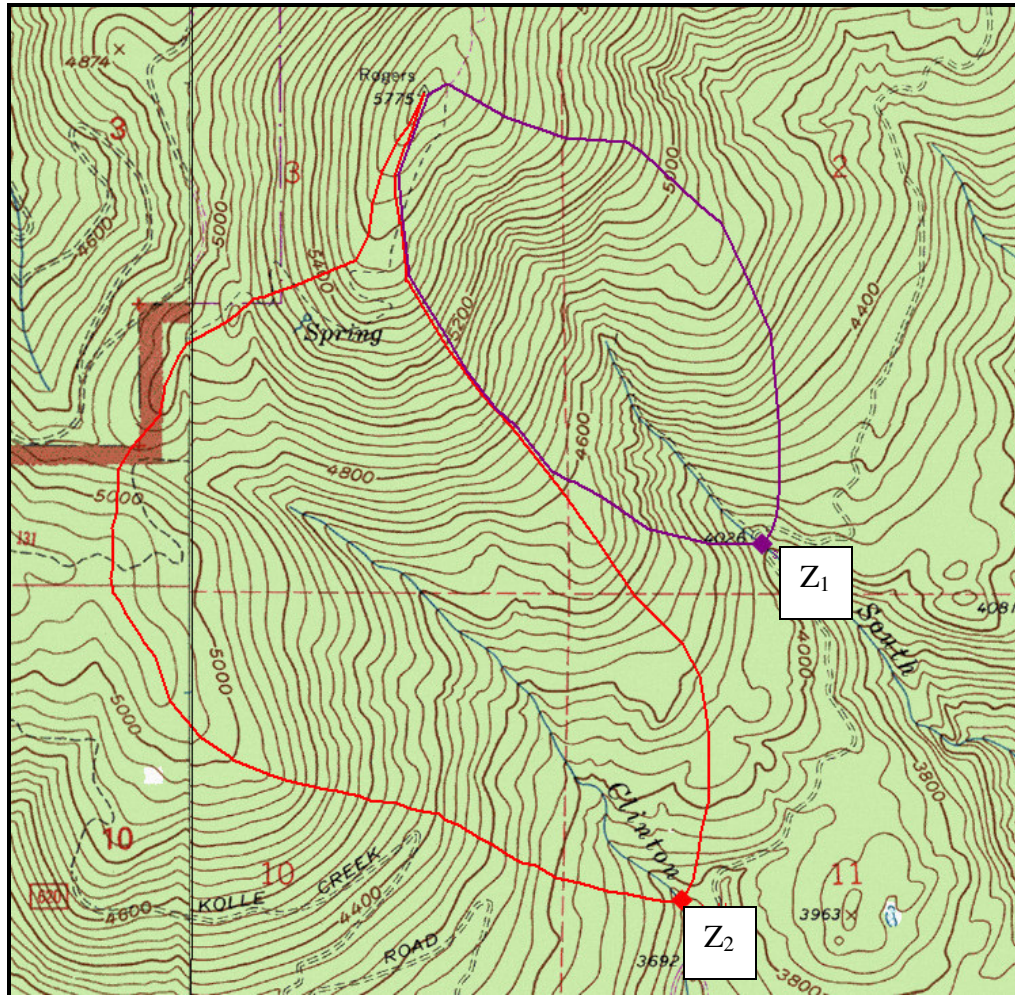
Table 1: Site descriptions for study sites on low-order streams in Colville National Forest, northeastern Washington. Number of wood pieces verifies that Sites X_2, Y_2, and Z_2 had more wood pieces than their paired sites.

Site	Name	Coordinates	Elevation (m)	Drainage Area (ha)	Woody Debris (number of pieces)	Average Canopy Cover (%)	Average Velocity (m/s)	Number of Riparian Plants Unique to Site in Each Pair
Pair 1								
X_1	Unnamed tributary to Rocky Creek	48° 40' 17.20" N 117° 35' 59.59" W	970	958	20	61	0.37	4
X_2	Headwaters of Rocky Creek	48° 39' 40.88" N 117° 38' 4.60" W	1,024	414	40	58	0.15	2
Pair 2								
Y_1	Middle Rocky Creek Upper Site	48° 40' 39.54" N 117° 36' 7.84" W	921	2,046	13	70	0.50	3
Y_2	Middle Rocky Creek Lower Site	48° 41' 14.84" N 117° 36' 10.13" W	900	2,331	24	23	0.50	8
Pair 3								
Z_1	South Fork of Rogers Creek	48° 43' 51.52" N 117° 43' 38.98" W	1,226	191	15	51	0.50	4
Z_2	Clinton Creek	48° 43' 27.79" N 117° 44' 58.80" W	1,145	90	28	77	0.23	6

Table 2: Riparian vegetation composition of one transect at each study site along low-order streams in Colville National Forest, northeastern Washington.

Common name	Scientific name	Present at					
		X_1	X_2	Y_1	Y_2	Z_1	Z_2
Grand fir	*Abies grandis*	x	x	x		x	x
Quaking aspen	*Populus tremuloides*	x				x	
Red alder	*Alnus rubra*				x	x	x
Rocky Mountain maple	*Acer glabrum*			x		x	
Water birch	*Betula occidentalis*			x			
Western red cedar	*Thuja plicata*	x	x	x	x	x	
Western hemlock	*Tsuga heterophylla*		x				
Baneberry	*Actaea arguta*		x	x		x	
Devil's club	*Oplopanax horrida*				x		
Douglas's aster	*Symphyotrichum subspicatum* (*Aster subspicatus*)				x		
Great hedge-nettle	*Stachys cooleyae*				x		
Oregon boxwood	*Paxistima myrsinites*	x			x	x	x
Pathfinder	*Adenocaulon bicolor*					x	
Prickly currant (Swamp gooseberry)	*Ribes lacustre*			x	x		x
Queen's cup	*Clintonia uniflora*	x				x	
Red osier dogwood	*Cornus stolonifera*			x	x		x
Starry false solomon's seal	*Maianthemum stellatum (Smilacina stellata)*			x	x	x	x
Stream violet	*Viola glabella*	x	x	x	x	x	x
Sweet woodruff	*Galium odoratum*			x	x		x
Thimbleberry	*Rubus parviflorus*			x	x	x	x
Twinflower	*Linnaea borealis*	x	x	x	x	x	x
Western foamflower	*Tiarella trifoliata (Tiarella unifoliata)*	x	x	x	x	x	x
Unknown 1					x		
Unknown 2					x		
Ferns		x	x	x	x	x	x
Grasses		x	x		x	x	x

PAIR 1

Figure 5: Site X_2, a first-order, "more wood" site on the headwaters of Rocky Creek

Figure 4: Site X_1, a first order, "less wood" site on an unnamed tributary to the headwaters of Rocky Creek

PAIR 2

Figure 7: Site Y_2, a third-order, "more wood" site on lower Rocky Creek

Figure 6: Site Y_1, a second-order, "less wood" site on Rocky Creek, upstream of Site Y_2

Figure 9: Site Z_2, a first-order, "more wood" site on

Clinton Creek

PAIR 3

Figure 8: Site Z_1, a first-order, "less wood" site on the

South Fork of Rogers Creek

PAIR 1: Sites X_1 *and* X_2

Pair 1 consisted of two sites located in the headwaters of Rocky Creek, one on an

unnamed tributary to the upper reaches of Rocky Creek (X_1) and one on Rocky Creek (X_2). Both

of these sites were on first-order stream segments. The site X_1 watershed (958 ha or 3.7 mi^2) was

over twice the area of the adjacent watershed of site X_2 (414 ha or 1.6 mi^2).

Site X_1 (Figure 4), a "less wood" site, was about 41 m (134 ft) south and upstream of

Rocky Creek Road. This unnamed tributary to the headwaters of Rocky Creek possessed pool-

riffle morphology. The study segment, located upstream from a breached log check, had a very

steep right bank. With a larger watershed than site X_2, the stream at site X_1 was wider. Measured

stream's velocity was greater at site X_1 than site X_2, with an average riffle velocity of

approximately 0.37 m/s (1.2 ft/s) in late August. Canopy cover over the stream at this site was

similar to site X_2, averaging 61%. This site had slightly more diversity in riparian vegetation

composition than site X_2 including queen's cup (*Clintonia uniflora*) and Oregon boxwood

(*Paxistima myrsinites*) as well as quaking aspen (*Populus tremuloides*) and grass for Pair 1.

Site X_2 (Figure 5), a "more wood" site, was found about 40 m (130 ft) from Rocky Creek

Road. This site on the headwaters of Rocky Creek also had pool-riffle morphology but very low

flow in the late summer. The average riffle velocity at the site in late August was approximately

0.15 m/s (0.5 ft/s). Canopy cover over the stream was about 58%. Baneberry (*Actaea arguta*) and

western hemlock (*Tsuga heterophylla*) were only found at X_2 in this pair.

PAIR 2: Sites Y_1 *and* Y_2

Pair 2 was made up of two sites on the same stream. Site Y_1 was located on a second

order segment of Rocky Creek, downstream of both sites X_1 and X_2. The site Y_1 watershed, over

2,000 ha or 7.9 mi^2, included the watersheds for sites X_2 and X_1. Site Y_2 is further downstream, on a third order segment, below an unnamed tributary. Therefore, the site Y_2 watershed, about 2,300 ha or 9 mi^2, included the entire watershed of site Y_1.

Site Y_1 (Figure 6), a "less wood" site, was on Rocky Creek downstream from Pair 1 and upstream from Y_2. The study site was about 12 m (40 ft) west of Rocky Creek Road. At site Y_1, the study reach segment, was located near a breached log check. Despite being of lower order and above a tributary, the width of the stream at site Y_1 was similar to the width of the stream at site Y_2. The average riffle velocity in late August at site Y_1 was similar to Y_2, approximately 0.5 m/s (1.7 ft/s). Canopy coverage was about 70% at site Y_2. In this pair, baneberry (*Actaea arguta*), water birch (*Betula occidentalis*), Rocky Mountain maple (*Acer glabrum*), and grand fir (*Abies grandis*) were found only at this site.

Site Y_2 (Figure 7), a "more wood" site, was downstream from Pair 1 and site Y_1, and about 50 m (165 ft) from Rocky Creek Road. The average late August riffle velocity at site Y_2 was approximately 0.5 m/s (1.7 ft/s). Site Y_2 had the least canopy cover over the stream of all the study sites (23%). However, reduced canopy cover corresponds to the longitudinal predictions set forth by the River Continuum Concept since site Y_2 is of the highest order in the study. Oregon boxwood (*Paxistima myrsinites*), Rocky Mountain maple (*Acer glabrum*), and grass were unique to this site in this pair. In addition, site Y_2 was found to have the most diverse riparian vegetation composition out of all the study sites. Devil's club (*Oplopanax horrida*), great hedge-nettle (*Stachys cooleyae*), Douglas's aster (*Symphyotrichum subspicatum*), and two different unknowns were found only at this site in the study. Devil's club (*Oplopanax horrida*), a hydrophyte, indicates that the soil alongside the creek is saturated with water (Hachmoller et al. 1991).

PAIR 3: Sites Z_1 and Z_2

The third pair of study sites was situated on two tributaries to the upper reaches of the South Fork of Deep Creek. Both sites in pair 3 were located on first order streams, site Z_1 on the South Fork of Rogers Creek and site Z_2 on Clinton Creek. The site Z_1 watershed (90 ha or 0.348 mi^2) was a little less than half of the area of site Z_2's watershed (191 ha or 0.738 mi^2). The geomorphology of these two sites resembled step-pool morphology.

Site Z_1 (Figure 9), a "less wood" site, was about 12 m (40 ft) from a forest service road, downstream from a culvert where the road passes over the stream. The average riffle velocity in late August was about 0.5 m/s (1.5 ft/s), higher than the average riffle velocity at site Z_2. Average canopy cover at this site was about 51%. Riparian vegetation composition unique to site Z_1 in Pair 3 included pathfinder (*Adenocaulon bicolor*), queen's cup (*Clintonia uniflora*), baneberry (*Actaea arguta*), Rocky Mountain maple (*Acer glabrum*), and western red cedar (*Thuja plicata*).

Site Z_2 (Figure 8), a "more wood" site, was about 186 m (610 ft) from the Clinton Creek horse camp hitch station, adjacent to a Forest Service road. This site was the least potentially influenced by human disturbance such as roads. The average riffle velocity at this site was about 0.23 m/s (0.74 ft/s). Average canopy cover over Clinton Creek was measured to be about 77%. The riparian vegetation composition unique to this site in Pair 3 included stream violet (*Viola glabella*), sweet woodruff (*Galium odoratum*), prickly currant (*Ribes lacustre*), red osier dogwood (*Cornus stolonifera*), as well as ferns and grass.

Wood

At each site, woody debris was counted from within the study reach. Measurements were taken in late May, when many pieces had been deposited after high spring flows. Walking upstream, logs, sticks, trunks, and roots were counted and their location within, above, and along the channel was recorded. Also, the diameter of each piece was measured. Diameters were fairly consistent along their lengths. Debris was classified as small (less than 6.4 cm or 0.21 ft), medium (6.41 cm to 15.24 cm or 0.21 to 0.50 ft), or large (greater than 15.24 cm or 0.50 ft).

Physical Environment

Cross-sectional and longitudinal profiles were measured across the stream channel and along the streambed. Bankfull width, bankfull depth, slope and substrate were measured.

Cross-Sectional Profile

At one point in the selected reach at each site, with uniform flow and representative bed topography, a cross-sectional area was chosen, benchmarked, and measured. Starting from the left bank, a piece of rebar was inserted into the ground at bankfull level, as determined by indicators such as a change in slope or a change in vegetation (Carlson et al. 1990, Harrelson et al. 1994, Leopold 1994). Rebar benchmarks were then reinforced with a concrete collar and tagged with an identification number. A yellow stopper was placed on top of the rebar, and other painting and flagging were added to aid in location. This same procedure was repeated on the right bank.

Pins were then inserted into the ground above these benchmarks to hold a measuring tape connecting the two sides of the stream. The measuring tape was held taut, perpendicular to the

stream flow, with the zero mark on the left bank permitting measurement of bankfull width. Slope was measured with an LB-1 laser beacon model 3900 by Laser Alignment, Inc., leveled on a tripod next to the stream to maximize the laser range.

A Rod Eye-4 detector attached to the top of a surveying rod referenced to the laser measured elevations along the measuring tape. Elevations recorded from the rod corresponded with a station number from the measuring tape indicating the cross-sectional width. Left and right bank benchmark elevations were also measured, as well as any significant changes in the streambed, such as top of bank, the water's edge, thalweg, etc. Points were measured from above the left benchmark to above the right benchmark transecting the stream. The recorded height of the water surface in the thalweg gave the depth of the stream at the deepest point in the cross-section. Plotting the recorded elevations produced graphs of the cross-sectional profiles. Width/depth ratios, the bankfull width at the cross-section divided by an average bankfull depth, were taken from the graphs (Rosgen 1996).

Longitudinal Profile

Longitudinal profiles show the changes in the stream elevation over a specified distance (Gordon et al. 1992). Longitudinal profiles of streams in forested, mountainous areas can be highly variable and often very complex (Frissell et al. 1986). For this study, it was desired that paired sites had similar slopes as determined by a longitudinal profile of the water surface and channel bed (Harrelson et al. 1994).

To measure a longitudinal profile, a measuring tape was hooked to a pin in the stream at the cross-section, and laid down the thalweg of the stream. Elevations for channel slope and water surface slope were taken with the LB-1 laser and the Rod Eye-4 detector. All

measurements were taken in the thalweg. Bankfull elevations were taken where evidence was easily observable (e.g., an obvious change in the elevation of a bank or a change in vegetation or substrate). Elevation measurements of important features, such as the tops and bottoms of steps created by a log, woody debris jams, and habitats (e.g., pools, riffles, runs), and their placement along the stream reach, were recorded.

Recorded elevations were plotted to produce a graph of the longitudinal profile for each study reach. Jagged peaks in the longitudinal profiles may be attributed to logs or other wood pieces. Graphs were used to calculate the stream gradient (or slope) by measuring the change in elevation over change in distance within the same habitat (e.g., top of riffle to top of riffle, or end of pool to end of pool).

Substrate

The Wolman Pebble Count technique provided an overview of the substrate on the streambed. To get an accurate portrayal of the streambed, a representative sample was needed from pools and riffles (Harrelson et al. 1994), with a minimum of 100 particles measured. Representative proportions of these habitats were determined by estimating the total lengths of pools versus riffles along the length of each study reach. Particle samples were allocated to pools or riffles according to their percentage within the reach. For example, if the pool/riffle composition were 20%/80%, then 20 particles were sampled from pools and 80 particles were sampled from riffles.

A pool or riffle was selected randomly within the study reach; then, beginning at the bankfull elevation, the stream was crossed perpendicular to flow. At every step, while looking away from the stream, the first particle touched by the tip of the index finger was measured. A

ruler was used to measure the intermediate axis. Particles too large to be picked up or removed were measured in place in the streambed and were recorded more than once if touched more than once. Particles were sized within classes according to the Wentworth scale. Transects were conducted until the necessary number of particles was met or exceeded. Wolman Pebble Counts were plotted by size and frequency. Percent compositions of each substrate type (silt/sand, gravel, cobble, and boulder) were calculated.

Macroinvertebrate Community

Three stratified random samples for benthic macroinvertebrates were collected from riffle habitats at each site using a Surber sampler. Samples were collected from riffles for diversity and for proper equipment function.

Because of the height of the Surber sampler, the collection net would be completely submersed in water deeper than 41 cm, which could occur in some pools, obviating proper equipment function. In addition, because sampling occurred in the late summer during low flow conditions, only riffles had enough flow to transport organisms into the collection net of the Surber sampler.

The Surber sampler was a 0.09 m^2 (approximately 1 ft^2) square with a 500 µm mesh net allowing the current, and the macroinvertebrates stirred up, to flow into the net. The sampler frame was laid out on the streambed. Sediment and rocks within the frame were scrubbed to release insects into the current where they collected in the net. For these small headwater streams in September, the Surber sampler was centered about the thalweg (deepest part of channel) but often extended across the entire wetted perimeter of the stream.

Samples from the net were placed in plastic bags labeled with date, site, and sample number. These samples often contained leaves, twigs, gravel, and sand in addition to macroinvertebrates. The nets were then handpicked with forceps to remove any remaining macroinvertebrates. For preservation, 70% ethanol was added to the bags. Samples were stored at 4°C until processing.

Laboratory Processing

In the lab, samples were handpicked to separate all organisms from debris. Organisms were identified to the family level using a stereo microscope and the key by Merritt and Cummins (1996) and were counted. The organisms were then placed in vials containing 70% ethanol with the original sample label for preservation as part of a reference collection (Erman 1981).

Community Parameters

Parameters used to determine the effects of woody debris on the macroinvertebrate community population at each site included abundance, family richness, Shannon-Wiener diversity index, Pielou's evenness metric, percent contributions, and functional feeding group compositions. Mean abundance was the average number of individuals found in each sample for each site. Mean family richness was the average of the total number of families found in each sample for each site.

The Shannon-Wiener heterogeneity index was a calculated using the following formula:

$$H' = - \Sigma \, p_i \log_2 p_i$$

where p_i is the proportion of the total number of individuals in the ith species (or family) in a sample (Allan 1995). A higher result (H') indicates more richness and equitability (Hauer and Resh 1996) with H' expected to decrease with disturbance. At each site, a diversity value was assigned for each of the three collections, and then an average was calculated to determine the overall site diversity.

Evenness metrics are used to examine the distribution of taxa in a community. For this study, Pielou's J' was calculated as:

$$J' = H' / (\log t)$$

where t is the total number of species (or families) and H' is the Shannon-Wiener heterogeneity index. Less stressed communities tend to have a more even distribution of individuals, meaning that a higher evenness is seen as characteristic of a healthier community. Again, values were determined for each sample and averaged for each site.

The percent contribution of certain families to each community was also examined. The percentages of the top family, the top three families, and the top five families, were calculated based on the total at each site. Functional feeding group compositions were assessed based on family level determinations (Merritt and Cummins 1996). The composition of feeding guilds were determined at each site from all three sample combined.

Statistical Analysis

Study data were analyzed using two-way analysis of variance (ANOVA), two-sample t-tests, and chi-squares tests (Ott and Longnecker 2001) performed with the Minitab 13.20 statistical software (Minitab, Inc. 2000). Two-way analysis of variance (ANOVA) was used to test for differences between the numbers of wood pieces at "more wood" versus "less wood"

sites. An interaction component to this test was used to detect differences in wood size class compositions.

Two-sample t-tests were used to evaluate similarities of physical parameters such as mean slope, mean width/depth ratio, or mean particle size between site pairs. Particle size distributions were compared using a two-way ANOVA with an interaction component.

Macroinvertebrate communities at "more wood" and "less wood" sites were compared. Average abundance, mean family richness, average Shannon-Wiener diversity index values, and mean Pielou's evenness index values were analyzed with two-sample t-tests. A chi-square test was used to evaluate differences in functional feeding groups.

CHAPTER FOUR

RESULTS

One site in each pair contained approximately twice as many pieces of wood (classifying it as a "more wood" site) than the other site in the pair (classifying that site as a "less wood" site) (Table 3). The two-way ANOVA proved that a significant difference existed between the numbers of wood pieces at "more wood" versus "less wood" sites ($F = 5.04$, $p = 0.044$). The interaction component of the two-way ANOVA determined that there was no detectable difference in the wood size class composition in "more wood" sites than in "less wood" sites.

The width/depth ratio, determined by cross-sectional profiles (Appendix A), and slope, determined by longitudinal profiles (Appendix B), of the study sites were similar in each pair (Table 3). There was no significant difference in substrate composition between "more wood" and "less wood" sites; however mean particle size at "more wood" sites was lower in all three pairs (Appendix C). Streambed composition was determined using the particle size distribution for each study site (Figure 10).

Table 3: Wood, physical features, and macroinvertebrate communities of paired (X, Y, Z) "less wood" and "more wood" sites on low-order streams in Colville National Forest, northeastern Washington.

	SITE X_1	SITE X_2	SITE Y_1	SITE Y_2	SITE Z_1	SITE Z_2
Pair	1		2		3	
WOOD						
Wood Designation	less	more	less	more	less	more
Pieces < 6.4 cm	3	3	0	4	3	11
Pieces 6.4 cm to 15 cm	13	29	9	15	6	12
Pieces > 15 cm	4	8	4	4	6	5
Total Number of Wood Pieces	20	40	13	24	15	28
PHYSICAL						
Width/depth Ratio	6	4	11	13	4	5
Slope (%)	6	6	4	2	13	11
Mean Particle Size (mm)	39.0	14.4	17.8	14.8	34.3	16.7
BIOLOGICAL						
Mean Abundance	498	82	361	336	285	154
Total Abundance	1493	245	1084	1007	854	463
Mean Family Richness	19	12	16	16	20	13
Average Shannon's H' diversity	2.56	3.08	2.41	3.24	3.03	2.19
Average Pielou's J' evenness	2.02	2.83	2.02	2.70	2.32	2.06

Figure 10: Streambed substrate for six sites (pairs X, Y, Z) on low-order streams in Colville National Forest.
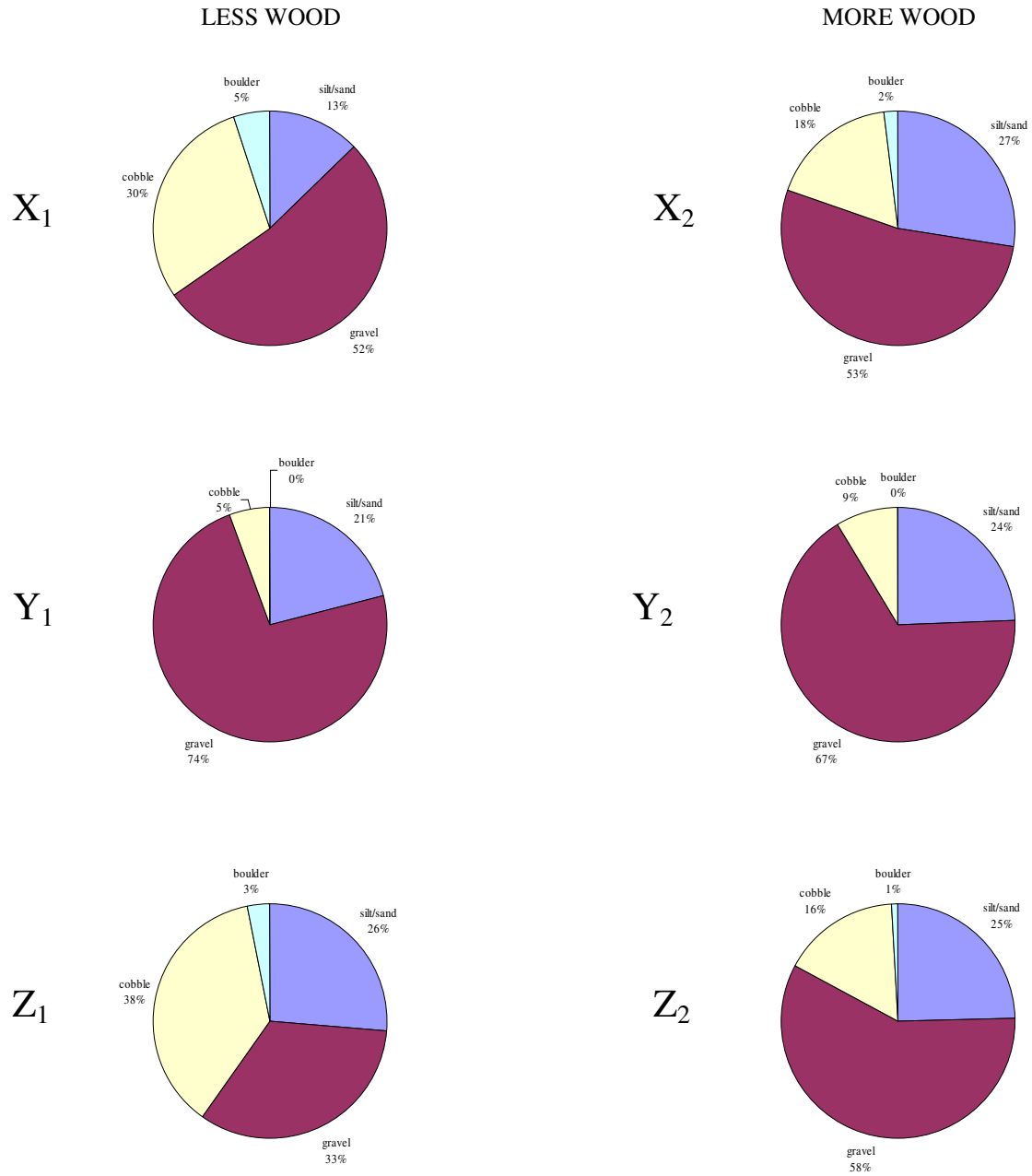
The goal of this study was to assess differences in the macroinvertebrate communities at "more wood" and "less wood" sites on forested, low-order streams. Specifically, abundance, richness, diversity, evenness, and functional feeding group compositions of the macroinvertebrate communities were used as indicators of the effects of large amounts of wood. There were no statistically significant differences for mean or total abundance; however, "less wood" sites had approximately twice the average number of macroinvertebrates (381) as "more wood" sites (191) (Table 4). No statistically significant difference was detected in family richness either, but the "less wood" sites had a higher overall mean family richness (18.3) than the "more wood" sites (13.7). For average diversity and evenness values, no statistical differences were detected; but "more wood" sites had higher average diversity (2.84) and evenness (2.53) than "less wood" sites (2.67 and 2.12 respectively). Functional feeding group composition was determined for each site to compare the macroinvertebrate community structure at "more wood" and "less wood" sites (Figure 11). The chi-square test showed a strong significant difference between proportions of functional feeding groups at "more wood" sites compared with "less wood" sites ($x^2 = 271.184$, $p < 0.001$).

Table 4: Biological parameters averaged for "less wood" and "more wood" sites on low-order streams of Colville National Forest with standard deviations.

	"LESS WOOD"		"MORE WOOD"	
Average Abundance	381	± 108	191	± 131
Average family richness	18.3	± 2.1	13.7	± 2.1
Average Shannon-Wiener diversity index value	2.67	± 0.32	2.84	± 0.57
Average Pielou's J' evenness metric	2.12	± 0.17	2.53	± 0.41
Average percent contributions of functional feeding group (%)				
Shredder	10.0	±11.3	7.0	± 4.4
Gatherer	50.7	± 9.6	35.0	± 19.1
Scraper	21.7	± 10.6	33.0	± 33.1
Predator	14.0	± 4.6	23.7	± 11.9
Filterer	3.7	± 3.0	1.3	± 1.5

Figure 11: Composition of the macroinvertebrate communities for six sites, pairs X, Y and Z, on low-order streams in Colville National Forest.
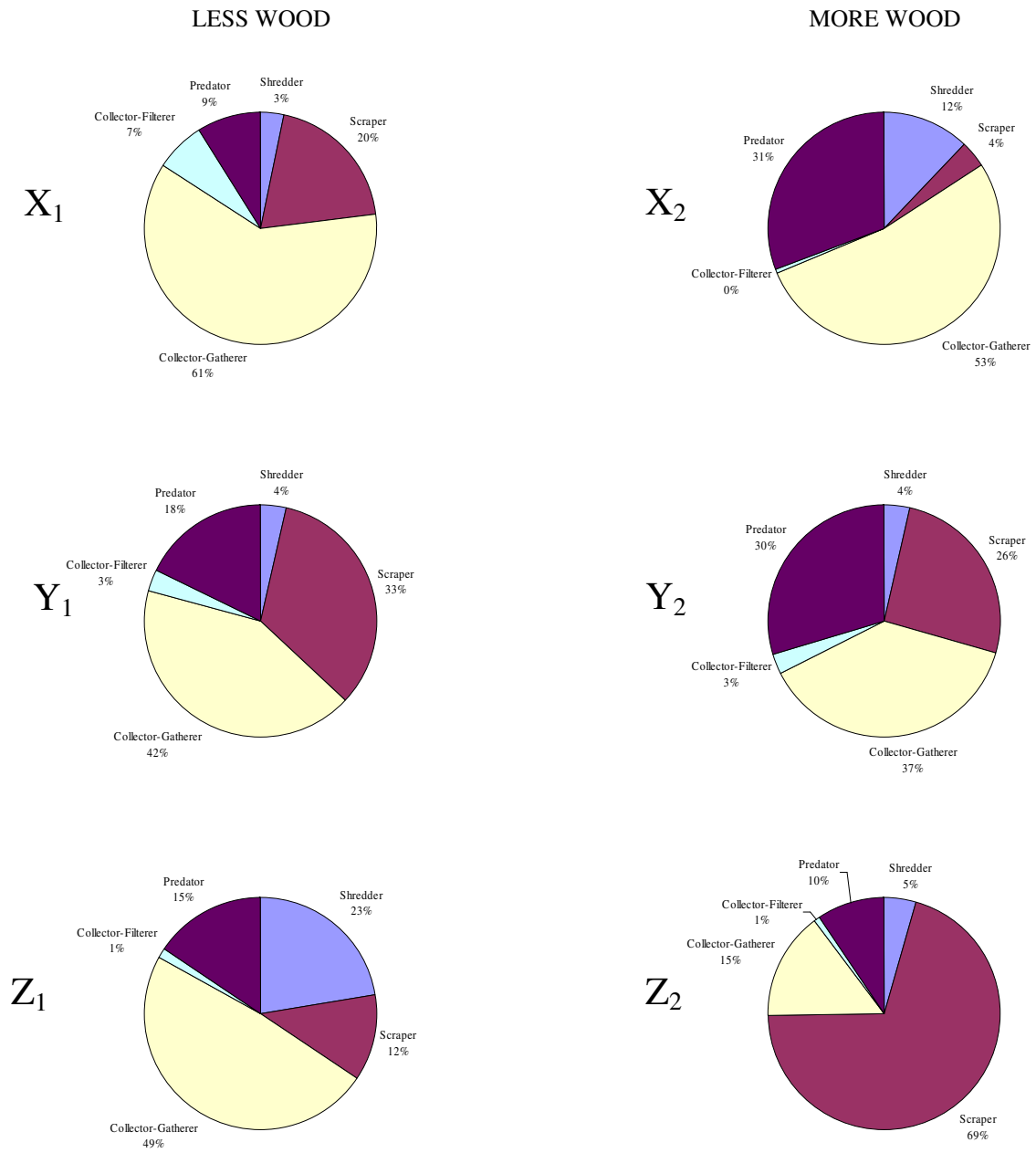
CHAPTER FIVE

DISCUSSION

The study hypothesis predicted lower abundance, richness, and diversity at the "more wood" sites, but no statistically significant differences were detected in any of these parameters between "more wood" and "less wood" sites. However, the mean values themselves offer vital information on the effects of large amounts of wood on macroinvertebrate communities in low-order streams. Furthermore, a strong, statistically significant difference was found in the functional feeding group composition at "more wood" sites compared to "less wood" sites.

Wood

By chance, all three study pairs had one site with approximately twice as many pieces of wood in it. Besides the number of wood pieces in the stream, their sizes could have been an important determinant of macroinvertebrate community structure. A significant difference in the size class composition of the wood pieces was not detected between sites. However, "more wood" sites had greater counts of large pieces (Table 3). Larger pieces of wood may persist in the stream longer than small pieces, influencing the stream over a longer time period. In addition, large pieces have greater surface area to capture and retain organic matter. Small pieces, on the other hand, also in greater numbers at the "more wood" sites, may not offer the same degree of stability as large pieces, favoring opportunistic and rapid colonizing organisms. The quantity of wood pieces in each size class at a site could be a significant variable in this study, altering the abundance and diversity of the macroinvertebrate community.

Physical Environment

Width/depth ratio, gradient (slope), and streambed substrate provided insight to the influence of large amounts of wood on the physical environment of low-order streams. Both the cross-sectional (Appendix A) and longitudinal profiles (Appendix B) contained wood pieces represented by jagged peaks on the streambed. Although no significant differences in slope and substrate were detected between the two types of sites, there were differences within each pair.

Since the study was designed as a paired experiment on low-order streams, minimal differences in slope were desired. The average slope for "more wood" sites (6.3%) was slightly less than at "less wood" sites (7.7%), although not statistically significant. In study pairs Y and Z, the "less wood" sites had steeper slopes, with one pair (X) having no difference in slope. This is somewhat unexpected because wood has been associated with creating steps, which increase gradient. Perhaps, "more wood" sites retained more particulate matter, thereby decreasing slopes. Future studies of low-order streams with large amounts of wood could examine the relationship between wood and slope.

Wood jams tend to retain organic debris and sediments, a factor on which the study hypothesis was based. The possibility that "more wood" sites, with more wood pieces and jams, would collect small substrate and fine particles increased the potential for lower abundance, richness, diversity, and evenness in the macroinvertebrate communities. Particle size distribution graphs (Appendix C) show all of the study sites were dominated by gravel or cobble. Although significant differences were not detected in the mean particle size or substrate size classes, the silt/sand composition at "more wood" sites ranged from 24-27%, higher than the silt/sand composition at "less wood" sites (13-26%) (Figure 10).

Overall, the three "more wood" sites appear more similar to each other in their substrate composition than the three "less wood" sites. Sites X_2, Y_2, and Z_2 were all dominated by gravel (53-67%), with roughly 25% silt/sand, some cobbles (9-18%), and few boulders (less than 2%). Of the study sites, two "less wood" sites, X_1 and Z_1, were comprised of more cobbles than silt/sand. Large amounts of wood may, therefore, increase the amount of small particles (silt/sand) in a stream. High proportions of small substrate have been linked to low abundance and diversity in the macroinvertebrate community because silt/sand can be unstable, harm macroinvertebrate respiration, suffocate larva, and interfere with egg-laying. However, silt/sand may be stable at these study sites during the low flow conditions of late summer-early autumn. If sand is stable under low flow conditions, more areas of the streambed can be inhabited, allowing greater abundance and diversity of the macroinvertebrate communities at the time the samples were collected.

The lack of a detectable, statistically significant difference in substrate composition between "more wood" and "less wood" sites does not infer the absence of a biological impact. Year-to-year variation in the macroinvertebrate community is often exhibited in streams with substrate composition varying with sediment carried in and transported out (Richards and Minshall 1992). In addition, streams experiencing frequent disturbances to their substrate have low diversity, inhabited by those species that have adapted to a fluctuating environment (Robinson and Minshall 1986). Substrate composition has been found to be important to the abundance of filterers and shredders (Hawkins et al. 1982). Preference for substrate in the 1.0- to 3.5-cm particle size range by macroinvertebrates was due to the substrate's ability to collect and retain detritus (Rabeni and Minshall 1977), an important food resource for shredders and gatherers. Therefore, shredders and gatherers may be more abundant at sites dominated by gravel

(substrate class containing the 1.0- to 3.5-cm particle size range). All of these study sites were dominated by gravel, with the exception of Z_1.

Macroinvertebrate Community

Since significant differences were not found in the width/depth ratio, slope, and substrate composition, there was a high likelihood that differences in the macroinvertebrate communities were a function of the amount of wood. Although statistical differences were not detected, the total abundances and the mean family richness values were lower at the "more wood" sites compared with "less wood" sites (Table 4). Therefore, large amounts of wood may lower abundance and richness, as hypothesized. Future studies with additional samples from various seasons, regions, and habitats could investigate the relationship between large amounts of wood in low-order streams and decreased abundance and richness in macroinvertebrate communities.

Significant differences were also not detected in the average Shannon-Wiener diversity index values and in the mean Pielou's evenness metric values at "more wood" versus "less wood" sites. However, the average diversity index and mean evenness values for "more wood" sites were slightly higher than the average for "less wood" sites (Table 4). This contradicts the prediction that "more wood" sites would have less diversity and evenness. Pair Z was the only study pair that followed the hypothesis; the "more wood" site (Z_2) was found to have less diversity and evenness (Table 3). Therefore, it is possible that large amounts of wood in low-order streams create more complex habitats or offer more surface area for biological utilization, and may not lower the diversity or evenness of the aquatic macroinvertebrate community.

Percent contributions made by the dominant families were examined at "more wood" and "less wood" sites in each pair (Appendix D). At all sites, the five dominant families comprised at

least 69% of the community. At site X_2, the dominant taxa title was shared by Baetidae and Leptophlebiidae, mayfly families, each comprising about 16% of the community. Chironomidae was a close third with slightly less than 16%. To round out the top five families at site X_2, Rhyacophilidae and Chloroperlidae were included, and these five families made up over 69% of the population. Site X_1 was also dominated by Baetidae, representing almost 48% of the community. In addition, the top five families, including Heptageniidae, Chironomidae, Hydropsychidae, and Chloroperlidae, comprised over 86% of the community at site X_1. Overall for pair X, Baetidae, Chironomidae, and Chloroperlidae families were abundant at both sites.

Pair Y, the second- and third-order streams pair, was dominated by some of the same families as pair X. Top five families at site Y_2 were Heptageniidae, Chironomidae, Chloroperlidae, Elmidae, and Glossosomatidae, comprising over 70% of the community. Elmidae, a member of the beetle order, was a known wood gouger and was abundant at the "more wood" site. At site Y_1, Baetidae, Heptageniidae, Chloroperlidae, Chironomidae, and Rhyacophilidae were the top five families, 86% of the community. Again, Chironomidae and Chloroperlidae were represented, similar to pair X, but Heptageniidae was also common at both Y sites.

Chironomidae and Chloroperlidae were also represented in the top five families at both sites in pair Z. About 84% of the community at site Z_2 consisted of Uenoidae, Chironomidae, Heptageniidae, Rhyacophilidae, and Chloroperlidae families, in that order. At site Z_1, over 70% of the community was found in the dominant five taxa: Chironomidae, Peltoperlidae, Uenoidae, Chloroperlidae, and Leptophlebiidae families. The Uenoidae family was found to be common at both Z sites.

Chironomidae and Chloroperlidae were in the top five families at all study sites, and the mayfly family, Baetidae, was the most frequent family at half of the study sites (two "less wood" and one "more wood"). Members of the Baetidae and Chironomidae families are known to have short generation times and rapid colonizing rates which allow them to survive fluctuations in their environment and quickly increase their populations opportunistically (Newbold et al. 1980). High numbers of baetids and chironomids were found in streams disturbed by logging in California (Mahoney and Erman 1984) and by wildfires in Idaho (Richards and Minshall 1992), illustrating their opportunistic nature.

In a study of fishless Alaskan streams, Leuctridae was the most abundant shredder family (Piccolo and Wipfli 2002). In the Colville National Forest, leuctrids were found at every site, but another stonefly family, Peltoperlidae, was the most abundant shredder (Appendix D). Peltoperlids, particularly the local genus Yoraperla, feeds on wood, not leaves like leuctrids. This relates back to the abundance of wood in these small streams, the food resource for peltoperlids. However, the site where the greatest numbers of peltoperlids were found was a "less wood" site (Z_1) (Appendix D). Although wood was present at Z_1, the high numbers of peltoperlids suggests there may be other factors, besides large amounts of wood, which determined their abundance.

Rhyacophilidae was one of the most common predator families in fishless Alaskan streams (Piccolo and Wipfli 2002). Rhyacophilidae was represented in the top five families at two of the six study sites in Colville National Forest (Appendix D). An abundance of rhyacophilids has been attributed to open canopy areas (Behmer and Hawkins 1986). Indeed, the most rhyacophilids per site was found at Y_2, the site least covered by canopy. However, other results in the study show little preference for canopy by rhyacophilids. For example, site X_1 and

X_2 had similar canopy coverage (61% and 58% respectively), but site X_1 had more rhyacophilids (45) than site X_2 (28).

Feeding guilds, or functional feeding groups, were found to be significantly different between the "more wood" and "less wood" sites. Functional feeding groups include shredders, gatherers, scrapers, predators, and filterers, although very few filterers were found. The RCC predicts low-order streams should have an abundance of shredders as a result of allochthonous inputs from riparian areas (Vannote et al. 1980). Typically, shredders make up about 30% of the community of forested streams (Hawkins and Sedell 1981, Minshall et al. 1983). However, shredders did not exceed 23% of the population at any of the study sites, with most sites containing less than 10% shredders. Greater quantities of coarse particulate organic matter can support higher densities of shredders (Peckarsky 1980); therefore, sampling only riffles may have underestimated shredder abundance, preferring pools (Huryn and Wallace 1987) or other habitats that retain particulate organic matter.

The RCC predicts a codominance of shredders with gatherers in forested headwater streams (Vannote et al. 1980). Shredders have been found to impact the nutrient availability to gatherers (Short and Maslin 1977). In laboratory experiments, gatherer growth was greater when shredders were present (Dietrich et al. 1997). Field experiments also support the shredder-gatherer interaction (Reice 1981, Heard and Richardson 1995, Grafius and Anderson 1980, Mulholland et al. 1985). Excess particulate matter as a result of the feeding activities of shredders increases food availability for gatherers. In this study, sites with more shredders did not necessarily have a correspondingly higher percentage of gatherers. However, gatherers were the dominant feeding group, with the exception of site Z_2. As mentioned previously, by sampling

riffles, shredder abundance may have been underestimated; therefore, the shredder-gatherer correlation might not be strong in the results of this study, even if it exists in the stream.

A shredder-gatherer correlation, using the proportion of shredders to total collectors (gatherers and filterers combined) has been suggested to assess the riparian-shredder interaction (Rawler-Jost et al. 2000). Although not in widespread use, this correlation could be an important analysis to examine the condition of the stream-riparian system. In particular, these study sites contained dense, even-aged, small diameter stands in their riparian areas which may have altered riparian functions. Shredder-to-collector ratios greater than 0.25 indicate a "normal" association between shredders and a functioning riparian system (Rawler-Jost et al. 2000). The ratio of shredders-to-collectors ranged from 0.05 to 0.45 (Table 5). Two of the sites, Z_2 (ratio of 0.30) and Z_1 (ratio of 0.46) contained communities associated with a functioning riparian system according to this indicator, despite each representing a different site type ("more wood" and "less wood"). Site X_2 (ratio of 0.23) was on the borderline of the 0.25 limit as an indication of a functioning riparian system. This concept has not been widely implemented; however, it offers another way of looking at these results. The site with the highest ratio of shredders to collectors was a "lesser wood" site with the second, third, and fourth highest ratios from "more wood" sites. Future studies can examine if the riparian areas at the "more wood" study sites function differently, as these results and this ratio imply.

Table 5: Ratio of shredders to collectors (gatherers plus filters) in low-order streams of Colville National Forest. Rawler-Jost et al. (2000) suggest ratios greater than 0.25 indicate a "normal" association between shredders and a functioning riparian area.

	LESS WOOD	MORE WOOD
Pair 1	Site X_1 – 0.05	Site X_2 – 0.23
Pair 2	Site Y_1 – 0.08	Site Y_2 – 0.09
Pair 3	Site Z_1 – 0.45	Site Z_2 – 0.29

A third functional feeding group is scrapers, organisms that feed on algae, biofilm, bacteria, and fungi growing on wood, substrate, and leaves. More scrapers were observed in the West than in the eastern United States (Wiggins and MacKay 1978) and in riffles than other habitat types (Huryn and Wallace 1987). The composition of scrapers at the study sites ranged from only 4-33%, with the exception of site Z_2 (69%). Still, several of these values seem high for forested, headwater streams, where predicted canopy cover was expected to restrict the growth of algae, an important food resource for many scrapers. Perhaps, scrapers were feeding on bacteria, fungi, or biofilm that may promote greater abundances under decreased light conditions at the study sites. Therefore, a prediction of scraper density cannot be made based on canopy (Hawkins et al.1982) and the results of this experiment support that idea.

Predators, another functional feeding group, have been found to be nearly constant in relative abundance across stream orders (Hawkins and Sedell 1981), rarely exceeding 30% of the total abundance in many streams (Minshall et al. 1983). Predators at site Y_2 comprised 30% of the population, and at site X_2, 31% of the population. Although wood offers protection to some organisms, both sites X_2 and Y_2 are "more wood" sites with high proportions of predators. Therefore, the presence of wood may influence higher trophic levels through more prey variety and availability (Bragg and Kershner 1999).

There were many similarities in the functional feeding group compositions between sites within the study pairs (Figure 11). Sites X_1 and X_2 both had over half of their communities represented by gatherers. Sites Y_1 and Y_2 were close matches. Shredders represented 4% and filterers represented 3% of the communities in pair Y, and gatherers made up another approximately 40% (37-42%). Scrapers were 26-33% of the communities at Y sites. However, the one difference in composition between the sites of pair Y was in predators, which comprised

46

30% of the community at site Y_2 but only 18% at site Y_1. On the other hand, there were many differences in the composition of the communities at sites Z_1 and Z_2. Pair Z had a higher percentage of shredders at the "more wood" site. Site Z_2 was the only study site dominated by scrapers. Sites Z_1 and Z_2 had similar percentages of filterers (both at 1%) and predators (15% and 10% respectively).

The macroinvertebrate community results discussed thus far have been based on three samples per site. This is a fairly small sample size on which to generalize. In addition, the scope of this study only represented the community found in riffles in late summer-early autumn. A patchy distribution of organic matter in a stream, as a result of the distribution and abundance of various riparian vegetation types, potentially impacts how organisms that use these resources distribute themselves (Delong and Brusven 1994). If an area, or patch, where proportionately more organisms were present was randomly selected, bias would be introduced. More samples (from various habitats and regions as well as in all seasons) and further studies are necessary to test the hypothesis and minimize potential bias in the sampling regimen.

Future Studies

Future studies on the effects of large amounts of wood on stream ecology are needed. In particular, various amounts of wood in low-order streams must be examined. In this study, a factor of two was used (one site in each pair had approximately twice as many pieces as the other site). It is possible that macroinvertebrate communities may respond differently to, for example, ten times more wood than they do to twice as much wood.

One characteristic of the wood that may have influenced the results was the quality of the wood. The wood pieces were counted and diameters were measured, but their texture, age, stage

of decomposition, and species were not addressed. Trees in the riparian areas of the study sites are believed to be of the same relative ages. However, the quality of riparian litter is dependent on the successional stage of the riparian trees and has been found to influence macroinvertebrate abundance and community composition (Irons et al. 1988). Therefore, the macroinvertebrate communities surveyed could be associated with wood quality, in addition to wood quantity.

Elements of the experimental design could also have influenced the results, such as the stratified sampling technique (only riffle habitats), equipment selection, and limited taxonomic identification. Only one type of habitat was represented in the results presented here, and macroinvertebrate communities can vary depending on the habitat sampled. Future studies should incorporate a sampling method from a variety of habitats, representing the entire study reach. By selecting to use the Surber sampler, the streambed was disturbed when the frame was put in place immediately prior to collection. This may have resulted in some organisms entering as drift before the sample was taken, altering the communities collected and used in the analyses (Kroger 1972, Resh 1979).

Even if a variety of habitats were sampled, and sampled efficiently, in all seasons, there is still the consideration of identification to the lowest practical taxonomic level. After some training, and with a library of resources available, the lowest taxonomic level that could be achieved with some degree of accuracy in this study was family. Sampling in early September meant the collection consisted of many early instars. These small organisms are hard to identify without specialized equipment (greater magnification) and years of experience recognizing certain characteristics of young macroinvertebrates specific to this region. Taxonomic levels lower than family, however, would more accurately portray abundance, richness, diversity, and evenness, as well as provide feeding guilds designations that are more specific to the organisms.

These suggestions for future studies are just a few ideas to expand the available research on how large amounts of wood may influence stream ecology and aquatic macroinvertebrate communities in particular. In addition, the indirect effects of large amounts of wood on the physical environments of streams provide information to predict impacts on macroinvertebrate communities in low-order streams with large amounts of wood. Further analysis of these topics are essential to understanding the implications of very dense, even-aged, small diameter stands in riparian areas on the aquatic environment of headwater streams.

CHAPTER SIX

CONCLUSION

This study compared three pairs of sites, with each pair containing one "more wood" and one "less wood" site, in Colville National Forest to investigate the influence large amounts of wood have on low-order streams. Although there was a significant difference in the amount of wood found at "more wood" versus "less wood" sites, significant differences in physical parameters, such as slope and substrate, were not detected. Abundance, richness, diversity, and evenness were hypothesized to be lower at the "more wood" sites as a result of impacts to the aquatic environment by wood (e.g., creating a fluctuating environment by altering stream gradients; forming habitats such as pools where only certain macroinvertebrates are adapted for; retaining sediments that eventually change habitat complexity, fill in refuges, impact respiration and reproductive processes). However, statistically significant differences were not detected in any of these biological parameters between "more wood" and "less wood" sites.

Despite the lack of statistical differences in the abundance, richness, diversity, and evenness, this study does provide information on the differences in macroinvertebrate communities of low-order streams with "more wood". Total abundance for "less wood" sites was twice that of the "more wood" sites and average family richness was slightly higher for the "less wood" sites, in agreement with the study hypothesis. Deviating from the prediction stated in the hypothesis, average diversity and evenness values were slightly higher at the "more wood" sites when compared with "less wood" sites. Nevertheless, a strong statistically significant difference was found in the functional feeding group compositions at "more wood" sites compared to "less

wood" sites. This finding indicates more research is needed to address the influence large amounts of wood have on feeding guilds in low-order streams.

Fire suppression has altered the density and composition of riparian areas throughout the western United States. Management strategies to improve forests tend to avoid riparian areas in an attempt to protect aquatic resources from disturbances. However, just as fuel loads are accumulating on the forest floor, large amounts of wood are collecting in the adjacent streams. This study has shown that the addition of wood as a result of dense, even-aged, small diameter stands has the potential to alter the macroinvertebrate community, particularly abundances and the functional feeding group compositions, in low-order streams. Furthermore, changes in the functional feeding group composition of the macroinvertebrate communities in headwater streams could have profound influences on food availability for aquatic biota (fish and invertebrates) in downstream reaches. Therefore, it is important for more research to be conducted on the effects of large amounts of wood on low-order streams.

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APPENDIX A

CROSS-SECTIONAL PROFILES

Graph A1: Cross-sectional profile of site X_1, a "less wood" site, of pair 1.
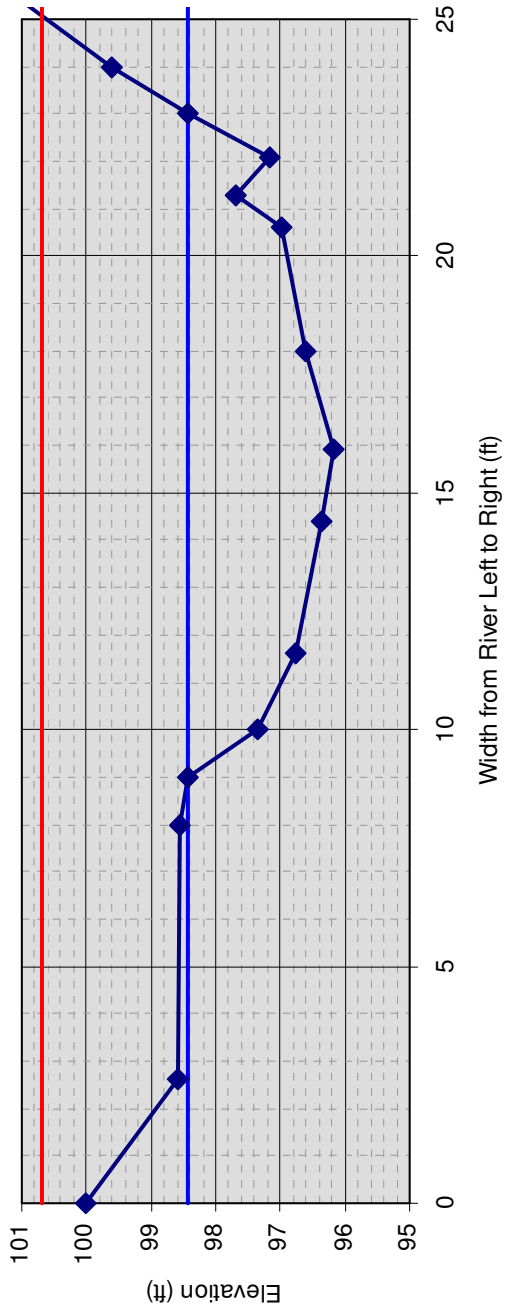
Graph A2: Cross-sectional profile of site X_2, a "more wood" site, of pair 1.
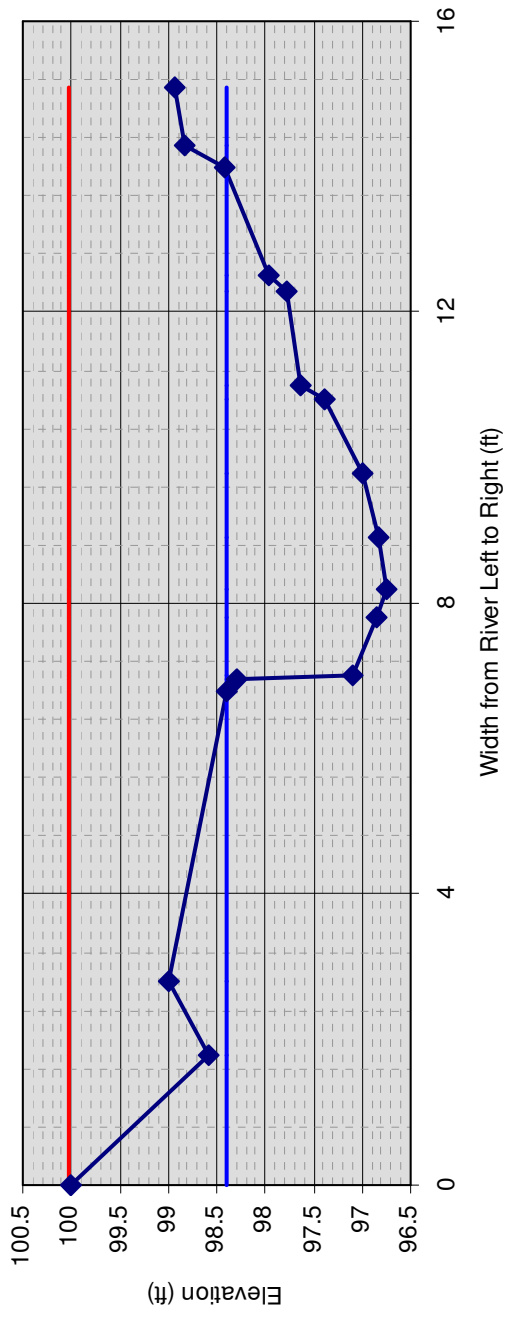
Graph A3: Cross-sectional profile of site Y_1, a "less wood" site, of pair 2.
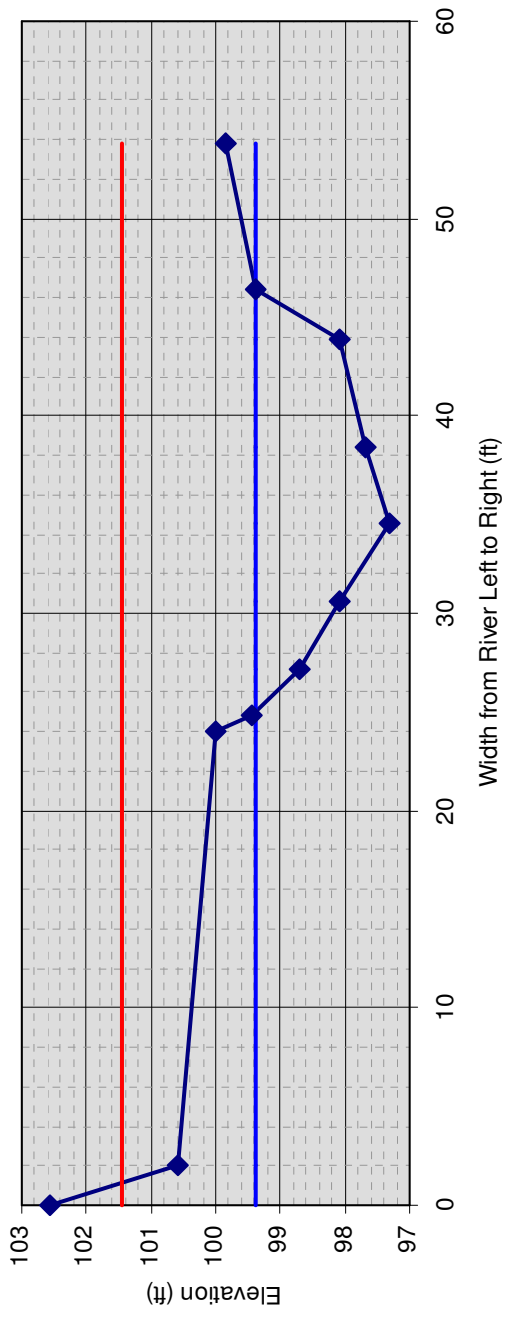
Graph A4: Cross-sectional profile of site Y_2, a "more wood" site, of pair 2.
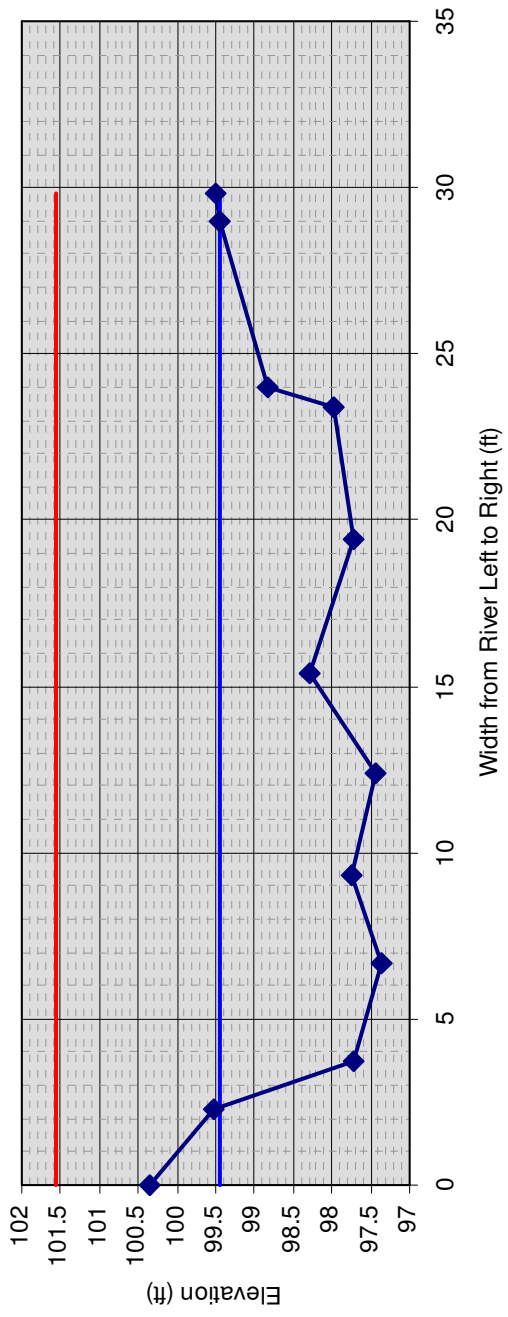
Graph A5: Cross-sectional profile of site Z_1, a "less wood" site, of pair 3.
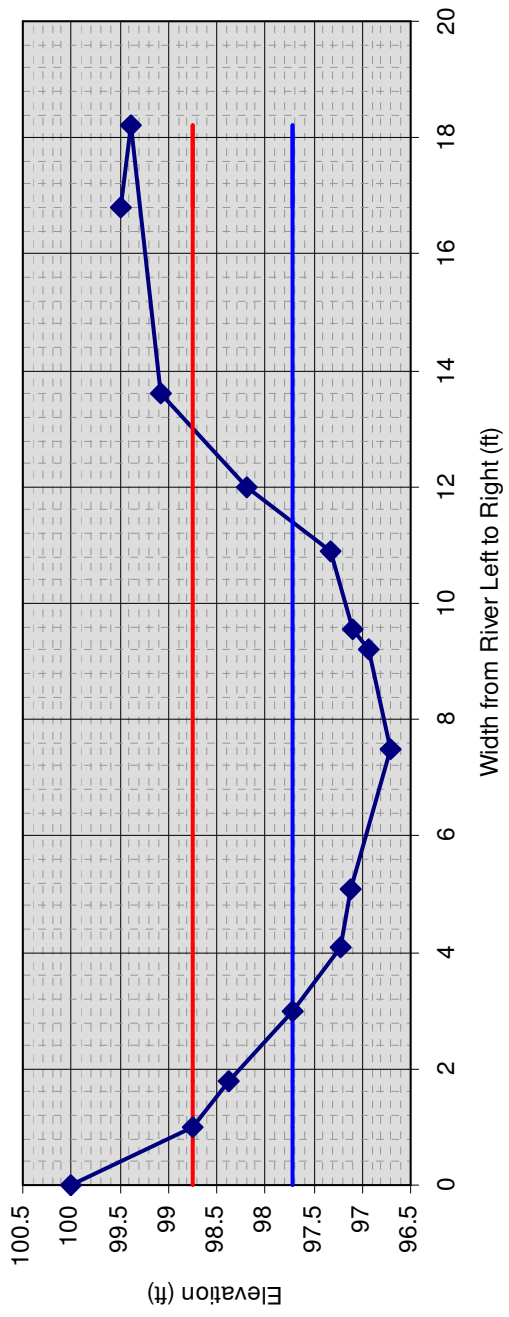
Graph A6: Cross-sectional profile of site Z_2, a "more wood" site, of pair 3.
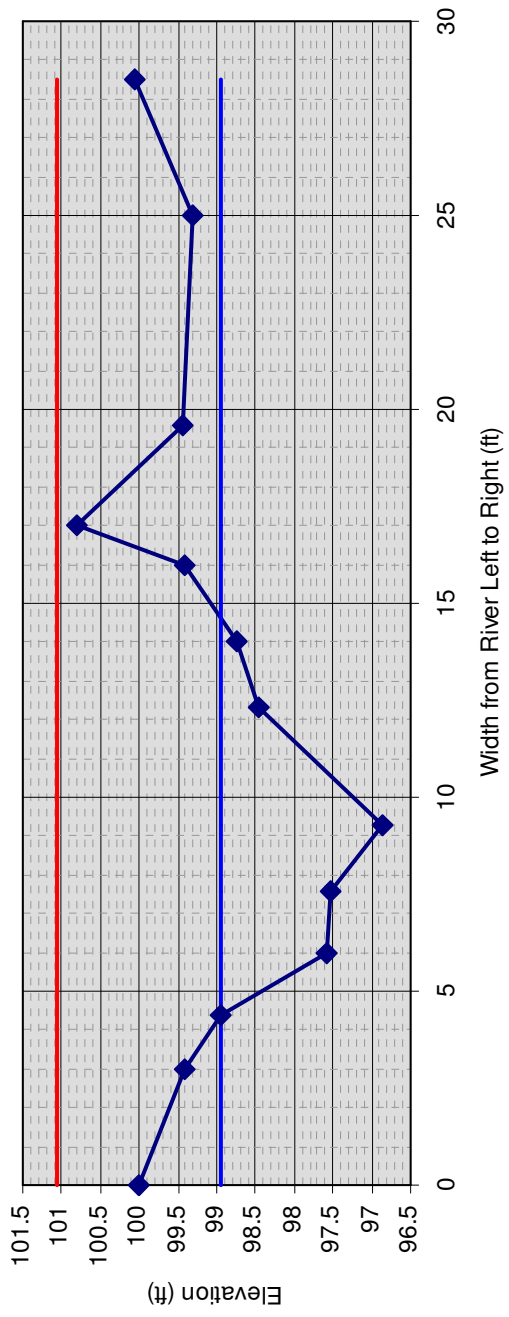
APPENDIX B

LONGITUDINAL PROFILES

Graph B1: Longitudinal profile of site X_1, a "less wood" site, of pair 1.
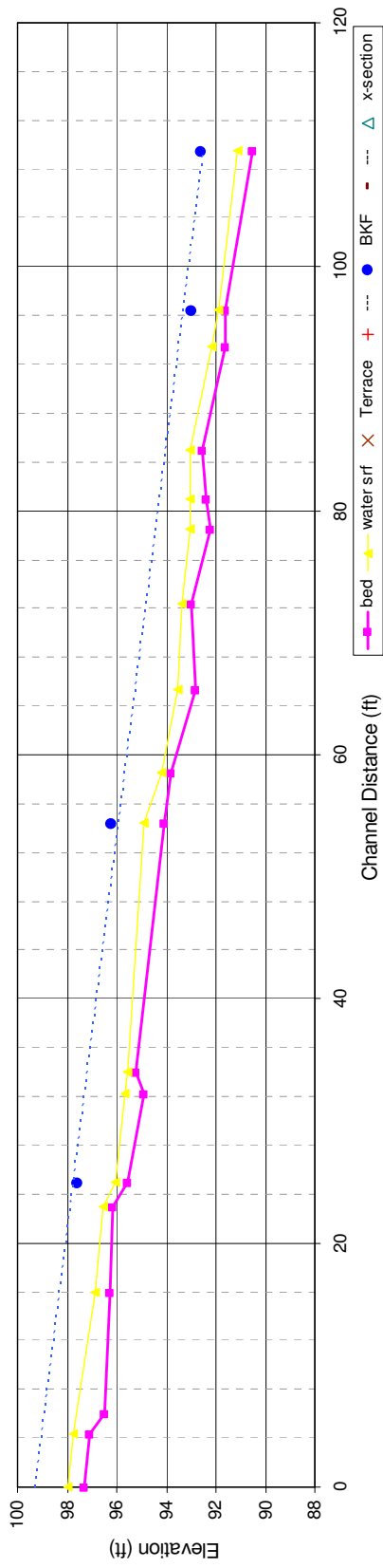
Graph B1: Longitudinal profile of site X_2, a "more wood" site, of pair 1.
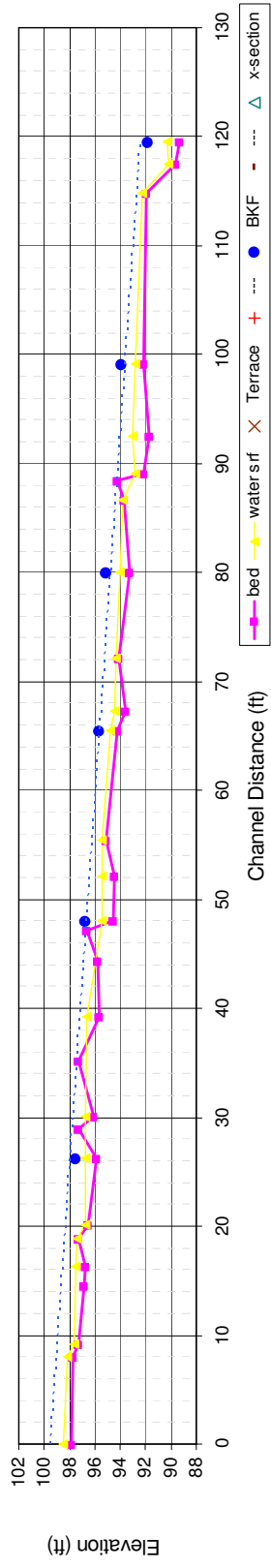
Graph B3: Longitudinal profile of site Y_1, a "less wood" site, of pair 2.
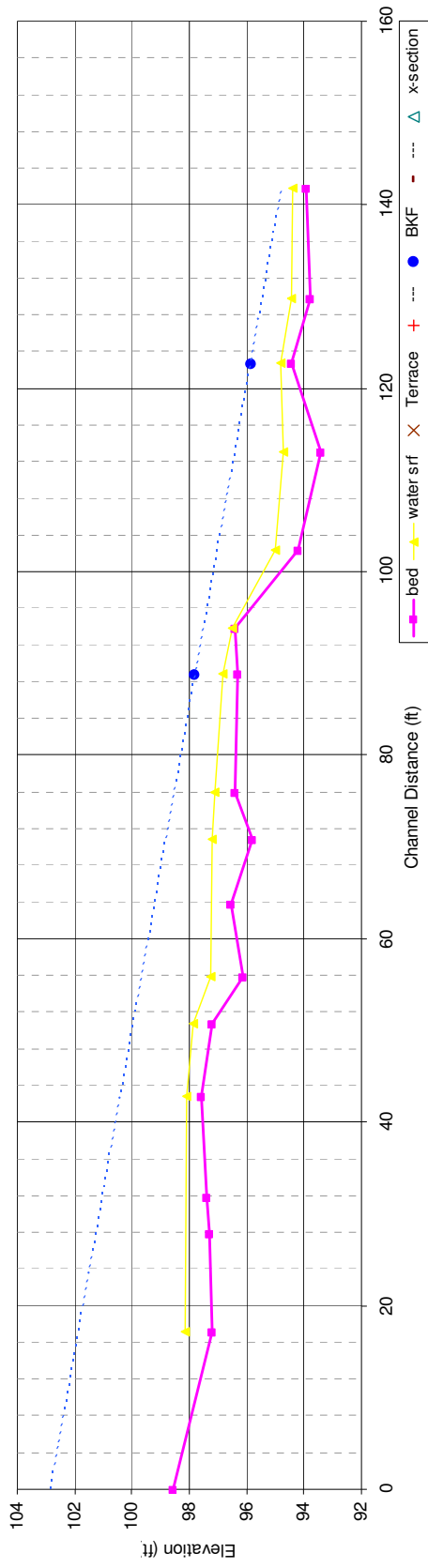
Graph B4: Longitudinal profile of site Y_2, a "more wood" site of pair 2.
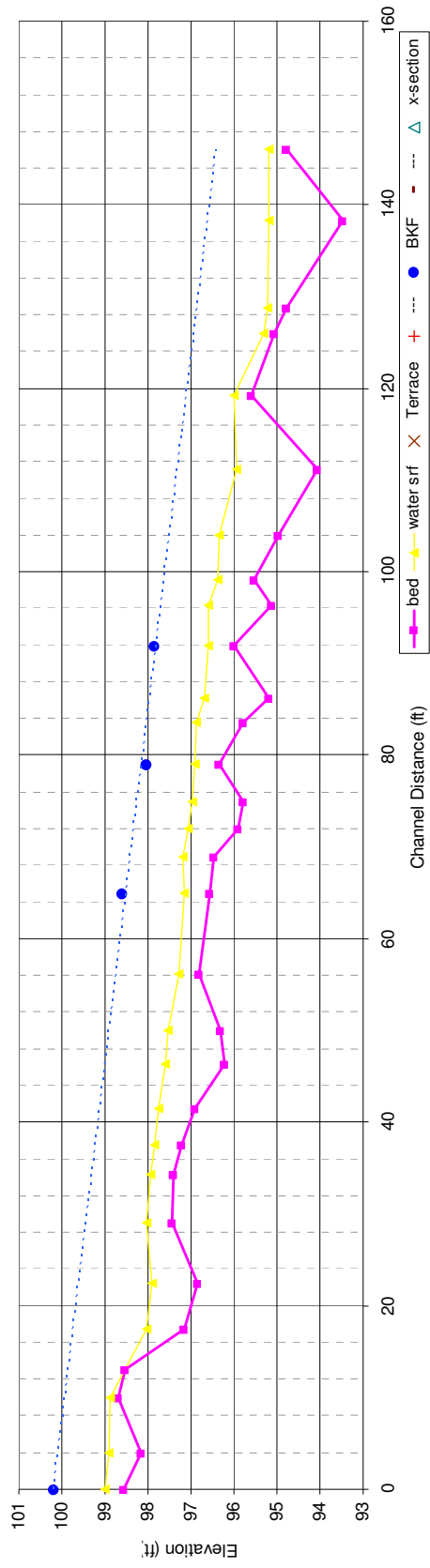
Graph B5: Longitudinal profile of site Z_1, a "less wood" site, of pair 3.
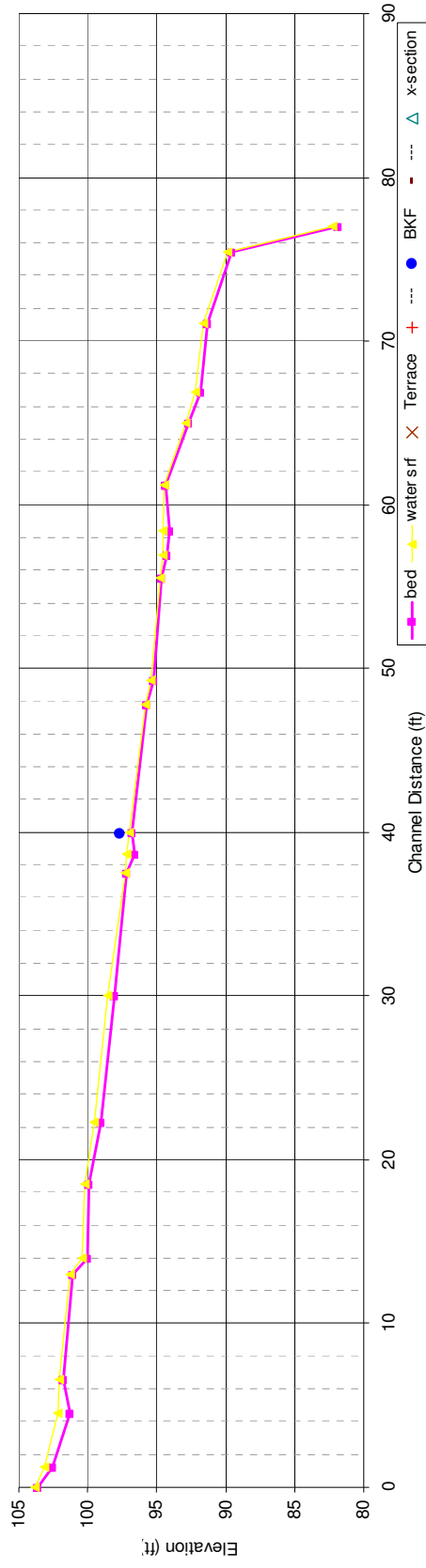
Graph B6: Longitudinal profile of site Z_2, a "more wood" site, of pair 3.

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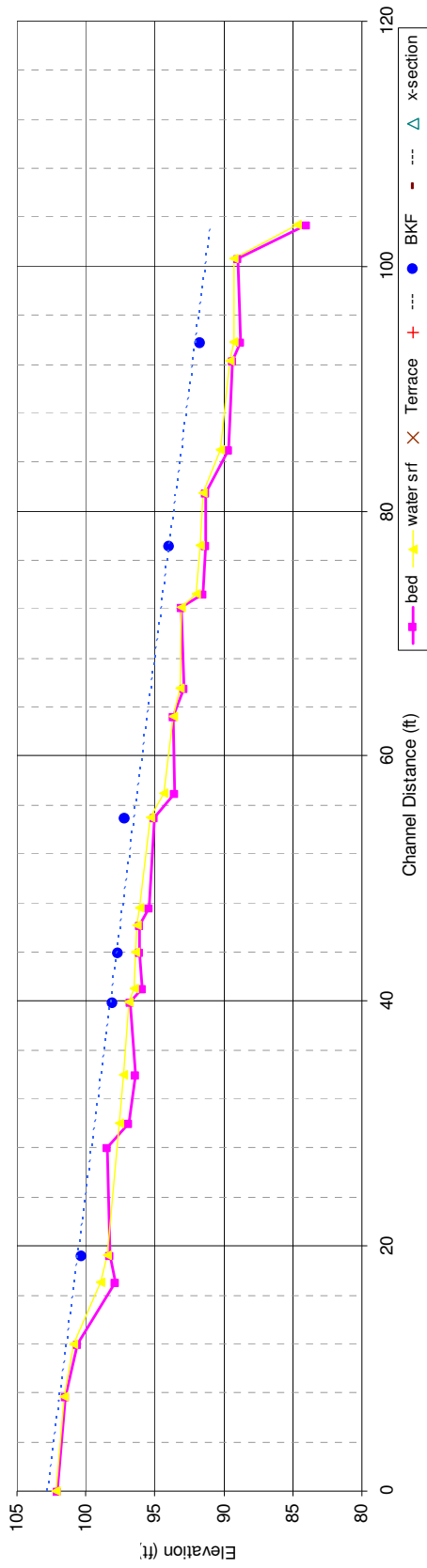
APPENDIX C

SUBSTRATE DATA

Graph C1: Particle size distribution for site X_1, a "less wood" site, of pair 1.
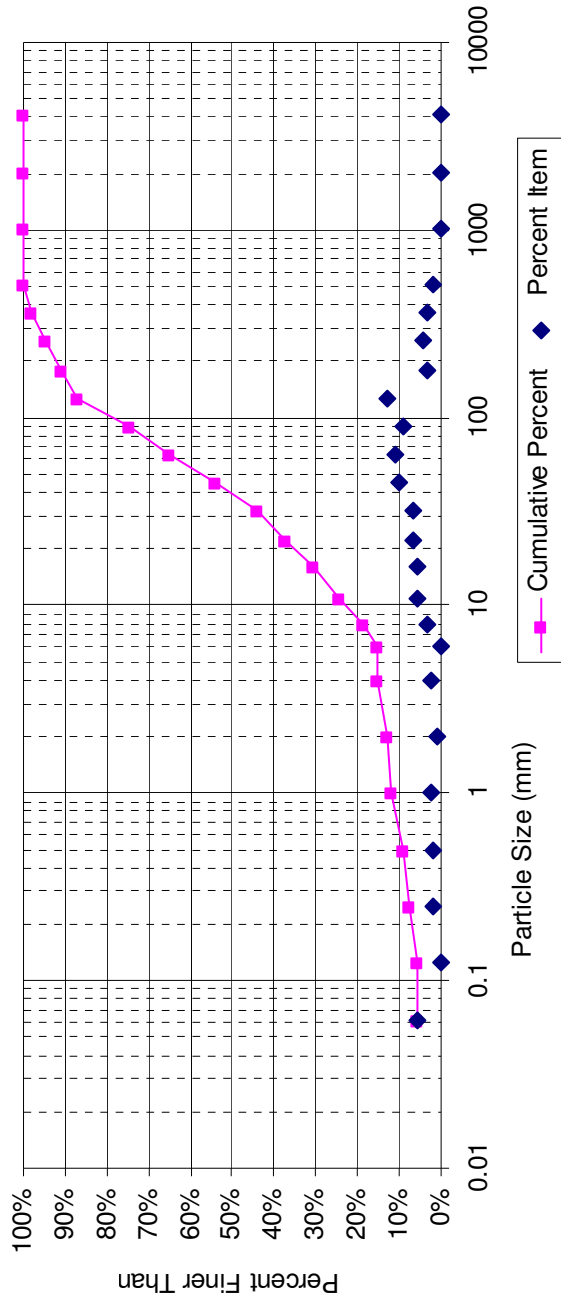
Size	percent	less	than	(mm)
D16	D35	D50	D84	D95
6.392	19.76	39.0	117	258

Percent	by	substrate	type		
silt/clay	sand	gravel	cobble	boulder	bedrock
6%	7%	53%	30%	5%	0%

Graph C2: Particle size distribution for site X_2, a "more wood" site, of pair 1.
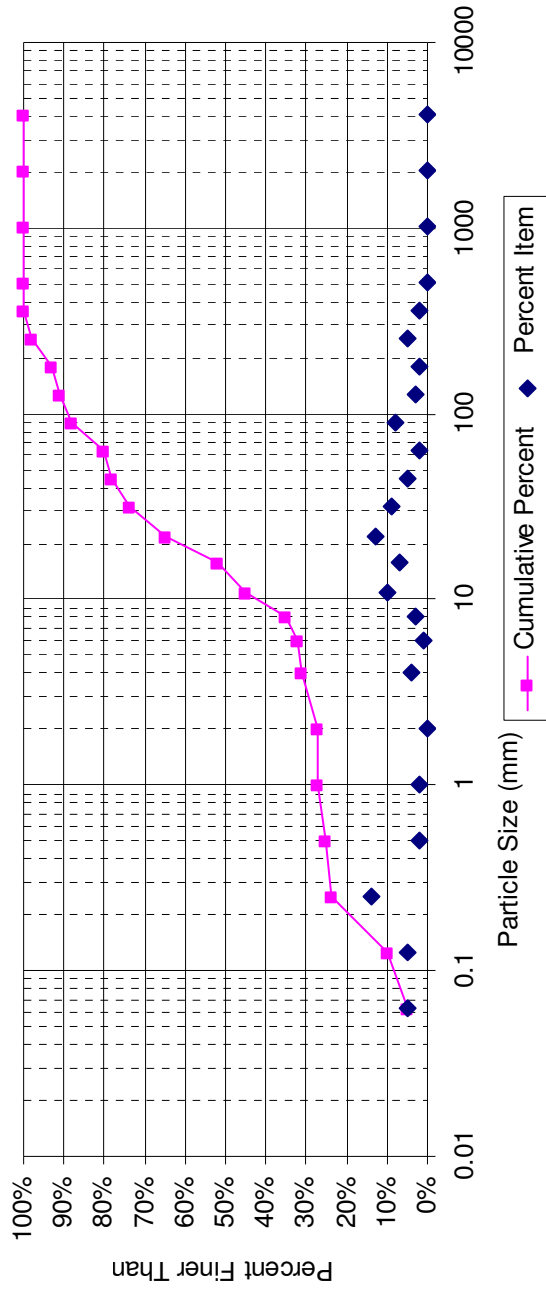
Size	percent	less	than	(mm)	Percent	by	substrate	type		
D16	D35	D50	D84	D95	silt/clay	sand	gravel	cobble	boulder	bedrock
0.171	7.77	14.4	75	206	5%	23%	53%	18%	2%	0%

Graph C3: Particle size distribution for site Y_1, a "less wood" site, of pair 2.
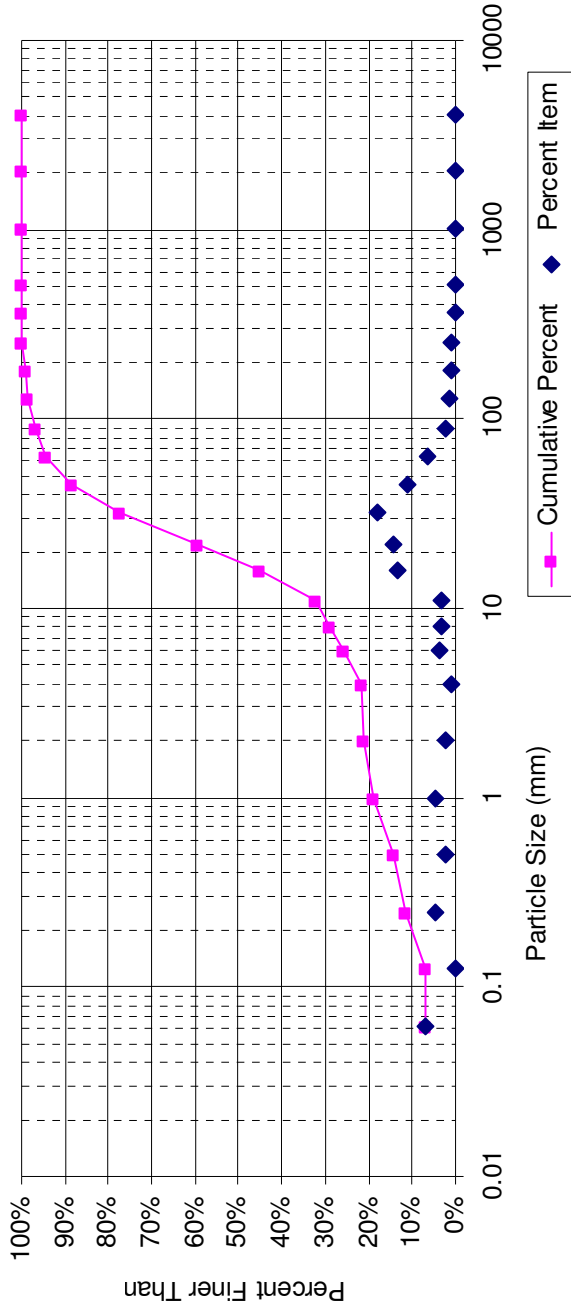
Percent Finer Than

Particle Size (mm)

—■— Cumulative Percent   ◆ Percent Item

Size	percent	less	than	(mm)
D16	D35	D50	D84	D95
0.666	11.96	17.8	39	69

Percent	by	substrate	type		
silt/clay	sand	gravel	cobble	boulder	bedrock
7%	14%	73%	5%	0%	0%

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Graph C4: Particle size distribution for site Y_2, a "more wood" site, of pair 2.
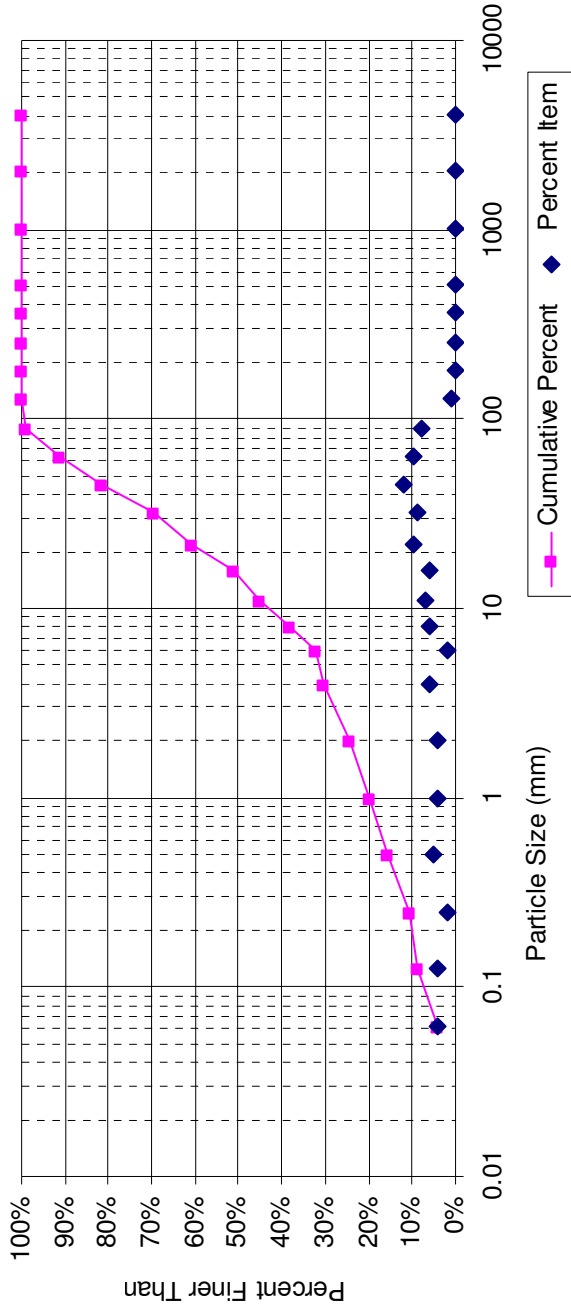
Size	percent	less	than	(mm)	Percent	by	substrate	type		
D16	D35	D50	D84	D95	silt/clay	sand	gravel	cobble	boulder	bedrock
0.529	6.86	14.8	49	75	4%	20%	67%	9%	0%	0%

Graph C5: Particle size distribution for site Z_1, a "less wood" site, of pair 3.
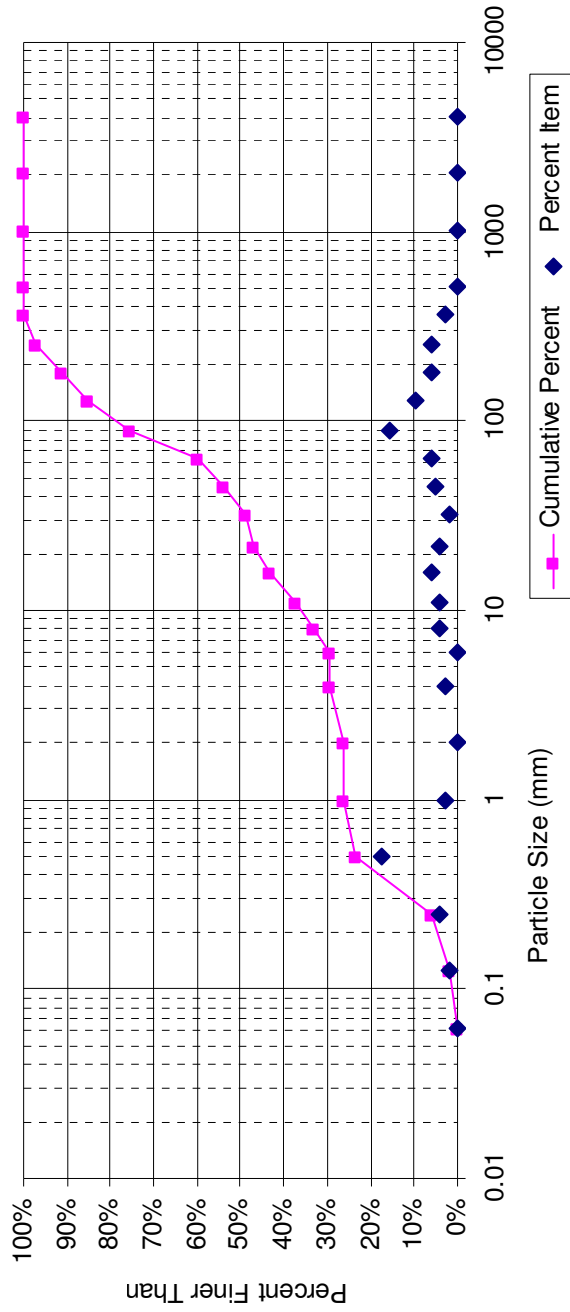
Size percent		less	than	(mm)	Percent	by	substrate	type		
D16	D35	D50	D84	D95	silt/clay	sand	gravel	cobble	boulder	bedrock
0.372	9.16	34.3	122	226	0%	26%	33%	37%	3%	0%

Graph C6: Particle size distribution for site Z_2, a "more wood" site, of pair 3.

Size	percent	less	than	(mm)	Percent	by	substrate	type		
D16	D35	D50	D84	D95	silt/clay	sand	gravel	cobble	boulder	bedrock
0.559	7.03	16.7	69	126	0%	25%	58%	16%	1%	0%

APPENDIX D

MACROINVERTEBRATE DATA

Table D1: Percent contribution of the dominant macroinvertebrate family in low-order study sites in Colville National Forest. The top half of the table represents the cumulative sample for each site. The bottom half of the table gives the dominant family from each sample per site (a, b, and c).

	Family	Number	Total	Contribution
X_1	Baetidae	716	1492	47.99
X_2	Baetidae & Leptophlebiidae	80	246	32.52
Y_1	Baetidae	379	1084	34.96
Y_2	Heptageniidae	187	1009	18.53
Z_1	Chironomidae	296	855	34.62
Z_2	Uenoidae	305	463	65.87
X_{1a}	Baetidae	95	277	34.30
X_{1b}	Baetidae	385	763	50.46
X_{1c}	Baetidae	236	453	52.10
X_{2a}	Chironomidae	17	87	19.54
X_{2b}	Heptageniidae	18	51	35.29
X_{2c}	Chironomidae	18	107	16.82
Y_{1a}	Baetidae	144	352	40.91
Y_{1b}	Heptageniidae	229	414	55.31
Y_{1c}	Baetidae	172	318	54.09
Y_{2a}	Chironomidae	83	469	17.70
Y_{2b}	Chloroperlidae	57	256	22.27
Y_{2c}	Heptageniidae	80	282	28.37
Z_{1a}	Chironomidae	108	333	32.43
Z_{1b}	Chironomidae	78	346	22.54
Z_{1c}	Chironomidae	110	175	62.86
Z_{2a}	Uenoidae	73	153	47.71
Z_{2b}	Uenoidae	215	271	79.34
Z_{2c}	Uenoidae	17	39	43.59

Table D2: Percent contributions of the three dominant families in the top half of the table for each study site on low-order streams of Colville National Forest. The bottom half of the table provides the three dominant families found in each sample (a, b, and c).

	Family 1		Family 2		Family 3		Total	Contribution
X_1	Baetidae	716	Heptageniidae	261	Chironomidae	144	1492	75.13
X_2	Baetidae	40	Leptophlebiidae	40	Chironomidae	39	246	48.37
Y_1	Heptageniidae	187	Chironomidae	185	Chloroperlidae	144	1009	78.04
Y_2	Baetidae	379	Heptageniidae	347	Chloroperlidae	120	1084	51.14
Z_1	Chironomidae	296	Peltoperlidae	134	Uenoidae	72	855	58.71
Z_2	Uenoidae	305	Chironomidae	32	Heptageniidae	20	463	77.11
X_{1a}	Baetidae	95	Heptageniidae	79	Chironomidae	26	277	72.20
X_{1b}	Baetidae	385	Heptageniidae	131	Chironomidae	68	763	76.54
X_{1c}	Baetidae	236	Heptageniidae	51	Chironomidae	50	453	74.39
X_{2a}	Chironomidae	17	Rhyacophilidae	14	Heptageniidae	12	87	49.43
X_{2b}	Heptageniidae	18	Baetidae	15	Chloroperlidae	5	51	74.51
X_{2c}	Chironomidae	18	Baetid/Peltoperlid	28	Rhyacophilidae	14	107	56.07
Y_{1a}	Baetidae	144	Heptageniidae	80	Chloroperlidae	41	352	75.28
Y_{1b}	Heptageniidae	229	Chloroperlidae	65	Baetidae	63	414	86.23
Y_{1c}	Baetidae	172	Heptageniidae	38	Hydropsychidae	27	318	74.53
Y_{2a}	Chironomidae	83	Heptageniidae	70	Chloroperlidae	67	469	46.91
Y_{2b}	Chloroperlidae	57	Elmidae	38	Heptageniidae	37	256	51.56
Y_{2c}	Heptageniidae	80	Chironomidae	70	Elmidae	21	282	60.64
Z_{1a}	Chironomidae	108	Peltoperlidae	49	Uenoidae	33	333	57.06
Z_{1b}	Chironomidae	78	Peltoperlidae	76	Chloroperlid/Uenoid	56	346	60.69
Z_{1c}	Chironomidae	110	Uenoidae	11	Leuctrid/Peltoperlid	18	175	79.43
Z_{2a}	Uenoidae	73	Chironomidae	19	Rhyacophilid/ Entomobryid	11	153	67.32
Z_{2b}	Uenoidae	215	Chloroperlidae	10	Chironomidae	9	271	86.35
Z_{2c}	Uenoidae	17	Heptageniidae	8	Chironomidae	4	39	74.36

Table D3: Top half of table gives the top five dominant families at each study site on low-order streams in Colville National Forest.

The bottom half of the table provides the five dominant families in each sample (a, b, and c).

	Family 1		Family 2		Family 3		Family 4		Family 5		Total	Contrib.
X_1	Baetidae	716	Heptageniidae	261	Chironomidae	144	Hydropsychidae	104	Chloroperlidae	67	1492	86.60
X_2	Baetidae	40	Leptophlebiidae	40	Chironomidae	39	Rhyacophilidae	28	Chloroperlidae	23	246	69.11
Y_1	Heptageniidae	187	Chironomidae	185	Chloroperlidae	144	Elmidae	123	Glossosomatidae	74	1009	86.07
Y_2	Baetidae	379	Heptageniidae	347	Chloroperlidae	120	Chironomidae	52	Rhyacophilidae	35	1084	70.66
Z_1	Chironomidae	296	Peltoperlidae	134	Uenoidae	72	Chloroperlidae	53	Leptophlebiidae	48	855	70.53
Z_2	Uenoidae	305	Chironomidae	32	Heptageniidae	20	Rhyacophilidae	19	Chloroperlidae	13	463	84.02
X_{1a}	Baetidae	95	Heptageniidae	79	Chironomidae	26	Chloroperlidae	20	Glossosomatidae	13	277	84.12
X_{1b}	Baetidae	385	Heptageniidae	131	Chironomidae	68	Hydropsychidae	47	Rhyacophilidae	29	763	86.50
X_{1c}	Baetidae	236	Heptageniidae	51	Chironomidae	50	Hydropsychidae	48	Chloroperlidae	19	453	89.18
X_{2a}	Chironomidae	17	Rhyacophilidae	14	Heptageniidae	12	Baetidae	11	Chloroperlidae	8	87	71.26
X_{2b}	Heptageniidae	18	Baetidae	15	Chloroperlidae	5	Chironomidae	4	Leptophlebiid/Limnephilid/Entomobryid	6	51	94.12
X_{2c}	Chironomidae	18	Baetidae	14	Rhyacophilidae	14	Peltoperlidae	14	Heptageniid/Chloroperlid	20	107	74.77
Y_{1a}	Baetidae	144	Heptageniidae	80	Chloroperlidae	41	Chironomidae	17	Rhyacophilidae	13	352	83.81
Y_{1b}	Heptageniidae	229	Chloroperlidae	65	Baetidae	63	Chironomidae	12	Perlodid/Rhyacophilid	16	414	93.00
Y_{1c}	Baetidae	172	Heptageniidae	38	Hydropsychidae	38	Chironomidae	27	Chloroperlid/Rhyacophilid	28	318	90.57
Y_{2a}	Chironomidae	83	Heptageniidae	70	Chloroperlidae	70	Elmidae	64	Glossosomatidae	43	469	69.72
Y_{2b}	Chloroperlidae	57	Elmidae	38	Heptageniidae	37	Chironomidae	32	Glossosomatidae	25	256	73.83
Y_{2c}	Heptageniidae	80	Chironomidae	70	Elmidae	21	Chloroperlidae	20	Perlodidae	20	282	74.82
Z_{1a}	Chironomidae	108	Peltoperlidae	49	Uenoidae	33	Leptophlebiidae	32	Chironomidae	20	333	72.67
Z_{1b}	Chironomidae	78	Peltoperlidae	76	Chloroperlidae	28	Uenoidae	28	Entomobryidae	26	346	68.21
Z_{1c}	Uenoidae	110	Uenoidae	11	Leuctridae	9	Peltoperlidae	9	Rhyacophilidae	7	175	83.43
Z_{2a}	Uenoidae	73	Chironomidae	19	Rhyacophilidae	11	Entomobryidae	11	Heptageniidae	7	153	79.08
Z_{2b}	Uenoidae	215	Chloroperlidae	10	Chironomidae	9	Baetidae	6	Peltoperlidae	6	271	90.77
Z_{2c}	Uenoidae	17	Heptageniidae	8	Chironomidae	4	Leptophlebiidae	3	Rhyacophilidae	3	39	89.74

Table D4: Raw data of macroinvertebrate counts in each sample and for each site on low-order streams in Colville National Forest.

	X_{1a}	X_{1b}	X_{1c}	Total at X_1	X_{2a}	X_{2b}	X_{2c}	Total at X_2	Y_{1a}	Y_{1b}	Y_{1c}	Total at Y_1	Y_{2a}	Y_{2b}	Y_{2c}	Total at Y_2	Z_{1a}	Z_{1b}	Z_{1c}	Total at Z_1	Z_{2a}	Z_{2b}	Z_{2c}	Total at Z_2	Overall Totals
Ephemeroptera	**185**	**531**	**291**	**1007**	**26**	**35**	**27**	**88**	**232**	**300**	**210**	**742**	**109**	**53**	**100**	**262**	**56**	**29**	**6**	**91**	**17**	**12**	**12**	**41**	**2231**
Baetidae	95	385	236	716	11	15	14	40	144	63	172	379	18	6	12	36	7	6	2	15	6	6	0	12	1198
Ephemerellidae	10	11	3	24	0	0	0	0	8	6	0	14	21	7	5	33	0	0	0	0	1	0	1	2	73
Heptageniidae	79	131	51	261	12	18	10	40	80	229	38	347	70	37	80	187	17	8	3	28	7	5	8	20	883
Leptophlebiidae	1	4	1	6	3	2	3	8	0	2	0	2	0	3	3	6	32	15	1	48	3	1	3	7	77
Plecoptera	**31**	**63**	**37**	**131**	**24**	**8**	**34**	**66**	**71**	**83**	**40**	**194**	**116**	**84**	**69**	**269**	**105**	**139**	**33**	**277**	**16**	**23**	**2**	**41**	**978**
Chloroperlidae	20	28	19	67	8	5	10	23	41	65	14	120	67	57	20	144	20	28	5	53	1	10	2	13	420
Leuctridae	1	4	2	7	6	1	2	9	6	4	3	13	4	2	12	18	6	6	9	21	0	1	0	1	69
Nemouridae	2	23	12	37	3	0	1	4	5	2	13	20	13	1	1	15	10	11	4	25	6	1	0	7	108
Perlidae	4	4	2	10	3	0	7	10	6	4	8	18	31	21	16	68	19	12	6	37	6	5	0	11	154
Perlodidae	3	3	1	7	4	1	0	5	11	8	1	20	1	3	20	24	1	6	0	7	0	0	0	0	63
Peltoperlidae	1	1	1	3	0	1	14	15	2	0	1	3	0	0	0	0	49	76	9	134	3	6	0	9	164
Trichoptera	**28**	**91**	**66**	**185**	**15**	**2**	**15**	**32**	**28**	**11**	**45**	**84**	**95**	**46**	**13**	**154**	**53**	**49**	**19**	**121**	**87**	**224**	**20**	**331**	**907**
Brachycentridae	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	3
Glossosomatidae	13	4	3	20	0	0	1	1	7	1	1	9	43	25	6	74	0	1	1	2	0	0	0	0	106
Hydropsychidae	9	47	48	104	0	0	0	0	5	1	27	33	16	7	0	23	2	6	0	8	0	1	0	1	169
Limnephilidae	0	0	0	0	0	2	0	2	2	1	1	4	0	0	1	1	2	6	0	8	2	2	0	4	19
Philopotamidae	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	1	3	1	0	4	1	1	0	2	8
Rhyacophilidae	4	29	12	45	14	0	14	28	13	8	14	35	33	13	6	52	13	7	7	27	11	5	3	19	206
Uenoidae	2	11	3	16	0	0	0	0	1	0	2	3	0	0	0	0	33	28	11	72	73	215	17	305	396
Collembola	**2**	**1**	**0**	**3**	**0**	**2**	**1**	**3**	**0**	**3**	**0**	**3**	**0**	**1**	**0**	**1**	**0**	**26**	**1**	**27**	**11**	**0**	**0**	**11**	**48**
Entomobryidae	2	1	0	3	0	2	1	3	0	3	0	3	0	1	0	1	0	26	1	27	11	0	0	11	48
Coleoptera	**4**	**8**	**6**	**18**	**2**	**0**	**6**	**8**	**4**	**2**	**0**	**6**	**64**	**38**	**21**	**123**	**6**	**6**	**1**	**13**	**3**	**0**	**1**	**4**	**172**
Curculionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1
Elmidae	4	8	5	17	2	0	6	8	4	2	0	6	64	38	21	123	6	4	0	10	3	0	1	4	168
Hydrophilidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1
Melyridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1
Staphylinidae	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Diptera	**27**	**69**	**53**	**149**	**20**	**4**	**24**	**48**	**17**	**15**	**23**	**55**	**85**	**34**	**79**	**198**	**113**	**97**	**115**	**325**	**19**	**12**	**4**	**35**	**810**
Ceratopogonidae	0	0	0	0	0	0	0	0	0	0	0	0	2	0	5	7	1	0	1	2	0	0	0	0	9
Chironomidae	26	68	50	144	17	4	18	39	17	12	23	52	83	32	70	185	108	78	110	296	19	9	4	32	748
Dixidae	0	0	1	1	0	0	0	0	0	3	0	3	0	0	0	0	0	3	4	7	0	2	0	2	13
Empididae	1	0	1	2	3	0	6	9	0	0	0	0	0	2	4	6	1	0	0	1	0	1	0	1	19
Pelecorhynchidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	4	0	0	0	0	4
Psychodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	12	0	0	0	0	12
Tipulidae	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	3	0	0	0	0	5
TOTALS	**277**	**763**	**453**	**1493**	**87**	**51**	**107**	**245**	**352**	**414**	**318**	**1084**	**469**	**256**	**282**	**1007**	**333**	**346**	**175**	**854**	**153**	**271**	**39**	**463**	**5146**